MATHEMATICS

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COLLEGE OF SCIENCE

Ban, Dubravka, Associate Professor, Ph.D., University of Zagreb, Croatia, 1998; 2002. Algebra, Representation theory, Automorphic L-functions.
Bhattacharyya, **Bhaskar**, Professor, Ph.D., University of Iowa, 1993; 1993. Order restricted statistical inference, I-projections, linear models, multivariate analysis.
Budzban, **Gregory**, Professor, Ph.D., University of South Florida, 1991; 1991. Probability on algebraic structures, markov random fields, neural networks.
Burton, **Theodore A**., Professor, *Emeritus*, Ph.D., Washington State University, 1964; 1966.
Clark, **Lane**, Professor, Ph.D., University of New Mexico, 1980; 1991. Combinatorics and graph theory.
Crenshaw, **James A**., Associate Professor, *Emeritus*, Ph.D., University of Illinois, 1967; 1967.
Danhof, **Kenneth**, Professor, *Emeritus*, Ph.D., Purdue University, 1969; 1969.
Dharmadhikari, **Sudhakar**, Professor, *Emeritus*, Ph.D., University of California, Berkeley, 1962; 1978.
Earnest, **Andrew G**., Professor and *Chair*, Ph.D., Ohio State University, 1975; 1981. Algebra and algebraic number theory, arithmetic theory of quadratic forms.
Feinsilver, **Philip**, Professor, Ph.D., New York University (Courant), 1975; 1978. Probability theory, representation theory.
Fitzgerald, **Robert W**., Professor, Ph.D., University of California-Los Angeles, 1980; 1982. Quadratic forms, algebra.
Foland, **Neal E**., Professor, *Emeritus,* Ph.D., University of Missouri, 1961; 1965.
Gregory, **John**, Professor, Ph.D., University of California, Los Angeles, 1969; 1972. Optimization theory, numerical analysis, applied functional analysis.
Grimmer, **Ronald C**., Professor, *Emeritus,* Ph.D., University of Iowa, 1967; 1967.
Hooker, **John W**., Professor, *Emeritus*, Ph.D., University of Oklahoma, 1967; 1967.
Hughes, **Harry R**., Associate Professor, Ph.D., Northwestern University, 1988; 1989. Stochastic processes, stochastic geometry.
Hunsaker, **Worthen N**., Professor, *Emeritus*, Ph.D., Washington State University, 1966; 1969.
Jeyaratnam, **Sakthivel**, Professor, Ph.D., Colorado State University, 1978; 1981. Statistics, linear models, variance components, robust inference.
Kammler, **David W**., Professor, *Emeritus*, Ph.D., University of Michigan, 1971; 1971.
Kirk, **Ronald B**., Professor, *Emeritus*, Ph.D., California Institute of Technology, 1968; 1968.
Koch, **Charles**, Assistant Professor, *Emeritus,* Ph.D., University of Illinois, 1961; 1966.
Kocik, Jerzy, Assistant Professor; Ph.D., Southern Illinois University, 1989; 2002. Differential Geometry and Lie Algebras.
Langenhop, **Carl E**., Professor, *Emeritus,* Ph.D., Iowa State University, 1948; 1961.
Mark, **Abraham M**., Professor, *Emeritus,* Ph.D., Cornell University, 1947; 1950.
Maxwell, **Charles**, Professor, *Emeritus,* Ph.D., University of Illinois, 1955; 1963.
McSorley, John, Assistant Professor, Ph.D., University of Oxford, England, 1988; 2004. Combinatorics, graph theory, design theory.
Mills, Donald, Assistant Professor; Ph.D., Clemson University, 1999; 2002. Algebra.
Mohammed, **Salah-Eldin A**., Professor, Ph.D., University of Warwick, England, 1976; 1984. Functional differential equations, stochastic differential equations, global analysis.
Moore, **Robert A**., Associate Professor, *Emeritus,* Ph.D., Indiana University, 1961; 1965.
Mugdadi, Abdel-Razzaq, Associate Professor, Ph.D., Northern Illinois University, 1999; 2000. Nonparametric statistical methods and goodness of fit tests.
Neuman, **Edward**, Professor, Ph.D., University of Wroclaw, Poland, 1972; 1984. Numerical analysis, spline functions, approximation theory, special functions.
Olive, David, Associate Professor, Ph.D., University of Minnesota, 1998; 1999. Applied robust statistics, regression graphics, applied probability.
Paine, **Thomas B**., Assistant Professor, *Emeritus,* Ph.D., University of Oregon (Eugene), 1966; 1966.
Panchapakesan, **S**., Professor, *Emeritus*, Ph.D., Purdue University, 1969; 1970.
Parker, **George D**., Associate Professor, Ph.D., University of California at San Diego, 1971; 1972. Differential geometry, classical geometry, linear programming, computer modeling of coal industry and environmental legislation.
Patula, **William T**., Professor, *Emeritus* Ph.D., Carnegie-Mellon University, 1971; 1972.
Pedersen, **Franklin D**., Associate Professor, *Emeritus,* Ph.D., Tulane University, 1967; 1965.
Pericak-Spector, **Kathleen A**., Professor, Ph.D., Carnegie-Mellon University, 1980; 1981. Hyperbolic partial differential equations, continuum mechanics, science education.
Porter, **Thomas**, Professor, Ph.D., University of New Mexico, 1990; 1990. Combinatorial analysis, graph theory.
Redmond, **Donald**, Associate Professor, Ph.D., University of Illinois, 1976; 1979. Analytic number theory, elementary number theory, classical analysis, history of mathematics.
Schurz, Henri U., Assistant Professor, Ph.D., Humboldt University (Berlin), 1997; 2001. Stochastic analysis, stochastic dynamical systems, mathematical finance.

Spector, **Scott J**., Professor, Ph.D., Carnegie-Mellon University, 1978; 1981. Continuum mechanics, elasticity, nonlinear partial differential equations.
Sullivan, **Michael C**., Professor, Ph.D., The University of Texas at Austin, 1992; 1996. Topological Dynamics.
Tall, Issa A., Assistant Professor, Ph.D., National Institute of Applied Science of Roen, France, 2000; 2006. Analysis.
Wallis, **Walter D**., Professor, Ph.D., University of Sydney, 1968; 1985. Combinatorics, neural networks.
Wilson, **Joseph C**., Professor, *Emeritus,* Ph.D., Louisiana State University, 1954; 1957.
Wright, **Mary H**., Professor, Ph.D., McGill University, Montreal, Quebec, 1977; 1980. Rings and modules: structure of modules, prime ideals and localization over serial rings with Krull dimension.
Xiao, Mingqing, Associate Professor, University of Illinois at Urbana-Champaign, 1997; 1999. Partial differential equations, dynamical systems, control theory and applications
Xu, Dashun, Assistant Professor, Ph.D., Memorial University of Newfoundland, St. John's, Canada, 2004; 2006. Mathematical biology.
Xu, Jianhong, Assistant Professor, Ph.D., University of Illinois, 1997; 2005. Partial differential equations, control theory, optimization theory, dynamical systems, computational science.
Yucas, **Joseph**, Professor, Ph.D., Pennsylvania State University, 1978; 1980. Algebra, combinatorics.
Zeman, **Marvin**, Professor, Ph.D., New York University, 1974; 1979. Partial differential equations, integro-differential equations, numerical analysis.

The Department of Mathematics offers graduate degree programs leading to the Master of Arts or Master of Science degree in mathematics and the Doctor of Philosophy degree in mathematics. Students in the master's program can choose from a rich assortment of courses in both pure and applied mathematics and statistics. Each master's degree candidate works closely with a professor in writing a research paper in an area of interest to the student. A double major at the master's level between mathematics and a related discipline is also an option. At the doctoral level, a student may specialize in any one of a large number of fields such as algebra, applied mathematics, combinatorics, computational mathematics, control theory, differential equations, geometry, numerical analysis, probability, or statistics. Interdisciplinary programs are also available.

The department is committed to providing a challenging and rewarding experience for its graduate students. With over 30 graduate faculty and approximately 33 full-time graduate students, the department offers individual attention and mentoring, strives to establish a friendly, supportive environment, and assists students as much as possible to achieve their professional goals. Graduate students have 24 hour access to the departmental computer lab which has thirty state of the art PCs, all with internet connections. For more computing needs, students can access the university Unix computer servers from the lab.

Students interested in the teaching of mathematics may select a minor concentration in education within the Master of Science program in mathematics. Minor work for graduate degrees in other fields, which allow for a minor, is also offered.

Acceptance for graduate study in mathematics and subsequent continuation in the graduate program are at the discretion of the Department of Mathematics, provided that the student has been admitted to the Graduate School and meets the retention standards of the Graduate School. All applicants for the graduate program are considered for teaching assistantships. In order to be considered for a fellowship the applicant must take the GRE exam, and all applicants are strongly encouraged to take the GRE General Test.

Prospective students are encouraged to contact the Department of Mathematics at <gradinfo@math.siu.edu> or the web site at <www.math.siu.edu> for application forms or additional information.

In addition to the general rules, regulations, and requirements of the Graduate School, the following specific requirements pertain to the degrees available in mathematics.

This program requires a nonrefundable $45.00 application fee that must be submitted with the application for Admissions to Graduate Study in Mathematics. Applicants may pay this fee by credit card if applying electronically. Applicants submitting a paper application must pay by personal check, cashier's check, or money order made out to SIU, and payable to a U.S. Bank.

Master of Science Degree in Mathematics

Students will be considered for acceptance into the M.S. degree program in mathematics if they have completed an undergraduate major in mathematics or a strong undergraduate minor in mathematics together with a major in a closely related discipline.

Once accepted, the requirements are as follows:

1. The candidate must complete a total of at least 30 semester hours of graduate credit approved by the Director of Graduate Studies of which 15 hours must be at the 500 level and at least 21 hours must be in courses (exclusive of 400, 458, 511) offered by the Department of Mathematics. A minor concentration may be taken outside of the department if approved by the Director of Graduate Studies during the student's first semester in the master's program.
2. The candidate's program must include: (a) Math 453 and Math 419 AND (b) at least one 400- or 500-level mathematics course from two of the following three areas: (1) alegebra and analysis (excluding Math 452 and Math 419); (2) geometry and topology (3) probability and statistics. These requirements may be met

in whole or in part by means of equivalent courses taken here or elsewhere prior to acceptance for graduate study in the department.

3. The candidate must prepare a research paper or thesis (3 hours credit in MATH 595 or 599) under the supervision of a research adviser and two other faculty members from the department. This committee will be appointed by the Director of Graduate Studies after consultation with all those involved.

The candidate must demonstrate satisfactory performance on a final oral examination covering the graduate course work and the research paper or thesis. This examination will be conducted by the 3 members of the candidate's committee and moderated by the research adviser. The student will pass the examination if the research adviser and at least 1 of the other 2 committee members so agree.

Master of Arts Degree in Mathematics

Students will be considered for acceptance into the M.A. degree program in mathematics if they have completed with distinction the equivalent of a strong undergraduate major in mathematics. Once accepted, the requirements are as follows:

1. The candidate must complete a total of 30 semester hours of graduate level mathematics courses of which at least 15 must be at the 500 level.
2. The candidate must complete with a grade of *B* or better each of the courses MATH 419, 421, 430, 452, 455, and at least 2 of the courses MATH 501, 519, 530. This requirement may be met in whole or in part by means of equivalent courses taken elsewhere.
3. The candidate must demonstrate the ability to read mathematical literature in French, German, or Russian. This may be certified by passing with a grade of *B* or better the research tool course 488 offered by the Department of Foreign Languages and Literatures, by passing with a score of 465 or better an examination given by the Educational Testing Service of Princeton, NJ, or by passing a suitable examination given by a faculty member from the Department of Mathematics who has been approved by the Director of Graduate Studies.
4. The candidate must prepare a thesis (3 hours credit in MATH 599) under the supervision of a thesis adviser and 2 other faculty members from the department. This committee will be appointed by the Director of Graduate Studies after consultation with all those involved.

The candidate must demonstrate satisfactory performance on a final oral examination covering the graduate course work and the thesis. This examination will be given by the 3 members of the candidate's committee and chaired by the thesis adviser. The student will pass the examination if the thesis adviser and at least 1 of the other 2 committee members so agree.

Doctor of Philosophy Degree

Students will be considered for acceptance into the doctoral program if they have completed with distinction a graduate program comparable to that required for a master's degree in mathematics, statistics, or computer science at SIUC. Additional evidence of outstanding scholarly ability or achievement (e.g., a high score on the advanced section of the Graduate Record Examination or published research papers of high quality) will lend strength to the application. Students must have completed 419, 421, 430, 452, and 455 or their equivalent before entering the doctoral program.

Once admitted, the requirements are as follows:

1. The candidate must pass the departmental qualifying examination by the end of the January following the second fall semester in the doctoral program. This qualifying examination, which is given twice annually in January and August, covers 3 areas each of which is commensurate with a regularly scheduled 500 level graduate course at SIUC. After consultation with the Director of Graduate Studies candidates will choose the 3 areas over which they are to be examined, with 2 of 3 chosen from MATH 501, 519, 530, 580 including at least one of 501 and 519. The coursework in two courses chosen from the list of four above will not be counted toward completing the major area discussed in 3. below. The third area normally corresponds to another regularly scheduled 500 level mathematics course, but with the approval of the Director of Graduate Studies the third area may be chosen from a related field outside the department. A candidate who fails to pass the qualifying examination within the allotted time will be dropped from the doctoral program.
2. The candidate must demonstrate competence with two research tools, one of which is a foreign language and the other computer programming. The foreign language research tool requirement will be met by exhibiting the ability to read mathematics in any one of the languages French, German, or Russian. This may be certified by passing with a grade of B or better the research tool course 488 offered by the Department of Foreign Languages and Literatures, by passing with a score of 465 or better an examination given by the Educational Testing Service of Princeton, NJ, or by passing a suitable examination given by a member from the Department of Mathematics who has been appointed by the Director of Graduate Studies. The computer programming research tool requirement will be met by passing with a grade of B or better CS 202 and 220 or their equivalent or by passing a suitable examination given by a faculty member from the Department of Mathematics appointed by the Director of Graduate Studies.

3. Mathematics 501 and 519 or their equivalent are required courses for all doctoral students. The candidate must complete a major area (12 hours) and two minor areas (6 hours each). The course work in the major and minor areas must be at the 500 level and must be exclusive of the courses used to satisfy the qualifying examination. Normally the major and minor areas will be based on courses currently taught in the department. However, one of the minor areas may be taken outside the department, subject to the approval of the Director of Graduate Studies. With regard to the major and two minor areas, at least one of the three must be an applied area. The final definition of "applied" will be determined by the dissertation adviser.
4. The candidate must file a request with the Director of Graduate Studies to appoint a dissertation committee to supervise the remaining doctoral work. This committee shall consist of 5 members with the candidate's dissertation adviser as chair. At least one member of the committee must represent each of the minor areas, and the dissertation adviser and one other member will represent the major area. One member of the committee will be chosen from outside of the department. This committee will be appointed by the Director of Graduate Studies after consultation with the candidate, the proposed dissertation adviser, the department chair, and the other faculty members involved.
5. The candidate must pass a preliminary examination over the major area and one minor area chosen by the candidate. This examination will normally be given after satisfying the research tools requirement and within 18 months after passing the qualifying examination. The preliminary examination will consist of a written examination over the major area and an oral examination over the major area and the chosen minor area. This examination will be prepared, administered, and evaluated by the dissertation committee. Any member of the graduate faculty may attend the oral portion of the preliminary examination and (at the discretion of the committee chair) question the candidate. The candidate will pass the preliminary examination provided that 4 members of the committee including the chair so agree. A report on the examination will be included with the candidate's official academic records. In the event that the candidate's performance is unsatisfactory, the committee as a whole shall decide on the time and content of an appropriate re-examination. A candidate who fails the re-examination will be dropped from the doctoral program.

   In unusual circumstances a candidate who has passed the preliminary examination may wish to change the major area or dissertation adviser. This will be allowed if the Director of Graduate Studies and department Chair so agree, in which case the dissertation committee will be reconstituted in an appropriate manner. The revised committee may then prescribe additional course work and require the candidate to retake the preliminary examination.
6. The candidate must be officially admitted to candidacy for the Ph.D. degree. This will be done after all of the above requirements have been met.
7. The candidate must complete a dissertation (representing at least 24 hours in MATH 600) under the supervision of the candidate's dissertation adviser. The dissertation adviser and the other 4 members of the dissertation committee will evaluate the quality of the completed work which must conform to high literary and scholastic standards and constitute an original and publishable contribution to mathematics. A final oral examination will be conducted by the dissertation committee. During this examination the candidate will first present the major results of the dissertation and then respond to questions. Any member of the University graduate faculty may attend and (at the discretion of the dissertation adviser) ask related questions. The dissertation will be accepted provided the dissertation adviser and at least 3 of the other 4 members of the committee so agree.

For students interested in the doctoral degree program with an emphasis in computational mathematics, the entrance requirements are 419, 421, 452, and CS 451. Once students are admitted, the preceding paragraphs 1 through 7 apply except for the following. Courses for the qualifying exam are CS 555, one from 501 or 519, and one other 500 level mathematics course (preferably 549 or 575). For the preliminary examination, computer science should be a minor area. The program must also include mathematics 501, 519, and 549 or their equivalents.

As a matter of policy, the Department of Mathematics does not provide any student working for a master's degree financial support for more than two years nor a Ph.D. student more than four years past the master's or master's equivalent.

Courses (MATH)

405-3 Intermediate Differential Equations. This course features the study of several sets of differential equations with the aid of computers. The equations are actual applications taken from the areas of biology, chemistry, economics, engineering, finance, medicine, and physics; where possible, problems will be chosen to match student's interests. Student from these areas are particularly welcome. Basic theory of differential equations is cited, particularly as it is needed or encountered in the problems. Prerequisite: 305, but highly motivated students with a good calculus background and an interest in learning to use mathematical software may enroll with permission of the instructor.

406-3 Linear Analysis. An elementary introduction to function spaces and operators as used in quantum mechanics, partial differential equations, etc. Topics include: discrete and continuous models for the vibrating string; separation of variables and eigenfunction analysis; inner product spaces; operators on inner product spaces; the spectral theorem for Hermitian operators on finite dimensional spaces with selected applications; the Courant-Fisher max-min characterization of eigenvalues; the spectral theorem for compact Hermitian operators with selected applications to Sturm-Liouville boundary value problems and Fredholm integral equations. Prerequisite: 221 and 305.

407-3 Introduction to Partial Differential Equations. The purpose of this course is to teach the student how to solve linear partial differential equations that arise in engineering and the sciences. Topics studied will include: the heat equation, the wave equation, Laplace's equation, separation of variables, boundary and initial value problems, uniqueness via the energy methods, the maximum principle, and characteristics. Solutions to the vibrating string and dissipation of heat in a bar will be discussed. Prerequisite: 251 and 305.

409-3 Fourier Analysis. A practical modern introduction to the theory, techniques and applications of elementary Fourier analysis. Topics include: the Fourier synthesis and analysis equations for periodic and aperiodic functions on the reals and the integers; convolution; the calculus for finding Fourier transforms, Fourier series, and DFT's; operators and their Fourier transforms; the FFT and related algorithms; generalized functions, such as Dirac's delta, the comb, and "1/x"; and selected applications of Fourier analysis to sampling theory, partial differential equations, probability, the synthesis of musical tones, diffraction, and wavelets. Prerequisite: 221 and 305.

411-1 to 6 (1 to 3, 1 to 3) Mathematical Topics for Teachers. Variety of short courses in mathematical ideas useful in curriculum enrichment in elementary and secondary mathematics. May be repeated as topics vary. Does not count toward a mathematics major.

412-3 Problem Solving Approaches to Basic Mathematical Skills. Content of basic skills at all levels of education and the development of these skills from elementary school through college; emphasis on problem solving and problem solving techniques; determination of student skills and proficiency level. Credit may not be applied toward degree requirements in mathematics. Prerequisite: 314 or equivalent.

417-3 Applied Matrix Theory. Selected applications of matrices to physics, chemistry and economics. This material is also useful for engineering and computer science. Topics will include matrix representation of symmetry groups, non-negative matrices and the subsidy problem, location of eigenvalues. Prerequisite: 221.

418-3 Computer Algebra Systems. This course presents modern computer algebra systems (CAS) as a research tool in mathematics. The use of a CAS in the preparation of reports, theses and dissertations will also be covered. Topics will include: Solving differential equations with a CAS; Plotting techniques with a CAS; Symbolic packages for such areas as abstract algebra, number theory; and combinatorics: Programming with a CAS; Exporting result to TeX or word processing software; The AMS–LaTeX package. Prerequisite: graduate standing and consent of instructor.

419-3 Introduction to Abstract Algebra II. A detailed study of polynomial equations in one variable. Solvable groups and the Galois theory of field extensions are developed and applied to extensions of the quadratic formula, proving the impossibility of trisecting an angle with only a straight-edge and a compass, and to the basic facts about finite fields as needed in coding theory and computer science. Prerequisite: 319 or consent of instructor.

421-3 Linear Algebra. The extension of basic linear algebra to arbitrary scalars. The theory and computation of Jordan forms of matrices (as needed, e.g., for certain diffusion equations). Inner products, quadratic forms and Sylvester's Law of Inertia. Prerequisite: 221.

425-3 Introduction to Number Theory. Properties of integers, primes, divisibility, congruences, quadratic forms, diophantine equations, and other topics in number theory. Prerequisite: 319 or consent of department.

430-3 Introduction to Topology. Study of the real line and the plane, metric spaces, topological spaces, compactness, connectedness, continuity, products, quotients and fixed point theorems. This course will be particularly useful to students who intend to study analysis or applied mathematics. Prerequisite: 302 or 352 or consent of instructor.

435-3 Elementary Differential Geometry. An introduction to modern differential geometry through the study of curves and surfaces in R^3. Local curve theory with emphasis on the Serret-Frenet formulas; global curve theory including Fenchel's theorem; local surface theory motivated by curve theory; global surface theory including the Gauss-Bonnet theorem. Prerequisite: 251 and 221.

447-3 Introduction to Graph Theory. (Same as Computer Science 447.) Graph theory is an area of mathematics which is fundamental to future problems such as computer security, parallel processing, the structure of the World Wide Web, traffic flow, and scheduling problems. It is also playing an increasingly important role within computer science. Topics covered include: trees, coverings, planarity, colorability, digraphs, depth-first and breadth-first searches. Prerequisite: 349 or consent of instructor.

449-3 Introduction to Combinatorics. (Same as Computer Science 449.) This course will introduce the student to various basic topics in Combinatorics that are widely used throughout applicable mathematics. Possible topics include: elementary counting techniques, pigeonhole principle, multinomial principle, inclusion and exclusion, recurrence relations, generating functions, partitions, designs, graphs, finite geometry, codes and cryptography. Prerequisite: 349 or consent of instructor.

450-3 Methods of Advanced Calculus. This course presents multivariable calculus, an area that is fundamental to fields such as continuum mechanics, differential geometry, electromagnetism, relativity, and thermodynamics. Topics will include: parametric curves and surfaces, the inverse and implicit function theorems, contraction mapping and fixed point theorems, differentials, convergence of multivariate integrals, coordinate systems in space, Jacobians, surfaces, volumes, and Green's, Gauss', and Stokes' theorems. The emphasis in this course will be on explicit computations. Prerequisite: 251.

452-3 Introduction to Analysis. This course develops the basic mathematical tools that are necessary for the understanding of all other advanced courses in analysis. Its principal content is a rigorous development of one-variable calculus. Topics will include: sets, axioms for the real numbers, continuity and limits, differentiation, the Riemann integral, and infinite sequences and series of functions. If time allows, additional topics may be chosen from areas such as Riemann–Stieltjes integration or the analysis of functions of several variables. Prerequisite: 250.

455-3 Complex Analysis with Applications. This course introduces the mathematical techniques that are commonly used to analyze those problems in the sciences and engineering that are inherently two dimensional in nature. Its content is the analysis of differentiable functions of a single complex variable. Topics will include: the complex plane, analytic functions, the Cauchy–Riemann equations, line integrals, the Cauchy integral formula, Taylor and Laurent series, the residue theorem, and conformal mappings. Applications will be made to topics selected from fluids, electrostatics, and control theory. Prerequisite: 251 or consent of instructor.

458-3 Statistical Methods in Business and Industry. The course gives an introduction to statistical techniques using a limited calculus background. Topics covered include probability; random variables; standard distributions such as the binomial, Poisson, normal and exponential; estimation including the method of moments and of maximum likelihood; tests of hypotheses; simple linear regression. Applications to business and engineering problems will be emphasized. The course does not count toward a mathematics major or a mathematics minor. Prerequisite: 140 or equivalent.

460-3 Transformation Geometry. Geometry viewed as the study of properties invariant under the action of a group. Topics include collineations, isometries, Frieze groups, Leonardo's Theorem, the classification of isometries of Euclidean and hyperbolic geometries. Recommended elective for secondary education majors in mathematics. Prerequisite: 221 and 319.

471-3 Optimization Techniques. (Same as Computer Science 471.) An elementary introduction to algorithms for finding extreme values of nonlinear functions of several variables with and without constraints. Topics include: convex sets and functions; the arithmetic-geometric mean inequality; Taylor's theorem for functions of several variables; positive definite, negative definite, and indefinite matrices; iterative methods for unconstrained optimization such as the method of steepest descent; the Kuhn-Tucker algorithm; unconstrained and constrained geometric programming; Lagrange multipliers, and penalty function methods. Students will use a computer to study the numerical properties of these algorithms. Prerequisite: 250 and 221.

472-3 Linear Programming. (Same as Computer Science 472.)An introduction to the theory for finding extreme values of linear functionals subject to linear constraints. Topics include: recognition, formulation, and solution of real problems via the simplex algorithm; development of the simplex algorithm; artificial variables; the dual problem and the duality theorem; complementary slackness; sensitivity analysis; and applications of linear programming to integer programming, cutting plane algorithms, the distribution problem, the transportation problem, and the assignment problem. Students will use a computer to study the numerical performance of these algorithms. Prerequisite: 221.

473-3 Reliability and Survival Models. The course provides an introduction to the statistical analysis of data on lifetimes. Topics covered include hazard functions and failure distributions; multicomponent systems; estimation and hypothesis testing in life testing experiments with complete as well as censored data. Engineering applications include standby redundancy; repairable systems; preventive maintenance. Biomedical and actuarial applications will also be discussed. Prerequisite: 458 or 483 or 480 or consent of instructor.

475-6 (3,3) Numerical Analysis. (Same as Computer Science 475.) A practical introduction to the theory and techniques for computation with digital computers. Topics include: the solution of nonlinear equations; interpolation and approximation; solution of systems of linear equations; numerical integration, solution of ordinary differential equations; computation of eigenvalues and eigenvectors; and solution of partial differential equations. Students will use MATLAB to study the numerical performance of the algorithms introduced in the course. Prerequisite: (a) 221 and 250 (b) 305 and 475a.

480-3 Probability, Stochastic Processes and Applications I. An introduction to the central topics of modern probability including some elementary stochastic processes. A student taking this course will learn about random variables and properties, including sum of independent random variables and the Central Limit Theorem. In addition, random walks and discrete-time finite state Markov chains will be introduced. Applications to random number generators and image and signal processing will be discussed. Principal topics studied, in addition to those already listed, include generating functions, conditional probability and independence, expectation and moments, covariance and correlation, and characteristic functions. Prerequisite: 251.

481-3 Probability, Stochastic Processes and Applications II. A continuation of Part 1 with additional emphasis on stochastic processes and their applications. Students will see a through introduction to Markov processes and Martingales. Principal topics include the laws of large numbers, classification of states, recurrence and convergence to the stationary distribution in Markov chains, birth processes and Poisson processes, stopping times, and the Martingale convergence theorem. Additional topics may include the renewal equation, stationary processes and the ergodic theorem and their applications, diffusion, and Kalman filtering with applications to signal processing and estimation. Prerequisite: 480.

483-4 Mathematical Statistics in Engineering and the Sciences. The course develops the basic statistical techniques used in applied fields like engineering, and the physical and natural sciences. Principal topics include probability; random variables; expectations; moment generating functions; transformations of random variables; point and interval estimation; tests of hypotheses. Applications include one-way classification data and chi-square tests for cross classified data. Prerequisite: 250.
484-3 Applied Regression Analysis and Experimental Design. The course provides an introduction to linear models and design of experiments used extensively in applied statistical work. Principal topics include linear models; analysis of variance; analysis of residuals; regression diagnostics; randomized blocks; Latin squares; factorial designs. Applications include response surface methodology and model building. Computations are an integral part of the course and will require the use of a statistical package such as SAS. Prerequisite: 483 and 221 or consent of instructor.
485-3 Applied Statistical Methods. The course gives an introduction to sampling methods and categorical data analysis which are widely used in applied areas such as social and biomedical sciences and business. In sampling methods, topics covered include: simple random and stratified sampling; ratio and regression estimators. In categorical data analysis; topics covered include: contingency tables; loglinear models; logistic regression; model selection; use of a computer package. Prerequisite: 483 or consent of instructor.
495-1 to 6 Special Topics in Mathematics. Individual study or small group discussions in special areas of interest under the direction of a member of the faculty. Prerequisite: consent of chair and instructor.
501-3 Measure and Integration. This course is an introduction to measure theory and the Lebesgue integral. Its purpose is to develop many of the advanced mathematical tools that are necessary for the understanding of all other advanced courses in analysis. Topics will include: measures and measurable functions, Egoroff's theorem, the Lebesgue integral, Fatou's lemma, the monotone and dominated convergence theorems, functions of bounded variation and absolutely continuous functions, L^p-spaces, the Radon-Nikodým theorem, product measures, and Tonelli's and Fubini's theorems. Prerequisite: 452.
502-3 Linear Analysis. This course is an introduction to analysis in linear infinite-dimensional spaces. Its purpose is to introduce function spaces that are used in the formulation of modern mathematical models in economics, the sciences, and engineering involving topics such as control theory, partial differential equations, and probability. Topics will include: Banach spaces, the Hahn-Banach Theorem, the uniform boundedness principle, the closed-graph theorem, the open-mapping theorem, weak convergence, reflexive and separable spaces, adjoin operators, Hilbert spaces, and the Riesz representation theorem. Prerequisite: 501.
505-3 Ordinary Differential Equations. Existence and uniqueness theorems; general properties of solutions; linear systems; geometric theory of nonlinear equations; stability; self-adjoin boundary value problems; oscillation theorems. Theory will be illustrated with computer simulation of several real-world problems. Prerequisite: 452 and 421 or consent of instructor.
506-1 to 12 Advanced Topics in Ordinary Differential Equations. Selected advanced topics in ordinary differential equations chosen from such areas as: stability, oscillations, functional differential equations, perturbations, boundary value problems. Prerequisite: consent of instructor.
507-3 Partial Differential Equations. This course introduces the student to the mathematical techniques that are used to analyze qualitative properties of solutions to partial differential equations that arise in engineering and the sciences. Topics studied will include: function spaces including Sobolev spaces; weak derivatives; the Sobolev and Poincaré inequalities; existence, uniqueness, and continuous dependence for model equations. Prerequisite: 407 and 501.
508-3 Integral Equations. Origins of integral equations. Volterra equations of the first and second kind. Fredholm equations of the first and second kind. Fredholm's alternative theorem. The resolvent equation. Orthonormal eigensystems of a symmetric Fredholm operator. The Hilbert-Schmidt expansion theorem and its applications to Sturm-Liouville problems. Exact and approximation methods of solution. Prerequisite: 452 and 406 or 421.
511-3 Advanced Topics in the Teaching of Mathematics. (Same as Curriculum and Instruction 529.) Selected advanced topics in the teaching of mathematics chosen from such areas as: pedagogical theories; instructional strategies; applications of mathematics; problem solving. This course is counted by the Mathematics department only as part of an approved minor. Prerequisite: consent of instructor.
512-1 to 21 Topics in Mathematics for Teachers of Elementary, Middle School and Junior High Mathematics. (a) Abstract Algebra. **(b)** Geometry. **(c)** Probability and Statistics. **(d)** Sets, Logic and Number Systems. **(e)** Applications of Mathematics. **(f)** Algebra. **(g)** History of Mathematics. This course is counted by the Mathematics department only as part of an approved minor.
513-1 to 27 Topics in Mathematics for Teachers of Secondary Mathematics. (a) Abstract Algebra. **(b)** Geometry. **(c)** Probability and Statistics. **(d)** Sets, Logic and Number Systems. **(e)** Applications of Mathematics. **(f)** Analysis. **(g)** Discrete Mathematics. **(h)** Topology. **(i)** Computer Simulation. This course is counted by the Mathematics department only as part of an approved minor.
516-8 (4,4) Statistical Analysis in the Social Sciences. (a) Descriptive statistics; graphic display of data; concepts of probability; statistical estimation, and hypothesis testing. Applications to social science data. **(b)** Matrix algebra; general linear model; multivariate statistics, ordinal and nominal measures of associations and causal modeling. Applications to social science data. This course does not give credit toward a mathematics major. Prerequisite: one year of high school algebra or equivalent.

519-3 Algebraic Structures I. Introduction to the basic techniques in the classification of finite groups, including homomorphism theorems, classification of finitely generated abelian groups, Sylow's theorems and classification of small groups, divisibility theory in rings, especially polynomial rings. Prerequisite: 419 or consent of instructor.
520-3 Algebraic Structures II. Algebraic field extensions; splitting fields, algebraic closure, separable and inseparable extensions; finite fields; norms and traces, the fundamental theorem of Galois theory. Free modules, torsion modules, tensor products of modules, finitely generated modules over principal ideal domains, application of abelian groups. Prerequisite: 519.
522-1 to 12 Advanced Topics in Algebra and Number Theory. Selected topics in modern algebra and number theory chosen from such areas as: group theory, commutative algebra, non-commutative algebra, field theory, representation theory, analytical number theory, algebraic number theory, additive number theory. Diophantine approximations, Dirichlet series and automorphic form. Prerequisite: consent of instructor.
525-3 Number Theory. Introduction to modern analytic and algebraic techniques used in the study of quadratic forms, the distribution of prime numbers, diophantine approximations and other topics of classical number theory. Prerequisite: 425.
530-3 Geometry and Topology I. First part of a sequence that provides students with foundational material useful for research in dynamical systems, classical mechanics, relativity as well as other areas of mathematics. Topics include a review of point set topology, an introduction to differentiable manifolds and the fundamental group. Prerequisite: 430 or consent of instructor.
531-3 Geometry and Topology II. Second part of a sequence that provides students with foundational material useful for research in dynamical systems, classical mechanics, relativity as well as other areas of mathematics. Topics include homology and cohomology with differential forms. Prerequisite: 530 or consent of instructor.
532-1 to 12 Topics in Geometry and Topology. Topics may include dynamical systems, topological groups, knot theory, complexity theory, uniform spaces and frames, differential and Riemannian geometry, voting theory and mathematical physics. Prerequisite: consent of instructor.
540-3 Convex Analysis. The course develops the basic results on convex sets and functions which are extensively used in several areas of applied mathematics and in business and engineering. Both finite and infinite dimensional spaces will be discussed. Topics covered include separation theorems, extreme points and the Krein-Milman Theorem. For infinite dimensional spaces elementary aspects of locally convex spaces will be covered. Applications include inequalities, constrained optimization and minimax theory. Prerequisite: 452 or consent of instructor.
549-3 Combinatorial Theory. This course will introduce the student to various advanced topics in Combinatorial theory that are basic to modern methods in applicable mathematics. Possible topics include: Enumeration, Polya-Burnside theory, DeBruijn sequences, Graph theory, Cayley's Theorem, Ramsey's Theorem, Hall's Theorem, Design Theory, Distinct representatives, Latin squares and Finite geometries. Prerequisite: 449 or consent of instructor.
551-3 Functional Analysis. This course will introduce the student to various and advanced topics in functional analysis that are basic to modern methods in differential equations, mathematical physics, probability theory and quantum theory. Possible topics include: Banach algebras, distributions, locally convex spaces, quantum probability, self-adjoint operators, the spectral theory of operators and topological vector spaces. Prerequisite: 502.
553-1 to 12 Advanced Topics in Analysis and Functional Analysis. Advanced topics in analysis and functional analysis from such areas as: harmonic analysis, approximation theory, integration theory, advanced complex variables, topological vector spaces, operator theory, Banach algebras, distribution theory. Prerequisite: consent of instructor.
559-1 to 12 Advanced Topics in Combinatorics. Selected advanced topics in combinatorics chosen from such areas as: graph theory; combinatorial designs; enumeration; random graphs; finite geometry; coding theory; cryptography; combinational algorithms. Prerequisite: consent of instructor.
566-3 Continuum Mechanics. This course will provide a rigorous development of the mechanics of solids and fluids. Topics will include: elements of tensor analysis; kinematics; balance of mass, linear momentum and angular momentum; the concept of stress; constitutive equations for fluid and solid bodies; and invariance of constitutive equations under a change in observer. Applications of continuum mechanics to the solution of problems in materials science will be included as time permits. Prerequisite: 450 or 452.
569-1 to 12 Advanced Topics in Applied Mathematics. Selected advanced topics in applied mathematics chosen from such areas as: continuum mechanics; electromagnetic theory; control theory; mathematical physics. Prerequisite: consent of instructor.
570-1 to 12 Advanced Topics in Optimization. Selected advanced topics in optimization and operations research chosen from such areas as: calculus of variations, optimal control theory, nonlinear programming, convex analysis, non-smooth analysis, new flows, advanced computer simulation, large scale linear programming. Prerequisite: consent of instructor.
572-1 to 12 Advanced Topics in Numerical Analysis. (Same as Computer Science 572.) Selected advanced topics in numerical analysis chosen from such areas as: approximation theory, spline theory; special functions; wavelets; numerical solution of initial value problems; numerical solution of boundary value problems;

numerical linear algebra; numerical methods of optimization; and functional analytic methods. Prerequisite: consent of instructor.

574-3 Approximation Theory. A study of techniques for approximating functions by polynomials, trigonometric polynomials, polynomial splines, wavelets, etc. Topics include: existence, uniqueness and characterization of best approximations in normed linear spaces; projection methods for good approximation; the Weierstrass, Muntz-Szasz, and Stone-Weierstrass theorems; degree of approximation and the Jackson theorems; construction of optimal min-max and least squares approximation using rational functions, splines, wavelets. Students will use MATLAB to study the quality of various approximations developed in the course. Prerequisite: 452, 475a, and one of 406, 421.

575-3 Matrix Computations. A practical introduction to modern numerical linear algebra. Topics include: vector and matrix norms; Householder, Givens and Gauss transforms; factorization methods for solving systems of linear equations with roundoff error analysis; QR and SVD methods for solving linear least squares problems; the QR algorithm for computing the eigenvalues of a matrix. Students will use MATLAB to study the algorithms developed in the course. Prerequisite: 475a and one of 406, 421.

580-3 Statistical Theory. The course gives a rigorous introduction to statistical inference. Topics covered include statistical models; sufficiency and completeness; Cramér-Rao bound; Rao-Blackwell theorem; best estimators; most powerful tests; likelihood ratio tests; elements of Bayes and minimax procedures. Prerequisite: 483 or 480.

581-3 Probability. A rigorous, measure-theoretic introduction to probability theory. Principal topics include general probability spaces, product spaces and product measures, random variables as measurable functions, distribution functions, conditional expectation, types of convergence, characteristic functions and the Central Limit theorem, tail events and 0-1 laws, the Borel-Cantelli lemma, and the weak and strong law of large numbers. Prerequisite: Concurrent course in real variables, 501.

582-1 to 6 Advanced Topics in Probability. Selected advanced topics in probability chosen from such areas as: martingales, Markov processes, Brownian motion, infinitely divisible laws. Prerequisite: consent of instructor.

583-1 to 12 Advanced Topics in Statistics. Selected advanced topics in statistics chosen from such areas as: advanced linear models, advanced experimental design, multivariate statistical analysis, decision theory, advanced nonparametric theory. Prerequisite: consent of instructor.

585-1 to 2 Statistical Consulting. Consulting with university researchers under the supervision of a member of the statistics faculty. A write up of each consultation will be required. Prerequisite: 484 or 485 and consent of instructor.

590-1 to 6 Contemporary Mathematics Research. Lectures on various mathematical topics of current research interest by members of the department and by distinguished visitors. Prerequisite: consent of the graduate adviser.

595-1 to 12 per topic Special Project. An individual project, including a written report. **(a)** Algebra. **(b)** Geometry. **(c)** Analysis. **(d)** Probability and Statistics. **(e)** Mathematics Education. **(f)** Logic and Foundations. **(g)** Topology. **(h)** Applied mathematics. **(i)** Differential Equations. **(j)** Number Theory **(k)** Combinatorics and Graph Theory. Graded *S/U* only. Prerequisite: consent of instructor.

599-1 to 6 Thesis. Minimum of three hours to be counted toward the Master of Arts degree.

600-1 to 30 (1 to 16 per semester) Dissertation. Minimum of 24 hours to be earned for the Doctor of Philosophy degree.

601-1 per semester Continuing Enrollment. For those graduate students who have not finished their degree programs and who are in the process of working on their dissertation, thesis, or research paper. The student must have completed a minimum of 24 hours of dissertation research, or the minimum thesis, or research hours before being eligible to register for this course. Concurrent enrollment in any other course is not permitted. Graded *S/U* or *DEF* only.