Department of Mathematics and Statistics

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Graduate Study in Computational and Applied Mathematics

The master's and doctoral programs in computational and applied mathematics offered by the Department of Mathematics and Statistics are designed to produce applied mathematicians and statisticians who can meet the growing demand for analytical and computational skills in traditional scientific and multi-disciplinary fields. Students in the program can choose to pursue an option in either applied mathematics, statistics, or biostatistics.

Applied mathematics is the application of mathematics to the solution of non-mathematical problems. Such problems may originate in math-oriented fields (physics, chemistry, and engineering) as well as in such areas such as geology, oceanography, meteorology, biology, ecology, environmental health, economics, actuarial science, business (operations and market research), banking, and medicine. Students will learn to use methods of applied mathematics, probability, statistics, biostatistics, numerical analysis, and scientific computing in seeking solutions to such problems. For work in computational and applied mathematics, training in an additional field of application is a necessity.

The desire and ability to use mathematics to bring together various disciplines is the unique characteristic of an applied mathematician. Not only has mathematical modeling and solving of societal and scientific problems increased the demand for applied mathematicians, but the flexibility and breadth of knowledge inherent in this discipline make it attractive for those who do not want to become irreversibly specialized.

Old Dominion University is one of the few American institutions offering a program expressly in applied mathematics. There are approximately 22 graduate program faculty members in the Department of Mathematics and Statistics, and current enrollment in the program is about 50 students. Areas of faculty research include analytical and numerical modeling in oceanography and meteorology, computational fluid dynamics and stability theory, elasticity and fracture mechanics, combustion theory, magnetohydrodynamics, mathematical biology, numerical analysis and approximation, optimization, applied probability, statistical inference, reliability, multivariate statistics, generalized linear models, estimating equations, biostatistics, nonparametric statistics, bioinformatics, and high performance computing.

Facilities within the metropolitan area include the NASA/Langley Research Center, the Virginia Modeling, Analysis and Simulation Center (VMASC), and the Eastern Virginia Medical School.

Program Financial Aid. Graduate assistantships in the Department of Mathematics and Statistics offer stipends ranging from $15,000 to $18,000. The level of award is determined on the basis of previous experience and performance as a graduate assistant and on the student's academic achievement and potential in applied mathematics or statistics. In addition, a number of teaching and research positions are available for financial support of graduate assistants during the summer months (June and July).

Writing Proficiency. All students in the graduate program are expected to demonstrate an acceptable level of writing ability. Students needing help to remedy their writing deficiencies will be referred to the Writing Center for diagnosis and assistance. All M.S. candidates will enroll in MATH 632 or in STAT 632 for a master's project.

Master of Science - Computational and Applied Mathematics

Admission

An applicant to the master's program in computational and applied mathematics should have a bachelor's degree in mathematics, statistics, computer science, or an application area with a strong mathematics component (e.g., physics or engineering). Undergraduate mathematics preparation should include course work in linear algebra, advanced calculus, differential equations, probability, and numerical methods. Undergraduate averages of 2.80 overall (4.00 scale) and 3.00 in the major and related mathematics courses are required.

A student who does not fully meet all requirements for admission as a regular graduate student may be allowed, with permission of the program director, to enroll as a provisional graduate student. Students lacking adequate preparation will be required to make up their deficiencies by taking appropriate undergraduate courses in addition to those specified for the master's program.

A formal application form, official transcripts, and two letters of recommendation should be forwarded to the Office of Admissions. It is recommended that applicants supply Graduate Record Examination aptitude scores.

The following material should be mailed directly to the director of the graduate program in computational and applied mathematics, Department of Mathematics and Statistics: a list of all mathematics courses taken and other courses closely allied to the applicant's primary interests in applied math or statistics along with the texts used (titles and authors), chapters studied or topics covered, and grades. This information should be enclosed with the financial aid application (if the applicant is submitting one).

Students may enroll in the program on either a full-time or part-time basis. Courses are offered on a regular basis during the late afternoon and early evening hours which allows part-time students to obtain master's degrees or post-master's graduate credit.

Requirements

The M.S. candidate must complete a minimum of 31 normal credit hours of course work designed to fulfill an option in either applied mathematics, statistics or biostatistics. With approval of the graduate program director, up to six of these credits may be chosen from a field of application (e.g., geology, oceanography, ecosystem analysis, computer science, economics, health sciences, operations research, physics and engineering mechanics) in which the student applies analytical and numerical techniques to another discipline. All programs of study must be approved by the graduate program director, and substitutions may be made only with his or her approval.

Master's Project Requirement

The M.S. candidate will be assigned to a faculty advisor for a master's project. Each student will enroll in MATH 632 or STAT 632 to complete his/her project. The master's project is designed not only to broaden students' analytical competency but also to enhance students' writing and reporting skills on a technical subject.

Colloquium Requirement

In order to develop an appreciation for the breadth of contemporary research in applied mathematics and statistics, all M.S. candidates will attend and succinctly summarize and evaluate in writing at least eight professional seminars given by research faculty or external seminar visitors. The Richard F. Barry Colloquium Series is run by the department throughout the academic year. The department also conducts seminars jointly with other departments.

Prerequisites

Prerequisite courses for the applied mathematics concentration are:

At most, three from the following can be applied towards the 31-credit degree requirement:

MATH 501	Partial Differential Equations	3
MATH 508	Applied Numerical Methods I	3
MATH 509	Applied Numerical Methods II	3
MATH 517	Intermediate Real Analysis I	3
MATH 518	Intermediate Real Analysis II	3
MATH 522	Applied Complex Variables	3

Prerequisite courses for the statistics and biostatistics concentrations are:

MATH 316	Introductory Linear Algebra	3
STAT 331	Theory of Probability	3
STAT 431/531	Theory of Statistics	3
STAT 532	Sampling Theory *	3
STAT 535	Design and Analysis of Experiments *	3
STAT 537	Applied Regression and Time Series Analysis *	3

* Only these courses can be applied towards the 31-credit degree requirement.

Applied Mathematics Concentration

MATH 617	Measure and Integration	3
MATH 618	Applied Functional Analysis	3
MATH 632	Master's Project	3
MATH 637	Tensor Calculus and Differential Geometry	3
MATH 693	Engineering Analysis III	3
MATH 622	Numerical Solutions to Differential Equations	3
or MATH 721	Advanced Applied Numerical Methods I	
And at least 13 additional credit hours of approved graduate course work		13
Total Hours		31

Statistics Concentration

STAT 505	Introduction to Data Handling	3
STAT 535	Design and Analysis of Experiments	3
STAT 537	Applied Regression and Time Series Analysis	3
STAT 625	Mathematical Statistics I	3
STAT 626	Mathematical Statistics II	3
STAT 627	Linear Statistical Models	3
or STAT 628	Applied Multivariate Analysis	
STAT 632	Master's Project	3
STAT 640	Survival Analysis	3
At least 7 additional credits of approved graduate course work		7
Total Hours		31

Biostatistics Concentration

STAT 505	Introduction to Data Handling	3
STAT 535	Design and Analysis of Experiments	3
STAT 537	Applied Regression and Time Series Analysis	3
STAT 550	Categorical Data Analysis	3
or STAT 547	Analysis of Longitudinal Data	
STAT 625	Mathematical Statistics I	3
STAT 626	Mathematical Statistics II	3
STAT 627	Linear Statistical Models	3
or STAT 628	Applied Multivariate Analysis	
STAT 640	Survival Analysis	3
STAT 632	Master's Project	3
At least 4 additional credits of approved graduate work		4
Total Hours		31

Graduate Certificate in Modeling and Simulation for Mathematics and Statistics

The Department of Mathematics and Statistics at Old Dominion University plays an integral part in the University's campus-wide initiative to promote its research in Modeling and Simulation. The Department offers a Graduate Certificate in Modeling and Simulation for Mathematics and Statistics.
In order to obtain this certificate, a student must complete four graduate courses that include MSIM 601 (Introduction to Modeling and Simulation). MSIM 601 is offered by the Department of Engineering Management and System Engineering. Students may select three other simulation courses from the following Modeling and Simulation courses.

Modeling and Simulation courses in Computational Mathematics

Required Course		3
MSIM 601	Introduction to Modeling and Simulation	
Select three from the following:		9
MATH 508	Applied Numerical Methods I	
MATH 509	Applied Numerical Methods II	
MATH 622	Numerical Solutions to Differential Equations	
MATH 632	Master's Project	
MATH 721/821	Advanced Applied Numerical Methods I	
MATH 722/822	Advanced Applied Numerical Methods II	
Total Hours		12

Modeling and Simulation courses in Statistics

Required Course		3
MSIM 601	Introduction to Modeling and Simulation	
Select three from the following:		9
STAT 535	Design and Analysis of Experiments	
STAT 537	Applied Regression and Time Series Analysis	
STAT 560	Statistical Simulation/Programming Using Statistical Software Packages	
STAT 597/697	Topics in Statistics	
STAT 630	Time Series Models	
STAT 632	Master's Project	
STAT 640	Survival Analysis	
Total Hours		12

Doctor of Philosophy - Computational and Applied Mathematics

Admission

Applicants who appear to be qualified for study at an advanced graduate level may be admitted to the doctoral program in computational and applied mathematics. These will be students with very strong backgrounds in mathematics, statistics, computer science, or application areas with a mathematics component (e.g. physics or engineering).

Students may be admitted directly to the Ph.D. program with either a bachelor's or a master's degree. A grade point average of 3.00 (4.00 scale) in the major and related mathematics courses is required.

Students are required to submit three letters of recommendation, and GRE aptitude scores, if the student will not have completed a master's degree in the mathematical sciences by the intended date of admission.

Requirements

Course Requirements

A minimum of 55 normal credit hours of course work beyond the bachelor's degree (24 credit hours beyond the master's degree) and exclusive of doctoral dissertation work is required. Each student will be assigned a guidance committee, and together they will plan a complete program of course work designed to meet the student's objectives and to fulfill an option in applied mathematics, statistics or biostatistics. The student is strongly encouraged to select courses in more than one of these option areas and in a field of application whenever such courses contribute appropriately to his or her program. Each program, however, must be directed and approved by the student's guidance committee. A student receiving a grade of C+ or lower in any graduate course may be suspended from the program.

While the individual program will depend on the nature of the student's preparation prior to entering, each participant will ordinarily be required to complete one of the following concentrations:

Applied Mathematics Concentration

MATH 605	Complex Variables I	3
MATH 617	Measure and Integration	3
MATH 618	Applied Functional Analysis	3
MATH 622	Numerical Solutions to Differential Equations	3
MATH 637	Tensor Calculus and Differential Geometry	3
MATH 638	Mathematical Theories of Continua	3
MATH 693	Engineering Analysis III	3
MATH 801 & MATH 802	Asymptotic and Perturbation Methods and Integral Equations	6
MATH 821 & MATH 822	Advanced Applied Numerical Methods I and Advanced Applied Numerical Methods II	6
MATH 803	Advanced Applied Mathematics I	3
or MATH 825	Computational Fluid Dynamics and Solid Mechanics	
Total Hours		36

Statistics or Biostatistics Concentrations

MATH 517	Intermediate Real Analysis I	3
STAT 547	Analysis of Longitudinal Data	3
STAT 550	Categorical Data Analysis	3
STAT 625	Mathematical Statistics I	3
STAT 626	Mathematical Statistics II	3
STAT 627	Linear Statistical Models	3
STAT 628	Applied Multivariate Analysis	3
STAT 630	Time Series Models	3
STAT 640	Survival Analysis	3
STAT 827	Advanced Statistical Inference I	3
STAT 828	Advanced Statistical Inference II	3
Total Hours		33

Students who wish to concentrate in Biostatistics must take STAT 540 and at least six credits at the 700-level from either the College of Health Sciences or the Eastern Virginia Medical School offerings in epidemiology, community health, or history of diseases.

Colloquium Requirement

In order to develop an appreciation for the breadth of contemporary research in applied mathematics and statistics, all Ph.D. candidates will attend and succinctly summarize and evaluate in writing at least 16 professional seminars given by research faculty or external seminar visitors. The Richard F. Barry Colloquium Series is run by the department throughout the academic year. The department also conducts seminars jointly with other departments.

Foreign Language

A foreign language is not required.

Residency Requirement

An essential feature of doctoral study is the provision of total concentration on the field of study for significant periods of time. Students who wish to pursue a part of their doctoral study on a part-time basis may do so, but all doctoral students shall spend at least two academic years engaged in full-time graduate study.

Admission to Candidacy Examination

At the end of the core mathematics or statistics course work and prior to selecting a dissertation advisor, the student must pass an Admission to Candidacy Examination designed to test scholarly competence and knowledge and to give the examiners a basis for constructive recommendations on subsequent study. The written portion of this examination will be based upon an examination syllabus that will be provided to each student. The outcome of this examination will be reported to the vice provost for graduate studies and research as passed, failed, additional work to be completed, or to be re-examined. In the event of a re-examination, the outcome must be reported as passed or failed. This decision is final. The examination must be passed at least eight months prior to the granting of the degree.

Dissertation

A doctoral dissertation representing an achievement in research and a significant contribution to the field is required. Students must register for MATH 898 or MATH 899 each semester in which they are doing substantial work on their dissertations. A minimum of 24 hours of such research credit is required.

Defense of Dissertation

This examination will be oral and must be completed at least four weeks before the date on which the degree is to be conferred. The dissertation committee members must have the completed dissertation at least two weeks before the date of the oral examination. Under normal circumstances, it is expected that the student will have had a research paper accepted for publication prior to the dissertation defense.

MATHEMATICAL SCIENCES Courses

MATH 500. History of Mathematics. 3 Credits.
This course considers some of the major events in the development of mathematics from ancient times through the seventeenth century, including the discovery of incommensurability, the origins of the axiomatic method, trigonometry, solution of equations, calculation of areas and volumes, analytic geometry, probability, and calculus. Students will be graded on tests which consist mostly of problems typical of the periods considered.

MATH 501. Partial Differential Equations. 3 Credits.
Not available to students with credit in MATH 691. Separation of variable techniques, Sturm-Liouville systems, generalized Fourier series, orthogonal functions of the trigonometric, Legendre and Bessel type boundary value problems associated with the wave equation and the heat conduction equation in various coordinate systems, applications to physics and engineering.

MATH 504. Fundamental Concepts of Geometry. 3 Credits.
Fundamentals of Euclidean and non-Euclidean geometry. Alternatives to Euclidean geometry are examined using a variety of mathematical techniques. Special topics such as "Taxicab" geometry, the hyperbolic plane, the art of M.C. Escher, and the mathematics of maps may be included.

MATH 506. Number Theory and Discrete Mathematics. 3 Credits.
A survey course. Topics include the prime number theorem, congruences, Diophantine equations, continued fractions, quadratic reciprocity, combinatorics, logic, graphs, trees, algorithms, coding and linear programming.

MATH 508. Applied Numerical Methods I. 3 Credits.
An introduction to the numerical methods commonly used by scientists and engineers. Topics include solutions of equations of one variable, direct methods for solving linear systems, matrix factorization, stability analysis, iterative techniques, polynomial interpolation, numerical differentiation and integration, approximation theory, and initial and boundary value problems for ordinary differential equations.

MATH 509. Applied Numerical Methods II. 3 Credits.
Topics include least squares problems, the QR factorization, the conjugate gradient method, Householder transformation and the QR method for approximating eigenvalues and singular values of a matrix. For applications, the finite difference method and the finite element method for solving partial differential equations, trigonometric interpolation and FFT as well as introductory study of optimization are discussed. Prerequisites: A grade of C or better in MATH 508.

MATH 517. Intermediate Real Analysis I. 3 Credits.
A rigorous course in classical real analysis. Topics include the topology of Euclidean n-space, properties of vector valued functions of several variables such as limits, continuity, differentiability and integrability, pointwise and uniform convergence of sequences and series of functions; Fourier series.

MATH 518. Intermediate Real Analysis II. 3 Credits.
A rigorous course in classical real analysis. Topics include the topology of Euclidean n-space, properties of vector valued functions of several variables such as limits, continuity, differentiability and integrability, pointwise and uniform convergence of sequences and series of functions; Fourier series. Prerequisite: A grade of C or better in MATH 517.

MATH 520. Applied Mathematics I: Biomathematics. 3 Credits.
An introduction to current developments in the mathematical investigation of biological problems. Topics include scaling systems of differential equations, stability, perturbation methods, bifurcation phenomena and wave propagation. Applications are chosen from interacting populations, transport and reaction diffusion kinetics, transmission of nerve impulses, and cardiovascular modeling.

MATH 521. Applied Mathematics II: Mathematical Modeling. 3 Credits.
A one semester course in formulating, evaluating and validating mathematical models of physical phenomena. Models of traffic flow, mechanical vibrations, combustion, quantum mechanics, wave propagation or other fields of applied mathematics will be examined. Techniques learned in previous courses are used to simplify, analyze and solve these models. New methods introduced include phase-plane analysis, characteristics, calculus of variations and perturbation methods.

MATH 522. Applied Complex Variables. 3 Credits.
Not available to students with credit in MATH 692. Topics include complex numbers, analytical functions and their properties, derivatives, integrals, series representations, residues and conformal mappings. Applications of the calculus of residues and mapping techniques to the solution of boundary value problems in physics and engineering.

MATH 527. Applied Mathematics III: Elasticity. 3 Credits.
An introduction to the mathematical theory of linear and non-linear elastic continua. Topics include vectors, tensors, deformation, stress, nonlinear constitutive theory, exact solutions, infinitesimal theory, antiplane strain, plane strain, plane stress, extension, torsion, bending and elastic wave propagation.

MATH 528. Applied Mathematics IV: Fluid Mechanics. 3 Credits.
A mathematical investigation of the differential equations governing fluid flow with an emphasis on steady state incompressible flows. The Navier-Stokes equations are derived and some exact solutions are presented including the potential flow solutions. Topics therefore include classical ideal fluid flow and its complex variable representation, various approximations to the Navier-Stokes equations, boundary layer theory, and also surface and internal gravity wave motion, aspects of hydrodynamic stability theory and convection. Other topics may be introduced by the instructor. Corequisite: MATH 501.

MATH 557. Mathematics in Nature. 3 Credits.
A calculus and differential equations based description of many patterns observable in the natural world including wave motion in the air, oceans, rivers, and puddles; rainbows, halos and other meteorological phenomena; arrangement of leaves, petals and branches; height of trees; river meanders; animal and insect markings; mudcracks; spider webs; and others. Partial differential equations will be discussed as needed but a knowledge of ordinary differential equations will be assumed.

MATH 596. Topics in Mathematics. 1-3 Credits.
Study of selected topics. Prerequisite: permission of the instructor.

MATH 598. Tutorial Work in Special Topics in Mathematics. 1-3 Credits.
Independent study under the direction of an instructor including library research and reports. Prerequisite: permission of the instructor.

MATH 605. Complex Variables I. 3 Credits.
An advanced course in complex analysis. Prerequisites: MATH 501, MATH 518 and MATH 522.

MATH 615. Advanced Calculus for Teachers. 3 Credits.
An introduction to real analysis. Topics include the field and order axioms, completeness of the real line, theory of sequences, limits of function, continuity, differentiablility, sequences and series of functions, uniform convergence. Prerequisites: MATH 212.

MATH 617. Measure and Integration. 3 Credits.
An introduction to measure theory and integration theory with special emphasis on Lebesgue measure and the Lebesgue integral including Fatou's Lemma, the Monotone Convergence Theorem and the Dominated Convergence Theorem. Prerequisite: MATH 518.

MATH 618. Applied Functional Analysis. 3 Credits.
Topics include orthogonal projections to subspaces, duality, the Hahn-Banach theorem and the Banach-Steinhaus theorem, L-2 spaces and convolution operators, fixed point theory, construction of Hilbert spaces, approximation procedures in Hilbert spaces, and spectral theory. Prerequisites: MATH 617.

MATH 620. Optimization Techniques. 3 Credits.
Theory and computational algorithms for the optimization of constrained linear and nonlinear systems or for locating the maximum of a constrained nonlinear function. Applications to problems in economics, operations research and systems theory. Prerequisites: MATH 312 and MATH 316.

MATH 622. Numerical Solutions to Differential Equations. 3 Credits.
An in-depth study of the numerical solution to ordinary and partial differential equations. Topics include linear multi-step methods, Runge-Kutta methods, stiff differential equations, collocation methods, and strong and weak stability analysis for ODEs. For PDEs, finite difference methods are examined. Prerequisites: MATH 509.

MATH 632. Master's Project. 3 Credits.
Under the guidance of a faculty member in the Department of Mathematics and Statistics, the student will undertake a significant data analysis problem in a scientific setting outside the department. A written report and/or public presentation of results will be required. Prerequisite: permission of graduate program director.

MATH 637. Tensor Calculus and Differential Geometry. 3 Credits.
Topics include metric spaces, bilinear and quadratic forms, tensors, point manifolds, theory of curves, geodesic differentiation, theory of surfaces, curvature of general manifolds, integrability. Prerequisites: MATH 517.

MATH 638. Mathematical Theories of Continua. 3 Credits.
Topics include deformation, motion, stress, conservation laws, and constitutive theories. Prerequisites: MATH 501 and MATH 637.

MATH 691. Engineering Analysis I. 3 Credits.
Not available to students with credit in MATH 501. Separation of variable techniques, Sturm-Liouville systems, generalized Fourier series, orthogonal functions of the trigonometric, Legendre and Bessel type, boundary value problems associated with the wave equation and the heat conduction equation in various coordinate systems, applications to physics and engineering.

MATH 692. Engineering Analysis II. 3 Credits.
Not available to students with credit in MATH 522. Topics include complex numbers, analytical functions and their properties, derivatives, integrals, series representations, residues and conformal mappings. Applications of the calculus of residues and mapping techniques to the solution of boundary value problems in physics and engineering. Prerequisites: MATH 312.

MATH 693. Engineering Analysis III. 3 Credits.
Advanced topics in the theory and application of ordinary differential equations, distributions, Green's functions, classification of partial differential equations, initial-value problems, eigenfunction expansions for boundary-value problems, selected special functions, singular perturbation theory for differential equations. Prerequisites: MATH 501 or MATH 691.

MATH 695. Seminar in Mathematics. 1-3 Credits.
Seminar in advanced topics. Prerequisites: permission of the instructor.

MATH 696. Topics in Mathematics. 1-3 Credits.
Advanced study of selected topics. Prerequisites: permission of the instructor.

MATH 697. Topics in Mathematics. 1-3 Credits.
Advanced study of selected topics.

MATH 698. Research. 3 Credits.

MATH 699. Thesis. 3 Credits.

MATH 702. Integral Equations. 3 Credits.
Advanced material in theory and application of integral equations. Formulation of the integral equation problems, cause and effect, connection with differential equations, scattering theory, boundary values of partial differential equations, Fredholm and Volterra theory, expansions in orthogonal functions, theory of Hilbert-Schmidt singular integral equations, method of Wiener-Hopf, monotone operator theory, and direct methods. Prerequisites: MATH 618 and MATH 693.

MATH 705. Numerical Linear Algebra. 3 Credits.
Topics include orthogonal vectors and matrices, norms, singular value decomposition, QR factorization, Gram-Schmidt orthogonalization, least squares problems, condition numbers, stability of backward substitution, stability of least squares algorithm, reduction to Hessenberg or tridiagonal form, and the QR algorithm. Prerequisites: MATH 509.

MATH 720. Advanced Applied Functional Analysis. 3 Credits.
In the first half of this course, several concepts in the classical functional analysis are studied. Topics include Banach Spaces, the dual spaces, the Baire category theorem, the adjoint operator, weak convergence, spectral theory and compact operators. In the second half, at the instructor's discretion, special topics are studied. Possible topics include ill-posed problems, inverse scattering theory, the regular Sturm-Liouville problem and the Dirichlet problem for Laplace's equation. Prerequisites: MATH 617 and MATH 618.

MATH 721. Advanced Applied Numerical Methods I. 3 Credits.
Numerical solutions of partial differential equations and integral equations. For PDEs, the finite difference method, the finite element method and the boundary element method are studied. A priori and a posteriori error estimates are examined. For integral equations, topics include Galerkin methods, collocation methods, and the Petrov-Galerkin method. Prerequisites: MATH 501, MATH 508 and MATH 509.

MATH 722. Advanced Applied Numerical Methods II. 3 Credits.
Numerical solutions of partial differential equations and integral equations. For PDEs, the finite difference method, the finite element method and the boundary element method are studied. A priori and a posteriori error estimates are examined. For integral equations, topics include Galerkin methods, collocation methods, and the Petrov-Galerkin method. Prerequisites: MATH 501, MATH 508 and MATH 509.

MATH 725. Computational Fluid Dynamics and Solid Mechanics. 3 Credits.
An introduction to the theory and methodology of computational fluid dynamics and solid mechanics, with an emphasis on the interplay of the two fields, the study of fluid-structure interactions. Topics will include numerical methods for Navier-Stokes equations, computational techniques for free surfaces, theory of Lagrange multipliers, constrained dynamic problems, fluid-structure coupling problems, differential-algebraic equations, and others. Prerequisites: MATH 501, MATH 508 and MATH 509.

MATH 745. Transform Methods. 3 Credits.
Use of integral transforms for students of applied mathematics, physics and engineering. Integral transforms studied are Laplace, Fourier, Hankel, finite Z-transforms and other special transforms. Prerequisites: MATH 691 and MATH 692.

MATH 750. Calculus of Variations. 3 Credits.
Maximum and minimum techniques in calculus and dynamic programming. Derivation of Euler-Lagrange equations for a variety of conditions, formulation of extremum problems with side conditions for ordinary and partial differential equations. Application to dynamics, elasticity, heat and mass transfer, energy principles and finite element techniques. Prerequisites: MATH 691 and MATH 692.

MATH 755. Introduction to Kinetic Theory and Mesoscopic Methods for Computational Mechanics I. 3 Credits.
The goal of this course is to provide an introduction to kinetic theory and nonequilibrium statistical mechanics, which bridges the microscopic theories and the macroscopic continuum theories of flows. Topics include the molecular dynamics of N particles, Hamiltonian equation, Liouville equation, Boltzmann equation, binary collision, linearized collision operator and its eigen theory, the H-theorem and irreversibility, calculation of the transport coefficients. Prerequisites: MATH 501 or MATH 691 or permission of the instructor.

MATH 756. Introduction to Kinetic Theory and Mesoscopic Methods for Computational Mechanics II. 3 Credits.
This is the second part of the study of the interaction between kinetic theory and nonequilibrium statistical mechanics. Models of Boltzmann equation and numerical techniques for hydrodynamic equations (Euler and Navier-Stokes equations) and the Boltzmann equation are studied. Topics include Non-normal and moment method, Maxwell's moment method, BGK model equation, gas mixtures and transport phenomena in mixtures, the Wang-Chang-Uhlenbeck equation, Enskog equation for dense gases, the lattice Boltzmann equation for incompressible flows, the gas-kinetic scheme for compressible flows and the Direct Simulation Monte Carlo (DSMC) method. Prerequisites: MATH 755/MATH 855.

MATH 771. Scientific Computing in Applied Mathematics. 3 Credits.
Numerical methods for algebraic systems, partial differential equations, integral equations, optimization, Monte Carlo method, and statistics, with emphasis on computational performance using modern programming languages such as Fortran 90 or C/C++ and modern computer architecture. Basic techniques of parallel computing using MPI (Message Passing Interface), openMP, or other distributed/multicore computing platforms. Common tools in scientific computing, such as Unix shell commands, debuggers, version control systems, scientific libraries, graphics and visualization, will also be introduced. Prerequisites: MATH 501, MATH 508 and MATH 509.

MATH 795. Seminar in Mathematics. 1-3 Credits.
Seminar in advanced topics. Prerequisites: permission of the instructor.

MATH 796. Topics in Mathematics. 1-3 Credits.
Advanced study of selected topics. Prerequisites: permission of the instructor.

MATH 797. Topics in Mathematics. 1-3 Credits.
Advanced study of selected topics. Prerequisites: permission of instrictor.

MATH 801. Asymptotic and Perturbation Methods. 3 Credits.
Asymptotic and perturbation methods are developed and used to solve linear and nonlinear differential equations. Included are analyses of Duffing's Equation, Van der Pol's Equation, and Mathieu's Equation. Singular perturbation theory and the Method of Matched Asymptotic Expansions are used to solve equations with boundary layer type solutions. Asymptotic expansions of integrals using Laplace's Method, Method of Steepest Descent and Method of Stationary Phase are developed. Applications from all areas of applied mathematics are given. Prerequisites: MATH 693.

MATH 802. Integral Equations. 3 Credits.
Advanced material in theory and application of integral equations. Formulation of the integral equation problems cause and effect, connection with differential equations, scattering theory, boundary values of partial differential equations, Fredholm and Volterra theory, expansions in orthogonal functions, theory of Hilbert-Schmidt singular integral equations, method of Wiener-Hopf, monotone operator theory, and direct methods. Prerequisites: MATH 618 and MATH 693.

MATH 803. Advanced Applied Mathematics I. 3 Credits.
Advanced techniques of mathematics applied to specific topics of physical interest. Examples could include high activation energy asymptotics applied to combustion, singular integral equations applied to fracture mechanics, or bifurcation theory applied to non-linear phenomena such as transition to turbulence, phase transitions and hydrodynamic stability. Prerequisites: MATH 702.

MATH 804. Advanced Applied Mathematics II. 3 Credits.
Advanced techniques of mathematics applied to specific topics of physical interest. Examples could include high activation energy asymptotics applied to combustion, singular integral equations applied to fracture mechanics, or bifurcation theory applied to non-linear phenomena such as transition to turbulence, phase transitions and hydrodynamic stability. Prerequisites: MATH 702.

MATH 805. Numerical Linear Algebra. 3 Credits.
Topics include orthogonal vectors and matrices, norms, singular value decomposition, QR factorization, Gram-Schmidt orthogonalization, least squares problems, condition numbers, stability of backward substitution, stability of least squares algorithm, reduction to Hessenberg or tridiagonal form, and the QR algorithm. Prerequisites: MATH 509.

MATH 817. Mathematical Analysis III. 3 Credits.
Topics in mathematical analysis. Measure and integration; classical Banach spaces; operators on linear spaces; Fourier series and integrals. Prerequisites: MATH 617 and MATH 618.

MATH 820. Advanced Applied Functional Analysis. 3 Credits.
In the first half of this course, several concepts in the classical functional analysis are studied. Topics include Banach Spaces, the dual spaces, the Baire category theorem, the adjoint operator, weak convergence, spectral theory and compact operators. In the second half, at the instructor's discretion, special topics are studied. Possible topics include ill-posed problems, inverse scattering theory, the regular Sturm-Liouville problem and the Dirichlet problem for Laplace's equation. Prerequisites: MATH 617 and MATH 618.

MATH 821. Advanced Applied Numerical Methods I. 3 Credits.
Numerical solutions of partial differential equations and integral equations. For PDEs, the finite difference method, the finite element method and the boundary element method are studied. A priori and a posteriori error estimates are examined. For integral equations, topics include Galerkin methods, collocation methods, and the Petrov-Galerkin method. Prerequisites: MATH 501, MATH 508 and MATH 509.

MATH 822. Advanced Applied Numerical Methods II. 3 Credits.
Numerical solutions of partial differential equations and integral equations. For PDEs, the finite difference method, the finite element method and the boundary element method are studied. A priori and a posteriori error estimates are examined. For integral equations, topics include Galerkin methods, collocation methods, and the Petrov-Galerkin method. Prerequisites: MATH 821.

MATH 823. Approximation and Optimization I. 3 Credits.
Introductory and advanced topics representing current research in approximation and optimization techniques for various application problems. Topics include recent developments in algorithms, their analysis, and applications such as data fitting and pattern separation. Prerequisites: permission of the graduate program director.

MATH 825. Computational Fluid Dynamics and Solid Mechanics. 3 Credits.
An introduction to the theory and methodology of computational fluid dynamics and solid mechanics, with an emphasis on the interplay of the two fields, the study of fluid-structure interactions. Topics will include numerical methods for Navier-Stokes equations, computational techniques for free surfaces, theory of Lagrange multipliers, constrained dynamic problems, fluid-structure coupling problems, differential-algebraic equations, and others. Prerequisites: MATH 501, MATH 508 and MATH 509.

MATH 845. Transform Methods. 3 Credits.
Use of integral transforms for students of applied mathematics, physics and engineering. Integral transforms studied are Laplace, Fourier, Hankel, finite Z-transforms and other special transforms. Prerequisites: MATH 691 and MATH 692.

MATH 850. Calculus of Variations. 3 Credits.
Maximum and minimum techniques in calculus and dynamic programming. Derivation of Euler-Lagrange equations for a variety of conditions, formulation of extremum problems with side conditions for ordinary and partial differential equations. Application to dynamics, elasticity, heat and mass transfer, energy principles and finite element techniques. Prerequisites: MATH 691 and MATH 692.

MATH 855. Introduction to Kinetic Theory and Mesoscopic Methods for Computational Mechanics I. 3 Credits.
The goal of this course is to provide an introduction to kinetic theory and nonequilibrium statistical mechanics, which bridges the microscopic theories and the macroscopic continuum theories of flows. Topics include the molecular dynamics of N particles, Hamiltonian equation, Liouville equation, Boltzmann equation, binary collision, linearized collision operator and its eigen theory, the H-theorem and irreversibility, calculation of the transport coefficients. Prerequisites: MATH 501 or MATH 691 or permission of the instructor.

MATH 856. Introduction to Kinetic Theory and Mesoscopic Methods for Computational Mechanics II. 3 Credits.
This is the second part of the study of the interaction between kinetic theory and nonequilibrium statistical mechanics. Models of Boltzmann equation and numerical techniques for hydrodynamic equations (Euler and Navier-Stokes equations) and the Boltzmann equation are studied. Topics include Non-normal and moment method, Maxwell’s moment method, BGK model equation, gas mixtures and transport phenomena in mixtures, the Wang-Chang-Uhlenbeck equation, Enskog equation for dense gases, the lattice Boltzmann equation for incompressible flows, the gas-kinetic scheme for compressible flows and the Direct Simulation Monte Carlo (DSMC) method. Prerequisites: MATH 755/MATH 855.

MATH 871. Scientific Computing in Applied Mathematics. 3 Credits.
Numerical methods for algebraic systems, partial differential equations, integral equations, optimization, Monte Carlo method, and statistics, with emphasis on computational performance using modern programming languages such as Fortran 90 or C/C++ and modern computer architecture. Basic techniques of parallel computing using MPI (Message Passing Interface), openMP, or other distributed/multicore computing platforms. Common tools in scientific computing, such as Unix shell commands, debuggers, version control systems, scientific libraries, graphics and visualization, will also be introduced. Prerequisites: MATH 501, MATH 508 and MATH 509.

MATH 895. Seminar in Mathematics. 1-3 Credits.
Seminar in advanced topics. Prerequisite: permission of the instructor.

MATH 896. Topics in Mathematics. 1-3 Credits.
Advanced study of selected topics. Prerequisite: permission of the instructor.

MATH 897. Topics in Mathematics. 1-3 Credits.
Advanced study of selected topics.

MATH 898. Research. 1-9 Credits.

MATH 899. Dissertation. 1-9 Credits.

MATH 999. Doctoral Graduate Credit. 1 Credit.
This course is a pass/fail course doctoral students may take to maintain active status after successfully passing the candidacy examination. All doctoral students are required to be registered for at least one graduate credit hour every semester until their graduation.

STATISTICS Courses

STAT 505. Introduction to Data Handling. 3 Credits.
Use of SAS and R to handle data sets. Topics for SAS include data input, creating permanent data sets, merging data sets, creating new variables, sorting, printing, charting, formatting, IML programming, macro programming, and an overview of proc SQL and other statistical procedures. Topics for R include data structure, control structure, writing functions, and graphics. Prerequisites: A grade of C or better in STAT 130M or equivalent, and a grade of C or better in MATH 316 or equivalent, or permission of the instructor.

STAT 531. Theory of Statistics. 3 Credits.
Topics include point and interval estimation, tests of hypotheses, introduction to linear models, likelihood techniques, and regression and correlation analysis. Prerequisites: A grade of C or better in STAT 331 or permission of the instructor.

STAT 532. Sampling Theory. 3 Credits.
Sampling from finite populations is discussed. Topics such as simple random sampling, stratified random sampling and ratio and regression estimation are included. Also discussed are aspects of systematic sampling, cluster sampling, and multi-stage sampling. Prerequisites: A grade of C or better in STAT 431/STAT 531.

STAT 535. Design and Analysis of Experiments. 3 Credits.
Topics include analysis of variance with one or more factors, multiple comparisons, randomized blocks, Latin squares and related designs: multifactor factorial experiments; blocking and confounding in the 2(k) factorial design; two-level fractional factorial designs. Statistical software will be used to analyze real life data. Prerequisites: A grade of C or better in STAT 405 or STAT 505 and STAT 437 or STAT 537.

STAT 537. Applied Regression and Time Series Analysis. 3 Credits.
Topics include theory of least squares, simple linear regression, multiple regression and residual analysis. Multicollinearity issues, regression on dummy variables, extensions to dependent errors and introduction to elementary time series, including auto-regressive and moving-average models will also be discussed. Fitting and interpreting the models using SAS and R software for real data is emphasized. Prerequisites: A grade of C or better in STAT 531. Pre- or corequisite: STAT 405 or STAT 505.

STAT 540. Clinical Trials. 3 Credits.
An introduction to statistical methods used in the design, conduct, and analysis of clinical trials. Topics include: study designs, treatment allocation, sample size and power, clinical life tables, log rank test, cross-over designs, and sequential methods of monitoring clinical trials. Prerequisites: A grade of C or better in STAT 431 or STAT 531.

STAT 542. Environmental Statistics. 3 Credits.
Topics include nonlinear and generalized linear models, quantitative risk assessment, analysis of stimulus-response and spatially correlated data, methods of combining data from several independent studies. Regression settings are emphasized where one or more predictor variables are used to make inferences on an outcome variable of interest. Applications include modeling growth inhibition of organisms exposed to environmental toxins, spatial associations of like species, risk estimation, and spatial prediction. SAS is used extensively in the course. Prerequisites: A grade of C or better in STAT 431 or STAT 531; STAT 437 or STAT 537 recommended.

STAT 547. Analysis of Longitudinal Data. 3 Credits.
Topics include general linear models, weighted least squares (WLS), maximum likelihood (ML), restricted maximum likelihood (REML) methods of estimation, analysis of continuous response repeated measures data, parametric models for covariance structure, generalized estimating equations (GEE) and quasi least squares (QLS), models for discrete longitudinal data: marginal, random effects, and transition models. Limitations of existing approaches will be discussed. Emphasis will be on the application of these tools to data related to the biological and health sciences. Methods will be implemented using statistical software. Prerequisites: A grade of C or better in STAT 431 or STAT 531. Pre- or corequisite: STAT 405 OR STAT 505.

STAT 549. Nonparametric Statistics. 3 Credits.
Topics include the theory and applications of binomial tests and rank tests, including the tests of McNemar, Mann-Whitney, Friedman, Kruskal-Wallis, and Smirnov. Prerequisites: A grade of C or better in STAT 330 or STAT 331 or departmental permission.

STAT 550. Categorical Data Analysis. 3 Credits.
Topics include relative risk and odds ratio measures for 2 x 2 tables, the chi-square and Mantel-Haenszel tests, Fisher's exact test, analysis of sets of 2 x 2 tables using Cochran-Mantel-Haenszel methodology, analysis of I x J and sets of I x J tables for both nominal and ordinal data, logistic regression including the logit and probit models, and building and applying loglinear models. Emphasis will be on the application of these statistical tools to data related to the health and social sciences. Interpretation of computer output will be stressed. Prerequisites: A grade of C or better in STAT 431 or STAT 531.

STAT 560. Statistical Simulation/Programming Using Statistical Software Packages. 3 Credits.
This course is a data-based tour of advanced statistical techniques using software packages, exploring a catalog of data sets (simulated or otherwise) spanning a variety of fields and applications, including data suitable for regression, ANOVA, time series modeling, longitudinal data analysis and multivariate techniques. Approaches will include parametric, nonparametric, simulation, and bootstrapping. SAS and R (S-plus) will be used extensively, with some other specialized products. For writing actual (not packaged) code, PROC IML and R will be used. This is a finishing course for applied statisticians, highly recommended for students planning a career in statistical programming and simulation. Prerequisites: A grade of C or better in STAT 505 and two of STAT 535, STAT 537, STAT 547 and STAT 550.

STAT 597. Topics in Statistics. 1-3 Credits.
The advanced study of selected topics. Prerequisites: permission of the instructor.

STAT 613. Applied Statistical Methods I. 3 Credits.
Intended for graduate students in all academic disciplines; not available for credit to graduate students in the Department of Mathematics and Statistics. Topics include descriptive statistics, probability computations, estimation, hypothesis testing, linear regression, analysis of variance and categorical data analysis. Emphasis will be on statistical analysis of data arising in a research setting. The rationale for selecting methods to address research questions will be emphasized. Examples will be given from the health sciences, social sciences, engineering, education and other application areas. Prerequisites: A grade of C or better in STAT 130M or STAT 330 or MATH 211 or MATH 226 or permission of the instructor.

STAT 625. Mathematical Statistics I. 3 Credits.
An introduction to probability. Topics include axiomatic foundations of probability, conditional probability, Bayes formula, random variables, density and mass functions, stochastic independence, expectation, moment generating functions, transformations, common families of distributions, multiple random variables, covariance and correlation, multivariate distributions, convergence concepts, law of large numbers, limit theorems. Prerequisites: A grade of C+ or better in STAT 531.

STAT 626. Mathematical Statistics II. 3 Credits.
An introduction to statistical inference. Principles of data reduction, sufficiency, completeness, ancillary, likelihood principle, point estimation, method of moments, maximum likelihood and Bayes estimation, Cramer-Rao inequality, hypothesis testing, likelihood ratio tests, Bayesian tests, most powerful tests, Neyman-Pearson Lemma, interval estimates, pivotal quantities, asymptotic evaluations, consistency and asymptotic relative efficiency. Prerequisites: A grade of C+ or better in STAT 625.

STAT 627. Linear Statistical Models. 3 Credits.
Topics include the multivariate normal distribution, distributions of quadratic forms, the general linear model, estimability, the Gauss-Markov theorem and general linear hypotheses, analysis of variance (ANOVA) and covariance (ANCOVA) with special attention to unbalanced data, and analysis of mixed effects and variance components models including repeated measures and split-plot designs. Prerequisites: STAT 626.

STAT 628. Applied Multivariate Analysis. 3 Credits.
Topics include the multivariate normal distribution, graphical display of multivariate data and tests for normality, Hotelling's T2, multivariate analysis of variance (MANOVA) and regression, profile analysis, growth curve models, canonical correlation analysis, principal components, factor models, clustering, and discriminant analysis. All methods are implemented using the SAS statistical software. Prerequisites: STAT 537 or STAT 627 or permission of the instructor.

STAT 630. Time Series Models. 3 Credits.
This course examines the principles and concepts of time series and forecasting. Study includes theory, methods, and model parameter estimation taking into account correlation and autocorrelation structures with data applications from pollution, economics, seasonal trends, and the stock market. Notions of autoregressive, moving, average, stationary and nonstationary ARIMA models will be discussed. The multivariate version and state-space models will also be introduced. Simulation of time series data will be discussed in depth. Prerequisites: STAT 626, STAT 505, and STAT 537.

STAT 632. Master’s Project. 3 Credits.
Under the guidance of a faculty member in the Department of Mathematics and Statistics, the student will undertake a significant data analysis problem in a scientific setting outside the department. A written report and/or public presentation of results will be required. Prerequisites: permission of graduate program director.

STAT 635. Statistical Consulting. 3 Credits.
This course is intended to teach statistical consulting techniques to graduate students in statistics. Students are expected to work on statistical consulting problems brought by faculty and graduate students in various fields. Prerequisites: STAT 626.

STAT 640. Survival Analysis. 3 Credits.
Survival time models, clinical life tables, nonparametric methods for estimating survival functions, Cox regression, survival distributions, mathematical and graphical methods for goodness of fit, proportional hazards models, comparison of treatment groups, regression models. Prerequisite: STAT 626.

STAT 667. Cooperative Education. 1-3 Credits.
1-3 credits. Student participation for credit based on academic relevance of the work experience, criteria, and evaluative procedures as formally determined by the department and the cooperative education program prior to the semester in which the work experience is to take place.

STAT 697. Topics in Statistics. 1-3 Credits.
Advanced study of selected topics. Prerequisites: permission of the instructor.

STAT 727. Advanced Statistical Inference I. 3 Credits.
Topics to be covered include introduction to measure theoretic probability, properties of group and exponential families, sufficiency, unbiasedness, equivariance, properties of estimators, large sample theory, maximum likelihood estimation, EM algorithm, information inequality, asymptotic optimality. Prerequisites: A grade of C+ or higher in MATH 517 and STAT 626.

STAT 728. Advanced Statistical Inference II. 3 Credits.
Topics to be covered include convergence concepts, limit theorems, large sample theory, asymptotic distributions, decision theory, minimax, admissibility, Bayes estimates, generalized Neyman-Pearson Lemma, uniformly most powerful tests, unbiased tests, invariant tests, and Bayesian tests. Prerequisites: A grade of C+ or higher in STAT 727 or STAT 827.

STAT 795. Seminar in Statistics. 1-3 Credits.
1-3 credits. Prerequisite: permission of the instructor.

STAT 797. Topics in Statistics. 1-3 Credits.
Advanced study of selected topics. Prerequisites: Permission of the instructor.

STAT 827. Advanced Statistical Inference I. 3 Credits.
Topics to be covered include introduction to measure theoretic probability, properties of group and exponential families, sufficiency, unbiasedness, equivariance, properties of estimators, large sample theory, maximum likelihood estimation, EM algorithm, information inequality, asymptotic optimality. Prerequisites: A grade of C+ or higher in MATH 517 and STAT 626.

STAT 828. Advanced Statistical Inference II. 3 Credits.
Topics to be covered include convergence concepts, limit theorems, large sample theory, asymptotic distributions, decision theory, minimax, admissibility, Bayes estimates, generalized Neyman-Pearson Lemma, uniformly most powerful tests, unbiased tests, invariant tests, and Bayesian tests. Prerequisites: A grade of C+ or higher in STAT 727 or STAT 827.

STAT 895. Seminar in Statistics. 1-3 Credits.
1-3 credits. Prerequisite: permission of the instructor.

STAT 897. Topics in Statistics. 1-3 Credits.

STAT 898. Research. 1-9 Credits.

STAT 899. Dissertation. 1-9 Credits.

STAT 999. Doctoral Graduate Credit. 1 Credit.
This course is a pass/fail course doctoral students may take to maintain active status after successfully passing the candidacy examination. All doctoral students are required to be registered for at least one graduate credit hour every semester until their graduation.