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=14DE1634FEFCBE32542A001C07860506?view=catalog&catalog=&page=0&q=CME&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" (http://exploredegrees.stanford.edu/graduatedegrees) 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; those who pass this examination and secure a research adviser (three quarters of continuous documented research) may continue into the Ph.D. program upon acceptance by the institute.

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.

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, probabilities, introductory courses in PDEs, stochastics, and numerical methods and proficiency in programming.

Applications to the M.S. program and all supporting documents must be submitted and received online by January 9, 2018, the deadline published on ICME admissions web page (https://icme.stanford.edu/admissions/deadlines).

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 (http://exploredegrees.stanford.edu/cotermdegrees)" section. University requirements for the master's degree are described in the "Graduate Degrees (http://exploredegrees.stanford.edu/graduatedegrees/#masterstext)" 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 sophomore year may be used to meet master's degree requirements.

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 graduate 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. Master's students interested in continuing to the doctoral program must maintain a 3.5 or better grade point average in the program.

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. Deviations from the core curriculum must be justified in writing and approved by the student's ICME adviser and the chair of the ICME curriculum committee. Courses that are waived may not be counted towards the master's degree.

		Units
CME 302	Numerical Linear Algebra	3
CME 303	Partial Differential Equations of Applied Mathematics	3
CME 305	Discrete Mathematics and Algorithms	3
CME 306	Numerical Solution of Partial Differential Equations	3
CME 307	Optimization	3
CME 308	Stochastic Methods in Engineering	3
or CME 298	Basic Probability and Stochastic Processes with Engineering Applications	

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; students may only place out of CME 211 with prior written approval. CME 211 can be applied towards elective requirement.

		Units
CME 212	Advanced Software Development for Scientists and Engineers	3

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 ICME adviser.

		Units
Aeronautics and Astronautics		
AA 214B	Numerical Methods for Compressible Flows	3
AA 214C	Numerical Computation of Viscous Flow	3
AA 218	Introduction to Symmetry Analysis	3
Computational and Mathematical Engineering		
CME 215A/215B	Advanced Computational Fluid Dynamics	3
CME 263	Introduction to Linear Dynamical Systems	3

CME 279	Computational Biology: Structure and Organization of Biomolecules and Cells	3
CME 342	Parallel Methods in Numerical Analysis	3
CME 364A	Convex Optimization I	3
CME 371	Computational Biology in Four Dimensions	3
Computer Science		
CS 205A	Mathematical Methods for Robotics, Vision, and Graphics	3
CS 221	Artificial Intelligence: Principles and Techniques	3-4
CS 228	Probabilistic Graphical Models: Principles and Techniques	3-4
CS 229	Machine Learning	3-4
CS 255	Introduction to Cryptography	3
CS 261	Optimization and Algorithmic Paradigms	3
CS 340	Topics in Computer Systems	3-4
CS 348A	Computer Graphics: Geometric Modeling & Processing	3-4
Electrical Engineering		
EE 223	Applied Quantum Mechanics II	3
EE 256	Numerical Electromagnetics	3
EE 376A	Information Theory	3
Management Science and Engineering		
MS&E 220	Probabilistic Analysis	3-4
MS&E 221	Stochastic Modeling	3
MS&E 223	Simulation	3
MS&E 238	Leading Trends in Information Technology	3
MS&E 251	Stochastic Control	3
MS&E 310	Linear Programming	3
MS&E 316	Discrete Mathematics and Algorithms	3
MS&E 321	Stochastic Systems	3
MS&E 322	Stochastic Calculus and Control	3
Mathematics		
MATH 136	Stochastic Processes	3
MATH 171	Fundamental Concepts of Analysis	3
MATH 221B	Mathematical Methods of Imaging	3
MATH 236	Introduction to Stochastic Differential Equations	3
MATH 238	Mathematical Finance	3
Mechanical Engineering		
ME 335A/335B/335C	Finite Element Analysis	3
ME 346B	Introduction to Molecular Simulations	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
ME 484	Computational Methods in Cardiovascular Bioengineering	3
Statistics		
STATS 208	Introduction to the Bootstrap	3
STATS 217	Introduction to Stochastic Processes I	3
STATS 219	Stochastic Processes	3
STATS 250	Mathematical Finance	3
STATS 305A	Introduction to Statistical Modeling	3
STATS 310A/310B/310C	Theory of Probability I	2-4
STATS 362	Topic: Monte Carlo	3
Other		
CEE 281	Mechanics and Finite Elements	3
CEE 362G	Imaging with Incomplete Information	3-4
ENGR 209A	Analysis and Control of Nonlinear Systems	3
ENERGY 274	Complex Analysis for Practical Engineering	3

Requirement 4: Specialized Electives (9 units)

Nine units of focused graduate application electives, approved by the ICME graduate 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.

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.

Note: 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 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; students may ONLY place out of CME 211 with prior written approval. CME 211 can be applied towards elective requirement.

		Units
CME 212	Advanced Software Development for Scientists and Engineers	3
CME 214	Software Design in Modern Fortran for Scientists and Engineers	3
GEOPHYS 257	Introduction to Computational Earth Sciences	2-4

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.

		Units
Environmental/Climate/Hydrogeology		
ESS 220	Physical Hydrogeology	4
ESS 221	Contaminant Hydrogeology and Reactive Transport	4
ESS 246B	Atmosphere, Ocean, and Climate Dynamics: the Ocean Circulation	3
CEE 262A	Hydrodynamics	3-4
CEE 262B	Transport and Mixing in Surface Water Flows	3-4
CEE 262C	Hydrodynamics and Sediment Transport Modeling	3
CEE 263A	Air Pollution Modeling	3-4
CEE 361	Turbulence Modeling for Environmental Fluid Mechanics	2-4
Geophysical Imaging		
EE 256	Numerical Electromagnetics	3
GEOPHYS 210	Basic Earth Imaging	2-3
GEOPHYS 211	Environmental Soundings Image Estimation	3
GEOPHYS 280	3-D Seismic Imaging	2-3
GEOPHYS 287	Earthquake Seismology	3-5
General Computational/Mathematical Geoscineces		
CEE 362G	Imaging with Incomplete Information	3-4
CHEM 275	Advanced Physical Chemistry	3
CME 372	Applied Fourier Analysis and Elements of Modern Signal Processing	3
CME 321B	Mathematical Methods of Imaging	3
ESS 211	Fundamentals of Modeling	3-5
ENERGY 291	Optimization of Energy Systems	3-4
GS 240	Data science for geoscience	2-3
ME 335A	Finite Element Analysis	3
ME 346B	Introduction to Molecular Simulations	3
ME 361	Turbulence	3
ME 469B	Computational Methods in Fluid Mechanics	3
MS&E 211	Introduction to Optimization	4
Reservoir Simulation/Fluid Flow		
ENERGY 223	Reservoir Simulation	3-4
ENERGY 224	Advanced Reservoir Simulation	3
Subsurface/Reservoir Characterization		
ENERGY 241	Seismic Reservoir Characterization	3-4
GEOPHYS 202	Reservoir Geomechanics	3
GEOPHYS 260	Rock Physics for Reservoir Characterization	3
Structural/Tectonophysics/Geomechanics		
CEE 292	Continuum Mechanics	3
CEE 294	Computational Poromechanics	3
GEOPHYS 220	Ice, Water, Fire	3-5
GEOPHYS 288A	Crustal Deformation	3-5
GEOPHYS 288B	Crustal Deformation	3-5
GEOPHYS 290	Tectonophysics	3

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
EARTH 401	Curricular Practical Training	1

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. Deviations from the core curriculum must be justified in writing and approved by the student's ICME adviser and the chair of the ICME curriculum committee. Courses that are waived may not be counted towards the master's degree.

		Units
CME 302	Numerical Linear Algebra	3
CME 305	Discrete Mathematics and Algorithms	3
CME 307	Optimization	3

CME 308	Stochastic Methods in Engineering	3
or CME 309	Randomized Algorithms and Probabilistic Analysis	

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; students may only place out of 211 with prior written approval. CME 211 can be applied towards elective requirement.

		Units
Advanced Scientific Programming; take 3 units		
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	Parallel Computer Architecture and 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. Petitions for approval should be submitted to student services.

		Units
STATS 200	Introduction to Statistical Inference	3
STATS 203	Introduction to Regression Models and Analysis of Variance	3
or STATS 305A	Introduction to Statistical Modeling	
STATS 315A	Modern Applied Statistics: Learning	3
STATS 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. Petitions for approval should be submitted to student services.

		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
ENERGY 240	Data science for geoscience	3
CS 448	Topics in Computer Graphics	3-4
OIT 367	Business Intelligence from Big Data	3
PSYCH 204A	Human Neuroimaging Methods	3
STATS 290	Paradigms for Computing with Data	3
STATS 366	Modern Statistics for Modern Biology	3

Requirement 5: Practical component (6 units)

Students are required to take 6 units of practical component that may include any combination of:

- Master's Research(CME 291): A capstone project, supervised by a faculty member and approved by the steering committee; should be taken for letter grade only. The capstone 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.
- Project labs offered by Stanford Data Lab: ENGR 150 Data Challenge Lab, ENGR 350 Data Impact Lab. (Limited enrollment; application required.)
- Other courses that have a strong hands-on and practical component, such as STATS 390 Consulting Workshop up to 1unit.

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; students may only place out of CME 211 with prior written approval). CME 211 can be applied towards elective requirement.

		Units
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 /HPCComputing; 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
GEOPHYS 257	Introduction to Computational Earth Sciences	2-4

Requirement 3: Imaging Sciences electives (18 units)

Imaging Sciences 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. Petitions for approval should be submitted to student services.

		Units
Take 18 units of the following:		
APPPHYS 232	Advanced Imaging Lab in Biophysics	4
BIOE 220	Introduction to Imaging and Image-based Human Anatomy	3
CEE 362G	Imaging with Incomplete Information	3-4
CME 279	Computational Biology: Structure and Organization of Biomolecules and Cells	3
CME 371	Computational Biology in Four Dimensions	3
CS 231N	Convolutional Neural Networks for Visual Recognition	3-4
EE 236A	Modern Optics	3
EE 262	Two-Dimensional Imaging	3
EE 355	Imaging Radar and Applications	3
EE 367	Computational Imaging and Display	3
EE 368	Digital Image Processing	3
EE 369A	Medical Imaging Systems I	3
EE 369B	Medical Imaging Systems II	3
EE 369C	Medical Image Reconstruction	3
GEOPHYS 210	Basic Earth Imaging	2-3
GEOPHYS 211	Environmental Soundings Image Estimation	3
GEOPHYS 280	3-D Seismic Imaging	2-3
MATH 221B	Mathematical Methods of Imaging	3
MATH 262	Applied Fourier Analysis and Elements of Modern Signal Processing	3
PSYCH 204A	Human Neuroimaging Methods	3

Requirement 4: Specialized electives (6 units)

6 units of focused graduate application electives, approved by the ICME graduate 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.

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.

The Institute for Computational and Mathematical Engineering, in close cooperation with Mathematics, Management Science and Engineering and Statistics provides many of the basic courses. All 45 units must be taken for letter grade only.

Note: This new track in the ICME master's program supersedes, beginning in the Autumn Quarter of 2014, the interdisciplinary master's program (IDP) in Financial Mathematics in the School of Humanities & Sciences.

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. Deviations from the core curriculum must be justified in writing and approved by the student's ICME adviser and the chair of the ICME curriculum committee. Courses that are waived may not be counted towards the master's degree.

		Units
CME 302	Numerical Linear Algebra	3
or CME 303	Partial Differential Equations of Applied Mathematics	
or CME 305	Discrete Mathematics and Algorithms	
CME 307	Optimization	3
or CME 364A	Convex Optimization I	
CME 308	Stochastic Methods in Engineering	3
or MATH 236	Introduction to Stochastic Differential Equations	

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; students may only place out of CME 211 with prior written approval.

		Units
Advanced Scientific Programming; take 3-6 units		
CME 211	Software Development for Scientists and Engineers	3
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
CME 323	Distributed Algorithms and Optimization	3
CME 342	Parallel Methods in Numerical Analysis	3
CS 149	Parallel Computing	3-4
CS 315A	Parallel Computer Architecture and Programming	3
CS 316	Advanced Multi-Core Systems	3

Requirement 3: Finance electives (9 units)

Choose three courses from the following list; all nine units must be taken for letter grades.

		Units
Financial Mathematics		
MATH 238	Mathematical Finance	3
Financial Markets		
FINANCE 320	Debt Markets	3
FINANCE 620	Financial Markets I	3
STATS 244	Quantitative Trading: Algorithms, Data, and Optimization	2-4
Other		
CS 251	Bitcoin and Crypto Currencies	3

Requirement 4: Data Science electives (9 units)

Data Science electives should demonstrate breadth of knowledge in the technical area; all nine units should be taken for letter grade. The elective course list is defined below. Courses outside this list can be accepted as electives subject to approval prior to taking the course. Petitions for approval should be submitted to student services.

		Units
Learning		
CS 229	Machine Learning	3-4
STATS 315A	Modern Applied Statistics: Learning	2-3
Mining		
STATS 315B	Modern Applied Statistics: Data Mining	2-3
CS 246	Mining Massive Data Sets	3-4
Other		
CS 224N	Natural Language Processing with Deep Learning	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 for letter grade ONLY from the courses listed below.

		Units
CME 238	Artificial Intelligence in Financial Technology	3
CME 244	Project Course in Mathematical and Computational Finance	1-6
MS&E 347	Credit Risk: Modeling and Management	3
MS&E 348	Optimization of Uncertainty and Applications in Finance	3
MS&E 349	Financial Statistics	3
MS&E 447	Systemic and Market Risk : Notes on Recent History, Practice, and Policy	3
MS&E 448	Big Financial Data and Algorithmic Trading	3

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 5, 2017. 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

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.

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 364A/364B	Convex Optimization I	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 335A/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	Platform and Marketplace Design	3
STATS 305A	Introduction to Statistical Modeling	3
STATS 305B	Methods for Applied Statistics I: Exponential Families in Theory and Practice	3
STATS 305C	Methods for Applied Statistics II: Applied Multivariate Statistics	3
STATS 318	Modern Markov Chains	3
STATS 366	Modern Statistics for Modern Biology	3

Note: Students who need to complete 135 units at Stanford, should necessarily complete the 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.

Emeriti: (Professors) Gunnar Carlsson (Mathematics), *(Professors, Research)* Walter Murray (Management Science and Engineering), Arogyaswami Paulraj (Electrical Engineering), Michael Saunders (Management Science and Engineering)

Director: Margot Gerritsen (Energy Resources Engineering)

Co-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), 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), 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), Vijay Pande (Chemistry), George Papanicolaou (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), Andras Vasy (Mathematics), Lawrence Wein (Graduate School of Business), Wing Wong (Statistics), Yinyu Ye (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), Margot Gerritsen (Energy Resources Engineering), Kay Giesecke (Management Science and Engineering), Gianluca Iaccarino (Mechanical Engineering), Ramesh Johari (Management Science and Engineering), Adrian Lew (Mechanical Engineering), Alison Marsden (Pediatrics, Bioengineering), Amin Saberi (Management Science and Engineering), Andrew Spakowitz (Chemical Engineering)

Assistant Professors: Ali Mani (Mechanical Engineering), Marco Pavone (Aeronautics and Astronautics), Bala Rajaratnam (Statistics, Enviornmental and Earth System Sciences), Aaron Daniel Sidford (Management Science and Engineering), Jenny Suckale (Geophysics), Johan Ugander (Management Science and Engineering)

Professors (Research): Antony Jameson (Aeronautics and Astronautics)

Senior Lecturer: Vadim Khayms

Lecturer: Hung Le

Adjunct Professor: Reza Bosagh-Zadeh, Hadley Wickham

Academic Staff: William Behrman, Kapil Jain

Courses of interest to students in the department may include:

		Units
CEE 262A	Hydrodynamics	3-4
CEE 262B	Transport and Mixing in Surface Water Flows	3-4
CEE 263A	Air Pollution Modeling	3-4
CEE 263B	Numerical Weather Prediction	3-4
CEE 294	Computational Poromechanics	3
CEE 362	Numerical Modeling of Subsurface Processes	3-4
CEE 362G	Imaging with Incomplete Information	3-4
CS 205A	Mathematical Methods for Robotics, Vision, and Graphics	3
CS 221	Artificial Intelligence: Principles and Techniques	3-4
CS 228	Probabilistic Graphical Models: Principles and Techniques	3-4
CS 229	Machine Learning	3-4
CS 232	Digital Image Processing	3
CS 261	Optimization and Algorithmic Paradigms	3
CS 268	Geometric Algorithms	3
CS 348A	Computer Graphics: Geometric Modeling & Processing	3-4
EE 256	Numerical Electromagnetics	3
EE 368	Digital Image Processing	3
ENERGY 223	Reservoir Simulation	3-4
ENERGY 224	Advanced Reservoir Simulation	3
ENERGY 241	Seismic Reservoir Characterization	3-4
ENERGY 281	Applied Mathematics in Reservoir Engineering	3
ENERGY 284	Optimization and Inverse Modeling	3
ENERGY 290	Numerical Modeling of Fluid Flow in Heterogeneous Porous Media	3
GEOPHYS 190	Near-Surface Geophysics	3
GEOPHYS 202	Reservoir Geomechanics	3
GEOPHYS 210	Basic Earth Imaging	2-3
GEOPHYS 211	Environmental Soundings Image Estimation	3
GEOPHYS 240	Borehole Seismic Modeling and Imaging	3
GEOPHYS 257	Introduction to Computational Earth Sciences	2-4
GEOPHYS 260	Rock Physics for Reservoir Characterization	3
GEOPHYS 262	Rock Physics	3
GEOPHYS 280	3-D Seismic Imaging	2-3

GEOPHYS 281	Geophysical Inverse Problems	3
GEOPHYS 287	Earthquake Seismology	3-5
GEOPHYS 288A	Crustal Deformation	3-5
GEOPHYS 288B	Crustal Deformation	3-5
GEOPHYS 290	Tectonophysics	3
MATH 136	Stochastic Processes	3
MATH 205A	Real Analysis	3
MATH 215A	Algebraic Topology	3
MATH 236	Introduction to Stochastic Differential Equations	3
MATH 238	Mathematical Finance	3
ME 335A	Finite Element Analysis	3
ME 335B	Finite Element Analysis	3
ME 335C	Finite Element Analysis	3
ME 346B	Introduction to Molecular Simulations	3
ME 351A	Fluid Mechanics	3
ME 351B	Fluid Mechanics	3
ME 361	Turbulence	3
ME 408	Spectral Methods in Computational Physics	3
ME 469	Computational Methods in Fluid Mechanics	3
STATS 219	Stochastic Processes	3
STATS 250	Mathematical Finance	3
STATS 310A	Theory of Probability I	2-4
STATS 310B	Theory of Probability II	2-3
STATS 310C	Theory of Probability III	2-4
STATS 318	Modern Markov Chains	3
ENERGY 274	Complex Analysis for Practical Engineering	3