

COMPUTATIONAL APPLIED MATHEMATICS AND OPERATIONS RESEARCH

Contact Information

Computational Applied Mathematics and Operations Research

<https://www.caam.rice.edu/>

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The department of Computational Applied Mathematics and Operations Research offers undergraduate majors in Computational and Applied Mathematics, and Operations Research. The coursework within the Computational and Applied Mathematics (CAAM) major provides foundations applicable to the many fields of engineering, physical sciences, life sciences, behavioral and social sciences, and computer science. CAAM majors receive training in foundational mathematics for newly developed algorithms in data science and training in all aspects of computation from algorithmic analysis to cost-accuracy performance. CAAM majors can plan a course of study consistent with their particular interests.

The coursework within the Operations Research (OPRE) major offers undergraduate students an education that emphasizes models for decision-making in complex systems, and tools for making the best possible decisions. The Operations Research major will provide students with both a deep set of analytical skills and contextual knowledge of important problem domains, such as healthcare and energy. Program graduates will have the knowledge and tools to help companies and governments make the best possible decisions in changing and uncertain environments.

At the graduate level, the department oversees two advanced professional degree programs. The Master of Computational and Applied Mathematics (MCAAM) is a professional degree program designed for students interested in a technical career path in industry or business. Similarly, the Master of Industrial Engineering (MIE) is a professional degree program designed to provide students with a deep set of analytical and engineering skills to make data-driven decisions needed in every major economic sector. The Computational and Applied Mathematics MA and PhD program concentrates on research. Faculty research interests fall in the four general areas of numerical analysis and scientific computing; numerical methods for partial differential equations; operations research and optimization; and mathematical modeling in physical, biological, or behavioral sciences.

A further advanced interdisciplinary degree program in computational science and engineering (CSE) addresses the current need for sophisticated computation in both engineering and the sciences. For more information, see [Computational Science and Engineering \(https://ga.rice.edu/programs-study/departments-programs/engineering/computational-science-engineering/\)](https://ga.rice.edu/programs-study/departments-programs/engineering/computational-science-engineering/).

The Master of Industrial Engineering degree is an advanced professional degree program also administered by the Department of Computational Applied Mathematics and Operations Research. The program is designed to explore modern industrial systems, which arise in fields such as manufacturing, services, supply chain management, energy, transportation and healthcare.

Bachelor's Programs

- [Bachelor of Arts \(BA\) Degree with a Major in Computational and Applied Mathematics \(https://ga.rice.edu/programs-study/departments-programs/engineering/computational-applied-mathematics-operations-research/computational-applied-mathematics-ba/\)](https://ga.rice.edu/programs-study/departments-programs/engineering/computational-applied-mathematics-operations-research/computational-applied-mathematics-ba/)
- [Bachelor of Arts \(BA\) Degree with a Major in Operations Research \(https://ga.rice.edu/programs-study/departments-programs/engineering/operations-research/operations-research-ba/\)](https://ga.rice.edu/programs-study/departments-programs/engineering/operations-research/operations-research-ba/)

Minor

- [Minor in Computational and Applied Mathematics \(https://ga.rice.edu/programs-study/departments-programs/engineering/computational-applied-mathematics-operations-research/computational-applied-mathematics-minor/\)](https://ga.rice.edu/programs-study/departments-programs/engineering/computational-applied-mathematics-operations-research/computational-applied-mathematics-minor/)

Master's Programs

- [Master of Computational and Applied Mathematics \(MCAAM\) Degree \(https://ga.rice.edu/programs-study/departments-programs/engineering/computational-applied-mathematics-operations-research/computational-applied-mathematics-mcaam/\)](https://ga.rice.edu/programs-study/departments-programs/engineering/computational-applied-mathematics-operations-research/computational-applied-mathematics-mcaam/)
- [Master of Industrial Engineering \(MIE\) Degree \(https://ga.rice.edu/programs-study/departments-programs/engineering/industrial-engineering/industrial-engineering-mie/#outcomestext\)](https://ga.rice.edu/programs-study/departments-programs/engineering/industrial-engineering/industrial-engineering-mie/#outcomestext)
- Master of Arts (MA) Degree in the field of Computational and Applied Mathematics*

Doctoral Program

- [Doctor of Philosophy \(PhD\) Degree in the field of Computational and Applied Mathematics \(https://ga.rice.edu/programs-study/departments-programs/engineering/computational-applied-mathematics-operations-research/computational-applied-mathematics-phd/\)](https://ga.rice.edu/programs-study/departments-programs/engineering/computational-applied-mathematics-operations-research/computational-applied-mathematics-phd/)

* *Although students are not normally admitted to a Master of Arts (MA) degree program, graduate students may earn the MA as they work towards the PhD.*

Chair

Illya V. Hicks

Professors

Maarten V. de Hoop

Matthias Heinkenschloss

Illya V. Hicks

Guodong Pang

Beatrice M. Rivière

Andrew J. Schaefer

Richard A. Tapia

Associate Professor

Shiqian Ma

Assistant Professors

Jesse Chan

Sebastian Perez-Salazar

Professors Emeriti

Robert E. Bixby

Steven J. Cox

Sam H. Davis, Jr.

John E. Dennis

Henry H. Rachford, Jr.

Danny C. Sorensen

William W. Symes

Chao-Cheng Wang

Yin Zhang

Lecturers

Randy Davila

Anastasiya Protasov

Charles Puelz

Eylem Tekin

Darius Walczak

Pfeiffer Postdoctoral Instructors

Bo Jones

Tyler Perini

Professor, Joint Appointment

John Edward Akin

Adjunct Professors

Amr El-Bakry

Detlef Hohl

Hector Klie

Adjunct Associate Professors

Edward Castillo

David T. Fuentes

C. David Fuller

Craig Rusin

Adjunct Assistant Professors

Sebastian Acosta

Randy Davila

Paul Hand

Taewoo Lee

For Rice University degree-granting programs:

To view the list of official course offerings, please see [Rice's Course Catalog \(https://courses.rice.edu/admweb!/SWKSCAT.cat?p_action=cata\)](https://courses.rice.edu/admweb!/SWKSCAT.cat?p_action=cata)

To view the most recent semester's course schedule, please see [Rice's Course Schedule \(https://courses.rice.edu/admweb!/SWKSCAT.cat\)](https://courses.rice.edu/admweb!/SWKSCAT.cat)

Computational & Applied Mathematics (CAAM)

CAAM 210 - INTRODUCTION TO ENGINEERING COMPUTATION

Short Title: INTRO TO ENG COMPUTATION

Department: Comp Appl Math Operations Rsch

Grade Mode: Standard Letter

Course Type: Lecture/Laboratory

Distribution Group: Distribution Group III

Credit Hours: 3

Restrictions: Enrollment is limited to Undergraduate, Undergraduate Professional or Visiting Undergraduate level students.

Course Level: Undergraduate Lower-Level

Description: Modeling, Simulation, and Visualization via MATLAB. Numerical methods: Newton's method in one and several dimensions. Gaussian elimination and optimization. Application to problems in science and engineering. Lectures are held Monday and Wednesdays. In a laboratory component held on Fridays, students work in small groups on computational projects led by a Rice Learning Assistant. Fall/Spring semester: meeting 3 times per week (50min each meeting) Summer semester: meeting 5 times per week (65min each meeting) OR refer to the current schedule. Recommended Prerequisite(s): MATH 101.

CAAM 238 - SPECIAL TOPICS

Short Title: SPECIAL TOPICS

Department: Comp Appl Math Operations Rsch

Grade Mode: Standard Letter

Course Type: Internship/Practicum, Laboratory, Lecture, Seminar, Independent Study

Credit Hours: 1-4

Restrictions: Enrollment is limited to Undergraduate, Undergraduate Professional or Visiting Undergraduate level students.

Course Level: Undergraduate Lower-Level

Description: Topics and credit hours vary each semester. Contact department for current semester's topic(s). Repeatable for Credit.

CAAM 334 - MATRIX ANALYSIS FOR DATA SCIENCE

Short Title: MATRIX ANALYSIS DATA SCIENCE

Department: Comp Appl Math Operations Rsch

Grade Mode: Standard Letter

Course Type: Lecture

Distribution Group: Distribution Group III

Credit Hours: 3

Restrictions: Enrollment is limited to Undergraduate, Undergraduate Professional or Visiting Undergraduate level students.

Course Level: Undergraduate Upper-Level

Description: Solution of linear systems and linear least squares problems. Eigenvalue problem and singular value decomposition. Introduction to gradient based methods. Applications to data science. Recommended Prerequisite(s): (MATH 212 or MATH 222) and (CAAM 210 or COMP 140 or STAT 405) Mutually Exclusive: Cannot register for CAAM 334 if student has credit for CAAM 335.

CAAM 335 - MATRIX ANALYSIS**Short Title:** MATRIX ANALYSIS**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Lecture**Distribution Group:** Distribution Group III**Credit Hours:** 3**Restrictions:** Enrollment is limited to Undergraduate, Undergraduate Professional or Visiting Undergraduate level students.**Course Level:** Undergraduate Upper-Level**Description:** Equilibria and the solution of linear systems and linear least squares problems. Eigenvalue problem and its application to solve dynamical systems. Singular value decomposition and its application. Recommended Prerequisite(s): (MATH 212 or MATH 222) and (COMP 140 or CAAM 210) Mutually Exclusive: Cannot register for CAAM 335 if student has credit for CAAM 334.**CAAM 336 - DIFFERENTIAL EQUATIONS IN SCIENCE AND ENGINEERING****Short Title:** DIFF EQUATIONS SCI & ENG**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Lecture**Distribution Group:** Distribution Group III**Credit Hours:** 3**Restrictions:** Enrollment is limited to Undergraduate, Undergraduate Professional or Visiting Undergraduate level students.**Course Level:** Undergraduate Upper-Level**Description:** Classical and numerical solution techniques for ordinary and partial differential equations. Fourier series and the finite element method for initial and boundary value problems arising in diffusion and wave propagation phenomena. Recommended Prerequisite(s): (MATH 212 or MATH 222) AND CAAM 210.**CAAM 378 - INTRODUCTION TO OPERATIONS RESEARCH AND OPTIMIZATION****Short Title:** INTRO TO O.R. AND OPTIMIZATION**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Lecture**Distribution Group:** Distribution Group III**Credit Hours:** 3**Restrictions:** Enrollment is limited to Undergraduate, Undergraduate Professional or Visiting Undergraduate level students.**Course Level:** Undergraduate Upper-Level**Description:** Formulation of mathematical models of complex decisions arising in management, economics, and engineering. Models using linear, nonlinear, stochastic and integer programming, as well as networks. Linear programming duality and its modeling implications. Overview of basic solution methods for these optimization models. Recommended Prerequisite(s): MATH 212 and (CAAM 335 OR MATH 211 OR MATH 355).**CAAM 382 - STOCHASTIC MODELS****Short Title:** STOCHASTIC MODELS**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Lecture**Credit Hours:** 3**Restrictions:** Enrollment is limited to Undergraduate, Undergraduate Professional or Visiting Undergraduate level students.**Course Level:** Undergraduate Upper-Level**Prerequisite(s):** MATH 102 or MATH 106**Description:** Fundamentals of stochastic modeling. Topics include discrete & continuous time Markov models, Poisson processes, renewal theory, queueing systems, reliability, Markov decision processes, optimal design and control. Recommended Prerequisite(s): (STAT 280 or 305 or 310 or 315) and MATH 212 and (CAAM 210 or COMP 140) and (CAAM 335 or MATH 355)**CAAM 415 - THEORETICAL NEUROSCIENCE: FROM CELLS TO LEARNING SYSTEMS****Short Title:** THEORETICAL NEUROSCIENCE**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Lecture**Credit Hours:** 3**Restrictions:** Enrollment is limited to Undergraduate, Undergraduate Professional or Visiting Undergraduate level students.**Course Level:** Undergraduate Upper-Level**Description:** We present the theoretical foundations of cellular and systems neuroscience from distinctly quantitative point of view. We develop the mathematical and computational tools as they are needed to model, analyze, visualize and interpret a broad range of experimental data. Cross-list: ELEC 488, NEUR 415. Graduate/Undergraduate Equivalency: CAAM 615. Recommended Prerequisite(s): CAAM 210 or MATH 211 or CAAM 335 or MATH 355. Mutually Exclusive: Cannot register for CAAM 415 if student has credit for CAAM 615.**CAAM 416 - NEURAL COMPUTATION****Short Title:** NEURAL COMPUTATION**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Lecture**Credit Hours:** 3**Restrictions:** Enrollment is limited to Undergraduate, Undergraduate Professional or Visiting Undergraduate level students.**Course Level:** Undergraduate Upper-Level**Description:** How does the brain work? Understanding the brain requires sophisticated theories to make sense of the collective actions of billions of neurons and trillions of synapses. Word theories are not enough; we need mathematical theories. The goal of this course is to provide an introduction to the mathematical theories of learning and computation by neural systems. These theories use concepts from dynamical systems (attractors, oscillations, chaos) and concepts from statistics (information, uncertainty, inference) to relate the dynamics and functions of neural networks. We will apply these theories to sensory computation, learning and memory, and motor control. Students will learn to formalize and mathematically answer questions about neural computations, including "what does a network compute?", "how does it compute?", and "why does it compute that way?" Prerequisites: knowledge of calculus, linear algebra, and probability and statistics. Cross-list: ELEC 489, NEUR 416.

CAAM 419 - COMPUTATIONAL SCIENCE I**Short Title:** COMPUTATIONAL SCIENCE I**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Lecture**Credit Hours:** 3**Restrictions:** Enrollment is limited to Undergraduate, Undergraduate Professional or Visiting Undergraduate level students.**Course Level:** Undergraduate Upper-Level**Description:** Scientific programming using high level languages, including C, Fortran, and C++. Emphasis on use of numerical libraries. Basic techniques of project planning, source management, documentation, program construction, i/o, visualization. Object-oriented design for numerical computing. Grading and assignments would be different between the 400/500 level. Graduate/Undergraduate Equivalency: CAAM 519. Recommended Prerequisite(s): (CAAM 210 and CAAM 335) or CAAM 453. Mutually Exclusive: Cannot register for CAAM 419 if student has credit for CAAM 519.**CAAM 420 - COMPUTATIONAL SCIENCE II****Short Title:** COMPUTATIONAL SCIENCE II**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Lecture**Credit Hours:** 3**Restrictions:** Enrollment is limited to Undergraduate, Undergraduate Professional or Visiting Undergraduate level students.**Course Level:** Undergraduate Upper-Level**Description:** Theory and application of the message passing interface for programming scientific computing applications. Introduction to the architecture and programming of multicore and massively parallel processors, including general purpose graphics processing units, Insight for designing efficient numerical algorithms to improve parallelization of memory access and utilization of non-uniform memory architectures. Application interfaces include OpenMP, MPI, CUDA, OpenCL, and parallel numerical algorithm libraries. Grading and assignments would be different between the 400/500 level. Instructor Permission Required. Graduate/Undergraduate Equivalency: CAAM 520. Recommended Prerequisite(s): CAAM 419 Mutually Exclusive: Cannot register for CAAM 420 if student has credit for CAAM 520.**CAAM 421 - LOGISTICS AND SUPPLY CHAIN MANAGEMENT****Short Title:** LOG & SUPPLY CHAIN MANAGEMENT**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Lecture**Credit Hours:** 3**Restrictions:** Enrollment is limited to Undergraduate, Undergraduate Professional or Visiting Undergraduate level students.**Course Level:** Undergraduate Upper-Level**Prerequisite(s):** CAAM 378 and CAAM 382**Description:** Inventory management: EOQ, newsvendor, reorder point order quantity, multi-echelon models. Scheduling, distribution & location models. Vehicle routing problems. Supply chain coordination. Sustainability in supply chains. Graduate/Undergraduate Equivalency: INDE 561. Mutually Exclusive: Cannot register for CAAM 421 if student has credit for INDE 561.**CAAM 423 - PARTIAL DIFFERENTIAL EQUATIONS I****Short Title:** PARTIAL DIFFERENTIAL EQNS I**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Lecture**Credit Hours:** 3**Restrictions:** Enrollment is limited to Undergraduate, Undergraduate Professional or Visiting Undergraduate level students.**Course Level:** Undergraduate Upper-Level**Description:** First order of partial differential equations. The method of characteristics. Analysis of the solutions of the wave equation, heat equation and Laplace's equation. Integral relations and Green's functions. Potential theory, Dirichlet and Neumann problems. Asymptotic methods: the method of stationary phase, geometrical optics, regular and singular perturbation methods. Cross-list: MATH 423. Graduate/Undergraduate Equivalency: CAAM 523. Recommended Prerequisite(s): MATH 321 AND MATH 322 Mutually Exclusive: Cannot register for CAAM 423 if student has credit for CAAM 523.**CAAM 435 - DYNAMICAL SYSTEMS****Short Title:** DYNAMICAL SYSTEMS**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Lecture**Credit Hours:** 3**Restrictions:** Enrollment is limited to Undergraduate, Undergraduate Professional or Visiting Undergraduate level students.**Course Level:** Undergraduate Upper-Level**Description:** Existence and uniqueness for solutions of ordinary differential equations and difference equations, linear systems, nonlinear systems, stability, periodic solutions, bifurcation theory. Theory and theoretical examples are complemented by computational, model driven examples from biological and physical sciences. Cross-list: MATH 435. Recommended Prerequisite(s): (MATH 212 or MATH 221) and (CAAM 335 or MATH 355 or MATH 354) and (MATH 302 or MATH 321 or MATH 331) **Course URL:** math.rice.edu (<http://math.rice.edu>)**CAAM 436 - MODELING MATHEMATICAL PHYSICS****Short Title:** MODELING MATHEMATICAL PHYSICS**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Lecture**Credit Hours:** 3**Restrictions:** Enrollment is limited to Undergraduate, Undergraduate Professional or Visiting Undergraduate level students.**Course Level:** Undergraduate Upper-Level**Description:** Derivation and properties of solutions of the partial differential equations of continuum physics. Basic concepts of continuum mechanics, ideal fluids, Navier-Stokes equations, linear elasticity, acoustics, basic principles of thermodynamics, Newtonian heat flow, porous flow, Maxwell's equations, electrical circuits. Graduate/Undergraduate Equivalency: CAAM 535. Recommended Prerequisite(s): CAAM 336. Mutually Exclusive: Cannot register for CAAM 436 if student has credit for CAAM 535.

CAAM 440 - APPLIED MATRIX ANALYSIS**Short Title:** APPLIED MATRIX ANALYSIS**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Lecture**Credit Hours:** 3**Restrictions:** Enrollment is limited to Undergraduate, Undergraduate Professional or Visiting Undergraduate level students.**Course Level:** Undergraduate Upper-Level**Description:** A second course in matrix analysis that presents advanced theoretical results alongside motivating applications. Topics include: properties of Hermitian, positive definite, nonnegative and stochastic matrices; Perron-Frobenius Theorem; spectral perturbation theory; singular value inequalities; generalized eigenvalue problems; functions of matrices; Lyapunov, Sylvester, and Riccati matrix equations. Applications include dynamical systems, control theory, and Markov chains.**CAAM 452 - NUMERICAL METHODS FOR PARTIAL DIFFERENTIAL EQUATIONS****Short Title:** NUMERICAL METHODS FOR PDES**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Lecture/Laboratory**Credit Hours:** 3**Restrictions:** Enrollment is limited to Undergraduate, Undergraduate Professional or Visiting Undergraduate level students.**Course Level:** Undergraduate Upper-Level**Description:** This course covers various numerical methods for solving partial differential equations: aspects of finite difference methods, finite element methods, finite volume methods, mixed methods, discontinuous Galerkin methods, and meshless methods. Both theoretical convergence and practical implementation of the methods are studied for elliptic and parabolic problems. Cross-list: CEVE 455. Graduate/Undergraduate Equivalency: CAAM 536. Recommended Prerequisite(s): CAAM 336 Mutually Exclusive: Cannot register for CAAM 452 if student has credit for CAAM 536.**CAAM 453 - NUMERICAL ANALYSIS I****Short Title:** NUMERICAL ANALYSIS I**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Lecture**Credit Hours:** 3**Restrictions:** Enrollment is limited to Undergraduate, Undergraduate Professional or Visiting Undergraduate level students.**Course Level:** Undergraduate Upper-Level**Prerequisite(s):** (CAAM 334 or CAAM 335) and CAAM 336**Description:** Construction and application of numerical algorithms for root finding, interpolation and approximation of functions, quadrature, and the solution of differential equations; fundamentals of computer arithmetic; solution of linear systems, linear least squares problems, and eigenvalue problems via matrix factorizations; Newton and Newton-like methods for nonlinear systems of equations. Computer programming in MATLAB is required. Graduate/Undergraduate Equivalency: CAAM 550. Mutually Exclusive: Cannot register for CAAM 453 if student has credit for CAAM 550.**CAAM 454 - ITERATIVE METHODS FOR SYSTEMS OF EQUATIONS AND UNCONSTRAINED OPTIMIZATION****Short Title:** SYST OF EQNS & UNCONST OPTIM**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Lecture**Credit Hours:** 3**Restrictions:** Enrollment is limited to Undergraduate, Undergraduate Professional or Visiting Undergraduate level students.**Course Level:** Undergraduate Upper-Level**Description:** Iterative methods for linear systems of equations including Krylov subspace methods; Newton and Newton-like methods for nonlinear systems of equations; Gradient and Newton-like methods for unconstrained optimization and nonlinear least squares problems; techniques for improving the global convergence of these algorithms; linear programming duality and primal-dual interior-point methods. Graduate/Undergraduate Equivalency: CAAM 554. Recommended Prerequisite(s): CAAM 453. Mutually Exclusive: Cannot register for CAAM 454 if student has credit for CAAM 554.**CAAM 467 - OPTIMIZATION METHODS IN FINANCE****Short Title:** OPT METHODS IN FINANCE**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Lecture**Credit Hours:** 3**Restrictions:** Enrollment is limited to Undergraduate, Undergraduate Professional or Visiting Undergraduate level students.**Course Level:** Undergraduate Upper-Level**Prerequisite(s):** CAAM 378**Description:** Portfolio optimization and asset allocation models. Risk management and option pricing. Deterministic and stochastic optimization approaches, as well as linear and nonlinear approaches will be used to model decisions arising in finance. Graduate/Undergraduate Equivalency: INDE 567. Mutually Exclusive: Cannot register for CAAM 467 if student has credit for INDE 567.**CAAM 470 - GRAPH THEORY****Short Title:** GRAPH THEORY**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Lecture**Credit Hours:** 3**Course Level:** Undergraduate Upper-Level**Description:** Study of the structure and properties of graphs, together with a variety of applications. Includes paths, cycles, trees, connectivity, matchings, colorings, planarity, directed graphs, and algorithms. Some knowledge of linear algebra is recommended. Graduate/Undergraduate Equivalency: CAAM 570. Mutually Exclusive: Cannot register for CAAM 470 if student has credit for CAAM 570.

CAAM 471 - LINEAR AND INTEGER PROGRAMMING**Short Title:** LINEAR AND INTEGER PROGRAMMING**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Lecture**Credit Hours:** 3**Restrictions:** Enrollment is limited to Undergraduate, Undergraduate Professional or Visiting Undergraduate level students.**Course Level:** Undergraduate Upper-Level

Description: Linear and integer programming involve formulating and solving fundamental optimization models widely used in practice. This course introduces the basic theory, algorithms, and software of linear and integer programming. Topics studied in the linear programming part include polyhedron concepts, simplex methods, duality, sensitivity analysis and decomposition techniques. Building on linear programming, the second part of this course introduces modeling with integer variables and solution methodologies in integer programming including branch-and-bound and cutting-plane techniques. This course will provide a basis for further studies in convex and combinatorial optimization. Graduate/Undergraduate Equivalency: CAAM 571. Recommended Prerequisite(s): CAAM 335 and CAAM 378 Mutually Exclusive: Cannot register for CAAM 471 if student has credit for CAAM 571.

CAAM 476 - LARGE-SCALE OPTIMIZATION**Short Title:** LARGE-SCALE OPTIMIZATION**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Lecture**Credit Hours:** 3**Restrictions:** Enrollment is limited to Undergraduate, Undergraduate Professional or Visiting Undergraduate level students.**Course Level:** Undergraduate Upper-Level**Prerequisite(s):** CAAM 378 and COMP 215

Description: Decomposition of large-scale linear, nonlinear and integer programs. Minkowski representation of polyhedral. Benders' and Dantzig-Wolfe decomposition. Relaxations, including Lagrangian relaxation. Examples include multicommodity flow and stochastic linear programs. Design and testing of computational strategies for difficult optimization problems. Students will implement projects in Python and JuMP. Graduate/Undergraduate Equivalency: INDE 546. Mutually Exclusive: Cannot register for CAAM 476 if student has credit for INDE 546.

CAAM 477 - SPECIAL TOPICS**Short Title:** SPECIAL TOPICS**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Independent Study, Internship/Practicum, Laboratory, Lecture, Seminar, Lecture/Laboratory**Credit Hours:** 1-4**Restrictions:** Enrollment is limited to Undergraduate, Undergraduate Professional or Visiting Undergraduate level students.**Course Level:** Undergraduate Upper-Level**Description:** Topics and credit hours vary each semester. Contact department for current semester's topic(s). Repeatable for Credit.**CAAM 480 - PEDAGOGY FOR CAAM 210 RICE LEARNING ASSISTANTS****Short Title:** PEDAGOGY FOR RLAs**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Seminar**Credit Hours:** 2**Restrictions:** Enrollment is limited to Undergraduate, Undergraduate Professional or Visiting Undergraduate level students.**Course Level:** Undergraduate Upper-Level

Description: This course is designed to support Rice Learning Assistants (RLAs) as they instruct their own lab sections of CAAM 210. Topics include analysis of computational science and engineering concepts, issues of problem-based learning (PBL), theories of learning, and fundamental teaching skills. Required for CAAM 210 RLAs. Instructor Permission Required. Repeatable for Credit.

CAAM 485 - SIMULATION MODELING AND ANALYSIS**Short Title:** SIM MODELING AND ANALYSIS**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Lecture**Credit Hours:** 3**Restrictions:** Enrollment is limited to Undergraduate, Undergraduate Professional or Visiting Undergraduate level students.**Course Level:** Undergraduate Upper-Level**Prerequisite(s):** CAAM 382 (may be taken concurrently)

Description: This course introduces simulation techniques that uses statistical sampling, probability models and computational tools to study complex stochastic systems arising in service operations, healthcare, telecommunications, production, logistics, inventory and financial systems. Topics covered include generating random objects (random variables and stochastic processes, discrete-event systems), input and output analysis, steady-state simulation, variance-reduction methods, rare-event simulation, Markov chain Monte Carlo methods, and simulation-based optimization. The course lectures are supplemented with programming components in homework and projects. Graduate/Undergraduate Equivalency: CAAM 586. Recommended Prerequisite(s): MATH 212, (STAT 310 or STAT 311 or STAT 418), (CAAM 334 or CAAM 335), and MATH 302

CAAM 490 - UNDERGRADUATE RESEARCH PROJECTS**Short Title:** UNDERGRAD RESEARCH PROJECTS**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Satisfactory/Unsatisfactory**Course Type:** Research**Credit Hours:** 1-6**Restrictions:** Enrollment is limited to Undergraduate, Undergraduate Professional or Visiting Undergraduate level students.**Course Level:** Undergraduate Upper-Level**Description:** Semester-long undergraduate-level research on a topic in Computational and Applied Mathematics. Instructor Permission Required. Repeatable for Credit.

CAAM 491 - UNDERGRADUATE RESEARCH PROJECTS**Short Title:** UNDERGRAD RESEARCH PROJECTS**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Satisfactory/Unsatisfactory**Course Type:** Research**Credit Hours:** 1-6**Restrictions:** Enrollment is limited to Undergraduate, Undergraduate Professional or Visiting Undergraduate level students.**Course Level:** Undergraduate Upper-Level**Description:** Semester-long undergraduate-level research on a topic in Computational and Applied Mathematics. Instructor Permission Required. Repeatable for Credit.**CAAM 495 - SENIOR DESIGN PROJECT I****Short Title:** SENIOR DESIGN PROJECT I**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Lecture/Laboratory**Credit Hours:** 2**Restrictions:** Enrollment is limited to Undergraduate, Undergraduate Professional or Visiting Undergraduate level students.**Course Level:** Undergraduate Upper-Level**Description:** Students engage in team-oriented year-long design projects that utilize modeling, analysis, and scientific computing skills to solve a problem motivated by an application in engineering or the physical, biological, or social sciences. Participants attend regular seminars addressing research techniques and effective written and verbal presentation of mathematics.**CAAM 496 - SENIOR DESIGN PROJECT II****Short Title:** SENIOR DESIGN PROJECT II**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Lecture/Laboratory**Credit Hours:** 2**Restrictions:** Enrollment is limited to Undergraduate, Undergraduate Professional or Visiting Undergraduate level students.**Course Level:** Undergraduate Upper-Level**Prerequisite(s):** CAAM 495**Description:** Continuation of CAAM 495. Seminars focus on the presentation of results from design groups and provide guidance on the composition of a substantial project report.**CAAM 497 - LOSING THE PRECIOUS FEW****Short Title:** LOSING THE PRECIOUS FEW**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Satisfactory/Unsatisfactory**Course Type:** Lecture**Credit Hour:** 1**Restrictions:** Enrollment is limited to Undergraduate, Undergraduate Professional or Visiting Undergraduate level students.**Course Level:** Undergraduate Upper-Level**Description:** The class will read from Tapia's text: Losing the Precious Few: How America Fails to Educate Minorities in Science and Engineering and then discuss in class issues associated with the underrepresentation of Blacks and Hispanics in academic and national science and engineering activities. Topics will include racism, immigration, student admissions, faculty hiring, faculty promotion, the role of minority serving institutions, mistaking foreign minorities for the Precious Few, support issues and leadership.**CAAM 498 - RESEARCH THEMES IN THE MATHEMATICAL SCIENCES****Short Title:** RESEARCH THEMES IN MATH. SCI.**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Seminar**Credit Hours:** 1-3**Restrictions:** Enrollment is limited to Undergraduate, Undergraduate Professional or Visiting Undergraduate level students.**Course Level:** Undergraduate Upper-Level**Description:** A seminar course that will cover a selected theme of general research in the mathematical sciences from the perspectives of mathematics, computational and applied mathematics and statistics. The course may be repeated multiple times for credit. Cross-list: MATH 498, STAT 498. Graduate/Undergraduate Equivalency: CAAM 698. Mutually Exclusive: Cannot register for CAAM 498 if student has credit for CAAM 698. Repeatable for Credit.**CAAM 499 - COMPUTATIONAL AND APPLIED MATHEMATICS SEMINAR****Short Title:** COMP & APPLIED MATH SEMINAR**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Seminar**Credit Hours:** 1-6**Restrictions:** Enrollment is limited to Undergraduate, Undergraduate Professional or Visiting Undergraduate level students.**Course Level:** Undergraduate Upper-Level**Description:** This course prepares a student for research in the mathematical sciences on a specific topic. Each section is dedicated to a different topic. Current topics include eigenvalues, model reduction, combinatorial optimization, optimization algorithms, scientific computing, and numerical analysis. The topics may vary each semester. Graduate/Undergraduate Equivalency: CAAM 699. Repeatable for Credit.**CAAM 501 - ANALYSIS I****Short Title:** ANALYSIS I**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Lecture**Credit Hours:** 3**Restrictions:** Enrollment is limited to Graduate level students.**Course Level:** Graduate**Description:** Real numbers, completeness, sequences and convergence, compactness, continuity, the derivative, the Riemann integral, fundamental theorem of calculus. Vector spaces, dimension, linear maps, inner products and norms, derivatives in \mathbb{R}^d , inverse function theorem, implicit function theorem, multiple integration, change of variable theorem. Instructor Permission Required. Recommended Prerequisite(s): CAAM 501 Mutually Exclusive: Cannot register for CAAM 501 if student has credit for CAAM 401.

CAAM 502 - ANALYSIS II**Short Title:** ANALYSIS II**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Lecture**Credit Hours:** 3**Restrictions:** Enrollment is limited to Graduate level students.**Course Level:** Graduate

Description: Vector spaces of functions, sequences and series, convergence. Continuity and differentiability of functions of several variables, the derivative as a linear map, the contraction mapping principle, fundamental theorems on differential equations, multivariable integration, Stoke's theorem and relatives. Instructor Permission Required. Recommended Prerequisite(s): CAAM 501. Mutually Exclusive: Cannot register for CAAM 502 if student has credit for CAAM 402.

CAAM 508 - NONLINEAR SYSTEMS: ANALYSIS AND CONTROL**Short Title:** NONLINEAR SYSTEMS**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Lecture**Credit Hours:** 3**Restrictions:** Enrollment is limited to Graduate level students.**Course Level:** Graduate

Description: Mathematical background and fundamental properties of nonlinear systems: Vector norms, matrix norms, matrix measures, existence and uniqueness of solutions of ordinary differential equations. Linearization, second order systems, periodic solutions, approximate methods. Lyapunov stability: Stability definitions, Lyapunov's direct method, invariance theory, stability of linear systems, Lyapunov's linearization method, converse theorems. Selected topics in nonlinear systems analysis and nonlinear control from: Input/Output stability: Small gain theorem, passivity theorem. Perturbation theory, averaging, and singular perturbations. Feedback linearization control. Other methods in the control of nonlinear systems such as backstepping, sliding mode and other Lyapunov-based design methods. Advanced nonlinear and adaptive robot control. Cross-list: ELEC 508, MECH 508.

CAAM 519 - COMPUTATIONAL SCIENCE I**Short Title:** COMPUTATIONAL SCIENCE I**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Lecture**Credit Hours:** 3**Restrictions:** Enrollment is limited to Graduate level students.**Course Level:** Graduate

Description: Scientific programming using high level languages, including C, Fortran, and C++. Emphasis on use of numerical libraries. Basic techniques of project planning, source management, documentation, program construction, i/o, visualization. Object-oriented design for numerical computing. Grading and assignments would be different between the 400/500 level. Graduate/Undergraduate Equivalency: CAAM 419. Recommended Prerequisite(s): (CAAM 210 and CAAM 335) or CAAM 453. Mutually Exclusive: Cannot register for CAAM 519 if student has credit for CAAM 419.

CAAM 520 - COMPUTATIONAL SCIENCE II**Short Title:** COMPUTATIONAL SCIENCE II**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Lecture**Credit Hours:** 3**Restrictions:** Enrollment is limited to Graduate level students.**Course Level:** Graduate

Description: Theory and application of the message passing interface for programming scientific computing applications. Introduction to the architecture and programming of multicore and massively parallel processors, including general purpose graphics processing units, Insight for designing efficient numerical algorithms to improve parallelization of memory access and utilization of non-uniform memory architectures. Application interfaces include OpenMP, MPI, CUDA, OpenCL, and parallel numerical algorithm libraries. Grading and assignments would be different between the 400/500 level. Instructor Permission Required. Graduate/Undergraduate Equivalency: CAAM 420. Recommended Prerequisite(s): CAAM 519 Mutually Exclusive: Cannot register for CAAM 520 if student has credit for CAAM 420.

CAAM 523 - PARTIAL DIFFERENTIAL EQUATIONS I**Short Title:** PARTIAL DIFFERENTIAL EQNS I**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Lecture**Credit Hours:** 3**Restrictions:** Enrollment is limited to Graduate level students.**Course Level:** Graduate

Description: First order of partial differential equations. The method of characteristics. Analysis of the solutions of the wave equation, heat equation and Laplace's equation. Integral relations and Green's functions. Potential theory, Dirichlet and Neumann problems. Asymptotic methods: the method of stationary phase, geometrical optics, regular and singular perturbation methods. Additional course work is required beyond the undergraduate course requirements. Cross-list: MATH 513. Graduate/Undergraduate Equivalency: CAAM 423. Recommended Prerequisite(s): MATH 321 AND MATH 322 Mutually Exclusive: Cannot register for CAAM 523 if student has credit for CAAM 423.

CAAM 535 - MODELING MATHEMATICAL PHYSICS**Short Title:** MODELING MATHEMATICAL PHYSICS**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Lecture**Credit Hours:** 3**Restrictions:** Enrollment is limited to Graduate level students.**Course Level:** Graduate

Description: This course combines basic physical principles with vector calculus to derive many important partial differential equations governing motion of fluids and solids. Topics include stress, strain, idealized fluids, linear elasticity, acoustics, basics of thermodynamics, Navier-Stokes. Graduate/Undergraduate Equivalency: CAAM 436. Recommended Prerequisite(s): CAAM 336 Mutually Exclusive: Cannot register for CAAM 535 if student has credit for CAAM 436.

CAAM 536 - NUMERICAL METHODS FOR PARTIAL DIFFERENTIAL EQUATIONS**Short Title:** NUMERICAL METHODS FOR PDES**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Lecture**Credit Hours:** 3**Restrictions:** Enrollment is limited to Graduate level students.**Course Level:** Graduate

Description: This course covers various numerical methods for solving partial differential equations: aspects of finite difference methods, finite element methods, finite volume methods, mixed methods, discontinuous Galerkin methods, and meshless methods. Both theoretical convergence and practical implementation of the methods are studied for elliptic and parabolic problems. May receive credit for only one of the following courses: CAAM 452/CEVE 455/CAAM 536/CEVE 555. Cross-list: CEVE 555. Graduate/Undergraduate Equivalency: CAAM 452. Recommended Prerequisite(s): CAAM 336 Mutually Exclusive: Cannot register for CAAM 536 if student has credit for CAAM 452.

CAAM 540 - APPLIED FUNCTIONAL ANALYSIS**Short Title:** APPLIED FUNCTIONAL ANALYSIS**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Lecture**Credit Hours:** 3**Restrictions:** Enrollment is limited to Graduate level students.**Course Level:** Graduate**Prerequisite(s):** CAAM 402 or CAAM 502

Description: Hilbert spaces, Banach spaces, spectral theory, and weak topologies with applications to signal processing, control, and partial differential equations. Biennial; Offered in Odd Years. Recommended Prerequisite(s): CAAM 402 and MATH 322.

CAAM 542 - DISCONTINUOUS GALERKIN METHODS FOR SOLVING ENGINEERING PROBLEMS**Short Title:** DISCONTINUOUS GALERKIN METHODS**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Lecture**Credit Hours:** 3**Restrictions:** Enrollment is limited to Graduate level students.**Course Level:** Graduate

Description: The course will present the theory and implementation of discontinuous Galerkin methods for partial differential equations common in engineering applications. Two main classes of problems are covered: steady-state and time-dependent elliptic/parabolic and hyperbolic equations. These include (but are not limited to) the Poisson and heat equations, linear wave equations, and nonlinear conservation laws. Recommended Prerequisite(s): CAAM 453 or CAAM 553

CAAM 545 - APPLIED AND COMPUTATIONAL MICROLOCAL AND HARMONIC ANALYSIS**Short Title:** MICROLOCAL & HARMONIC ANALYSIS**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Lecture**Credit Hours:** 3**Restrictions:** Enrollment is limited to Graduate level students.**Course Level:** Graduate**Prerequisite(s):** CAAM 423 and CAAM 502

Description: Introduction to microlocal and harmonic analysis. Oscillatory integrals, Wavefront set, Pseudodifferential and Fourier Integral Operators and their calculus, and basic symplectic geometry. Egorov's theorem and propagation of singularities. Wavepackets, matrix classes and discretization; USFFT and fast curvelet transform. Parametrix construction for wave equations and applications in imaging. Recommended Prerequisite(s): MATH 302, (CAAM 334 or CAAM 335), MATH 401, CAAM 453

CAAM 550 - NUMERICAL ANALYSIS I**Short Title:** NUMERICAL ANALYSIS I**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Lecture**Credit Hours:** 3**Restrictions:** Enrollment is limited to Graduate level students.**Course Level:** Graduate

Description: Construction and application of numerical algorithms for root finding, interpolation and approximation of functions, quadrature, and the solution of differential equations; fundamentals of computer arithmetic; solution of linear systems, linear least squares problems, and eigenvalue problems via matrix factorizations; Newton and Newton-like methods for nonlinear systems of equations. Computer programming in MATLAB is required. Graduate/Undergraduate Equivalency: CAAM 453. Mutually Exclusive: Cannot register for CAAM 550 if student has credit for CAAM 453.

CAAM 551 - NUMERICAL LINEAR ALGEBRA**Short Title:** NUMERICAL LINEAR ALGEBRA**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Lecture**Credit Hours:** 3**Restrictions:** Enrollment is limited to Graduate level students.**Course Level:** Graduate

Description: Iterative methods for solving linear systems: Jacobi, Gauss-Seidel, geometric multigrids, p-multigrids, algebraic multigrids. Connection between multigrid methods and some special architectures of neural networks. Randomized methods for matrix computations: randomized matrix multiplications, randomized SVD, randomized least squares and QR. Recommended Prerequisite(s): CAAM 453 or CAAM 550 or CAAM 553

CAAM 552 - FOUNDATIONS OF FINITE ELEMENT METHODS**Short Title:** FINITE ELEMENT METHODS**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Lecture**Credit Hours:** 3**Restrictions:** Enrollment is limited to Graduate level students.**Course Level:** Graduate**Description:** This course addresses the theory and implementation of finite element methods. Topics include weak solutions of partial differential equations, Sobolev spaces, approximation theory, convergence and reliability of the numerical methods. Continuous and discontinuous finite element methods are considered.**CAAM 553 - ADVANCED NUMERICAL ANALYSIS I****Short Title:** ADV NUMERICAL ANALYSIS I**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Lecture**Credit Hours:** 3**Restrictions:** Enrollment is limited to Graduate level students.**Course Level:** Graduate**Prerequisite(s):** CAAM 401 (may be taken concurrently) or CAAM 501 (may be taken concurrently)**Description:** Construction and analysis of numerical algorithms for root finding, interpolation and approximation of functions, quadrature, and the solution of differential equations; fundamentals of computer arithmetic; solution of linear systems, least squares problems, and eigenvalue problems via matrix factorizations; the singular value decomposition (SVD) and basic sensitivity analysis. Computer programming in MATLAB is required. This course covers fewer topics than CAAM 453 with greater theoretical depth. Prerequisite CAAM 501 may be taken concurrently with CAAM 553. Instructor Permission Required.**CAAM 554 - ITERATIVE METHODS FOR SYSTEMS OF EQUATIONS AND UNCONSTRAINED OPTIMIZATION****Short Title:** SYST OF EQNS & UNCONST OPTIM**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Lecture**Credit Hours:** 3**Restrictions:** Enrollment is limited to Graduate level students.**Course Level:** Graduate**Description:** This course covers the same lecture material as CAAM 454, but fosters greater theoretical sophistication through more challenging problem sets and exams. Graduate/Undergraduate Equivalency: CAAM 454. Recommended Prerequisite(s): CAAM 550 or CAAM 553. Mutually Exclusive: Cannot register for CAAM 554 if student has credit for CAAM 454.**CAAM 558 - INTRO TO PARTIAL DIFFERENTIAL EQUATION BASED SIMULATION AND OPTIMIZATION****Short Title:** PDE SIMULATION AND OPTIM**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Lecture**Credit Hours:** 3**Restrictions:** Enrollment is limited to Graduate level students.**Course Level:** Graduate**Prerequisite(s):** CAAM 501 and CAAM 553**Description:** Introduction to the theory and numerical methods for the solution of elliptic partial differential equations (PDEs) and optimization problems governed by these PDEs. Topics include functional analysis, well-posedness of elliptic problems, optimality conditions for PDE constrained optimization problems and finite element discretizations. Recommended Prerequisite(s): CAAM 554**CAAM 560 - OPTIMIZATION THEORY****Short Title:** OPTIMIZATION THEORY**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Lecture**Credit Hours:** 3**Restrictions:** Enrollment is limited to Graduate level students.**Course Level:** Graduate**Description:** Derivation and application of necessity conditions and sufficiency conditions for constrained optimization problems.**CAAM 564 - NUMERICAL OPTIMIZATION****Short Title:** NUMERICAL OPTIMIZATION**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Lecture**Credit Hours:** 3**Restrictions:** Enrollment is limited to Graduate level students.**Course Level:** Graduate**Description:** Numerical algorithms for constrained optimization problems in engineering and sciences, including simplex and interior-point methods for linear programming, penalty, barrier, augmented Lagrangian and SQP methods for nonlinear programming. Recommended Prerequisite(s): CAAM 560 (may be taken concurrently) and CAAM 454.**CAAM 565 - CONVEX OPTIMIZATION****Short Title:** CONVEX OPTIMIZATION**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Lecture**Credit Hours:** 3**Restrictions:** Enrollment is limited to Graduate level students.**Course Level:** Graduate**Description:** Convex optimization problems arise in communication, system theory, VLSI, CAD, finance, inventory, network optimization, computer vision, learning, statistics, etc., even though oftentimes convexity may be hidden and unrecognized. Recent advances in interior-point methodology have made it much easier to solve these problems and various solvers are now available. This course will introduce the basic theory and algorithms for convex optimization, as well as its many applications to computer science, engineering, management science and statistics. Biennial; Offered in Odd Years. Recommended Prerequisite(s): CAAM 335 and MATH 321.

CAAM 567 - SIGNAL RECOVERY: THEORY AND SIMULATION**Short Title:** SIGNAL RECOVERY**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Lecture**Credit Hours:** 3**Restrictions:** Enrollment is limited to Graduate level students.**Course Level:** Graduate

Description: This course introduces the theory and numerical algorithms for several fundamental signal recovery tasks. Topics include L1 minimization, sparse regression, compressed sensing, orthogonal matching pursuit, proximal operators, ADMM algorithms, Iterative Reweighted Least Squares. Nuclear norm minimization, matrix completion, robust Principal Component Analysis. Recommended Prerequisite(s): CAAM 378 or MATH 302 or STAT 310.

CAAM 568 - INDUSTRIAL AND APPLIED DATA SCIENCE AND CONTROL THEORY**Short Title:** DATA SCIENCE & CONTROL THEORY**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Lecture**Credit Hours:** 3**Restrictions:** Enrollment is limited to Graduate level students.**Course Level:** Graduate

Description: This graduate level course presents a pragmatic introduction to the foundational theory of data science and optimal control along with multiple practical applications. It includes modern (post-1990) aspects of data science driven by massively more data and computer power such as deep neural networks. Dynamical systems and optimal control methods are deeply impacted by these developments, and the course includes relevant sections on nonlinear control and reinforcement learning. It is supplemented by practical programming exercises to be completed every week by all students. Several industrial-strength applications from the energy sector are discussed in appropriate detail. Recommended Prerequisite(s): Equivalent of advanced course work in computer programming (e.g. COMP 321), calculus (e.g. MATH 212), statistics or probability theory (e.g. STAT 331), linear algebra (e.g. CAAM 334 or 335). Proficiency in MATLAB (course programming language) or Python (alternative to MATLAB available to course participants).

CAAM 570 - GRAPH THEORY**Short Title:** GRAPH THEORY**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Lecture**Credit Hours:** 3**Restrictions:** Enrollment is limited to Graduate level students.**Course Level:** Graduate

Description: Study of the structure and properties of graphs, together with a variety of applications. Includes paths, cycles, trees, connectivity, matchings, colorings, planarity, directed graphs, and algorithms. Some knowledge of linear algebra is recommended. This course covers the same lecture material as CAAM 470, but fosters greater theoretical sophistication through more challenging problem sets and exams on the graduate side. Graduate/Undergraduate Equivalency: CAAM 470. Mutually Exclusive: Cannot register for CAAM 570 if student has credit for CAAM 470.

CAAM 571 - LINEAR AND INTEGER PROGRAMMING**Short Title:** LINEAR AND INTEGER PROGRAMMING**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Lecture**Credit Hours:** 3**Restrictions:** Enrollment is limited to Graduate level students.**Course Level:** Graduate

Description: This course covers the same lecture material as CAAM 471, but fosters greater theoretical sophistication through more challenging problem sets and exams. Graduate/Undergraduate Equivalency: CAAM 471. Mutually Exclusive: Cannot register for CAAM 571 if student has credit for CAAM 471.

CAAM 574 - COMBINATORIAL OPTIMIZATION**Short Title:** COMBINATORIAL OPTIMIZATION**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Lecture**Credit Hours:** 3**Restrictions:** Enrollment is limited to Graduate level students.**Course Level:** Graduate

Description: General theory and approaches for solving combinatorial optimization problems are studied. Specific topics include basic polyhedral theory, minimum spanning trees, shortest paths, network flow, matching and matroids. The course also covers the traveling salesman problem. A student may not receive credit for both CAAM 474 and CAAM 574. Mutually Exclusive: Cannot register for CAAM 574 if student has credit for CAAM 474.

CAAM 581 - MATHEMATICAL PROBABILITY I**Short Title:** MATHEMATICAL PROBABILITY I**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Lecture**Credit Hours:** 3**Restrictions:** Enrollment is limited to Graduate level students.**Course Level:** Graduate

Description: Measure-theoretic foundations of probability. Open to qualified undergraduates. Required for PhD students in statistics. Cross-list: STAT 581.

CAAM 583 - INTRODUCTION TO RANDOM PROCESSES AND APPLICATIONS**Short Title:** INTRO RANDOM PROCESSES & APPL**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Lecture**Credit Hours:** 3**Restrictions:** Enrollment is limited to Graduate level students.**Course Level:** Graduate

Description: Review of basic probability; Sequences of random variables; Random vectors and estimation; Basic concepts of random processes; Random processes in linear systems, expansions of random processes; Wiener filtering; Spectral representation of random processes, and white-noise integrals. Cross-list: ELEC 533, STAT 583.

CAAM 585 - STOCHASTIC OPTIMIZATION**Short Title:** STOCHASTIC OPTIMIZATION**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Lecture**Credit Hours:** 3**Restrictions:** Enrollment is limited to Graduate level students.**Course Level:** Graduate**Prerequisite(s):** CAAM 571**Description:** Stochastic optimization models arise in many contexts. This course focuses on stochastic programs, including stochastic integer programs and multi-stage stochastic programs. It will emphasize the interplay between theory and computational approaches.**CAAM 586 - STOCHASTIC SIMULATION: ALGORITHMS AND ANALYSIS****Short Title:** STOCHASTIC SIMULATION**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Lecture**Credit Hours:** 3**Restrictions:** Enrollment is limited to Graduate level students.**Course Level:** Graduate**Description:** Simulation methods and algorithms to modeling and analysis of real-world complex stochastic systems. Generating random objects (random variables and stochastic processes, discrete-event systems), input and output analysis, steady-state simulation, variance-reduction methods, rare-event simulation, Markov chain Monte Carlo methods, simulation-based optimization. This course discusses simulation algorithms and their analysis for applications in operations research (service operations, healthcare, queueing, networks, inventory, finance). It is supplemented by practical programming exercises. Graduate/Undergraduate Equivalency: CAAM 485. Recommended Prerequisite(s): MATH 212, (STAT 310 or STAT 311 or 418), (CAAM 334 or CAAM 335), CAAM 382, MATH 302**CAAM 590 - INDEPENDENT STUDY****Short Title:** GRADUATE RESEARCH PROJECTS**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Research**Credit Hours:** 1-15**Restrictions:** Enrollment is limited to Graduate level students.**Course Level:** Graduate**Description:** Semester-long graduate-level research on a topic in Computational and Applied Mathematics. Instructor Permission Required. Repeatable for Credit.**CAAM 591 - GRADUATE RESEARCH PROJECTS****Short Title:** GRADUATE RESEARCH PROJECTS**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Research**Credit Hours:** 1-15**Restrictions:** Enrollment is limited to Graduate level students.**Course Level:** Graduate**Description:** Semester-long graduate-level research on a topic in Computational and Applied Mathematics. Instructor Permission Required. Repeatable for Credit.**CAAM 600 - THESIS WRITING****Short Title:** THESIS WRITING**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Lecture**Credit Hours:** 3**Restrictions:** Enrollment is limited to Graduate level students.**Course Level:** Graduate**Description:** Assists the student in preparation of the CAAM MA/PhD thesis and in other writing projects. Structure of a scientific paper, effective approaches to technical writing, building literature review, results, and discussion sections, how to write a good abstract, oral presentation skills. Prerequisite: Advisor approval of topic and consent of the instructor(s). Instructor Permission Required. Repeatable for Credit.**CAAM 615 - THEORETICAL NEUROSCIENCE I: BIOPHYSICAL MODELING OF CELLS AND CIRCUITS****Short Title:** THEORETICAL NEUROSCIENCE**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Lecture**Credit Hours:** 3**Restrictions:** Enrollment is limited to Graduate level students.**Course Level:** Graduate**Description:** We present the theoretical foundations of cellular and systems neuroscience from distinctly quantitative point of view. We develop the mathematical and computational tools as they are needed to model, analyze, visualize and interpret a broad range of experimental data. Additional course work required beyond the undergraduate course requirements. Cross-list: ELEC 588, NEUR 615. Graduate/Undergraduate Equivalency: CAAM 415. Mutually Exclusive: Cannot register for CAAM 615 if student has credit for CAAM 415.**CAAM 620 - TOPICS IN COMPUTATIONAL SCIENCE****Short Title:** TOPICS IN COMPUTATIONL SCIENCE**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Lecture**Credit Hours:** 1-3**Restrictions:** Enrollment is limited to Graduate level students.**Course Level:** Graduate**Description:** Content varies from year to year. Instructor Permission Required. Repeatable for Credit.**CAAM 640 - OPTIMIZATION WITH SIMULATION CONSTRAINTS****Short Title:** OPTIMIZATION W/SIM CONSTRAINTS**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Lecture**Credit Hours:** 3**Restrictions:** Enrollment is limited to Graduate level students.**Course Level:** Graduate**Description:** Content varies from year to year. Recommended Prerequisite(s): CAAM 564. Repeatable for Credit.

CAAM 641 - TOPICS IN INVERSE PROBLEMS**Short Title:** TOPICS IN INVERSE PROBLEMS**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Lecture**Credit Hours:** 3**Restrictions:** Enrollment is limited to Graduate level students.**Course Level:** Graduate**Description:** Theoretical, computational and practical issues for inverse problems in science and engineering. Selected topics will vary depending on instructor and student interests. Instructor Permission Required. Repeatable for Credit.**CAAM 642 - TOPICS IN SEISMIC IMAGING****Short Title:** TOPICS IN SEISMIC IMAGING**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Lecture**Credit Hours:** 1-3**Restrictions:** Enrollment is limited to Graduate level students.**Course Level:** Graduate**Description:** Content varies from year to year. Instructor Permission Required. Repeatable for Credit.**CAAM 643 - TOPICS IN GEOMATHEMATICS****Short Title:** TOPICS IN GEOMATHEMATICS**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Lecture**Credit Hours:** 1-3**Restrictions:** Enrollment is limited to Graduate level students.**Course Level:** Graduate**Description:** Content varies from year to year. Instructor Permission Required. Recommended Prerequisite(s): CAAM 335 and CAAM 336 Repeatable for Credit.**CAAM 651 - TOPICS IN NUMERICAL LINEAR ALGEBRA****Short Title:** TOPICS IN NUM LINEAR ALGEBRA**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Lecture**Credit Hours:** 1-3**Restrictions:** Enrollment is limited to Graduate level students.**Course Level:** Graduate**Description:** Selected topics will vary depending on instructor and student interests. Derivation and analysis of Krylov and subspace iteration methods for large eigenvalue problems (Lanczos, Arnoldi, Jacobi-Davidson algorithms); preconditioning for linear systems and eigenvalue problems (incomplete LU, domain decomposition, multigrid); convergence analysis including potential theory and pseudospectra. Applications: regularization of discrete inverse problems; dimension reduction for large dynamical control systems; effects on non-normality on behavior of dynamical systems and iterative processes. Recommended Prerequisite(s): CAAM 551. Repeatable for Credit.**CAAM 652 - TOPICS IN NUMERICAL DIFFERENTIAL EQUATIONS****Short Title:** TOPICS IN NUM DIFF EQNS**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Lecture**Credit Hours:** 1-3**Restrictions:** Enrollment is limited to Graduate level students.**Course Level:** Graduate**Description:** Content varies from year to year. Instructor Permission Required. Repeatable for Credit.**CAAM 654 - TOPICS IN OPTIMIZATION****Short Title:** TOPICS IN OPTIMIZATION**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Lecture**Credit Hours:** 1-3**Restrictions:** Enrollment is limited to Graduate level students.**Course Level:** Graduate**Description:** Content varies from year to year. Instructor Permission Required. Repeatable for Credit.**CAAM 664 - TOPICS IN NONLINEAR PROGRAMMING****Short Title:** TOPICS NONLINEAR PROGRAMMING**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Lecture**Credit Hours:** 3**Restrictions:** Enrollment is limited to Graduate level students.**Course Level:** Graduate**Description:** Content varies from year to year.**CAAM 677 - SPECIAL TOPICS****Short Title:** SPECIAL TOPICS**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Laboratory, Internship/Practicum, Lecture, Seminar, Independent Study, Lecture/Laboratory**Credit Hours:** 1-4**Restrictions:** Enrollment is limited to Graduate or Visiting Graduate level students.**Course Level:** Graduate**Description:** Topics and credit hours vary each semester. Contact department for current semester's topic(s). Repeatable for Credit.**CAAM 698 - RESEARCH THEMES IN THE MATHEMATICAL SCIENCES****Short Title:** RESEARCH THEMES IN MATH. SCI.**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Seminar**Credit Hours:** 1-3**Restrictions:** Enrollment is limited to Graduate level students.**Course Level:** Graduate**Description:** A seminar course that will cover a selected theme of general research in the mathematical sciences from the perspectives of mathematics, computational and applied mathematics and statistics. The course may be repeated multiple times for credit. Cross-list: MATH 698, STAT 698. Graduate/Undergraduate Equivalency: CAAM 498. Mutually Exclusive: Cannot register for CAAM 698 if student has credit for CAAM 498. Repeatable for Credit.

CAAM 699 - COMPUTATIONAL AND APPLIED MATHEMATICS SEMINAR**Short Title:** COMP & APPLIED MATH SEMINAR**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Seminar**Credit Hours:** 1-9**Restrictions:** Enrollment is limited to Graduate level students.**Course Level:** Graduate

Description: This course prepares a student for research in the mathematical sciences on a specific topic. Each section is dedicated to a different topic. Current topics include bioinformatics, biomathematics, computational finance, simulation driven optimization, data simulation, and spectral optimization in rational mechanics. The topics may vary each semester. Instructor Permission Required. Graduate/Undergraduate Equivalency: CAAM 499. Repeatable for Credit.

CAAM 800 - RESEARCH AND THESIS**Short Title:** RESEARCH AND THESIS**Department:** Comp Appl Math Operations Rsch**Grade Mode:** Standard Letter**Course Type:** Research**Credit Hours:** 1-15**Restrictions:** Enrollment is limited to Graduate level students.**Course Level:** Graduate

Description: This course is for CAAM MA or PhD students working on their thesis research. Repeatable for Credit.

Description and Code Legend

Note: Internally, the university uses the following descriptions, codes, and abbreviations for this academic program. The following is a quick reference:

Course Catalog/Schedule

- Course offerings/subject code: CAAM

Department Description and Code

- Computational Applied Mathematics and Operations Research: CMOR

Undergraduate Degree Description and Code

- Bachelor of Arts degree: BA

Undergraduate Major Descriptions and Codes

- Major in Computational and Applied Mathematics: CAAM
- Major in Operations Research: OPRE

Undergraduate Minor Description and Code

- Minor in Computational and Applied Mathematics: CAMT

Graduate Degree Descriptions and Codes

- Master of Arts degree: MA
- Master of Computational and Applied Mathematics degree: MCAAM
- Master of Industrial Engineering degree: MIE
- Doctor of Philosophy degree: PhD

Graduate Degree Program Description and Code

- Degree Program in Computational and Applied Mathematics: CAAM
- Degree Program in Industrial Engineering: INDE

CIP Code and Description ¹

- **CAAM** Major/Program: CIP Code/Title: 27.0304 - *Computational and Applied Mathematics*
- **INDE** Major/Program: CIP Code/Title: 14.3701 - *Operations Research*
- **OPRE** Major/Program: CIP Code/Title: 14.3701 - *Operations Research*
- **CAMT** Minor: CIP Code/Title: 27.0304 - *Computational and Applied Mathematics*

¹ Classification of Instructional Programs (CIP) 2020 Codes and Descriptions from the National Center for Education Statistics: <https://nces.ed.gov/ipeds/cipcode/>