APPLIED MATHEMATICS AND COMPUTATIONAL SCIENCE PROGRAM – PRELIMINARY RELEASE

Aims and Scope of the Graduate Program

The Applied Mathematics and Computational Sciences (AMCS) program trains students to construct and solve mathematical and computational models of real-world problems. Two degree programs are offered: the M.S. degree (under either a Thesis or a Non-Thesis option) and the Ph.D. degree. Admission to one degree program does not guarantee transfer to another.

The program has identified six focal areas, each of which leads to a frontier of applied and computational mathematics. The areas are (1) partial differential equations; (2) geometric modeling and scientific visualization; (3) information science; (4) modeling and numerical simulation; (5) computational geosciences; and (6) computational and mathematical biosciences. The courses in each area are intended only as a recommendation to students interested in a particular area. A student is not required to follow any particular area in his/her ultimate selection of courses; course selection is made with the advice and approval of the student's advisor.

Master's Degree

Admission to the M.S. program in AMCS is open to holders of a B.S. degree in mathematics, physics, or engineering that includes satisfactory completion of appropriate mathematics courses and passing standardized tests such as TOEFL and GRE. Minimum preparation in mathematics includes four semesters of calculus (including multivariate), and one semester each of ordinary differential equations, linear algebra, and an introduction to probability and statistics. Strongly recommended preparation includes a semester-length course in each of the following: partial differential equations, complex analysis, real analysis, numerical analysis and optimization. Research experience is also preferable.

There are two M.S. degree options in AMCS, a thesis and a non-thesis option. Both programs require at least 36 credits and can be completed in three semesters and a summer session. The program requirements are listed below.

1. Core Curriculum: Five courses (15 credits) constituting the core of the AMCS degree program. The Core course requirements are:
    - Numerical Optimization (AMCS 211) or Applied Real and Functional Analysis (AMCS 238)
    - Applied Partial Differential Equations I (AMCS 231)
    - Probability and Random Processes (AMCS 241)
    - Numerical Linear Algebra (AMCS 251)
    - Numerical Analysis of Differential Equations (AMCS 252)

2. Elective Curriculum: Three additional courses (nine credits), which are selected with the approval of the student's academic or research advisor. Six example track areas are outlined below.
3. Research/Capstone Experience: The remaining 12 credits are completed based on the M.S. option (Thesis or Non-Thesis) that is being pursued.

Thesis Option

A minimum of 6 credits of thesis research (AMCS 297) is required although it is expected that a student will enroll in 12 credits of M.S. thesis work. With permission of the M.S. thesis advisor, a student who enrolls in only 6 credits of thesis research may use one of the following options to earn the six remaining credits of degree requirements:

- **Internship:** 6 credits of research-based summer internship (administered as directed research, AMCS 299)
- **Non-Technical Broadening Experience Courses:** 3 to 6 credits of courses that broaden a student's M.S. experience.
- **Ph.D.-Level Courses:** 6 credits of AMCS courses numbered 300 or greater. Any course in the Ph.D. core requirements that is passed with a minimum grade of B– may be used towards meeting the core Ph.D. requirements of the AMCS program if the student chooses to continue for a Ph.D. degree in AMCS at KAUST.

Students are permitted to register for more than 12 credits of M.S. thesis research as necessary and with the permission of the thesis advisor.

Evaluation of satisfactory completion of MS thesis work is performed by a committee comprising the M.S. thesis advisor and two other faculty members. The chair of the committee must be a faculty member in the AMCS program. The evaluation of M.S. thesis credits is through a pass or a fail grade. The requirement of a public AMCS seminar based on the student's work is left to the discretion of the M.S. thesis advisor. For additional details on thesis requirements and committee formation, see General Degree Program Guidelines.

The student is responsible for scheduling the thesis defense date with his/her supervisor and committee members. It is advisable that the student submits a written copy of the thesis to the thesis committee members at least two weeks prior the defense date.

Non-Thesis Option

Research requirement: A minimum of 6 credits of directed research credits (AMCS 299) is required. Summer internship credits may be used to fulfill the research requirement provided that the summer internship is research-based. Summer internships are subject to approval by the student's academic advisor.

Students must complete the remaining credits through one or a combination of the options listed below:

- **Two Courses:** Any two 3-credit graduate-level courses in any program at KAUST.
- **Non-technical Broadening Experience Courses:** 6 credits of courses that

broaden a student's M.S. experience.

- **Ph.D.-Level Courses:** 6 credits of AMCS courses numbered 300 or greater. Any course in the Ph.D. core requirements that is passed with a minimum grade of B– may be used towards meeting the core Ph.D. requirements of the AMCS program if the student chooses to continue for a Ph.D. degree in AMCS at KAUST.
- **Internship:** 6 credits of research-based summer internship (administered as directed research, AMCS 299)

It should be noted that a student may also mix and match courses to satisfy the six-credit requirement. For example, a student could take one Ph.D.-level course and one graduate-level course in another program. A student may not enroll in two summer internships.

Degree of Doctor of Philosophy

In accordance with KAUST regulations, the Ph.D. program in AMCS includes the following requirements:

1. Successful completion of Ph.D. coursework;
2. Designating a research advisor;
3. Passing a comprehensive examination;
4. Obtaining candidacy status;
5. Preparing and submitting a doctoral dissertation and successfully defending it.

Completing the Ph.D. program in AMCS generally takes three years beyond the completion of the M.S. program requirements.

Coursework Requirements

Students seeking to earn a Ph.D. in AMCS must first satisfy the coursework requirements for the program. In addition of the M.S. in AMCS coursework requirements, the Ph.D. program requires a minimum of 6 credit hours of coursework at the 300-level or above. Generally, more will be recommended in the process of arriving at a research frontier for the dissertation. Ph.D. coursework in AMCS is designed to ensure that graduates are equipped to conduct multidisciplinary research and communicate in the language of and understand the intellectual culture of each contributing discipline – from formulation, to mathematical technique, to computational implementation, to analysis and interpretation of results. If a student is admitted to the Ph.D. program in AMCS after obtaining a Master's degree from a university other than KAUST, some or all of the M.S. coursework requirements may be waived, at the discretion of the student's advisor and with the approval of the dean.

Designation of a Research Advisor

A faculty advisor is either immediately designated (in the case of a student being recruited by a specific faculty member) or temporarily assigned (in the case of KAUST fellowship, self-supported, or externally sponsored students); in the latter case, the student is expected to identify a research advisor by the end of the first year of enrollment in the program.

Comprehensive Examination

The comprehensive examination covers material from the student's Masters and Ph.D. coursework. The student will be provided a list of examination topics in advance. The possible outcomes of the exam are: pass, fail, or fail with possibility of retake. In the case of a retake, the student must retake and pass the exam within 3 months of the date of the first exam. The exam is administered by an examination committee, which does not include the student's advisor. The committee may waive the exam based on the student's preparation and academic performance in courses taken at KAUST.

Supervisory Committee

The supervisory committee is formed by the student under the guidance of the advisor. The committee is chaired by the advisor and must include at least three other faculty members, one of whom must be external to the program. The committee may additionally include one or more appropriate persons external to KAUST. The committee must meet at least once annually (as arranged by the student) with the student to discuss the student's progress. The research advisor and two other committee members must be designated as readers.

Candidacy Status

After successfully completing all coursework requirements, passing the comprehensive examination, identifying an advisor and forming a dissertation committee, a student gains candidacy status by presenting a doctoral research proposal and obtaining approval to pursue the proposed research from the dissertation committee.

Doctoral Candidacy Exam

The doctoral candidacy exam tests the student's preparedness to pursue thesis research. It is a public oral presentation of a research proposal, together with questioning by the advisory committee. The student must submit a written research proposal to the committee at least two weeks prior to the exam. The committee shall consist of a minimum of three KAUST faculty members, one of whom must be external to the degree program. The candidate must convince the committee that the chosen research area is suitable and demonstrate an appropriate breadth of knowledge in the chosen area. The committee should decide if there is a thesis topic in the area and whether the candidate is capable of completing such a thesis. There are four possible outcomes: pass, conditional pass, failure with retake permitted, and failure. Passing the qualification phase is achieved by acceptance of all committee members of the written proposal and a positive vote of all but, at most, one member of the oral exam. If more than one member casts a negative vote, one retake of the oral defense is permitted if the entire committee agrees. A conditional pass involves conditions (e.g., another course in a perceived area of weakness) imposed by the committee, with the conditional status removed when the conditions have been met. Each student is expected to complete the candidacy exam by the end of the second year.

Dissertation

The student must prepare and submit a doctoral dissertation on original research conducted by the student.

Dissertation Defense
The student must schedule the final oral defense after completion of the doctoral research (including completion of at least 60 credits (or five semesters of research residency) of AMCS 397) and writing of the dissertation. This examination will be a defense of the doctoral dissertation and a test of the candidate's knowledge in the specialized field of research. The format of the examination will be a public seminar presented by the candidate, with an open question period, followed by a private examination by the final examination committee. The final examination committee shall consist of a minimum of four members, one of whom should be a KAUST faculty member external to the degree program and one of whom should be external to KAUST (holding a faculty position or equivalent position at another institution, with approval by both the faculty research advisor and division Dean). The only requirement for commonality with the proposal examination committee is the research advisor, although it is expected that other members will carry forward to the dissertation committee. Passing the dissertation phase is achieved by acceptance of all committee members of the written dissertation, with a minimum of a positive vote of all but, at most, one member of the oral defense. If more than one member casts a negative vote, one retake of the oral defense is permitted if the entire committee agrees.

Additional Program Information

The following courses for commonly chosen options for the following focal areas.

Partial Differential Equations:

- Applied Partial Differential Equations II (AMCS 331)
- Mathematical Modeling (AMCS 332)
- Hyperbolic Conservation Laws and Godunov-type Methods (AMCS 333)
- Mathematical Fluid Dynamics (AMCS 334)
- Stochastic Differential Equations (AMCS 236)

Geometric Modeling and Scientific Visualization:

- Scientific Visualization (AMCS 247)
- Computer Graphics (AMCS 248)
- Applied Geometry (AMCS 271)
- Geometric Modeling (AMCS 272)
- Computational Geometry (AMCS 372)
- GPU and GPGPU Programming (AMCS 380)
- Mathematical Modeling in Computer Vision (AMCS 396)

Information Science:

- Machine Learning (AMCS 229)
- Information Networks (AMCS 337)
- Computational Methods in Data Mining (AMCS 340)
- Advanced Topics in Data Management (AMCS 341)

Information theory (AMCS 342)
Computational Multivariate Statistics (AMCS 309)

Modeling and Numerical Simulation:
Stochastic Methods in Engineering (AMCS 308)
Computational Science and Engineering (AMCS 330)
Mathematical Modeling (AMCS 332)
Computational Methods in Data Mining (AMCS 340)
Applied Partial Differential Equations II (AMCS 331)
Computational Multivariate Statistics (AMCS 309)

Computational Geosciences
Geophysical Fluid Dynamics I (ErSE 201)
Geophysical Continuum Mechanics (ErSE 203)
Seismology I (ErSE 210)
Global Geophysics (ErSE 211)
Seismic Imaging (ErSE 260)
Thermodynamics of Subsurface Reservoirs (ErSE 209/309)
Data Assimilation (ErSE 353)
Numerical Methods of Geophysics (AMCS 303/ErSE 303)
Stochastic Methods in Engineering (AMCS 308)
High Performance Computing I (AMCS 311)
Computational Science and Engineering (AMCS 330)
Applied Partial Differential Equations II (AMCS 331)
Hyperbolic Conservation Laws and Godunov-type Methods (AMCS 333)

Computational and Mathematical Biosciences
Genomics (B 204)
Protein Structure and Function (B 205)
Fundamentals of Cell Biology (B 224)
Applied Probability and Biostatistics (AMCS 210)
Mathematical Modeling (AMCS 332)
Stochastic Differential Equations (AMCS 236)
Stochastic Methods in Engineering (AMCS 308)
Computational Methods in Data Mining (AMCS 340)
Computational Multivariate Statistics (AMCS 309)

APPLIED MATHEMATICS AND COMPUTATIONAL 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.) *No degree credit for AMCS majors.* 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.

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, medicine, 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. 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 238. Applied Real and Functional Analysis (3-0-3)
Prerequisites: Advanced calculus and linear algebra and basic familiarity with PDE. Students taking this course are also recommended to take AMCS 231. Fulfills University Mathematics Requirement. This course aims to introduce the principles of measure and integration theory, the elements of functional analysis in Banach spaces, and spectral theory in Hilbert spaces, and to discuss two classical areas of applications, integral and differential equations. Additional topics will include differential and integral calculus in Banach spaces, fundamental results of distribution theory and Sobolev spaces.

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 parameterizations, 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. M.S. Thesis (variable credit)

AMCS 298. Graduate Seminar (variable credit) Master's-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 303. Numerical Methods of Geophysics (3-0-3) (Same as ErSE 303)
Prerequisite: ErSE 203 or consent of instructor. Built on the modeling and simulation foundation developed in ErSE203, this specialized course will discuss advanced ideas of multi-scale modeling, linear and non-linear finite element methods, investigate modern approaches to numerical simulations of hydrodynamic and geophysical turbulence, problems of theoretical glaciology and material science of ice for the prediction of ice sheet evolution, and wave propagation in linear and non-linear media.

AMCS 308. Stochastic Methods in Engineering (3-0-3) (Same as CS 308 / EE340)
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.

AMCS 309 -- Computational Multivariate Statistics
The course introduces multivariate statistical models, balancing three equally important elements: mathematical theory, applications to real data, and computational techniques. Traditional multivariate models and their recent generalizations to tackle regression, data reduction and dimensionality reduction, classification, predictor and classifier instability problems. Tools for analyzing unstructured multivariate data.

AMCS 311. High Performance Computing I (3-0-3) (Same as 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 321. Applications of AI in Bioinformatics (3-0-3) (Same as CS 330)

AMCS 330. Computational Science and Engineering (3-0-3) (Same as CS 330)
Prerequisites: 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 mesh-based methods, particle methods, ray-tracing methods, and 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-dimensionalization, 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, small-world phenomena. 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 credit without project; 3 credits requires final project.

AMCS 342 Information theory (same as EE 341)
Prerequisite: EE 241 or consent of an instructor. The concepts of source, channel, rate of transmission of information. Entropy and mutual information. The noiseless coding theorem. Noisy channels, the coding theorem for finite state zero memory channels. Channel capacity. Error bounds. Parity check codes. Source encoding.

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 compute 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 396 Mathematical Modeling in Computer Vision (3-0-3) (same as EE 396)
Prerequisites: multivariable calculus, and basic probability theory. This is a research course that covers topics of interest in computer vision, including image denoising/deblurring, image segmentation/object detection, and image registration / matching. The emphasis will be on creating mathematical models via the framework of Bayesian estimation theory, analyzing these models, and constructing computational algorithms to realize these models. Techniques from calculus of variations, differential geometry, and partial differential equations will be built up as the need arises.

AMCS 397. Doctoral Dissertation (variable credit)

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

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