MATH 8016  INTRODUCTION TO THE THEORY OF RECURSIVE FUNCTIONS (3 credits)
This is a proof-oriented course presenting the foundations of Recursion Theory. We present the definition and properties of the class of primitive recursive functions, study the formal models of computation, and investigate partially computable functions, universal programs. We prove Rice's Theorem, the Recursion Theorem, develop the arithmetic hierarchy, demonstrate Post's theorem. Introduction to the formal theories of computability and complexity is also given. (Cross-listed with CSCI 4010, CSCI 8016, MATH 4010).
Prerequisite(s)/Corequisite(s): MATH 2320 or CSCI 3660 or instructor's permission

MATH 8036  MODERN ALGEBRA (3 credits)
Algebra is the study of mathematical manipulations that preserve something (like equality - when solving equations). The areas in which Algebra finds application are quite diverse, from Ancient Greek Geometry through to Modern Information Protection and Security (error correcting codes, data compression, and cryptography). This course begins with topics that should be familiar (such as ruler-and-compass constructions, and modular arithmetic) and builds upon this foundation through polynomial rings up to finite fields and basic group theory. (Cross-listed with MATH 4030).
Prerequisite(s)/Corequisite(s): MATH 2320 with a C- or better or MATH 2030 with a C- or better

MATH 8050  ALGORITHMIC GRAPH THEORY (3 credits)
Review of the basic concepts of graph theory. Introduction to perfect graphs and their characterizations. Main classes of perfect graphs and their properties. Algorithms for main problems of perfect graphs. Applications of perfect graphs in several fields such as scheduling, VLSI and communication networks. (Cross-listed with CSCI 8050).
Prerequisite(s)/Corequisite(s): CSCI 3320 or CSCI 8325 and MATH 4150 or MATH 8156 or permission of instructor. Not open to non-degree graduate students.

MATH 8056  LINEAR ALGEBRA (3 credits)
The theory of vectors, vector spaces, inner product spaces, linear transformations, eigenvalues, canonical forms, complex vectors and matrices and orthogonality. Unlike MATH 2050, this course emphasizes the theoretical aspects of linear algebra. (Cross-listed with MATH 4050).
Prerequisite(s)/Corequisite(s): MATH 2050; MATH 2030 or MATH 2230 or equivalent; or permission

MATH 8060  ALGORITHMIC COMBINATORICS (3 credits)
This course includes classical combinatorial analysis graph theory, trees, network flow, matching theory, external problems, and block designs. (Cross-listed with CSCI 8060).
Prerequisite(s)/Corequisite(s): MATH 3100, CSCI 3100, MATH 8105 or CSCI 8105 or instructor's permission.

MATH 8080  DESIGN AND ANALYSIS OF ALGORITHMS (3 credits)
The study of algorithms important in computer programming. Principles and underlying concepts of algorithm design, fundamental techniques of algorithm analysis, typical types of algorithms. Related topics such as algorithms and computer architecture. (Cross-listed with CSCI 8080).
Prerequisite(s)/Corequisite(s): CSCI 3320 or CSCI 8325 or equivalent. Not open to non-degree graduate students.

MATH 8105  APPLIED COMBINATORICS (3 credits)
Basic counting methods, generating functions, recurrence relations, principle of inclusion-exclusion. Polya's formula. Elements of graph theory, trees and searching network algorithms. (Cross-listed with CSCI 3100, CSCI 8105, MATH 3100).
Prerequisite(s)/Corequisite(s): MATH 2300 with a C- or better or MATH 2040 with a C- or better or MATH 2230 with a C- or better. Mathematical logic; Set theory; Relations; Functions; Congruences; Inductive and recursive definitions; Discrete probability; sets, graphs, trees, & matrices

MATH 8116  ABSTRACT ALGEBRA I (3 credits)
An introduction to group theory. Various classes of group are studied: symmetric groups, abelian, cyclic, and permutation groups. Basic tools are developed and used: subgroups, normal subgroups, cosets, the Lagrange theorem, group homomorphisms, quotient groups, direct products, and group actions on a set. The course culminates with the Sylow theorems in finite group theory. The theory is illustrated with examples from geometry, linear algebra, number theory, crystallography, and combinatorics. (Cross-listed with MATH 4110).
Prerequisite(s)/Corequisite(s): MATH 4050/MATH 8056 with a C- or better or MATH 4560/MATH 8566 with a C- or better or permission of instructor

MATH 8126  ABSTRACT ALGEBRA II (3 credits)
An introduction to ring and field theory. Various classes of commutative rings are considered including polynomial rings, and the Gaussian integers. Examples of fields include finite fields and various extensions of the rational numbers. Concepts such as that of an ideal, integral domain, characteristic and extension field are studied. The course culminates with an introduction to Galois theory. Applications include the resolution of two classical problems: the impossibility of angle-trisection and the general insolvability of polynomial equations of degree 5 or higher. (Cross-listed with MATH 4120).
Prerequisite(s)/Corequisite(s): MATH 4110/MATH 8116 with a C- or better or permission of instructor

MATH 8156  GRAPH THEORY & APPLICATIONS (3 credits)
Introduction to graph theory. Representations of graphs and graph isomorphism. Trees as a special case of graphs. Connectivity, covering, matching and coloring in graphs. Directed graphs and planar graphs. Applications of graph theory in several fields such as networks, social sciences, VLSI, chemistry and parallel processing. (Cross-listed with CSCI 4150, CSCI 8156, MATH 4150).
Prerequisite(s)/Corequisite(s): MATH 2300 or permission of instructor.

MATH 8225  INTRODUCTION TO ANALYSIS (3 credits)
Provides a theoretical foundation for the concepts of elementary calculus. Topics include the real number system, topology of the real line, limits, functions of one variable, continuity, differentiation, integration. (Cross-listed with MATH 3230).
Prerequisite(s)/Corequisite(s): MATH 1970, and MATH 2030 or MATH 2230 or equivalent.

MATH 8236  MATHEMATICAL ANALYSIS I (3 credits)
Provides a theoretical foundation for the concepts of elementary calculus. Topics include ordered fields and the real number system, basic properties of complex numbers, metric space topology, sequences and series in R, limits and continuity in a metric space, monotonic functions. (Cross-listed with MATH 4230).
Prerequisite(s)/Corequisite(s): MATH 3230/MATH 8235 or equivalent CSCI 8105, MATH 3100.

MATH 8246  MATHEMATICAL ANALYSIS II (3 credits)
Provides a theoretical foundation for the concepts of elementary calculus. Topics include differentiation and Riemann-Stieltjes Integration, sequences and series of functions, uniform convergence, power series, functions of several variables, Implicit Function Theorem. (Cross-listed with MATH 4240).
Prerequisite(s)/Corequisite(s): MATH 4230/MATH 8236
MATH 8250 PARTIAL DIFFERENTIAL EQUATIONS (3 credits)
Partial differential equations (PDEs) are fundamental in the application of mathematics to science and engineering. Topics to be covered will include: Linear and nonlinear first-order equations, classification of second-order linear equations, elliptic, hyperbolic and parabolic equations and boundary value problems, and Green’s functions.
Prerequisite(s)/Corequisite(s): MATH 1970, MATH 2350, or instructor’s permission. MATH 4330/MATH 8336 is recommended, but not required.

MATH 8276 COMPLEX VARIABLES (3 credits)
Differentiation, integration and power series expansions of analytic functions, conformal mapping, residue calculus, and applications. (Cross-listed with MATH 4270).
Prerequisite(s)/Corequisite(s): MATH 3230/MATH 8235 or equivalent

MATH 8305 NUMERICAL METHODS (3 credits)
This course involves solving nonlinear algebraic equations and systems of equations, interpolation and polynomial approximation, numerical differentiation and integration, numerical solutions to ordinary differential equations, analysis of algorithms and errors, and computational efficiency. (Cross-listed with CSCI 3300, CSCI 8305, MATH 3300).
Prerequisite(s)/Corequisite(s): MATH 1960 with a C- or better or permission of instructor.

MATH 8306 DETERMINISTIC OPERATIONS RESEARCH MODELS (3 credits)
This is a survey course of deterministic operations research models and algorithms. Topics include linear programming, network programming, and integer programming. (Cross-listed with CSCI 4300, CSCI 8306, MATH 4300).
Prerequisite(s)/Corequisite(s): MATH 2050 with a C- or better or permission of instructor.

MATH 8316 PROBABLISTIC OPERATIONS RESEARCH MODELS (3 credits)
This is a survey course of probabilistic operations research models and algorithms. Topics include Markov chains, queuing theory, inventory models, forecasting, and simulation. (Cross-listed with CSCI 4310, CSCI 8316, MATH 4310).
Prerequisite(s)/Corequisite(s): MATH 2050 and either MATH 4740 or MATH 8746 or STAT 3800 or STAT 8805 all with a C- or better or permission of instructor.

MATH 8326 COMPUTATIONAL OPERATIONS RESEARCH (3 credits)
Survey of computational methods used in the solution of operations research problems. Topics include scripting to guide optimization software, metaheuristics for optimization, and basic machine learning algorithms. (Cross-listed with MATH 4320).
Prerequisite(s)/Corequisite(s): MATH 3200 and MATH 4300 each with a grade of C- or better or permission of instructor.

MATH 8336 INTRODUCTION TO PARTIAL DIFFERENTIAL EQUATIONS (3 credits)
This course introduces the basic methods of PDEs guided by applications in physics and engineering. The main topics to be covered include The Linear First order PDEs, Transport equations, Characteristics, Classification of PDEs, Separation of variables, Heat conduction, vibrating membranes, boundary value problems, Maximum principle, Sturm-Liouville problems, Fourier series, Fourier integrals, Harmonic functions, Legendre polynomials, Distributions, Green’s functions. (Cross-listed with MATH 4330).
Prerequisite(s)/Corequisite(s): MATH 1970 with a C- or better and MATH 2350 with a C- or better, or permission of instructor; MATH 2050 recommended, not required.

MATH 8356 ORDINARY DIFFERENTIAL EQUATIONS (3 credits)
Ordinary Differential Equations develops the theory of initial-, boundary-, and eigenvalue problems, existence theorems, real and complex linear systems of differential equations, and stability theory. There will be a strong emphasis on methods for finding solutions of initial and boundary value problems and analyzing properties of these solutions for various differential equations. (Cross-listed with MATH 4350).
Prerequisite(s)/Corequisite(s): MATH 2050 with a C- or better and MATH 2350 with a C- or better or instructor’s permission. It is recommended, but not required, that students take MATH 3230, which would require a C- or better.

MATH 8370 FUZZY SET THEORY AND ITS APPLICATIONS (3 credits)
The course is focused on the fundamental theory of fuzzy sets and its applications to data mining and decision making.
Prerequisite(s)/Corequisite(s): MATH 2030, MATH 2230, MATH 3230/MATH 8355, or permission of instructor.

MATH 8400 DYNAMICAL SYSTEMS AND CHAOS (3 credits)
Review of difference equations and differential equations, stability theory, periodic orbits, lyapunov exponents, fractals, chaos, state reconstruction from time series data.
Prerequisite(s)/Corequisite(s): Permission from Instructor

MATH 8406 FINITE ELEMENT METHODS FOR SOLVING ORDINARY AND PARTIAL DIFFERENTIAL EQUATIONS (3 credits)
Prerequisite(s)/Corequisite(s): MATH 1970 with a C- or better, MATH 2050 with a C- or better, and MATH 2350 with a C- or better, or instructor’s permission. MATH 3300/MATH 8305 and MATH 4330/MATH 8336 are recommended, but not required. Familiarity with MATLAB programming is assumed.

MATH 8410 TOPICS IN DISCRETE DYNAMICAL SYSTEMS: BOOLEAN NETWORKS (3 credits)
This course is focused on introduction to discrete dynamical networks, in particular logical networks, and their applications.
Prerequisite(s)/Corequisite(s): MATH 1960 (Calculus II), MATH 2230 (proof writing skills), MATH 4740 or equivalent (basic probability theory), basic computer skills; or permission of the instructor.

MATH 8430 LINEAR PROGRAMMING (3 credits)
This course includes a complete development of theoretical and computational aspects of linear programming. Basic theoretical foundations covered include polyhedra, convexity, linear inequalities and duality. Advanced topics such as decomposition and column generation are covered. Both simplex methods and interior point methods are included.
Prerequisite(s)/Corequisite(s): MATH 4300/MATH 8306

MATH 8440 NETWORK PROGRAMMING (3 credits)
A presentation of network flow models and optimization algorithms. Topics include pure, generalized, integer, and constrained network problems, plus special cases of each, including transportation, assignment, shortest-path, transshipment, and multicommodity.
Prerequisite(s)/Corequisite(s): MATH 4300/MATH 8306

MATH 8450 CALCULUS OF VARIATIONS (3 credits)
Functional, the Euler-Lagrange Equation, the Brachistochrone, minimum surface of revolution, isoperimetric problem, Fermat’s Principle, Hamilton’s Principle, least action, the vibrating string and membrane, max-min characterization of eigenvalues, further applications.
Prerequisite(s)/Corequisite(s): MATH 3230/MATH 8235 and MATH 3350/MATH 8355.
MATH 8460 INTEGER PROGRAMMING (3 credits)
Advanced study in mathematical programming with integer or mixed integer variables. Topics include integer programming, model creation, developing solution algorithms, and applications of integer programming.
Prerequisite(s)/Corequisite(s): MATH 2030 or MATH 2230 Not open to non-degree graduate students.

MATH 8480 MULTI-AGENT SYSTEMS AND GAME THEORY (3 credits)
This course covers advanced topics in the area of coordination of distributed agent-based systems with a focus on computational aspects of game theory. The main topics covered in this course include distributed constraint satisfaction, distributed constraint optimization, and competitive and cooperative game theory. (Cross-listed with CSCI 8480).
Prerequisite(s)/Corequisite(s): CSCI 4450 or CSCI 8456. Suggested background courses: CSCI 4480 or CSCI 8486; CSCI 8080. Not open to non-degree graduate students.

MATH 8490 APPLIED COMPLEX VARIABLES (3 credits)
Applications of complex variables to potential theory, Fourier and Laplace transforms, ordinary and partial differential equations, number theory, chaotic dynamical systems, etc.
Prerequisite(s)/Corequisite(s): MATH 4270/MATH 8276

MATH 8500 NUMERICAL ANALYSIS I (3 credits)
Topics covered in this course include error propagation, solutions of nonlinear equations, solutions of linear and nonlinear systems by various schemes, matrix norms and conditioning, and computation of eigenvalues and eigenvectors. (Cross-listed with CSCI 8500).
Prerequisite(s)/Corequisite(s): MATH 1960 and MATH 2050, or permission of instructor. Familiarity with computer programming is assumed.

MATH 8502 SELECTED TOPICS IN MATHEMATICS (1-6 credits)
This is a variable content course with selected topics in the mathematical sciences which may be of interest to students in other disciplines such as mathematics education, psychology and business. The course may be taken more than once for credit provided topics differ, with a maximum credit of nine hours. Mathematics majors may apply no more than three hours of MATH 3500 toward the minimum major requirements. MATH 8502 does not apply to M.A. or M.S. in mathematics. (Cross-listed with MATH 3500).
Prerequisite(s)/Corequisite(s): Permission of instructor

MATH 8510 NUMERICAL ANALYSIS II (3 credits)
Topics covered in this course include interpolation and approximations, numerical differentiation, numerical integration, and numerical solutions of ordinary and partial differential equations. (Cross-listed with CSCI 8510)
Prerequisite(s)/Corequisite(s): MATH 1970, MATH 2350, or permission of instructor. Familiarity with computer programming is assumed.

MATH 8520 ADVANCED TOPICS IN OPERATIONS RESEARCH (3 credits)
Advanced treatment of a specific topic in the area of operations research not available in the regular curriculum. Topics, developed by individual faculty members, will reflect their special interests and expertise. The course may be repeated for credit as topics differ. (Cross-listed with CSCI 8520).
Prerequisite(s)/Corequisite(s): MATH 4300 or MATH 8306 or CSCI 4300 or CSCI 8306 or permission of the instructor.

MATH 8530 NONLINEAR OPTIMIZATION WITH NONLINEAR INTEGRALS (3 credits)
The course is focused on using a new mathematical aggregation tool, the nonlinear integral, in nonlinear optimizations and on its applications in information fusion and data mining, where a soft computing technique (genetic algorithms and/or neural networks) is adopted to search numerical optimal solutions approximately.
Prerequisite(s)/Corequisite(s): MATH 1960 and MATH 4740. Preferred MATH 4300 and CIST 1400 or equivalent.

MATH 8550 NUMBER THEORY & CRYPTOGRAPHY (3 credits)
An overview of one of the many beautiful areas of mathematics and its modern application to secure communication. The course is ideal for any student who wants a taste of mathematics outside of, or in addition to, the calculus sequence. Topics to be covered include: prime numbers, congruences, perfect numbers, primitive roots, quadratic reciprocity, sums of squares, and Diophantine equations. Applications include error-correcting codes, symmetric and public key cryptography, secret sharing, and zero knowledge proofs. (Cross-listed with CSCI 4560, CSCI 8566, MATH 4560).
Prerequisite(s)/Corequisite(s): MATH 2230 with a C- or better or MATH 2030 with a C- or better or permission of instructor

MATH 8560 TENSOR ANALYSIS (3 credits)
Prerequisite(s)/Corequisite(s): MATH 1970, MATH 2050, MATH 2350

MATH 8566 DIFFERENTIAL GEOMETRY (3 credits)
Curvature, torsion, Frenet frames, Fundamental theorem of curve theory, Frenchel's theorem, tangent spaces, first and second fundamental forms, shape operator, Fundamental theorem of surfaces theory, covariant derivative, parallel transport, geodesics. (Cross-listed with MATH 4600).
Prerequisite(s)/Corequisite(s): MATH 1970 with a C- or better, MATH 2050 with a C- or better, and MATH 2350 with a C- or better, or permission of instructor.

MATH 8616 ELEMENTARY TOPOLOGY (3 credits)
This course covers topological spaces, connectedness, compactness, homotopy of paths, covering spaces, and fundamental groups. (Cross-listed with MATH 4610).
Prerequisite(s)/Corequisite(s): MATH 1960 with a C- or better and MATH 3230 with a C- or better or permission of instructor.

MATH 8620 GENERAL TOPOLOGY (3 credits)
The concepts of MATH 4610/MATH 8616 are studied at an advanced level in conjunction with ordinal and cardinal numbers, open and closed maps, separation axioms and countable compactness.
Prerequisite(s)/Corequisite(s): MATH 4610/MATH 8616

MATH 8645 MODERN GEOMETRY (3 credits)
Axiomatic systems, finite geometries, modern foundations of Euclidean geometry, hyperbolic and other non-Euclidean geometries, projective geometry. (Cross-listed with MATH 3640).
Prerequisite(s)/Corequisite(s): MATH 2230 or MATH 2030, or equivalent mathematical maturity.

MATH 8650 INTRODUCTION TO PROBABILITY MODELS (3 credits)
This is an introduction to probability modeling including Poisson Processes, Markov chains, birth-death processes, queuing models and renewal theory. Applications will be an important part of the course.
Prerequisite(s)/Corequisite(s): MATH 4740/MATH 8746, MATH 4760/MATH 8766/CSCI 4760/CSCI 8766, STAT 3800/STAT 8805, or permission of instructor.

MATH 8656 TRANSFORM METHODS & APPLICATIONS (3 credits)
Laplace transform and the inversion integral. Fourier transform. Other transforms and special techniques. Applications to differential equations, boundary value problems of mathematical physics, and signal analysis. (Cross-listed with MATH 4650).
Prerequisite(s)/Corequisite(s): MATH 3350/MATH 8355 and MATH 4270/MATH 8276
MATH 8666 AUTOMATA, COMPUTABILITY, AND FORMAL LANGUAGES (3 credits)
This course presents a sampling of several important areas of theoretical computer science. Definition of formal models of computation and important properties of such models, including finite automata and Turing machines. Definition and important properties of formal grammars and their languages. Introduction to the formal theories of computability and complexity. (Cross-listed with CSCI 4660, CSCI 8666, MATH 4660).
Prerequisite(s)/Corequisite(s): MATH 2030. Recommended: CSCI 3320/CSCI 8325.

MATH 8670 TOPICS IN PROBABILITY AND STATISTICS (3 credits)
A variable topics course in probability and/or statistics. Topics covered will include one or more of the following: reliability theory and applications in engineering and science, advanced probability and statistical models, theory of parametric estimation and applications, and advanced probability theory and application.
Prerequisite(s)/Corequisite(s): MATH 4740/MATH 8740 or STAT 3800/STAT 8800 or permission from instructor

MATH 8746 INTRODUCTION TO PROBABILITY AND STATISTICS I (3 credits)
A mathematical introduction to probability theory including the properties of probability; probability distributions; expected values and moments; specific discrete and continuous distributions; and transformations of random variables. (Cross-listed with MATH 4740).
Prerequisite(s)/Corequisite(s): MATH 1970 and MATH 2030 or MATH 2230

MATH 8756 INTRODUCTION TO PROBABILITY AND STATISTICS II (3 credits)
Theory and methods of statistical inference including estimators, statistical hypotheses, multivariate estimation, chi-square tests, analysis of variance, and statistical software. (Cross-listed with MATH 4750).
Prerequisite(s)/Corequisite(s): MATH 4740/MATH 8746

MATH 8766 TOPICS IN MODELING (3 credits)
Selection of such topics as formulation and analysis of various models involving Markov chains, Markov processes (including birth and death processes), queues, cellular automata, difference and differential equations, chaotic systems and fractal geometries. (Cross-listed with CSCI 4760, CSCI 8766, MATH 4760).
Prerequisite(s)/Corequisite(s): MATH 2350 and MATH 4740 or MATH 8746.

MATH 8850 ADVANCED AUTOMATA AND FORMAL LANGUAGES (3 credits)
A continuation of MATH 4660/MATH 8666/CSCI 4660/CSCI 8666. The course will be an introduction to computational complexity. Topics that will be covered include space and time complexities of Turing Machines, deterministic versus non-deterministic machines, NP-Complete problems, alternating Turing machines, and concepts of reducibility. (Cross-listed with CSCI 8850).
Prerequisite(s)/Corequisite(s): Not open to non-degree graduate students.

MATH 8855 HISTORY OF MATHEMATICS (3 credits)
An overview of the historical development of mathematical concepts and methods. Brief biographies of major mathematicians, descriptions of the cultural context of selected major advances, and examples of the solution of problems using the knowledge and methods appropriate for each time period will be included. (Cross-listed with MATH 3850).
Prerequisite(s)/Corequisite(s): Students who enroll in this course should have completed MATH 1970 and MATH 2230 in order to have the minimum amount of mathematical background needed to appreciate the mathematical content of the course.

MATH 8880 ADVANCED PLACEMENT INSTITUTE: CALCULUS (3 credits)
A workshop for teachers planning to offer an advanced placement course in calculus. Objectives include increasing teacher competencies in single-variable calculus, discussion and study of AP calculus exams, implementations of AP courses in calculus, and development and presentation of projects for graduate credit. (This course will not count toward the M.A. or M.S. degrees in Mathematics.)
Prerequisite(s)/Corequisite(s): Graduate in mathematics or mathematics education.

MATH 8960 MASTER'S PROJECT (1-6 credits)
An applied project, designed and executed under the supervision of both a faculty and industry advisor. In the project the student will apply their mathematical and/or statistical skills to an applied problem. The student will present their results via a written report and oral presentation. (Cross-listed with STAT 8960).
Prerequisite(s)/Corequisite(s): Permission of faculty advisor and graduate program chair. Not open to non-degree graduate students.

MATH 8970 INDEPENDENT GRADUATE STUDIES (1-3 credits)
Under this number a graduate student may pursue studies in an area that is not normally available to him/her in a formal course. The topics studied will be a graduate area in mathematics to be determined by the instructor.
Prerequisite(s)/Corequisite(s): Permission of instructor and graduate classification.

MATH 8980 GRADUATE SEMINAR (1-3 credits)
A graduate seminar in mathematics.

MATH 8990 THESIS (1-6 credits)
Master's Thesis.

MATH 9110 ADVANCED TOPICS IN APPLIED MATHEMATICS (3 credits)

MATH 9230 THEORY OF FUNCTION OF REAL VARIABLES (3 credits)
Real number system, convergence, continuity, bounded variation, differentiation, Lebesque-Stieltjes integration, abstract measure theory, the Lp spaces.
Prerequisite(s)/Corequisite(s): MATH 4230/MATH 8236 and MATH 8240 or equivalent.