Mathematics and Statistics

Mathematics has always held a central position in the liberal arts, and over time it has also come to play an important role in more and more aspects of our lives. Mathematical analysis and modeling are involved in many areas far beyond the traditional association of mathematics with the physical sciences and engineering. This fact is reflected in the diversity of the students who study at least some mathematics during their time at Washington University — students who recognize the importance of quantitative skills in a world that becomes more and more technological.

Students major in mathematics for many reasons. Some are planning academic careers in mathematics or statistics that involve teaching or research. Others plan to work as actuaries or at other jobs in industry or government. Some plan careers in secondary education. Many majors do not intend to become "mathematicians" at all but simply realize that quantitative training is a valuable asset in many kinds of careers; often, work in mathematics or statistics is meant to complement their study in other areas. Still other majors just view mathematics as an interesting concentration in their liberal arts education, even though they plan to enter professional fields such as medicine or law.

The Mathematics and Statistics program gives majors and minors a broad introduction to the subject. Majors choose among several tracks to complete their study; these tracks add different emphases to their programs and reflect individual interests or professional goals. Majors are encouraged to complete additional work (perhaps even a minor or a second major) in other related areas.

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Faculty

Chair

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Algebraic and topological combinatorics

Directors

José Figueroa-López (https://math.wustl.edu/people/jose-e-figueroa-lopez/)
Director of Undergraduate Studies
PhD, Georgia Institute of Technology
Statistics; probability and stochastic processes; mathematical finance

Brett Wick (https://math.wustl.edu/people/brett-wick/)
Director of Graduate Studies; Professor of Mathematics
PhD, Brown University
Complex analysis; harmonic analysis; operator theory; several complex variables

Endowed Professors

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Stanley A. Sawyer Professor
PhD, Michigan State University
Mathematical statistics and data science

John E. McCarthy (https://math.wustl.edu/people/john-e-mccarthy/)
Spencer T. Olin Professor of Mathematics
PhD, University of California, Berkeley
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Rachel Roberts (https://math.wustl.edu/people/rachel-roberts/)
Elinor Anheuser Professor of Mathematics
PhD, Cornell University
Low-dimensional topology

Professors

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Debashis Mondal
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Combinatorics and algebraic geometry

Steven Frankel (https://math.wustl.edu/people/steven-frankel/)
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Geometric topology and dynamics

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Applied mathematics

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Professors Emeriti

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Differential topology

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General topology

Gary R. Jensen (https://math.wustl.edu/people/gary-r-jensen/)
PhD, University of California, Berkeley
Differential geometry

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General topology

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Postdoctoral Lecturers

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Geometric topology

Program Coordinator

Lisa M. Kuehne (https://math.wustl.edu/people/lisa-kuehne/)
Program Coordinator, University College & Center for Advanced Learning
AM Mathematics, Washington University
Undergraduate mathematics education

Majors

Requirements for All Majors

Total units required: 12 units

- The three-course calculus sequence (9 units)* and an introductory computer science course (3 units)**:

Code	Title	Units
Math 131	Calculus I	3
Math 132	Calculus II	3
Math 233	Calculus III	3
CSE 131	Introduction to Computer Science	3
Total Units		12

* AP credit can be applied, and students who have completed Math 203 Honors Mathematics I and Math 204 Honors Mathematics II will have this requirement waived.

** This course may be waived after consultation with the director of undergraduate studies of the Department of Computer Science & Engineering.

The Major in Mathematical Sciences

Total units required: 24 units of upper-level courses, including the following:

Code	Title	Units
Math 309	Matrix Algebra	3
Math 310	Foundations for Higher Mathematics	3
Math 3200	Elementary to Intermediate Statistics and Data Analysis	3

- One of the following full-year 400-level sequences*:

Code	Title	Units
Math 4111 & Math 4121	Introduction to Analysis and Introduction to Lebesgue Integration	6
Math 4171 & Math 4181	Topology I and Topology II	6
Math 429 & Math 430	Linear Algebra and Modern Algebra	6
Math 449 & Math 450	Numerical Applied Mathematics and Topics in Applied Mathematics	6
Math 494 & Math 439	Mathematical Statistics and Linear Statistical Models	6

* Students whose primary major is secondary education may fulfill this requirement by taking Math 302 Elementary Geometry from an Advanced Point of View and Math 331 Algebraic Systems.

- At least one course from the following list (that has not already been used to fulfill any of the previous requirements listed):

Code	Title	Units
Math 370	Introduction to Combinatorics	3
Math 371	Graph Theory	3
Math 410	Introduction to Fourier Series and Integrals	3
Math 4111	Introduction to Analysis	3
Math 415	Partial Differential Equations	3
Math 416	Complex Variables	3
Math 4171	Topology I	3
Math 429	Linear Algebra	3
Math 434	Survival Analysis	3
Math 4351	Number Theory and Cryptography	3
Math 439	Linear Statistical Models	3
Math 449	Numerical Applied Mathematics	3

The Major in Mathematics

Total units required: 30 units of upper-level courses, including the following:

Code	Title	Units
Math 310	Foundations for Higher Mathematics	3
Math 4111	Introduction to Analysis	3
Math 4121	Introduction to Lebesgue Integration	3
Math 429	Linear Algebra	3
Math 430	Modern Algebra	3
Math 416	Complex Variables	3
Math 4171	Topology I	3
At least one of the following:		
Math 407	An Introduction to Differential Geometry	3
Math 415	Partial Differential Equations	3
Math 4181	Topology II	3
Math 4351	Number Theory and Cryptography	3

The Major in Applied Mathematics

Total units required: 30 units of upper-level courses, including the following:

Code	Title	Units
Math 310	Foundations for Higher Mathematics	3
Math 4111	Introduction to Analysis	3
Math 4121	Introduction to Lebesgue Integration	3
Math 429	Linear Algebra	3
Math 449	Numerical Applied Mathematics	3
Math 450	Topics in Applied Mathematics	3
At least two of the following:		
Math 410	Introduction to Fourier Series and Integrals	3
Math 415	Partial Differential Equations	3
Math 416	Complex Variables	3
Math 4351	Number Theory and Cryptography	3

The Major in Statistics

Total units required: 30 units of upper-level courses, including the following:

Code	Title	Units
Math 309	Matrix Algebra	3
Math 3200	Elementary to Intermediate Statistics and Data Analysis	3
Math 493	Probability	3

Math 494	Mathematical Statistics	3
Math 439	Linear Statistical Models	3
Math 459	Bayesian Statistics	3
or Math 475	Statistical Computation	

- At least two probability or statistics courses at the 400 level or above

The Major in Mathematics and Computer Science

The McKelvey School of Engineering and the College of Arts & Sciences developed a new major that efficiently captures the intersection of the complementary studies of computer science and math.

McKelvey Engineering students who declare this major must fulfill the core course requirements listed below and all other requirements for the Applied Science degree (http://bulletin.wustl.edu/undergrad/engineering/requirements/) in the McKelvey School of Engineering. They must also complete Engr 310 Technical Writing and 8 units of courses designated as NSM (Natural Sciences & Math) from Anthropology (L48 Anthro), Biology and Biomedical Sciences (L41 Biol), Chemisty (L07 Chem), Earth and Planetary Sciences (L19 EPSc), Physics (L31 Physics) or Environmental Studies (L82 EnSt).

Arts & Sciences students who declare this major must fulfill the distribution requirements and all other requirements for an AB degree (http://bulletin.wustl.edu/undergrad/artsci/requirements/) in addition to the specific requirements listed below.

Core Course Requirements

Code	Title	Units
Math 131	Calculus I (AP credit may satisfy this requirement)	3
Math 132	Calculus II (AP credit may satisfy this requirement)	3
Math 233	Calculus III	3
CSE 131	Introduction to Computer Science	3
Math 310	Foundations for Higher Mathematics	3
or Math 310W	Foundations for Higher Mathematics with Writing	
or CSE 240	Logic and Discrete Mathematics	
CSE 247	Data Structures and Algorithms	3
Math 309	Matrix Algebra	3
Math 3200	Elementary to Intermediate Statistics and Data Analysis	3
or ESE 326	Probability and Statistics for Engineering	
CSE 347	Analysis of Algorithms	3

Electives

Eight upper-level courses from Math or Computer Science & Engineering can be chosen from an approved list (https://docs.google.com/spreadsheets/d/1nVxiw2jVScJ7tpwThw5OQ6vPiljGmyAi19Q37_RBsxQ/edit/#gid=0), with the following caveats:

- No fewer than three courses can be chosen from each department.
- Up to two preapproved courses from outside both departments can be selected.

The Major in Mathematics and Economics

Required courses:

Code	Title	Units
CSE 131	Introduction to Computer Science	3
Econ 1011	Introduction to Microeconomics	3
Econ 1021	Introduction to Macroeconomics	3
Econ 4011	Intermediate Microeconomic Theory	3
Econ 4021	Intermediate Macroeconomic Theory	3
Econ 413	Introduction to Econometrics	3
or Econ 413W	Introduction to Econometrics with Writing	
Math 131	Calculus I	3
Math 132	Calculus II	3
Math 233	Calculus III	3
Math 309	Matrix Algebra	3
Math 3200	Elementary to Intermediate Statistics and Data Analysis	3
or Math 493	Probability	
Math 310	Foundations for Higher Mathematics	3

Elective courses:

Majors must complete seven electives, with three in each discipline and one from either department.

In Economics:

One of the three electives can be any economics course with Econ 4011 or Econ 4021 as a prerequisite, including from an approved study abroad program. The other two economics electives must come from the following list:

Code	Title	Units
Econ 404	Behavioral Economics and Experimental Economics	3
Econ 407	Market Design	3
Econ 410	Macroeconomics of Inequality	3
Econ 4151	Applied Econometrics	3
Econ 435	Open Economy Macroeconomics	3

Econ 437	The Economics of Financial Intermediation	3
Econ 452	Industrial Organization	3
Econ 460	Urban Economics	3
Econ 467	Game Theory	3
Econ 471	Development Economics	3
Econ 477	Topics in Financial Economics: Asset Pricing	3
Econ 480	Labor Economics	3
Econ 484	Computational Macroeconomics	3

- With instructor permission, students may use any of the following for economics elective credit: Econ 501, Econ 502, Econ 503, Econ 504, Econ 511, or Econ 513.
- Econ 413 may be taken from an approved study abroad program. Consult with Academic Coordinator Dorothy Petersen in the Department of Economics for more information.

In Mathematics:

For Mathematics, the electives can come from the following list:

Code	Title	Units
Math 410	Introduction to Fourier Series and Integrals	3
Math 415	Partial Differential Equations	3
Math 416	Complex Variables	3
Math 4111	Introduction to Analysis	3
Math 4121	Introduction to Lebesgue Integration	3
Math 429	Linear Algebra	3
Math 439	Linear Statistical Models	3
Math 4392	Advanced Linear Statistical Models	3
Math 449	Numerical Applied Mathematics	3
Math 450	Topics in Applied Mathematics	3
Math 460	Multivariate Statistical Analysis	3
Math 461	Time Series Analysis	3
Math 462	Mathematical Foundations of Big Data	3
Math 475	Statistical Computation	3
Math 494	Mathematical Statistics	3
Math 495	Stochastic Processes	3
Math 459	Bayesian Statistics	3

Advising, Questions, and Further Considerations:

- Students may declare a prime or a second major in Math + Economics via L24 (Math) or L11 (Econ), and that will determine their major adviser.
- It is possible to earn the Certificate in Financial Economics in conjunction with this major (prime or second).
- It is possible to graduate with Latin Honors or with "English" honors. Students should refer to the departments' websites or consult with either Professor Blake Thornton (bthornton@wustl.edu) in the Department of Mathematics and Statistics or Academic Coordinator Dorothy Petersen (dottie@wustl.edu) in the Department of Economics for more information.
- Substitutions for mathematics courses and study abroad approval for mathematics courses will be determined by the Department of Mathematics and Statistics.
- Substitutions for economics courses and study abroad approval will be determined by Academic Coordinator Dorothy Petersen in the Department of Economics.
- Substitutions for CSE 131 are subject to approval by the McKelvey School of Engineering.

The Bachelor of Science in Data Science

The McKelvey School of Engineering and the College of Arts & Sciences developed a new major that efficiently captures the intersection of mathematics and statistics with computer science for data science. The Bachelor of Science in Data Science (BSDS) will give students the formal foundation needed to understand the applicability and consequences of the various approaches to analyzing data with a focus on statistical modeling and machine learning.

McKelvey Engineering students who declare this major must fulfill the core course requirements listed below and all other requirements for the Applied Science degree (http://bulletin.wustl.edu/undergrad/engineering/requirements/) in the McKelvey School of Engineering. They must also complete Engr 310 Technical Writing and 8 units of courses designated as NSM (Natural Sciences & Math) from Anthropology (L48 Anthro), Biology and Biomedical Sciences (L41 Biol), Chemistry (L07 Chem), Earth and Planetary Sciences (L19 EPSc), Physics (L31 Physics) or Environmental Studies (L82 EnSt).

Arts & Sciences students who declare this major must fulfill the distribution requirements and all other requirements for an AB degree (http://bulletin.wustl.edu/undergrad/artsci/requirements/) in addition to the specific requirements listed below.

Data Science Core Requirements

Code	Title	Units
Math 131	Calculus I	3
Math 132	Calculus II	3
Math 233	Calculus III	3
CSE 131	Introduction to Computer Science	3
CSE 247	Data Structures and Algorithms	3
CSE 217A	Introduction to Data Science	3
CSE 314A	Data Manipulation and Management	3

Math 309	Matrix Algebra	3
Math 3211	Statistics for Data Science I	3
Math 4211	Statistics for Data Science II	3
Math 439	Linear Statistical Models	3
CSE 417T	Introduction to Machine Learning (or Math 4601)	3

Data Science Technical Electives

Four courses from Mathematics & Statistics or Computer Science & Engineering can be chosen from an approved list (https://docs.google.com/document/d/1NiVuvtLjsdLxde9fdYVNjAkWQFr2ADY-jyIC3yb96wY/edit/), with the following caveats:

- At least one course from Mathematics & Statistics (at the 400 level or above)
- At least one course from CSE (ending in S, T, M, or A)

Ethics and Professional Responsibility Requirement

- One course (3 units) from an approved list (https://docs.google.com/document/d/1dGO9VXCY94IpDrF1oRBm7rWP4lLlUzU7UBsD6WbEmDc/edit/)

Practicum Requirement

- 3 units of CSE 400E Independent Study taken at the same time the student is embedded in a research group (on campus or in a company) or industry, with a sponsor or adviser serving as the student's mentor

Notes to All Majors in Mathematics and Statistics

1. Students who entered Washington University **before fall 2020** should visit the Prior Bulletins (http://bulletin.wustl.edu/prior/) section of this *Bulletin* to view the major requirements that were in place for the appropriate year of matriculation.
2. Upper-level mathematics courses are those with course numbers that begin with a "3" or higher (e.g., Math 3200). Lower-level courses do not count toward upper-level mathematics requirements, even if they are cross-listed as an upper-level course in another department or program. For example, if Math 2200 were cross-listed by another department as 3XXX, then registering for that 3XXX course would not satisfy an upper-level mathematics requirement.
3. All required courses (both lower- and upper-level courses) must be completed with a grade of C- or better.
4. Math 318 and Math 308 cannot both be used to fulfill major requirements.
5. Courses transferred from other accredited colleges and universities with department approval can be counted, with the following caveats:
   a. Courses transferred from a two-year college (e.g., a community college) cannot be used to satisfy upper-level requirements.
   b. At least half the upper-level units required in a major must be earned at Washington University or in a Washington University-approved overseas study program.
   c. Courses from University College cannot be used to fulfill major requirements.
6. At most 3 units of independent study or research work can count toward the major requirements.
7. No **upper-level** course used to satisfy a major requirement can be counted toward the requirements of any other major or minor (i.e,. no double-counting of courses).
8. Certain approved substitutions are found on the Department of Mathematics and Statistics webpage (https://math.wustl.edu/major-and-minor-details/). However, in all cases, at most one substitution can be used that involves a course not home-based in the department.

Additional Information

Additional Requirements

- All mathematics majors must take Math 131 Calculus I, Math 132 Calculus II, and Math 233 Calculus III. There are other ways to fulfill this requirement, including AP credit and Math 203 Honors Mathematics I-Math 204 Honors Mathematics II. Some students may obtain a waiver if they took similar courses before coming to Washington University.
- All required courses must be completed with a letter grade of C- or better.
- University College courses cannot be counted toward major requirements.
- No double-counting of upper-level courses with other majors or minors is allowed.
- At most 3 units for independent study or research work can count toward the major requirements.
- At most 3 units from a different department at Washington University can count toward the major requirements.
- Courses transferred from other accredited colleges and universities can be counted toward a major or minor with departmental approval.
- At least half of the upper-level credits required in a mathematics major or minor program must be fulfilled by Department of Mathematics and Statistics courses taken at Washington University or in Washington University–approved overseas study programs.
- A student cannot declare more than one major or minor in the department.

Course Substitutions

At most one approved substitution can be made using a course not home-based in the Department of Mathematics and Statistics. Please note the policy that at most one course from a different department at Washington University can count toward a major or minor.

- ESE 326 can be taken in place of Math 3200. ESE 326 and Math 3200 cannot both count toward a major or minor.
- Any course from another department that is cross-listed as a mathematics L24 course can count as an upper-level elective. Examples include L24 501C, L24 440C, and L24 403C. Such L24 courses always end with a "C."
- The following courses can count as upper-level mathematics electives:
  - L30 Phil 401, Phil 403, and Phil 404
  - Econ 4151 (this course can count as a statistics elective)
  - ESE 319, ESE 403, and E35 ESE 411

Courses in Probability and Statistics

The major and minor in statistics require electives in probability and statistics. Below is the list of allowed such courses:

- Math 3200 Elementary to Intermediate Statistics and Data Analysis
- Math 322 Biostatistics
- Math 420 Experimental Design
- Math 434 Survival Analysis
- Math 439 Linear Statistical Models
- Math 4392 Advanced Linear Statistical Models
- Math 459 Bayesian Statistics
- Math 460 Multivariate Statistical Analysis
- Math 461 Time Series Analysis
- Math 462 Mathematical Foundations of Big Data
- Math 475 Statistical Computation
- Math 493 Probability
- Math 494 Mathematical Statistics
- Math 495 Stochastic Processes
- Math 496: Topics In Statistics

Distinctions in Mathematical Sciences, Mathematics, Applied Mathematics and Statistics

Distinction

- Complete at least 33 units of upper-level mathematics and/or statistics courses.
- The GPA for these 33 upper-level units must be at least 3.7. If more than 33 units are taken for a letter grade, then the courses with the lowest grades can be omitted when computing GPA for this purpose.
- Complete at least five courses, each with a B or better, at level 400+.
- All of these courses must be classroom courses (not independent study or study for honors), and they must all be taken for a letter grade.

High Distinction

- Complete all requirements for Distinction.
- Complete an honors thesis.

Highest Distinction

- Complete at least five courses, each with a grade of B+ or better, at the 400 level or higher.
- Complete one of the two paths described below:
  - **Graduate Qualifier Path:** Graduate qualifier courses in mathematics and statistics are two-semester sequences that start in the fall. In mathematics, a two-semester graduate qualifier sequence has a qualifier exam at the end of each semester. In statistics, a two-semester sequence has a qualifier exam only at the end of the sequence in spring.
    Students must complete and pass one of the following:
    a. Two semesters of qualifier courses* and their corresponding exams in mathematics (These courses can involve a single year-long sequence or be the first semesters of two different sequences.)
    b. One full-year qualifier course sequence* and its corresponding exam in statistics
  - **Course Work Path:**
    1. Complete at least 42 units of upper-level mathematics and/or statistics courses. The GPA for these 42 upper-level units must be at least 3.7. If more than 42 units are taken for a letter grade, then the courses with the lowest grades can be omitted when computing GPA for this purpose.
    2. Complete at least nine total courses at the 400 level or above, all with a B+ or better. These can include the five courses taken for distinction. All of these courses must be classroom courses (not independent study or study for honors), and they must all be taken for a letter grade.

* These qualifier courses can count toward the additional course requirements for Distinction.

Distinctions in Mathematics and Computer Science

Distinction

- For Distinction in Mathematics and Computer Science, a student must take an additional two electives, for a total of 10 electives.
- The student's GPA in the 10 electives must be at least 3.7. If the student takes additional courses that satisfy these requirements, then the courses with the lowest grades may be omitted when calculating GPA for this purpose.
- The student must complete at least four courses from the list of approved courses, each with a grade of B or better. These courses can be in either department (i.e., Mathematics and Statistics or Computer Science & Engineering). The list of courses will be maintained by both departments. Current approved courses include the following:
  - Math 4111, Math 4351, Math 429, Math 439, Math 4392, Math 449, Math 450, Math 456, Math 459, Math 461, Math 475, Math 494, Math 470, Math 4111, Math 4121, Math 4171, Math 4181
  - CSE 411A, CSE 416A, CSE 417T, CSE 427S, CSE 442T, CSE 468T, CSE 511A, CSE 513T, CSE 514A, CSE 515T, CSE 516A, CSE 517A, CSE 518A, CSE 541T, CSE 543T, CSE 544T, CSE 546T, CSE 547T, CSE 554A, CSE 581T, CSE 587A

High Distinction

- Complete all requirements for Distinction.
- Complete an honors thesis in either department (Mathematics and Statistics or Computer Science & Engineering).

Highest Distinction

- Complete the requirements for High Distinction.
- Complete one of the two options described below:
  - **Qual Option:** Complete two semesters of graduate course work and qualifier exams in the Department of Mathematics and Statistics, as described above for Highest Distinction for mathematics and statistics majors.
  - **Course Option:** Complete three additional electives, for a total of 13. As with Distinction, the student's GPA in the 13 electives must be at least 3.7, and additional courses beyond 13 can be disregarded when calculating the GPA. The 13 electives must include at least eight courses selected from the list under Distinction, each with a grade of B+ or better. At least two of these eight courses must be from each department (Mathematics and Statistics and Computer Science & Engineering).

Latin Honors

At the time of graduation, the Department of Mathematics and Statistics will recommend that a candidate receive Latin Honors (cum laude, magna cum laude, or summa cum laude) if that student has completed the department's requirements for High Distinction or Highest Distinction in Mathematics, each of which requires an Honors Thesis. The College of Arts & Sciences will then approve the recommendation if the student's final cumulative overall GPA is at least 3.65 (subject to change by the College).

The Honors Thesis

Arts & Sciences mathematics and statistics majors who want to be candidates for Latin Honors, High Distinction, or Highest Distinction must complete an honors thesis. Writing an honors thesis involves a considerable amount of independent work, reading, creating mathematics, writing a paper that meets acceptable professional standards, and making an oral presentation of results.

Types of Projects

An honors thesis can take three forms:

1. A thesis that presents significant work by the student on one or more nontrivial mathematics problems.
2. A project in mathematical or applied statistics that involves an in-depth analysis of a large data set. To do an honors thesis involving data analysis, it is usually necessary to have completed Math 3200-Math 493-Math 494 by the end of the junior year and to have the ability to work with statistical software such as SAS, R, or Python.
3. A substantial expository paper that follows independent study on an advanced topic under the guidance of a department faculty member. Such a report would involve the careful presentation of ideas and the synthesis of materials from several sources.

Process and Suggested Timeline

Junior Year, Spring Semester:

1. Talk with a faculty adviser about possible projects.
2. Complete the Honors Proposal Form and submit it to Blake Thornton.

Senior Year:

1. By the end of January, provide the adviser with a draft abstract and outline of the paper.
2. By the end of February, submit a rough draft, including an abstract, to the adviser.
3. The student and the adviser should agree on a date that the writing will be complete and on a data and time for the oral presentation in mid-March (the deadline is March 31).

Departmental Prizes

Each year, the department considers graduating majors for three departmental prizes. Recipients are recognized at an annual awards ceremony in April, where they each receive a certificate and a set of honors cords to be worn as part of the academic dress at Commencement. Awards are noted on the student's permanent university record.

Ross Middlemiss Prize

The Ross Middlemiss Prize is awarded to a graduating math major with an outstanding record. The award was established by former Professor Ross Middlemiss, who taught at Washington University for 40 years. From 1936 through the 1960s, Middlemiss authored several books, including a widely popular calculus text that was used in University College courses until the late 1970s.

Putnam Exam Prize

The Putnam Exam Prize is awarded to a graduating senior who has participated regularly in the Putnam Exam Competition and done exceptionally well throughout their time at Washington University.

Martin Silverstein Award

The Martin Silverstein Award was established in memory of Professor Martin Silverstein, who, until his death in 2004, was a pioneer in work at the interface of probability theory and harmonic analysis. Each year, the department considers for this award students in any major track, but especially those with strengths in probability or statistics.

Brian Blank Award

The Brian Blank Award was established in memory of Professor Brian Blank, who passed away in 2018. Each year, the Department of Mathematics and Statistics selects for this prize distinguished junior(s) majoring in mathematics and statistics.

Minors

The Minor in Mathematics

Units required: 27

Required courses:

Code	Title	Units
CSE 131	Introduction to Computer Science	3
Math 131	Calculus I	3
Math 132	Calculus II	3
Math 233	Calculus III	3
Math 309	Matrix Algebra	3
or Math 429	Linear Algebra	
Math 310	Foundations for Higher Mathematics (or any 400-level course with Math 310 as a prerequisite)	3
Three additional upper-level electives (any 300- or 400-level course in the Department of Mathematics & Statistics)		9
Total Units		27

The Minor in Statistics

Units required: 27

Required courses:

Code	Title	Units
CSE 131	Introduction to Computer Science	3
Math 131	Calculus I	3
Math 132	Calculus II	3
Math 233	Calculus III	3
Math 309	Matrix Algebra	3
or Math 429	Linear Algebra	
Math 3200	Elementary to Intermediate Statistics and Data Analysis	3
or Math 494	Mathematical Statistics	
Three upper-level statistics electives chosen from the list below		9
Total Units		27

Statistics electives:

Code	Title	Units
Math 3200	Elementary to Intermediate Statistics and Data Analysis	3
Math 322	Biostatistics	3
Math 420	Experimental Design	3
Math 434	Survival Analysis	3
Math 439	Linear Statistical Models	3
Math 4392	Advanced Linear Statistical Models	3
Math 459	Bayesian Statistics	3
Math 460	Multivariate Statistical Analysis	3
Math 461	Time Series Analysis	3
Math 462	Mathematical Foundations of Big Data	3
Math 475	Statistical Computation	3
Math 493	Probability	3
Math 494	Mathematical Statistics	3
Math 495	Stochastic Processes	3
Math 496	Topics in Statistics	3

Additional Information

1. Students who entered Washington University **before fall 2015** should visit the Prior Bulletins (http://bulletin.wustl.edu/prior/) section of this *Bulletin* to view the minor requirements that were in place for the appropriate year of matriculation. These requirements can also be found from the department's undergraduate webpage (https://math.wustl.edu/major-and-minor-details/).
2. All required courses (both lower- and upper-level courses) must be completed with a letter grade of C- or better.
3. Math 318 and Math 308 cannot both be used to fulfill minor requirements.
4. Courses transferred from other accredited colleges and universities with department approval can be counted, with the following caveats:
   a. Courses transferred from a two-year college (e.g., a community college) cannot be used to satisfy upper-level requirements.
   b. At least 6 of the upper-level units required in a minor must be earned at Washington University or in a Washington University–approved overseas study program.
   c. Courses from University College cannot be used to fulfill minor requirements.
5. No upper-level course used to satisfy a minor requirement can be counted toward the requirements of any other major or minor (i.e., no double-counting of courses).
6. At most one approved upper-level course from another department may be used for the upper-level courses for the minor. Approved substitutions can be found on the Department of Mathematics and Statistics webpage (https://math.wustl.edu/major-and-minor-details/).

Courses

Visit online course listings to view semester offerings for L24 Math (https://courses.wustl.edu/CourseInfo.aspx?sch=L&dept=L24&crslvl=1:4).

L24 Math 100 Foundations for Calculus
A limited enrollment class for students planning to take calculus but who need additional precalculus preparation. The course aims to build both the technical skills and the conceptual understanding needed to succeed in calculus. Course emphasizes links between the graphical, numeric and algebraic viewpoints. A variety of approaches are used to present the material. Prerequisites: two years of high school algebra and a course in geometry (or the equivalent).
Credit 3 units. A&S IQ: NSM

L24 Math 1011 Introduction to Statistics
Basic concepts of statistics. Data collection (sampling, designing experiments), data organization (tables, graphs, frequency distributions, numerical summarization of data), statistical inference (elementary probability and hypothesis testing). Prerequisite: two years of high school algebra.
Credit 3 units. A&S IQ: NSM, AN Arch: NSM Art: NSM

L24 Math 109 Mathematics and Music
An elementary introduction to the connections between mathematics and musical sound. Review of integers, ratios, prime numbers, functions, rationality, exponents, logarithms, trigonometry. Review of scales, clefs, key signatures, intervals, time signatures. Frequency and pitch. The connection between intervals and logarithms. Tuning and temperament, just intonation. Scales and modular arithmetic. The mathematics of harmony; the sound of the low prime numbers and their roles in harmony. Harmonics, partials and overtones. Numerical integration and basic Fourier analysis. The nature of complex tones. Analysis of instrument sounds. Human vowels and formants. Prerequisites: two years of high school algebra, and trigonometry.
Credit 3 units. A&S IQ: NSM, AN Arch: NSM Art: NSM

L24 Math 131 Calculus I
Derivatives of algebraic, trigonometric and transcendental functions, techniques of differentiation, Mean Value Theorem, applications of the derivative. The definite integral and Fundamental Theorem of Calculus. Areas. Simpler integration techniques. Prerequisites: high-school algebra and precalculus, including trigonometry.
Credit 3 units. A&S IQ: NSM, AN Arch: NSM Art: NSM

L24 Math 131E Calculus I Extended
Math 131E covers the same content as Math 131 but includes the additional review of precalculus concepts integrated throughout the semester. It is aimed at students whose precalculus skills are not yet fully developed. By the end of this course, students should be ready to enroll in Math 132.
Credit 4 units. A&S IQ: NSM, AN Arch: NSM Art: NSM

L24 Math 132 Calculus II
Continuation of Math 131. A brief review of the definite integral and Fundamental Theorem of Calculus. Techniques of integration, applications of the integral, sequences and series, Taylor polynomials and series, and some material on differential equations. Prerequisite: Math 131 or a B or better in a one-year high school calculus course, or permission of the department.
Credit 3 units. A&S IQ: NSM, AN Arch: NSM Art: NSM

L24 Math 139A Real Mathematical Applications: Solving Problems with Calculus I
The purpose of this course is to show how mathematics can solve real-world problems and how calculus dramatically expands the range of problems that can be tackled. Each class will be devoted to the analysis of some problems, which may include dimensional analysis, the mathematics of convoys, Fibonacci numbers, fractals, linear regression, Euclid's algorithm, Stein's algorithm, network capacities, Braess's paradox, Galton's approach to surnames, how genes

spread through populations, and the SIR model of infectious diseases. The first few classes will not use differentiation. Course enrollment preference is given to first-year students. Corequisite: Math 131.
Credit 1 unit. A&S: FYO Arch: NSM Art: NSM

L24 Math 203 Honors Mathematics I
This is the first half of a one-year calculus sequence for first year students with a strong interest in mathematics with an emphasis on rigor and proofs. The course begins at the beginning but assumes the students have already studied the material from a more "mechanical" view. Students who complete both semesters will have completed the material Calc III and other topics that may let them move through the upper-level math curriculum more quickly. Sets, functions, real numbers, and methods of proof. The Riemann-Darboux integral, limits and continuity, differentiation, and the fundamental theorems of calculus. Sequences and series of real numbers and of functions. Vector spaces and linear maps. Prerequisite: Score of 5 on the AP Calculus Exam, BC version, or the equivalent.
Credit 4 units. A&S IQ: NSM, AN Arch: NSM Art: NSM

L24 Math 204 Honors Mathematics II
Matrices, linear systems, and determinants. Eigenvalues and eigenvectors, diagonalization, and the spectral theorem. Scalar and vector fields, differential and integral calculus of several variables, and the fundamental theorems of Green, Gauss, and Stokes. Restricted to first year students who have completed Math 203 in the fall semester. Math 204 can replace Math 233 in major/minor requirements.
Credit 4 units. A&S IQ: NSM, AN Art: NSM

L24 Math 217 Differential Equations
Introduction to ordinary differential equations: first-order equations, linear equations, systems of equations, series solutions, Laplace transform methods, numerical solutions. Prerequisite: Math 233 (or Math 233 concurrently).
Credit 3 units. A&S IQ: NSM, AN Arch: NSM Art: NSM

L24 Math 220 Finite Mathematics
Topics from discrete mathematics will be explored with an emphasis on problem-solving and methods of proofs. Modules on counting; combinatorial tools; binomial coefficients and Pascal's triangle; Fibonacci numbers; combinatorial probability; integers, divisors and primes; and graphs will be covered as well as additional topics as time permits. Addressed mainly to college freshmen and sophomores; it would also be suitable to advanced high school students with an interest in mathematics. Prerequisites: A good understanding of high school mathematics.
Credit 3 units. A&S IQ: NSM, AN Art: NSM

L24 Math 2200 Elementary Probability and Statistics
An elementary introduction to statistical concepts, reasoning and data analysis. Topics include statistical summaries and graphical presentations of data, discrete and continuous random variables, the logic of statistical inference, design of research studies, point and interval estimation, hypothesis testing, and linear regression. Students will learn a critical approach to reading statistical analyses reported in the media, and how to correctly interpret the outputs of common statistical routines for fitting models to data and testing hypotheses. A major objective of the course is to gain familiarity with basic R commands to implement common data analysis procedures. Students intending to pursue a major or minor in mathematics or wishing to take 400-level or above statistics courses should instead take Math 3200. Prerequisite: Math 131.
Credit 3 units. A&S IQ: NSM, AN Arch: NSM Art: NSM

L24 Math 233 Calculus III
Multivariable calculus. Topics include differential and integral calculus of functions of two or three variables: vectors and curves in space, partial derivatives, multiple integrals, line integrals, vector calculus at least through Green's Theorem. Prerequisite: Math 132 or a score of 4-5 on the Advanced Placement Calculus Exam (BC version).
Credit 3 units. A&S IQ: NSM, AN Arch: NSM Art: NSM

L24 Math 302 Elementary Geometry from an Advanced Point of View
A rigorous modern treatment of Euclidean geometry and an introduction to non-Euclidean geometry. Prerequisite: Math 310 or permission of instructor.
Credit 3 units. A&S IQ: NSM Arch: NSM Art: NSM

L24 Math 308 Mathematics for the Physical Sciences
Continuation of Math 233 emphasizing topics of interest in the physical sciences. Topics in multivariable and vector calculus (div, grad, curl); line, surface integrals and connections to electromagnetism; Fourier series and integrals; boundary value problems (diffusion and wave equations); additional topics if time permits. Students may not receive credit toward a math major or minor for both Math 308 and Math 318. Prerequisite: Math 233 and 217, or permission of instructor.
Credit 3 units. A&S IQ: NSM Arch: NSM Art: NSM BU: SCI

L24 Math 309 Matrix Algebra
An introductory course in linear algebra that focuses on Euclidean n-space, matrices and related computations. Topics include: systems of linear equations, row reduction, matrix operations, determinants, linear independence, dimension, rank, change of basis, diagonalization, eigenvalues, eigenvectors, orthogonality, symmetric matrices, least square approximation, quadratic forms. Introduction to abstract vector spaces. Prerequisite: Math 132.
Credit 3 units. A&S IQ: NSM, AN Arch: NSM Art: NSM

L24 Math 310 Foundations for Higher Mathematics
Introduction to the rigorous techniques used in more advanced mathematics. Topics include postpositional logic, use of quantifiers, set theory, methods of proof and disproof (counterexamples), foundations of mathematics. Use of these tools in the construction of number systems and in other areas such as elementary number theory, combinatorial arguments and elementary proofs in analysis. Prerequisite: Math 233.
Credit 3 units. A&S IQ: NSM Arch: NSM Art: NSM

L24 Math 310W Foundations for Higher Mathematics with Writing
Introduction to the rigorous techniques used in more advanced mathematics. Topics include basic logic, set theory, methods of proof and counterexamples, foundations of mathematics, construction of number systems, counting methods, combinatorial arguments and elementary analysis. At least 3 papers will be required, which with at least one revision. Prerequisite: Math 233.
Credit 3 units. A&S IQ: NSM, WI

L24 Math 312 Differential Equations and Dynamical Systems
Qualitative theory of ordinary differential equations. Picard's existence and uniqueness theorem, the phase plane, Poincare-Bendixon theory, stationary points, attractors and repellors, graphical methods. Physical applications, including chaos, are indicated. Prerequisite: Math 217.
Credit 3 units. A&S IQ: NSM Arch: NSM Art: NSM

L24 Math 318 Introduction to Calculus of Several Variables
Selected topics for functions of several variables involving some matrix algebra and presented at a level of rigor intermediate between that of Calculus III and higher-level analysis courses. Students may not receive credit toward a mathematics major or minor for both Math 308 and 318. Prerequisites: Math 233 and Math 309.
Credit 3 units. A&S IQ: NSM Arch: NSM Art: NSM

L24 Math 3200 Elementary to Intermediate Statistics and Data Analysis
An introduction to probability and statistics. Major topics include elementary probability, special distributions, experimental design, exploratory data analysis, estimation of mean and proportion, hypothesis testing and confidence, regression, and analysis of variance. Emphasis is placed on development of statistical reasoning, basic analytic skills, and critical thinking in empirical research studies. The use of the statistical software R is integrated into lectures and weekly assignments. Required for students pursuing a major or minor in mathematics or wishing to take 400-level or above statistics courses. Prerequisite: Math 132. Though Math 233 is not essential, it is recommended.
Credit 3 units. A&S IQ: NSM, AN Arch: NSM Art: NSM

L24 Math 3211 Statistics for Data Science I
Credit 3 units. A&S IQ: NSM, AN

L24 Math 322 Biostatistics
A second course in elementary statistics with applications to life sciences and medicine. Review of basic statistics using biological and medical examples. New topics include incidence and prevalence, medical diagnosis, sensitivity and specificity, Bayes' rule, decision making, maximum likelihood, logistic regression, ROC curves and survival analysis. Prerequisites: Math 3200, or a strong performance in Math 2200 and permission of the instructor.
Credit 3 units. A&S IQ: NSM Arch: NSM Art: NSM

L24 Math 331 Algebraic Systems
Polynomials, binomial expansions, factoring, rings (integers and polynomials), unique factorization, and other topics relevant to the high school curriculum. Designed for future secondary school teachers and other students looking for a course in algebra at a less abstract level than Math 430. Prerequisite: Math 310 or permission of instructor.
Credit 3 units. A&S IQ: NSM Arch: NSM Art: NSM

L24 Math 370 Introduction to Combinatorics
Basics of enumeration (combinations, permutations and enumeration of functions between finite sets), generating functions; the inclusion-exclusion principle, partition theory and introductory graph theory. As time permits, additional topics may include Ramsey's Theorem, probabilistic methods in combinatorics and algebraic methods in combinatorics. Prerequisites: Math 132, 309 and 310, or permission of the instructor.
Credit 3 units. A&S IQ: NSM, AN Arch: NSM Art: NSM

L24 Math 371 Graph Theory
Introduction to graph theory including the basic definitions and theorems and some more advanced topics that drive much current research in graph theory: Ramsey's Theorem, random graph theory and, if time permits, Szemeredi's regularity lemma. Graphs are studied as abstract objects; however, graph theory is also of interest to applied mathematicians because graphs are natural models for networks (social, electric). Prerequisite: Math 310 or a roughly equivalent course, or permission of instructor. Students should know what a proof is and how to produce one. Some informal understanding of probability is helpful, but students need not have taken a probability course.
Credit 3 units. A&S IQ: NSM Arch: NSM Art: NSM

L24 Math 407 An Introduction to Differential Geometry
A study of properties of curves and surfaces in 3-dimensional Euclidean space. The course is essentially a modern recounting of a seminal paper of Gauss. Prerequisites: Math 233, Math 309, Math 310.
Credit 3 units. A&S IQ: NSM

L24 Math 410 Introduction to Fourier Series and Integrals
The basic theory of Fourier series and Fourier integrals including different types of convergence. Applications to certain differential equations. Prerequisites, Math 233, Math 309, Math 310.
Credit 3 units. A&S IQ: NSM

L24 Math 4111 Introduction to Analysis
The real number system and the least upper-bound property; metric spaces (completeness, compactness and connectedness); continuous functions (in R^n; on compact spaces; on connected spaces); C(X) (pointwise and uniform convergence; Weierstrass approximation theorem); differentiation (mean value theorem; Taylor's theorem); the contraction mapping theorem; the inverse and implicit function theorems. Prerequisite: Math 310 or permission or instructor.
Credit 3 units. A&S IQ: NSM Arch: NSM Art: NSM

L24 Math 4121 Introduction to Lebesgue Integration
Riemann integration; measurable functions; measures; Lebesgue measure; the Lebesgue integral; integrable functions; L^p spaces; modes of convergence; decomposition of measures; product measures. Prerequisite: Math 4111 or permission of the instructor.
Credit 3 units. A&S IQ: NSM Arch: NSM Art: NSM

L24 Math 415 Partial Differential Equations
Introduction to the theory of PDE's with applications to selected classical problems in physics and engineering. Linear and quasilinear first order equations, derivation of some of the classical PDE's of physics, and standard solution techniques for boundary and initial value problems. Preliminary topics such as orthogonal functions, Fourier series, and variational methods introduced as needed. Prerequisites: Math 217, Math 309, Math 310, or permission of instructor.
Credit 3 units. A&S IQ: NSM Arch: NSM Art: NSM

L24 Math 416 Complex Variables
Analytic functions, elementary functions and their properties, line integrals, the Cauchy integral formula, power series, residues, poles, conformal mapping and applications. Prereq: Math 310 and (Math 318 or Math 4111), or permission of instructor.
Credit 3 units. A&S IQ: NSM Art: NSM

L24 Math 4171 Topology I
An introduction to the most important ideas of topology. Course includes necessary ideas from set theory, topological spaces, subspaces, products and quotients, compactness and connectedness. Some time is also devoted to the particular case of metric spaces (including topics such as separability, completeness, completions, the Baire Caregory Theorem, and equivalents of compactness in metric spaces). Prerequisite: Math 310 or permission of instructor.
Credit 3 units. A&S IQ: NSM

L24 Math 4181 Topology II
A continuation of Math 4171 featuring more advanced topics in topology. The content may vary with each offering. Prerequisite: Math 4171, or permission of instructor.
Credit 3 units. A&S IQ: NSM Arch: NSM Art: NSM

L24 Math 420 Experimental Design
A first course in the design and analysis of experiments, from the point of view of regression. Factorial, randomized block, split-plot, Latin square, and similar design. Prerequisite: CSE 131 or 200, Math 3200, or permission of instructor.
Credit 3 units. A&S IQ: NSM Arch: NSM Art: NSM

L24 Math 429 Linear Algebra
This course is an introduction to the linear algebra of finite-dimensional vector spaces. It includes systems of equations, matrices, determinants, inner product spaces, and spectral theory. Prerequisite: Math 310 or permission of instructor. Math 309 is not an explicit prerequisite, but students should already be familiar with such basic topics from matrix theory as matrix operations, linear systems, row reduction, and Gaussian elimination. (Material on these topics in early chapters of the text will be covered very quickly.)
Credit 3 units. A&S IQ: NSM Art: NSM

L24 Math 430 Modern Algebra
Introduction to groups, rings, and fields. Includes permutation groups, group and ring homomorphisms, field extensions, connections with linear algebra. Prerequisite: Math 310, Math 429 or permission of the instructor.
Credit 3 units. A&S IQ: NSM Arch: NSM Art: NSM

L24 Math 434 Survival Analysis
Life table analysis and testing, mortality and failure rates, Kaplan-Meier or product-limit estimators, hypothesis testing and estimation in the presence of random arrivals and departures, and the Cox proportional hazards model. Techniques of survival analysis are used in medical research, industrial planning and the insurance industry. Prerequisites: CSE 131 or 200, Math 309 and 3200, or permission of the instructor.
Credit 3 units. A&S IQ: NSM Art: NSM

L24 Math 4351 Number Theory and Cryptography
The course covers many of the basics of elementary number theory, providing a base from which to approach modern algebra, algebraic number theory and analytic number theory. It also introduces one of the most important real-world applications of mathematics, namely the use of number theory and algebraic geometry in public key cryptography. Topics from number theory involve divisibility (Euclidean algorithm, primes, Fundamental Theorem of Arithmetic), congruences (modular arithmetic, Chinese Remainder Theorem, primality testing and factorization). Topics from cryptography include RSA encryption, Diffie-Hellman key exchange and elliptic curve cryptography. Topics about algebraic numbers may be include if time permits. Prerequisites: Math 233, 309 and 310 (or permission of instructor).
Credit 3 units. A&S IQ: NSM Arch: NSM Art: NSM

L24 Math 436 Algebraic Geometry
Introduction to affine and projective algebraic varieties, the Zariski topology, regular and rational mappings, simple and singular points, divisors and differential forms, genus, the Riemann-Roch theorem. Prerequisites: Math 310, 429, and 430, or permission of the instructor.
Credit 3 units. A&S IQ: NSM Arch: NSM Art: NSM

L24 Math 439 Linear Statistical Models
Theory and practice of linear regression, analysis of variance (ANOVA) and their extensions, including testing, estimation, confidence interval procedures, modeling, regression diagnostics and plots, polynomial regression, colinearity and confounding, model selection, geometry of least squares, etc. The theory will be approached mainly from the frequentist perspective, and use of the computer (mostly R) to analyze data will be emphasized. Prerequisite: CSE 131 or 200, Math 3200 and a course in linear algebra (such as Math 309 or 429), or permission of instructor.
Credit 3 units. A&S IQ: NSM Arch: NSM Art: NSM

L24 Math 4392 Advanced Linear Statistical Models
Review of basic linear models relevant for the course; generalized linear models including logistic and Poisson regression (heterogeneous variance structure, quasilikelihood); linear mixed-effects models (estimation of variance components, maximum likelihood estimation, restricted maximum likelihood, generalized estimating equations), generalized linear mixed-effects models for discrete data, models for longitudinal data, optional multivariate models as time permits. The computer

software R will be used for examples and homework problems. Implementation in SAS will be mentioned for several specialized models. Prerequisites: Math 439 and a course in linear algebra (such as Math 309 or 429), or consent of instructor.
Credit 3 units. A&S IQ: NSM Arch: NSM Art: NSM

L24 Math 449 Numerical Applied Mathematics
Computer arithmetic, error propagation, condition number and stability; mathematical modeling, approximation and convergence; roots of functions; calculus of finite differences; implicit and explicit methods for initial value and boundary value problems; numerical integration; numerical solution of linear systems, matrix equations and eigensystems; Fourier transforms; optimization. Various software packages may be introduced and used. Prerequisites: CSE 200 or CSE 131 (or other computer background with permission of the instructor); Math 217 and Math 309.
Credit 3 units. A&S IQ: NSM Arch: NSM Art: NSM

L24 Math 450 Topics in Applied Mathematics
Topic may vary with each offering of the course. Prerequisites: CSE 131 (or 200) and Math 449, or permission of the instructor.
Credit 3 units. A&S IQ: NSM Arch: NSM Art: NSM

L24 Math 456 Topics in Financial Mathematics
An introduction to the principles and methods of financial mathematics, with a focus on discrete-time stochastic models. Topics include no-arbitrage pricing of financial derivatives, risk-neutral probability measures, the Cox-Ross-Rubenstein and Black-Scholes-Merton options pricing models, and implied volatility. Prerequisites: Math 233, Math 3200, Math 310 or permission of instructor.
Credit 3 units. A&S IQ: NSM Arch: NSM Art: NSM

L24 Math 459 Bayesian Statistics
Introduces the Bayesian approach to statistical inference for data analysis in a variety of applications. Topics include: comparison of Bayesian and frequentist methods, Bayesian model specification, choice of priors, computational methods such as rejection sampling, and stochastic simulation (Markov chain Monte Carlo), empirical Bayes method, hands-on Bayesian data analysis using appropriate software. Prerequisites: Math 493 and either Math 3200 or 494; or permission of the instructor. Some programming experience such as CSE 131 is also helpful (consult with the instructor).
Credit 3 units. A&S IQ: NSM Arch: NSM Art: NSM

L24 Math 460 Multivariate Statistical Analysis
A modern course in multivariate statistics. Elements of classical multivariate analysis as needed, including multivariate normal and Wishart distributions. Clustering; principal component analysis. Model selection and evaluation; prediction error; variable selection; stepwise regression; regularized regression. Cross-validation. Classification; linear discriminant analysis. Tree-based methods. Time permitting, optional topics may include nonparametric density estimation, multivariate regression, support vector machines, and random forests. Prerequisite: multivariable calculus (Math 233), linear or matrix algebra (Math 429 or Math 309), multivariable-calculus-based probability and mathematical statistics (Math 493, Math 494) and linear models (Math 439). Prior knowledge of R at the level introduced in Math 439 is assumed.
Credit 3 units. A&S IQ: NSM Arch: NSM Art: NSM

L24 Math 461 Time Series Analysis
Time series data types; autocorrelation; stationarity and nonstationarity; autoregressive moving average models; model selection methods; bootstrap confidence intervals; trend and seasonality; forecasting; nonlinear time series; filtering and smoothing; autoregressive conditional heteroscedasticity models; multivariate time series; vector autoregression; frequency domain; spectral density; state-space models; Kalman filter. Emphasis on real-world applications and data analysis using statistical software. Prerequisites: Math 493 and either Math 3200 or 494; or permission of the instructor. Some programming experience may also be helpful (consult with the instructor).
Credit 3 units. A&S IQ: NSM Arch: NSM Art: NSM

L24 Math 462 Mathematical Foundations of Big Data
Mathematical foundations of data science. Core topics include: probability in high dimensions; curses and blessings of dimensionality; concentration of measure; matrix concentration inequalities. Essentials of random matrix theory. Randomized numerical linear algebra. Data clustering. Depending on time and interests, additional topics will be chosen from: compressive sensing; efficient acquisition of data; sparsity; low-rank matrix recovery. Divide, conquer and combine methods. Elements of topological data analysis; point cloud; Cech complex; persistent homology. Selected aspects of high-dimensional computational geometry and dimension reduction; embeddings; Johnson-Lindenstrauss; sketching; random projections. Diffusion maps; manifold learning; intrinsic geometry of massive data sets. Optimization and stochastic gradient descent. Random graphs and complex networks. Combinatorial group testing. Prerequisite: multivariable calculus (Math 233), linear or matrix algebra (Math 429 or 309), and multivariable-calculus-based probability and mathematical statistics (Math 493-494). Prior familiarity with analysis, topology, and geometry is strongly recommended. A willingness to learn new mathematics as needed is essential.
Credit 3 units. A&S IQ: NSM Arch: NSM Art: NSM

L24 Math 475 Statistical Computation
Introduction to modern computational statistics. Pseudo-random number generators; inverse transform and rejection sampling. Monte Carlo approximation. Nonparametric bootstrap procedures for bias and variance estimation; bootstrap confidence intervals. Markov chain Monte Carlo methods; Gibbs and Metropolis-Hastings sampling; tuning and convergence diagnostics. Cross-validation. Time permitting, optional topics include numerical analysis in R, density estimation, permutation tests, subsampling, and graphical models. Prior knowledge of R at the level used in Math 494 is required. Prerequisite: Math 233, 309, 493, 494 (not concurrently); acquaintance with fundamentals of programming in R.
Credit 3 units. A&S IQ: NSM Arch: NSM Art: NSM

L24 Math 493 Probability
Mathematical theory and application of probability at the advanced undergraduate level; a calculus based introduction to probability theory. Topics include the computational basics of probability theory, combinatorial methods, conditional probability including Bayes' theorem, random variables and distributions, expectations and moments, the classical distributions, and the central limit theorem. permission of the instructor. Prerequisites: Math 233. Math 310 is recommended but not required.

Credit 3 units. A&S IQ: NSM Arch: NSM Art: NSM

L24 Math 494 Mathematical Statistics

Theory of estimation, minimum variance and unbiased estimators, maximum likelihood theory, Bayesian estimation, prior and posterior distributions, confidence intervals for general estimators, standard estimators and distributions such as the Student-t and F-distribution from a more advanced viewpoint, hypothesis testing, the Neymann-Pearson Lemma (about best possible tests), linear models, and other topics as time permits. Prerequisite: CSE 131 or 200, Math 3200 and 493, or permission of the instructor. Math 310 is recommended but not required.
Credit 3 units. A&S IQ: NSM Arch: NSM Art: NSM

L24 Math 495 Stochastic Processes

Content varies with each offering of the course. Past offerings have included such topics as random walks, Markov chains, Gaussian processes, empirical processes, Markov jump processes, and a short introduction to martingales, Brownian motion and stochastic integrals. Prerequisites: Math 233 and 493, or permission of instructor. Math 310 is recommended but not required.
Credit 3 units. A&S IQ: NSM Arch: NSM Art: NSM

L24 Math 4971 Topics in Mathematics: Stochastic Differential Equations

Credit 3 units.
