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 Statistics, Mathematics, Computer Science, and Management Science & Engineering, 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 mathematics;
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, Multivariable Calculus, and Modern Applications/MATH 52 Integral Calculus of Several Variables/MATH 53 Ordinary Differential Equations with Linear Algebra) and one of the required Statistics core 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 should ordinarily first meet with an MCS peer adviser to create a proposed study plan and with the program director to discuss the major. Students ordinarily have taken two of the required MATH 50 series courses and a core Statistics course prior to declaration. Once the student has created a proposed study plan, they may submit the plan to MCS student services and declare the major through Axess.

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

<table>
<thead>
<tr>
<th>Units</th>
<th>Mathematics (MATH)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Single-variable calculus or AP credit. 1</td>
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<tr>
<td></td>
<td>MATH 19 Calculus</td>
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<td></td>
<td>MATH 20 Calculus</td>
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<td>MATH 21 Calculus</td>
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</table>

Students may choose one of the following sequences:

<table>
<thead>
<tr>
<th>Units</th>
<th>Multivariable Calculus and Linear Algebra</th>
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<tbody>
<tr>
<td>15</td>
<td>MATH 51 Linear Algebra, Multivariable Calculus, and Modern Applications</td>
</tr>
<tr>
<td></td>
<td>MATH 52 Integral Calculus of Several Variables</td>
</tr>
<tr>
<td></td>
<td>MATH 53 Ordinary Differential Equations with Linear Algebra</td>
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</tbody>
</table>

Modern Mathematics: Continuous Methods (a proof-oriented sequence)

<table>
<thead>
<tr>
<th>Units</th>
<th>Mathematics (MATH)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>MATH 61CM Modern Mathematics: Continuous Methods</td>
</tr>
<tr>
<td></td>
<td>MATH 62CM Modern Mathematics: Continuous Methods</td>
</tr>
<tr>
<td></td>
<td>MATH 63CM Modern Mathematics: Continuous Methods</td>
</tr>
</tbody>
</table>

Modern Mathematics: Discrete Methods (a proof-oriented sequence)

<table>
<thead>
<tr>
<th>Units</th>
<th>Mathematics (MATH)</th>
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<tbody>
<tr>
<td></td>
<td>MATH 61DM Modern Mathematics: Discrete Methods</td>
</tr>
<tr>
<td></td>
<td>MATH 62DM Modern Mathematics: Discrete Methods</td>
</tr>
<tr>
<td></td>
<td>MATH 63DM Modern Mathematics: Discrete Methods</td>
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</tbody>
</table>

Select one of the following:

<table>
<thead>
<tr>
<th>Units</th>
<th>Computer Science (CS)</th>
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<tbody>
<tr>
<td>3</td>
<td>MATH 104 Applied Matrix Theory</td>
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<tr>
<td></td>
<td>MATH 113 Linear Algebra and Matrix Theory</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Units</th>
<th>Management Science and Engineering (MS&amp;E)</th>
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<tbody>
<tr>
<td>7-9</td>
<td>CME 108 Introduction to Scientific Computing</td>
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<tr>
<td></td>
<td>CS 107 Computer Organization and Systems</td>
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<tr>
<td></td>
<td>CS 154 Introduction to Automata and Complexity Theory</td>
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<tr>
<td></td>
<td>CS 161 Design and Analysis of Algorithms</td>
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<tr>
<td></td>
<td>CS 181W Computers, Ethics, and Public Policy</td>
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</table>

<table>
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<tr>
<th>Units</th>
<th>Management Science and Engineering (MS&amp;E)</th>
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<tbody>
<tr>
<td>7-11</td>
<td>MS&amp;E 211 Introduction to Optimization</td>
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<tr>
<td></td>
<td>MS&amp;E 212 Introduction to Stochastic Modeling</td>
</tr>
<tr>
<td></td>
<td>MS&amp;E 213 Introduction to Optimization Theory</td>
</tr>
</tbody>
</table>
MS&E 221 Stochastic Modeling
MS&E 251 Introduction to Stochastic Control with Applications

Statistics (STATS)
STATS 116 Theory of Probability 5
STATS 200 Introduction to Statistical Inference 3
Select one of the following:
STATS 191 Introduction to Applied Statistics 3-4
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). Students who place out of MATH 19, 20, & 21 will be required to take additional Math classes as discussed with MCS Student Services and the student’s faculty adviser.

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 requirement.

Choose one from the MCS-designated WIM courses to fulfill the Writing in the Major requirement:
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:

Choose three courses from the following:
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

Units 9

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 Computational Logic
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

EE 364A Convex Optimization I
EE 364B Convex Optimization II
MS&E 220 Probabilistic Analysis
MS&E 223 Simulation
MS&E 226 “Small” Data: Prediction, Inference, Causality
MS&E 251 Introduction to Stochastic Control with Applications
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 A Course in Bayesian Statistics
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 'C+' 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.

<table>
<thead>
<tr>
<th>STAT/BI0 141</th>
<th>Biostatistics 1</th>
<th>3-5</th>
</tr>
</thead>
</table>

**Allowable Elective Course Substitutions:**

Take three courses from Foundational Biology Core:

<table>
<thead>
<tr>
<th>BIO 82</th>
<th>Genetics</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>BIO 83</td>
<td>Biochemistry &amp; Molecular Biology</td>
<td></td>
</tr>
<tr>
<td>BIO 84</td>
<td>Physiology</td>
<td>3-5</td>
</tr>
<tr>
<td>BIO 85</td>
<td>Evolution</td>
<td>3-4</td>
</tr>
<tr>
<td>BIO 86</td>
<td>Cell Biology</td>
<td>3-4</td>
</tr>
<tr>
<td>BIO 104</td>
<td>Advance Molecular Biology: Epigenetics and Proteostasis</td>
<td></td>
</tr>
<tr>
<td>BIO 133</td>
<td>Network analysis for community ecology and conservation research</td>
<td></td>
</tr>
<tr>
<td>BIO 144</td>
<td>Conservation Biology: A Latin American Perspective</td>
<td></td>
</tr>
<tr>
<td>BIO 183</td>
<td>Theoretical Population Genetics (offered alternate years)</td>
<td></td>
</tr>
<tr>
<td>BIO 230</td>
<td>Molecular and Cellular Immunology</td>
<td></td>
</tr>
</tbody>
</table>

Honors students select the following three courses:

| BI0 113 | Fundamentals of Molecular Evolution | |
| BI0 146 | Population Studies | |

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

| BI0 102, 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 Statistics 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.

| CME 100 | Vector Calculus for Engineers | 15 |
| CME 102 | Ordinary Differential Equations for Engineers | |
| CME 104/155B | 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:**

Select one of the following:

| MATH 106 | Functions of a Complex Variable | 3-4 |
| MATH 108 | Introduction to Combinatorics and Its Applications | |
| MATH 116 | Complex Analysis | |
| PHIL 151 | Metalogic | |

Select two of the following:

| ENGR 15 | Dynamics | 3-5 |
| ENGR 20 | Introduction to Chemical Engineering | |
| ENGR 25B | Biotechnology | |
| 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**

| STAT 217 | Introduction to Statistical Inference | 9 |
| Advanced CS, such as: | |

1
In addition to meeting all requirements for the B.S., the student must:

- 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:
  - An approved upper-level or graduate course
  - Participation in a small group seminar
  - At least 3 units of directed reading

- Prepare a statement describing major area of concentration for honors work.

- Describe how each course selected added to the student’s knowledge and understanding in area chosen for concentration.

- 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/sites/default/files/mcs_honors_approval_form_2016-17_3.pdf).

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:
   - An approved upper-level or graduate course
   - Participation in a small group seminar
   - 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/sites/default/files/mcs_honors_approval_form_2016-17_3.pdf).

### 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:

Select one of the following:

- MATH 51 Linear Algebra, Multivariable Calculus, and Modern Applications
- MATH 104 Applied Matrix Theory

Select two of the following:

- CS 106A Programming Methodology
- CS 106B Programming Abstractions
- CS 106X Programming Abstractions (Accelerated)

Select one of the following:

- CS 106A Programming Methodology
- CS 106B Programming Abstractions
- CS 106X Programming Abstractions (Accelerated)

Select two of the following:

- MS&E 211 Introduction to Optimization
- MS&E 221 Stochastic Modeling
- MS&E 222 Simulation

Select three of the following:

- MS&E 212 Mathematical Programming and Combinatorial Optimization
- MS&E 221 Stochastic Modeling
- MS&E 222 Simulation
- STATS 191 Introduction to Applied Statistics
- 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:

<table>
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<th>Units</th>
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<td>3-5</td>
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Select three of the following:

- 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 251 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 222 Simulation
- STATS 191 Introduction to Applied Statistics
- STATS 200 Introduction to Statistical Inference

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<th>Units</th>
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<tr>
<td>9</td>
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</table>
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 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), David Rogosa (Education & Statistics), Tim Roughgarden (Computer Science), Chiara Sabatti (Biomedical Data Science & Statistics), David Siegmund (Statistics), Jonathan Taylor (Statistics), Brian White (Mathematics)