MATH - MATHEMATICS

MATH 601 Methods of Applied Mathematics I

Credits 3. 3 Lecture Hours. Methods of linear algebra, vector analysis and complex variables. **Prerequisite:** MATH 308 or equivalent; also taught at Galveston campus.

MATH 602 Methods and Applications of Partial Differential Equations

Credits 3. 3 Lecture Hours. Classification of linear partial differential equations of the second order; Fourier series, orthogonal functions, applications to partial differential equations; special functions, Sturm-Liouville theory, application to boundary value problems; introduction to Green's functions; finite Fourier transforms. **Prerequisites:** MATH 601 or MATH 308 and MATH 407.

MATH 603 Methods of Applied Mathematics II

Credits 3. 3 Lecture Hours. Tensor algebra and analysis; partial differential equations and boundary value problems; Laplace and Fourier transform methods for partial differential equations. **Prerequisite:** MATH 601 or MATH 311.

MATH 604 Mathematical Foundations of Continuum Mechanics

Credits 3. 3 Lecture Hours. Mathematical description of continuum mechanics principles, including: tensor analysis, generalized description of kinematics and motion, conservation laws for mass and momentum; invariance and symmetry principles; application to generalized formulation of constitutive expressions for various fluids and solids. **Prerequisites:** MATH 410; MATH 451 or equivalent.

MATH 605 Mathematical Fluid Dynamics

Credits 3. 3 Lecture Hours. Derivation of basic equations of motion; Navier-Stokes equations; potential equations; some exact solutions in two and three dimensions; equations of boundary layer theory; vorticity-stream function formulation and vortex dynamics; introduction to hydrodynamic stability; introduction to equations of turbulence. **Prerequisite:** MATH 601 or equivalent.

MATH 606 Theory of Probability I

Credits 3. 3 Lecture Hours. Measure and integration, convergence concepts, random variables, independence and conditional expectation, laws of large numbers, central limit theorems, applications. **Prerequisite:** MATH 607 or approval of instructor.

MATH 607 Real Variables I

Credits 3. 3 Lecture Hours. Lebesgue measure and integration theory, differentiation, Lp-spaces, abstract integration, signed measures; Radon-Nikodym theorem, Riesz representation theorem, integration on product spaces. **Prerequisite:** MATH 447 or equivalent.

MATH 608 Real Variables II

Credits 3. 3 Lecture Hours. Banach spaces, theorems of Hahn-Banach and Banach-Steinhaus, the closed graph and open mapping theorems, Hilbert spaces, topological vector spaces and weak topologies. **Prerequisite:** MATH 607.

MATH 609 Numerical Analysis

Credits 4. 3 Lecture Hours. 3 Lab Hours. Interpolation, numerical evaluation of definite integrals and solution of ordinary differential equations; stability and convergence of methods and error estimates. **Prerequisite:** Knowledge of computer programming (C or FORTRAN).

MATH 610 Numerical Methods in Partial Differential Equations

Credits 3. 3 Lecture Hours. Introduction to finite difference and finite element methods for solving partial differential equations; stability and convergence of methods and error bounds. **Prerequisite:** MATH 417 or MATH 609 or equivalent; knowledge of computer programming.

MATH 611 Introduction to Ordinary and Partial Differential Equations

Credits 3. 3 Lecture Hours. Basic theory of ordinary differential equations; existence and uniqueness, dependence on parameters, phase portraits, vector fields. Partial differential equations of first order, method of characteristics. Basic linear partial differential equations: Laplace equation, heat (diffusion) equation, wave equation and transport equation. Solution techniques and qualitative properties. **Prerequisite:** MATH 410 or equivalent or instructor's approval.

MATH 612 Partial Differential Equations

Credits 3. 3 Lecture Hours. Theory of linear partial differential equations; Sobolev spaces; elliptic equations (including boundary value problems and spectral theory); linear evolution equations of parabolic and hyperbolic types (including initial and boundary value problems). As time permits, additional topics might be included. **Prerequisite:** MATH 611 and MATH 607 or MATH 641, or approval of instructor.

MATH 613 Graph Theory

Credits 3. 3 Lecture Hours. One or more broad areas of graph theory or network theory, such as planarity, connectivity, Hamiltonian graphs, colorings of graphs, automorphisms of graphs, or network theory. **Prerequisite:** Graduate classification; MATH 431 or equivalent; or approval of instructor.

MATH 614 Dynamical Systems and Chaos

Credits 3. 3 Lecture Hours. Discrete maps; continuous flows; dynamical systems; Poincaré maps; symbolic dynamics; chaos, strange attractors; fractals; computer simulation of dynamical systems. **Prerequisite:** MATH 308 or equivalent.

MATH 615 Introduction to Classical Analysis

Credits 3. 3 Lecture Hours. Review of analysis on the real line and cardinality; the study of general metric spaces, including convergence, continuity, completeness, and compactness; properties of the space of continuous functions on the real line; convergence and approximation; Fourier series; may include infinite products, Riemann-Stieltjes integration, or measure theory. **Prerequisites:** MATH 409 or equivalent.

MATH 617 Theory of Functions of a Complex Variable I

Credits 3. 3 Lecture Hours. Holomorphic functions, complex integral theorems, Runge's theorem, residue theorem, Laurent series, conformal mapping, harmonic functions. **Prerequisite:** MATH 410.

MATH 618 Theory of Functions of a Complex Variable II

Credits 3. 3 Lecture Hours. Infinite products, Weierstrass factorization theorem, Mittag-Leffler's theorem, normal families, Riemann mapping theorem, analytic continuation, Picard's theorems and selected topics. **Prerequisite:** MATH 617.

MATH 619 Applied Probability

Credits 3. 3 Lecture Hours. Measure Theory; Lebesgue integration; random variables; expectation; condition expectation martingales and random walks; designed for beginning graduate students in mathematics, statistics, the sciences and engineering and students in economics and finance with a strong mathematical background. **Prerequisites:** MATH 409 and MATH 411.

MATH 620 Algebraic Geometry I

Credits 3. 3 Lecture Hours. Affine and projective varieties; sheaves; cohomology; Riemann-Roch Theorem for curves. **Prerequisite:** MATH 653 or approval of instructor.

MATH 622 Differential Geometry I

Credits 3. 3 Lecture Hours. Surfaces in 3-D space and generalizations to submanifolds of Euclidean space; smooth manifolds and mappings; tensors; differential forms; Lie groups and algebras; Stokes' theorem; deRham cohomology; Frobenius theorem; Riemannian manifolds. **Prerequisites:** MATH 304 or equivalent; approval of instructor.

MATH 623 Differential Geometry II

Credits 3. 3 Lecture Hours. Curvature of Riemannian manifolds; vector bundles; connections; Maurer-Cartan Form; Laplacian; geodesics; Chern-Gauss-Bonnet theorem; additional topics to be selected by the instructor. **Prerequisites:** MATH 622 or approval of instructor.

MATH 625 Applied Stochastic Differential Equations

Credits 3. 3 Lecture Hours. Stochastic integration, Ito Calculus and applications of stochastic differential equations to finance and engineering. **Prerequisite:** MATH 619.

MATH 626 Analytic Number Theory

Credits 3. 3 Lecture Hours. Analytic properties of the Riemann zeta function and Dirichlet L-functions; Dirichlet characters; prime number theorem; distribution of primes in arithmetic progressions; Siegel's theorem; the large sieve inequalities; Bombieri-Vinogradov theorem. **Prerequisite:** MATH 617.

MATH 627 Algebraic Number Theory

Credits 3. 3 Lecture Hours. Algebraic number fields and rings of algebraic integers; arithmetic in algebraic number fields; ideals; unique factorization of ideals; ideal classes and the class group; finiteness of the class number; Minkowski's theorem; Dirichlet's unit theorem; quadratic and cyclotomic number fields; splitting of primes in extension fields. **Prerequisite:** MATH 653 or approval of instructor.

MATH 628 Mathematical Tools in Finance

Credits 3. 3 Lecture Hours. Advanced linear algebra, orthogonality and projections, eigenvalue and SV decomposition, pseudoinverse, least squares and minimum norm solutions, hyperplane separation theorem; applications to Mean-Variance portfolio analysis and capital asset pricing model, arbitrage and fundamental theorem of asset pricing, 1-period asset replication in incomplete markets; optimization and calculus of variations; Lagrange multipliers, dynamical programming, numerical methods; applications to utility theory, multi-period asset replication in incomplete markets; application of probability topics including conditional expectations, Markov chains and Martingales, extreme value theory; applications in optional stopping theorem and trading strategies, Markov Chains in credit risk modeling. **Prerequisite:** MATH 251 and MATH 411, or equivalent, or approval of instructor.

MATH 629 History of Mathematics

Credits 3. 3 Lecture Hours. Major events in the evolution of mathematical thought from ancient times to the present, the development of various important branches of mathematics, including numeration, geometry, algebra, analysis, number theory, probability, and applied mathematics. **Prerequisite:** MATH 304 or equivalent.

MATH 630 Combinatorics

Credits 3. 3 Lecture Hours. This is an introduction at the graduate level to the fundamental ideas and results of combinatorics, including enumerative techniques, sieve methods, partially ordered sets and generating functions. **Prerequisite:** MATH 302, MATH 431, or equivalent; or approval of instructor.

MATH 632 A Transition to Graduate Level Mathematics

Credits 3. 3 Lecture Hours. Important concepts and techniques in Linear Algebra, Real Analysis, and Differential Equations with an emphasis on problem solving and proofs. **Prerequisites:** MATH 171, MATH 172, MATH 221, and MATH 323, or equivalent; or approval of instructor.

MATH 634 Stochastic Calculus

Credits 3. 3 Lecture Hours. Topics include Brownian motion, Ito integrals, Ito formula, Martingale Theorem, stochastic differential equations, random time change, Girsanov theorem, and application to mathematical finance. **Prerequisites:** MATH 221 or equivalent, MATH 308, MATH 411, or approval of instructor.

MATH 636 Topology I

Credits 3. 3 Lecture Hours. Set theory, topological spaces, generalized convergence, compactness, metrization, connectedness, uniform spaces, function spaces. **Prerequisite:** Approval of instructor.

MATH 637 Topology II

Credits 3. 3 Lecture Hours. Continuation of MATH 636. **Prerequisite:** MATH 636 or approval of instructor.

MATH 638 Hyperbolic Conservation Laws

Credits 3. 3 Lecture Hours. Introduction to basic theory and numerical methods for first order nonlinear partial differential equations; basic existence-uniqueness theory for scalar conservation laws; special equations and systems of interest in various applications and Riemann problem solutions for such systems; design of numerical methods for general hyperbolic systems; stability and convergence properties of numerical methods. **Prerequisite:** MATH 610 or MATH 612 or approval of instructor.

MATH 639 Iterative Techniques

Credits 4. 3 Lecture Hours. 3 Lab Hours. Numerical methods for solving linear and nonlinear equations and systems of equations; eigenvalue problems. **Prerequisites:** Elementary linear algebra and knowledge of computer programming (C or FORTRAN).

MATH 640 Linear Algebra for Applications

Credits 3. 3 Lecture Hours. Review of linear algebra; spectral theory in inner product spaces; decomposition theorems; duality theory and multilinear algebra; tensor products; applications. May be taken concurrently with MATH 641. **Prerequisite:** MATH 304 or equivalent.

MATH 641 Analysis for Applications I

Credits 3. 3 Lecture Hours. Review of preliminary concepts; sequence and function spaces; normed linear spaces, inner product spaces; spectral theory for compact operators; fixed point theorems; applications to integral equations and the calculus of variations. **Prerequisites:** MATH 447 and MATH 640 or approval of instructor.

MATH 642 Analysis for Applications II

Credits 3. 3 Lecture Hours. Distributions and differential operators; transform theory; spectral theory for unbounded self-adjoint operators; applications to partial differential equations; asymptotics and perturbation theory. **Prerequisite:** MATH 641.

MATH 643 Algebraic Topology I

Credits 3. 3 Lecture Hours. Fundamental ideas of algebraic topology, homotopy and fundamental group, covering spaces, polyhedra. **Prerequisite:** Approval of instructor.

MATH 644 Algebraic Topology II

Credits 3. 3 Lecture Hours. Homology and cohomology theory. **Prerequisite:** MATH 643.

MATH 645 A Survey of Mathematical Problems I

Credits 3. 3 Lecture Hours. A survey of problems in various branches of mathematics, such as logic, probability, graph theory, number theory, algebra and geometry. **Prerequisites:** MATH 409, MATH 415, MATH 423 or approval of instructor.

MATH 646 A Survey of Mathematical Problems II

Credits 3. 3 Lecture Hours. A survey of problems in various branches of mathematics such as algebra, geometry, differential equations, real analysis, complex analysis, calculus of variations. **Prerequisite:** MATH 645 or approval of instructor.

MATH 647 Mathematical Modeling

Credits 3. 3 Lecture Hours. The process and techniques of mathematical modeling; covers a variety of application areas and models such as ordinary and partical differential equations, stochastic models, discrete models and problems involving optimization. **Prerequisite:** MATH 304, MATH 309, MATH 311, or MATH 323; MATH 308; or approval of instructor.

MATH 648 Computational Algebraic Geometry

Credits 3. 3 Lecture Hours. Broad introduction to algorithmic algebraic geometry, including numerical and complexity theoretic aspects; theory behind the most efficient modern algorithms for polynomial system solving and the best current quantitative/geometric estimates on algebraic sets over various rings is derived. **Prerequisite:** MATH 653 or approval of instructor.

MATH 649 Principles of Deep Learning

Credits 3. 3 Lecture Hours. Theory and practice of deep learning, including topics concerning approximation, generalization and optimization; study of the theory of universal approximation, stochastic gradient-based optimizers and statistical learning bounds, but also computational aspects including backpropagation and batch normalization. **Prerequisite:** MATH 304, MATH 251, MATH 411, and MATH 679 or equivalent; or approval of instructor.

MATH 650 Several Complex Variables

Credits 3. 3 Lecture Hours. Introduction to function theory in several complex variables with an emphasis on the analytic and partial differential equations aspects of the subject. **Prerequisites:** MATH 608 and MATH 618 or equivalents.

MATH 651 Optimization I

Credits 3. 3 Lecture Hours. Fundamentals of mathematical analysis underlying theory of constrained optimizations for a finite number of variables, necessary and sufficient conditions for constrained extrema of equality constraint problems, sufficient conditions for fulfillment of constraint qualification, computational methods for concave programming problems and applications. **Prerequisite:** MATH 410 or approval of instructor.

MATH 652 Optimization II

Credits 3. 3 Lecture Hours. Necessary conditions of calculus of variations, elementary theory of games, formulation of basic control problem, Hestenes' necessary conditions for optimal control, transformations, methods of computation and applications. **Prerequisite:** MATH 651.

MATH 653 Algebra I

Credits 3. 3 Lecture Hours. Survey of groups, rings, ideals. **Prerequisite:** MATH 415 or approval of instructor.

MATH 654 Algebra II

Credits 3. 3 Lecture Hours. Survey of modules, field extensions, Galois theory. **Prerequisite:** MATH 653 or approval of instructor.

MATH 655 Functional Analysis I

Credits 3. 3 Lecture Hours. Normed linear spaces, duality theory, reflexivity, operator theory. Banach algebras, spectral theory, representation theory. **Prerequisite:** MATH 608.

MATH 656 Functional Analysis II

Credits 3. 3 Lecture Hours. Topological linear spaces, locally convex spaces, duality in locally convex spaces, ordered topological vector spaces, distribution theory, applications to analysis. **Prerequisite:** MATH 655.

MATH 658 Applied Harmonic Analysis

Credits 3. 3 Lecture Hours. Fourier series and Fourier Transform; discrete (fast) Fourier transform; discrete cosine transform; local cosine transform; Radon transform; filters; harmonic analysis on the sphere; radial, periodic and spherical basis functions; applications. **Prerequisites:** MATH 304; MATH 308 or equivalent.

MATH 660/CSCE 660 Computational Linear Algebra

Credits 3. 3 Lecture Hours. Techniques in matrix computation including elimination methods, matrix decomposition, generalized inverses, orthogonalization and least-squares, eigenvalue problems and singular value decomposition, iterative methods and error analysis. **Prerequisite:** MATH 417 or equivalent or CSCE 442 or equivalent. **Cross Listing:** CSCE 660/MATH 660.

MATH 661 Mathematical Theory of Finite Element Methods

Credits 3. 3 Lecture Hours. Will develop basic mathematical theory of finite element method; construction of finite element spaces and piece-wise polynomial approximation; Ritz-Galerkin methods and variational crimes; energy and maximum norm estimates; mixed finite element method; applications to diffusion-reaction problems.

MATH 662 Seminar in Algebra

Credits 3. 3 Lecture Hours. Problems, methods and recent developments in algebra. May be repeated for credit. **Prerequisite:** Approval of instructor.

MATH 663 Seminar in Analysis

Credits 3. 3 Lecture Hours. Problems, methods and recent developments in analysis. May be repeated for credit. **Prerequisite:** Approval of instructor.

MATH 664 Seminar in Applied Mathematics

Credits 3. 3 Lecture Hours. Problems, methods and recent developments in applied mathematics. May be repeated for credit. **Prerequisite:** Approval of instructor.

MATH 666 Seminar in Geometry

Credits 3. 3 Lecture Hours. Problems, methods and recent developments in geometry. May be repeated for credit. **Prerequisite:** Undergraduate linear algebra and multivariable calculus or approval of instructor.

MATH 667 Foundations and Methods of Approximation

Credits 3. 3 Lecture Hours. Existence, uniqueness and characterization of best approximations; polynomial and rational approximants; Bernstein polynomials; Bernstein and Markov inequalities; ridge functions; approximation from shift-invariant subspaces; orthogonal polynomials; neural networks, radial basis functions, scattered-data surface fitting; subdivision analysis. **Prerequisites:** MATH 407 and MATH 409.

MATH 669 Seminar in Mathematical Biology

Credits 3. 3 Lecture Hours. Problems, methods and recent developments in Mathematical Biology. May be repeated for credit. **Prerequisite:** Approval of instructor.

MATH 672 Hydrodynamic Stability

Credits 3. 3 Lecture Hours. Instability mechanisms; instability of interfacial and free surface flows; thermal instability, centrifugal instability, instability of inviscid and viscous parallel shear flows; fundamental concepts and applications of nonlinear instability; the onset of turbulence; various transitions to turbulence. **Prerequisites:** MATH 601 or equivalent; MATH 605 or equivalent.

MATH 673 Mathematical Foundations of Cryptography

Credits 3. 3 Lecture Hours. Overview of modern cryptography from a mathematical perspective including public key cryptosystems, digital signatures, identification, and secret sharing schemes; mathematical underpinnings include the quadratic sieve, elliptic curves over finite fields, and short vector problems in lattices. **Prerequisites:** Graduate classification, and MATH 409 and MATH 416 or equivalent; or approval of instructor.

MATH 676 Finite Element Methods in Scientific Computing

Credits 3. 3 Lecture Hours. Basic finite element methods; structure of finite element codes; assembling linear systems of equations and algorithmic aspects; linear iterative solvers; adaptive mesh refinement; vector-valued and mixed problems; nonlinear problems; visualization; parallelization aspects. Additional topics may be chosen by instructor. **Prerequisites:** MATH 610; ENGR finite element class on MATH 419 or MATH 609; approval of instructor. Knowledge of C++.

MATH 677 Mathematical Foundations for Data Science

Credits 3. 3 Lecture Hours. Linear systems; least squares problems; eigenvalue decomposition; singular value decomposition; Perron–Frobenius theory; dynamic programming; convex optimization; gradient descent; linear programming; semidefinite programming; compressive sensing. **Prerequisites:** MATH 304, MATH 309, MATH 311, MATH 323, or equivalent; enrolled in MS in Data Science, MS in Quantitative Finance, or MS in Mathematics.

MATH 678 Introduction to Topological Data Analysis

Credits 3. 3 Lecture Hours. Topological Data Analysis with a view toward persistent homology of point clouds for applications to data analysis; homology of simplicial complexes over a field; functorial clustering methods; persistent homology; real-world applications to data analysis. **Prerequisites:** MATH 304, MATH 309, MATH 311, MATH 323, or equivalent; admission to master of science in data science.

MATH 679 Mathematical Algorithms and their Implementations

Credits 3. 3 Lecture Hours. Mathematical theory and implementation with Python of modern algorithms; project based. **Prerequisite:** MATH 323 and MATH 409, or equivalent, or approval of instructor.

MATH 680 Topics in Mathematical Data Science

Credits 3. 3 Lecture Hours. Rigorous introduction to several subfields of data science; machine learning; optimal recovery; compressive sensing; optimization; neural networks. **Prerequisite:** MATH 323, MATH 409, and MATH 411, or equivalent; approval of instructor.

MATH 684 Professional Internship

Credits 1 to 6. 1 to 6 Other Hours. Directed internship in an organization to provide students with professional experience in organization settings appropriate to the student's career objectives. **Prerequisite:** Approval of department head.

MATH 685 Directed Studies

Credits 1 to 6. 1 to 6 Other Hours. Offered to enable students to undertake and complete, with credit, limited investigations not within their thesis research and not covered by any other courses in the curriculum. **Prerequisite:** Approval of instructor.

MATH 689 Special Topics in...

Credits 1 to 4. 1 to 4 Lecture Hours. Selected topics in an identified area of mathematics. May be repeated for credit. **Prerequisite:** Approval of instructor.

MATH 691 Research

Credits 1 to 23. 1 to 23 Other Hours. Research for thesis or dissertation.

MATH 695 Frontiers in Mathematical Research

Credits 3. 3 Lecture Hours. This course is designed to acquaint the graduate student with the present status of investigative work in a variety of mathematical fields. Content will depend on the availability of visiting lecturers who will be selected because of distinguished international recognition in their fields of research. May be taken two times for credit. **Prerequisite:** Graduate classification.

MATH 696 Mathematical Communication and Technology

Credits 3. 3 Lecture Hours. Techniques of effective oral, written and electronic communication of mathematics; introduction to contemporary computing tools. **Prerequisite:** Approval of instructor.