INSTITUTE FOR COMPUTATIONAL AND MATHEMATICAL ENGINEERING

Courses offered by the Institute for Computational and Mathematical Engineering are listed under the subject code CME on the (http://explorecourses.stanford.edu/search;jsessionid=14DE1634FEFCE32542A001C07860506?view=on&filter-catalognumber-CME=on&filter-coursestatus-Active=on)Stanford Bulletin’s ExploreCourses web site.

ICME is a degree granting (M.S./Ph.D.) interdisciplinary institute at the intersection of mathematics, computing, engineering and applied sciences. ICME was founded in 2004, building upon the Scientific Computing and Computational Mathematics Program (est. 1989).

At ICME, we design state-of-the-art mathematical and computational models, methods, and algorithms for engineering and science applications. The program collaborates closely with engineers and scientists in academia and industry to develop improved computational approaches and advance disciplinary fields. In particular, it leverages Stanford’s strength in engineering applications in the physical, biological, mathematical, and information sciences, and has established connections with nearly 20 departments across five schools at Stanford.

The program identifies research areas that would benefit from a multidisciplinary approach in which computational mathematics plays a role. This multidisciplinary intellectual environment is a core strength of ICME, with interaction among students and faculty with diverse backgrounds and expertise. Students and faculty are active in many research areas: aerodynamics and space applications, fluid dynamics, protein folding, data science including machine learning and recommender systems, ocean dynamics, climate modeling, reservoir engineering, computer graphics, financial mathematics, and many more.

The program trains students and scholars from across Stanford in mathematical modeling, scientific computing, and advanced computational algorithms at the undergraduate and graduate levels. Courses typically provide strong theoretical foundations for the solution of real world problems and numerical computations to facilitate application of mathematical techniques and theories. Training offered includes matrix computations, computational probability and combinatorial optimization, optimization, stochastics, numerical solution of partial differential equations, parallel computer algorithms, and new computing paradigms, amongst others.

ICME offers service courses for undergraduates and graduate students to fulfill departmental requirements, core courses for master’s and doctoral students in Computational and Mathematical Engineering, and specialized electives in various application areas.

The ICME master’s program offers both specialized and general tracks. Currently, the program is offering specialized tracks in Computational Geosciences, Data Science, Imaging Science, and Mathematical and Computational Finance.

Graduate Programs in Computational and Mathematical Engineering

University regulations governing the M.S. and Ph.D. degrees are described in the “Graduate Degrees (http://exploredegrees.stanford.edu/graduatedegrees)” section of this bulletin.

Learning Outcomes (Graduate)

The purpose of the master’s program is to provide students with the knowledge and skills necessary for a professional career or doctoral studies. This is done through coursework in mathematical modeling, scientific computing, advanced computational algorithms, and a set of courses from a specific area of application or field. The latter includes computational geoscience, data sciences, imaging sciences, mathematical and computational finance and other interdisciplinary areas that combine advanced mathematics with the classical physical sciences or with challenging interdisciplinary problems emerging within disciplines such as business, biology, medicine, and information.

The Ph.D. is conferred upon candidates who have demonstrated substantial scholarship and the ability to conduct independent research. Through course work and guided research, the program prepares students to make original contributions in Computational and Mathematical Engineering and related fields.

Master of Science in Computational and Mathematical Engineering

The University’s basic requirements for the M.S. degree are discussed in the “Graduate Degrees” section of this bulletin. The following are specific departmental requirements.

The M.S. degree in Computational and Mathematical Engineering is intended as a terminal professional degree and does not lead to the Ph.D. program. Students interested in the doctoral program should apply directly to the Ph.D. program. Master’s students who have maintained a minimum grade point average (GPA) of 3.5 are eligible to take the Ph.D. qualifying exam. Qualifying exams in all six areas must be completed before the start of the second year in the program. Those who pass the qualifying examination and secure a research adviser (three quarters of continuous documented research) may continue into the Ph.D. program upon acceptance by the institute before the end of the second year in the program.

Admission

Prospective applicants should consult the Graduate Admissions (https://studentaffairs.stanford.edu/gradadmissions) and the ICME admissions web pages (https://icme.stanford.edu/admissions) for complete information on admission requirements and deadlines.

Applications to the M.S. program and all supporting documents must be submitted and received online by January 8, 2019, the deadline published on ICME admissions web page (https://icme.stanford.edu/admissions/deadlines).

Prerequisites

Fundamental courses in mathematics and computing may be needed as prerequisites for other courses in the program. Check the prerequisites of each required course. Recommended preparatory courses include advanced undergraduate level courses in linear algebra, probability, differential equations, stochastics, and numerical methods and proficiency in programming.
Coterminal Master’s Program

Stanford undergraduates who want to apply for the coterminal master’s degree must submit their application no later than eight weeks before the start of the proposed admit quarter. The application must give evidence that the student possesses a potential for strong academic performance at the graduate level. Graduate Record Examination (GRE) General Test scores are required for application review. A student is eligible to apply for admission once the following conditions have been met:

- completion of six non-Summer quarters at Stanford or two non-Summer quarters at Stanford for transfer students
- completion of 120 units toward graduation (UTG) as shown on the undergraduate transcript, including transfer, Advanced Placement exam, and other external test credit
- declaration of an undergraduate major

University Coterminal Requirements

Coterminal master’s degree candidates are expected to complete all master’s degree requirements as described in this bulletin. University requirements for the coterminal master’s degree are described in the “Coterminal Master’s Program” sections. University requirements for the master’s degree are described in the “Graduate Degrees” section of this bulletin.

After accepting admission to this coterminal master’s degree program, students may request transfer of courses from the undergraduate to the graduate career to satisfy requirements for the master’s degree. Transfer of courses to the graduate career requires review and approval of both the undergraduate and graduate programs on a case by case basis.

In this master’s program, courses taken two quarters prior to the first graduate quarter, or later, are eligible for consideration for transfer to the graduate career. No courses taken prior to the first quarter of the graduate quarter are eligible for consideration for transfer to the graduate career. Requirements for the master’s degree must be completed by the student and approved by the department by the end of the student’s first quarter.

Course transfers are not possible after the bachelor’s degree has been conferred.

The University requires that the graduate adviser be assigned in the student’s first graduate quarter even though the undergraduate career may still be open. The University also requires that the Master’s Degree Program Proposal be completed by the student and approved by the department by the end of the student’s first quarter.

Requirements for the Master of Science in Computational and Mathematical Engineering

The master’s program consists of 45 units of course work taken at Stanford. No thesis is required; however, students may become involved in research projects during the master’s program, particularly to explore an interest in continuing to the doctoral program. Although there is no specific background requirement, significant exposure to mathematics and engineering course work is necessary for successful completion of the program.

There are five tracks in the master’s program:

- General CME
- Computational Geosciences
- Data Science
- Imaging Science
- Mathematical and Computational Finance

General CME Track

This track is designed for students interested in studying and developing computational tools in those aspects of applied mathematics central to modeling in the physical and engineering sciences. The curriculum consists of core computational and mathematical engineering courses and programming course work, extensive breadth and depth electives, and seminars. Core courses provide instruction in mathematical and computational tools applicable to a wide range of scientific, industrial, and engineering disciplines and augment breadth and depth electives of one’s choosing. Programming requirement ensures proficiency in scientific computing and professional computing skills. Seminars highlight emerging research in engineering and sciences.

Requirements

A candidate is required to complete a program of 45 units of courses numbered 200 or above. Courses below 200 level require special approval from the program office. At least 36 of these must be graded units, passed with a grade point average (GPA) of 3.0 (B) or better.

Requirement 1: Foundational (12 units)

Students must demonstrate foundational knowledge in the field by completing four of the six core courses. Courses in this area must be taken for letter grades.

<table>
<thead>
<tr>
<th>Units</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>CME 302 Numerical Linear Algebra</td>
</tr>
<tr>
<td>3</td>
<td>CME 303 Partial Differential Equations of Applied Mathematics</td>
</tr>
<tr>
<td>3</td>
<td>CME 305 Discrete Mathematics and Algorithms</td>
</tr>
<tr>
<td>3</td>
<td>CME 306 Numerical Solution of Partial Differential Equations</td>
</tr>
<tr>
<td>3</td>
<td>CME 307 Optimization</td>
</tr>
<tr>
<td>3</td>
<td>CME 308 Stochastic Methods in Engineering or CME 298 Basic Probability</td>
</tr>
<tr>
<td></td>
<td>and Engineering Applications</td>
</tr>
</tbody>
</table>

Requirement 2: Programming (3 units)

Three units of programming course work demonstrating programming proficiency. All graduate students in the program are required to complete this programming course for letter grade. Programming proficiency at the level of CME 211 is a hard prerequisite; CME 211 can be applied towards elective requirement.

<table>
<thead>
<tr>
<th>Units</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>CME 211 Software Development for Scientists and Engineers (*)can be counted</td>
</tr>
<tr>
<td></td>
<td>as an elective</td>
</tr>
<tr>
<td>3</td>
<td>CME 212 Advanced Software Development for Scientists and Engineers</td>
</tr>
</tbody>
</table>

Requirement 3: Breadth Electives (18 units)

18 units of general electives to demonstrate breadth of knowledge in technical area. The elective course list represents automatically accepted electives within the program. However, electives are not limited to the list below, and the list is expanded on a continuing basis. The elective part of the ICME program is meant to be broad and inclusive of relevant courses of comparable rigor to ICME courses. It is recommended that the selected courses include offerings from (at least) two engineering departments, in addition to CME course work. Courses outside this list can be accepted as electives subject to approval by the student’s program adviser.

<table>
<thead>
<tr>
<th>Units</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>AA 214B Numerical Methods for Compressible Flows</td>
</tr>
<tr>
<td>3</td>
<td>AA 214C Numerical Computation of Viscous Flow</td>
</tr>
</tbody>
</table>
### Computational Geosciences Track

The Computational Geosciences (CompGeo) track is designed for students interested in the skills and knowledge required to develop efficient and robust numerical solutions to Earth Science problems using high-performance computing. The CompGeo curriculum is based on four fundamental areas: modern programming methods for Science and Engineering, applied mathematics with an emphasis on numerical methods, algorithms and architectures for high-performance computing and computationally oriented Earth Sciences courses. Earth Sciences/computational project courses give practice in applying methodologies and concepts. CompGeo students are required to complete general and focused application electives (Requirements 3 and 4) from the approved list of courses from the Computational Geosciences program. All other requirements remain the same as set forth above.

### Requirement 1: Foundational (12 units)
Identical to the general CME master's track requirement.

### Requirement 2: Programming (3 units)
3 units of programming course work demonstrating programming proficiency. All graduate students in the program are required to complete programming course for letter grade. Programming proficiency at the level of CME 211 is a hard prerequisite for CME 212; CME 211 can be applied towards elective requirement.

### Requirement 3: Mathematics and Engineering Electives (18 units)

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>ME 136</td>
<td>Stochastic Processes</td>
<td>3</td>
</tr>
<tr>
<td>CME 211</td>
<td>Software Development for Scientists and Engineers</td>
<td>3</td>
</tr>
<tr>
<td>CME 212</td>
<td>Advanced Software Development for Scientists and Engineers</td>
<td>3</td>
</tr>
<tr>
<td>CME 214</td>
<td>Software Design in Modern Fortran for Scientists and Engineers</td>
<td>3</td>
</tr>
<tr>
<td>ENGR 209A</td>
<td>Analysis and Control of Nonlinear Systems</td>
<td>3</td>
</tr>
<tr>
<td>GEOPHYS 257</td>
<td>Introduction to Computational Earth Sciences</td>
<td>2-4</td>
</tr>
</tbody>
</table>

### Requirement 4: Specialized Electives (9 units)
Nine units of focused graduate application electives approved by the program adviser, in the areas of engineering, mathematics, physical, biological, information, and other quantitative sciences. These courses should be foundational depth courses relevant to the student's professional development and research interests.

### Requirement 5: Seminar (3 units)
One unit of seminar must come from CME 500; two units are up to the student’s choice of ICME graduate seminars or other approved seminars. Additional seminar units may not be counted towards the 45-unit requirement.

### Notes
- Students interested in pursuing the ICME M.S. in the Computational Geosciences (CompGeo) track are encouraged to contact the Computational Geosciences program director before applying.
- Students are required to take 45 units of course work, and research credits to earn a master's degree in Computational Geosciences track. The course work follows the requirements of the ICME M.S. degree as above with additional restrictions placed on the general and focused electives.

### Requirement 1: Foundational (12 units)
Identical to the general CME master's track requirement.
Requirement 3: Breadth Electives in Geosciences (18 units)
18 units of general electives to demonstrate breadth of knowledge in technical area. Courses are currently offered but are not limited to the following specific areas of the School of Earth Sciences:

1. Reservoir Simulation
2. Geophysical Imaging
3. Tectonophysics/Geomechanics
4. Climate/Atmosphere/Ocean
5. Ecology/Geobiology

The Earth Science courses, offered in EESS, ERE, GES, and Geophysics is selected based on the area of the student’s interest and their research/thesis work, along with the advice and consent of the student’s adviser. Students are encouraged to choose a range of courses in order to guarantee breadth of knowledge in Earth Sciences. A maximum of one non-computationally-oriented course can be counted towards the master’s degree requirements. Following is a list of recommended courses (grouped by area) that can be taken to fulfill the Geosciences course requirement.

<table>
<thead>
<tr>
<th>Course</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmental/Climate/Hydrogeology</td>
<td></td>
</tr>
<tr>
<td>ESS 220 Physical Hydrogeology</td>
<td>4</td>
</tr>
<tr>
<td>ESS 221 Contaminant Hydrogeology and Reactive Transport</td>
<td>4</td>
</tr>
<tr>
<td>ESS 246B Atmosphere, Ocean, and Climate Dynamics: the Ocean Circulation</td>
<td>3</td>
</tr>
<tr>
<td>CEE 262A Hydromechanics</td>
<td>3-4</td>
</tr>
<tr>
<td>CEE 262B Transport and Mixing in Surface Water Flows</td>
<td>3-4</td>
</tr>
<tr>
<td>CEE 262C Modeling Environmental Flows</td>
<td>3</td>
</tr>
<tr>
<td>CEE 263A Air Pollution Modeling</td>
<td>3-4</td>
</tr>
<tr>
<td>CEE 361 Turbulence Modeling for Environmental Fluid Mechanics</td>
<td>2-4</td>
</tr>
<tr>
<td>Geophysical Imaging</td>
<td></td>
</tr>
<tr>
<td>EE 256 Numerical Electromagnetics</td>
<td>3</td>
</tr>
<tr>
<td>GEOPHYS 210 Basic Earth Imaging</td>
<td>2-3</td>
</tr>
<tr>
<td>GEOPHYS 211 Environmental Soundings Image Estimation</td>
<td>3</td>
</tr>
<tr>
<td>GEOPHYS 280 3-D Seismic Imaging</td>
<td>2-3</td>
</tr>
<tr>
<td>GEOPHYS 287 Earthquake Seismology</td>
<td>3-5</td>
</tr>
<tr>
<td>General Computational/Mathematical Geosciences</td>
<td></td>
</tr>
<tr>
<td>CEE 362G Imaging with Incomplete Information</td>
<td>3-4</td>
</tr>
<tr>
<td>CHEM 275 Advanced Physical Chemistry - Single Molecules and Light</td>
<td>3</td>
</tr>
<tr>
<td>CME 372 Applied Fourier Analysis and Elements of Modern Signal Processing</td>
<td>3</td>
</tr>
<tr>
<td>CME 321B Mathematical Methods of Imaging</td>
<td>3</td>
</tr>
<tr>
<td>ESS 211 Fundamentals of Modeling</td>
<td>3-5</td>
</tr>
<tr>
<td>ENERGY 291 Optimization of Energy Systems</td>
<td>3-4</td>
</tr>
<tr>
<td>GS 240</td>
<td>2-3</td>
</tr>
<tr>
<td>ME 335A Finite Element Analysis</td>
<td>3</td>
</tr>
<tr>
<td>ME 346B Introduction to Molecular Simulations</td>
<td>3</td>
</tr>
<tr>
<td>ME 361 Turbulence</td>
<td>3</td>
</tr>
<tr>
<td>ME 469B Computational Methods in Fluid Mechanics</td>
<td>3</td>
</tr>
<tr>
<td>Reservoir Simulation/Fluid Flow</td>
<td></td>
</tr>
<tr>
<td>ENERGY 223 Reservoir Simulation</td>
<td>3-4</td>
</tr>
<tr>
<td>ENERGY 224 Advanced Reservoir Simulation</td>
<td>3</td>
</tr>
<tr>
<td>Subsurface/Reservoir Characterization</td>
<td></td>
</tr>
<tr>
<td>ENERGY 241 Seismic Reservoir Characterization</td>
<td>3-4</td>
</tr>
<tr>
<td>GEOPHYS 202 Reservoir Geomechanics</td>
<td>3</td>
</tr>
<tr>
<td>GEOPHYS 260 Rock Physics for Reservoir Characterization</td>
<td>3</td>
</tr>
</tbody>
</table>

Requirement 4: Practical Component (9 units)
9 units of focused research in computational geosciences. Students are required to either complete a Research Project or an Internship as described below.

Internship and/or Research Project, enrolling in a course such as:
- EARTH 400 Directed Research (3 units)
- EARTH 401 Curricular Practical Training (1 unit)

Research Project
Students who plan to apply to the Ph.D. program need to take 9 units of research. Students will work with the CompGeo program director to find an appropriate adviser and research topic and then enroll in EARTHSCI 400: Directed Research (or a similar SES research course). The successful outcome of a Research Project can be:
1. an oral presentation at an international meeting requiring an extended abstract
2. a publication submission in a peer reviewed journal.
3. a written report

Internship
As an alternative to the Research Project, students have the option of an internship which is recommended for those students interested in a terminal degree. The individual student is responsible for securing and organizing the internship and is required to obtain a faculty adviser and submit a written report on the internship project. Credit for the internship will be obtained through EARTHSCI401: Curricular Practical Training (1 unit) and in this case only 8 units of research are required.

Requirement 5: Seminar (3 units)
3 units of ICME graduate seminars or other approved seminars. Additional seminar units may not be counted towards the 45-unit requirement. One of the required seminars for CompGeo must be a seminar course chosen in concert with the student’s academic adviser among the seminars offered by the the School of Earth, Energy and Environmental Sciences.

Data Science Track
The Data Science track develops strong mathematical, statistical, computational and programming skills through the foundational and programming requirements. In addition, it provides a fundamental data science education through general and focused electives requirement from courses in data sciences and related areas. Course choices are limited to predefined courses from the data sciences and related courses group. Programming requirement (requirement 2) is extended to 6 units and includes course work in advanced scientific programming and high performance computing. The final requirement is a practical component (requirement 5) for 6 units to be completed through capstone project, data science clinic, or other courses that have strong hands-on or practical component such as statistical consulting.

Requirement 1: Foundational (12 units)
Students must demonstrate foundational knowledge in the field by completing the following core courses. Courses in this area must be taken for letter grades.

<table>
<thead>
<tr>
<th>Course</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEE 292 Continuum Mechanics</td>
<td>3</td>
</tr>
<tr>
<td>CEE 294 Computational Poromechanics</td>
<td>3</td>
</tr>
<tr>
<td>GEOPHYS 220 Ice, Water, Fire</td>
<td>3-5</td>
</tr>
<tr>
<td>GEOPHYS 288A Crustal Deformation</td>
<td>3-5</td>
</tr>
<tr>
<td>GEOPHYS 288B Crustal Deformation</td>
<td>3-5</td>
</tr>
<tr>
<td>GEOPHYS 290 Tectonophysics</td>
<td>3</td>
</tr>
</tbody>
</table>
Requirement 2: Programming (6 units)
To ensure that students have a strong foundation in programming, 3 units of advanced scientific programming for letter grade at the level of CME 212 and three units of parallel computing for letter grades are required. Programming proficiency at the level of CME 211 is a hard prerequisite for CME 212; CME 211 can be applied towards elective requirement.

Advanced Scientific Programming; take 3 units
- CME 211 Software Development for Scientists and Engineers (*can only be used as an elective) 3
- CME 212 Advanced Software Development for Scientists and Engineers 3

Parallel/HPC Computing; take 3 units
- CME 213 Introduction to parallel computing using MPI, openMP and CUDA 3
- CME 323 Distributed Algorithms and Optimization 3
- CME 342 Parallel Methods in Numerical Analysis 3
- CS 149 Parallel Computing 3-4
- CS 315A Advanced Scientific Programming 3
- CS 316 Advanced Multi-Core Systems 3

Requirement 3: Data Science electives (12 units)
Data Science electives should demonstrate breadth of knowledge in the technical area. The elective course list is defined. Courses outside this list can be accepted as electives subject to approval by the student’s program adviser. Courses that are waived may not be counted towards the master’s degree.

Units
- STATS 200 Introduction to Statistical Inference and STAT 300A Theory of Statistics I 3
- STATS 203 Introduction to Regression Models and Analysis of Variance and STAT 305A Introduction to Statistical Modeling 3
- STAT 315B Modern Applied Statistics: Data Mining 3

Requirement 4: Specialized electives (9 units)
Choose three courses in specialized areas from the following list. Courses outside this list can be accepted as electives subject to approval by the student’s program adviser.

Units
- BIOE 214 Representations and Algorithms for Computational Molecular Biology 3-4
- BIOMEDIN 215 Data Driven Medicine 3
- BIOS 221 Modern Statistics for Modern Biology 3
- CS 224W Analysis of Networks 3-4
- CS 229 Machine Learning 3-4
- CS 231N Convolutional Neural Networks for Visual Recognition 3-4
- CS 246 Mining Massive Data Sets 3-4

Requirement 5: Practical component (6 units)
Students are required to take 6 units of practical component that may include any combination of:
- Project labs offered by Stanford Data Lab: ENGR 150 Data Challenge Lab, ENGR 350 Data Impact Lab. (limited enrollment; application required.)
- Master’s Research (CME 291): a research project, supervised by a faculty member and approved by the adviser; should be taken for letter grade only. The research project should be computational in nature. Students should submit a one-page proposal, supported by the faculty member, to ICME student services for approval at least one quarter before.
- Other courses that have a strong hands-on and practical component, such as STATS 390 Consulting Workshop up to 1 unit.

Imaging Science Track
The Imaging Science track is designed for students interested in the skills and knowledge required to develop efficient and robust computational tools for imaging science. The curriculum is based on four fundamental areas: mathematical models and analysis for imaging sciences and inverse problems, tools and techniques from modern imaging sciences from medicine, biology, physics/chemistry, and earth science, algorithms in numerical methods and scientific computing and high performance computing skills and architecture oriented towards imaging sciences.

The course work follows the requirements of the general master’s degree in the core course requirement. The general and focused elective requirements (requirements 3 and 4 below) are limited to approved courses listed below. Programming requirement (requirement 2) is extended to 6 units and includes course work in advanced scientific programming and high performance computing.

Requirement 1: Foundational (12 units)
Identical to the general ICME master’s program; see above.

Requirement 2: Programming (6 units)
To ensure that students have a strong foundation in programming, 3 units of advanced scientific programming for letter grade at the level of CME 212 and three units of parallel computing for letter grades are required. Programming proficiency at the level of CME 211 is a hard prerequisite for CME 212; CME 211 can be applied towards elective requirement.

Units
- CME 211 Software Development for Scientists and Engineers (*can only be used as an elective) 3
- Advanced Scientific Programming; take 3 units
- CME 212 Advanced Software Development for Scientists and Engineers 3
- CME 214 Software Design in Modern Fortran for Scientists and Engineers 3
- Parallel/HPC Computing; take 3 units
- CME 213 Introduction to parallel computing using MPI, openMP, and CUDA 3
The Institute for Computational and Mathematical Engineering, in close cooperation with Mathematics, Management Science and Engineering and Statistics provides many of the basic courses.

**Requirement 1: Foundational (9 units)**
Students must demonstrate foundational knowledge in the field by completing the following core courses. Courses in this area must be taken for letter grades.

- **Requirement 2: Programming (9 units)**
  To ensure that students have a strong foundation in programming, six units of advanced programming for letter grade at the level of CME 212 and 3 units of parallel computing for letter grade are required. Programming proficiency at the level of CME 211 is a hard prerequisite for CME 212.

- **Requirement 3: Finance electives (9 units)**
  Choose three courses from the following list. Courses outside this list can be accepted as electives subject to approval by the student's program adviser.

**Mathematical and Computational Finance Track**
The Mathematical & Computational Finance (MCF) track is an interdisciplinary program that provides education in applied and computational mathematics, statistics, and financial applications for individuals with strong mathematical skills. Upon successful completion of the MCF track in the ICME master’s program, students will be prepared to assume positions in the financial industry as data and information scientists, quantitative strategists, risk managers, regulators, financial technologists, or to continue on to their Ph.D. in ICME, MS&E, Mathematics, Statistics, Finance, and other disciplines.
Requirements

superior academic achievement and passing the qualifying examination. 
admission to the Ph.D. program does not imply that the student is a 
candidate for the Ph.D. degree. Advancement to candidacy requires 
application is submitted.

Record Examination by October of the academic year in which the 
admissions) 

must be received by December 4, 2018. See Graduate Admissions 
graduatedegrees) 
The University's basic requirements for the Ph.D. degree are outlined 
and Mathematical Engineering 
Doctor of Philosophy in Computational 

Learning

CS 229 Machine Learning 3-4
CS 230 Deep Learning 3-4
CS 246 Mining Massive Data Sets 3-4
MS&E 338 Reinforcement Learning 3
STATS 315A Modern Applied Statistics: Learning 2-3
Minning
STATS 315B Modern Applied Statistics: Data Mining 2-3
Other
CS 224N Natural Language Processing with Deep Learning 3-4
MS&E 349 Financial Statistics 3
STATS 240 Statistical Methods in Finance 3-4
STATS 241 Data-driven Financial and Risk Econometrics 3-4

Requirement 5: Practical component (9 units)

Students are required to take nine units of practical and project courses 

Units

MS&E 246 Financial Risk Analytics 3
CME 240 Statistical and Machine Learning Approaches to 
Problems in Investment Management 3
CME 241 Reinforcement Learning for Stochastic Control 
Problems in Finance 3
CME 291 Master's Research 1-6
MS&E 448 Big Financial Data and Algorithmic Trading 3

Specialized Elective List

See requirement 1b above.

Units

CEE 362G Imaging with Incomplete Information 3-4
CME 279 Computational Biology: Structure and Organization 
of Biomolecules and Cells 3
CME 364B Convex Optimization II 3
CME 371 Computational Biology in Four Dimensions 3
CS 348A Computer Graphics: Geometric Modeling & 
Processing 3-4
EE 368 Digital Image Processing 3
MATH 205A Real Analysis 3
MATH 215A Algebraic Topology 3
MATH 221A Mathematical Methods of Imaging 3
MATH 221B Mathematical Methods of Imaging 3
MATH 227 Partial Differential Equations and Diffusion 
Processes 3
MATH 236 Introduction to Stochastic Differential Equations 3
MATH 238 Mathematical Finance 3
ME 335/335B/335C Finite Element Analysis 3
ME 346B Introduction to Molecular Simulations 3
ME 351A/351B Fluid Mechanics 3
ME 361 Turbulence 3
ME 408 Spectral Methods in Computational Physics 3
ME 412 Engineering Functional Analysis and Finite 
Elements 3
ME 469 Computational Methods in Fluid Mechanics 3
MS&E 319 Approximation Algorithms 3
MS&E 336
STATS 305A Introduction to Statistical Modeling 3
STATS 305B Methods for Applied Statistics I 3
STATS 305C Methods for Applied Statistics II: Applied 
Multivariate Statistics 2-3
STATS 318 Modern Markov Chains 3
STATS 366 Modern Statistics for Modern Biology 3

1. Complete a minimum of 135 units of residency at Stanford, including:
   a. 45 units from the master's program requirements; all six core 
courses have to be completed for letter grade.
   b. 27 units of electives for letter grade in an area planned with 
the student's Ph.D. adviser; 12 of these units should come from 
ICME specialized electives with significant computational 
content such as the CME 320-380 series. The focused and 
specialized elective component of the ICME program is meant to 
be broad and inclusive of relevant courses of comparable rigor 
to ICME courses. The elective course list following represents 
automatically accepted electives within the program. However, 
electives are not limited to the list below, and the list is expanded 
on a continuing basis; courses outside the list can be accepted 
as electives subject to approval by the student's ICME adviser. 
Research, directed study, and seminar units are excluded.

c. 3 units of programming elective demonstrating programming 
proficiency. Students are required to complete programming 
course at the level of CME 213 Introduction to parallel computing 
using MPI, openMP, and CUDA or higher for letter grade.

d. 60 units of thesis research

2. Maintain a grade point average (GPA) of 3.5.

3. Pass the ICME qualifying examination before the beginning of the 
second year.

4. Declare candidacy by the end of the second year

5. File dissertation reading committee form by the end of third year

6. Complete an approved program of original research.

7. Complete a written dissertation based on research.

8. Pass the oral examination that is a defense of the dissertation 
research.

Doctor of Philosophy in Computational 
and Mathematical Engineering

The University's basic requirements for the Ph.D. degree are outlined 
in the "Graduate Degrees" (http://exploredegrees.stanford.edu/ 
graduatedegrees) section of this bulletin.

Applications to the Ph.D. program and all required supporting documents 
must be received by December 4, 2018. See Graduate Admissions 
(http://gradadmissions.stanford.edu) for information and application 
materials. See the institute's admissions site (https://icme.stanford.edu/ 
admissions) for additional details. Applicants should take the Graduate 
Record Examination by October of the academic year in which the 
application is submitted.

Admission to the Ph.D. program does not imply that the student is a 
candidate for the Ph.D. degree. Advancement to candidacy requires 
superior academic achievement and passing the qualifying examination.

Requirements

STATS 244 Quantitative Trading: Algorithms, Data, and 
Optimization 2-4

Requirements

1. Complete a minimum of 135 units of residency at Stanford, including:
   a. 45 units from the master’s program requirements; all six core 
courses have to be completed for letter grade.
   b. 27 units of electives for letter grade in an area planned with 
the student’s Ph.D. adviser; 12 of these units should come from 
ICME specialized electives with significant computational 
content such as the CME 320-380 series. The focused and 
specialized elective component of the ICME program is meant to 

- Requirements
- Table: Courses and Units
- Specialized Elective List
- Doctor of Philosophy in Computational
- Mathematical Engineering
- Applications
- Admission
- Requirements
Note: Students who need to complete 135 units at Stanford, should necessarily complete CME master’s requirements (p. 1). All courses listed under “Requirement 2” under the “Master of Science in Computational and Mathematical Engineering (p. 1)” section can be used for fulfilling the general elective requirement.

Financial Assistance
The department awards a limited number of fellowships, course assistantships, and research assistantships to incoming graduate students. Applying for such assistance is part of submitting the application for admission to the program. Students are appointed for half-time assistantships which provide a tuition scholarship at the 8, 9, 10 unit rate during the academic year and a monthly stipend. Half-time appointments generally require 20 hours of work per week. Most course assistantships and research assistantships are awarded to students in the doctoral program in ICME. If the number of Ph.D. students is not sufficient to staff all course and research assistantship positions available, these positions may be open to master’s students. However, master’s students are not guaranteed financial assistance.

Ph.D. Minor in Computational and Mathematical Engineering
For a minor in Computational and Mathematical Engineering (CME), a doctoral candidate must complete 21 units of approved graduate level courses. These should include three ICME core courses and three ICME graduate electives at the 300 level or above and a programming course at the level of CME212 or higher. All courses must be taken for a letter grade and passed with a grade of ‘B’ or better. Elective courses cannot be cross listed with the primary department. Minor programs should be developed in close discussion between the student and the student’s primary Ph.D. adviser.

Master’s Student Advising:
The Institute for Computational and Mathematical Engineering (ICME) is committed to providing academic advising in support of our MS students’ education and professional development. When most effective, this advising relationship entails collaborative engagement by both the advisor and the advisee. As a best practice, advising expectations should be discussed and reviewed to ensure mutual understanding. Both the advisor and the advisee are expected to maintain professionalism and integrity.

At the start of graduate study, each student is assigned a master’s program advisor, a member of our faculty who will provide guidance in course selection, exploring academic opportunities, and professional pathways. Typically, the same faculty member serves as program advisor for the duration of a master’s study. Advisors are assigned during New Student Orientation at the beginning of autumn quarter. The first meeting between the program advisor and student should occur once in the first quarter of the first year to discuss the student’s goals and objectives.

Students are expected to initiate the meeting with the advisor and complete the master’s program proposal before the final study list deadline of the first quarter in the program. Subsequent meetings with the advisor are strongly encouraged as need arises. Students are required to get approval from advisors for changes to the course plan on file before the changed courses are taken.

In addition, the Director of ICME meets all the master’s students during the ICME New Student Orientation at the start of the first year and is available during the academic year by email and during office hours. The Director also schedules open advising meetings every quarter. In addition to the individual advisors, ICME also provides scholarly and professional development opportunities, including a teaching training program and workshops that address skills relevant to both industrial and academic careers.

ICME also conducts an annual review of all students’ progress. The Director, in conjunction with ICME Student Services, may initiate a meeting with any student deemed to be in academic distress.

The ICME Student Services team is also an important part of the master’s advising team. They inform students and advisors about university and department requirements, procedures, opportunities, and maintain the official records of advisor assignments and course approvals.

Finally, graduate students are active contributors to the advising relationship and we urge them to proactively seek academic and professional guidance and take responsibility for informing themselves about policies and degree requirements for their graduate program. We therefore expect students to read regular communication from the Registrar’s office and ICME Student Services regarding upcoming academic deadlines and policy updates, and to be responsible for complying with the university and program requirements.

A statement of University policy on graduate advising is posted under "Graduate Advising (http://exploredegrees.stanford.edu/graduatedegrees/#advisingandcredentialstext)” section of this bulletin.

Ph. D. Student Advising:
ICME is committed to providing academic advising in support of our Ph.D. students’ education and professional development. When most effective, this advising relationship entails collaborative engagement by both the advisor and the advisee. As a best practice, advising expectations should be discussed and reviewed to ensure mutual understanding. Both the advisor and the advisee are expected to maintain professionalism and integrity.

The program advisor initially guides students in key areas such as course selection, navigating policies and degree requirements, developing teaching pedagogy, identifying doctoral research opportunities and exploring academic opportunities and professional pathways. The Director of ICME serves as the program advisor for all incoming Ph.D. students. The program advisor meets with all the doctoral students during the New Student Orientation at the start of the first year and is available during the academic year by email and during office hours. The program advisor or Research advisor/Co-Advisor in conjunction with ICME Student Services may initiate a meeting with any student deemed to be in academic or research distress.

ICME does not require formal research rotations, but students are strongly encouraged to explore research activities in two or three research groups/labs during their first academic year.

In addition to the individual advisors, ICME also provides scholarly and professional development opportunities, including a teaching training program and workshops that address skills relevant to both industrial and academic careers.

Students are required to declare candidacy with a doctoral research advisor by the end of their second year in the program. ICME students can align with faculty across the university who are well versed in supervising research, mentoring doctoral students, and providing funding for the duration of the program. This research supervisor supersedes the program advisor in assuming primary responsibility for advising and mentoring the student. When the research advisor is from outside our department, the student will also identify a doctoral research Co-Advisor from ICME affiliated faculty to provide guidance on departmental requirements, core coursework, and opportunities. We encourage students to decide on their thesis committee within one year after start of candidacy in order to avail themselves of advice from multiple faculty members on the reading committee.

ICME also conducts an annual review of all students’ progress on milestones and research. Research input is solicited and an individual
progress report spelling out the forthcoming milestones and any remedial action needed to maintain status is compiled.

The ICME Student Services team is also an important part of the doctoral advising team. They inform students and advisors about university and department requirements, procedures, opportunities, and they maintain the official records of advisor assignments and course approvals. Students are encouraged to talk with the program advisor and the student services office as they consider courses.

Finally, our doctoral students are active contributors to the advising relationship and we urge them to proactively seek academic and professional guidance and take responsibility for informing themselves of policies and degree requirements for their graduate program. We therefore expect students to read regular communication from the Registrar’s office and ICME Student Services regarding upcoming academic deadlines and policy updates, and to be responsible for complying with the university and program requirements.

A statement of University policy on graduate advising is posted under "Graduate Advising [http://exploredegrees.stanford.edu/ graduatedegrees/#advisingandcredentialtext]" section of this bulletin.

Emeriti: (Professors) Gunnar Carlsson (Mathematics), Antony Jameson (Aeronautics and Astronautics), Walter Murray (Management Science and Engineering), Arogyaswami Paulraj (Electrical Engineering), Amin Saberi (Management Science and Engineering), Ali Mani (Mechanical Engineering), Alison Saunders (Management Science and Engineering)

Director: Gianluca Iaccarino (Mechanical Engineering)

Professors: Juan Alonso (Aeronautics and Astronautics), Biondo Biondi (Geophysics), Stephen Boyd (Electrical Engineering), Carlos D. Bustamante (Biomedical Data Science, Genetics), Emanuel Candes (Mathematics, Statistics), Persi Diaconis (Mathematics, Statistics), David Donoho (Statistics), Charbel Farhat (Aeronautics and Astronautics, Mechanical Engineering), Ronald Fedkiw (Computer Science), Margot Gerritsen (Energy Resources Engineering), Kay Gieskecke (Management Science and Engineering), Peter Glynn (Management Science and Engineering), Ashish Goel (Management Science and Engineering), Leonidas Guibas (Computer Science), Pat Hanrahan (Computer Science, Electrical Engineering), Jerry Harris (Geophysics), Trevor Hastie (Mathematics, Statistics), Gianluca Iaccarino (Mechanical Engineering), Doug James (Computer Science), Peter Kitanidis (Civil and Environmental Engineering), Tze Leung Lai (Statistics), Sanjiva Lele (Mechanical Engineering, Aeronautics and Astronautics), Parviz Moin (Mechanical Engineering), Brad Osgood (Electrical Engineering), George Papandreou (Mathematics), Peter Pinsky (Mechanical Engineering), Lenya Ryzhik (Mathematics), Eric Shaqfeh (Chemical Engineering, Mechanical Engineering), Jonathan Taylor (Statistics), Hamdi Tchelepi (Energy Resources Engineering), Benjamin Van Roy (Management Science and Engineering, Electrical Engineering), Andreas Vasy (Mathematics), Lawrence Wein (Graduate School of Business), Wing Wong (Statistics), Yin Yu (Management Science and Engineering), Lexing Ying (Mathematics, Institute for Computational and Mathematical Engineering)

Associate Professors: Eric Darve (Mechanical Engineering), Ron Dror (CS, Institute for Computational and Mathematical Engineering), Eric Dunham (Geophysics), Oliver Fringer (Civil and Environmental Engineering), Ramesh Johari (Management Science and Engineering), Adrian Lew (Mechanical Engineering), Ali Mani (Mechanical Engineering), Allison Marsden (Pediatrics, Bioengineering), Amin Saberi (Management Science and Engineering), Andrew Spakowitz (Chemical Engineering)

Assistant Professors: Marco Pavone (Aeronautics and Astronautics), Bala Rajaratnam (Statistics, Environmental and Earth System Sciences), Aaron Daniel Sidford (Management Science and Engineering), Jenny Suckale (Geophysics), Johan Ugander (Management Science and Engineering), Mary Wootters (Computer Science)

Senior Lecturer: Vadim Krayms

Lecturer: Hung Le, Ashwin Rao

Academic Staff: William Behrman, Reza Bosagh-Zadeh, Jeremy Evnine, Kari Hanson, Vijay Pandre, Hadley Wickham

Courses of interest to students in the department may include:

<table>
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<tr>
<th>Subject</th>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
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<tbody>
<tr>
<td>CEE 262A</td>
<td>Hydrodynamics</td>
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<tr>
<td>CEE 262B</td>
<td>Transport and Mixing in Surface Water Flows</td>
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<td>CEE 263A</td>
<td>Air Pollution Modeling</td>
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<td>CEE 263B</td>
<td>Numerical Weather Prediction</td>
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<td>Computational Poromechanics</td>
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<td>CEE 362</td>
<td>Numerical Modeling of Subsurface Processes</td>
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<td>CEE 362G</td>
<td>Imaging with Incomplete Information</td>
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<td>Artificial Intelligence: Principles and Techniques</td>
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<td>CS 228</td>
<td>Probabilistic Graphical Models: Principles and Techniques</td>
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<td>CS 229</td>
<td>Machine Learning</td>
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<td>Computer Graphics: Geometric Modeling &amp; Processing</td>
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<td>ENERGY 224</td>
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<td>Numerical Modeling of Fluid Flow in Heterogeneous Porous Media</td>
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<td>3-D Seismic Imaging</td>
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