Mathematics

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COLLEGE OF SCIENCE

Graduate Faculty:

Ban, Dubravka, Professor, Ph.D., University of Zagreb, Croatia, 1998; 2002. Algebra, Representation theory, Automorphic L-functions.
Bhattacharya, Bhaskar, Professor and *Chair*, Ph.D., University of Iowa, 1993; 1993. Order restricted statistical inference, I-projections, linear models, multivariate analysis.
Burton, Theodore A., Professor, *Emeritus,* Ph.D., Washington State University, 1964; 1966.
Calvert, Wesley, Associate Professor, University of Notre Dame, 2005; 2010.
Choiy, Kwangho, Assistant Professor, Ph.D., Purdue University, West Lafayette, 2012; 2015. Number Theory, Automorphic Forms and Representation Theory.
Clark, Lane, Professor, *Emeritus,* 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, *Emeritus,* Ph.D., Ohio State University, 1975; 1981.
Feinsilver, Philip, Professor, *Emeritus,* Ph.D., New York University (Courant), 1975; 1978.
Fitzgerald, Robert W., Professor, *Emeritus,* Ph.D., University of California-Los Angeles, 1980; 1982.
Foland, Neal E., Professor, *Emeritus,* Ph.D., University of Missouri, 1961; 1965.
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, *Emeritus,* Ph.D., Colorado State University, 1978; 1981.
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, Associate 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.
McSorley, John, Professor, Ph.D., University of Oxford, England, 1988; 2004. Combinatorics, graph theory, design theory.
Moore, Robert A., Associate Professor, *Emeritus,* Ph.D., Indiana University, 1961; 1965.
Neuman, Edward, Professor, *Emeritus,* Ph.D., University of Wroclaw, Poland, 1972; 1984.
Olive, David, 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.
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.
Redmond, Donald, Associate Professor, Ph.D., University of Illinois, 1976; 1979. Analytic number theory, elementary number theory, classical analysis, history of mathematics.
Samadi, S. Yaser, Assistant Professor, Ph.D., University of Georgia, 2014; 2014. Multivariate and Matrix Time Series Analysis.
Schurz, Henri U., Professor, Ph.D., Humboldt University (Berlin), 1997; 2001. Stochastic analysis, stochastic dynamical systems, mathematical finance.
Spector, Scott J., Professor, *Emeritus,* Ph.D., Carnegie-Mellon University, 1978; 1981.
Sullivan, Michael C., Professor, Ph.D., The University of Texas at Austin, 1992; 1996. Topological Dynamics.
Wallis, Walter D., Professor, *Emeritus,* Ph.D., University of Sydney, 1968; 1985.
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, Professor, University of Illinois at Urbana-Champaign, 1997; 1999. Partial differential equations, dynamical systems, control theory and applications
Xu, Dashun, Associate Professor, Ph.D., Memorial University of Newfoundland, St. John's, Canada, 2004; 2006. Mathematical biology.
Xu, Jianhong, Associate Professor, Ph.D., University of Illinois, 1997; 2005. Partial differential equations, control theory, optimization theory, dynamical systems, computational science.
Yucas, Joseph, Professor, Ph.D., *Emeritus,* Pennsylvania State University, 1978; 1980.
Zeman, Marvin, Professor, *Emeritus,* Ph.D., New York University, 1974; 1979.

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 <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 $65 application fee that must be submitted with the application for Admissions to Graduate Study in Mathematics. Applicants must pay this fee by credit card.

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, only three of which can be for 595, 598 or 599, and at least 21 hours must be in courses (exclusive of 411, 412, 511, 512A-G and 513A-I) 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 452 and MATH 419 AND (b) at least one 400- or 500-level mathematics course from two of the following three areas: (1) algebra 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. Students who do not receive a B or better in MATH 452 on the first attempt are required to repeat it. Students who do not receive a B or better in MATH 419 on the first attempt are required to repeat it.
3. The candidate must prepare a research paper or thesis (3 hours credit in MATH 598 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.
4. The candidate must demonstrate competence with the research tool of computer programming. This research tool requirement will be met by passing with a grade of B or better in CS 202 or the equivalent, or by passing a suitable examination given by a faculty member from the Department of Mathematics who has been appointed by the Director of Graduate Studies.
5. 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 three 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 one of the other two 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 two 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 (three hours credit

in MATH 599) under the supervision of a thesis 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 thesis. This examination will be given by the three 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 one of the other two 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 SIU. 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. Normally students will have completed MATH 419, 421, 430, 452, and 455 or their equivalent before entering the doctoral program; those who have not must make up any deficiencies during their first year in the Ph.D. program. Once admitted, the requirements are as follows:

1. The candidate must pass the departmental qualifying examination within four regular semesters after admission. Qualifying examinations are given twice annually, in January and in August. The student will be allowed to take qualifying exams at most three times. A student who fails to pass the qualifying examination within the allotted time will be dropped from the doctoral program at the end of the semester. The qualifying exam consists of three parts, each covering a regularly scheduled 500-level MATH course exclusive of MATH 511, MATH 521A-G, MATH 513A-I, MATH 516A,B, MATH 584, MATH 585 and MATH 586.. The student will decide which courses to be tested on in consultation with the Director of Graduate Studies. Two of the three must be chosen from MATH 501, 519, 530 and 580, and must include either 501 or 519. All three parts must be passed, but not necessarily all at once. One of the parts may be from a related field provided, if in judgement of the Graduate Programs Committee, it has mathematically rigorous content.
2. The candidate must demonstrate competence with a computer programming research tool. This requirement will be met by passing with a grade of B or better in CS 202 or its equivalent, or by passing a suitable examination given by a faculty member from the Department of Mathematics who has been appointed by the Director of Graduate Studies.
3. MATH 501 and 519 or their equivalent with a B or better are required courses for all doctoral students. The candidate must complete a major area (12 hours) and two minor areas (six 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 in an applied area. The final definition of "applied" will be determined by the dissertation adviser. The following courses cannot be used to satisfy requirements of the PhD program: MATH 400, MATH 401, MATH 402, MATH 403, MATH 404, MATH 411, MATH 412, MATH 511, MATH 512A-G, MATH 513A-I, and MATH 516A,B.
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 five 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 four 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 four 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 three of the other four members of the committee so agree.

For students interested in the doctoral degree program with an emphasis in computational mathematics, the entrance requirements are MATH 419, 421, 452, and CS 451. Once students are admitted, the preceding paragraphs one through seven apply except for the following: courses for the qualifying exam are CS 555, one from MATH 501 or 519, and one other 500-level MATH course (preferably MATH 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)

MATH 400-4 Interest Theory and Financial Derivatives. This course examines financial mathematics and actuarial models for investments including interest, annuities, stocks, bonds, and mutual funds. There is an introduction to financial derivatives, options, and futures. Preparation for Exam FM/2. Prerequisite: MATH 250 (Calculus II) with C or better.

MATH 401-3 Life Contingencies I. This course examines actuarial models for life insurance. Life contingency models include life insurance liability calculations, annuities, and credit risk. Basic properties of survival models and Poisson processes are covered. This course and MATH 402 prepare students for Exam MLC/3L. Prerequisite: MATH 483 with C or better.

MATH 402-3 Life Contingencies II. This is a second course in actuarial models for life insurance including multiple contingencies, multiple survivals and claim frequency models. Basic properties of Markov Chains are covered. This course and MATH 401 prepare students for Exam MLC/3L. Prerequisites: MATH 221 and MATH 401 with C or better.

MATH 403-3 Loss Models I. This course examines loss models including severity models, ruin models, and estimating and fitting the models. This course and MATH 404 prepare students for Exam C/4. Prerequisite: MATH 483 with C or better.

MATH 404-3 Loss Models II. This is a second course in loss models including estimation and fitting of severity and ruin models, and credibility theory. This course and MATH 403 prepare students for Exam C/4. Prerequisite: MATH 403 with C or better.

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 in biology, chemistry, economics, engineering, finance, medicine and physics. Where possible, problems will be chosen to match student`s interests. Students from these areas are particularly welcome. Basic theory of differential equations is cited as needed. Prerequisite: MATH 305 with C or better.

MATH 406-3 Linear Analysis. Introduction to function spaces and operators used in quantum mechanics, partial differential equations, etc. Topics include: discrete and continuous models for the vibrating string, separation of variables, eigenfunction analysis, inner product spaces; operators on inner produce spaces; the spectral theorem for Hermitian operators on finite dimensional spaces, the Courant-Fisher characterization. Prerequisite: MATH 221 and MATH 305 with C or better.

MATH 407-3 Partial Differential Equations. Solution methods for linear partial differential equations arising in engineering and science. Topics 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: MATH 251 and MATH 305 with C or better.

MATH 409-3 Fourier Analysis. Introduction to the theory, techniques and applications of Fourier analysis. Topics include: Fourier synthesis and analysis equations for periodic and aperiodic functions; convolution; the calculus of Fourier transforms, Fourier series of DFT`s; operators and Fourier transforms; FFT and related algorithms; generalized functions such as Dirac`s delta and others; selected applications. Prerequisite: MATH 221 and MATH 305 with C or better.

MATH 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.

MATH 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: MATH 321 or CI 321.

MATH 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 include matrix representation of symmetry groups, non-negative matrices and the subsidy problem, location of eigenvalues. Prerequisite: MATH 221 with C or better.

MATH 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 results to TeX or word processing software; The AMS-LaTeX package. Restricted to graduate standing. Special approval needed from the instructor.

MATH 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 compass, and to the basic facts about finite fields as needed in coding theory and computer science. Prerequisite: MATH 319 with C or better.

MATH 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: MATH 221 with C or better.

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

MATH 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: MATH 352 with C or better.

MATH 435-3 Elementary Differential Geometry. Introduction to modern differential geometry through the study of curves in R3. 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: MATH 221 and MATH 251 with C or better.

MATH 447-3 Introduction to Graph Theory. (Same as CS 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 also plays an increasingly important role within computer science. Topics include: trees, coverings, planarity, colorability, digraphs, depth-first and breadth-first searches. Prerequisite: MATH 349 with C or better.

MATH 449-3 Introduction to Combinatorics. (Same as CS 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: MATH 349 with C or better.

MATH 450-3 Methods of Advanced Calculus. Multivariable calculus fundamental to continuum mechanics, differential geometry, electromagnetism, relativity, thermodynamics, etc. Includes: parametric curves and surfaces, 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. Prerequisite: MATH 251 with C or better.

MATH 452-3 Introduction to Analysis. A rigorous development of one-variable calculus providing the tools necessary for understanding all other advanced courses in analysis. Topics include: sets, axioms for the real numbers, continuity, limits, differentiation, the Riemann integral, infinite sequences and series of functions. Additional topics may include areas such as Riemann-Stieltjes integration or the analysis of multivariable functions. Prerequisite: MATH 352 with C or better.

MATH 455-3 Complex Analysis with Applications. Analysis of differentiable functions of a single complex variable. Introduces mathematical techniques used to analyze problems in the sciences and engineering that are inherently two dimensional. Topics include: the complex plane, analytic functions, the Cauchy-Riemann equations, line integrals, the Cauchy integral formula, Taylor and Laurent series, the residue theorem, conformal mappings, applications. Prerequisite: MATH 251 with C or better.

MATH 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: MATH 319 with C or better.

MATH 471-3 Optimization Techniques. (Same as CS 471) Introduction to algorithms for finding extreme values of nonlinear multivariable functions with or without constraints. Topics include: convex sets and functions; the arithmetic-geometric mean inequality; Taylor`s theorem for multivariable functions; positive definite, negative definite, and indefinite matrices; iterative methods for unconstrained optimization. Prerequisite: MATH 221 and MATH 250 with C or better.

MATH 472-3 Linear Programming. (Same as CS 472) Introduction to 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 duality theorem; complementary slackness; sensitivity analysis; and selected applications of linear programming. Prerequisite: MATH 221 with C or better.

MATH 473-3 Reliability and Survival Models. Introduction to statistical analysis of data on lifetime, including hazard functions and failure distributions; estimation and hypothesis testing in life testing experiments with complete as well as censored data. Prerequisite: MATH 480 or MATH 483 with C or better.

MATH 474-3 Time Series. An introduction to time series: AR, MA and ARIMA models; estimation, time series models. Prerequisite: MATH 480 or MATH 483 with C or better.

MATH 475-3 Numerical Analysis I. (Same as CS 475) Introduction to theory & techniques for computation with digital computers. Topics include: solution of nonlinear equations; interpolation & approximation; solution of systems of linear equations; numerical integration. Students will use MATLAB to study the numerical performance of the algorithms introduced in the course. Prerequisites: MATH 221 and MATH 250 with C or better.

MATH 476-3 Numerical Analysis II. (Same as CS 476) Continuation of MATH 475. Topics include: 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. Prerequisites: MATH 305 and MATH 475 with a C or better.

MATH 480-3 Probability, Stochastic Processes and Applications I. Introduction to the central topics of modern probability including elementary stochastic processes; random variables and their properties; sum of independent random variables and the Central Limit Theorem; random walks; discrete time finite state Markov chains; applications to random number generators and image and signal processing. Also generating functions, conditional probability, expectation, moments. Prerequisite: MATH 251 with C or better.

MATH 481-3 Probability, Stochastic Processes and Applications II. Continuation of MATH 480. Thorough introduction to Markov processes and Martingales, including the laws of large numbers, classification of states, recurrence, convergence to the stationary distribution in Markov chains, birth processes, Poisson processes, stopping times, and the Martingale convergence theorem. Important and current applications will be included. Prerequisite: MATH 480 with C or better.

MATH 483-4 Mathematical Statistics in Engineering and the Sciences. 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: MATH 250 with C or better.

MATH 484-3 Applied Regression Analysis and Experimental Design. Introduction to linear models and experimental design widely used in applied statistical work. 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 will require the use of a statistical package such as SAS. Prerequisite: MATH 221 and MATH 483 with C or better.

MATH 485-3 Applied Statistical Methods. Introduction to sampling methods and categorical data analysis widely used in applied areas such as a social and biomedical sciences and business. Sampling methods topics include: simple random and stratified sampling; ratio and regression estimators. Categorical data analysis topics include: contingency tables; loglinear models; logistic regression; model selection; use of a computer package. Prerequisite: MATH 483 with C or better.

MATH 490-3 Topics in Mathematics. Selected topics in mathematics chosen from such areas as: (a) Financial Mathematics, Mathematical Biology or Actuarial Mathematics; (b) Probability, Statistics or Stochastic Processes; (c) Mathematical topics not including Statistics, such as Operations Research, Cryptography and High Dimensional computing in Numerical Analysis, etc. May be repeated up to 3 times as topics vary. Special approval needed from the instructor.

MATH 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. Special approval needed from the chair and instructor.

MATH 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, Lp-spaces, the Radon-Nikodym theorem, product measures, and Tonelli`s and Fubini`s theorems. Prerequisite: MATH 452.

MATH 502-3 Functional and Linear Analysis. This course is an introduction to infinite-dimensional spaces and their analysis. Topics include Hilbert and Banach spaces, separable and reflexive spaces, operators and their adjoints, and major theorems such as the Banach-Steinhaus, Open-Mapping, Closed Graph, Hahn-Banach, Riesz and matrix representation, Lax-Milgram, Arzela-Ascoli, Katos theorems. Spectral theory and applications to such areas as differential equations, Block iterations, quantum probability, fixed point theory or other areas are covered as time permits. Prerequisite: MATH 501 with a grade of B or better.

MATH 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: MATH 452 and MATH 421 or consent of instructor.

MATH 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. Special approval needed from the instructor.

MATH 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 Poincare inequalities; existence, uniqueness, and continuous dependence for model equations. Prerequisite: MATH 407 and MATH 501.

MATH 511-3 Advanced Topics in the Teaching of Mathematics. (Same as CI 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. Special approval needed from the instructor.

MATH 512A-1 to 3 Topics in Mathematics for Teachers of Elementary, Middle School and Junior High Mathematics-Abstract Algebra. This course is counted by the Mathematics department only as part of an approved minor.

MATH 512B-1 to 3 Topics in Mathematics for Teachers of Elementary, Middle School and Junior High Mathematics-Geometry. This course is counted by the Mathematics department only as part of an approved minor.

MATH 512C-1 to 3 Topics in Mathematics for Teachers of Elementary, Middle School and Junior High Mathematics-Probability and Statistics. This course is counted by the Mathematics department only as part of an approved minor.

MATH 512D-1 to 3 Topics in Mathematics for Teachers of Elementary, Middle School and Junior High Mathematics-Sets, Logic and Number Systems. This course is counted by the Mathematics department only as part of an approved minor.

MATH 512E-1 to 3 Topics in Mathematics for Teachers of Elementary, Middle School and Junior High Mathematics-Applications of Mathematics. This course is counted by the

Mathematics department only as part of an approved minor.

MATH 512F-1 to 3 Topics in Mathematics for Teachers of Elementary, Middle School and Junior High Mathematics-Algebra. This course is counted by the Mathematics department only as part of an approved minor.

MATH 512G-1 to 3 Topics in Mathematics for Teachers of Elementary, Middle School and Junior High Mathematics-History of Mathematics. This course is counted by the Mathematics department only as part of an approved minor.

MATH 513A-1 to 3 Topics in Mathematics for Teachers of Secondary Mathematics- Abstract Algebra. This course is counted by the Mathematics department only as part of an approved minor.

MATH 513B-1 to 27 Topics in Mathematics for Teachers of Secondary Mathematics- Geometry. This course is counted by the Mathematics department only as part of an approved minor.

MATH 513C-1 to 3 Topics in Mathematics for Teachers of Secondary Mathematics-Probability and Statistics. This course is counted by the Mathematics department only as part of an approved minor.

MATH 513D-1 to 3 Topics in Mathematics for Teachers of Secondary Mathematics-Sets, Logic and Number Systems. This course is counted by the Mathematics department only as part of an approved minor.

MATH 513E-1 to 3 Topics in Mathematics for Teachers of Secondary Mathematics-Applications of Mathematics. This course is counted by the Mathematics department only as part of an approved minor.

MATH 513F-1 to 3 Topics in Mathematics for Teachers of Secondary Mathematics-Analysis. This course is counted by the Mathematics department only as part of an approved minor.

MATH 513G-1 to 3 Topics in Mathematics for Teachers of Secondary Mathematics- Discrete Mathematics. This course is counted by the Mathematics department only as part of an approved minor.

MATH 513H-1 to 3 Topics in Mathematics for Teachers of Secondary Mathematics-Topology. This course is counted by the Mathematics department only as part of an approved minor.

MATH 513I-1 to 3 Topics in Mathematics for Teachers of Secondary Mathematics-Computer Simulation. This course is counted by the Mathematics department only as part of an approved minor.

MATH 516A-4 Statistical Analysis in the Social Sciences. Descriptive statistics; graphic display of data; concepts of probability; statistical estimation, and hypothesis testing. Applications to social science data. This course does not give credit toward a mathematics major. Prerequisite: one year of high school algebra or equivalent.

MATH 516B-4 Statistical Analysis in the Social Sciences. 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.

MATH 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: MATH 419 or consent of instructor.

MATH 520-3 Algebraic Structures II. Free modules, torsion modules, tensor products of modules, finitely generated modules over principal ideal domains, application of abelian groups, algebraic geometry, homological algebra and group cohomology. Prerequisite: MATH 519.

MATH 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. Special approval needed from the instructor.

MATH 525-3 Analytic Number Theory. Introduction to modern analytic techniques used in the study of quadratic forms, the distribution of prime numbers, Diophantine approximations and other topics of classical number theory. Prerequisites: MATH 425 and MATH 419 with grades of C or better.

MATH 526-3 Algebraic Number Theory. Introduction to the modern algebraic techniques used in the study of number theory. Advanced Galois Theory, algebraic integers, prime factorization of ideals, Dirichlet unit theorem, ramification theory, local fields, and other topics. Prerequisites: MATH 425 and MATH 455 with grades of C or better.

MATH 530-3 Topology. This course covers the basics of point-set topology, Urysohn`s lemma, Tychonoff`s theorem, the Barie category theorem, manifolds and the fundamental group. Prerequisite: MATH 430 or MATH 452 with a C or better.

MATH 531-3 Algebraic Topology. This course covers homotopy and homology groups, exact sequences, CW complexes, axioms of homology, and beginnings of cohomology. Prerequisite: MATH 530 with a C or better.

MATH 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. Special approval needed from the instructor.

MATH 535-3 Differential Geometry. This course covers differential forms, curvature, connections, integration on manifolds and may include Riemannian geometry or Lie groups. Prerequisite: MATH 530 with a C or better.

MATH 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: MATH 452 or consent of instructor.

MATH 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: MATH 449 or consent of instructor.

MATH 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. Special approval needed from the instructor.

MATH 555-3 Complex Analysis. We review the field of complex numbers, differentiability, series convergence and the Cauchy integral formula for functions of a single complex variable. We go on to study the properties analytic, entire, meromorphic, and harmonic functions. We develop rigorous proofs of the Maximum modulus theorem, the Riemann mapping theorem, the residue theorem, and the Weierstrass factorization theorem and related results. If time permits the gamma and Riemann zeta functions are presented. Prerequisite: MATH 455.

MATH 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. Special approval needed from the instructor.

MATH 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: MATH 450 or MATH 452.

MATH 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. Special approval needed from the instructor.

MATH 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. Special approval needed from the instructor.

MATH 572-1 to 12 Advanced Topics in Numerical Analysis. (Same as CS 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. Special approval needed from the instructor.

MATH 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: MATH 452, MATH 475, and one of MATH 406, MATH 421.

MATH 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: MATH 475 and one of MATH 406, MATH 421.

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

MATH 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. Concurrent course in real variables, MATH 501.

MATH 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. Special approval needed from the instructor.

MATH 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. Special approval needed from the instructor.

MATH 584-3 Linear Models. This course examines the theory of linear models with applications to the analysis of variance and regression and to the design of experiments. Least squares estimation, and testing for full rank and less than full rank models are covered. Prerequisites: MATH 221 and MATH 484 with grades of C or better.

MATH 585-3 Multivariate Analysis. This course examines the multivariate normal and elliptically contoured distributions, estimators of multivariate location and dispersion, Hotelling`s T^2 test, MANOVA, multivariate regression, principal component analysis, factor analysis, canonical correlation analysis, discriminant analysis, and clustering. Prerequisites: MATH 483 and MATH 221 with grades of C or better.

MATH 586-3 Statistical Computing and Learning. This course covers Statistical Computing and Learning, including supervised and unsupervised learning, statistical computations in software packages such as R and SAS, loops, approximation of distribution functions, computation of maximum likelihood estimations, random number generation, bootstrap, Monte Carlo, permutation tests, and Bayesian techniques. Prerequisites: MATH 483 and MATH 221 with grades of C or better.

MATH 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. Special approval needed from the graduate adviser.

MATH 595-1 to 12 Individual Study. Individual study supervised by a member of the continuing faculty. Graded S/U only. Special approval needed from the instructor.

MATH 598-1 to 6 Master`s Research Paper. Minimum of three hours to be counted toward the Master of Arts or Science in Mathematics degree. Graded S/U only. Special approval needed from the instructor.

MATH 599-1 to 6 Master`s Thesis. Minimum of three hours to be counted toward the Master of Arts or Science in Mathematics degree. Graded S/U only. Special approval needed from the instructor.

MATH 600-1 to 30 (1 to 16 per semester) PhD Dissertation. Minimum of 24 hours to be earned for the Doctor of Philosophy degree in Mathematics. Special approval needed from the instructor.

MATH 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.

MATH 699-1 Postdoctoral Research. Must be a Postdoctoral Fellow. Concurrent enrollment in any other course is not permitted.