# SCHOOL OF ENGINEERING

# INSTITUTE FOR COMPUTATIONAL AND MATHEMATICAL ENGINEERING



*Emeritus: (Professor)* Joe Keller (Mathematics, Mechanical Engineering)

*Director:* Peter Glynn (Management Science and Engineering)

*Director of Student Affairs:* Walter Murray (Management Science and Engineering)

*Professors:* 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), Peter Glynn (Management Science and Engineering), Leonidas Guibas (Computer Science), Pat Hanrahan (Computer Science, Electrical Engineering), Jerry Harris (Geophysics), Peter Kitanidis (Civil and Environmental Engineering), Tze Leung Lai (Statistics), Sanjiva Lele (Mechanical Engineering, Aeronautics and Astronautics), Parviz Moin (Mechanical Engineering), Brad Osgood (Electrical Engineering), George Papanicolaou (Mathematics), Peter Pinsky ( Mechanical Engineering), Eric Shaqfeh (Chemical Engineering, Mechanical Engineering), Andras Vasy (Mathematics), Lawrence Wein (Graduate School of Business), Wing Wong (Statistics), Yinyu Ye (Management Science and Engineering)

*Associate Professors:* Juan Alonso (Aeronautics and Astronautics), Ronald Fedkiw (Computer Science), Margot Gerritsen (Energy Resources Engineering), Ashish Goel (Management Science and Engineering), Heinz Pitsch (Mechanical Engineering), Charles Taylor (Bioengineering, Surgery), Benjamin Van Roy (Management Science and Engineering, Electrical Engineering)

*Assistant Professors:* Eric Darve (Mechanical Engineering), Oliver Fringer (Civil and Environmental Engineering), Gianluca Iaccarino (Mechanical Engineering), Ramesh Johari (Management Science and Engineering), Adrian Lew (Mechanical Engineering), Amin Saberi (Management Science and Engineering), Andrew Spakowitz (Chemical Engineering)

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

*Senior Lecturer:* Vadim Khayms

*Consulting Assistant Professor:* Sepandar Kamvar

*Web Site:* http://icme.stanford.edu

*Mail Code:* 94305-4042

*Phone:* (650) 736-9038

Courses offered by the Institute for Computational and Mathematical Engineering are listed under the subject code CME on the *Stanford Bulletin's* ExploreCourses web site.

The central research mission of the Institute for Computational and Mathematical Engineering (iCME) is to develop sophisticated algorithmic and mathematical tools that impact many applied disciplines. iCME leverages Stanford's strengths in engineering applications and the physical, biological, and information sciences to guide the development of modern methods for research and education in computational mathematics.

iCME's teaching mission is to provide courses for graduate students and undergraduates from all departments in the mathematical sciences focusing on theoretical work and its role in the solution of real problems, integrating numerical computation to facilitate application of mathematical techniques and theories. The institute identifies research areas that benefit from a multidisciplinary approach in which computational mathematics plays a key role such as discrete mathematics, including computational probability and combinatorial optimization, optimization, stochastics, and numerical solution of partial differential equations. Research applications include the physical sciences, business, medicine, and information science.

A strength of iCME is its multidisciplinary intellectual environment, with interaction among students and faculty with diverse backgrounds and expertise. iCME offers service courses for undergraduates and graduate students to fulfill departmental requirements, core courses for M.S. and Ph.D. students in Scientific Computing and Computational Mathematics, and specialized electives in various application areas.

## GRADUATE PROGRAMS IN COMPUTATIONAL AND MATHEMATICAL ENGINEERING

University regulations governing the M.S. and Ph.D. degrees are described in the "Graduate Degrees" section of this bulletin.

## MASTER OF SCIENCE IN COMPUTATIONAL AND MATHEMATICAL ENGINEERING

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.

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.

Applications to the M.S. program and all required supporting documents must be received by January 12, 2010. See http://icme.stanford.edu/admissions for up-to-date information including departmental deadlines. See http://gradadmissions.stanford.edu for information and application materials.

For University coterminal degree program rules and University application forms, see http://registrar.stanford.edu/shared/publications.htm#Coterm.

### REQUIREMENTS

A candidate is required to complete a program of 45 units of courses numbered 200 or above. Courses below 200 level will require special approval from the program office. At least 36 of these must be graded units, passed with a grade point average (GPA) of 3.0 (B) or better. Master's students interested in continuing to the doctoral program must maintain a 3.5 or better grade point average in the program.

*Requirement 1*—The following courses may be needed as prerequisites for other courses in the program: MATH 41, 42, 51, 52, 53, 103, 113; CME 100, 102, 104, 108, 200, 204, 302; CS 106A, 106X, 108, 205, 229; ENGR 62; STATS 116 or 202.

*Requirement 2*—Students must demonstrate foundational knowledge in the field by completing the following core courses:
CME 302. Numerical Linear Algebra

CME 303. Partial Differential Equations of Applied Mathematics
CME 304. Numerical Optimization
CME 305. Discrete Mathematics and Algorithms
CME 306. Numerical Solution of Partial Differential Equations
CME 308. Stochastic Methods in Engineering

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.

*Requirement 3*—12 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.

1. *Aeronautics and Astronautics:*
   AA 214A. Numerical Methods in Fluid Mechanics
   AA 214B. Numerical Computation of Compressible Flow
   AA 214C. Numerical Computation of Viscous Flow
   AA 218. Introduction to Symmetry Analysis
2. *Computational and Mathematical Engineering:*
   CME 208. Mathematical Programming and Combinatorial Optimization
   CME 212. Introduction to Large Scale Computing in Engineering
   CME 215 A,B. Advanced Computational Fluid Dynamics
   CME 324. Advanced Methods in Matrix Computation
   CME 340. Large-Scale Data Mining
   CME 342. Parallel Methods in Numerical Analysis
   CME 380. Constructing Scientific Simulation Codes
3. *Computer Science:*
   CS 164. Computing with Physical Objects: Algorithms for Shape and Motion
   CS 205. Mathematical Methods for Robotics, Vision, and Graphics
   CS 221. Artificial Intelligence: Principles and Techniques
   CS 228. Probabilistic Models in Artificial Intelligence
   CS 229. Machine Learning
   CS 255. Introduction to Cryptography
   CS 261. Optimization and Algorithmic Paradigms
   CS 268. Geometric Algorithms
   CS 315A. Parallel Computer Architecture and Programming
   CS 340. Level Set Methods
   CS 348A. Computer Graphics: Geometric Modeling
   CS 364A. Algorithmic Game Theory
4. *Electrical Engineering:*
   EE 222. Applied Quantum Mechanics I
   EE 223. Applied Quantum Mechanics II
   EE 256. Numerical Electromagnetics
   EE 262. Two-Dimensional Imaging
   EE 278. Introduction to Statistical Signal Processing
   EE 292E. Analysis and Control of Markov Chains
   EE 363. Linear Dynamic Systems
   EE 364. Convex Optimization
   EE 376A. Information Theory
5. *Management Science and Engineering:*
   MS&E 220. Probabilistic Analysis
   MS&E 221. Stochastic Modeling
   MS&E 223. Simulation
   MS&E 238. Network Structures and Analysis
   MS&E 251. Stochastic Decision Models
   MS&E 310. Linear Programming
   MS&E 313. Vector Space Optimization
   MS&E 316. Pricing Algorithms and the Internet
   MS&E 321. Stochastic Systems
   MS&E 322. Stochastic Calculus and Control
   MS&E 323. Stochastic Simulation
6. *Mathematics:*
   MATH 136. Stochastic Processes
   MATH 171. Fundamental Concepts of Real Analysis
   MATH 221. Mathematical Methods of Imaging
   MATH 227. Partial Differential Equations and Diffusion Processes
   MATH 236. Introduction to Stochastic Differential Equations
   MATH 237. Stochastic Equations and Random Media
   MATH 238. Mathematical Finance
7. *Mechanical Engineering:*
   ME 335A,B,C. Finite Element Analysis
   ME 346B. Introduction to Molecular Simulations
   ME 408. Spectral Methods in Computational Physics
   ME 412. Engineering Functional Analysis and Finite Elements
   ME 469A,B. Computational Methods in Fluid Mechanics
   ME 484. Computational Methods in Cardiovascular Bioengineering
8. *Statistics:*
   STATS 208. Introduction to the Bootstrap
   STATS 217. Introduction to Stochastic Processes
   STATS 219. Stochastic Processes
   STATS 227. Statistical Computing
   STATS 237. Time Series Modeling and Forecasting
   STATS 250. Mathematical Finance
   STATS 305. Introduction to Statistical Modeling
   STATS 310A,B,C. Theory of Probability
   STATS 324. Classical Multivariate and Random Matrix Theory
   STATS 345. Computational Molecular Biology
   STATS 362. Monte Carlo Sampling
   STATS 366. Computational Biology
9. *Other:*
   CEE 281. Finite Element Structural Analysis
   CEE 362G. Stochastic Inverse Modeling and Data Assimilation Methods
   ENGR 209A. Analysis and Control of Nonlinear Systems

*Requirement 4*—9 units of focused graduate application electives, approved by the iCME graduate adviser, in the areas of engineering, mathematics, physical, biological, information, and other quantitative sciences. These courses should be foundational depth courses relevant to the student's professional development and research interests.

*Requirement 5*—3 units of an iCME graduate seminar or other approved seminar.

## DOCTOR OF PHILOSOPHY IN COMPUTATIONAL AND MATHEMATICAL ENGINEERING

Applications to the Ph.D. program and all required supporting documents must be received by December 12, 2009. See http://icme.stanford.edu /admissions for up-to-date information. Prospective graduate students should see http://gradadmissions.stanford.edu for information and application materials. Applicants should take the Graduate Record Examination by October of the year 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
   b. 27 units of focused electives 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.
   c. 60 units of thesis research
   d. 3 units of free elective
2. Maintain a grade point average (GPA) of 3.5
3. Pass the qualifying examination administered by iCME
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.

CEE 362G. Stochastic Inverse Modeling and Data Assimilation Methods
CS 348A. Computer Graphics: Geometric Modeling
EE 363. Linear Dynamical Systems
EE364A,B. Convex Optimization I,II
EE 368. Digital Image Processing
MATH 205A. Real Analysis
MATH 215A. Complex Analysis, Geometry and Topology
MATH 217A. Differential Geometry
MATH 221. Mathematical Methods of Imaging
MATH 227. Partial Differential Equations and Diffusion Processes
MATH 236. Introduction to Stochastic Differential Equations
MATH 237. Stochastic Equations and Random Media
MATH 238. Mathematical Finance
ME 335A,B,C. Finite Element Analysis
ME 346B. Introduction to Molecular Simulations
ME 351A,B. Fluid Mechanics
ME 361. Turbulence
ME 408. Spectral Methods in Computational Physics
ME 412. Engineering Functional Analysis and Finite Elements
ME 469A,B. Computational Methods in Fluid Mechanics
MS&E 319. Approximation Algorithms
MS&E 336. Topics in Game Theory with Engineering Applications
STATS 305. Introduction to Statistical Modeling
STATS 306A. Methods for Applied Statistics
STATS 306B. Methods of Applied Statistics
STATS 318. Modern Markov Chains
STATS 366. Computational Biology

Note: All courses listed under "Requirement 3" under the "Master of Science in Computational and Mathematical Engineering" 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 provides 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 20 units of approved graduate level courses. These should include three iCME core courses and three iCME graduate electives at the 300 level or above. A maximum of two units can be taken as iCME seminar units. All courses, except the seminar courses, must be taken for a letter grade and passed with a grade of 'B' or better. Minor programs must receive approval from the iCME curriculum chair prior to completing any of the iCME graduate electives. Minor programs should be developed in close discussion between the student and the student's primary Ph.D. adviser. Courses taken in fulfillment of the minor cannot be used for the student's Ph.D. degree.

# COMPUTATIONAL AND MATHEMATICAL ENGINEERING (CME)

## UNDERGRADUATE COURSES IN CME

**CME 100. Vector Calculus for Engineers**
(Same as ENGR 154) 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. Integral vector calculus: multiple integrals in Cartesian, cylindrical, and spherical coordinates, line integrals, scalar potential, surface integrals, Green's, divergence, and Stokes' theorems. Examples and applications drawn from various engineering fields. Prerequisites: MATH 41 and 42, or 10 units AP credit. GER:DB-Math
*5 units, Aut (Khayms, V)*

**CME 102. Ordinary Differential Equations for Engineers**
(Same as ENGR 155A) 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 non-linear 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: CME 100/ENGR 154 or MATH 51. GER:DB-Math
*5 units, Win (Darve, E)*

**CME 104. Linear Algebra and Partial Differential Equations for Engineers**
(Same as ENGR 155B) Linear algebra: matrix operations, systems of algebraic equations, Gaussian elimination, undertermined 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. GER:DB-Math
*5 units, Spr (Khayms, V)*

**CME 105. Introduction to Discrete Mathematics and Algorithms**
Discrete mathematics and algorithms as used in modeling and problem solving technique emphasizing contemporary problems. Topics: introduction to set theory, logic, combinatorics, and graphs theory; formal proof techniques in induction, recursion, and contradiction; algorithms for sorting, shortest paths, minimum spanning trees, and bipartite matching. Applications to Internet advertising, viral marketing, routing, social networks and games of chance. Recommended: background in linear algebra/matrix theory.
*3 units, not given this year*

**CME 106. Introduction to Probability and Statistics for Engineers**
(Same as ENGR 155C) 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. GER:DB-Math
*3-4 units, Win (Khayms, V), Sum (Khayms, V)*

**CME 108. 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, polynomial interpolation, numerical differentiation and integration, numerical solution of ordinary differential equations, truncation error, numerical stability for time dependent problems and stiffness. Prerequisites: CS106A or familiarity with MATLAB; MATH 51, 52, 53; inappropriate for students who have taken CME 102,104/ENGR 155A,B. GER:DB-EngrAppSci
*3-4 units, Win (Staff)*

**CME 191. Special Studies or Projects**
Independent work under faculty direction. Individual or team activities involving lab work or directed reading.
*1 unit, Aut (Murray, W), Win (Staff), Spr (Staff)*

## GRADUATE COURSES IN CME

**CME 200. Linear Algebra with Application to Enginering Computations**
(Same as ME 300A) Computer based solution of systems of algebraic equations obtained from engineering problems and eigensystem 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 MATH103, 130, or equivalent.
*3 units, Aut (Moin, P)*

**CME 204. Partial Differential Equations in Engineering**
(Same as ME 300B) 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.
*3 units, Win (Staff)*

**CME 206. Introduction to Numerical Methods for Engineering**
(Same as ME 300C) 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.
*3 units, Spr (Staff)*

**CME 211. Computer Programming in C++ for Earth Scientists and Engineers**
(Same as ENERGY 211) Computer programming methodology emphasizing modern software engineering principles: object-oriented design, decomposition, encapsulation, abstraction, and modularity. Fundamental data structures. Time and space complexity analysis. Basic facilities of C++. Numerical problems from various science and engineering applications.
*3 units, Win (Gerritsen, M)*

**CME 212. Introduction to Large-Scale Computing in Engineering**
Advanced programming methodologies for solving fundamental engineering problems using algorithms with pervasive application across disciplines. Overview of computer systems from a programming perspective including processor architectures, memory hierarchies, machine arithmetic, performance tuning techniques. Algorithms include iterative, direct linear solvers, fft, and divide and conquer strategies for n-body problems. Software development; other practical UNIX tools including shell scripting, vi/emacs, gcc, make, gdb, gprof, version control systems and LaTeX. Prerequisites: CME 200/ME 300A, CME 211, and CS 106X or equivalent level of programming in C/C++.
*3 units, Spr (Gerritsen, M)*

**CME 215A. Advanced Computational Fluid Dynamics**
(Same as AA 215A) 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.
*3 units, Win (Jameson, A)*

**CME 215B. Advanced Computational Fluid Dynamics**
(Same as AA 215B) 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.
*3 units, Spr (Jameson, A)*

**CME 291. Master's Research**
Students require faculty sponsor. (Staff)
*1-5 units, Aut (Staff), Win (Staff), Spr (Staff), Sum (Staff)*

**CME 300. Departmental Seminar Series**
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.
*1 unit, Aut (Murray, W), Win (Murray, W)*

**CME 302. Numerical Linear Algebra**
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.
*3 units, Aut (Gerritsen, M)*

**CME 303. Partial Differential Equations of Applied Mathematics**
(Same as MATH 220) 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.
*3 units, Aut (Vasy, A)*

**CME 304. Numerical Optimization**
(Same as MS&E 315) 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.
*3 units, Win (Murray, W)*

**CME 305. Discrete Mathematics and Algorithms**
(Same as MS&E 316) Topics: enumeration such as Cayley's theorem and Prufer codes, SDR, flows and cuts (deterministic and randomized algorithms), probabilistic methods and random graphs, asymptotics (NP-hardness and approximation algorithms). Topics illustrated with EE, CS, and bioinformatics applications. Prerequisites: MATH 51 or 103 or equivalents.
*3 units, Win (Saberi, A)*

**CME 306. Numerical Solution of Partial Differential Equations**
(Same as MATH 226) 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.
*3 units, Spr (Staff)*

**CME 308. Stochastic Methods in Engineering**
(Same as MATH 228) Review of basic probability; Monte Carlo simulation; state space models and time series; parameter estimation, prediction, and filtering; Markov chains and processes; stochastic control; and stochastic differential equations. Examples from various engineering disciplines. Prerequisites: exposure to probability; background in real variables and analysis.
*3 units, Spr (Papanicolaou, G)*

**CME 325. Numerical Approximations of Partial Differential Equations in Theory and Practice**
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.
*1-2 units, not given this year*

**CME 326. Numerical Methods for Initial Boundary Value Problems**
Initial boundary value problems are solved in different areas of engineering and science modeling phenomena, such as wave propagation and vibration, and fluid flow. Numerical techniques for such simulations in the context of applications. Emphasis is on stability and convergence theory for methods for hyperbolic and parabolic initial boundary value problems, and the development of efficient methods for these problems.
*3 units, not given this year*

**CME 330. Applied Mathematics in the Chemical and Biological Sciences**
(Same as CHEMENG 300) 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.
*3 units, not given this year*

**CME 334. Advanced Methods in Numerical Optimization**
(Same as MS&E 312) 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.
*3 units, not given this year*

**CME 335. Advanced Topics in Numerical Linear Algebra**
Possible topics: Eigenvalue problems, including perturbation theory, algorithms, and related problems such as the SVD or generalized eigenvalue problems; iterative methods, including stationary and non-stationary methods; matrix functions, including applications of moments and quadrature; polynomial equations and Parallel implementation of matrix computations. May be repeated for credit.
*3 units, offered occasionally*

**CME 336. Linear and Conic Optimization with Applications**
(Same as MS&E 314) 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.
*3 units, alternate years, not given this year*

**CME 337. Information Networks**
(Same as MS&E 337) Network structure of the Internet and the web. Modeling, scale-free graphs, small-world phenomenon. Algorithmic implications in searching and inter-domain routing; the effect of structure on performance. Game theoretic issues, routing games, and network creation games. Security issues, vulnerability, and robustness. Prerequisite: basic probability and graph theory.
*3 units, Spr (Saberi, A), alternate years, not given next year*

**CME 338. Large-Scale Numerical Optimization**
(Same as MS&E 318) 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. Interior methods. The simplex method. Factorization and updates. The reduced-gradient, augmented Lagrangian, and SQP methods. Recommended: MS&E 310, 311, 312, 314, or 315; CME 108 or 302.
*3 units, Spr (Saunders, M)*

**CME 340. Large-Scale Data Mining**
(Same as CS 345L) Focus is on very large scale data mining on the web and on social networks. Topics include network models, ranking algorithms, reputation, collaborative filtering, and supervised and unsupervised learning. Individual or group applications-oriented programming project. i unit without project; 3 units with final project. Prerequisites: programming at the level of CS 108; statistics at the level of MATH 103 and STATS 116. Recommended: machine learning at the level of CS 229; knowledge of Java.
*1-3 units, not given this year*

**CME 342. Parallel Methods in Numerical Analysis**
Emphasis is on techniques for obtaining maximum parallelism in numerical algorithms, especially those occurring when solving matrix problems and partial differential equations, and the subsequent mapping onto the computer. Implementation issues on parallel computers. Topics: parallel architecture, programming models, matrix computations, FFT, fast multiple methods, domain decomposition, and graph partitioning. Prerequisite: CME 302 or 200/ME300A, or consent of instructor. Recommended: differential equations and advanced programming language such as C or C++.
*3 units, Spr (Alonso, J)*

**CME 352. Molecular Algorithms**
Recent research in DNA and RNA based nanotechnology, mathematical models of DNA self-assembly, algorithmic techniques and stochastic analyses for efficient and robust DNA self-assembly, experimental advances in molecular motors and machines which use DNA migration/enzymes, and algorithmic issues in the design of molecular motors and machines. Prerequisite: consent of instructor.
*3 units, alternate years, not given this year*

**CME 356. Engineering Functional Analysis and Finite Elements**
(Same as ME 412) 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.
*3 units, Win (Lew, A)*

**CME 358. Finite Element Method for Fluid Mechanics**
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.

*3 units, not given this year*

**CME 380. Constructing Scientific Simulation Codes**
Practical methods for writing and combining software components to generate simulation applications. Practical methodologies for constructing simulation code applications. How to design, write, and combine software components to generate simulation applications. Steering: using a small driver language like Python to script or steer the progress of a code. Data models and formats: how data is represented and shared inside an application and its external representation on disk. Mixed language programming using C, C++, F77, F90, and Python. Rational software engineering including testing, configuration control, code generation and makefiles. Other technologies needed to create real world applications regardless of scientific discipline.

*3 units, not given this year*

**CME 400. Ph.D. Research**

*1-15 units, Aut (Staff), Win (Staff), Spr (Staff), Sum (Staff)*

**CME 444. Computational Consulting**
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.

*1-3 units, Aut (Gerritsen, M), Win (Gerritsen, M), Spr (Gerritsen, M)*

**CME 500. Numerical Analysis and Computational and Mathematical Engineering Seminar**
Weekly research lectures by experts from academia, national laboratories, industry, and doctoral students. May be repeated for credit.

*1 unit, Aut (Staff), Win (Staff), Spr (Staff)*

**CME 510. Linear Algebra and Optimization Seminar**
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.

*1 unit, Aut (Saunders, M), Win (Saunders, M), Spr (Saunders)*