Stevens Institute of Technology 2006-2007 Catalog

The Arthur E. Imperatore School of Sciences and Arts

Department of Mathematical Sciences

ROBERT GILMAN, DIRECTOR

FACULTY*

Professors

Douglas I. Bauer, Ph.D. (1978), Stevens Institute of Technology
Milos Dostal, Ph.D. (1966), Mathematical Institute of the Czechoslovak Academy of Sciences
Robert H. Gilman, Ph.D. (1969), Columbia University
Lawrence E. Levine, Ph.D. (1968), University of Maryland
Roger S. Pinkham, Ph.D. (1955), Harvard University
Charles L. Suffel, Dean of Academic Administration, Ph.D. (1969), Brooklyn Polytechnic Institute

Associate Professors

Darinka Dentcheva, Ph.D. (1989), Humboldt University, Berlin
Marco Lenci, Ph.D. (1999), Rutgers University
Yi Li, Ph.D. (1995), Pennsylvania State University

Assistant Professors

Murray Elder, Ph.D. (2000), University of Melbourne
Ionut Florescu, Ph.D. (2004), Purdue University

Visiting Assistant Professor

Ayan Mahalanobis, Ph.D. (2005), Florida Atlantic University

Affiliate Professor

Khaldoun Khashanah, Director of Professional Programs, Ph.D. (1994), University of Delaware

Visiting Affiliate Professor

Pavel Dubovski, Dr.Sci. (2001), Russian Academy of Sciences

Senior Lecturer

Varoujan Mazmanian, M.S. (1971), Stevens Institute of Technology

*The list indicates the highest earned degree, year awarded, and institution where earned.

UNDERGRADUATE PROGRAMS

Mathematics is essential to science and engineering, and is a fascinating field in its own right. Scientific and engineering problems

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have often inspired new developments in mathematics, and, conversely, mathematical results have frequently had an impact on business, engineering, the sciences, and technology. At Stevens, we think that an undergraduate program in mathematics should be broad enough to prepare you for a job in industry, while giving you the background to continue your education at the graduate level, should you choose to do so.

The standard program for a concentration in mathematics includes the courses listed below, although not necessarily in exactly the order listed. If these courses do not meet your needs and goals, your program can be changed with the consent of your advisor. For example, you may wish to write a senior thesis, or you may be eligible for advanced placement or the honors calculus sequence. Alternatively, you may want to strengthen your grasp of fundamental concepts by taking MA 134 Discrete Mathematics. See the Department of Mathematics web page for information on when particular courses are offered.

Freshman Year

Term I

		Hrs. Per Wk.		
		Class	Lab	Sem. Cred.
MA 115	Calculus I	3	0	3
CH 115	General Chemistry I	3	0	3
CH 117	General Chemistry Lab I	0	3	1
CS 105 Or	Intro. to Scientific Computing	2	2	3
CS 115	Intro. to Computer Science	3	2	4
PEP 111	Mechanics	3	0	3
HUM	Humanities	3	0	3
PE 200	Physical Education I	0	2	1
	TOTAL	**14(15)**	**7**	**17(18)**

Term II

		Hrs. Per Wk.		
		Class	Lab	Sem. Cred
MA 116	Calculus II	3	0	3
CH 116	General Chemistry II	3	0	3
CH 118	General Chemistry Lab II	0	3	1
CH 281	Biology and Biotechnology	3	0	3
PEP 112	Electricity and Magnetism	3	0	3
HUM	Humanities	3	0	3
PE 200	Physical Education II	0	2	1
	TOTAL	**15**	**5**	**17**

Sophomore Year

Term III

		Hrs. Per Wk.		
		Class	Lab	Sem. Cred.
MA 234	Complex Variables	3	0	3
MA 221	Differential Equations	4	0	4
MA 232	Linear Algebra	3	0	3
PEP 221	Physics Lab I	0	3	1
HUM	Humanities	3	0	3
PE 200	Physical Education III	0	2	1
	TOTAL	**13**	**5**	**15**

Term IV

		Hrs. Per Wk.		
		Class	Lab	Sem. Cred
MA 222	Probability & Statistics	3	0	3
MA 227	Multivariable Calculus	3	0	3
PEP 222	Physics Lab II	0	3	1
E 234	Thermodynamics 1	3	0	3
HUM	Humanities	3	0	3
PE 200	Physical Education IV	0	2	1
	TOTAL	**12**	**5**	**14**

Junior Year

Term V

		Hrs. Per Wk. Class	Lab	Sem. Cred.
MA 346	Numerical Methods	3	0	3
MA 331	Intermediate Statistics	3	0	3
MGT 244	Microeconomics 2	3	0	3
HUM	Humanities	3	0	3
PE 200	Physical Education V	0	2	1
	TOTAL	**12**	**2**	**13**

Term VI

		Hrs. Per Wk. Class	Lab	Sem. Cred
MA 336	Modern Algebra	3	0	3
MA 463	Seminar in Mathematics	3	0	3
PEP 242	Modern Physics	3	0	3
HUM	Humanities	3	0	3
PE 200	Physical Education VI	0	2	1
	TOTAL	**12**	**2**	**13**

Senior Year

Term VII

		Hrs. Per Wk. Class	Lab	Sem. Cred.
MA 441	Intro. to Mathematical Analysis	3	0	3
MA 360 or MA 361	Intermediate ODE or Intermediate PDE	3	0	3
MA 498	Senior Project	0	8	3
HUM	Humanities	3	0	3
	Elective	3	0	3
	TOTAL	**12**	**8**	**15**

Term VIII

		Hrs. Per Wk. Class	Lab	Sem. Cred
MA 442	Real Variables	3	0	3
MA 410	Differential Geometry	3	0	3
MA 335	Number Theory	3	0	3
HUM	Humanities	3	0	3
	Elective	3	0	3
	TOTAL	**15**	**0**	**15**

1. Students may substitute CH 321 (Thermodynamics) for E 234.
2. Students may substitute MGT 243 (Macroeconomics) for MGT 244**.**

Minor in Mathematical Sciences

A minor in mathematical sciences can be a valuable qualification for students concentrating in other areas. A minor consists of the courses MA 115, MA 116, MA 134, MA 221, MA 222, MA 227, MA 232, MA 234 and one other course chosen with the consent of the Department. The 300-level mathematics courses are typical choices. A student with sufficient background and the consent of the Department may substitute another course for a required course. The average grade in the nine courses must be at least 2.50 to be awarded the Minor in Mathematical Sciences.

Interdisciplinary Program in Computational Science

For students interested in interdisciplinary science and engineering, Stevens offers an undergraduate computational science program. Computational science is a new field in which techniques from mathematics and computer science are used to solve scientific and engineering problems. See the description of the Program in Computational Science in the Interdisciplinary Programs section.

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GRADUATE PROGRAMS

Admission Criteria

Adequate undergraduate preparation for admission to any masters degree or certificate program, except Financial Engineering, includes analytic geometry and calculus, elementary differential equations, one semester of linear algebra, and one semester of probability or probability and statistics. It is possible to be admitted with the requirement that you make up a deficiency in preparation. For Financial Engineering see below.

Admission to the Doctoral Program requires the preparation specified above. See below for a guide to how applicants will be evaluated. If your goal is a Ph.D., you should apply directly to the Doctoral Program and not to a master's program. In order to receive full consideration, applications to the Doctoral Program should be received by March 15 for admission in the Fall Semester, and September 15 for admission in the Spring Semester. Because of constraints due to course scheduling, admission for the Spring Semester is not always feasible and may depend on the student’s preparation.

Master of Science - Applied Mathematics

This program provides a background in mathematical techniques which are useful in solving practical problems in science and engineering. You are encouraged to include courses from other departments in your program of study.

The program requires 30 credits (10 courses) of coursework. You may transfer up to one third of this amount from outside Stevens. If you know the material in one of the required courses, you may substitute another course. In both cases, you will need the approval of a department advisor. All elective courses must be chosen with the consent of a department advisor.

Core Courses

MA 547 Advanced Calculus I **or** MA 635 Real Variable I
MA 552 Linear Algebra
MA 611 Probability
MA 615 Numerical Analysis I
MA 649 Differential Equations I
MA 681 Functions of a Complex Variable I

Typical Electives

PEP 520 Computational Physics
CS 580 The Logic of Program Design
CS 590 Introduction to Data Structures and Algorithms
CE 601 Theory of Elasticity
MA 548 Advanced Calculus II
CE 519 Advanced Structural Analysis
MA 627 Combinatorial Analysis
ME 674 Fluid Dynamics
ME 653 Numerical Solutions of Partial Diff. Eqs.

Master of Science - Mathematics

A master’s degree in mathematics requires 30 credits of courses including the following core courses.

Core Courses

MA 552 Linear Algebra
MA 605 Foundations of Algebra I
MA 611 Probability
MA 635 Real Variables I
MA 651 Topology I
MA 681 Functions of a Complex Variable I

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Master of Science - Stochastic Systems

This program focuses on analysis and optimal decision-making for complex systems involving uncertain data and risk. The program integrates courses in statistics, stochastic processes, stochastic optimization, and stochastic optimal control theory. The application of these mathematical methods to financial systems, network design and routing, supply-chain management, telecommunication systems, pattern recognition, and other areas is outlined. Students are encouraged to apply the techniques they learn to problems derived from their professional work and interests.

Ten courses are required for the degree; six are core courses. Elective courses are chosen with the consent of the student's academic advisor.

Core Courses

MA 547 Advanced Calculus **or** MA 635 Real Variables I
MA 611 Probability
MA 612 Mathematical Statistics
MA 623 Stochastic Processes
MA 629 Convex Analysis and Optimization
MA 661 Stochastic Optimal Control and Dynamic Programming

Typical Electives

MA 615 Numerical Analysis I
MA 627 Combinatorial Analysis
MA 632 Theory of Games
MA 641 Time Series Analysis I
MA 655 Optimal Control Theory
MA 661 Stochastic Optimal Control and Dynamic Programming
MA 662 Stochastic Programming
MA 720 Advanced Statistics
CS 535 Financial Computing
MGT 730 Design and Analysis of Experiments
EN 780 Nonlinear Correlation and System Identification

Master of Science – Financial Engineering

The financial services industry has an increasing need for graduates who are trained in the mathematical methods which are now used to solve problems in finance. In our financial engineering program, you learn how to use relevant techniques from applied mathematics, statistics, and economics to solve problems involving securities valuation, risk management, portfolio structuring, and regulatory concerns. Training in quantitative analysis, modeling, optimization, simulation techniques, and technology interface is emphasized.

The master's program consists of 10 one-semester courses for a total of 30 credits; the 4-course certificate program (see below) counts towards the master's degree Students wishing to enroll in either program must have an undergraduate degree in a related discipline, and must have completed coursework equivalent to the following courses in the Stevens catalog.

1. MA 115, MA 116, MA 221, MA 227, Calculus and Differential Equations
2. MA 222, MA 540, Probability and Statistics
3. MA 232, MA 552, Linear Algebra
4. CS 570, Programming languages C++ or Java and spreadsheets
5. FE 510, Basic knowledge of financial engineering

There are two tracks in the MFE program: Quantitative Financial Engineering and Financial Engineering Technology. Both tracks require the same core courses.

Core Courses

FE 610 Probability and Stochastic Calculus
FE 620 Pricing and Hedging
FE 621 Computational Finance
FE 630 Portfolio Theory and Applications
FE 699 Project in Financial Engineering **or** FE 700 Masters Thesis in Financial Engineering

Quantitative FE Track

In addition to the core courses, the following courses are required:

Required Courses

- MA 547 Advanced Calculus
- MGT 625 Investments and Capital Markets
- MA 650 Partial Differential Equations

Electives

Choose two courses from the following list:

- FE 680 Advanced Derivatives
- MA 653 Numerical Solutions of Partial Differential Equations
- MA 615 Numerical Analysis I
- MA 641 Time Series Analysis I
- MGT 700 Econometrics
- MGT 730 Design and Analysis of Experiments
- MGT 710 Risk Management Methods and Applications

FE Technology Track

There are two concentrations within the FE Technology track; the first emphasizes databases and networks and the second stresses data analysis and modeling.

FE Technology in Databases and Networks

Required courses

- CS 540 Fundamentals of Quantitative Software Engineering
- CS 561 Database Management Systems I
- CS 573 Fundamentals of Cybersecurity

Electives

Choose two of the following:

- FE 680 Advanced Derivatives
- CS 666 Information Networks I
- CS 668 Fundamentals of Cryptography
- CS 694 E-Business Security and Information Assurance
- MIS 620 Analysis and Development of Information Systems
- MIS 630 Data and Knowledge Management
- MGT 710 Risk Management Methods and Applications
- MGT 770 Economics of Network

FE Technology in Information and Modeling

Required Courses

- SYS 611 Modeling and Simulation
- SYS 660 Decision and Risk Analysis
- SYS 670 Forecasting and Demand Modeling Systems

Electives

Choose two courses from the following:

- FE 680 Advanced Derivatives
- SYS 740 Dynamics of Economic Systems I
- SYS 760 Advanced Decision and Risk Analysis

- MIS 620 Analysis and Development of Information Systems
- MGT 630 Data and Knowledge Management
- MGT 710 Risk Management Methods and Applications

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Graduate Certificate Programs

The Mathematical Science department offers a number of graduate certificate programs. Each program consists of four courses, including one elective chosen with the consent of the departmental advisor. Most courses may be used toward a master's degree, as well as for the certificate. Admission requirements are the same as for the corresponding master's program. Requirements for the Applied Statistics Certificate Program are the same as those listed above for all programs, except Financial Engineering.

Applied Statistics

MA 552 Linear Algebra
MA 611 Probability
MA 612 Mathematical Statistics

Typical electives:

— MGT 718 Multivariate Analysis
— MA 641 Time Series Analysis I
— CE 679 Regression and Stochastic Methods
— MGT 730 Design and Analysis of Experiments

Financial Engineering

FE 610 Probability and Stochastic Calculus
FE 620 Pricing and Hedging
FE 621 Computational Methods in Finance
FE 630 Portfolio Theory and Risk Management

Stochastic Systems

Choose three courses:

MA 612 Mathematical Statistics
MA 623 Stochastic Process
MA 629 Convex Analysis and Optimization
MA 661 Stochastic Optimal Control and Dynamic Programming

Choose one elective:

MA 627 Combinatorial Analysis
MA 662 Stochastic Programming
MA 641 Time Series Analysis I
MA 720 Advanced Statistics

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Doctoral Program

The primary requirement for a doctoral degree in mathematics is that you produce a dissertation containing an original and significant result in mathematics and its application. You will work under the guidance of a faculty advisor who is an expert in your area of research.

Preparation for dissertation work includes both courses in mathematical fundamentals and practice in communicating mathematics orally and in writing. The courses you take will not necessarily include everything you will need to know. As a doctoral student you will be expected to learn mathematics on your own outside of class when necessary.

Admission to the Program

Applications to the Doctoral Program must be prepared and sent according to the Stevens Office of Graduate Admissions regulations. Forms may be found on the Graduate Admissions Web page. Notice that the procedure is different for domestic and international applicants.

The Mathematics Department will base its evaluation of applicants on the following items:

- A personal statement, describing the student's mathematical background and interests, motivations, and goals for pursuing a Ph.D. degree. This should not exceed two pages.
- Official transcripts and diplomas. For non-English-speaking institutions, these documents must be accompanied by a certified English translation.
- Letters of recommendation: at least two; at most, four.
- GRE scores.
- TOEFL score for international students. The TOEFL score is particularly important if the student wants to be considered for a Teaching Assistantship (see the section on Teaching Assistantships).

Degree Requirements

- **A total of 90 credits**. At least 48 must be course credits (see the Mathematics Graduate Catalog) and at least 30 must be research credits. Incoming students who have already taken graduate classes elsewhere (e.g., for a master's degree) may have a maximum of 30 credits transferred. Transfer credit will be determined by the Department's Graduate Program Committee.
- **General Exam**. This is a written exam covering analysis, complex variables, and algebra. A detailed description of the subjects covered, as well as suggested references, are available from the Mathematics Department. This exam is offered twice a year, at the beginning of the fall and spring semesters. The General Exam should be taken before the student has accumulated 30 credits beyond the bachelor's degree or within the first year of study at Stevens. One failure of the General Exam is allowed. A second failure will result in the students being dropped from the Ph.D. program.
- **Ph.D. Candidacy Presentation**. After the General Exam, the student will choose a thesis advisor in the area of his/her special interest. The Ph.D. Committee can provide help and advice with this important choice. In collaboration with the thesis advisor, the student will write a (relatively) comprehensive plan of study in the field of interest. This plan will be distributed to the entire faculty to be possibly modified through the advice of other professors. When the student feels ready, and before work on the dissertation begins, (s)he shall give an oral presentation to the Department on the subjects studied. At this point, the student will be officially considered a Ph.D. Candidate.
- **Dissertation**. The final and most important step of the Ph.D. Program is writing a dissertation of publishable quality. This will embody the results of the student's original research in mathematics, and the dissertation will be presented by the student at a public defense. If the suitably appointed Dissertation Committee approves the defense, the student will be recommended to the Office of Graduate Admissions for the Ph.D. degree.

Financial Aid

The Department supports a limited number of Ph.D. students through teaching assistantships which entitle the recipients to a salary and a waiver of their tuition costs. Teaching assistants are considered for renewal each year, depending on teaching skills and progress towards graduation. Save for exceptional cases, Teaching Assistantships are not granted for more than five years. Teaching assistantships are usually available only for students entering in the Fall. In any case, applications should be received by the deadlines mentioned above under the heading Admission Criteria.

Students who wish to be considered for a Teaching Assistantship beginning their first year should mention this in their Personal Statement. If they already possess some teaching experience, they are encouraged to send any useful documents that address their teaching skills, such as letters of recommendation, evaluation forms, teaching awards, etc. However, no teaching experience is required for an incoming student to be considered for a Teaching Assistantship.

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UNDERGRADUATE COURSES

MA 90 Pre-Calculus
(non-credit)
Partial fractions, polynomials, Remainder Theorem, Fundamental Theorem of Algebra, Descartes' Rule, exponential and log functions, trigonometric functions, trigonometry of triangles, right triangles, laws of sines and cosines, and conic sections.

MA 115 Calculus I
(3-0-3)
Functions of one variable, limits, continuity, derivatives, chain rule, maxiMA and miniMA , exponential functions and logarithms, inverse functions, antiderivatives, elementary differential equations, Riemann sums, the Fundamental Theorem of Calculus, vectors, and determinants.

MA 116 Calculus II
(3-0-3)
Techniques of integration, infinite series and Taylor series, polar coordinates, double integrals, improper integrals, parametric curves, arc length, functions of several variables, partial derivatives, gradients, and directional derivatives. Prerequisite: MA 115.

MA 117 Calculus for Business and Liberal Arts
(3-0-3)
This course is designed for undergraduate students in Business and Liberal Arts majors. It includes the following basic topics in calculus: the definition of functions, their graphs, limits and continuity; derivatives and differentiation of functions; applications of derivatives; and definite and indefinite integrals. Properties of some elementary functions, such as the power functions, exponential functions, and logarithmic functions, will be discussed as examples. The course also covers methods of solving the first-order linear differential equations and separable equations, and some basic concepts in multi-variable calculus, such as partial derivatives, double integrals, and optimization of functions.

MA 118 Probability for Business and Liberal Arts
(3-0-3)
This course is designed only for undergraduate students in Business and Liberal Arts majors. It introduces basic concepts and methods in probability. Topics includes the definition of sample spaces, events, and their probabilities; elementary combinatorics and counting techniques; and conditional probability, the total probability, and Bayes' Theorem. The course also deals with concepts of discrete and continuous random variables and probability distributions; multi-random variables and their joint distributions; the mean,

variance, and covariance of random variables; and the Central Limit Theorem and t-distributions. Prerequisite: MA 117.

MA 134 Discrete Mathematics
(3-0-3)
This course provides the background necessary for advanced study of mathematics or computer science. Topics include propositional calculus, predicates and quantifiers, elementary set theory, countability, functions, relations, proof by induction, elementary combinatorics, elements of graph theory, mends, and elements of complexity theory.

MA 182 Honors Mathematical Analysis II
(4-0-4)
Covers the same material as MA 116, but with more breadth and depth. Additional topics discussed. By invitation or permission only.

MA 188 Seminar in Mathematical Sciences
(1-0-1)
Introduction to the modern applications of mathematics. The applications chosen demonstrate the power, beauty, and effectiveness of mathematics in establishing a rigorous understanding and treatment of scientific phenomena. Typical topics include optimization, chaotic dynamical systems, probability, information theory and coding, and computational mathematics. Permission of the instructor is required. This course may be taken more than once. If a student takes MA 188 at least three times, the student may earn three credits and count the course as an elective for the degree requirement.

MA 221 Differential Equations
(4-0-4)
Ordinary differential equations of first and second order, and homogeneous and non-homogeneous equations; improper integrals, Laplace transforms; review of infinite series, and series solutions of ordinary differential equations near an ordinary point; boundary-value problems; orthogonal functions; Fourier series; and separation of variables for partial differential equations. Prerequisite: MA 116.

MA 222 Probability and Statistics
(3-0-3)
Introduces the essentials of probability theory and elementary statistics. Lectures and assignments greatly stress the manifold applications of probability and statistics to computer science, production management, quality control, and reliability. A statistical computer package is used throughout the course for teaching and for assignments. Contents include: descriptive statistics, pictorial and tabular methods, and measures of location and of variability; sample space and events, probability axioms, and counting techniques; conditional probability and independence, and Bayes' formula; discrete random variables, distribution functions and moments, and binomial and Poisson distributions; continuous random variables, densities and moments, normal, gamma, and exponential and Weibull distributions unions; distribution of the sum and average of random samples; the Central Limit Theorem; confidence intervals for the mean and the variance; hypothesis testing and p-values, and applications for the mean; simple linear regression, and estimation of and inference about the parameters; and correlation and prediction in a regression model. Prerequisite: MA 116.

MA 227 Multivariable Calculus
(3-0-3)
Review of matrix operations, Cramer’s rule, and row reduction of matrices; inverse of a matrix, eigenvalues, and eigenvectors; systems of linear algebraic equations; matrix methods for linear systems of differential equations, normal form, homogeneous constant coefficient systems, complex eigenvalues, nonhomogeneous systems, and the

matrix exponential; double and triple integrals; polar, cylindrical and spherical coordinates; surface and line integrals; and integral theorems of Green, Gauss and Stokes. Engineering curriculum requirement. Corequisite: MA 221.

MA 230 Multivariable Calculus and Optimization
(3-0-3)
Begins with a study of n-dimensional geometry (hyperplanes, hyperspheres, convex hulls, and convex polyhedra), and moves on to study the differential calculus of functions of several variables. In this context, classical optimization theory is studied - that is, the application of calculus to the basic problem of finding the maxima and minima of a continuous function of one or more variables, using Lagrange multipliers, and paying particular attention to convex and concave functions. The final major topic studied is linear programming through the simplex method. Computational methods are stressed throughout. Other topics, such as search techniques, are taken up as time permits. Prerequisite: MA 116 or knowledge of matrix algebra.

MA 232 Linear Algebra
(3-0-3)
This course introduces basic concepts of linear algebra from a geometric point of view. Topics include the method of Gaussian elimination to solve systems of linear equations; linear spaces and dimension; independent and dependent vectors; norms, inner product, and bases in vector spaces; determinants, eigenvalues and eigenvectors of matrices; symmetric, unitary, and normal matrices; matrix representations of linear transformations and orthogonal projections; the fundamental theorems of linear algebra; and the least-squares method and LU-decomposition.

MA 234 Complex Variables with Applications
(3-0-3)
This course introduces basic concepts and methods in complex analysis. Topics include complex numbers and their properties, followed by limits, continuity, complex differentiation, analytic functions, the Cauchy-Riemann equations, complex integrations, Cauchy's integral formula, Taylor and Laurent series, Cauchy residue theorem, applications of contour integrals, conformal mappings, and applications in physics and engineering. Corequisite: MA 227.

MA 281 Honors Mathematical Analysis III
(4-0-4)
Covers the same material as that dealt with in MA 221, but with more breadth and depth. By invitation only.

MA 282 Honors Mathematical Analysis IV
(4-0-4)
Covers the same material as that dealt with in MA 227, but with more breadth and depth. By invitation only.

MA 293 Supplementary Topics of Differential Equations
(1-0-1)
This course is designed for the completion of transferring credits for MA 221 Differential Equations. The transfer students, who need to learn some topics of MA 221 not included in the courses taken elsewhere, may enroll in this course only once with permission of an undergraduate adviser in the Math Department, and are required to complete this course under the guidance of the MA 221 course coordinator. The students who pass this course will receive the full transfer credits for MA 221. The students who fail will then be required to enroll in the full course of MA 221 at Stevens. Pass/Fail.

MA 294 Supplementary Topics of Calculus IV
(1-0-1)
This course is designed for the completion of transferring credits for MA 227 Multivariable Calculus. The transfer students, who need to

learn some topics of MA 227 not included in the courses taken elsewhere, may enroll in this course only once with permission of an undergraduate adviser in the Math Department. The students are required to complete this course under the guidance of the MA 227 course coordinator. The students who pass this course will receive the full transfer credits for MA 227. The students who fail will then be required to enroll in the full course of MA 227 at Stevens. Pass/Fail.

MA 331 Intermediate Statistics
(3-0-3)
An introduction to statistical inference and to the use of basic statistical tools. Topics include descriptive and inferential statistics; review of point estimation, method of moments, and maximum likelihood; interval estimation and hypothesis testing; simple and multiple linear regression; analysis of variance and design of experiments; and nonparametric methods. Selected topics, such as quality control and time series analysis, may also be included. Statistical software is used throughout the course for exploratory data analysis and statistical inference based in examples and in real data relevant for applications. Prerequisite: MA 222.

MA 335 Introduction to Number Theory
(3-0-3)
This is an introductory course to number theory. Topics include divisibility, prime numbers and modular arithmetic, arithmetic functions, the sum of divisors and the number of divisors, rational approximation, linear Diophantine equations, congruences, the Chinese Remainder Theorem, quadratic residues, and continued fractions. Prerequisite: MA 232.

MA 336 Modern Algebra
(3-0-3)
A rigorous introduction to group theory and related areas with applications as time permits. Topics include proof by induction, greatest common divisor, and prime factorization; sets, functions, and relations; definition of groups and examples of other algebraic structures; and permutation groups, Lagrange's Theorem, and Sylow's Theorems. Typical application: error correcting group codes. Sample text: *Numbers Groups and Codes*, Humphries and Prest, Cambridge U.P. Prerequisite: MA 232.

MA 346 Numerical Methods
(3-0-3)
This course begins with a brief introduction to writing programs in a higher level language, such as Matlab. Students are taught fundamental principles regarding machine representation of numbers, types of computational errors, and propagation of errors. The numerical methods include finding zeros of functions, solving systems of linear equations, interpolation and approximation of functions, numerical integration and differentiation, and solving initial value problems of ordinary differential equations. Prerequisite: MA 116; Corequisite: MA 221 or permission of the instructor.

MA 360 Intermediate Differential Equations
(3-0-3)
This course offers more in-depth coverage of differential equations. Topics include ordinary differential equations as finite-dimensional dynamical systems; vector fields and flows in phase space; existence/uniqueness theorems; invariant manifolds; stability of equilibrium points; bifurcation theory; Poincaré-Bendixson Theorem and chaos in both continuous and discrete dynamical systems; and applications to physics, biology, economics, and engineering. Prerequisites: MA 221, MA 232.

MA 361 Intermediate Partial Differential Equations
(3-0-3)

This course offers a rigorous approach to classical partial differential equations. It begins with definitions, properties, and derivations of some basic equations of mathematical physics followed by the topics: solving of first order equations with the method of characteristics; classification of second order equations; the heat equation and wave equation; Fourier series and separation of variables; Green's functions and elliptic theory; examples of the first and second order nonlinear partial differential equations. Prerequisites: MA 221, MA 227.

MA 410 Differential Geometry
(3-0-3)
This course is an introduction to the geometry of curves and surfaces. Topics include tangent vectors, tangent bundles, directional derivatives, differential forms, Euclidean geometry and calculus on surfaces, Gaussian curvatures, Riemannian geometry, and geodesics. Prerequisite: MA 227.

MA 441 Introduction to Mathematical Analysis
(3-0-3)
This course introduces students to the fundamentals of mathematical analysis at an adequate level of rigor. Topics include fundamental mathematical logic and set theory, the real number systems, sequences, limits and completeness, elements of topology, continuity, derivatives and related theorems, Taylor expansions, the Riemann integral, and the Fundamental Theorem of Calculus. Prerequisite: MA 227 or permission of the instructor.

MA 442 Real Variables
(3-0-3)
This course introduces principles of real analysis and the modern treatment of functions of one and several variables. Topics include metric spaces, the Heine-Borel theorem in R-n, Lebesgue measure, measurable functions, Lebesgue and Stieltjes integrals, Fubini's theorem, abstract integration, L-p classes, metric and Banach space properties, and Hilbert space. Prerequisite: MA 232, MA 227.

MA 460 Chaotic Dynamics, with Computations and Applications
(3-0-3)
This course introduces students to the concepts behind the modern theory of dynamical systems, particularly chaotic systems. Although the course is mathematical in nature, the emphasis is on the underpinning ideas and applications, rather than a systematic exposition of results. Topics include: standard examples and definitions, solutions of ODEs as dynamical systems, flows, and maps; fixed points of linear maps, periodic orbits, limit cycles, and asymptotic stability; rudiments of hyperbolicity; and symbolic dynamics and the Horse Shoe. Further topics may include: fundamentals of topological dynamics, fundamentals of ergodic theory, attractors, and fractals. A good part of the assigned work involves computer experimentation and computations. Prerequisite: MA 232, MA 221, or permission of the instructor.

MA 461-462 Special Problems I-II
(0-3-2)(0-3-2)
Individual projects in pure and applied mathematics; enrollment limited. Departmental approval required.

MA 463-464 Seminar in Mathematics I-II
(3-0-3)(3-0-3)
Seminar in selected topics such as: combinatorial topology, differential geometry, finite groups, number theory, or statistical techniques. Enrollment limited. Instructor’s permission required. May be taken twice for credit.

MA 498-499 Senior Research Project I-II
(0-8-3), (0-8-3)
Students will do a research project under the guidance of a faculty

advisor. Senior standing and prior approval are required. Topics may be selected from any area of mathematics with the instructor's approval. Each student will be required to present results in both a written and oral report. The written report may be in the form of a senior thesis.

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GRADUATE COURSES

All Graduate courses are 3 credits except where noted.

MA 501 Introduction to Mathematical Analysis
This course is an introduction to the basic ideas of pre-calculus and calculus for the people who need preparation or review before taking more advanced courses. The exact content depends upon the particular needs of those enrolled and the requirements of degree programs they are pursuing. Topics covered will be selected from the following: algebra, functions, and graphs; slopes and secant lines; derivatives; chain rule; optimization; curve sketching; integration; the exponential and natural logarithm; and probability density functions and integration by parts. This course may not be taken for credit towards a degree at Stevens. Variable credits: 0-3.

MA 502 Mathematical Foundations of Computer Science
This course provides the necessary mathematical prerequisites for the computer science master’s program and also serves as a foundation for further study in mathematics. The topics covered include prepositional calculus: predicates and quantifiers; elementary number theory and methods of proof; mathematical induction; elementary set theory; combinatorics; functions and relations; countability; recursion; and O-notation. Applications to computer science are stressed.

MA 503 Discrete Mathematics for Cryptography
Topics include basic discrete probability, including urn models and random mappings; a brief introduction to information theory; elements of number theory including the prime number theorem, the Euler phi function, the Euclidean algorithm, the Chinese remainder theorem; and elements of abstract algebra and finite fields including basic fundamentals of groups, rings, polynomial rings, vector spaces, and finite fields. Carries credit toward the Applied Mathematics degree only when followed by CS 668. Prerequisite: MA 502 or equivalent.

MA 505 Introduction to Mathematical Methods
Elementary mathematical techniques important to applied mathematics. Topics covered include review of functions and continuity; ordinary and partial derivatives; integration; ordinary and partial differential equations; infinite series and numerical techniques for solving differential equations; and multiple integration and surface integrals. Applications to problems of applied mathematics are given where feasible.

MA 525 Introduction to Computational Science
This course is primarily for students interested in using numerical methods to solve problems in mathematics, science, engineering, and management. Computational projects will be a significant part of this course and it is expected that students already have experience programming in at least one high level language. Standard topics include numerical solutions of ordinary and partial differential equations, techniques in numerical linear algebra, the Fast Fourier Transform, optimization methods, and an introduction to parallel programming. Additional topics will depend on the interests of the instructor and students. Prerequisite: MA 232, MA 346, or the permission of the instructor.

MA 529 Applied Mathematics for Engineers and Scientists I
Review of limits, continuity, partial differentiation, and Leibnitz's rule; implicit functions and Jacobians; gradients, divergence, curl, line and surface integrals; theorems of Stokes, Gauss, and Green; complex numbers, elementary functions, analytic functions, complex integration, power series, residue theorem, and evaluation of real definite integrals; and systems of linear equations, rank, eigenvalues, and eigenvectors. Prerequisite: MA 227 or equivalent.

MA 530 Applied Mathematics for Engineers and Scientists II
Review of first order and second order constant coefficient differential equations, and nonhomogeneous equations; series solutions, and Bessel and Legendre functions; boundary value problems, Fourier-Bessel series, and separation of variables for partial differential equations; classification of partial differential equations; Laplace transform methods; calculus of variations; and introduction to finite-difference methods. Prerequisite: MA 227.

MA 534 Methods of Applied Mathematics
Difference equations; calculus of variations; integral equations; and applications to engineering and science. Prerequisite: MA 227.

MA 540 Introduction to Probability Theory
Sample space, events, and probability; basic counting techniques and combinatorial probability; random variables, discrete and continuous; probability mass, probability density, and cumulative distribution functions; expectation and moments; some common distributions; jointly distributed random variables, conditional distributions and independence, bivariate normal, and transformations of variables; and Central Limit Theorem. Some additional topics may include an introduction to confidence intervals and hypothesis testing.

MA 541 Statistical Methods
This course offers an introduction to exploratory data analysis and the use of basic statistical tools. Topics will include: data collection; descriptive statistics, and graphical and tabular treatment of quantitative, qualitative, and count data; detecting relations between variables; confidence intervals and hypothesis testing for one and two samples; simple and multiple linear regression; analysis of variance; design of experiments; and nonparametric methods. Selected topics, such as quality control and time series analysis, may also be included. Statistical software will be used throughout the course and statistical inference will be based on examples using real data. Students will participate in group projects of data analysis. They will be trained in the different phases of the professional statistician's work, namely: data collection, description, analysis, testing, and presentation of the conclusions. Prerequisite: MA 540 or the equivalent.

MA 547 Advanced Calculus I
Elementary topology of Euclidean spaces; differential calculus of functions of several variables; inverse and implicit function theorems; integration; differential forms; and theorems of Gauss, Green, and Stokes. Prerequisite: MA 227 or equivalent.

MA 548 Advanced Calculus II
A continuation of MA 547, but with greater emphasis on mathematical rigor. Topics covered may include convergence of series, Riemann-Stieltjes integration, functions of bounded variation, metric spaces, introduction to measure theory, and functional analysis. Prerequisite: MA 547.

MA 552 Linear Algebra
Fields and vector spaces; subspaces and quotient spaces; basis and dimension; linear transformations and matrices; determinants; and the theory of a single linear transformation.

MA 603-604 Methods of Mathematical Physics I-II*
A unified development of mathematical tools for treating a variety of problems in physics and engineering. Linear algebra, normed and inner product spaces, and spectral theory of operators; integral equations; boundary value problems for ordinary and partial differential equations; Green's functions; calculus of variations; and other related topics as time permits. Problem solving is stressed. Prerequisites: MA 548 and a reasonable knowledge of complex variables and ordinary differential equations.

MA 605-606 Foundations of Algebra I-II
Topics include elementary number theory, basic group theory, Lagrange's theorem, isomorphism theorems, solvability, direct products, Jordan-Holder theorem, Sylow theorems, basic properties of rings, quotient rings, field of quotients of an integral domain, polynomial rings, factorization, elementary properties of fields, field extensions, and Galois theory.

MA 611 Probability
Foundations of probability, random variables and their distributions, discrete and continuous random variables, independence, expectation and conditioning, generating functions, multivariate distributions, convergence of random variables, and classical limit theorems. Prerequisite: MA 222, MA 540, or equivalent.

MA 612 Mathematical Statistics
Point estimation, method of moments, maximum likelihood, and properties of point estimators; confidence intervals and hypothesis testing; sufficiency; Neyman-Pearson theorem, uniformly most powerful tests, and likelihood ratio tests; and Fisher information and the Cramer-Rao inequality. Additional topics may include nonparametric statistics, decision theory, and linear models. Prerequisite: MA 540, MA 611, or equivalent.

MA 615-616 Numerical Analysis I-II
Errors and accuracy; polynomial approximation; interpolation; numerical differentiation and integration; numerical solution of differential equations; least square and minimum-maximum error approximations; nonlinear equations; simultaneous linear equations; sunning series, Fourier series, filter design, the frequency approach, design of numerical tools, and statistics of error analysis; eigenvalues and eigenvectors of matrices; and the orientation throughout is toward computers. MA 615 Corequisite: MA 547.

MA 619 Introductory Sampling*
This course covers basic ideas in sampling theory and uses only elementary mathematics. Topics include multistage sampling, stratified sampling, systematic sampling, self-weighting samples, and optimum allocation.

MA 623 Stochastic Process
Random walks and Markov chains; Brownian motions and Markov processes; and applications, stationary (wide sense) processes, infinite divisibility, and spectral decomposition. Prerequisite: Permission of instructor.

MA 625 Fundamentals of Geometry
Absolute geometry as founded on axioms of incidence, order, congruence, and continuity; models of absolute geometry and problems of consistency; independence and categoricity of an axiom system; Euclidean and non-Euclidean geometry; brief description of the Erlangen program; and classical differential geometry of surfaces.

MA 627 Combinatorial Analysis
Fundamental laws of counting, permutations, combinations, recurrence relations, Mšbius inversion, probleme des menages,

probleme des recontres, partitions, trees, generating functions, Ramsey theory, transversal theory, and matroid theory.

MA 629 Convex Analysis and Optimization
The objective of this course is to introduce the students to the basic results of convex analysis and optimization. The properties of nonlinear non-smooth optimization models will be analyzed. Examples of optimization models from probability, statistics, and approximation theory will be discussed. Some basic models from management, finance, optimal design, scheduling, telecommunications, and other practical situations will be introduced, as well. The models will be used in conjunction with theoretical considerations as illustrations and to demonstrate the scope of applications. Topics include basic optimization models, separation and representation of convex sets, properties of convex functions, optimality conditions, saddle points, constraint qualifications, Fenchel and Lagrange duality, and sensitivity analysis. Prerequisite: MA 547 or equivalent.

MA 630 Numerical Methods of Optimization
The objective of this course is to introduce the students to the most popular numerical methods for solving nonlinear and non-smooth optimization problems. The techniques will be based on the properties of nonlinear non-smooth optimization models and optimality conditions. Linear optimization techniques will be treated as a special case. Some emphasis will be put on using optimization software. Examples using AMPL and CPLEX will be demonstrated in class. Topics include line search, non-derivative methods, basic decent methods, conjugate gradient methods, subgradient methods, Newton methods, projection methods, penalty, barrier, interior point methods, Lagrangian methods, bundle methods, trust-region method, numerical treatment of non-convex models, and decomposition methods. Prerequisite: MA 629.

MA 632 Game Theory
Strategic games and Nash equilibrium, strictly competitive (zero-sum) games and max-minimization, sStrategic games with imperfect information (Bayesian games), extensive games with perfect information (bargaining and repeated games), extensive games with imperfect information and signaling games, coalitional games (the core, stable sets, and bargaining sets), and auctions. Prerequisite: MA 611, MA 629, or permission of the instructor.

MA 633 Generalized Functions and Other Operational Methods*
Modern theory of the delta function and other generalized functions: Fourier and Laplace transforms and applications to ordinary and partial differential equations. Prerequisite: MA 548.

MA 634 Methods of Operations Research*
Queuing theory, transportation problem, traffic theory, inventory control, search theory, and methods of optimization. Prerequisites: MA 540, MA 520.

MA 635 Real Variables I
The real number system. Introduction to metric spaces and their applications. Lebesque measure and integral from a classical and/or modern approach. Prerequisite: MA 548.

MA 636 Real Variables II
L-p spaces and applications to Fourier series and Lebesque-Stieltjes integral. Prerequisite: MA 635.

MA 637 Mathematical Logic I
Prepositional calculus; syntax and semantics of first order theories; completeness theorem; elementary model theory: axiomatic development of Zermelo-Fraenkel or Bernays-Gödel set theory; and ordinals, cardinals, the axiom of choice, and several equivalent axioms.

MA 638 Mathematical Logic II
First order number theory; primitive and general recursive functions; arithmetization; Gödel's incompleteness theorems; Tarski's theorems; and syntax and semantics of second order theories. Prerequisite: MA 637.

MA 641-642 Time Series Analysis I-II
Scope and applications of time series analysis: process control, financial data analysis and forecasting, and signal processing. Exploratory data analysis: graphical analysis, trend and seasonality detection and removal, and moving-average filtering. Review of basic statistical concepts related to the characterization of stationary processes. ARMA models and prediction of stationary processes. Estimation of ARMA models and model building and forecasting with ARMA models. Spectral analysis: periodogram testing for seasonality and periodicities and the maximum entropy and maximum-likelihood estimators. Asymptotic convergence. Selected topics, such as multivariate time series, nonlinear models, Kalman filtering, econometric forecasting, and long-memory processes. Selected applications, such as the unit-root problem in economics, forecasting and testing for market efficiency in financial time series, process control, and quality control. MA 641 Prerequisite: basic working knowledge of probability and statistics, MA 540 or equivalent, or instructor's permission. MA 642 Prerequisite: MA 641.

MA 649 Differential Equations
Theory and application of ordinary differential equations (ODEs) with an emphasis on ODEs as continuous dynamical systems on a finite-dimensional phase space. Standard topics include existence and uniqueness theorems, general theory for linear equations, the exponential of linear map, stability of equilibrium points, hyperbolicity and structural stability, Lyapunov's method, invariant manifolds, Floquet theory for periodic orbits, and Poincare-Bendixon theorem. Prerequisites: MA 227, MA 112 (or MA 502). Corequisite: MA 547.

MA 650 Partial Differential Equations
This course discusses the classical theory and applications of partial differential equations and introduces the student to the modern theory. Classification of second order equations; well-posedness; existence and uniqueness for the Cauchy problem; Riemann function; Dirichlet and Neumann problems; Green's functions; perturbation theory; elliptic operators; variational formulation for the Laplace equation; weak solutions; and Sobolev spaces. Prerequisite: MA 227 or equivalent. Corequisite: MA 547.

MA 651 Topology
Metric spaces and topological spaces, bases and sub-bases, connectivity, local (path) connectivity, separation axioms, compactness and local compactness, concepts of convergence, Tychonoff's theorem, Urysohn's lemma, Tietze extension theorem, and selected topics as time permits.

MA 653 Numerical Solutions of Partial Differential Equations
This course is an introduction to methods and theory in numerical solutions of partial differential equations. The finite difference and pseudo-spectral methods will be used as examples to solve partial differential equations, including parabolic, hyperbolic, and elliptic equations in one or higher dimensional space. The theory on consistency, convergence, and Von Neumann stability analysis of numerical schemes will be emphasized for a basic understanding about how to control numerical errors and to achieve higher order accuracy for numerical solutions. Students will also be assigned projects to obtain the first-hand experience in numerical computations. Prerequisite: MA 650.

MA 655 Optimal Control Theory

The main purpose of this course is to present the foundations of the optimal control theory, some applications, and their solutions. The students will be introduced to the core concepts and results of control and system theory. The foundational and basic results will be derived for discrete and continuous time scales, and state variables. Topics to be covered: proportional-derivative control; state-space and spectrum assignment; outputs and dynamic feedback; reachability; controllability; feedback and stability; Lyapunov theory; linearization principle of observability; dynamic programming algorithm; multipliers for unconstrained and constrained controls; and Pontryagin maximum principle. Prerequisite: Advanced Calculus.

MA 661 Stochastic Optimal Control and Dynamic Programming
The main purpose of this course is to present the foundations of the stochastic control theory, the corresponding numerical methods, and some applications. The focus will be on the idea of dynamic programming which will be developed starting from deterministic models, through finite-horizon stochastic problems, to infinite-horizon stochastic problems of various types. Applications to queuing systems, network design, and routing; supply-chain management and others will be discussed in detail. Topics to be covered: basic concepts of control theory for stochastic dynamic systems; controlled Markov chains; dynamic programming for finite horizon problems; infinite horizon discounted problems; numerical methods for infinite horizon problems; linear stochastic dynamic systems in discrete time; tracking and Kalman filtering; linear quadratic models; controlled Markov processes in continuous time; and elements of stochastic control theory in continuous time and state space. Prerequisites: Advanced Calculus, MA 623.

MA 662 Stochastic Programming
This course introduces students to basic modeling and numerical techniques for making optimal decisions under uncertainty. The methodology to optimize the design and operation of stochastic systems by the use of mathematical programming tolls is known as stochastic programming. It is a rapidly developing area on the borderline with optimization, probability theory, and mathematical statistics. Prerequisites: Advanced Calculus, MA 540.

MA 681 Functions of a Complex Variable
Complex numbers; elementary functions; Möbius transformations; analytic functions; power series; integration; Cauchy-Goursat theorems; Cauchy integral formula; Taylor and Laurent series; singularities; residue theory; and meromorphic and entire functions. Prerequisite: MA 548.

MA 691 Dynamical Systems I
Theory and methods in continuous and discrete dynamical systems. Topics may vary, but will typically include local bifurcation theory for vector fields and maps, center manifold reductions, normal forms, periodic orbits and Poincaré maps, averaging methods, Melnikov methods, chaotic dynamics, the Smale horseshoe map, and symbolic dynamics. Prerequisite: MA 649 or consent of instructor.

MA 707 Integral Transforms*
Study of the classical transforms, the Laplace, Fourier, Hilbert, and other transforms; inversion and application to solution of differential, difference, and integral equations; and Abelian and Tauberian theorems, including Wiener's theory. Prerequisites: MA 635-636, MA 681-682.

MA 708 Hilbert Space Theory*
Geometry of Hilbert space; spectral theory of self-adjoint and normal operators; applications to differential operators; multiplicity theory; and families of operators, Stone's theorem, and introduction to rings of operators. Prerequisites: MA 635-636, MA 681-682.

MA 712 Mathematical Models of Risk
The course will introduce the students to the fundamental mathematical models of risk and approaches to decision-making under uncertainty and risk-aversion. The mathematical models will range from classical models as Expected Utility Theory, Prospect Theory, Dual Utility Theory, to state-of-the-art work on stochastic dominance, the theory of coherent risk measures, and general deviation measures. The course also surveys recent developments in particular applied areas as portfolio optimization, asset pricing, nuclear safety, reliability, etc. Prerequisite: Permission of instructor.

MA 715-716 Functional Analysis I-II
Linear topological spaces, local convexity, and spaces of distribution; Banach spaces; three fundamental theorems and applications to classical analysis; operators, operational calculus, compact operators, and applications to integral equations; Klein-Milman theorems; and fixed point theorems with applications to nonlinear problems. Prerequisites: MA 635-636, MA 681.

MA 717 Algebraic Topology
Notion of simplicial complex, absolute, and relative homology groups of a space; exact sequences; cohomology; axioms for homology theory; introduction to homological algebra; and homotopy and the fundamental group. Prerequisites: MA 605, MA 651.

MA 719, 729, 739 Advanced Probability*
Martingales; generalized weak and strong laws; infinitely divisible distribution; stable distributions and limiting distributions for triangular arrays; semigroup theory applications; bilateral Laplace transforms; renewal equation; random walks; and Markov processes. Prerequisite: MA 611.

MA 720, 730, 740 Advanced Statistics*
Selected topics may include: distribution theory; theory of inference; foundations of probability; spectral analysis; and multivariant analysis.

MA 721-722 Advanced Ordinary Differential Equations I-II*
Existence and uniqueness of solutions; dependence on parameters; periodic solutions; nonlinear autonomous systems; Poincare-Bendixon theory; continuous transformation groups; linear systems; Floquet theory; linear systems in complex domain; regular and irregular singularities; asymptotic expansions; Stokes' phenomenon; and boundary value problems. Prerequisite: MA 649. Fall and spring semesters.

MA 723-724 Advanced Partial Differential Equations I-II*
Characteristics and classification of equations; Cauchy-Kowalewski theorem; linear and quasilinear systems; elliptic equations and potential theory; Green's functions; mean value theorems; a priori estimates; functions space methods; hyperbolic equations; Riemann's solution of the Cauchy problem; discontinuities and shocks; Huyghen's principle; method of spherical means; and parabolic equations. Prerequisite: MA 650.

MA 725, 735, 745 Advanced Numerical Analysis
Selected topics in numerical analysis not treated in MA 615-616. Topics may include: numerical solution of partial differential equations, boundary value problems, and approximation theory, Monte Carlo methods, power spectral methods as they apply to numerical analysis, and optimal search problems. Prerequisites: MA 615 and MA 616.

MA 727 Theory of Algebraic Numbers*
Algebraic number fields; rings of algebraic integers and integral basis of field discriminant; unique factorication for ideals; splitting and

ramifications of primes; Kummer's theorem with applications to quadratic and roots of unity fields; padic numbers; Hensel's lemMA ; geometry of numbers; units in an algebraic extension; finiteness of class numbers of a field; and computation of class numbers in special cases. Prerequisites: MA 605 and MA 606.

MA 751, 761, 771 Advanced Topics in Analysis*
Selected topics in advanced analysis not treated in other courses. Topics may include: integral transforms, general convolution transform, approximation theory, theorems of Jackson and Bernstein, functions of exponential type, Nevalinna's theory of memomoprhic functions, asymptotic development, and perturbation theory. Prerequisite: Permission of instructor.

MA 752, 762, 772 Advanced Topics in Algebra*
Selected topics in algebra not treated in other courses. Topics may include: group representations, Lie algebra, structure of rings, valuation theory, algebraic curves, Galois theory of non-commutative fields, polynomial ideals, and elimination theory. Prerequisites: MA 605 and MA 606.

MA 753, 763, 773 Advanced Topics in Mathematical Logic*
Selected topics in mathematical logic. Topics may include: a study of the connection between the semantical and syntactical treatments of prepositional calculus and quantification theory, including references to the works of Harbrand, Dreben, and Hintikka; and Gödel's completeness for theorem for the first order and predicate calculus; recursive function theory; decidable theories; and Gödel's incompleteness theorem for arithmetic, axiomatic set theory, and model theory. Prerequisites: MA 637 and MA 638.

MA 754, 764, 774 Advanced Topics in Topology*
Selected topics in topology. Topics may include: K theory, infinite dimensional analysis, knot theory, and applications of algebraic topology to algebraic geometry. Prerequisite: Permission of instructor.

MA 758, 768, 778 Special Topics in Graph Theory
This course will focus on one or more topics of current interest in graph theory and its applications. Possible topics include: linear algebra and graph theory; graphs and groups and graphical enumeration; extremal graph theory; graph equations; covering and packing problems; graph algorithms; and graph theoretic models of computation. Prerequisites: An introductory course in graph theory (such as EE 606) and/or permission of the instructor.

MA 775-776 Nonlinear Analysis I-II
Existence and uniqueness of solutions to nonlinear partial differential equations with applications to equations from physics and engineering. Topics covered will include degree theory, the Mountain Pass lemMA , variational methods, index theory, and Nash-Moser iteration schemes. The course will also include a review of Hilbert space methods. Prerequisite: Permission of instructor.

MA 800 Special Problems in Mathematics*
One to six credits. Limit of six credits for the degree of Master of Science.

MA 801 Special Problems in Mathematics*
One to six credits. Limit of six credits for the degree of Doctor of Philosophy.

MA 900 Thesis in Mathematics
For the degree of Master of Science. Five to ten credits with departmental approval.

MA 960 Research in Mathematics
Original research carried out under the guidance of a member of the

faculty which may serve as the basis for the dissertation required for the degree of Doctor of Philosophy. Hours and credits to be arranged.

FINANCIAL ENGINEERING COURSES

FE 510 Introduction to Financial Engineering
This course introduces a range of topics that the current scope of financial engineering encompasses. Topics include basic terminology and definitions, markets, instruments, positions, conventions, cash flow engineering, simple derivatives, mechanics of options, derivatives engineering, arbitrage-free theorem, efficient market hypothesis, introductory pricing tools, and volatility engineering. This course has no prerequisites and does not count towards the Master's degree in Financial Engineering.

FE 590 Introduction to Knowledge Engineering
Introduction to information theory: the thermodynamic approach of Shannon and Brillouin. Data conditioning, model dissection, extrapolation, and other issues in building industrial strength data-driven models. Pattern recognition-based modeling and data mining: theory and algorithmic structure of clustering, classification, feature extraction, Radial Basis Functions, and other data mining techniques. Non-linear data-driven model building through pattern identification and knowledge extraction. Adaptive learning systems and genetic algorithms. Case studies emphasizing financial applications: handling financial, economic, market, and demographic data; and time series analysis and leading indicator identification.

FE 610 Probability and Stochastic Calculus
This course provides the mathematical foundation for understanding modern financial theory. It includes topics such as basic probability, random variables, discrete continous distributions, random processes, Brownian motion, and an introduction to Ito's calculus. Applications to financial instruments are discussed throughout the course.

FE 620 Pricing and Hedging
This course deals with basic financial derivatives theory, arbitrage, hedging, and risk. The theory discusses Ito's lemma , the diffusion equation and parabolic partial differential equations, and the Black-Scholes model and formulae. The course includes applications of asset price random walks, the log-normal distribution, and estimating volatility from historic data. Numerical techniques, such as finite difference and binomial methods, are used to value options for practical examples. Financial information and software packages available on the Internet are used for modeling and analysis. Prerequisites: Multivariable Calculus, FE 610, and programming in C, C++, or Java.

FE 621 Computational Methods in Finance
This course provides computational tools used in industry by the modern financial analyst. The current financial models and algorithms are further studied and numerically analyzed using regression and time series analysis, decision methods, and simulation techniques. The results are applied to forecasting involving asset pricing, hedging, portfolio and risk assessment, some portfolio and risk management models, investment strategies, and other relevant financial problems. Emphasis will be placed on using modern software. Prerequisite: FE 610.

FE 630 Portfolio Theory and Applications
This course introduces the modern portfolio theory and optimal portfolio selection using optimization techniques, such as linear programming. Topics include contingent investment decisions, deferral options, combination options, and mergers and acquisitions. Prerequisites: FE 620, FE 621.

FE 680 Advanced Derivatives

This course deals with fixed-income securities and interest-rate sensitive instruments. Topics include term structure of interest rates, treasury securities, strips, swaps, swaptions, one-factor, two-factor interest rate models, Heath-Jarrow-Merton (HJM) models and credit derivatives: credit default swaps (CDS), collateralized debt obligations (CDOs), and Mortgage-backed securities (MGS). Prerequisite: FE 620.

FE 699 Project in Financial Engineering
A student is given a particular problem in financial engineering to be completed in one semester. The nature of the problem may be computational or theoretical depending on the student's track. It is encouraged that the problems be related and, in some instances, posed by the financial engineering industry.

FE 700 Master's Thesis in Financial Engineering
This is the thesis option equivalent to one elective and FE 699. The thesis option requires the approval of the advisor and is recommended only for full-time students. The student will produce a Master's thesis in financial engineering.

*By request.

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