Applied Mathematics & Statistics

Degrees Offered
- Master of Science (Applied Mathematics and Statistics)
- Doctor of Philosophy (Applied Mathematics and Statistics)

Program Description
The Department of Applied Mathematics and Statistics (AMS) at Colorado School of Mines prepares the next generation of mathematical and statistical scientists to be leaders in a world driven by increasingly complex technology and challenges. Our department is at the forefront of research in mathematical and statistical methods that are used to address the opportunities and challenges of the future. The AMS department offers two graduate degrees: A Master of Science in Applied Mathematics and Statistics and a Doctor of Philosophy in Applied Mathematics and Statistics. The master's program is designed to prepare candidates for careers in industry or government or for further study at the PhD level. The PhD program is sufficiently flexible to prepare candidates for careers in industry, government and academia. A course of study leading to the PhD degree can be designed either for students who have completed a Master of Science degree or for students with a Bachelor of Science degree.

The AMS department is also involved in the curriculum of three different interdisciplinary master's degree programs: Data Science, Operations Research with Engineering, and Quantitative Biosciences and Engineering. Please view "Interdisciplinary Programs" for more information on these programs.

Research within AMS is conducted in the following areas:

Computational and Applied Mathematics
- Deep Learning
- Differential and Integral Equations
- Dynamical Systems
- Geophysical and Environmental Applications
- High Performance Scientific Computing
- Mathematical Biology
- Meshfree Approximation Methods
- Multi-scale Analysis and Simulation
- Numerical Methods for PDEs
- Optimal Control and Transport
- Wave Phenomena and Inverse Problems

Statistics
- Geophysical and Environmental Applications
- Methods for Massive Data Sets
- Spatial and Space-Time Processes
- Functional Data Analysis
- Inverse Problems
- Uncertainty Quantification

Master of Science Program Requirements

The Master of Science degree (non-thesis option) requires 30 credits of coursework. Students pursuing the degree may count up to six credits from courses at the 400-level. For both the Computational & Applied Mathematics and Statistics specialties, the curriculum structure consists of (i) a set of required courses, (ii) a pair of MATH electives, and (iii) general elective courses that serve to supplement the student's technical interests.

Specialty in Computational & Applied Mathematics

Required Courses

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Furthermore, students are required to complete two additional MATH courses, either at the 500-level or chosen from the following 400-level courses.

MATH Elective Courses (400-level)

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Finally, the remaining nine credits come from general elective courses and may be selected from any other graduate courses offered by the Department of Applied Mathematics and Statistics, except for specially designated service courses. Alternatively, up to 6 credits of elective courses may be taken in other departments on campus to satisfy this requirement.

Specialty in Statistics

Required Courses

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Doctoral students must pass the comprehensive examination (a qualifying examination and thesis proposal), complete a satisfactory thesis, and successfully defend their thesis.

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The Master of Science degree (thesis option) requires 30 credits of acceptable coursework and research, completion of a satisfactory thesis, and successful oral defense of this thesis. A minimum of 6 (and a maximum of 12) of the 30 credits must be designated for supervised research, which will be in lieu of electives. The coursework includes the required core curriculum for the chosen specialty described above.

**Mines Combined Undergraduate / Graduate Degree Program**

The Department of Applied Mathematics and Statistics offers a combined Bachelor of Science/Master of Science program that enables students to work on a Bachelor of Science and a Master of Science in either specialty simultaneously. Students take 30 credits of coursework at the graduate level in addition to the undergraduate requirements, and work on both degrees at the same time. As described above, students pursuing the Master of Science degree may count up to six credits from courses at the 400-level. Additionally, students enrolled within the combined program may choose up to six credits of MATH coursework at the 500-level (that has been successfully completed with a grade of B or above) to "double-count"; that is, apply towards both their Bachelor of Science degree requirements and their Master of Science degree requirements simultaneously. Interested students are encouraged to apply for the combined program once they have completed five classes with a MATH prefix numbered 225 or higher.

**Specialty in Computational & Applied Mathematics**

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**Fields of Research:**
- Geophysical and Environmental Applications
- Scientific Data Compression
- Spatial and Space-Time Processes
- Methods for Massive Data Sets
- Functional Data Analysis
- Inverse Problems in Statistics
- Machine Learning
- Uncertainty Quantification
- Numerical Methods for PDEs
- High Performance Scientific Computing
- Biological Fluid Dynamics
- Meshfree Approximation Methods
- PDEs and Kinetic Theory
- Computational Hydrology
- Mathematical Biology including:
  - Sleep and Circadian Rhythms
  - Blood Coagulation
  - Microorganism Motility
  - Epidemiology

**Courses**

**MATH500. LINEAR VECTOR SPACES.** 3.0 Semester Hrs.
(I) Finite dimensional vector spaces and subspaces: dimension, dual bases, annihilators. Linear transformations, matrices, projections, change of basis, similarity. Determinants, eigenvalues, multiplicity. Jordan form. Inner products and inner product spaces with orthogonality and completeness. Prerequisite: MATH301, MATH332. 3 hours lecture; 3 semester hours.

**MATH501. APPLIED ANALYSIS.** 3.0 Semester Hrs.
(II) Fundamental theory and tools of applied analysis. Students in this course will be introduced to Banach, Hilbert, and Sobolev spaces; bounded and unbounded operators defined on such infinite dimensional spaces; and associated properties. These concepts will be applied to understand the properties of differential and integral operators occurring in mathematical models that govern various biological, physical and engineering processes. Prerequisites: MATH301 or equivalent.

**MATH502. REAL AND ABSTRACT ANALYSIS.** 3.0 Semester Hrs.
(I) Normed space R, open and closed sets. Lebesgue measure, measurable sets and functions. Lebesgue integral and convergence theorems. Repeated integration and integration by substitution. Lp spaces, Banach and Hilbert spaces. Weak derivatives and Sobolev spaces. Weak solutions of two-point boundary value problems. Prerequisites: MATH301 or equivalent. 3 hours lecture; 3 semester hours.

**MATH503. FUNCTIONAL ANALYSIS.** 3.0 Semester Hrs.

**MATH506. COMPLEX ANALYSIS II.** 3.0 Semester Hrs.
(II) Analytic functions. Conformal mapping and applications. Analytic continuation. Schlicht functions. Approximation theorems in the complex domain. Taught every other year. Prerequisite: MATH454. 3 hours lecture; 3 semester hours.

**MATH510. ORDINARY DIFFERENTIAL EQUATIONS AND DYNAMICAL SYSTEMS.** 3.0 Semester Hrs.
(I) Topics to be covered: basic existence and uniqueness theory, systems of equations, stability, differential inequalities, Poincare-Bendixon theory, linearization. Other topics from: Hamiltonian systems, periodic and almost periodic systems, integral manifolds, Lyapunov functions, bifurcations, homoclinic points and chaos theory. Offered even years. 3 hours lecture; 3 semester hours. Prerequisite: MATH225 or MATH235 and MATH332 or MATH342 and MATH301.

**MATH514. APPLIED MATHEMATICS I.** 3.0 Semester Hrs.
(II) The course focuses on the application of mathematical ideas and methods for solving problems in the applied sciences and engineering. Topics include dimensional analysis, regular and singular perturbation methods, boundary layer analysis, kinetics. Other topics may include variational calculus, boundary value problems and integral equations, and discrete models. Where applicable, there will be numerical approaches to complement the analytic ones.

**MATH515. APPLIED MATHEMATICS II.** 3.0 Semester Hrs.
The course focuses on the application of mathematical ideas and methods for solving problems in the applied sciences and engineering. Topics include non-numerical techniques for dealing with partial differential equations, wave phenomena, continuum mechanics, conservation laws, and transform methods.

**MATH530. INTRODUCTION TO STATISTICAL METHODS.** 3.0 Semester Hrs.
(I) Review of probability, random variables, and discrete and continuous probability models. Descriptive statistics and graphical representations. General theory of Confidence intervals and hypothesis testing. Inferences for mean and variance of a single population. Inferences for means and variances for two populations. Inferences for proportions and count data.

**MATH531. THEORY OF LINEAR MODELS.** 3.0 Semester Hrs.
(II) Statistical framework for estimation and inference based on multiple regression, including distribution theory for sums of squares statistics and estimators. Principles of analysis of variance (ANOVA), multiple comparisons, and experimental design. Also included are some relevant topics in multivariate analysis and asymptotic, large sample theory. Prerequisites. MATH332 and MATH534.
MATH532. SPATIAL STATISTICS. 3.0 Semester Hrs.
(I) Modeling and analysis of data observed on a 2 or 3-dimensional surface. Random fields, variograms, covariances, stationarity, nonstationarity, kriging, simulation, Bayesian hierarchical models, spatial regression, SAR, CAR, QAR, and MA models, Geary/Moran indices, point processes, K-function, complete spatial randomness, homogeneous and inhomogeneous processes, marked point processes, spatio-temporal modeling. Course is offered every other year on even years. Prerequisites: MATH424 or equivalent.

MATH534. MATHEMATICAL STATISTICS I. 3.0 Semester Hrs.
(I) The basics of probability, discrete and continuous probability distributions, sampling distributions, order statistics, convergence in probability and in distribution, and basic limit theorems, including the central limit theorem, are covered. Prerequisite: none. 3 hours lecture; 3 semester hours.

MATH535. MATHEMATICAL STATISTICS II. 3.0 Semester Hrs.
(ii) The basics of hypothesis testing using likelihood ratios, point and interval estimation, consistency, efficiency, sufficient statistics, and some nonparametric methods are presented. Prerequisite: MATH534 or equivalent. 3 hours lecture; 3 semester hours.

MATH536. ADVANCED STATISTICAL MODELING. 3.0 Semester Hrs.
(ii) Modern extensions of the standard linear model for analyzing data. Topics include generalized linear models, generalized additive models, mixed effects models, and resampling methods. Offered every two years on odd years. 3 hours lecture; 3 semester hours. Prerequisite: MATH335, MATH424.

MATH537. MULTIVARIATE ANALYSIS. 3.0 Semester Hrs.
(i) Introduction to applied multivariate representations of data for use in data analysis. Topics include introduction to multivariate distributions; methods for data reduction, such as principal components; hierarchical and model-based clustering methods; factor analysis; canonical correlation analysis; multidimensional scaling; and multivariate hypothesis testing. Prerequisites: MATH530 and MATH332 or MATH500.

MATH538. STOCHASTIC MODELS. 3.0 Semester Hrs.
(ii) An introduction to the mathematical principles of stochastic processes. Discrete- and continuous-time Markov processes. Poisson processes, Brownian motion. Offered every two years on even years. 3 hours lecture; 3 semester hours.

MATH539. SURVIVAL ANALYSIS. 3.0 Semester Hrs.
(i) Basic theory and practice of survival analysis. Topics include survival and hazard functions, censoring and truncation, parametric and non-parametric inference, the proportional hazards model, model diagnostics. Offered on odd years. Prerequisite: MATH335, MATH535. 3 hours lecture; 3 semester hours.

MATH540. PARALLEL SCIENTIFIC COMPUTING. 3.0 Semester Hrs.
(ii) This course is designed to facilitate students' learning of parallel programming techniques to efficiently simulate various complex processes modeled by mathematical equations using multiple and multicore processors. Emphasis will be placed on the implementation of various scientific computing algorithms in FORTRAN/C/C++ using MPI and OpenMP. Prerequisite: MATH307. 3 hours lecture; 3 semester hours.

MATH542. SIMULATION. 3.0 Semester Hrs.
(i) Advanced study of simulation techniques, random number, and variate generation. Monte Carlo techniques, simulation languages, simulation experimental design, variance reduction, and other methods of increasing efficiency, practice on actual problems. 3 hours lecture; 3 semester hours. Prerequisite: CSCI262 (or equivalent), MATH201 (or MATH 424 or MATH530 or equivalent).

MATH544. ADVANCED COMPUTER GRAPHICS. 3.0 Semester Hrs.
Equivalent with CSCI544.
This is an advanced computer graphics course in which students will learn a variety of mathematical and algorithmic techniques that can be used to solve fundamental problems in computer graphics. Topics include global illumination, GPU programming, geometry acquisition and processing, point based graphics and non-photorealistic rendering. Students will learn about modern rendering and geometric modeling techniques by reading and discussing research papers and implementing one or more of the algorithms described in the literature.
MATH559. ASYMPTOTICS. 3.0 Semester Hrs.
Equivalent with MATH459.
(I) Exact methods for solving mathematical problems are not always available: approximate methods must be developed. Often, problems involve small parameters, and this can be exploited so as to derive approximations: these are known as asymptotic approximations. Many techniques for constructing asymptotic approximations have been devised. The course develops such approximations for algebraic problems, the evaluation of integrals, and the solutions of differential equations. Emphasis is placed on effective methods and, where possible, rigorous analysis. Prerequisites: Calculus and ordinary differential equations. 3 hours lecture; 3 semester hours.

MATH560. INTRODUCTION TO KEY STATISTICAL LEARNING METHODS I. 3.0 Semester Hrs.
(II) Part one of a two-course series introducing statistical learning methods with a focus on conceptual understanding and practical applications. Methods covered will include Introduction to Statistical Learning, Linear Regression, Cross validation, Basis Expansions, Regularization, Non linear Models, Model Assessment and Selection. Prerequisites: MATH530 or DSCI530.

MATH561. INTRODUCTION TO KEY STATISTICAL LEARNING METHODS II. 3.0 Semester Hrs.
(I) Part two of a two course series introducing statistical learning methods with a focus on conceptual understanding and practical applications. Methods covered will include Classification, Bootstrap, Tree-based Methods, Support Vector Machines, Unsupervised Learning. Prerequisites: MATH560.

MATH570. MATHEMATICAL MODELING OF SPATIAL PROCESSES IN BIOLOGY. 3.0 Semester Hrs.
(II) This course is an introduction to mathematical modeling of spatial processes in biology. The emphasis is on partial differential equation models from a diverse set of biological topics such as cellular homeostasis, muscle dynamics, neural dynamics, calcium handling, epidemiology, and chemotaxis. We will survey a variety of models and analyze their results in the context of the biology. Mathematically, we will examine the diffusion equation, advection equation, and combinations of the two that include reactions. There will be a significant computational component to the course including bi-weekly computational labs; students will solve the model equations and perform computations using MATLAB. Prerequisites: MATH331 and MATH455 or equivalent courses and familiarity with MATLAB.

MATH572. MATHEMATICAL AND COMPUTATIONAL NEUROSCIENCE. 3.0 Semester Hrs.
(II) This course will focus on mathematical and computational techniques applied to neuroscience. Topics will include nonlinear dynamics, hysteresis, the cable equation, and representative models such as Wilson-Cowan, Hodgkin-Huxley, and FitzHugh-Nagumo. Applications will be motivated by student interests. In addition to building basic skills in applied math, students will gain insight into how mathematical sciences can be used to model and solve problems in neuroscience; develop a variety of strategies (computational, theoretical, etc.) with which to approach novel mathematical situations; and hone skills for communicating mathematical ideas precisely and concisely in an interdisciplinary context. In addition, the strong computational component of this course will help students to develop computer programming skills and apply appropriate technological tools to solve mathematical problems. Prerequisite: MATH331. 3 hours lecture; 3 semester hours.

MATH574. THEORY OF CRYPTOGRAPHY. 3.0 Semester Hrs.
Equivalent with CSCI574. Students will draw upon current research results to design, implement and analyze their own computer security or other related cryptography projects. The requisite mathematical background, including relevant aspects of number theory and mathematical statistics, will be covered in lecture. Students will be expected to review current literature from prominent researchers in cryptography and to present their findings to the class. Particular focus will be given to the application of various techniques to real-life situations. The course will also cover the following aspects of cryptography: symmetric and asymmetric encryption, computational number theory, quantum encryption, RSA and discrete log systems, SHA, steganography, chaotic and pseudo-random sequences, message authentication, digital signatures, key distribution and key management, and block ciphers. Prerequisites: CSCI262 plus undergraduate-level knowledge of statistics and discrete mathematics. 3 hours lecture, 3 semester hours.

MATH582. STATISTICS PRACTICUM. 3.0 Semester Hrs.
(II) This is the capstone course in the Statistics Option. The main objective is to apply statistical knowledge and skills to a data analysis problem, which will vary by semester. Students will gain experience in problem-solving; working in a team; presentation skills (both orally and written); and thinking independently. Prerequisites: MATH 201 or 530 and MATH 424 or 531. 3 hours lecture and discussion; 3 semester hours.

MATH588. INTRODUCTION TO QUANTITATIVE AND COMPUTATIONAL RESEARCH. 1.0 Semester Hr.
Students will be expected to use applied mathematics and statistics principles to critically analyze research results in published literature and place them in the context of related literature. Skills to be developed and discussed include critical review of the literature and oral defense of these reviews.

MATH589. APPLIED MATHEMATICS AND STATISTICS TEACHING SEMINAR. 1.0 Semester Hr.
(I) An introduction to teaching issues and techniques within the AMS department. Weekly, discussion-based seminars will cover practical issues such as lesson planning, grading, and test writing. Issues specific to the AMS core courses will be included. 1 hour lecture; 1.0 semester hour.

MATH598. SPECIAL TOPICS. 6.0 Semester Hrs.
(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once, but no more than twice for the same course content. Prerequisite: none. Variable credit: 0 to 6 credit hours. Repeatable for credit under different titles.

MATH599. INDEPENDENT STUDY. 0.5-6 Semester Hr.
(I, II) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: ?Independent Study? form must be completed and submitted to the Registrar. Variable credit: 0.5 to 6 credit hours. Repeatable for credit under different topics/ experience and maximums vary by department. Contact the Department for credit limits toward the degree.

MATH610. ADVANCED TOPICS IN DIFFERENTIAL EQUATIONS. 3.0 Semester Hrs.
(II) Topics from current research in ordinary and/or partial differential equations; for example, dynamical systems, advanced asymptotic analysis, nonlinear wave propagation, solitons. Prerequisite: none. 3 hours lecture; 3 semester hours.
MATH614. ADVANCED TOPICS IN APPLIED MATHEMATICS. 3.0
Semester Hrs.
(I) Topics from current literature in applied mathematics; for example, wavelets and their applications, calculus of variations, advanced applied functional analysis, control theory. Prerequisite: none. 3 hours lecture; 3 semester hours.

MATH616. INTRODUCTION TO MULTI-DIMENSIONAL SEISMIC INVERSION. 3.0 Semester Hrs.
(II) Introduction to high frequency inversion techniques. Emphasis on the application of this theory to produce a reflector map of the earth's interior and estimates of changes in earth parameters across those reflectors from data gathered in response to sources at the surface or in the interior of the earth. Extensions to elastic media are discussed, as well. Includes high frequency modeling of the propagation of acoustic and elastic waves. Prerequisites: partial differential equations, wave equation in the time or frequency domain, complex function theory, contour integration. Some knowledge of wave propagation: reflection, refraction, diffraction. 3 hours lecture; 3 semester hours.

MATH620. ADVANCED TOPICS IN NUMERICAL ANALYSIS. 3.0 Semester Hrs.
(II) Topics from the current literature in numerical analysis and/or computational mathematics; for example, advanced finite element method, sparse matrix algorithms, applications of approximation theory, software for initial value ODE's, numerical methods for integral equations. 3 hours lecture; 3 semester hours. Prerequisite: Consent of Instructor.

MATH691. GRADUATE SEMINAR. 1.0 Semester Hr.
(I) Presentation of latest research results by guest lecturers, staff, and advanced students. Prerequisite: none. 1 hour seminar; 1 semester hour. Repeatable for credit to a maximum of 12 hours.

MATH692. GRADUATE SEMINAR. 1.0 Semester Hr.
Equivalent with CSCI692,
(II) Presentation of latest research results by guest lecturers, staff, and advanced students. Prerequisite: none. 1 hour seminar; 1 semester hour. Repeatable for credit to a maximum of 12 hours.

MATH693. WAVE PHENOMENA SEMINAR. 1.0 Semester Hr.
(I, II) Students will probe a range of current methodologies and issues in seismic data processing, with emphasis on underlying assumptions, implications of these assumptions, and implications that would follow from use of alternative assumptions. Such analysis should provide seed topics for ongoing and subsequent research. Topic areas include: Statistics estimation and compensation, deconvolution, multiple suppression, suppression of other noises, wavelet estimation, imaging and inversion, extraction of stratigraphic and lithologic information, and correlation of surface and borehole seismic data with well log data. Prerequisite: none. 1 hour seminar; 1 semester hour.

MATH698. SPECIAL TOPICS. 6.0 Semester Hrs.
(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once, but no more than twice for the same course content. Prerequisite: none. Variable credit: 0 to 6 credit hours. Repeatable for credit under different titles.

MATH699. INDEPENDENT STUDY. 0.5-6 Semester Hr.
(I, II, S) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: Independent Study form must be completed and submitted to the Registrar. Variable credit: 0.5 to 6 credit hours. Repeatable for credit under different topics/experience and maximums vary by department. Contact the Department for credit limits toward the degree.

MATH707. GRADUATE THESIS / DISSERTATION RESEARCH CREDIT. 1-15 Semester Hr.
(I, II, S) GRADUATE THESIS/DISSERTATION RESEARCH CREDIT Research credit hours required for completion of a Masters-level thesis or Doctoral dissertation. Research must be carried out under the direct supervision of the student's faculty advisor. Variable class and semester hours. Repeatable for credit.

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