APPLIED MATHEMATICS

The Department of Applied Mathematics in the College of Arts and Sciences offers courses that focus on providing students with the mathematical tools and problem-solving strategies that are useful in science and engineering. The department offers a range of courses and research opportunities in many areas, including computational mathematics, mathematical biology, nonlinear phenomena, physical applied mathematics and probability and statistics. Each of these areas is described below.

The undergraduate Bachelor of Science degree (https://catalog.colorado.edu/undergraduate/colleges-schools/engineering-applied-science/programs-study/applied-mathematics/) in Applied Mathematics is offered through the College of Engineering and Applied Science. The undergraduate Bachelor of Arts degree in Statistics and Data Science is offered through the College of Arts and Sciences.

Course codes for this program include APPM and STAT.

Computational Mathematics

Computational mathematics encompasses the techniques that allow practitioners to approximate quantities via a computer. These techniques are used to do a wide range of things including simulations of physical phenomena, reducing the cost of product design and providing the basis of machine learning. Some applications include weather forecasting, optimal design of materials and simulating flight paths of rockets. This field continues to grow as computational resources and needs of users change. The fast developments in this area have allowed mathematicians to answer questions and develop insights not possible only 20-30 years ago. Modern computational methods require an in-depth knowledge of a variety of mathematical subjects which include linear algebra, analysis, ordinary and partial differential equations, asymptotic analysis, elements of harmonic analysis and nonlinear equations.

Since computers are invaluable tools for an applied mathematician, students are expected to attain a highly professional level of computer literacy, to program in a language such as Python, know how to maintain a Git repository and understand the basics of parallel computing.

Computational mathematics courses include the study of numerical linear algebra, numerical integration, approximation of functions, optimization, numerical solution of ordinary and partial differential equations, and solution of nonlinear equations. There are two advanced seminars related to this topic: computational mathematics and optimization.

Mathematical Biosciences

Recent advances in our ability to quantitatively study biological phenomena have provided a tremendous number of exciting opportunities for applied mathematicians. The careful modeling, analysis and simulation of these systems using the standard tools of applied mathematics has led to novel and non-intuitive insights into biology.

Furthermore, deeper understanding of the inherently complex and multiscale nature of biological systems, in many cases, requires the development of new mathematical tools, techniques and methodologies (a challenge to which applied mathematics is particularly well suited). Research areas in APPM encompass cell migration, ecology, infectious diseases, neuroscience, population genetics and social systems as well as data-driven methods in biology. For more information, see the Mathematical Biology Group (http://mathbio.colorado.edu/) webpage.

Mathematical Geosciences

Mathematical geosciences encompass quantitative modeling, analysis and simulation of all aspects of the Earth system. Our faculty's research intersects a broad range of geosciences: from the geodynamo to ocean circulation, from computational methods for seismic imaging to the impacts of weather on epidemiology, from tsunamis to stochastic weather generators. The complex and multiscale nature of geophysical systems, in many cases, requires the development of new mathematical models and simulation strategies, a challenge to which applied mathematics is particularly well suited.

Appropriate coursework includes analysis and computation, probability and statistics, as well as background courses in one of the sciences or engineering fields in which one intends to do research.

Nonlinear Waves and Dynamical Systems

In recent years there has been an explosion of interest in the study of nonlinear waves and dynamical systems with analytical results often motivated by the use of computers. The faculty in the department is actively and intensively involved in this growing field; research areas include integrable and near-integrable systems, conservative and dissipative chaos, as well as numerical computation.

Topics of interest include solitons, dispersive shock waves, integrable systems, cellular automata, pattern formation, qualitative structure and bifurcation theory, onset of chaos and turbulence, analytic dynamics and transport phenomena. Program courses in this field include dynamical systems, nonlinear wave motion and many advanced seminars.

Suitable background courses are: analysis, computation, partial differential equations and methods in applied mathematics. Valuable supplemental courses include mechanics and fluid dynamics.

Physical Applied Mathematics

Physical applied mathematics is a term which generally refers to the study of mathematical problems with direct physical application. This area of research is intrinsically interdisciplinary. In addition to mathematical analysis, it requires a deep understanding of the underlying applications area, and usually requires knowledge and experience in numerical computation.

The department's affiliated faculty have a wide variety of expertise in various areas of application, e.g. atmospheric and fluid dynamics, theoretical physics, plasma physics, genetic structure, etc. The course requirements of the program are designed to provide students with a foundation for their study (analysis and computation).

The department also requires supplemental courses in one of the science or engineering fields which are needed to begin doing thesis research in physical applied mathematics.

See the Dispersive Hydrodynamics Lab (https://www.colorado.edu/amath/dispersive-hydrodynamics-lab/) page, APPM's own fluid dynamics laboratory.

Statistics, Data Science and Applied Probability

Almost all natural phenomena in the technological, biological, physical and social sciences have random components. Applied probability is the application of probabilistic methods to understand the random elements in real-life problems. Statistics and data science is the science of using data, which typically arises from the randomness inherent in nature, to gain new knowledge.

Research areas of the applied math and affiliated faculty exhibit this interplay between mathematics and real-life problems. Areas of current interest include optimization of stochastic networks; the study of stochastic processes and stochastic differential equations in hydrology, finance and telecommunications; probabilistic models and statistical tests based on these models, in genetics and RNA sequencing; extreme value theory in estimation of maximal wind speeds; applied deep learning; and the theory of machine learning.

Appropriate coursework includes analysis, probability and statistics, as well as background courses in one of the sciences or engineering fields in which one intends to do research.

For details on the range of courses and research opportunities available, visit the Department of Applied Mathematics (https://www.colorado.edu/amath/) website.

Bachelor's Degree

- Statistics and Data Science - Bachelor of Arts (BA) (https://catalog.colorado.edu/undergraduate/colleges-schools/arts-sciences/programs-study/applied-mathematics/statistics-data-science-bachelor-arts-ba/)
- Applied Mathematics - Bachelor of Science (BS (https://www.colorado.edu/amath/academics/bachelors-degree-statistics-data-science-masters-degree-applied-mathematics-specialization/)) (https://www.colorado.edu/amath/academics/bachelors-degree-statistics-data-science-masters-degree-applied-mathematics-specialization/)

Minors

- Applied Mathematics - Minor (https://catalog.colorado.edu/undergraduate/colleges-schools/arts-sciences/programs-study/applied-mathematics/applied-mathematics-minor/)
- Statistics - Minor (https://catalog.colorado.edu/undergraduate/colleges-schools/arts-sciences/programs-study/applied-mathematics/statistics-minor/)

Faculty

While many faculty teach both undergraduate and graduate students, some instruct students at the undergraduate level only. For more information, contact the faculty member's home department.

Ablowitz, Mark J. (https://experts.colorado.edu/display/fisid_100691/)
Distinguished Professor; PhD, Massachusetts Institute of Technology

Appelö, Daniel E. (https://experts.colorado.edu/display/fisid_159438/)
Assistant Professor Adjunct; PhD, KTH Royal Institute of Technology (Sweden)

Bebernes, Jerrold (https://experts.colorado.edu/display/fisid_103560/)
Professor Emeritus; PhD, University of Nebraska-Lincoln

Becker, Stephen R. (https://experts.colorado.edu/display/fisid_154263/)
Associate Professor; PhD, California Institute of Technology

Benim, W. Robert (https://experts.colorado.edu/display/fisid_167716/)
Assistant Teaching Professor

Beylkin, Gregory (https://experts.colorado.edu/display/fisid_100437/)
Professor; PhD, New York University

Bhat, Yermal Sujeet (https://experts.colorado.edu/display/fisid_146506/)
Associate Teaching Professor; PhD, University of Florida

Bortz, David Matthew (https://experts.colorado.edu/display/fisid_143348/)
Professor; PhD, North Carolina State University

Chang, Silva (https://experts.colorado.edu/display/fisid_145582/)
Teaching Professor; MS, Yale University

Corcoran, Jem (https://experts.colorado.edu/display/fisid_118142/)
Associate Professor Emeritus; PhD, Colorado State University

Curry, James H. (https://experts.colorado.edu/display/fisid_105730/)
Professor; PhD, University of California, Berkeley

Dougherty, Anne Margaret (https://experts.colorado.edu/display/fisid_101349/)
Associate Chair, Teaching Professor; PhD, University of Wisconsin–Madison

Dukic, Vanja (https://experts.colorado.edu/display/fisid_148718/)
Professor; PhD, Brown University

Fornberg, Bengt (https://experts.colorado.edu/display/fisid_108048/)
Professor Emeritus; PhD, University of Uppsala (Sweden)

Gillman, Adrianna (https://experts.colorado.edu/display/fisid_165224/)
Associate Professor; PhD, University of Colorado Boulder

Grooms, Ian G. (https://experts.colorado.edu/display/fisid_155588/)
Associate Professor; PhD, University of Colorado Boulder

Gunzburger, Max D.
Artist in Residence, Professor Adjoint; PhD, New York University

Hoefer, Mark (https://experts.colorado.edu/display/fisid_154264/)
Professor; PhD, University of Colorado Boulder

Huang, Yu-Jui (https://experts.colorado.edu/display/fisid_157746/)
Assistant Professor; PhD, University of Michigan Ann Arbor

Julien, Keith (https://experts.colorado.edu/display/fisid_108913/)
Chair, Professor; PhD, University of Cambridge (England)

Kilpatrick, Zachary Peter (https://experts.colorado.edu/display/fisid_155782/)
Associate Professor; PhD, University of Utah

Kleiber, William Paul (https://experts.colorado.edu/display/fisid_151943/)
Associate Professor; PhD, University of Washington

Li, Congming
Professor Emeritus

Lladser, Manuel E. (https://experts.colorado.edu/display/fisid_134170/)
Associate Professor; PhD, The Ohio State University

Manteuffel, Thomas A.
Professor Emeritus

Martinsson, Per-Gunnar
Visiting Professor

McCormick, Steven
Professor Emeritus

Mcnamara, Rich (https://experts.colorado.edu/display/fisid_167770/)
Lecturer

Meiss, James D. (https://experts.colorado.edu/display/fisid_103702/)
Professor; PhD, University of California, Berkeley

Meyer, Francois Georges (https://experts.colorado.edu/individual/fisid_115559/)
Professor; PhD, INRIA (France)

Mitchell, Colin
Lecturer

Nixon, Sean (https://experts.colorado.edu/display/fisid_167600/)
Instructor

Norris, Jan Adam (https://experts.colorado.edu/display/fisid_101412/)
Teaching Professor; PhD, University of Colorado Boulder

Pruitt, Kris
Associate Teaching Professor

Raissi, Maziar (https://experts.colorado.edu/individual/fisid_165748/)
Assistant Professor; PhD, University of Maryland, College Park

Restrepo, Juan G. (https://experts.colorado.edu/display/fisid_145811/)
Associate Professor; PhD, University of Maryland, College Park

Rodriguez, Nancy (https://experts.colorado.edu/display/fisid_164028/)
Assistant Professor; PhD, University of California-Los Angeles

Segur, Harvey (https://experts.colorado.edu/display/fisid_102287/)
Professor Emeritus; PhD, University of California, Berkeley

Thaler, Eric R. (https://experts.colorado.edu/display/fisid_155505/)
Associate Teaching Professor; PhD, University of Colorado Boulder

Vance, Eric (https://experts.colorado.edu/display/fisid_158342/)
Associate Professor; PhD, Duke University

Zaharatos, Brian R. (https://experts.colorado.edu/display/fisid_156225/)
Teaching Professor, Faculty Director; PhD, Colorado School of Mines

Courses

APPM 1235 (4) Pre-Calculus for Engineers
Prepares students for the challenging content and pace of the calculus sequence required for all engineering majors. Covers algebra, trigonometry and selected topics in analytical geometry. Prepares students for the calculus courses offered for engineering students. Requires students to engage in rigorous work sessions as they review topics that they must be comfortable with to pursue engineering course work. Structured to accustom students to the pace and culture of learning encountered in engineering math courses. For more information about the math placement referred to in the "Enrollment Requirements", please contact your academic advisor. Formerly GEEN 1235.
Equivalent - Duplicate Degree Credit Not Granted: MATH 1021 or MATH 1150
Requisites: Requires an ALEKS math exam taken in 2016 or earlier, or placement into pre-calculus based on your admissions data and/or CU Boulder coursework.

APPM 1236 (1) Precalculus Work Group
Develops and enhances problem solving skills for students enrolled in APPM 1235. Course is conducted in a collaborative learning environment with students working in groups under the guide of a facilitator.
Requisites: Requires enrollment in corequisite course of APPM 1235.

APPM 1340 (4) Calculus 1 with Algebra, Part A
Studies selected topics in analytical geometry and calculus: rates of change of functions, limits, derivatives and their applications. This course and APPM 1345 together are equivalent to APPM 1350. The sequence of this course and APPM 1345 is specifically designed for students whose manipulative skills in the techniques of high school algebra and precalculus may be inadequate for APPM 1350. For more information about the math placement referred to in the "Enrollment Requirements", please contact your academic advisor.
Requisites: Requires prerequisite course of APPM 1235 or MATH 1021 or MATH 1150 or MATH 1160 (minimum grade C-) or an ALEKS math exam taken in 2016 or earlier, or placement into pre-calculus based on your admissions data and/or CU Boulder coursework.
Additional Information: Arts Sci Gen Ed: Quantitative Reasoning Math

APPM 1345 (4) Calculus 1 with Algebra, Part B
Continuation of APPM 1340. Studies selected topics in calculus: derivatives and their applications, integration, differentiation and integration of transcendental functions. Algebraic and trigonometric topics are studied throughout, as needed.
Equivalent - Duplicate Degree Credit Not Granted: APPM 1350 or ECON 1088 or MATH 1081 or MATH 1300 or MATH 1310 or MATH 1330
Requisites: Requires prerequisite course of APPM 1340 (minimum grade C-).

APPM 1350 (4) Calculus 1 for Engineers
Topics in analytical geometry and calculus including limits, rates of change of functions, derivatives and integrals of algebraic and transcendental functions, applications of differentiations and integration. Students who have already earned college credit for calculus 1 are eligible to enroll in this course if they want to solidify their knowledge base in calculus 1. For more information about the math placement referred to in the "Enrollment Requirements", contact your academic advisor.
Equivalent - Duplicate Degree Credit Not Granted: APPM 1345 or ECON 1088 or MATH 1081 or MATH 1300 or MATH 1310 or MATH 1330
Requisites: Requires prerequisite course of APPM 1235 or MATH 1021 or MATH 1150 or MATH 1160 or MATH 1300 (minimum grade C-) or an ALEKS math exam taken in 2016 or earlier, or placement into calculus based on your admissions data and/or CU Boulder coursework.
Additional Information: GT Pathways: GT-MA1 - Mathematics
Arts Sci Core Curr: Quant Reasn Mathmat Skills
Arts Sci Gen Ed: Quantitative Reasoning Math

APPM 1351 (1) Calculus 1 Work Group
Provides problem-solving assistance to students enrolled in APPM 1350. Student groups work in collaborative learning environment. Student participation is essential.
Repeatable: Repeatable for up to 2.00 total credit hours.
Requisites: Requires enrollment in corequisite course of APPM 1350 or APPM 1345.

APPM 1360 (4) Calculus 2 for Engineers
Continuation of APPM 1350. Focuses on applications of the definite integral, methods of integration, improper integrals, Taylor's theorem, and infinite series.
Equivalent - Duplicate Degree Credit Not Granted: MATH 2300
Requisites: Requires prerequisite course of APPM 1345 or APPM 1350 or MATH 1300 (minimum grade C-).

APPM 1361 (1) Calculus 2 Work Group
Provides problem solving assistance for students enrolled in APPM 1360. Conducted in a collaborative learning environment. Student work groups solve calculus problems with assistance of facilitator.
Requisites: Requires enrollment in corequisite course of APPM 1360.

APPM 1390 (1) A Game for Calculus
Coaches students to implement study strategies geared specifically toward APPM Calculus in a structured, supportive, small group environment. Department consent required.
Repeatable: Repeatable for up to 3.00 total credit hours.

APPM 1650 (4) Python for Math and Data Science Applications
Uses Python to teach the fundamentals of computer programming with an emphasis on mathematical and statistical applications. Topics will include data types, data structures, iteration, visualization, and simulations. Techniques covered will be applicable to many scientific and technical fields. No prior programming experience is required. Formerly offered as a special topics course.
Requisites: Requires prerequisite or corequisite courses of APPM 1350 or APPM 1345 or MATH 1300 or MATH 1310 (all minimum grade C-).

APPM 2340 (4) Calculus 3 for Statistics and Data Science
Covers vectors and vector analysis, partial derivatives and the multivariable Taylor theorem, and multiple integrals. Introduces matrices and statistical applications.
Requisites: Requires prerequisite courses APPM 1360 or MATH 2300 (both minimum grade C-).

APPM 2350 (4) Calculus 3 for Engineers
Covers multivariable calculus, vector analysis, and theorems of Gauss, Green, and Stokes.
Equivalent - Duplicate Degree Credit Not Granted: MATH 2400
Requisites: Requires prerequisite course of APPM 1360 or MATH 2300 (minimum grade C-).

APPM 2351 (1) Calculus 3 Work Group
Provides problem solving assistance to students enrolled in APPM 2350. Conducted in a collaborative learning environment. Student work groups solve calculus problems with the assistance of a facilitator.
Requisites: Requires enrollment in corequisite course of APPM 2350.

APPM 2360 (4) Introduction to Differential Equations with Linear Algebra
Introduces ordinary differential equations, systems of linear equations, matrices, determinants, vector spaces, linear transformations, and systems of linear differential equations.
Equivalent - Duplicate Degree Credit Not Granted: both MATH 2130 and MATH 3430
Requisites: Requires prerequisite course of APPM 1360 or MATH 2300 (minimum grade C-).

APPM 2361 (1) Differential Equations Work Group
Provides problem solving assistance to students enrolled in APPM 2360. Conducted in a collaborative learning environment. Student work in groups solve ordinary differential equations and linear algebra problems with the assistance of a facilitator.
Requisites: Requires corequisite course of APPM 2360.

APPM 2450 (1) Calculus 3 Computer Lab
Selected topics in analytic geometry and calculus with a focus on symbolic computation using Mathematica.
Requisites: Requires a corequisite course of APPM 2350.

APPM 2460 (1) Differential Equations Computer Lab
Selected topics in differential equations and linear algebra with a focus on symbolic computation using MATLAB.
Requisites: Requires enrollment in a corequisite course of APPM 2360.

APPM 2720 (1-3) Open Topics in Lower Division Applied Mathematics
Provides a vehicle for the development and presentation of new topics that are accessible to lower division Applied Mathematics students. These topics have the potential to be incorporated into the core APPM curriculum.
Repeatable: Repeatable for up to 6.00 total credit hours. Allows multiple enrollment in term.
Requisites: Requires prerequisite course of APPM 1350 or MATH 1300 (minimum grade C-).
Grading Basis: Letter Grade

APPM 2750 (4) Java: Training, Mathematical Algorithms, and Mobile Apps
Preparatory course for Java programming. Provides necessary background for Java language: basic object-oriented concepts, analysis, and design. Learn to create Java applets, applications and mobile apps, create graphic context, and identify the key features of Java foundation classes as well as other Java-related technology. Material is taught in the context of mathematical algorithms from calculus. Department enforced requisite, knowledge of a programming language.
Requisites: Requires prerequisite course of APPM 1350 or MATH 1300 (minimum grade C-).

APPM 3010 (3) Chaos in Dynamical Systems
Introduces undergraduate students to chaotic dynamical systems. Topics include smooth and discrete dynamical systems, bifurcation theory, chaotic attractors, fractals, Lyapunov exponents, synchronization and networks of dynamical systems. Applications to engineering, biology and physics will be discussed.
Requisites: Requires prerequisite course of APPM 2360 or MATH 3430 (minimum grade C-).
Additional Information: Arts Sci Gen Ed: Distribution-Natural Sciences

APPM 3050 (3) Scientific Computing in Matlab
Topics covered include: approximations in computing, computer arithmetic, interpolation, matrix computations, nonlinear equations, optimization, and initial-value problems with emphasis on the computational cost, efficiency, and accuracy of algorithms. The problem sets are application-oriented with examples taken from orbital mechanics, physics, genetics, and fluid dynamics.
Requisites: Requires prerequisite course of APPM 2360 or MATH 3430 (minimum grade C-).

APPM 3170 (3) Discrete Applied Mathematics
Introduces students to ideas and techniques from discrete mathematics that are widely used in science and engineering. Mathematical definitions and proofs are emphasized. Topics include formal logic notation, proof methods; set theory, relations; induction, well-ordering; algorithms, growth of functions and complexity; integer congruences; basic and advanced counting techniques, recurrences and elementary graph theory. Other selected topics may also be covered.
Requisites: Requires a prerequisite of APPM 1360 or MATH 2300 (all minimum grade C-).

APPM 3310 (3) Matrix Methods and Applications
Introduces linear algebra and matrices with an emphasis on applications, including methods to solve systems of linear algebraic and linear ordinary differential equations. Discusses vector space concepts, decomposition theorems, and eigenvalue problems.
Equivalent - Duplicate Degree Credit Not Granted: MATH 2130 and MATH 2135
Requisites: Requires prerequisite course of APPM 2340 or APPM 2350 or APPM 2360 or MATH 2400 (minimum grade C-).
Additional Information: Arts Sci Gen Ed: Distribution-Natural Sciences

APPM 3350 (3) Advanced Engineering Calculus
Extends the treatment of engineering mathematics beyond the topics covered in Calculus 3 and differential equations. Topics include non-dimensionalization, elementary asymptotics and perturbation theory, Reynold's transport theorem and extensions of Leibnitz's rule, as applied to continuum conservation equations, Hamiltonian formulations, Legendre and Laplace transforms, special functions and their orthogonality properties.
Requisites: Requires prerequisite course of APPM 2350 or MATH 2400 and APPM 2360 (all minimum grade C-).

APPM 3570 (3) Applied Probability
Studies axioms, counting formulas, conditional probability, independence, random variables, continuous and discrete distribution, expectation, joint distributions, moment generating functions, law of large numbers and the central limit theorem.
Equivalent - Duplicate Degree Credit Not Granted: ECEN 3810 or MATH 4510 STAT 3100
Requisites: Requires a prerequisite or corequisite course of APPM 2350 or APPM 2340 or MATH 2400 (prereq minimum grade C-).
Additional Information: Arts Sci Gen Ed: Distribution-Natural Sciences

APPM 3650 (3) Algorithms and Data Structures in Python
Covers data structures (stacks, queues, linked lists, hash tables, heaps), algorithms (divide and conquer, sorting, greedy, graph, dynamic programming), and asymptotic complexity with an emphasis on applied math topics. Assignments will include programming projects written in Python
Requisites: Requires prerequisite courses of (APPM 1650 or ASTR 2600 or PHYS 2600) and (APPM 1360 or MATH 2300) (minimum grade C-).

APPM 4120 (3) Introduction to Operations Research
Studies linear and nonlinear programming, the simplex method, duality, sensitivity, transportation and network flow problems, some constrained and unconstrained optimization theory, and the Kuhn-Tucker conditions, as time permits.
Equivalent - Duplicate Degree Credit Not Granted: APPM 5120 and MATH 4120 and MATH 5120
Requisites: Requires a prerequisite course of APPM 3310 or MATH 2130 or MATH 2135 (minimum grade C-).
Additional Information: Arts Sci Gen Ed: Distribution-Natural Sciences

APPM 4320 (3) Introduction to Dynamics on Networks
Introduces modern approaches to model and analyze dynamical processes on complex networks. Many dynamical processes such as epidemic propagation, opinion formation, synchronization, and cascading processes take place on complex social or technological networks. This course will introduce the tools to understand the interplay between network structure and the outcome of these dynamical processes. Previously offered as a special topics course.
Equivalent - Duplicate Degree Credit Not Granted: APPM 5320
Requisites: Requires prerequisite courses of APPM 2360 and APPM 3310 (all minimum grade C-).
Grading Basis: Letter Grade

APPM 4350 (3) Methods in Applied Mathematics: Fourier Series and Boundary Value Problems
Reviews ordinary differential equations, including solutions by Fourier series. Physical derivation of the classical linear partial differential equations (heat, wave, and Laplace equations). Solution of these equations via separation of variables, with Fourier series, Fourier integrals, and more general eigenfunction expansions.
Equivalent - Duplicate Degree Credit Not Granted: APPM 5350
Requisites: Requires prerequisite courses of APPM 2350 or MATH 2400 and APPM 2360 (all minimum grade C-) and a prerequisite or corequisite course of APPM 3310 (prereq minimum grade C-).
Additional Information: Arts Sci Gen Ed: Distribution-Natural Sciences

APPM 4360 (3) Methods in Applied Mathematics: Complex Variables and Applications
Introduces methods of complex variables, contour integration and theory of residues. Applications include solving partial differential equations by transform methods, Fourier and Laplace transforms and Reimann-Hilbert boundary-value problems, conformal mapping to ideal fluid flow and/or electrostatics.
Equivalent - Duplicate Degree Credit Not Granted: APPM 5360
Requisites: Requires prerequisite courses of APPM 2350 or MATH 2400 and APPM 2360 (all minimum grade C-) and a prerequisite or corequisite course of APPM 3310 (prereq minimum grade C-).
Additional Information: Arts Sci Gen Ed: Distribution-Natural Sciences

APPM 4370 (3) Computational Neuroscience
Applies mathematical and computational methods to neuroscience. Techniques from linear algebra, differential equations, introductory dynamical systems, probability, stochastic processes, model validation, and machine learning will be learned and used. Neuroscience topics include neural spiking, network dynamics, probabilistic inference, learning, and plasticity. Will learn how the brain uses computational principles to enact decision making, vision, and memory. Recommended background includes linear algebra, differential equations, probability, and programming. Students will hone programming skills in MATLAB/Python and TensorFlow.
Equivalent - Duplicate Degree Credit Not Granted: APPM 5370
Requisites: Requires prerequisite courses of APPM 2360 and APPM 3310 (all minimum grade C-).
Recommended: Prerequisite APPM 3570/STAT 3100, STAT 2600 or CSCI 3022.
Additional Information: Arts Sci Gen Ed: Distribution-Natural Sciences

APPM 4380 (3) Modeling in Applied Mathematics
An exposition of a variety of mathematical models arising in the physical and biological sciences. Students' modeling projects are presented in class. Topics may include: GPS navigation, medical imaging, ocean waves, and computerized facial recognition.
Equivalent - Duplicate Degree Credit Not Granted: APPM 5380
Requisites: Requires prerequisite courses of APPM 2350 or MATH 2400 and APPM 2360 (all minimum grade C-).
Recommended: Prerequisites APPM 3310 and APPM 4350 and APPM 4650.
Additional Information: Arts Sci Gen Ed: Distribution-Natural Sciences

APPM 4390 (3) Modeling in Mathematical Biology
Investigates how complex systems in biology can be studied using applied mathematics. Examines several case studies which include topics from microbiology, enzyme reaction kinetics, neuroscience, ecology, epidemiology, physiology and bioengineering.
Equivalent - Duplicate Degree Credit Not Granted: APPM 5390
Requisites: Requires prerequisite courses of APPM 2360 and APPM 3310 or MATH 3130 or MATH 3135 (all minimum grade C-).
Additional Information: Arts Sci Gen Ed: Distribution-Natural Sciences

APPM 4440 (3) Undergraduate Applied Analysis 1
Provides a rigorous treatment of topics covered in Calculus 1 and 2. Topics include convergent sequences; continuous functions; differentiable functions; Darboux sums, Riemann sums, and integration; Taylor and power series and sequences of functions.
Requisites: Requires prerequisite courses of APPM 2350 or MATH 2400 and APPM 2360 (all minimum grade C-) and a prerequisite or corequisite course of APPM 3310 (prereq minimum grade C-).

APPM 4450 (3) Undergraduate Applied Analysis 2
Continuation of APPM 4440. Study of multidimensional analysis including n-dimensional Euclidean space, continuity and uniform continuity of functions of several variables, differentiation, linear and nonlinear approximation, inverse function and implicit function theorems, and a short introduction to metric spaces.
Requisites: Requires prerequisite course of APPM 4440 or MATH 3001 (minimum grade C-).

APPM 4490 (3) Theory of Machine Learning
Presents the underlying theory behind machine learning in proofs-based format. Answers fundamental questions about what learning means and what can be learned via formal models of statistical learning theory. Analyzes some important classes of machine learning methods. Specific topics may include the PAC framework, VC-dimension and Rademacher complexity.
Requisites: Requires prerequisite course of APPM 4440 (minimum grade C-).
Recommended: Prerequisite CSCI 5622 (minimum grade C-).
Additional Information: Arts Sci Gen Ed: Distribution-Natural Sciences

APPM 4510 (3) Data Assimilation in High Dimensional Dynamical Systems
Develops and analyzes approximate methods of solving the Bayesian inverse problem for high-dimensional dynamical systems. After briefly reviewing mathematical foundations in probability and statistics, the course covers the Kalman filter, particle filters, variational methods and ensemble Kalman filters. The emphasis is on mathematical formulation and analysis of methods.
Equivalent - Duplicate Degree Credit Not Granted: APPM 5510, STAT 4250 and STAT 5250
Requisites: Requires prerequisite courses of APPM 3310 and APPM 3570 or STAT 3100 or MATH 4510 (all minimum grade C-).
Additional Information: Arts Sci Gen Ed: Distribution-Natural Sciences

APPM 4515 (3) High-Dimensional Probability for Data Science
Provides students with an exposition of the most recent methods of high-dimensional probability for the analysis of high dimensional datasets. Applications include randomized algorithms and high-dimensional random models of datasets.
Equivalent - Duplicate Degree Credit Not Granted: APPM 5515
Requisites: Requires prerequisite courses of APPM 3310 and APPM 3570 (minimum grade C-).

APPM 4530 (3) Stochastic Analysis for Finance
Studies mathematical theories and techniques for modeling financial markets. Specific topics include the binomial model, risk neutral pricing, stochastic calculus, connection to partial differential equations and stochastic control theory.
Equivalent - Duplicate Degree Credit Not Granted: APPM 5530, STAT 4230 and STAT 5230
Requisites: Requires prerequisite courses of APPM 3310 and APPM 3570, or STAT 3100, or MATH 4510 (all minimum grade C-).

APPM 4560 (3) Markov Processes, Queues, and Monte Carlo Simulations
Brief review of conditional probability and expectation followed by a study of Markov chains, both discrete and continuous time, including Poisson point processes. Queuing theory, terminology and single queue systems are studied with some introduction to networks of queues. Uses Monte Carlo simulation of random variables throughout the semester to gain insight into the processes under study.
Equivalent - Duplicate Degree Credit Not Granted: APPM 5560 and STAT 4100
Requisites: Requires prerequisite courses of APPM 3570 or STAT 3100 or MATH 4510 (all minimum grade C-).
Additional Information: Arts Sci Gen Ed: Distribution-Natural Sciences

APPM 4565 (3) Random Graphs
Introduces mathematical techniques, including generating functions, the first- and second-moment method and Chernoff bounds to study the most fundamental properties of the Erdos-Renyl model and other celebrated random graph models such as preferential attachment, fixed degree distribution, and stochastic block models.
Equivalent - Duplicate Degree Credit Not Granted: APPM 5565
Requisites: Requires prerequisite APPM 3570 or MATH 4510 (both minimum grade C).

APPM 4600 (4) Numerical Methods and Scientific Computing
Provides an introduction to numerical analysis and scientific computing. Numerical analysis topics include root finding, interpolation, quadrature, linear system solution techniques, and techniques for approximating eigenvalues. Scientific computing topics include code development and repository management in addition to an introduction to shared and distributed memory computing. Involves hands-on learning with weekly group interactions and a final project including a report and in-class presentation.
Requisites: Requires prerequisite course of APPM 3310 (minimum grade C-).
Recommended: Prerequisite knowledge of a programming language such as Python, and C++.

APPM 4610 (3) Numerical Differential Equations
Provides an introduction to the most commonly used techniques for numerically solving boundary value problems and time dependent problems and the corresponding linear systems. Topics include finite difference methods, the finite element method, the spectral method, spectral collocation methods, Euler and Runge-Kutta methods. Scientific computing skills such as advanced code and memory management will be developed. Involves hands-on learning with weekly group interactions and a final project. Department enforced prerequisite: Knowledge of a programming language such as Python, and C++ is required.
Requisites: Requires prerequisite courses of APPM 2360 and APPM 4600 (all minimum grade C-).

APPM 4650 (3) Intermediate Numerical Analysis 1
Focuses on numerical solution of nonlinear equations, interpolation, methods in numerical integration, numerical solution of linear systems, and matrix eigenvalue problems. Stresses significant computer applications and software. Department enforced prerequisite: knowledge of a programming language.
Equivalent - Duplicate Degree Credit Not Granted: MATH 4650
Requisites: Requires a prerequisite course of MATH 3430 or APPM 2360 and APPM 3310 (minimum grade C-).

APPM 4720 (1-3) Open Topics in Applied Mathematics
Provides a vehicle for the development and presentation of new topics that may be incorporated into the core courses in applied mathematics. Department enforced prerequisite: variable, depending on the topic, see instructor.
Equivalent - Duplicate Degree Credit Not Granted: APPM 5720
Repeatable: Repeatable for up to 15.00 total credit hours. Allows multiple enrollment in term.

APPM 4840 (1-3) Reading and Research in Applied Mathematics
Introduces undergraduate students to the research foci of the Department of Applied Mathematics. Department enforced prerequisite: variable depending on the topic.
Repeatable: Repeatable for up to 9.00 total credit hours.

APPM 4950 (1-3) Seminar in Applied Mathematics
Introduces undergraduate students to the research foci of the program in applied mathematics. It is also designed to be a capstone experience for the program's majors. Department enforced prerequisite: variable depending on the topic.
Repeatable: Repeatable for up to 6.00 total credit hours. Allows multiple enrollment in term.

STAT 2600 (4) Introduction to Data Science
Introduces students to importing, tidying, exploring, visualizing, summarizing, and modeling data and then communicating the results of these analyses to answer relevant questions and make decisions. Students will learn how to program in R using reproducible workflows. During weekly lab sessions students will collaborate with their teammates to pose and answer questions using real-world datasets.
Requisites: Requires prerequisite or corequisite of APPM 1350 or APPM 1345 or MATH 1300 (minimum grade C-).
Grading Basis: Letter Grade

STAT 3100 (3) Applied Probability
Studies axioms, counting formulas, conditional probability, independence, random variables, continuous and discrete distribution, expectation, joint distributions, moment generating functions, law of large numbers and the central limit theorem.
Equivalent - Duplicate Degree Credit Not Granted: ECEN 3810 or MATH 4510 APPM 3570
Requisites: Requires a prerequisite or corequisite course of APPM 2350 or APPM 2340 or MATH 2400 (prereq minimum grade C-).

STAT 3400 (3) Applied Regression
Introduces methods, theory, and applications of linear statistical models, covering topics such as estimation, residual diagnostics, goodness of fit, transformations, and various strategies for variable selection and model comparison. Examples will be demonstrated using statistical programming language R.
Requisites: Requires prerequisite STAT 2600 and STAT 3100 or MATH 4510 (all minimum grade C-). Requires corequisite APPM 3310.
Grading Basis: Letter Grade

STAT 4000 (3) Statistical Methods and Application I
Introduces exploratory data analysis, probability theory, statistical inference, and data modeling. Topics include discrete and continuous probability distributions, expectation, laws of large numbers, central limit theorem, statistical parameter estimation, hypothesis testing, and regression analysis. Considerable emphasis on applications in the R programming language.
Equivalent - Duplicate Degree Credit Not Granted: STAT 5000
Requisites: Requires prerequisite APPM 1360 or MATH 2300 (both minimum grade C-).
Grading Basis: Letter Grade

STAT 4010 (3) Statistical Methods and Applications II
Expands upon statistical techniques introduced in STAT 4000. Topics include modern regression analysis, analysis of variance (ANOVA), experimental design, nonparametric methods, and an introduction to Bayesian data analysis. Considerable emphasis on application in the R programming language.
Equivalent - Duplicate Degree Credit Not Granted: STAT 5010
Requisites: Requires prerequisite STAT 4000 (minimum grade C-).
Grading Basis: Letter Grade

STAT 4100 (3) Markov Processes, Queues, and Monte Carlo Simulations
Brief review of conditional probability and expectation followed by a study of Markov chains, both discrete and continuous time, including Poisson point processes. Queuing theory, terminology and single queue systems are studied with some introduction to networks of queues. Uses Monte Carlo simulation of random variables throughout the semester to gain insight into the processes under study.
Equivalent - Duplicate Degree Credit Not Granted: APPM 4560 and APPM 5560
Requisites: Requires prerequisite courses of APPM 3570 or STAT 3100 or MATH 4510 (all minimum grade C-).

STAT 4230 (3) Stochastic Analysis for Finance
Studies mathematical theories and techniques for modeling financial markets. Specific topics include the binomial model, risk neutral pricing, stochastic calculus, connection to partial differential equations and stochastic control theory.
Equivalent - Duplicate Degree Credit Not Granted: APPM 4530, APPM 5530 and STAT 5230
Requisites: Requires prerequisite courses of APPM 3310 and APPM 3570, or STAT 3100, or MATH 4510 (all minimum grade C-).

STAT 4250 (3) Data Assimilation in High Dimensional Dynamical Systems
Develops and analyzes approximate methods of solving the Bayesian inverse problem for high-dimensional dynamical systems. After briefly reviewing mathematical foundations in probability and statistics, the course covers the Kalman filter, particle filters, variational methods and ensemble Kalman filters. The emphasis is on mathematical formulation and analysis of methods.
Equivalent - Duplicate Degree Credit Not Granted: APPM 5510, APPM 4510 and STAT 5250
Requisites: Requires prerequisite courses of APPM 3310 and APPM 3570 or STAT 3100 or MATH 4510 (all minimum grade C-).

STAT 4350 (3) Applied Deep Learning 1
Introduces students to state-of-the-art deep learning techniques employed in the industry. This course will focus on training neural networks and computer vision, including image classification and transformation, object detection, and facial recognition. Advanced topics will include domain adaptation and learning techniques. There will be an emphasis on reading current literature.
Equivalent - Duplicate Degree Credit Not Granted: STAT 5350
Requisites: Requires prerequisite courses of APPM 3570 or STAT 3100 and STAT 3400 or STAT 4520 and APPM 4650 or APPM 4600 (all minimum grade C-).
Recommended: Prerequisite knowledge of Python is required, and familiarity with TensorFlow and PyTorch is a plus but is not a requirement.

STAT 4360 (3) Applied Deep Learning 2
Introduces students to state-of-the-art deep learning techniques employed in the industry. This course will focus on natural language processing, multimodal learning, generative and graph neural networks, speech and music recognition, and reinforcement learning. Students will learn software engineering techniques using Python. There will be an emphasis on reading current literature.
Equivalent - Duplicate Degree Credit Not Granted: STAT 5360
Requisites: Requires prerequisite course of STAT 4350 (minimum grade C-).

STAT 4400 (3) Advanced Statistical Modeling
Introduces methods, theory and applications of modern statistical models, from linear to hierarchical linear models, to generalized hierarchical linear models, including hierarchical logistic and hierarchical count regression models. Topics such as estimation, residual diagnostics, goodness of fit, transformations, and various strategies for variable selection and model comparison will be discussed in depth. Examples will be demonstrated using statistical programming language R.
Equivalent - Duplicate Degree Credit Not Granted: STAT 5400
Requisites: Requires prerequisite STAT 3400 and (STAT 4520 or STAT 5010) (all minimum grade C-).
Grading Basis: Letter Grade

STAT 4430 (3) Spatial Statistics
Introduces the theory of spatial statistics with applications. Topics include basic theory for continuous stochastic processes, spatial prediction and kriging, simulation, geostatistical methods, likelihood and Bayesian approaches, spectral methods and an overview of modern topics such as nonstationary models, hierarchical modeling, multivariate processes, methods for large datasets and connections to splines.
Equivalent - Duplicate Degree Credit Not Granted: STAT 5430
Requisites: Requires prerequisite courses of STAT 3400 AND APPM 3310 (all minimum grade C-).
Additional Information: Arts Sci Gen Ed: Distribution-Natural Sciences

STAT 4520 (3) Introduction to Mathematical Statistics
Examines point and confidence interval estimation. Principles of maximum likelihood, sufficiency, and completeness: tests of simple and composite hypotheses, linear models, and multiple regression analysis if time permits. Analyzes various distribution-free methods.
Equivalent - Duplicate Degree Credit Not Granted: STAT 5520 and MATH 4520 and MATH 5520
Requisites: Requires prerequisites APPM 3570 or STAT 3100 or MATH 4510 (all minimum grade C-).
Additional Information: Arts Sci Gen Ed: Distribution-Natural Sciences

STAT 4540 (3) Introduction to Time Series
Studies basic properties, trend-based models, seasonal models modeling and forecasting with ARIMA models, spectral analysis and frequency filtration.
Equivalent - Duplicate Degree Credit Not Granted: STAT 5540 and MATH 4540 and MATH 5540
Requisites: Requires prerequisite course of APPM 4520 or STAT 4520 or MATH 4520 (minimum grade C-).
Additional Information: Arts Sci Gen Ed: Distribution-Natural Sciences

STAT 4610 (3) Statistical Learning
Consists of applications and methods of statistical learning. Reviews multiple linear regression and then covers classification, regularization, splines, tree-based methods, support vector machines, unsupervised learning and Gaussian process regression.
Equivalent - Duplicate Degree Credit Not Granted: STAT 5610
Requisites: Requires prerequisite course of STAT 3400 (minimum grade C-).
Additional Information: Arts Sci Gen Ed: Distribution-Natural Sciences

STAT 4630 (3) Computational Bayesian Statistics
Introduces Bayesian statistics, normal and non-normal approximation to likelihood and posteriors, the EM algorithm, data augmentation, and Markov Chain Monte Carlo (MCMC) methods. Additionally, introduces more advanced MCMC algorithms and requires significant statistical computing. Examples from a variety of areas, including biostatistics, environmental sciences, and engineering, will be given throughout the course.
Equivalent - Duplicate Degree Credit Not Granted: STAT 5630
Requisites: Requires prerequisite courses of (APPM 4560 or STAT 4100) and STAT 3400 and (STAT 4520 or MATH 4520) (minimum grade C-).
Recommended: Prerequisite prior programming experience.

STAT 4640 (3) Capstone in Statistics and Data Science
Course provides senior-level and graduate students the opportunity to apply the knowledge, skills, and abilities developed throughout the Statistics and Data Science major. Working in teams, students undertake a data-driven problem presented by domain experts from government, industry, or academia. The course provides valuable real-world experience for students intending to pursue graduate education or technical careers. Topics include team building, problem solving, research methods, project management, data ethics, and clear communication (oral, written, and visual).
Equivalent - Duplicate Degree Credit Not Granted: STAT 5640
Requisites: Requires prerequisite course of STAT 4400 or STAT 4610 (minimum grade C-)
Grading Basis: Letter Grade

STAT 4680 (3) Statistics and Data Science Collaboration
Educates and trains students to become effective interdisciplinary collaborators by developing the communication and collaboration skills necessary to apply technical statistics and data science skills to help domain experts answer research or policy questions. Topics include structuring effective meetings and projects; communicating statistics to non-statisticians; using peer feedback, self-reflection and video analysis to improve collaboration skills; creating reproducible statistical workflows; working ethically.
Equivalent - Duplicate Degree Credit Not Granted: STAT 5680
Requisites: Requires a prerequisite course of STAT 4400 or STAT 4010 (minimum grade C-).
Grading Basis: Letter Grade
Additional Information: Arts Sci Gen Ed: Distribution-Natural Sciences

STAT 4690 (2) Advanced Statistical Collaboration
Educates and trains students to become advanced interdisciplinary collaborators by developing and refining the communication, collaboration and technical statistics and data science skills necessary to collaborate with domain experts to answer research questions. Students work on multiple projects. Discussions center on technical skills necessary to solve research problems and video analysis to improve communication and collaboration skills.
Equivalent - Duplicate Degree Credit Not Granted: STAT 5690
Requisites: Requires prerequisite course of STAT 4680 or STAT 5680 (minimum grade C-).
Grading Basis: Letter Grade
Additional Information: Arts Sci Gen Ed: Distribution-Natural Sciences

STAT 4700 (3) Philosophical and Ethical Issues in Statistics
Introduces students to philosophical issues that arise in statistical theory and practice. Topics include interpretations of probability, philosophical paradigms in statistics, inductive inference, causality, reproducible, and ethical issues arising in statistics and data analysis.
Equivalent - Duplicate Degree Credit Not Granted: STAT 5700
Requisites: Requires prerequisites STAT 4520 or STAT 3400 or STAT 4000 (all minimum grade C-).
Grading Basis: Letter Grade

STAT 4720 (1-3) Open Topics in Statistics and Data Science
Provides a vehicle for the development and presentation of new topics that may be incorporated into the core courses in statistics and data science. Department enforced prerequisite: variable, depending on the topic, see instructor.
Equivalent - Duplicate Degree Credit Not Granted: STAT 5720
Repeatable: Repeatable for up to 15.00 total credit hours. Allows multiple enrollment in term.

STAT 4840 (1-3) Reading and Research in Statistics
Introduces undergraduate students to research in statistics and data science. Department enforced prerequisite: variable depending on the topic.
Repeatable: Repeatable for up to 9.00 total credit hours.