# Applied Mathematics & Statistics

## 2016-2017

### 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) 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.

Research within AMS is conducted in the following areas:

- **Computational and Applied Mathematics**
  - Study of Wave Phenomena and Inverse Problems
  - Numerical Methods for PDEs
  - Study of Differential and Integral Equations
  - Computational Radiation Transport
  - Computational Acoustics and Electromagnetics
  - Multi-scale Analysis and Simulation
  - High Performance Scientific Computing
  - Dynamical Systems
  - Mathematical Biology

- **Statistics**
  - Inverse Problems in Statistics
  - Multivariate Statistics
  - Spatial Statistics
  - Stochastic Models for Environmental Science
  - Survival Analysis
  - Uncertainty Quantification

### Master of Science Program Requirements
The Master of Science degree (thesis option) requires 30 credit hours of acceptable coursework and research, completion of a satisfactory thesis, and successful oral defense of this thesis. At least six of the 30 credit hours must be designated for supervised research. The coursework includes the following core curriculum.

### Specialty in Computational & Applied Mathematics

#### Required Courses

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For both specialties, elective courses may be selected from any other graduate courses offered by the Department of Applied Mathematics and Statistics, except for specially designated service courses. In addition,
up to 6 credits of elective courses may be taken in other departments on campus.

The Master of Science degree (non-thesis option) requires 30 credit hours of coursework. The coursework includes the required core curriculum for the chosen specialty.

Combined BS/MS 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 credit hours of coursework at the graduate level in addition to the undergraduate requirements, and work on both degrees at the same time. Students may apply for the program once they have completed five classes with a MATH prefix numbered 225 or higher.

Doctor of Philosophy Program

Requirements:

The Doctor of Philosophy requires 72 credit hours beyond the bachelor’s degree. At least 24 of these hours must be thesis hours. Doctoral students must pass the comprehensive examination (a qualifying examination and thesis proposal), complete a satisfactory thesis, and successfully defend their thesis. The coursework includes the following core curriculum.

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Further information can be found on the Web at ams.mines.edu. This website provides an overview of the programs, requirements and policies of the department.

Fields of Research

Computational and Applied Mathematics:

- Study of Wave Phenomena and Inverse Problems
- Numerical Methods for PDEs
- Study of Differential and Integral Equations
- Computational Radiation Transport
- Computational Acoustics and Electromagnetics
- Multi-scale Analysis and Simulation
- High Performance Scientific Computing
- Dynamical Systems
- Mathematical Biology

Statistics:

- Inverse Problems in Statistics
- Multivariate Statistics
Spatial Statistics
Stochastic Models for Environmental Science
Survival Analysis
Uncertainty Quantification

Department Head
Willy Hereman, Professor

Professors
Bernard Bialecki
Mahadevan Ganesh
Paul A. Martin
Barbara M. Moskal
William Navidi

Associate Professor
Luis Tenorio

Assistant Professors
Paul Constantine
Cecilia Diniz Behn
Amanda Hering
Stephen Pankavich
Aaron Porter

Teaching Professors
G. Gustave Greivel
Scott Strong

Teaching Associate Professors
Terry Bridgman
Debra Carney
Holly Eklund
Mike Mikucki
Mike Nicholas
Jennifer Strong
Rebecca Swanson

Emeriti Professors
William R. Astle
Norman Bleistein
Ardel J. Boes
Austin R. Brown

John A. DeSanto
Graeme Fairweather
Raymond R. Gutzman
Frank G. Hagin
Donald C.B. Marsh
Steven Pruess

Emeriti Associate Professors
Barbara B. Bath
Ruth Maurer
Robert G. Underwood

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. 3 hours lecture; 3 semester hours.

MATH501. APPLIED ANALYSIS. 3.0 Semester Hrs.
(I) 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. 3 hours lecture; 3 semester hours.

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.
Equivalent with MACS503,

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. Prerequisite: MATH454. 3 hours lecture; 3 semester hours.
MATH510. ORDINARY DIFFERENTIAL EQUATIONS AND DYNAMICAL SYSTEMS. 3.0 Semester Hrs.
Equivalent with MACS510.
(I) Topics to be covered: basic existence and uniqueness theory, systems of equations, stability, differential inequalities, Poincare-Bendixson theory, linearization. Other topics from: Hamiltonian systems, periodic and almost periodic systems, integral manifolds, Lyapunov functions, bifurcations, homoclinic points and chaos theory. Prerequisite: MATH225 or MATH325 and MATH332 or MATH 342 or equivalent courses. 3 hours lecture; 3 semester hours.

MATH514. APPLIED MATHEMATICS I. 3.0 Semester Hrs.
(I) The major theme in this course is various non-numerical techniques for dealing with partial differential equations which arise in science and engineering problems. Topics include transform techniques, Green's functions and partial differential equations. Stress is on applications to boundary value problems and wave theory. Prerequisite: MATH455 or equivalent. 3 hours lecture; 3 semester hours.

MATH515. APPLIED MATHEMATICS II. 3.0 Semester Hrs.
(II) Topics include integral equations, applied complex variables, an introduction to asymptotics, linear spaces and the calculus of variations. Stress is on applications to boundary value problems and wave theory, with additional applications to engineering and physical problems. Prerequisite: MATH514. 3 hours lecture; 3 semester hours.

MATH530. STATISTICAL METHODS I. 3.0 Semester Hrs.
(I) Introduction to probability, random variables, and discrete and continuous probability models. Elementary simulation. Data summarization and analysis. Confidence intervals and hypothesis testing for means and variances. Chi square tests. Distribution-free techniques and regression analysis. Prerequisite: MATH213 or equivalent. 3 hours lecture; 3 semester hours.

MATH531. STATISTICAL METHODS II. 3.0 Semester Hrs.
Equivalent with MACS531.
(II) Continuation of MATH530. Multiple regression and trend surface analysis. Analysis of variance. Experimental design (Latin squares, factorial designs, confounding, fractional replication, etc.) Nonparametric analysis of variance. Topics selected from multivariate analysis, sequential analysis or time series analysis. Prerequisite: MATH201 or MATH530 or MATH535. 3 hours lecture; 3 semester hours.

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. MATH424 or MATH531.

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.
Equivalent with MACS535.
(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.
(I) Modern extensions of the standard linear model for analyzing data. Topics include generalized linear models, generalized additive models, mixed effects models, and resampling methods. Prerequisite: MATH 335 and MATH 424. 3 hours lecture; 3.0 semester hours.

MATH537. MULTIVARIATE ANALYSIS. 3.0 Semester Hrs.
(II) 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: MATH 530 and MATH 332 or MATH 500. 3 hours lecture; 3.0 semester hours.

MATH538. STOCHASTIC MODELS. 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. Prerequisite: MATH335 or MATH535.

MATH540. PARALLEL SCIENTIFIC COMPUTING. 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. Prerequisite: CSC262 (or equivalent), MATH323 (or MATH530 or equivalent). 3 hours lecture; 3.0 semester hours.

MATH542. SIMULATION. 3.0 Semester Hrs.
Equivalent with MACS542.
(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. Prerequisite: CSC262 (or equivalent), MATH323 (or MATH530 or equivalent). 3 hours lecture; 3.0 semester hours.

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.
MATH547. SCIENTIFIC VISUALIZATION. 3.0 Semester Hrs.
Equivalent with CSCI547,
Scientific visualization uses computer graphics to create visual images which aid in understanding of complex, often massive numerical representation of scientific concepts or results. The main focus of this course is on techniques applicable to spatial data such as scalar, vector and tensor fields. Topics include volume rendering, texture based methods for vector and tensor field visualization, and scalar and vector field topology. Students will learn about modern visualization techniques by reading and discussing research papers and implementing one of the algorithms described in the literature.

MATH550. NUMERICAL SOLUTION OF PARTIAL DIFFERENTIAL EQUATIONS. 3.0 Semester Hrs.
Equivalent with MACS550,
(ii) Numerical methods for solving partial differential equations. Explicit and implicit finite difference methods; stability, convergence, and consistency. Alternating direction implicit (ADI) methods. Weighted residual and finite element methods. Prerequisite: MATH225 or MATH235, and MATH332 or MATH342. 3 hours lecture; 3 semester hours.

MATH551. COMPUTATIONAL LINEAR ALGEBRA. 3.0 Semester Hrs.
Equivalent with MACS551,
(ii) Numerical analysis of algorithms for solving linear systems of equations, least squares methods, the symmetric eigenproblem, singular value decomposition, conjugate gradient iteration. Modification of algorithms to fit the architecture. Error analysis, existing software packages. Prerequisites: MATH332, CSCH407/MATH407. 3 hours lecture; 3 semester hours.

MATH556. MODELING WITH SYMBOLIC SOFTWARE. 3.0 Semester Hrs.
(i) Case studies of various models from mathematics, the sciences and engineering through the use of the symbolic software package MATHEMATICA. Based on hands-on projects dealing with contemporary topics such as number theory, discrete mathematics, complex analysis, special functions, classical and quantum mechanics, relativity, dynamical systems, chaos and fractals, solitons, wavelets, chemical reactions, population dynamics, pollution models, electrical circuits, signal processing, optimization, control theory, and industrial mathematics. The course is designed for graduate students and scientists interested in modeling and using symbolic software as a programming language and a research tool. It is taught in a computer laboratory. Prerequisites: none. 3 hours lecture; 3 semester hours.

MATH557. INTEGRAL EQUATIONS. 3.0 Semester Hrs.
(i) This is an introductory course on the theory and applications of integral equations. Abel, Fredholm and Volterra equations. Fredholm theory: small kernels, separable kernels, iteration, connections with linear algebra and Sturm-Liouville problems. Applications to boundary-value problems for Laplace's equation and other partial differential equations. Prerequisite: MATH332 or MATH342, and MATH455.

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.

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, 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.

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.

MATH650. 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. Prerequisite: none. 3 hours lecture; 3 semester hours.

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 CSC692,MACS692, (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.