APPLIED MATHEMATICS AND COMPUTATONAL SCIENCE (AMCS) COURSE DESCRIPTIONS

Note: Some AMCS courses listed below are cross-listed in the Computer Science (CS) program.

AMCS 201. Applied Mathematics I (3-0-3)

Prerequisites: Advanced and multivariate calculus and elementary complex variables. Fulfills University Mathematics Requirement. No degree credit for AMCS majors.

AMCS 201 and 202 may be taken separately or in either order. Part of a fast-paced two-course sequence in graduate applied mathematics for engineers and scientists, with an emphasis on analytical technique. A review of practical aspects of linear operators (superposition, Green's functions, and eigenanalysis) in the context of ordinary differential equations, followed by extension to linear partial differential equations (PDEs) of parabolic, hyperbolic, and elliptic type through separation of variables and special functions. Integral transforms of Laplace and Fourier type.

Self-similarity. Method of characteristics for first-order PDEs. Introduction to perturbation methods for nonlinear PDEs, asymptotic analysis, and singular perturbations.

AMCS 202. Applied Mathematics II (3-0-3) *Prerequisites: Advanced and multivariate calculus and elementary complex variables. Fulfills University Mathematics Requirement. No degree credit for AMCS majors.* AMCS 201 and 202 may be taken separately or in either order. Part of a fast-paced two-course sequence in graduate applied mathematics for engineers and scientists, with an emphasis on analytical technique. A review of linear spaces (basis, independence, null space and rank, condition number, inner product, norm, and Gram-Schmidt orthogonalization) in the context of direct and iterative methods for the solution of linear systems of equations arising in engineering applications. Projections and least squares. Eigenanalysis, diagonalization, and functions of matrices. Complex analysis, Cauchy-Riemann conditions, Cauchy integral theorem, residue theorem, Taylor and Laurent series, contour integration, and conformal mapping.

AMCS 206. Applied Numerical Methods (3-0-3) *Prerequisites: Advanced and multivariate calculus. Fulfills University Mathematics Requirement. No degree credit for AMCS majors.* A fast-paced one-semester survey of numerical methods for engineers and scientists, with an emphasis on technique and software. Computer representation of numbers and floating point errors. Numerical solution of systems of linear and nonlinear algebraic equations, interpolation, least squares, quadrature, optimization, nonlinear equations, approximation of solutions of ordinary and partial differential equations. Truncation error, numerical stability, stiffness, and operation and storage complexity of numerical algorithms.

AMCS 207. Programming Methodology and Abstractions (3-0-3) (Same as CS 207.) Computer programming and the use of abstractions. Software-engineering principles of data abstraction and modularity. Object-oriented programming, fundamental data structures (such as stacks, queues, sets) and data-directed design. Recursion and recursive data structures (linked lists, trees, graphs). Introduction to basic time and space complexity analysis. The course teaches the mechanics of the C, C++ or Java language. This course is considered remedial training for students in the AMCS program and will not count toward any degree requirement.

AMCS 210 Applied Probability and Biostatistics (3-0-3) (Same as CS 210.) *Prerequisites: Advanced and multivariate calculus. Fulfills University Mathematics Requirement.* 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, nonparametric tests, regression and correlation analyses. Applications in engineering, industrial manufacturing, dimecine, biology, and other fields.

AMCS 211. Numerical Optimization (3-0-3) *Prerequisites: Advanced and multivariate calculus and elementary real analysis. Fulfills University Mathematics Requirement.* Solution of nonlinear equations. Optimality conditions for smooth optimization problems. Theory and algorithms to solve unconstrained optimization;

linear programming; quadratic programming; global optimization; general linearly and nonlinearly constrained optimization problems.

AMCS 212. Linear and Nonlinear Optimization (3-0-3) *Prerequisites: Advanced and multivariate calculus. Fulfills University Mathematics Requirement.* The role of duality, optimality conditions and algorithms in finding and recognizing solutions. Perspectives: problem formulation, analytical theory, computational methods and recent applications in engineering, finance and economics. Theories: finite dimensional derivatives, convexity, optimality, duality and sensitivity. Methods: simplex and interior-point, gradient, Newton and barrier.

AMCS 221. Artificial Intelligence (3-0-3) (Same as CS 221.) *Prerequisites: working knowledge of basic discrete mathematics (e.g., sets and functions) and proof techniques, programming ability (and exposure to probability.* An introduction to the principles and practices of artificial intelligence. Topics include: search, constraint satisfaction, knowledge representation, probabilistic models, machine learning, neural networks, vision, robotics and natural-language understanding.

AMCS 229. Machine Learning (3-0-3) (Same as CS 229.) *Prerequisites: linear algebra and basic probability and statistics.* Familiarity with artificial intelligence recommended. Topics: statistical pattern recognition, linear and non-linear regression, non-parametric methods, exponential family, GLIMs, support vector machines, kernel methods, model/feature selection, learning theory, VC dimension, clustering, density estimation, EM, dimensionality reduction, ICA, PCA, reinforcement learning and adaptive control, Markov decision processes, approximate dynamic programming and policy search.

AMCS 231. Applied Partial Differential Equations I (3-0-3) *Prerequisites: Advanced and multivariate calculus and elementary complex variables. Fulfills University Mathematics Requirement.* First part of a sequence of courses on partial differential equations (PDE) emphasizing theory and solution techniques for linear equations. Origin of PDE in science and engineering. Equations of diffusion, heat conduction, and wave propagation. The method of characteristics. Classification of PDE. Separation of variables, theory of the Fourier series and Fourier transform. The method of Green's functions. Sturm-Liouville problem, special functions, eigenfunction expansions. Higher dimensional PDE and their solution by separation of variables, transform methods, and Green's functions. Fractional PDE. Introduction to quasi-linear PDE and shock waves.

AMCS 236. Introduction to Stochastic Differential Equations (3-0-3) *Prerequisites: knowledge of basic probability, numerical analysis, and programming*. Brownian motion, stochastic integrals and diffusions as solutions of stochastic differential equations. Functionals of diffusions and their connection with partial differential equations. Weak and strong approximation, efficient numerical methods and error estimates. Jump diffusions.

AMCS 241. Probability and Random Processes (3-0-3) (Same as CS 241 and EE 241.*) Prerequisites: Advanced and multivariate calculus. Introduction to probability and random processes. Fulfills University Mathematics Requirement.* Topics include probability axioms, sigma algebras, random vectors, expectation, probability distributions and densities, Poisson and Wiener processes, stationary processes, autocorrelation, spectral density, effects of filtering, linear least-squares estimation and convergence of random sequences.

AMCS 247. Scientific Visualization (3-0-3) (Same as CS 247.) *Prerequisites: Advanced and multivariate calculus, and linear algebra, computer graphics, and programming experience.* Techniques for generating images of various types of experimentally measured, computer generated, or gathered data. Grid structures. Scalar field visualization. Vector field visualization. Particle visualization. Graph visualization. Animation. Applications in science, engineering, and medicine.

AMCS 248. Computer Graphics (3-0-3) (Same as CS 248.) *Prerequisites: solid programming skills and linear algebra.* Input and display devices, scan conversion of geometric primitives, 2D and 3D geometric transformations, clipping and windowing, scene modeling and animation, algorithms for visible surface determination, local and global shading models, color and real-time rendering methods.

AMCS 251. Numerical Linear Algebra (3-0-3) (Same as CS 251.*) Prerequisites: Programming skills (MATLAB preferred) and linear algebra. Fulfills University Mathematics Requirement.* Linear algebra from a numerical solution perspective. Singular Value Decomposition, matrix factorizations, linear least squares, Gram-Schmidt orthogonalization, conditioning and stability, eigenanalysis, Krylov subspace methods and preconditioning, and optimization and conjugate gradient methods.

AMCS 252. Numerical Analysis of Differential Equations (3-0-3)
Prerequisites: Analysis of PDEs and numerical analysis. Fulfills University Mathematics Requirement. Theory and technique for the numerical analysis of ODEs and of PDEs of parabolic, hyperbolic, and elliptic type: accuracy, stability, convergence and qualitative properties. Runge-Kutta and linear multistep methods, zero-stability, absolute stability, stiffness, and order conditions. Finite difference methods, multigrid, dimensional and operator splitting, and the CFL condition.

AMCS 260 Design and Analysis of Algorithms (3-0-3) (Same as CS 260**)**
Prerequisite: computer programming skills, probability, basic data structures, basic discrete mathematics. Fulfills University Mathematics Requirement. Review of algorithm analysis (search in ordered array, binary insertion sort, merge sort, 2-3 trees, asymptotic notation). Divide and conquer algorithms (master theorem, integer multiplication, matrix multiplication, fast Fourier transform). Graphs (breadth-first search, connected components, topological ordering, depth-first search). Dynamic programming (chain matrix multiplication, shortest paths, edit distance, sequence alignment). Greedy algorithms (binary heaps, Dijkstra's algorithm, minimum spanning tree, Huffman codes). Randomized algorithms (selection, quick sort, global minimum cut, hushing). P and NP (Cook's theorem, examples of NP-complete problems). Approximate algorithms for NP-hard problems (set cover, vertex cover, maximum independent set). Partial recursive functions (theorem of Post, Diophantine equations). Computations and undecidable problems (undecidability of halting problem, theorem of Rice, semantic and syntactical properties of programs).

AMCS 261 Algorithmic Paradigms (3-0-3) (Same as CS 261.) *Prerequisite: Familiarity with discrete algorithms at the level of AMCS 260. Fulfills University Mathematics Requirement.* Topics: algorithms for optimization problems such as matching, maxflow, min-cut and load balancing. Using linear programming, emphasis is on LP duality for design and analysis of approximation algorithms. Approximation algorithms for NP-complete problems such as Steiner trees, traveling salesman and scheduling problems. Randomized algorithms.

AMCS 271. Applied Geometry (3-0-3) Differential Geometry: selected topics from the classical theory of curves and surfaces, geometric variational problems, robust computation of differential invariants, discrete differential geometry. Projective Geometry: computing with homogeneous coordinates, projective maps, quadrics and polarity. Algebraic Geometry: algebraic curves and surfaces, rational parametrizations, basic elimination theory. Kinematical Geometry: geometry of motions, kinematic mappings. The practical use of these topics is illustrated at hand of sample problems from Geometric Modeling, Computer Vision, Robotics and related areas of Geometric Computing.

AMCS 272 Geometric Modeling (3-0-3) (Same as CS 272.) *Prerequisites: Advanced and multivariate calculus, and linear algebra, computer graphics, and programming experience. Fulfills University Mathematics Requirement.* Terminology, coordinate systems, and implicit forms. Parametric and spline representations of curves and surfaces and their uses. Basic differential geometry of curves and surfaces. Subdivision surfaces. Solid modeling paradigms and operations. Robustness and accuracy in geometric computations. Applications.

AMCS 291 Scientific Software Engineering (3-0-3) (Same as CS 291.) *Prerequisites: Programming experience and familiarity with basic discrete and numerical algorithms.*
Practical aspects of application development for high performance computing. Programming language choice; compilers; compiler usage. Build management using make and other tools. Library development and usage. Portability and the GNU autoconf system. Correctness and performance debugging, performance analysis.
Group development practices and version control. Use of third-party libraries and software licensing.

AMCS 292. Parallel Programming Paradigms (3-0-3) (Same as CS 292)
Prerequisites: Programming experience and familiarity with basic discrete and numerical algorithms. Distributed and shared memory programming models and frameworks. Thread programming and OpenMP. Message passing and MPI. Parallel Global Address Space (PGAS) languages. Emerging languages for many-core programming. Elements to be covered will include syntax and semantics, performance issues, thread safety and hybrid programming paradigms.

AMCS 297. MS Thesis (variable credit)

AMCS 298. Graduate Seminar (variable credit) Master-level seminar focusing on special topics within the field.

AMCS 299. Directed Research (variable credit) Prerequisite: Sponsorship of advisor and approved prospectus. Master-level supervised research.

AMCS 308. Stochastic Methods in Engineering (3-0-3) *Prerequisites: Basic probability, numerical analysis, and programming.* Review of basic probability; Monte Carlo simulation; state space models and time series; parameter estimation, prediction and filtering; Markov chains and processes; stochastic control; Markov chain Monte Carlo. Examples from various engineering disciplines.

CS 311.) *Prerequisites:*
Programming experience and familiarity with basic discrete and numerical algorithms.
Part one of a two-course sequence in high performance computing technology, with an emphasis on using KAUST's research computing systems, focusing primarily on hardware architectures. History of high performance computing. Hardware architectures. CMOS processor design. Cache architectures. Memory architectures.
Hardware counters. Processing benchmarks. Power. Single-node performance of real applications.

AMCS 312 High Performance Computing II (3-0-3) (Same as CS 312.)
Prerequisites: Programming experience and familiarity with basic discrete and numerical algorithms and AMCS 311. Part one of a two-course sequence in high performance computing technology, with an emphasis on using KAUST's research computing systems, focusing primarily on hardware architectures. I/O systems and communication networks. Communication benchmarks. Theoretical and achievable performance for processor, memory system, network, and I/O. Future architecture directions and limitations. The course is intended to develop a deep understanding of the underlying high performance computing architectures on which the student will develop and deploy applications.

AMCS 330. Computational Science and Engineering (3-0-3) (Same as CS 330.)
Programming experience and familiarity with basic discrete and numerical algorithms and experience with one or more computational applications. Case studies of representative and prototype applications in partial differential equations and meshbased methods, particle methods, ray-tracing methods, transactional methods.

AMCS 331. Applied Partial Differential Equations II (3-0-3) *Prerequisites: Multivariate calculus, elementary complex variables, ordinary differential equations. Recommended: AMCS 231 or AMCS 201. Fulfills University Mathematics Requirement.* Second part of a sequence of courses on partial differential equations (PDE) emphasizing theory and solution techniques for nonlinear equations. Quasi-linear and nonlinear PDE in applications. Conservation laws, first-order equations, the method of characteristics. Burgers' equation and wave breaking. Weak solutions, shocks, jump conditions, and entropy conditions. Hyperbolic systems of gas dynamics, shallow-water flow, traffic flow, and bio-fluid flow. Variational principles, dispersive waves, solitons. Nonlinear diffusion and reaction-diffusion equations in combustion and biology. Traveling waves and their stability. Dimensional analysis and similarity solutions. Perturbation methods. Turing instability and pattern formation. Eigenvalue problems. Stability and bifurcation.

AMCS 332. Introduction to Mathematical Modeling (3-0-3)
An introduction to mathematical modeling through a combination of practical problem-solving experience and applied mathematics techniques, including dimensional analysis, non-dimensionalisation, asymptotic expansions, perturbation analysis, boundary layers, computing and other topics.
AMCS 333. Hyperbolic Conservation Laws and Godunov-type Methods (3-0-3) Theory of linear and nonlinear hyperbolic PDEs, with applications including fluid dynamics, elasticity, acoustics, electromagnetics, shallow water waves, and traffic modeling. Theory of shock and rarefaction waves. Finite volume methods for numerical approximation of solutions; Godunov's method, TVD methods, and high order methods. Stability, convergence, and entropy conditions. Numerical solution of multidimensional problems.
AMCS 334. Mathematical Fluid Dynamics (3-0-3) *Prerequisites: AMCS 231 or AMCS 201. Recommended: AMCS 331.* Equations of fluid dynamics; inviscid flow and Euler equations; vorticity dynamics; viscous incompressible flow and Navier-Stokes equations; existence, uniqueness, and regularity of solutions of Navier-Stokes equations; Stokes flow; free-surface flows; linear and nonlinear instability and transition to turbulence; rotating flows; compressible flow and shock dynamics; detonation waves.
AMCS 337. Information Networks (3-0-3) (Same as CS 337.) *Prerequisite: probability.* Network structure of the Internet and the Web. Modeling, scale-free graphs, smallworld phenomenon. Algorithmic implications in searching and interdomain routing, the effect of structure on performance. Game theoretic issues, routing games and network creation games. Security issues, vulnerability and robustness.
AMCS 340. Computational Methods in Data Mining (3-0-3) *Prerequisites: Probability and scientific computing.* Focus is on very-large-scale data mining. Topics include computational methods in supervised and unsupervised learning, association mining and collaborative filtering. Individual or group applications-oriented programming project. 1 unit without project; 3 units requires final project.

AMCS 361 Combinatorial Machine Learning (3-0-3)
Prerequisites: AMCS/CS 260. Lower and upper bounds on complexity and algorithms for construction (optimization) of decision trees, decision rules and tests. Decision tables with one-valued decisions and decision tables with many-valued decisions. Approximate decision trees, rules and tests. Global and local approaches to the study of problems over infinite sets of attributes. Applications to discrete optimization, fault diagnosis, pattern recognition, analysis of acyclic programs, data mining and knowledge discovery. Current results of research.

AMCS 380. GPU and GPGPU Programming (3-0-3) *Prerequisite: CS 280.* Recommended optional prerequisites: CS 248, CS 292. Architecture and programming of GPUs (Graphics Processing Units). Covers both the traditional use of GPUs for graphics and visualization, as well as their use for general purpose computations (GPGPU). GPU many-core hardware architecture, shading and computer programming languages and APIs, programming vertex, geometry, and fragment shaders, programming with CUDA, Brook, OpenCL, stream computing, approaches to massively parallel computations, memory subsystems and caches, rasterization, texture mapping, linear algebra computations, alternative and future architectures.

AMCS 397. Doctoral Dissertation (variable credit)

AMCS 398. Graduate Seminar (variable credit) Graduate Seminar (variable credit)
Doctoral-level seminar focusing on special topics within the field.

AMCS 399. Directed Research (variable credit) Prerequisite: Sponsorship of advisor and approved prospectus. Doctoral-level supervised research.