# MATHEMATICAL AND COMPUTATIONAL SCIENCE

Courses offered by Mathematical and Computational Science program are listed under the subject code MCS on the Stanford Bulletin's ExploreCourses (http://explorecourses.stanford.edu) website.

This interdisciplinary undergraduate degree program in MCS is sponsored by Stanford's departments of Mathematics, Computer Science, Management Science & Engineering, and Statistics, providing students with a core of mathematics basic to all the mathematical sciences and an introduction to concepts and techniques of computation, optimal decision making, probabilistic modeling, and statistical inference.

Utilizing the faculty and courses of the departments listed above, this major prepares students for graduate study or employment in the mathematical and computational sciences or in those areas of applied mathematics which center around the use of computers and are concerned with the problems of the social and management sciences. A biology option is offered for students interested in applications of mathematics, statistics, and computer science to the biological sciences (bioinformatics, computational biology, statistical genetics, neurosciences); and in a similar spirit, an engineering and statistics option.

## Undergraduate Mission Statement for Mathematical and Computational Science

The mission of the Mathematical and Computational Science Program is to provide students with a core of mathematics basic to all the mathematical sciences and an introduction to concepts and techniques of computation, optimal decision making, probabilistic modeling and statistical inference. The program is interdisciplinary in its focus, and students are required to complete course work in mathematics, computer science, statistics, and management science and engineering. A computational biology track is available for students interested in biomedical applications. The program prepares students for careers in academic, financial and government settings as well as for study in graduate or professional schools.

## Learning Outcomes

The program expects undergraduate majors to be able to demonstrate the following learning outcomes. These learning outcomes are used in evaluating students and the department's undergraduate program. Students are expected to be able to demonstrate:

1. understanding of principles and tools of statistics.
2. command of optimization and its applications and the ability to analyze and interpret problems from various disciplines.
3. an understanding of computer applications emphasizing modern software engineering principles.
4. an understanding of multivariate calculus, linear algebra, and algebraic and geometric proofs.

## Bachelor of Science in Mathematical and Computational Science

### Suggested Preparation for the Major

Students ordinarily would have taken two of the required Math courses (MATH 51 Linear Algebra and Differential Calculus of Several Variables/MATH 52 Integral Calculus of Several Variables/MATH 53 Ordinary Differential Equations with Linear Algebra) and one of the required Statistics courses (STATS 116 Theory of Probability, STATS 191 Introduction to Applied Statistics) before declaring MCS during their freshman or sophomore year.

### How to Declare

To declare the major, a student must submit the Declaration of Major in Axess. Following a review of the student's transcript, a department adviser is assigned to the student upon declaration approval. It is recommended that students meet with their adviser at least once per quarter to discuss progress towards degree completion.

### Course Requirements for the MCS Bachelor's Degree (78-84 units)

| | | Units |
|---|---|---|
| **Mathematics (MATH)** | | 28 |
| Single-variable calculus or AP credit. [1] | | 10 |
| MATH 19 | Calculus | |
| MATH 20 | Calculus | |
| MATH 21 | Calculus | |
| Students may choose one of the following sequences: | | 15 |
| Multivariable Calculus and Linear Algebra | | |
| MATH 51 | Linear Algebra and Differential Calculus of Several Variables | |
| MATH 52 | Integral Calculus of Several Variables | |
| MATH 53 | Ordinary Differential Equations with Linear Algebra | |
| Modern Mathematics: Continuous Methods (a proof-oriented sequence) | | |
| MATH 61CM | Modern Mathematics: Continuous Methods | |
| MATH 62CM | Modern Mathematics: Continuous Methods | |
| MATH 63CM | Modern Mathematics: Continuous Methods | |
| Modern Mathematics: Discrete Methods (a proof-oriented sequence) | | |
| MATH 61DM | Modern Mathematics: Discrete Methods | |
| MATH 62DM | Modern Mathematics: Discrete Methods | |
| MATH 63DM | Modern Mathematics: Discrete Methods | |
| Select one of the following: | | 3 |
| MATH 104 | Applied Matrix Theory | |
| MATH 113 | Linear Algebra and Matrix Theory | |
| **Computer Science (CS)** | | 22-24 |
| CS 103 | Mathematical Foundations of Computing | 5 |
| CS 106A | Programming Methodology | 5 |
| and either | | |
| CS 106B | Programming Abstractions | 5 |
| or CS 106X | Programming Abstractions (Accelerated) | |
| Select two of the following: | | 7-9 |
| CME 108 | Introduction to Scientific Computing | |
| CS 107 | Computer Organization and Systems | |
| CS 154 | Introduction to Automata and Complexity Theory | |
| CS 161 | Design and Analysis of Algorithms | |
| CS 181W | Computers, Ethics, and Public Policy | |
| **Management Science and Engineering (MS&E)** | | 7-11 |
| MS&E 211 | Introduction to Optimization | 4 |
| MS&E 221 | Stochastic Modeling | 3 |
| Or select three of the following: | | |
| MS&E 111 | Introduction to Optimization | |
| MS&E 121 | Introduction to Stochastic Modeling | |
| MS&E 211 | Introduction to Optimization | |
| MS&E 213 | Introduction to Optimization Theory | |
| MS&E 221 | Stochastic Modeling | |
| MS&E 251 | Stochastic Control | |

| | | |
|---|---|---|
| **Statistics (STATS)** | | 11-12 |
| STATS 116 | Theory of Probability | 5 |
| STATS 200 | Introduction to Statistical Inference | 3 |
| Select one of the following: | | 3-4 |
| STATS 191 | Introduction to Applied Statistics | |
| STATS 203 | Introduction to Regression Models and Analysis of Variance | |

[1] Students who scored a 5 on both the Calculus AB and BC advanced placement exams (total of 10 units) can be waived out of MATH 19 Calculus, MATH 20 Calculus, MATH 21 Calculus; See also the Registrar's Advanced Placement (https://registrar.stanford.edu/students/transfer-credit/advanced-placement) web site (AP (https://registrar.stanford.edu/students/transfer-credit-and-advanced-placement/advanced-placement/ap-credit-chart) or IB (https://registrar.stanford.edu/students/transfer-credit-and-advanced-placement/advanced-placement/ib-credit-chart) exams).

## Writing in the Major Requirement

The University requires students to complete at least one approved writing-intensive course in each of their majors. See the Hume Center for Writing and Speaking (https://undergrad.stanford.edu/tutoring-support/hume-center/writing/writing-major) web site for a full description of the WIM (https://undergrad.stanford.edu/tutoring-support/hume-center/writing/writing-major/overview-wim-requirement) requirement.

| | | Units |
|---|---|---|
| **Choose one from the MCS-designated WIM courses to fulfill the Writing in the Major requirement:** | | 3-4 units |
| MATH 109 | Applied Group Theory | |
| MATH 110 | Applied Number Theory and Field Theory | |
| MATH 120 | Groups and Rings | |
| MATH 171 | Fundamental Concepts of Analysis | |
| CS 181W | Computers, Ethics, and Public Policy | |
| STATS 155 | Statistical Methods in Computational Genetics | |
| WIM courses offered by other majors may be used in cases of specific concentrations (e.g. biology, decision theory). Adviser approval required. | | |

## Mathematical and Computational Science Approved Electives

Choose three courses in Mathematical and Computational Science 100-level or above, at least 3 units each from two different departments. At least one must be from following list:

| | | Units |
|---|---|---|
| **Choose three courses from the following:** | | 9 units |
| ECON 102C | Advanced Topics in Econometrics | |
| ECON 140 | Introduction to Financial Economics | |
| ECON 160 | Game Theory and Economic Applications | |
| ECON 179 | Experimental Economics | |
| EE 261 | The Fourier Transform and Its Applications | |
| EE 263 | Introduction to Linear Dynamical Systems | |
| EE 278 | Introduction to Statistical Signal Processing | |
| EE 282 | Computer Systems Architecture | |
| EE 364A | Convex Optimization I | |
| EE 364B | Convex Optimization II | |
| MS&E 220 | Probabilistic Analysis | |
| MS&E 223 | Simulation | |
| MS&E 226 | "Small" Data | |
| MS&E 251 | Stochastic Control | |
| MS&E 334 | Topics in Social Data | |
| MCS 100 | Mathematics of Sports | |
| MATH 104 | Applied Matrix Theory | |
| MATH 106 | Functions of a Complex Variable | |
| MATH 107 | Graph Theory | |
| MATH 108 | Introduction to Combinatorics and Its Applications | |
| MATH 113 | Linear Algebra and Matrix Theory | |
| MATH 114 | Introduction to Scientific Computing | |
| MATH 115 | Functions of a Real Variable | |
| MATH 116 | Complex Analysis | |
| MATH 131P | Partial Differential Equations | |
| MATH 136 | Stochastic Processes | |
| MATH 158 | Basic Probability and Stochastic Processes with Engineering Applications | |
| MATH 159 | Discrete Probabilistic Methods | |
| MATH 171 | Fundamental Concepts of Analysis | |
| MATH 172 | Lebesgue Integration and Fourier Analysis | |
| PHIL 151 | Metalogic | |
| STATS 202 | Data Mining and Analysis | |
| STATS 206 | Applied Multivariate Analysis | |
| STATS 207 | Introduction to Time Series Analysis | |
| STATS 208 | Introduction to the Bootstrap | |
| STATS 215 | Statistical Models in Biology | |
| STATS 216 | Introduction to Statistical Learning | |
| STATS 217 | Introduction to Stochastic Processes I | |
| STATS 218 | Introduction to Stochastic Processes II | |
| STATS 219 | Stochastic Processes | |
| STATS 240 | Statistical Methods in Finance | |
| STATS 270 | Bayesian Statistics I | |
| **For Computer Science (CS), electives can include courses not taken as units under the CS list above and the following:** | | |
| CME 206 | Introduction to Numerical Methods for Engineering | |
| CME 211 | Software Development for Scientists and Engineers | |
| CME 302 | Numerical Linear Algebra | |
| CS 108 | Object-Oriented Systems Design | |
| CS 110 | Principles of Computer Systems | |
| CS 140 | Operating Systems and Systems Programming | |
| CS 143 | Compilers | |
| CS 157 | Logic and Automated Reasoning | |
| CS 161 | Design and Analysis of Algorithms | |
| CS 194 | Software Project | |
| CS 221 | Artificial Intelligence: Principles and Techniques | |
| CS 223A | Introduction to Robotics | |
| CS 225A | Experimental Robotics | |
| CS 228 | Probabilistic Graphical Models: Principles and Techniques | |
| CS 229 | Machine Learning | |
| CS 243 | Program Analysis and Optimizations | |
| CS 246 | Mining Massive Data Sets | |
| CS 248 | Interactive Computer Graphics | |

Electives that are not offered this year, but may be offered in subsequent years, are eligible for credit toward the major.

With the adviser's approval, courses other than those offered by the sponsoring departments may be used to fulfill part of the elective requirement. Courses must provide skills relevant to the MCS degree and do not overlap courses in the student's program. Depending on student's interests, these may be in fields such as, biology, economics, electrical engineering, industrial engineering, and medicine, are otherwise relevant to a mathematical sciences major.

### Grade and Course Requirements:

- All courses used to fulfill major requirements must be taken for a letter grade with the exception of courses offered satisfactory/no credit only.
- The student must have a grade point average (GPA) of 3.0 or better in all course work used to fulfill the major requirement.
- Students who earn less than a 'B-' in STATS 116 Theory of Probability or STATS 200 Introduction to Statistical Inference must repeat the course.
- Only one MCS core course can be substituted by filing a petition with their adviser (with the exception of STATS 200 Introduction to Statistical Inference which cannot be substituted). The Course Substitution Form (https://mcs.stanford.edu/sites/default/files/mcs-course-substitution_form_0.pdf) must be submitted the quarter prior to enrolling in the course.
- Course transfer credit is subject to department evaluation and to the Office of the Registrar's external credit evaluation. These courses may result in a replacement course for MCS required course or may establish placement in a higher-level course. Transfer requests must first be submitted to Student Services Center prior to being evaluated by your adviser. Submit the MCS Program Transfer Credit Form (https://mcs.stanford.edu/sites/default/files/mcs_ug_course_equiv_petition_1.pdf) to the student services office.
- At least three quarters before graduation, majors must file with their adviser a plan for completing degree requirements.

## Mathematical and Computational Science Biology Track (Option)

Students in the Biology track take the introductory courses for the Mathematics and Computational Science major with the following allowable substitutions as electives.

| | | Units |
|---|---|---|
| STATS/BIO 141 | Biostatistics [1] | 3-5 |
| **Allowable Elective Course Substitutions:** | | |
| Take three courses from Foundational Biology Core: | | 10 |
| BIO 82 | Genetics | |
| BIO 83 | Biochemistry & Molecular Biology | |
| BIO 84 | Physiology | |
| BIO 85 | Evolution | |
| BIO 86 | Cell Biology | |
| Or take two courses from the Biology core and one of the following: | | 3-4 |
| BIO 104 | Advanced Molecular Biology | |
| BIO 118 | Genetic Analysis of Biological Processes | |
| BIO 133 | Network analysis for community ecology and conservation research | |
| BIO 144 | Conservation Biology: A Latin American Perspective | |
| BIO 183 | Theoretical Population Genetics (offered alternate years) | |
| BIO 230 | Molecular and Cellular Immunology | |
| Honors students select the following three courses: | | 1-4 |
| STATS 155 | Statistical Methods in Computational Genetics | |
| BIO 113 | Fundamentals of Molecular Evolution | |
| BIO 146 | Population Studies | |

The following courses are no longer offered, but may be used by students who completed them in fulfillment of this requirement: BIO102, 160A & 160B

[1] Can replace STATS 191 Introduction to Applied Statistics or STATS 203 Introduction to Regression Models and Analysis of Variance from the major's Statistics core requirement.

## Mathematical and Computational Science Engineering Track (Option)

Students in the Engineering track take the introductory courses for the Mathematics and Computational Sciences major with the following allowable substitutions.

| | | Units |
|---|---|---|
| With consent of an MCS adviser, MATH 51, MATH 52, MATH 53 series may be substituted for CME 100, CME 102, CME 104. Depending on the exact material taught in relevant years, an additional math course may be necessary [1] | | 15 |
| CME 100 | Vector Calculus for Engineers | |
| CME 102 | Ordinary Differential Equations for Engineers | |
| CME 104/ ENGR 155B | Linear Algebra and Partial Differential Equations for Engineers | |
| STATS 116 may be replaced by: | | 3-5 |
| STATS 110 | Statistical Methods in Engineering and the Physical Sciences | |
| STATS 191/STATS 203 may be replaced by: | | 3-4 |
| STATS 202 | Data Mining and Analysis | |
| **Allowable Elective Course Substitutions:** | | 9 |
| Select one of the following: | | 3-4 |
| MATH 106 | Functions of a Complex Variable | |
| MATH 108 | Introduction to Combinatorics and Its Applications | |
| MATH 116 | Complex Analysis | |
| PHIL 151 | Metalogic | |
| Select two of the following: | | 3-5 |
| ENGR 15 | Dynamics | |
| ENGR 20 | Introduction to Chemical Engineering | |
| ENGR 25B | Biotechnology | |
| ENGR 30 | | |
| ENGR 40 | Introductory Electronics | |
| ENGR 50 | Introduction to Materials Science, Nanotechnology Emphasis | |
| ENGR 105 | Feedback Control Design | |

[1] Only M&CS majors pursuing the engineering track may petition their adviser to substitute the required Math series for CME courses listed above.

## Mathematical and Computational Science Statistics Track (Option)

Students in the Statistics track take the introductory courses for the Mathematics and Computational Sciences major with the following additional courses - (87 units total)

**Required:**

| | | Units |
|---|---|---|
| **Additional Courses for the Statistics Track:** | | 9 |
| STATS 217 | Introduction to Stochastic Processes I | |
| Advanced CS, such as: | | 3 |
| CS 246 | Mining Massive Data Sets | |

| | | |
|---|---|---|
| Advanced MS&E, such as: | | 3 |
| MS&E 220 | Probabilistic Analysis | |
| or | | |
| MS&E 223 | Simulation | |
| **Allowable Elective Course Substitutions:** | | 9 |
| Select three of the following: | | |
| STATS 202 | Data Mining and Analysis | |
| STATS 206 | Applied Multivariate Analysis | |
| STATS 207 | Introduction to Time Series Analysis | |
| STATS 208 | Introduction to the Bootstrap | |
| STATS 216 | Introduction to Statistical Learning | |
| STATS 219 | Stochastic Processes | |
| STATS 270 | Bayesian Statistics I | |

## Honors Program

The honors program is designed to encourage a more intensive study of mathematical sciences than the B.S. program. Students interested in honors should consult with their adviser no later than winter quarter of their junior year to prepare their program of study. Honors work may be concentrated in fields such as biological sciences, environment, physics, etc. Students are required to submit an outline describing the concentration for honors work, including the courses they intend to use two quarters prior to expected degree conferral. An MCS Honors Proposal Form is due no later than the Preliminary Study List deadline of the quarter in which the degree is expected to be conferred.

In addition to meeting all requirements for the B.S., the student must:

1. Maintain an average letter grade equivalent to at least a 3.5 in all academic work.
2. Complete at least 15 units in mathematical sciences in addition to the requirements for the major listed above. Include in these 15 units at least one of the following:
   a. An approved upper-level or graduate course
   b. Participation in a small group seminar
   c. At least 3 units of directed reading
3. Prepare a statement describing major area of concentration for honors work.
4. Describe how each course selected added to the student's knowledge and understanding in area chosen for concentration.
5. Honors statement should be submitted to the adviser by the late application deadline of the student's graduation quarter using the MCS Honors Approval form (https://mcs.stanford.edu/academics/honors).

**Suggested electives for students pursuing Honors:**

| | | |
|---|---|---|
| CME 206 | Introduction to Numerical Methods for Engineering | 3 |
| CS/STATS 229 | Machine Learning | 3-4 |
| CS 248 | Interactive Computer Graphics | 3-4 |
| EE 364A | Convex Optimization I | 3 |
| MATH 171 | Fundamental Concepts of Analysis | 3 |
| MATH 172 | Lebesgue Integration and Fourier Analysis | 3 |
| MATH 205A | Real Analysis | 3 |
| STATS 202 | Data Mining and Analysis | 3 |
| STATS 216 | Introduction to Statistical Learning | 3 |
| STATS 217 | Introduction to Stochastic Processes I | 2-3 |

# Minor in Mathematical and Computational Science

The minor in Mathematical and Computational Science is intended to provide an experience of the four constituent areas: Computer Science, Mathematics, Management Science and Engineering, and Statistics. Five basic courses are required:

| | | Units |
|---|---|---|
| Select one of the following: | | 3-5 |
| MATH 51 | Linear Algebra and Differential Calculus of Several Variables | |
| or | | |
| MATH 104 | Applied Matrix Theory | |
| Select two of the following: | | 10 |
| CS 106A | Programming Methodology | |
| and either | | |
| CS 106B | Programming Abstractions | |
| or CS 106X | Programming Abstractions (Accelerated) | |
| Select one of the following: | | 3-4 |
| MS&E 211 | Introduction to Optimization | |
| or | | |
| MS&E 221 | Stochastic Modeling | |
| Select two of the following: | | 8 |
| STATS 116 | Theory of Probability | 5 |
| and either | | |
| STATS 191 | Introduction to Applied Statistics | |
| or | | |
| STATS 200 | Introduction to Statistical Inference | |

In addition to the above, the minor requires three courses from the following, two of which must be in different departments:

| | | Units |
|---|---|---|
| Select three of the following: | | 9 |
| CME 108 | Introduction to Scientific Computing | |
| CS 103 | Mathematical Foundations of Computing | |
| CS 107 | Computer Organization and Systems | |
| CS 154 | Introduction to Automata and Complexity Theory | |
| CS 161 | Design and Analysis of Algorithms | |
| ECON 160 | Game Theory and Economic Applications | |
| EE 261 | The Fourier Transform and Its Applications | |
| MS&E 211 | Introduction to Optimization | |
| MS&E 212 | Mathematical Programming and Combinatorial Optimization | |
| MS&E 221 | Stochastic Modeling | |
| MS&E 251 | Stochastic Control | |
| MATH 104 | Applied Matrix Theory | |
| MATH 106 | Functions of a Complex Variable | |
| MATH 108 | Introduction to Combinatorics and Its Applications | |
| MATH 109 | Applied Group Theory | |
| MATH 110 | Applied Number Theory and Field Theory | |
| MATH 115 | Functions of a Real Variable | |
| MATH 131P | Partial Differential Equations | |
| MATH 171 | Fundamental Concepts of Analysis | |
| PHIL 151 | Metalogic | |
| STATS 191 | Introduction to Applied Statistics | |
| STATS 200 | Introduction to Statistical Inference | |
| STATS 202 | Data Mining and Analysis | |
| STATS 203 | Introduction to Regression Models and Analysis of Variance | |
| STATS 217 | Introduction to Stochastic Processes I | |

Other upper-division courses appropriate to the program major may be substituted with consent of MCS program director. Undergraduate majors in the constituent programs may not count courses in their own departments.

## Faculty

*Director:* Bradley Efron

*Faculty Advisers:* Assistant Professor John Duchi, Professor Bradley Efron, Associate Professor Ramesh Johari, Associate Professor David Rogosa, Professor Chiara Sabatti

*Steering Committee:* Takeshi Amemiya (Economics, emeritus), Emmanuel Candès (Mathematics, Statistics), Brian Conrad (Mathematics), Richard Cottle (Management Science and Engineering, emeritus), John Duchi (Electrical Engineering & Statistics), Darrel Duffie (Economics & GSB), Bradley Efron (Statistics), Peter Glynn (Management Science and Engineering), Ramesh Johari (Management Science and Engineering), Percy Liang (Computer Science & Statistics), Parviz Moin (Mechanical Engineering), George Papanicolaou (Mathematics), Eric Roberts (Computer Science, emeritus), David Rogosa (Education & Statistics), Tim Roughgarden (Computer Science), Chiara Sabatti (Biomedical Data Science & Statistics), David Siegmund (Statistics), Jonathan Taylor (Statistics), Brian White (Mathematics)