Department of Mathematical Sciences

MILOS DOSTAL, 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, Associate Dean of the Arthur E. Imperatore School of Sciences and Arts, 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 Graduate Studies), Ph.D. (1969), Brooklyn Polytechnic Institute

Associate Professors

Darinka Dentcheva, Ph.D. (1989), Humboldt University, Berlin
Patrick D. Miller, Ph.D. (1994), University of Massachusetts

Assistant Professors

Khaldoun Khashanah, Ph.D. (1994), University of Delaware
Marco Lenci, Ph.D. (1999), Rutgers University
Yi Li, Ph.D. (1995), Pennsylvania State University

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

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

Your program is created by you and your advisor to meet your needs and goals; it will probably include the traditional sequence of courses. If you are well prepared, you may be granted advanced placement, and you may want to minor in another field, such as civil, computer, electrical, environmental and material engineering, chemistry, chemical biology, computer science, economics, humanities or physics.

The course sequence for mathematics is as follows:

Freshman Year

Term I

		Hrs. Per Wk. Class	Lab	Sem. Cred.
Ma 115	Math Analysis I	3	0	3
Ch 115	General Chemistry I	3	0	3
Ch 117	General Chemistry Lab I	0	3	1
CS 115	Intro to Computer Science	2	2	3
PEP 111	Mechanics	3	0	3
Hu	Humanities	3	0	3
PE 200	Physical Education I	0	2	1
	TOTAL	**14**	**7**	**17**

Term II

		Hrs. Per Wk. Class	Lab	Sem. Cred
Ma 116	Math Analysis 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
PEP112	Electricity and Magnetism	3	0	3
Hu	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 221	Differential Equations	4	0	4
Ma 232	Linear Algebra	3	0	3
PEP 221	Physics Lab I	0	3	1
Ma 334	Discrete Math.	3	0	3
Hu	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	Multivariate Calculus	3	0	3
PEP222	Physics Lab II	0	3	1
E 234[1]	Thermodynamics	3	0	3
Hu	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 234	Analytical Methods	3	0	3
Ma 346	Numerical Methods	3	0	3
Mgt 244[2]	Microeconomics	3	0	3
Hu	Humanities	3	0	3
TE	Technical Elective	3	0	3
PE 200	Physical Education V	0	2	1
	TOTAL	15	2	16

Term VI

		Hrs. Per Wk. Class	Lab	Sem. Cred
Ma336	Modern Algebra	3	0	3
TE	Math Elective	3	0	3
TE	Math Elective	3	0	3
PEP242	Modern Physics	3	0	3
Hu	Humanities	3	0	3
PE 200	Physical Education VI	0	2	1
	TOTAL	15	2	16

Senior Year

Term VII

		Hrs. Per Wk. Class	Lab	Sem. Cred.
Ma 498	Senior Res. Project	0	8	3
Ma 547	Advanced Calc. I	3	0	3
Hu	Humanities	3	0	3
TE	Technical Elective	3	0	3
	Elective	3	0	3
	TOTAL	**12**	**8**	**15**

Term VIII

		Hrs. Per Wk. Class	Lab	Sem. Cred
Ma 499	Senior Res. Project	0	8	3
Ma 548	Advanced Calc. II	3	0	3
Hu	Humanities	3	0	3
	Elective	3	0	3
	TOTAL	**9**	**8**	**12**

[1] Students may take Ch 321 (Thermodynamics) to substitute for E 234.
[2] Students may take Mgt 243 (Macroeconomics) to substitute for Mgt 244

- The two math electives in term VI must be chosen from Ma 331 (Intermediate statistics), Ma 360 (Intermediate Differential Equations), Ma 520 (Computational Linear Algebra I) and Ma 525 (Introduction to Computational Science). The technical electives must be selected with the approval of students' advisors.

- Ma 346, 360, 498, 499, 525 are project based courses. It is recommended that project assignments contribute to at least 20% of the grade in Ma 346, 360 and 525, and most of the grade in Ma 498 and 499.

Minor in Mathematical Sciences

We encourage students concentrating in other areas to consider a minor in mathematical sciences. A minor consists of the courses Ma 115, Ma 116, Ma 221, Ma 222, Ma 227, MA 232, Ma 234, Ma 334 and one other course chosen with the consent of the Department. The required courses cover material which is useful in practical applications of mathematics. The average grade in these five courses must be at least a 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.

GRADUATE PROGRAMS

Master of Science – Applied Mathematics

This program is for engineers and scientists who want to improve their mathematical credentials. It provides a background in mathematical techniques which are useful in solving practical problems in other fields. You are encouraged to include courses from other departments in your program of study.

Except in unusual circumstances, entering students must have taken courses in calculus and differential equations. The program involves 30 credits (10 courses) of coursework. You may transfer up to one third of this amount from outside Stevens, and 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 the department advisor.) All elective courses must be chosen with the consent of the department advisor.

Core Courses:

Ma 520 Computational Linear Algebra I
Ma 530 Applied Mathematics for Engineers and Scientists II
Ma 540 Introduction to Probability Theory
Ma 547 Advanced Calculus I
Ma 615 Numerical Analysis I
Ma 681 Complex Variables 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
Ma 603 Mathematical Physics I
Ma 616 Numerical Analysis II
CE 519 Structural Analysis
Ma 627 Combinatorial Analysis
Ma 635 Real Variables I
Ma 649 Intermediate Differential Equations
Ma 650 Intermediate Partial Differential Equations
Ma 682 Functions of a Complex Variable II
ME 674 Fluid Dynamics
ME 706 Finite-Element Methods
Ma 900 Thesis in Mathematics

Master of Science – Mathematics

Prerequisite undergraduate preparation for the degree of Master of Science (Mathematics) includes analytic geometry and calculus elementary differential equations, one year of advanced calculus, and one semester of linear algebra. A master's degree in mathematics requires 30 credits of courses numbered over 550 and the following core:

Core Courses (3 one year sequences)

Ma 605-606 Foundations of Algebra I-II
Ma 635-636 Real Variables I-II
Ma 637-638 Mathematical Logic I-II
Ma 651-652 Topology I-II
Ma 649-650 Intermediate Differential Equations and
  Intermediate Partial Differential Equations
Ma 681-682 Functions of a Complex Variable I-II

Master of Science - Stochastic Systems

The Department of Mathematical Sciences offers an interdisciplinary program in Stochastic Systems. The program focuses in the area of analysis and optimal decision-making for complex systems involving uncertain data and risk. Emphasis is placed on the interaction of analyzing uncertainty (statistics and stochastic models) and optimization (optimal control theory) using cutting edge tools.

Statistics, stochastic processes, stochastic optimization and optimal control theory are integrated with applications in financial systems, networks design and routing, supply-chain management, actuarial science, telecommunication systems, statistical pattern recognition analysis and more. Students are encouraged to apply the tools and techniques they learn towards problems derived from the professional work and interests.

Entering students must have taken calculus, introductory probability and have knowledge of matrix linear algebra. 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 I
Ma 611 Probability
Ma 612 Mathematical Statistics
Ma 623 Stochastic Process
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 662 Stochastic Programming
Ma 655 Optimal Control Theory
Ma 720 Advanced Statistics
CS 535 Financial Computing
Mgt 730 Design and Analysis of Experiments
EN 780 Nonlinear Correlation and System Identification

Graduate Certificate Programs

The Mathematical Science department offers graduate certificate programs to students meeting the regular admission requirements for the master's programs. Each Graduate Certificate program is self-contained and highly focused, consisting of four courses, which includes one elective chosen with the consent of the departmental advisor. Most courses may be used toward the master's degree as well as for the certificate.

Applied Statistics

Ma 540 Introduction to Probability Theory*
Ma 541 Statistical Methods
Ma 520 Computational Linear Algebra I or Ma 552 Axiomatic Linear Algebra
and one elective (generally one of the following)
Mgt 552 Multivariate Analysis
Ma 641 Time Series Analysis I
CE 679 Regression and Stochastic Methods
Mgt 730 Design and Analysis of Experiments

** not for credit toward master's degree in Applied Statistics*

Financial Engineering

Ma/FE 610 Probability and Stochastic Calculus
Ma/FE 620 Pricing and Hedging
Ma/FE 621 Computational Methods in Finance
Ma/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

Doctoral Program

The Ph.D. Program in Mathematics at Stevens has as its goal the formation and maintenance of a community of students and scholars devoted to the understanding and practice of mathematics. In so doing the Stevens doctoral program intends the integration of theory with practice. Students shall acquire a background in mathematical fundamentals to subsequently undertake independent research. The art of communicating mathematics both orally and in writing is intentionally fostered, as is an appreciation of the utility of modern technology in conveying mathematical ideas.

Admission to the Program

Applications to the Ph.D. Program must be prepared and sent according to the Stevens Office of Graduate Admissions regulations. Forms are found in the Graduate Studies web page. Notice that the procedure is different for domestic and international applicants.

This is the material that the Department will consider for admission to the Ph.D. Program in Mathematics:

- **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.
- Students who wish to be considered for a Teaching Assistantship should mention this in their Personal Statement. Also, if they already possess some teaching experience, they are encouraged to send any useful document that addresses their teaching skills (letters of recommendation, evaluation forms, teaching awards, etc.). On the other hand, **no teaching experience is required** for an incoming student to be considered for a Teaching Assistantship (see the section on Teaching Assistantships).
- **Official transcripts** and **conferments of degrees**. 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).

Applications should be received by **April 1** for admission in the Fall Semester, and **October 1** for admission in the Spring Semester.

Degree Requirements

These are the requirements with which a student must comply before being considered for the Ph.D. degree:

- **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. This will be determined by the Ph.D. Committee.

- **Entrance Exam**. This is a short, straightforward, written exam on undergraduate advanced calculus and linear algebra. It is designed to test the student's readiness on elementary topics and fitness for the Ph.D. Program. It may be taken at any time **within one year of enrollment**. Save for extenuating circumstances, the student who fails this exam will be dropped from the Ph.D. Program.
- **General Exam**. This is a written exam and must be passed **within three years of enrollment**. Its purpose is to ensure that the student is well-versed on fundamental subjects in mathematics before moving on to research work. The exam will cover three subjects: **Analysis, Complex Variable and Algebra**. A more detailed description of the subjects covered as well as suggested references are available from the Mathematics Department. This exam is offered twice a year, usually during the first weeks of January and the first weeks of June. One failure of the General Exam is allowed. A second failure, however, will result in the student being dropped from the Ph.D. Program. At this point, he/she can still obtain a Master's degree, upon completion of the required course work.
- **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**, he/she 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 Graduate School for the Ph.D. degree.

Teaching Assistantships

The Department finances a certain number of Ph.D. students through Teaching Assistantships, which entitle the recipients to a salary and a waiver of their tuition costs. Teaching Assistantships are considered for renewal each year, depending on the student's teaching skills and progress towards graduation. Save for exceptional cases, Teaching Assistantships are **not granted for more than five years**.

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 document that addresses their teaching skills (letters of recommendation, evaluation forms, teaching awards, etc.). On the other hand, no teaching experience is required for an incoming student to be considered for a Teaching Assistantship.

UNDERGRADUATE COURSES

Ma 90 Pre-Calculus
(non-credit)
Partial fraction, 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, conic sections.

Ma 115 Mathematical Analysis I
(3-0-3)
Functions of one variable, limits, continuity, derivatives, chain rule, maxima and minima, exponential and logarithm, inverse functions, antiderivatives, elementary differential equations, Riemann sums, Fundamental Theorem of Calculus, vectors and determinants.

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

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 on a Pass/Fail basis. 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, homogeneous and non-homogeneous equations, improper integrals, Laplace transforms, infinite sequences and series, series solutions of ordinary differential equations, Bessel functions. Numerical methods included where appropriate. 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, measures of location and of variability; sample space and events, probability axioms, counting techniques; conditional probability and independence, Bayes formula; discrete random variables, distribution functions and moments, binomial and Poisson distributions; continuous random variables, densities and moments, normal, gamma, 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-val-

ues, applications for the mean; simple linear regression, estimation of and inference about the parameters; correlation and prediction in a regression model. Prerequisite: Ma 116.

Ma 227 Multivariate Calculus
(3-0-3)
Boundary-value problems; orthogonal functions; Fourier series; separation of variables for partial differential equations; matrices and determinants; Cramer's rule; row reduction of matrices; eigenvalues and eigenvectors; systems of equations; double and triple integrals; polar, cylindrical and spherical coordinates; surface and line integrals; integral theorems of Green, Gauss and Stokes. Engineering curriculum requirement. Prerequisite: Ma 221.

Ma 230 Multivariate Calculus and Optimization
(3-0-3)
Begins with a study of n-dimensional geometry (hyperplanes, hyperspheres, convex hulls, 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; the least-squares method and LU-decomposition.

Ma 234 Analytical Methods in Engineering
(3-0-3)
An introduction to functions of a complex variable. The topics covered include complex numbers, analytic and harmonic functions, complex integration, Taylor and Laurent series, residue theory, and improper and trigonometric integrals. Corequisite: Ma 227.

Ma 281 Honors Mathematical Analysis III
(4-0-4)
Covers same material as that in the former Ma 220 and existing 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 331 Intermediate Statistics
(4-0-4)
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;

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 334 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 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; permutation groups, Lagrange's Theorem, 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; Co-requisite: 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; applications to physics, biology, economics and engineering. Prerequisite: Ma 221, Ma 232.

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
(0-3-3), (0-3-3)
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.

GRADUATE COURSES

All Graduate courses are 3 credits except where noted.

Mathematical Sciences

Ma 501 Introduction to Mathematical Analysis

This course is an introduction to the basic ideas of precalculus 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; 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/CS 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; 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. Recommended for high-level undergraduate students. Prerequisite: Ma 502.

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, numerical techniques for solving differential equations; multiple integration and surface integrals. Applications to problems of applied mathematics are given where feasible.

Ma 520 Computational Linear Algebra I

This course stresses the fundamental techniques that are necessary in the applications of linear algebra, with emphasis on implementation, while Ma 552 offers a more abstract approach. The topics covered are: linear transformations and matrices; norms and inner products; triangular linear systems; Gaussian elimination; partial and complete pivoting; Cholesky factorization; LU and QR factorizations; quadratics forms, Rayleigh quotients, Schur's lemma, unitary matrices, normal matrices, singular value decomposition, determinants; orthogonal projections and least squares; eigenvalues and eigenvectors; symmetric eigenvalue problem.

Ma 521 Computational Linear Algebra II

This course is a continuation of Ma 520 and covers additional linear algebra topics frequently needed in applications. Topics covered are: Householder and Givens matrices; condition numbers; matrix norms; QR algorithm for symmetric matrices; Lanczos and practical Lanczos method; iterative methods for linear systems; Jacobi, Gauss-Seidel, SOR, SSOR and Chebyshev semi-iterative methods; conjugate gradient and preconditioned conjugate gradient methods. Prerequisite: Ma 520.

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, 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, evaluation of real definite integrals; 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, nonhomogeneous equations; series solutions, 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; introduction to finite-difference methods. Prerequisite: Ma 227.

Ma 534 Methods of Applied Mathematics

Difference equations; calculus of variations; integral equations; 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, transformations of variables; 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, 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; 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 Axiomatic Linear Algebra
Fields and vector spaces; subspaces and quotient spaces; basis and dimension; linear transformations and matrices; determinants; the theory of a single linear transformation. Students interested primarily in applications of linear algebra and techniques of computation should consider Ma 520.

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, spectral theory of operators; integral equations; boundary value problems for ordinary and partial differential equations; Green's functions; calculus of variations; other related topics as time permits; problem solving is stressed. Prerequisite: Ma 548, and a reasonable knowledge of complex variables and ordinary differential equations. Fall and spring semesters.

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/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 and continuous distributions, random processes, Brownian motion, and an introduction to Itô calculus. Applications to financial instruments are discussed throughout the course.

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, classical limit theorems. Prerequisite: Ma 222 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; Fisher information and the Cramer-Rao inequality. Additional topics may include non-parametric 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, statistics of error analysis; eigenvalues and eigenvectors of matrices; the orientation throughout is toward computers. Corequisite for Ma 615: 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/FE 620 Pricing and Hedging
This course deals with basic financial derivatives theory, arbitrage, hedging, and risk. The theory discusses Itô's lemma, the diffusion equation and parabolic partial differential equations, 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. Prerequisite: Multivariable Calculus, Ma/FE610, and programming in C, C++, or Java.

Ma/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.

Ma 623 Stochastic Process*
Random walks and Markov chains; Brownian motions and Markov processes; applications, stationary (wide sense) processes, infinite divisibility, 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; classical differential geometry of surfaces.

Ma 627 Combinatorial Analysis
Fundamental laws of counting, permutations combinations, recurrence relations, Möbius inversion, probleme des menages, probleme des recontres, partitions, trees, generating functions, Ramsey theory, transversal theory, 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. The students will be introduced to the basic models that appear in management, finance, optimal design, scheduling, telecommunications and other practical situations. The models will be used with the theoretical considerations to illustrate the discussed notions and phenomena, and to demonstrate the scope of applications. Numerical techniques for optimization will be discussed as well. Topics that will be covered: basic optimization models, separation and representation of convex sets, properties of convex functions, optimality conditions, saddle points, constraint qualifications; Fenchel and Lagrange duality, sensitivity analysis; basic descent methods; conjugate direction methods; primal constraint optimization methods; penalty and barrier methods; dual methods. Prerequisite: Advanced Calculus.

Ma/FE 630 Portfolio Theory and Risk Management
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. The course then focuses on financial risk management with emphasis on Value-at-Risk (VAR) methods using general and parametric distributions and VAR as a risk measure. Real world scenarios are studied. Prerequisite: FE610, 620, 621.

Ma 632 Theory of Games*
Rectangular games, games in extensive form, continuous games, separable games, zero sum n-person games, applications. Prerequisites: Ma 540, Ma 520.

Ma 633 Generalized Functions and Operational Methods*
Modern theory of the delta function and other generalized functions: Fourier and Laplace transforms; 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, 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
Lp spaces and applications to Fourier series, 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; 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; Gauodel's incompleteness theorems; Tarski's theorems; 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, signal processing. Exploratory data analysis: graphical analy-

sis, trend and seasonality detection and removal, moving-average filtering. Review of basic statistical concepts related to the characterization of stationary processes. ARMA models, prediction of stationary processes. Estimation of ARMA models, model building and forecasting with ARMA models. Spectral analysis: periodogram testing for seasonality and periodicities, the maximum entropy and maximum-likelihood estimators. Asymp-totic 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 Intermediate 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, Poincare-Bendixon theorem. Prerequisites: Ma 227, Ma 112 (or Ma 502). Corequisite: Ma 547.

Ma 650 Intermediate 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; Sobolev spaces. Prerequisite: Ma 227 or equivalent. Corequisite: Ma 547.

Ma 651-652 Topology I-II

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; homotopy type, fundamental group, covering spaces; topology of Euclidean space and manifold; selected topics as time permits. Fall and spring semesters.

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 discrete and continuous 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; 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; 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 I
Complex numbers; elementary functions; Möbius transformations; analytic functions; power series; integration; Cauchy-Goursat theorems; Cauchy integral formula; Taylor and Laurent series; singularities; residue theory; meromorphic and entire functions. Prerequisite: Ma 548.

Ma 682 Functions of a Complex Variable II
Analytic continuation; Riemann surfaces; elliptic functions; gamma function; conformal mapping. Prerequisite: Ma 681.

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 Poincare maps, averaging methods, Melnikov methods, chaotic dynamics, the Smale horseshoe map, symbolic dynamics. Prerequisite: MA 649 or consent of instructor.

Ma 692 Dynamical Systems II*
Advanced topics from ordinary differential equations and nonlinear dynamics to be determined by the instructor and/or interest of students. Prerequisite: Ma 691 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; 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; families of operators, Stone's theorem and introduction to rings of operators. Prerequisites: Ma 635-636, Ma 681-682.

Ma 715-716 Functional Analysis I-II
Linear topological spaces, local convexity, spaces of distribution; Banach spaces; three fundamental theorems, applications to classical analysis; operators, operational calculus, compact operators and applications to integral equations; Klein-Milman theorems; fixed point theorems with applications to nonlinear problems. Prerequisites: Ma 635-636, Ma 681-682.

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

Ma 718 Algebraic Topology II*
Topics selected from cohomology theory, homotopy theory, fibre bundles, extraordinary cohomology theory (especially K theory). Prerequisite: Permission of instructor.

Ma 719, 729, 739 Advanced Probability*
Martingales; generalized weak and strong laws; infinitely divisible distribution; stable distributions, limiting distributions for triangular arrays; semigroup theory applications; bilateral Laplace transforms; renewal equation; random walks; 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; 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; 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 function; 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; 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, approximation theory; Monte Carlo methods, power spectral methods as they apply to numerical analysis, optimal search problems. Prerequisites: Ma 615 and 616.

Ma 727 Theory of Algebraic Numbers*
Algebraic number fields; rings of algebraic integers, 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 num-

bers of a field; computation of class numbers in special cases. Prerequisites: Ma 605 and 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 memomoporhic functions, asymptotic development, 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, elimination theory. Prerequisites: Ma 605 and 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; 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, 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, 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, graphical enumeration; extremal graph theory; graph equations; covering and packing problems; graph algorithms; 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, Nash-Moser iteration schemes. The course will also include a review of Hilbert space methods. Prerequisite: permission of the 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.

** by request*