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 Geoscience (https://pangea.stanford.edu/programs/compgeo)s, Data Science, Imaging Science, and Mathematical and Computational Finance. The program is planning to implement a Computational Medicine track in the near future.

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 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 page (http://icme.stanford.edu/admissions/requirements)s 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 and probabilities, and introductory courses in PDEs, stochastics, numerical methods and proficiency in programming.

Applications to the M.S. program and all supporting documents must be submitted and received online by January 19, 2016, the deadline published on ICME admissions web page (http://icme.stanford.edu/admissions/requirements). Exceptions are made for applicants who are already students at Stanford and are applying to the coterminal program. See http://icme.stanford.edu/admissions/requirements.

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 (see the Computational Geosciences web site (https://pangea.stanford.edu/programs/compgeo) for more information)
- 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, unrestricted breadth and depth electives, programming coursework 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. The curriculum consists of core computational and mathematical engineering courses, breadth electives, depth electives, programming coursework and seminars and unrestricted electives. 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.

Requirement 1: Foundations (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 303	Partial Differential Equations of Applied Mathematics	3
CME 306	Numerical Solution of Partial Differential Equations	3
CME 302	Numerical Linear Algebra	3
CME 304	Numerical Optimization	3
or CME 364A	Convex Optimization I	
CME 305	Discrete Mathematics and Algorithms	3
CME 308	Stochastic Methods in Engineering	3

Requirement 2: 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. 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 212	Advanced Programming for Scientists and Engineers	3
CME 213	Introduction to parallel computing using MPI, openMP, and CUDA	3
CME 214	Software Design in Modern Fortran for Scientists and Engineers	3
CME 215A/215B	Advanced Computational Fluid Dynamics	3
CME 263	Introduction to Linear Dynamical Systems	3
CME 342	Parallel Methods in Numerical Analysis	3
CME 364A	Convex Optimization I	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	3-4
CS 364A	Algorithmic Game Theory	3
Electrical Engineering		
EE 223	Applied Quantum Mechanics II	3
EE 256	Numerical Electromagnetics	3
EE 376A	Information Theory	3
Management Science and Engineering		
MSE 220	Probabilistic Analysis	3-4
MSE 221	Stochastic Modeling	3
MSE 223	Simulation	3
MSE 238	Leading Trends in Information Technology	3
MSE 251	Stochastic Control	3
MSE 310	Linear Programming	3
MSE 316	Discrete Mathematics and Algorithms	3
MSE 321	Stochastic Systems	3
MSE 322	Stochastic Calculus and Control	3
Mathematics		
MATH 136	Stochastic Processes	3
MATH 171	Fundamental Concepts of Analysis	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
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	3
STATS 219	Stochastic Processes	3
STATS 237	Theory of Investment Portfolios and Derivative Securities	3
STATS 250	Mathematical Finance	3
STATS 305	Introduction to Statistical Modeling	3
STATS 310A/310B/310C	Theory of Probability	2-4
STATS 324	Multivariate Analysis	3
STATS 362	Topic: Monte Carlo	3
Other		
CEE 281	Mechanics and Finite Elements	3
CEE 362G	Stochastic Inverse Modeling and Data Assimilation Methods	3-4
ENGR 209A	Analysis and Control of Nonlinear Systems	3

Requirement 3: 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 4: Programming (3 units)

Three units of programming course work demonstrating programming proficiency. All graduate students in the program are required to complete programming course for letter grade at the level of CME 212 Advanced Programming for Scientists and Engineers or higher (students may ONLY place out of 211 with prior written approval).

		Units
CME 212	Advanced Programming for Scientists and Engineers	3
CME 213	Introduction to parallel computing using MPI, openMP, and CUDA	3
CME 214	Software Design in Modern Fortran for Scientists and Engineers	3
CME 323	Distributed Algorithms and Optimization	3
CME 342	Parallel Methods in Numerical Analysis	3

Requirement 5: Seminar (3 units)

Three units 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 2 and 3) from the approved list of courses from the Computational Geosciences program as well as completing EARTHSYS 310 seminar as part of Requirement 5. See http://pangea.stanford.edu/programs/compgeo/. 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 an M.S. in Computational and Mathematical Engineering with the 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: Fundamentals (12 units)

Identical to the general CME master's track requirement .

Requirement 2: Breadth Electives in Geosciences (18 units)

The M.S. CompGeo track requires 18 units of course work in the Geosciences. 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	Modeling Environmental Flows	3
CEE 263A	Air Pollution Modeling	3-4
CEE 263B	Numerical Weather Prediction	3-4
CEE 361	Turbulence Modeling for Environmental Fluid Mechanics	2-4
Geophysical Imaging		
EE 256	Numerical Electromagnetics	3
GEOPHYS 204	Spectral Finite Element Method (SPECFEM) Seismograms	3
GEOPHYS 210	Basic Earth Imaging	2-3
GEOPHYS 211	Environmental Soundings Image Estimation	3
GEOPHYS 240	Borehole Seismic Modeling and Imaging	3
GEOPHYS 280	3-D Seismic Imaging	2-3
GEOPHYS 287	Earthquake Seismology	3-5
General Computational/Mathematical Geoscinceces		
CEE 362G	Stochastic Inverse Modeling and Data Assimilation Methods	3-4
CHEM 275	Advanced Physical Chemistry	3
CME 372	Applied Fourier Analysis and Elements of Modern Signal Processing	3
CME 321A	Mathematical Methods of Imaging	3
CME 321B	Mathematical Methods of Imaging	3
ESS 211	Fundamentals of Modeling	3-5
ENERGY 242	Topics in Advanced Geostatistics	3-4
ENERGY 256	Electronic Structure Theory and Applications to Chemical Kinetics	3
ENERGY 260	Modeling Uncertainty in the Earth Sciences	3
ENERGY 284	Optimization and Inverse Modeling	3
ENERGY 291	Optimization of Energy Systems	3-4
GEOPHYS 257	Introduction to Computational Earth Sciences	2-4
GEOPHYS 258	Applied Optimization Laboratory (Geophys 258)	3-4
GEOPHYS 281	Geophysical Inverse Problems	3
GS 240	Geostatistics	2-3
STATS 253	Analysis of Spatial and Temporal Data	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
MSE 211	Linear and Nonlinear Optimization	3-4
Reservoir Simulation/Fluid Flow		
CME 358	Finite Element Method for Fluid Mechanics	3
ENERGY 223	Reservoir Simulation	3-4
ENERGY 224	Advanced Reservoir Simulation	3
ENERGY 281	Applied Mathematics in Reservoir Engineering	3
ENERGY 290	Numerical Modeling of Fluid Flow in Heterogeneous Porous Media	3
GES 255		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	Computational Micromechanics	3
CEE 294	Computational Poromechanics	3
CEE 362	Numerical Modeling of Subsurface Processes	3-4
GEOPHYS 220	Ice, Water, Fire	3-5
GEOPHYS 251	Structural Geology and Rock Mechanics	4
GEOPHYS 288A	Crustal Deformation	3-5
GEOPHYS 288B	Crustal Deformation	3-5
GEOPHYS 290	Tectonophysics	3

Requirement 3: Integrative courses in Computational Geosciences (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 advisor and submit a written report on the internship project. Credit for the internship will be obtained through EARTHSCI 401: Curricular Practical Training (1 unit) and in this case only 8 units of research are required.

Requirement 4: 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 at the level of CME 212 Advanced Programming for Scientists and Engineers or higher (students may ONLY place out of 211 with prior written approval).

		Units
CME 212	Advanced Programming for Scientists and Engineers	3
CME 213	Introduction to parallel computing using MPI, openMP, and CUDA	3
CME 214	Software Design in Modern Fortran for Scientists and Engineers	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 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 EARTH 310 Computational Geosciences Seminar (1 unit).

Data Science Track

The Data Science track develops strong mathematical, statistical, and computational and programming skills through the general master's core 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. The course work follows the requirements of the general master's degree in the core course requirement. The general and focused elective requirements (requirements 2 and 3 below) are limited to predefined courses from the data sciences and related courses group. Programming requirement (requirement 4) 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 304	Numerical Optimization	3
or CME 364A	Convex Optimization I	
CME 305	Discrete Mathematics and Algorithms	3
CME 308	Stochastic Methods in Engineering (or an equivalent course approved by the committee)	3

Requirement 2: 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 305	Introduction to Statistical Modeling	
STATS 315A	Modern Applied Statistics: Learning	3
STATS 315B	Modern Applied Statistics: Data Mining	3

Requirement 3: 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	Social Information and Network Analysis	3-4
CS 229	Machine Learning	3-4
CS 246	Mining Massive Data Sets	3-4
CS 347	Parallel and Distributed Data Management	3
CS 448	Topics in Computer Graphics	3-4
ENERGY 240	Geostatistics	2-3
OIT 367	Business Intelligence from Big Data	4
PSYCH 204A	Human Neuroimaging Methods	3

PSYCH 303	Human and Machine Hearing	3
STATS 290	Paradigms for Computing with Data	3
STATS 366	Modern Statistics for Modern Biology	3

Requirement 4: Advanced Scientific Programming and High Performance Computing Core (6 units)

To ensure that students have a strong foundation in programming, 3 units of advanced programming for letter grade at the level of CME 212 (students may ONLY place out of 211 with prior written approval) and three units of parallel computing for letter grades are required.

		Units
Advanced Scientific Programming; take 3 units		
CME 212	Advanced Programming 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
CS 344C, offered in previous years, may also be counted		3

Requirement 5: Practical component (6 units)

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

- A capstone project, supervised by a faculty member and approved by the steering committee. The capstone project should be computational in nature. Students should submit a one-page proposal, supported by the faculty member, to the steering committee (gwalther@stanford.edu) for approval at least one quarter before.
- Project labs offered by Stanford Data Lab: ENGR 250 Data Challenge Lab, and ENGR 350 Data Impact Lab.
- Other courses that have a strong hands-on and practical component, such as STATS 390 Consulting Workshop up to 3 units.

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 2 and 3 below) are limited to approved courses listed below. Programming requirement (requirement 4) 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.

1. general and focused application electives (Requirements 2 and 3) from the approved list of courses
2. high performance computing core (Requirement 4)
3. the ICME graduate seminar or other approved seminar series (Requirement 5)

Requirement 1: Fundamentals (12 units)

Identical to the general ICME master's program; see above.

Requirement 2: 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	Stochastic Inverse Modeling and Data Assimilation Methods	3-4
EE 236A	Modern Optics	3
EE 262	Two-Dimensional Imaging	3
EE 355	Imaging Radar and Applications	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 221A	Mathematical Methods of Imaging	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 3: 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 4: Advanced Scientific Programming and High Performance Computing Core (6 units)

To ensure that students have a strong foundation in programming, 3 units of advanced programming for letter grade at the level of CME 212 (students may ONLY place out of 211 with prior written approval) and three units of parallel computing for letter grades are required.

		Units
CME 212	Advanced Programming for Scientists and Engineers	3
CME 213	Introduction to parallel computing using MPI, openMP, and CUDA	3
CME 214	Software Design in Modern Fortran for Scientists and Engineers	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 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.

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 provide many of the basic courses.

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 MATH 239	Computation and Simulation in Finance	
or CME 303	Partial Differential Equations of Applied Mathematics	
CME 304	Numerical Optimization [1]	3
or CME 364A	Convex Optimization I	
CME 308	Stochastic Methods in Engineering (or an equivalent course approved by the committee) [2]	3
or MATH 236	Introduction to Stochastic Differential Equations	

Requirement 2: Finance electives (18 units)

Choose six units in each of the three Finance specialized areas: Financial Mathematics, Financial and Risk Modeling, and Financial Markets. Courses outside of 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
Financial Markets (6 units)		
FINANCE 320	Debt Markets	4
FINANCE 620	Financial Markets I	3
FINANCE 621	Financial Markets II	3
FINANCE 622	Dynamic Asset Pricing Theory	4
STATS 242	Algorithmic Trading and Quantitative Strategies	3
STATS 244	Quantitative Trading: Algorithms, Data, and Optimization	2-4
MSE 445	Projects in Wealth Management	3-4
MSE 448	Big Financial Data and Algorithmic Trading	3
Financial Mathematics (6 units)		
MATH 238	Mathematical Finance	3
MATH 239	Computation and Simulation in Finance	3
STATS 240	Statistical Methods in Finance	3-4
Financial and Risk Modeling (6 units)		
MATH 237	Default and Systemic Risk	3
MSE 246	Financial Risk Analytics	3
MSE 347	Credit Risk: Modeling and Management	3
MSE 348	Optimization of Uncertainty and Applications in Finance	3
MSE 447	Systemic and Market Risk : Notes on Recent History, Practice, and Policy	3
STATS 241	Data-driven Financial and Risk Econometrics	3-4
STATS 243	Financial Models and Statistical Methods in Active Risk Management	2-4

Note: CME 211 can be applied towards finance core and electives if necessary.

Requirement 3: Data Science electives (6 units)

Data Science electives should demonstrate breadth of knowledge in the technical area. 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
CS 229	Machine Learning	3-4
CS 246	Mining Massive Data Sets	3-4
STATS 362	Topic: Monte Carlo	3
STATS 315A	Modern Applied Statistics: Learning	2-3
STATS 315B	Modern Applied Statistics: Data Mining	2-3

Requirement 4: Advanced Scientific Programming and High Performance Computing Core (6 units)

To ensure that students have a strong foundation in programming, 3 units of advanced programming for letter grade at the level of CME 212 (students may ONLY place out of 211 with prior written approval) and three units of parallel computing for letter grades are required.

		Units
Advanced Scientific Programming; take 3 units		
CME 212	Advanced Programming 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
CS 344C, offered in previous years, may also be counted		3
CS 545	Information and Data Analytics Seminar	1

Requirement 5: Practical component (6 units)

Students are required to take 6 units of practical component, of which at least 3 units must be taken for letter grade:

		Units
CME 244	Project Course in Mathematical and Computational Finance	1-6
CME 245	Topics in Mathematical and Computational Finance	1
MSE 445	Projects in Wealth Management	3-4

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 8, 2015. See Graduate Admissions (http://gradadmissions.stanford.edu) for information and application materials. See the department's admissions site (http://icme.stanford.edu/admissions/requirements) 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; all six core courses have to be completed for letter grade.
    b. 27 units of focused 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. Complete an approved program of original research.
5. Complete a written dissertation based on research.
6. Pass the oral examination that is a defense of the dissertation research.

Specialized Elective List

See requirement 1b above.

		Units
CEE 362G	Stochastic Inverse Modeling and Data Assimilation Methods	3-4
CME 364A/364B	Convex Optimization I	3
CS 348A	Computer Graphics: Geometric Modeling	3-4
EE 368	Digital Image Processing	3
MATH 205A	Real Analysis	3
MATH 215A	Complex Analysis, Geometry, and Topology	3
MATH 217A		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
MSE 319	Approximation Algorithms	3
MSE 336	Platform and Marketplace Design	3
STATS 305	Introduction to Statistical Modeling	3
STATS 306A/306B	Methods for Applied Statistics	5-6
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 3" 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: (Professor) Joe Keller (Mathematics, Mechanical Engineering), *(Professor, Research)*Arogyaswami Paulraj (Electrical 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), Emanuel Candes (Mathematics, Statistics), Gunnar Carlsson (Mathematics), 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), 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: Marco Pavone (Aeronautics and Astronautics), Jack Poulson (Mathematics, Institute for Computational and Mathematical Engineering), Bala Rajaratnam (Statistics, Enviornmental and Earth System Sciences), Jenny Suckale (Geophysics)

Professors (Research): Antony Jameson (Aeronautics and Astronautics), Walter Murray (Management Science and Engineering), Michael A. Saunders (Management Science and Engineering)

Senior Lecturer: Vadim Khayms

Lecturers: Bill Behrman, Kapil Jain, Hung Le

Consulting Professors: Reza Bosagh-Zadeh, Sanjeeb Bose, Michael Minion

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	Stochastic Inverse Modeling and Data Assimilation Methods	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 348A	Computer Graphics: Geometric Modeling	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 252	Chemical Kinetics Modeling	3
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 258	Applied Optimization Laboratory (Geophys 258)	3-4
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	Complex Analysis, Geometry, and 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
MSE 211	Linear and Nonlinear Optimization	3-4
STATS 219	Stochastic Processes	3
STATS 250	Mathematical Finance	3
STATS 305	Introduction to Statistical Modeling	3
STATS 306A	Methods for Applied Statistics	3
STATS 306B	Methods for Applied Statistics: Unsupervised Learning	2-3
STATS 310A	Theory of Probability	2-4
STATS 310B	Theory of Probability	2-3
STATS 310C	Theory of Probability	2-4
STATS 318	Modern Markov Chains	3

Courses

CME 20Q. Computational Modeling for Future Leaders. 3 Units.
Preference to sophomores. How can we harness and exploit the power of computational modeling? What responsibilities are there in developing and using computer models? In this course we will analyze fundamental issues inherent to computational modeling such as uncertainty, predictability, error, and resolution. We will furthermore examine the social context of computational modeling including the public perception of computational models, how computer modeling impacts politics and policy, and how politics and policy, in turn, influence computer modeling.

CME 100. Vector Calculus for Engineers. 5 Units.
Computation and visualization using MATLAB. Differential vector calculus: analytic geometry in space, functions of several variables, partial derivatives, gradient, unconstrained maxima and minima, Lagrange multipliers. Introduction to linear algebra: matrix operations, systems of algebraic equations, methods of solution and applications. Integral vector calculus: multiple integrals in Cartesian, cylindrical, and spherical coordinates, line integrals, scalar potential, surface integrals, Greeniquest;s, divergence, and Stokesiquest; theorems. Examples and applications drawn from various engineering fields. Prerequisites: 10 units of AP credit (Calc BC with 4 or 5, or Calc AB with 5), or Math 41 and 42. Note: Students enrolled in section 100-02 and 100A-02 are required to attend the discussion sections on Thursdays 5:15-6:45.
Same as: ENGR 154

CME 100A. Vector Calculus for Engineers, ACE. 6 Units.
Students attend CME100/ENGR154 lectures with additional recitation sessions; two to four hours per week, emphasizing engineering mathematical applications and collaboration methods. Enrollment by department permission only. Prerequisite: application at:http://soe.stanford.edu/current_students/edp/programs/ace.html.

CME 102. Ordinary Differential Equations for Engineers. 5 Units.
Analytical and numerical methods for solving ordinary differential equations arising in engineering applications: Solution of initial and boundary value problems, series solutions, Laplace transforms, and nonlinear equations; numerical methods for solving ordinary differential equations, accuracy of numerical methods, linear stability theory, finite differences. Introduction to MATLAB programming as a basic tool kit for computations. Problems from various engineering fields. Prerequisite: 10 units of AP credit (Calc BC with 4 or 5, or Calc AB with 5), or Math 41 and 42. Recommended: CME100.
Same as: ENGR 155A

CME 102A. Ordinary Differential Equations for Engineers, ACE. 6 Units.
Students attend CME102/ENGR155A lectures with additional recitation sessions; two to four hours per week, emphasizing engineering mathematical applications and collaboration methods. Prerequisite: application at:http://soe.stanford.edu/current_students/edp/programs/ace.html.

CME 103. Introduction to Matrix Methods. 4-5 Units.
Introduction to applied linear algebra with emphasis on applications. Vectors, norm, and angle; linear independence and orthonormal sets. Matrices, left and right inverses, QR factorization. Least- squares and model fitting, regularization and cross-validation, time-series prediction, and other examples. Constrained least-squares; applications to least-norm reconstruction, optimal control, and portfolio optimization. Newton methods and nonlinear least-squares. Prerequisites: MATH 51 or CME 100.
Same as: EE 103

CME 104. Linear Algebra and Partial Differential Equations for Engineers. 5 Units.
Linear algebra: matrix operations, systems of algebraic equations, Gaussian elimination, undetermined and overdetermined systems, coupled systems of ordinary differential equations, eigensystem analysis, normal modes. Fourier series with applications, partial differential equations arising in science and engineering, analytical solutions of partial differential equations. Numerical methods for solution of partial differential equations: iterative techniques, stability and convergence, time advancement, implicit methods, von Neumann stability analysis. Examples and applications from various engineering fields. Prerequisite: CME 102/ENGR 155A.
Same as: ENGR 155B

CME 104A. Linear Algebra and Partial Differential Equations for Engineers, ACE. 6 Units.
Students attend CME104/ENGR155B lectures with additional recitation sessions; two to four hours per week, emphasizing engineering mathematical applications and collaboration methods. Prerequisite: application at:http://soe.stanford.edu/current_students/edp/programs/ace.html.

CME 106. Introduction to Probability and Statistics for Engineers. 4 Units.
Probability: random variables, independence, and conditional probability; discrete and continuous distributions, moments, distributions of several random variables. Topics in mathematical statistics: random sampling, point estimation, confidence intervals, hypothesis testing, non-parametric tests, regression and correlation analyses; applications in engineering, industrial manufacturing, medicine, biology, and other fields. Prerequisite: CME 100/ENGR154 or MATH 51 or 52.
Same as: ENGR 155C

CME 108. Introduction to Scientific Computing. 3-4 Units.
Introduction to Scientific Computing Numerical computation for mathematical, computational, physical sciences and engineering: error analysis, floating-point arithmetic, nonlinear equations, numerical solution of systems of algebraic equations, banded matrices, least squares, unconstrained optimization, polynomial interpolation, numerical differentiation and integration, numerical solution of ordinary differential equations, truncation error, numerical stability for time dependent problems and stiffness. Implementation of numerical methods in MATLAB programming assignments. Prerequisites: MATH 51, 52, 53; prior programming experience (MATLAB or other language at level of CS 106A or higher).nGraduate students should take it for 3 units and undergraduate students should take it for 4 units.
Same as: MATH 114

CME 151. Introduction to Data Visualization. 1 Unit.
Bring your data to life with beautiful and interactive visualizations. This course is designed to provide practical experience on combining data science and graphic design to effectively communicate knowledge buried inside complex data. Each lecture will explore a different set of free industry-standard tools, for example d3.js, three.js, ggplots2, and processing; enabling students to think critically about how to architect their own interactive visualization for data exploration, web, presentations, and publications. Geared towards scientists and engineers, and with a particular emphasis on web, this course assumes an advanced background in programming methodology in multiple languages (particularly R and Javascript). Assignments are short and focus on visual experimentation with interesting data sets or the students' own data. Topics: data, visualization, web. Prerequisites: some experience with general programming is required to understand the lectures and assignments.

CME 181. Projects in Applied and Computational Mathematics. 3 Units.
Teams of students use techniques in applied and computational mathematics to tackle problems of their choosing. Students will have the opportunity to pursue open-ended projects in a variety of areas: economics, physics, political science, operations research, etc. Projects can cover (but are not limited to!) topics such as mathematical modeling of real-world phenomena (population dynamics), data-driven applications (movie recommendations) or complex systems in engineering (optimal control). Each team will be paired with a graduate student mentor working in applied and computational mathematics. Limited enrollment. Prerequisites: CME 100/102/104 or equivalents, or instructor consent. Recommended: CME 106/108 and familiarity with programming at the level of CME 192/193.

CME 192. Introduction to MATLAB. 1 Unit.
This short course runs for the first eight weeks of the quarter and is offered each quarter during the academic year. It is highly recommended for students with no prior programming experience who are expected to use MATLAB in math, science, or engineering courses. It will consist of interactive lectures and application-based assignments.nThe goal of the short course is to make students fluent in MATLAB and to provide familiarity with its wide array of features. The course covers an introduction of basic programming concepts, data structures, and control/flow; and an introduction to scientific computing in MATLAB, scripts, functions, visualization, simulation, efficient algorithm implementation, toolboxes, and more.

CME 193. Introduction to Scientific Python. 1 Unit.
This short course runs for the first eight weeks of the quarter and is offered each quarter during the academic year. It is recommended for students who want to use Python in math, science, or engineering courses and for students who want to learn the basics of Python programming. The goal of the short course is to familiarize students with Pythoniquest;s tools for scientific computing. Lectures will be interactive with a focus on learning by example, and assignments will be application-driven. Some prior programming experience is highly recommended.nTopics covered include control flow, basic data structures, File I/O, and an introduction to NumPy/SciPy.

CME 194. Introduction to MPI. 1 Unit.
This short course runs for the first four weeks of the quarter. Recommended for students interested in writing parallel programs. Focus is on distributed memory programming via the Message Passing Interface (MPI). Topics include: parallel decomposition, basic communication primitives, collective operations, and debugging. Interactive lectures and homework assignments require writing software. Students should be comfortable and interested in writing software in C/C++ but no prior parallel programming experience is required.

CME 195. Introduction to R. 1 Unit.
This short course runs for the first four weeks of the quarter and is offered in fall and spring. It is recommended for students who want to use R in statistics, science, or engineering courses and for students who want to learn the basics of R programming. The goal of the short course is to familiarize students with R's tools for scientific computing. Lectures will be interactive with a focus on learning by example, and assignments will be application-driven. No prior programming experience is needed. Topics covered include basic data structures, File I/O, graphs, control structures, etc, and some useful packages in R.
Same as: STATS 195

CME 196. Practical Fortran. 1 Unit.
A five-week short course presenting the use of the Fortran programming language in science and engineering. Topics covered: basic language elements; good programming practices; testing and debugging; verification and validation; differences between Fortran-77 and Fortran-90 (95, 03, 08); calling numerical software libraries such as LAPACK; calling Fortran routines from C or C++; performance considerations. The course will be centered around solving iquest;realiquest; computational problems, emphasizing practice over theory. Programming proficiency in C/C++, or other modern compiled language, is required. Familiarity with the GNU development tools (compilers, debuggers, makefiles, etc.) is assumed. Prerequisites: CME 211 or equivalent.

CME 200. Linear Algebra with Application to Engineering Computations. 3 Units.
Computer based solution of systems of algebraic equations obtained from engineering problems and eigen-system analysis, Gaussian elimination, effect of round-off error, operation counts, banded matrices arising from discretization of differential equations, ill-conditioned matrices, matrix theory, least square solution of unsolvable systems, solution of non-linear algebraic equations, eigenvalues and eigenvectors, similar matrices, unitary and Hermitian matrices, positive definiteness, Cayley-Hamilton theory and function of a matrix and iterative methods. Prerequisite: familiarity with computer programming, and MATH51.
Same as: ME 300A

CME 204. Partial Differential Equations in Engineering. 3 Units.
Geometric interpretation of partial differential equation (PDE) characteristics; solution of first order PDEs and classification of second-order PDEs; self-similarity; separation of variables as applied to parabolic, hyperbolic, and elliptic PDEs; special functions; eigenfunction expansions; the method of characteristics. If time permits, Fourier integrals and transforms, Laplace transforms. Prerequisite: CME 200/ME 300A, equivalent, or consent of instructor.
Same as: ME 300B

CME 206. Introduction to Numerical Methods for Engineering. 3 Units.
Numerical methods from a user's point of view. Lagrange interpolation, splines. Integration: trapezoid, Romberg, Gauss, adaptive quadrature; numerical solution of ordinary differential equations: explicit and implicit methods, multistep methods, Runge-Kutta and predictor-corrector methods, boundary value problems, eigenvalue problems; systems of differential equations, stiffness. Emphasis is on analysis of numerical methods for accuracy, stability, and convergence. Introduction to numerical solutions of partial differential equations; Von Neumann stability analysis; alternating direction implicit methods and nonlinear equations. Prerequisites: CME 200/ME 300A, CME 204/ME 300B.
Same as: ME 300C

CME 207. Numerical Methods in Engineering and Applied Sciences. 3 Units.
Scientific computing and numerical analysis for physical sciences and engineering. Advanced version of CME206 that, apart from CME206 material, includes nonlinear PDEs, multidimensional interpolation and integration and an extended discussion of stability for initial boundary value problems. Recommended for students who have some prior numerical analysis experience. Topics include: 1D and multi-D interpolation, numerical integration in 1D and multi-D including adaptive quadrature, numerical solutions of ordinary differential equations (ODEs) including stability, numerical solutions of 1D and multi-D linear and nonlinear partial differential equations (PDEs) including concepts of stability and accuracy. Prerequisites: linear algebra, introductory numerical analysis (CME 108 or equivalent).
Same as: AA 214A, GEOPHYS 217

CME 211. Software Development for Scientists and Engineers. 3 Units.
Basic usage of the Python and C/C++ programming languages are introduced and used to solve representative computational problems from various science and engineering disciplines. Software design principles including time and space complexity analysis, data structures, object-oriented design, decomposition, encapsulation, and modularity are emphasized. Usage of campus wide Linux compute resources: login, file system navigation, editing files, compiling and linking, file transfer, etc. Versioning and revision control, software build utilities, and the LaTeX typesetting software are introduced and used to help complete programming assignments. Prerequisite: introductory programming course equivalent to CS 106A or instructor consent.
Same as: EARTH 211

CME 212. Advanced Programming for Scientists and Engineers. 3 Units.
Advanced topics in software development, debugging, and performance optimization are covered. The capabilities and usage of common libraries and frameworks such as BLAS, LAPACK, FFT, PETSc, and MKL/ACML are reviewed. Computer representation of integer and floating point numbers, and interoperability between C/C++ and Fortran is described. More advanced software engineering topics including: representing data in files, signals, unit and regression testing, and build automation. The use of debugging tools including static analysis, gdb, and Valgrind are introduced. An introduction to computer architecture covering processors, memory hierarchy, storage, and networking provides a foundation for understanding software performance. Profiles generated using gprof and perf are used to help guide the performance optimization process. Computational problems from various science and engineering disciplines will be used in assignments. Prerequisites: CME 200 / ME 300A and CME 211. The CME 211 requirement may be satisfied by passing a placement test administered by ICME.
Same as: ENERGY 212

CME 213. Introduction to parallel computing using MPI, openMP, and CUDA. 3 Units.
This class will give hands on experience with programming multicore processors, graphics processing units (GPU), and parallel computers. Focus will be on the message passing interface (MPI, parallel clusters) and the compute unified device architecture (CUDA, GPU). Topics will include: network topologies, modeling communication times, collective communication operations, parallel efficiency, MPI, dense linear algebra using MPI. Symmetric multiprocessing (SMP), pthreads, openMP. CUDA, combining MPI and CUDA, dense linear algebra using CUDA, sort, reduce and scan using CUDA. Pre-requisites include: C programming language and numerical algorithms (solution of differential equations, linear algebra, Fourier transforms).
Same as: ME 339

CME 213B. Parallel Computing Projects. 3 Units.
Students will discuss, devise and implement parallel applications for a discipline of mutual interest. The parallel implementation will focus on the use of MPI for clusters, OpenMP for multicore processors, and/or CUDA for GPU processors. Instructors will help guide students to relevant literature and resources. A short introduction to MPI, OpenMP, and CUDA will be given at the beginning of the quarter. Hardware will be available for the duration of the quarter including NVIDIA Jetson TK1 development kits, and the ICME GPU cluster. Prerequisites: CME 211/212 or equivalent.

CME 214. Software Design in Modern Fortran for Scientists and Engineers. 3 Units.
This course introduces software design and development in modern Fortran. Course covers the functional, object-oriented-, and parallel programming features introduced in the Fortran 95, 2003, and 2008 standards, respectively, in the context of numerical approximations to ordinary and partial differential equations; introduces object-oriented design and design schematics based on the Unified Modeling Language (UML) structure, behavior, and interaction diagrams; cover the basic use of several open-source tools for software building, testing, documentation generation, and revision control. Recommended: Familiarity with programming in Fortran 90, basic numerical analysis and linear algebra, or instructor approval.
Same as: EARTH 214

CME 215A. Advanced Computational Fluid Dynamics. 3 Units.
High resolution schemes for capturing shock waves and contact discontinuities; upwinding and artificial diffusion; LED and TVD concepts; alternative flow splittings; numerical shock structure. Discretization of Euler and Navier Stokes equations on unstructured meshes; the relationship between finite volume and finite element methods. Time discretization; explicit and implicit schemes; acceleration of steady state calculations; residual averaging; math grid preconditioning. Automatic design; inverse problems and aerodynamic shape optimization via adjoint methods. Pre- or corequisite: 214B or equivalent.
Same as: AA 215A

CME 215B. Advanced Computational Fluid Dynamics. 3 Units.
High resolution schemes for capturing shock waves and contact discontinuities; upwinding and artificial diffusion; LED and TVD concepts; alternative flow splittings; numerical shock structure. Discretization of Euler and Navier Stokes equations on unstructured meshes; the relationship between finite volume and finite element methods. Time discretization; explicit and implicit schemes; acceleration of steady state calculations; residual averaging; math grid preconditioning. Automatic design; inverse problems and aerodynamic shape optimization via adjoint methods. Pre- or corequisite: 214B or equivalent.
Same as: AA 215B

CME 232. Introduction to Computational Mechanics. 3 Units.
Provides an introductory overview of modern computational methods for problems arising primarily in mechanics of solids and is intended for students from various engineering disciplines. The course reviews the basic theory of linear solid mechanics and introduces students to the important concept of variational forms, including the principle of minimum potential energy and the principles of virtual work. Specific model problems that will be considered include deformation of bars, beams and membranes, plates, and problems in plane elasticity (plane stress, plane strain, axisymmetric elasticity). The variational forms of these problems are used as the starting point for developing the finite element method (FEM) and boundary element method (BEM) approaches shy; providing an important connection between mechanics and computational methods.
Same as: ME 332

CME 239B. Workshop in Quantitative Finance. 1 Unit.
Topics of current interest. May be repeated for credit.
Same as: STATS 239B

CME 242. Mathematical and Computational Finance Seminar. 1 Unit.
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Same as: STATS 239

CME 243. Financial Models and Statistical Methods in Active Risk Management. 2-4 Units.
(SCPD students register for 243P.) Market risk and credit risk, credit markets. Back testing, stress testing and Monte Carlo methods. Logistic regression, generalized linear models and generalized mixed models. Loan prepayment and default as competing risks. Survival and hazard functions, correlated default intensities, frailty and contagion. Risk surveillance, early warning and adaptive control methodologies. Banking and bank regulation, asset and liability management. Prerequisite: STATS 240 or equivalent.
Same as: STATS 243

CME 244. Project Course in Mathematical and Computational Finance. 1-6 Unit.
For graduate students in the MCF track; students will work individually or in groups on research projects.

CME 245. Topics in Mathematical and Computational Finance. 1 Unit.
Current topics for enrolled students in the MCF program; can be repeated up to three times.

CME 250. Introduction to Machine Learning. 1 Unit.
A Short course presenting the principles behind when, why, and how to apply modern machine learning algorithms. We will discuss a framework for reasoning about when to apply various machine learning techniques, emphasizing questions of over-fitting/under-fitting, regularization, interpretability, supervised/unsupervised methods, and handling of missing data. The principles behind various algorithms--the why and how of using them--will be discussed, while some mathematical detail underlying the algorithms--including proofs--will not be discussed. Unsupervised machine learning algorithms presented will include k-means clustering, principal component analysis (PCA), and independent component analysis (ICA). Supervised machine learning algorithms presented will include support vector machines (SVM), classification and regression trees (CART), boosting, bagging, and random forests. Imputation, the lasso, and cross-validation concepts will also be covered. The R programming language will be used for examples, though students need not have prior exposure to R. Prerequisite: undergraduate-level linear algebra and statistics; basic programming experience (R/Matlab/Python).

CME 251. The Shape of Data: Geometric and Topological Data Analysis. 3 Units.
Mathematical computational tools for the analysis of data with geometric content, such images, videos, 3D scans, GPS traces -- as well as for other data embedded into geometric spaces. Global and local geometry descriptors allowing for various kinds of invariances. The rudiments of computational topology and persistent homology on sampled spaces. Clustering and other unsupervised techniques. Spectral methods for geometric data analysis. Non-linear dimensionality reduction. Alignment, matching, and map computation between geometric data sets. Function spaces and functional maps.Networks of data sets and joint analysis for segmentation and labeling. The emergence of abstractions or concepts from data. Prerequisites: discrete algorithms at the level of 161; linear algebra at the level of CM103.
Same as: CS 233

CME 252. Introduction to Optimization. 1 Unit.
This course introduces mathematical optimization and modeling, with a focus on convex optimization. Topics include: varieties of mathematical optimization, convexity of functions and sets, convex optimization modeling with CVXPY, gradient descent and basic distributed optimization, in-depth examples from machine learning, statistics and other fields and applications of bi-convexity and non-convex gradient descent.nRecommended prerequisite: familiarity with linear algebra, differential multivariable calculus, and basic probability and statistics. Experience with Python will be helpful, but not required.

CME 257. Advanced Topics in Scientific Computing with Julia. 1 Unit.
This short course runs from the 2nd to the 5th week of the quarter. This course will rapidly introduce students to the new Julia language, with the goal of giving students the knowledge and experience necessary to begin contributing to the language and package ecosystem while using Julia for their own scientific computing needs. The course will begin with learning the basics of Julia with an emphasis on its object-oriented features, and then introduce students to Github and package development. Additional topics include: common packages, interfacing with C shared object libraries, and Julia's core linear algebra implementation. Lectures will be interactive, with an emphasis on collaboration and learning by example. Prerequisites: Data structures at the level of CS106B, experience with one or more scientific computing languages (e.g. Python, Matlab, or R), and some familiarity with C/C++ and the Unix shell. No prior experience with Julia or Github is required.

CME 263. Introduction to Linear Dynamical Systems. 3 Units.
Applied linear algebra and linear dynamical systems with applications to circuits, signal processing, communications, and control systems. Topics: least-squares approximations of over-determined equations, and least-norm solutions of underdetermined equations. Symmetric matrices, matrix norm, and singular-value decomposition. Eigenvalues, left and right eigenvectors, with dynamical interpretation. Matrix exponential, stability, and asymptotic behavior. Multi-input/multi-output systems, impulse and step matrices; convolution and transfer-matrix descriptions. Control, reachability, and state transfer; observability and least-squares state estimation. Prerequisites: linear algebra and matrices as in MATH104; differential equations and Laplace transforms as in EE102B.
Same as: EE 263

CME 279. Computational Biology: Structure and Organization of Biomolecules and Cells. 3 Units.
Computational approaches to understanding the three-dimensional spatial organization of biological systems and how that organization evolves over time. The course will cover cutting-edge research in both physics-based simulations and computational analysis of experimental data, at scales ranging from individual molecules to multiple cells. Prerequisites: elementary programming background (106A or equivalent) and an introductory course in biology or biochemistry.
Same as: BIOMEDIN 279, BIOPHYS 279, CS 279

CME 291. Master's Research. 1-6 Unit.
Students require faculty sponsor. (Staff).

CME 292. Advanced MATLAB for Scientific Computing. 1 Unit.
Short course running first four weeks of the quarter (8 lectures) with interactive lectures and application based assignment. Students will be introduced to advanced MATLAB features, syntaxes, and toolboxes not traditionally found in introductory courses. Material will be reinforced with in-class examples, demos, and homework assignment involving topics from scientific computing. MATLAB topics will be drawn from: advanced graphics (2D/3D plotting, graphics handles, publication quality graphics, animation), MATLAB tools (debugger, profiler), code optimization (vectorization, memory management), object-oriented programming, compiled MATLAB (MEX files and MATLAB coder), interfacing with external programs, toolboxes (optimization, parallel computing, symbolic math, PDEs). Scientific computing topics will include: numerical linear algebra, numerical optimization, ODEs, and PDEs.

CME 298. Basic Probability and Stochastic Processes with Engineering Applications. 3 Units.
Calculus of random variables and their distributions with applications. Review of limit theorems of probability and their application to statistical estimation and basic Monte Carlo methods. Introduction to Markov chains, random walks, Brownian motion and basic stochastic differential equations with emphasis on applications from economics, physics and engineering, such as filtering and control. Prerequisites: exposure to basic probability.
Same as: MATH 158

CME 300. First Year Seminar Series. 1 Unit.
Required for first-year ICME Ph.D. students; recommended for first-year ICME M.S. students. Presentations about research at Stanford by faculty and researchers from Engineering, H&S, and organizations external to Stanford. May be repeated for credit.

CME 302. Numerical Linear Algebra. 3 Units.
First in a three quarter graduate sequence. Solution of systems of linear equations: direct methods, error analysis, structured matrices; iterative methods and least squares. Parallel techniques. Prerequisites: CME 108, MATH 103 or 113.

CME 303. Partial Differential Equations of Applied Mathematics. 3 Units.
First-order partial differential equations; method of characteristics; weak solutions; elliptic, parabolic, and hyperbolic equations; Fourier transform; Fourier series; and eigenvalue problems. Prerequisite: foundation in multivariable calculus and ordinary differential equations.
Same as: MATH 220

CME 304. Numerical Optimization. 3 Units.
Solution of nonlinear equations; unconstrained optimization; linear programming; quadratic programming; global optimization; general linearly and nonlinearly constrained optimization. Theory and algorithms to solve these problems. Prerequisite: background in analysis and numerical linear algebra.
Same as: MSE 315

CME 305. Discrete Mathematics and Algorithms. 3 Units.
Topics: Basic Algebraic Graph Theory, Matroids and Minimum Spanning Trees, Submodularity and Maximum Flow, NP-Hardness, Approximation Algorithms, Randomized Algorithms, The Probabilistic Method, and Spectral Sparsification using Effective Resistances. Topics will be illustrated with applications from Distributed Computing, Machine Learning, and large-scale Optimization. Prerequisites: CS 261 is highly recommended, although not required.
Same as: MSE 316

CME 306. Numerical Solution of Partial Differential Equations. 3 Units.
Hyperbolic partial differential equations: stability, convergence and qualitative properties; nonlinear hyperbolic equations and systems; combined solution methods from elliptic, parabolic, and hyperbolic problems. Examples include: Burger's equation, Euler equations for compressible flow, Navier-Stokes equations for incompressible flow. Prerequisites: MATH 220A or CME 302.
Same as: MATH 226

CME 308. Stochastic Methods in Engineering. 3 Units.
The basic limit theorems of probability theory and their application to maximum likelihood estimation. Basic Monte Carlo methods and importance sampling. Markov chains and processes, random walks, basic ergodic theory and its application to parameter estimation. Discrete time stochastic control and Bayesian filtering. Diffusion approximations, Brownian motion and an introduction to stochastic differential equations. Examples and problems from various applied areas. Prerequisites: exposure to probability and background in analysis.
Same as: MATH 228

CME 309. Randomized Algorithms and Probabilistic Analysis. 3 Units.
Randomness pervades the natural processes around us, from the formation of networks, to genetic recombination, to quantum physics. Randomness is also a powerful tool that can be leveraged to create algorithms and data structures which, in many cases, are more efficient and simpler than their deterministic counterparts. This course covers the key tools of probabilistic analysis, and application of these tools to understand the behaviors of random processes and algorithms. Emphasis is on theoretical foundations, though we will apply this theory broadly, discussing applications in machine learning and data analysis, networking, and systems. Topics include tail bounds, the probabilistic method, Markov chains, and martingales, with applications to analyzing random graphs, metric embeddings, random walks, and a host of powerful and elegant randomized algorithms. Prerequisites: CS 161 and STAT 116, or equivalents and instructor consent.
Same as: CS 265

CME 321A. Mathematical Methods of Imaging. 3 Units.
Image denoising and deblurring with optimization and partial differential equations methods. Imaging functionals based on total variation and l-1 minimization. Fast algorithms and their implementation.
Same as: MATH 221A

CME 321B. Mathematical Methods of Imaging. 3 Units.
Array imaging using Kirchhoff migration and beamforming, resolution theory for broad and narrow band array imaging in homogeneous media, topics in high-frequency, variable background imaging with velocity estimation, interferometric imaging methods, the role of noise and inhomogeneities, and variational problems that arise in optimizing the performance of array imaging algorithms.
Same as: MATH 221B

CME 322. Spectral Methods in Computational Physics. 3 Units.
Data analysis, spectra and correlations, sampling theorem, nonperiodic data, and windowing; spectral methods for numerical solution of partial differential equations; accuracy and computational cost; fast Fourier transform, Galerkin, collocation, and Tau methods; spectral and pseudospectral methods based on Fourier series and eigenfunctions of singular Sturm-Liouville problems; Chebyshev, Legendre, and Laguerre representations; convergence of eigenfunction expansions; discontinuities and Gibbs phenomenon; aliasing errors and control; efficient implementation of spectral methods; spectral methods for complicated domains; time differencing and numerical stability.
Same as: ME 408

CME 323. Distributed Algorithms and Optimization. 3 Units.
The emergence of large distributed clusters of commodity machines has brought with it a slew of new algorithms and tools. Many fields such as Machine Learning and Optimization have adapted their algorithms to handle such clusters. Topics include distributed algorithms for: Optimization, Numerical Linear Algebra, Machine Learning, Graph analysis, Streaming and online algorithms, and other problems that are challenging to scale on a commodity cluster. Throughout the class, topics will be illustrated with hands-on exercises using the high-speed cluster programming framework, Spark, with computing resources provided by the instructor.

CME 325. Numerical Approximations of Partial Differential Equations in Theory and Practice. 1-2 Unit.
Finite volume and finite difference methods for initial boundary value problems in multiple space dimensions. Emphasis is on formulation of boundary conditions for the continuous and the discrete problems. Analysis of numerical methods with respect to stability, accuracy, and error behavior. Techniques of treating non-rectangular domains, and effects of non-regular grids.

CME 326. Numerical Methods for Initial Boundary Value Problems. 3 Units.
Initial boundary value problems model many phenomena in engineering and science such as, fluid flow problems, wave propagation, fluid-structure interaction, conjugate heat transfer and financial mathematics. We discuss numerical techniques for such simulations and focus on the underlying principles and theoretical understanding. Emphasis is on stability, convergence and efficiency for methods applied to hyperbolic and parabolic initial boundary value problems.

CME 327. Numerical Methods for Stiff Problems. 3 Units.
Focus is on analysis of numerical techniques for stiff ordinary differential equations, including those resulting from spatial discretization of partial differential equations. Topics include stiffness, convergence, stability, adaptive time stepping, implicit time-stepping methods (SDIRK, Rosenbrock), linear and nonlinear system solvers (Fixed Point, Newton, Multigrid, Krylov subspace methods) and preconditioning. Pre-requisites: CME200/ME300A or equivalent; or consent of instructor.

CME 328. Advanced Topics in Partial Differential Equations. 3 Units.
Contents change each time and is taught as a topics course, most likely by a faculty member visiting from another institution. May be repeated for credit. Topic in 2012-13: numerical solution of time-dependent partial differential equations is a fundamental tool for modeling and prediction in many areas of science and engineering. In this course we explore the stability, accuracy, efficiency, and appropriateness of specialized temporal integration strategies for different classes of partial differential equations including stiff problems and fully implicit methods, operator splitting and semi-implicit methods, extrapolation methods, multirate time integration, multi-physics problems, symplectic integration, and temporal parallelism. Prerequisites: recommended CME303 and 306 or with instructor's consent.

CME 330. Applied Mathematics in the Chemical and Biological Sciences. 3 Units.
Mathematical solution methods via applied problems including chemical reaction sequences, mass and heat transfer in chemical reactors, quantum mechanics, fluid mechanics of reacting systems, and chromatography. Topics include generalized vector space theory, linear operator theory with eigenvalue methods, phase plane methods, perturbation theory (regular and singular), solution of parabolic and elliptic partial differential equations, and transform methods (Laplace and Fourier). Prerequisites: CME 102/ENGR 155A and CME 104/ENGR 155B, or equivalents.
Same as: CHEMENG 300

CME 334. Advanced Methods in Numerical Optimization. 3 Units.
Topics include interior-point methods, relaxation methods for nonlinear discrete optimization, sequential quadratic programming methods, optimal control and decomposition methods. Topic chosen in first class; different topics for individuals or groups possible. Individual or team projects. May be repeated for credit.
Same as: MSE 312

CME 335. Advanced Topics in Numerical Linear Algebra. 3 Units.
Possible topics: Classical and modern (e.g., focused on provable communication minimization) algorithms for executing dense and sparse-direct factorizations in high-performance, distributed-memory environments; distributed dense eigensolvers, dense and sparse-direct triangular solvers, and sparse matrix-vector multiplication; unified analysis of distributed Interior Point Methods for symmetric cones via algorithms for distributing Jordan algebras over products of second-order cones and Hermitian matrices. May be repeated for credit. Prerequisites: CME 302 and CME 304 (or equivalents).

CME 336. Linear and Conic Optimization with Applications. 3 Units.
Linear, semidefinite, conic, and convex nonlinear optimization problems as generalizations of classical linear programming. Algorithms include the interior-point, barrier function, and cutting plane methods. Related convex analysis, including the separating hyperplane theorem, Farkas lemma, dual cones, optimality conditions, and conic inequalities. Complexity and/or computation efficiency analysis. Applications to combinatorial optimization, sensor network localization, support vector machine, and graph realization. Prerequisite: MS&E 211 or equivalent.
Same as: MSE 314

CME 337. Spectral Graph Theory and Algorithmic Applications. 3 Units.
Brings students to the forefront of a very active area of research. Reviews classic results relating graph expansion and spectra, random walks, random spanning trees, and their electrical network representation. Covers recent progress on graph sparsification, Kadison-Singer problem and approximation algorithms for traveling salesman problems.
Same as: MSE 237

CME 338. Large-Scale Numerical Optimization. 3 Units.
The main algorithms and software for constrained optimization emphasizing the sparse-matrix methods needed for their implementation. Iterative methods for linear equations and least squares. The simplex method. Basis factorization and updates. Interior methods. The reduced-gradient method, augmented Lagrangian methods, and SQP methods. Prerequisites: Basic numerical linear algebra, including LU, QR, and SVD factorizations, and an interest in MATLAB, sparse-matrix methods, and gradient-based algorithms for constrained optimization. Recommended: MS&E 310, 311, 312, 314, or 315; CME 108, 200, 302, 304, 334, or 335.
Same as: MSE 318

CME 342. Parallel Methods in Numerical Analysis. 3 Units.
Emphasis is on techniques for obtaining maximum parallelism in numerical algorithms, especially those occurring when solving matrix problems, partial differential equations, and the subsequent mapping onto the computer. Implementation issues on parallel computers. Topics: parallel architecture, programming models (MPI, GPU Computing with CUDA iquest; quick review), matrix computations, FFT, fast multiple methods, domain decomposition, graph partitioning, discrete algorithms. Prerequisites: 302 or 200 (ME 300A), 213 or equivalent, or consent of instructor. Recommended: differential equations and knowledge of a high-level programming language such as C or C++ (F90/95 also allowable).

CME 345. Model Reduction. 3 Units.
Model reduction is an indispensable tool for computational-based design and optimization, statistical analysis, embedded computing, and real-time optimal control. This course presents the basic mathematical theory for projection-based model reduction. Topics include: notions of linear dynamical systems and projection; projection-based model reduction; error analysis; proper orthogonal decomposition; Hankel operator and balancing of a linear dynamical system; balanced truncation method: modal truncation and other reduction methods for linear oscillators; model reduction via moment matching methods based on Krylov subspaces; introduction to model reduction of parametric systems and notions of nonlinear model reduction. Course material is complemented by a balanced set of theoretical, algorithmic and Matlab computer programming assignments. Prerequisites: CME 200 or equivalent, CME 263 or equivalent and basic numerical methods for ODEs.

CME 356. Engineering Functional Analysis and Finite Elements. 3 Units.
Concepts in functional analysis to understand models and methods used in simulation and design. Topology, measure, and integration theory to introduce Sobolev spaces. Convergence analysis of finite elements for the generalized Poisson problem. Extensions to convection-diffusion-reaction equations and elasticity. Upwinding. Mixed methods and LBB conditions. Analysis of nonlinear and evolution problems. Prerequisites: 335A,B, CME 200, CME 204, or consent of instructor. Recommended: 333, MATH 171.
Same as: ME 412

CME 358. Finite Element Method for Fluid Mechanics. 3 Units.
Mathematical theory of the finite element method for incompressible flows; related computational algorithms and implementation details. Poisson equation; finite element method for simple elliptic problems; notions of mathematical analysis of non-coercive partial differential equations; the inf-sup or Babushka-Brezzi condition and its applications to the Stokes and Darcy problems; presentation of stable mixed finite element methods and corresponding algebraic solvers; stabilization approaches in the context of advection-diffusion equation; numerical solution of the incompressible Navier-Stokes equations by finite element method. Theoretical, computational, and MATLAB computer programming assignments. Prerequisites: foundation in multivariate calculus and ME 335A or equivalent.

CME 362. An Introduction to Compressed Sensing. 3 Units.
Compressed sensing is a new data acquisition theory asserting that one can design nonadaptive sampling techniques that condense the information in a compressible signal into a small amount of data. This revelation may change the way engineers think about signal acquisition. Course covers fundamental theoretical ideas, numerical methods in large-scale convex optimization, hardware implementations, connections with statistical estimation in high dimensions, and extensions such as recovery of data matrices from few entries (famous Netflix Prize).
Same as: STATS 330

CME 364A. Convex Optimization I. 3 Units.
Convex sets, functions, and optimization problems. The basics of convex analysis and theory of convex programming: optimality conditions, duality theory, theorems of alternative, and applications. Least-squares, linear and quadratic programs, semidefinite programming, and geometric programming. Numerical algorithms for smooth and equality constrained problems; interior-point methods for inequality constrained problems. Applications to signal processing, communications, control, analog and digital circuit design, computational geometry, statistics, machine learning, and mechanical engineering. Prerequisite: linear algebra such as EE263, basic probability.
Same as: CS 334A, EE 364A

CME 364B. Convex Optimization II. 3 Units.
Continuation of 364A. Subgradient, cutting-plane, and ellipsoid methods. Decentralized convex optimization via primal and dual decomposition. Monotone operators and proximal methods; alternating direction method of multipliers. Exploiting problem structure in implementation. Convex relaxations of hard problems. Global optimization via branch and bound. Robust and stochastic optimization. Applications in areas such as control, circuit design, signal processing, and communications. Course requirements include project. Prerequisite: 364A.
Same as: EE 364B

CME 371. Computational Biology in Four Dimensions. 3 Units.
Computational approaches to understanding the three-dimensional spatial organization of biological systems and how that organization evolves over time. The course will cover cutting-edge research in both physics-based simulation and computational analysis of experimental data, at scales ranging from individual molecules to entire cells. Prerequisite: CS 106A or equivalent, and an introductory course in biology or biochemistry. Recommended: some experience in mathematical modeling (does not need to be a formal course).
Same as: BIOMEDIN 371, BIOPHYS 371, CS 371

CME 372. Applied Fourier Analysis and Elements of Modern Signal Processing. 3 Units.
Introduction to the mathematics of the Fourier transform and how it arises in a number of imaging problems. Mathematical topics include the Fourier transform, the Plancherel theorem, Fourier series, the Shannon sampling theorem, the discrete Fourier transform, and the spectral representation of stationary stochastic processes. Computational topics include fast Fourier transforms (FFT) and nonuniform FFTs. Applications include Fourier imaging (the theory of diffraction, computed tomography, and magnetic resonance imaging) and the theory of compressive sensing.
Same as: MATH 262

CME 375. Advanced Topics in Convex Optimization. 3 Units.
Modern developments in convex optimization: semidefinite programming; novel and efficient first-order algorithms for smooth and nonsmooth convex optimization. Emphasis on numerical methods suitable for large scale problems arising in science and engineering. Prerequisites: convex optimization (EE 364), linear algebra (Math 104), numerical linear algebra (CME 302); background in probability, statistics, real analysis and numerical optimization.
Same as: MATH 301

CME 390. Curricular Practical Training. 1 Unit.
May be repeated three times for credit.

CME 399. Special Research Topics in Computational and Mathematical Engineering. 1-15 Unit.
Graduate-level research work not related to report, thesis, or dissertation. May be repeated for credit.

CME 400. Ph.D. Research. 1-15 Unit.
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CME 444. Computational Consulting. 1-3 Unit.
Advice by graduate students under supervision of ICME faculty. Weekly briefings with faculty adviser and associated faculty to discuss ongoing consultancy projects and evaluate solutions. May be repeated for credit.

CME 500. Departmental Seminar. 1 Unit.
Weekly research lectures by experts from academia, national laboratories, industry, and doctoral students. May be repeated for credit. In autumn and winter 2014-15, this seminar will predominantly feature current graduate students talking about their research.

CME 510. Linear Algebra and Optimization Seminar. 1 Unit.
Recent developments in numerical linear algebra and numerical optimization. Guest speakers from other institutions and local industry. Goal is to bring together scientists from different theoretical and application fields to solve complex scientific computing problems. May be repeated for credit.

CME 520. Topics in Simulation of Human Physiology & Anatomical Systems. 1 Unit.
Biweekly interdisciplinary lecture series on the development of computational tools for modeling and simulation of human physiological and anatomical systems. Lectures by instructors and guest speakers on topics such as surgical simulation, anatomical & surgical Modeling, neurological Systems, and biomedical models of human movement. Group discussions, team based assignments, and project work.nPrerequisite: Medical students, residents or fellows from school of medicine, and computationally oriented students with a strong interest to explore computational and mathematical methods related to the health sciences.
Same as: SURG 253

CME 801. TGR Project. 0 Units.
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CME 802. TGR Dissertation. 0 Units.
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