Mathematical Sciences

Chair

Ho, Chih-Hsiang (1986), Professor; B.S., National Central University; M.S., New Mexico Highlands University; M.S., Ph.D., University of Minnesota.

Graduate Coordinator

Ding, Zhonghai (1995), Professor; B.S., Nanjing Institute of Technology; M.S., Institute of Systems Science; Ph.D., Texas A&M University.

Graduate Faculty

Aizley, Paul (1968), Professor; B.A., Harvard University; M.S., University of Arizona; Ph.D., Arizona State University.

Ananda, Malwane M.A. (1990), Professor; B.S., University of Sri Jayewardenepura; M.S., Ph.D., Purdue University.

Bachman, Gennady (1991),, Professor; B.A., Temple University; Ph.D., University of Illinois.

Baragar, Arthur (1997), Associate Professor; B.S., University of Alberta; Ph.D., Brown University.

Bellomo, Carryn (2003), Associate Professor; B.S., M.S., Ph.D., Old Dominion University.

Bhatnagar, Satish C. (1974) Professor; B.A. (honor), M.A., Panjab University, India; M.A., Ph.D. Indiana University.

Burke, Douglas (1994), Associate Professor; B.S., University of Wisconsin, Madison; M.A., University of California, Berkeley; Ph.D., University of California, Los Angeles.

Catlin, Sandra (1997), Associate Professor; B.A., University of California, Berkeley; M.S., Ph.D., University of Washington.

Cho, Hokwon (1999), Associate Professor; B.A., Korea University; M.A., Ph.D., University of California, Santa Barbara.

Costa, David (1993), Professor; B.S., Federal University of Pernambuco, Recife, Brazil; Ph.D., Brown University.

Dalpatadu, Rohan (1985), Associate Professor; B.S., University of Ceylon; M.S., Ph.D., Southern Illinois University at Carbondale.

DuBose, Derrick A. (1987), Associate Professor; B.A., California State University, Long Beach; M.A., Ph.D., University of California, Los Angeles.

Kern, Daniel (2003), Assistant Professor; B.S., College of William and Mary; M.S., University of Massachusetts, Amherst; Ph.D., University of Illinois, Chicago.

Li, Jichun (2000), Associate Professor; B.S., M.S., Nanjing University, China; Ph.D., Florida State University.

Li, Xin (1992), Associate Professor; B.S., M.S., Jilin University, Changchun; Ph.D., Texas A&M University.

Marcozzi, Michael (1997), Associate Professor; B.S., M.S., Ph.D., University of Delaware.

Muleshkov, Angel (1989), Associate Professor; M.S., Ph.D., University of Washington.

Phanord, Dieudonne´D. (2002), Professor; B.S., Gordon College; M.S., Ph.D., University of Illinois, Chicago.

Salehi, Ebrahim (1985), Associate Professor; B.S., University of Tehran; M.S., Institute of Mathematics, Tehran; M.S., Ph.D., University of Washington.

Robinette, Michelle (1996), Associate Professor; B.S., M.A., Ph.D., Western Michigan University.

Shiue, Peter (1985), Professor; B.S., National Taiwan Normal University; M.S., Ph.D., Southern Illinois University.

Tehrani, Hossein (1997), Associate Professor; B.S., Sharif University of Technology; M.S., Ph.D., Courant Institute of Mathematical Sciences.

Professors Emeriti

Bowman, Harold (1972-1999), Emeritus Associate Professor; B.E.E., City College of New York; M.A., Oklahoma University; Ph.D., Arizona State University.

Graham, Malcolm (1956-1985), Emeritus Professor; B.S., New Jersey State College; M.S., University of Massachusetts: Ed.D., Columbia University.

Miel, George, J. (1977-1985 & 1991-2006), Emeritus Professor; B.S., M.S., University of Illinois; Ph.D., University of Wyoming.

Nietling, Lloyd (1967-1992), Emeritus Associate Professor; B.A., St. Mary of the Plains College; B.S., Aquinas College; M.A., University of Michigan; Ph.D., Ohio State University.

The Department of Mathematical Sciences offers both the Master of Science and Doctor of Philosophy degrees. The M.S. program has areas of concentration in Pure Mathematics, Applied Mathematics, Applied Statistics, and Teaching Mathematics. The Ph.D. program has areas of concentration in Applied Mathematics, Computational Mathematics, Pure Mathematics, and Statistics. Specific disciplines include algebra, complex analysis, differential equations, foundations of mathematics, number theory, numerical analysis, real analysis, statistics and topology. Excellent computing facilities are available for classroom studies and research. The Department of Mathematical Sciences, through an active faculty, offers graduate students both an unusual amount of personal attention and a lively research atmosphere. The degree programs are designed to provide students with a strong theoretical background in graduate-level mathematics. Our graduates have been successful in finding employment in industry, government and education.

Admission Requirements for the Master of Science

Admission to the M.S. Program in Mathematical Sciences requires, in addition to the Graduate College admission requirements, that a student has completed a bachelor's degree with 18 upper-division credits in mathematics. To apply for admission to the M.S. Program prospective students must submit application material to both the Graduate College and the Department of Mathematical Sciences. First, applicants must submit the following material:

a. A completed application form.
b. Official transcripts from all colleges and universities the student has attended.
c. Recommended: Official scores from the GRE Aptitude and GRE Subject Test in Mathematics.
d. If interested: A completed application for a Graduate Assistantship to the Graduate College; additionally, international students must submit a completed financial statement and show competency in English (a TOEFL score of 550 or comparable evidence).

Second, applicants must submit the following material:

a. Copies of all transcripts sent to the Graduate College.
b. At least two letters of recommendation from persons familiar with the applicant's academic record and potential for advanced study in the mathematical sciences.
c. A Statement of Purpose describing the aim in applying for graduate study, the particular area of specialization within the mathematical sciences (if known), and any additional information that may aid the selection committee in evaluating preparation and aptitude for graduate study.
d. Recommended: Copies of GRE Aptitude and Subject scores to the Graduate Coordinator of the Department of Mathematical Sciences. Details of the admission procedure for the M.S. Program can be found on the department's web site.

Degree Requirements for the Master of Science

A minimum of 30 credits of graduate work is required for the M.S. in Mathematical Sciences, including at least 27 hours of course work. For the Pure Mathematics, Applied Mathematics, or Applied Statistics concentrations, at least 18 of the 27 credits must be at the 700 level. For the Teaching Mathematics Concentration, at least 15 of the 27 credits must be at the 700 level. A grade point average of 3.00 is required in all courses that are part of the degree program. The following specific requirements must be met:

Pure Mathematics Concentration

1. Core Requirement: Six credits of analysis drawn from MAT 707, 708, 709, 710, 771, 772, and three credits of algebra at the 700 level.
2. Six credits in a field of special interest to the student at the 700 level, exclusive of those used to meet the core requirement.
3. Six credits for thesis or an additional six credits of MAT courses at the 700 level.
4. Final Examination: This will be either an examination to defend the thesis or a written comprehensive examination based on requirements 1 and 2.

Applied Mathematics Concentration

1. Core Requirement: Six credits of analysis drawn from MAT 707, 708, 709, 710, 771, 772 and three credits of numerical analysis drawn from MAT 663, 765, 767.
2. Six credits of analysis and applied mathematics at the 700 level, exclusive of those used to meet the core requirement.
3. Six credits of thesis or an additional six credits of MAT or STA courses at the 700 level.
4. Final Examination: This will be either an examination to defend the thesis or a written comprehensive examination based on requirements 1 and 2.

Applied Statistics Concentration

1. Core Requirement: Twelve credits consisting of Mat 657, MAT 663, STA 667, STA 767.
2. Area of Specialization: Six credits in the selected area of specialization as follows:
   a. Applied Statistics: STA 763, 765
   b. Environmental Statistics: STA 751, 769
3. Six credits for thesis or an additional six credits of STA courses at the 700 level in the appropriate area of specialization.
4. Final Examination: This will be either an examination to defend the thesis or a written comprehensive examination based on requirements 1 and 2.

Teaching Mathematics Concentration

1. Mathematics Requirement: A total of 18 credits including nine credits from MAT 711, 712, and 714; three credits in algebra selected from 653, 654, 703, 704, 655, 669, 670; three credits in analysis selected from 657, 658, 707, 708, 659, 709, 710, 687, 665; and three credits in foundations selected from 651, 652, 701, 702, 680, 683, 684.
2. Education Requirement: Six credits in education from CIS 722 or CIS 724 and from CIG 720.
3. Three credits for a course in MAT, STA, CIS or CIG at the graduate level.
4. Three credits for an additional three credits of MAT or STA at the graduate level or six credits for thesis.
5. Final Examination: This will be either an examination to defend the thesis or a professional paper or an oral presentation addressing an appropriate area of specialization in mathematics.
   Note: MAT 711 and 712 do not count as credit toward a Master of Science in Mathematical Sciences degree with concentration in pure mathematics, applied mathematics or applied statistics.

Admission Requirements for the Doctor of Philosophy

In addition to the requirements of the Graduate College, applicants must satisfy the admission requirements of the Department of Mathematical Sciences summarized as follows. Applicants must have a minimum grade point average of 3.00 for all undergraduate work or a minimum 3.25 grade point average for the last two years of undergraduate

work. In addition, applicants seeking direct admission to the doctoral program without a previously earned Master of Science degree must have a minimum GPA of 3.00 for all undergraduate work or an overall 3.25 GPA for the last two years of mathematics undergraduate work.

Applicants with a master's degree must have an overall 3.00 GPA in their master's program and at least 15 credit hours of graduate level course work in Mathematical Sciences with a grade of B or better. Applicants must also submit official scores from the GRE General Test; successful applicants to the program are expected to have GRE scores among the upper 50th percentile of examinees taking the General GRE Test. To apply for admission to the Ph.D. Program prospective students must submit application material to both the Graduate College and the Department of Mathematical Sciences. First, applicants must submit the following material:

a. A completed application form.
b. Official transcripts from all colleges and universities the student has attended.
c. Official score from the GRE General Test.
d. If interested: A completed application for a Graduate Assistantship to the Graduate College; additionally, international students must submit a completed financial statement and show competency in English (a TOEFL score of 550 or comparable evidence).

Second, applicants must submit the following material:

a. Copies of all transcripts sent to the Graduate College.
b. Three letters of recommendation from persons familiar with the applicant's academic record and potential for doctoral study in the mathematical sciences.
c. A Statement of Purpose describing the aim in applying for doctoral study, the desired area of specialization within the mathematical sciences, and any additional information that may aid the selection committee in evaluating preparation and aptitude for advanced study.
d. Copy of the GRE General Test score to the Graduate Coordinator of the Department of Mathematical Sciences. Details of the admission procedure for the Ph.D. Program can be found on the department's web site.

Degree Requirements for the Doctor of Philosophy

1. ***Proficiency***. After admission to the doctoral program, each student must demonstrate proficiency in the subject matter of the following three courses:
   a. MAT 657: Introduction to Real Analysis
   b. MAT 663: Advanced Matrix Theory and Application
   c. STA 667: Introduction to Mathematical Statistics

   Each of the three parts of this requirement can be satisfied by earning a B or better grade in the course or by passing a proficiency exam on the course. The Department's Graduate Studies Committee in consultation with the Chair of the Department will rule on whether equivalent courses taken at another institution can count toward this entrance requirement. For students who take one or more of these courses, or who have taken equivalent courses at another institution, a maximum of 3 credits for students with a master's degree or a maximum of 6 credits for students with a baccalaureate can be counted toward the 60 credits total required for completion of the program.
2. ***Credit requirement.*** Doctoral students are required to complete a minimum of 60-credit hours beyond the baccalaureate, at least 36 of which must be in courses at the 700-level. For students entering the program with an M.S. degree, at least 30 credit hours must be completed at UNLV and at least 18 credit hours must be at the 700-level. Each doctoral student must complete a dissertation embodying the results of original research which is acceptable to the student's dissertation committee. Normally, a student will enroll in a minimum of 24 hours and a maximum of 36 hours of Dissertation/Research.
3. ***Qualifying Examination.*** The purpose of the Qualifying Examination is to measure the student's knowledge of basic graduate level coursework in selected areas and to make sure that the student is prepared to proceed to more advanced studies. The student will take the Qualifying Examination, usually within the second year, based on specified core courses in the student's concentration. The student must pass the Qualifying Examination within three years. For each concentration, these core courses are:

Applied Mathematics

MAT 707	Real Analysis I
MAT 709	Complex Function Theory I
MAT 771	Applied Functional Analysis I
Elective #1	
Elective #2	

Computational Mathematics

MAT 707	Real Analysis I
MAT 709	Complex Function Theory I
MAT 765	Advanced Numerical Analysis I
MAT 766	Advanced Numerical Analysis II
Elective #1	

Pure Mathematics

MAT 703	Abstract Algebra III
MAT 707	Real Analysis I
MAT 709	Complex Function Theory I
Elective #1	
Elective #2	

Statistics

STA 715	Multivariate Statistical Methods
STA 763	Regression Analysis
STA 767	Advanced Mathematical Statistics
STA 765	Statistical Decision Theory
Elective #1	

Students who fail the Qualifying Examination on the first attempt must complete a second examination within the next twelve months. Students who entered the program with a baccalaureate degree and who fail the second examination may be allowed to complete a Master of Science in Mathematical Sciences with the consent of the Graduate Studies Committee. To be eligible for the Master of Science the students must fulfill the requirements of

the Master of Science degree as stipulated in the Graduate Catalog. Such students will not be permitted to seek readmission to the Doctoral Program in Mathematical Sciences at UNLV. Students who fail the examination a second time and who entered the doctoral program with a master's or other graduate degree will be separated from the program.

4. ***Comprehensive Examination.*** The purpose of the Comprehensive Examination is to measure the student's knowledge of the advanced level graduate work that will be required as the student begins to do original research in his or her area of concentration. After passing the Qualifying Examination, the student will engage in approved course work specified by the Doctoral Advising Committee and submit to the latter a dissertation proposal. Usually a year after the Qualifying Examination, the student will complete a Comprehensive Examination, designed and administered by the Doctoral Advising Committee, based on the student's course work with focus on his/her ability to perform research on the dissertation proposal. Students who fail to pass the Comprehensive Examination on the first attempt must complete a second examination within the next semester. Students who fail the examination a second time will be separated from the program. A student who has successfully passed the Comprehensive Examination will be admitted to candidacy for the Ph.D. degree and thereby be allowed to proceed with the approved dissertation proposal.
5. ***Dissertation***. In addition to the 60 credits total listed earlier, each doctoral candidate must complete a minimum of 24 hours and a maximum of 36 hours of Dissertation/ Research.
6. ***Additional Requirements***. Skills in foreign languages, computer programming or interdisciplinary areas, dependent on the concentration of the student's program, will be determined by the Doctoral Advising Committee and the Graduate Study Committee in consultation with the Department Chair.
7. ***Dissertation Defense***. The candidate, having submitted to the Doctoral Advising Committee a dissertation draft, previously approved by the Dissertation Advisor, will orally defend the dissertation before said Committee and any other graduate faculty members who wish to attend. The Doctoral Advising Committee will recommend to the Department Chair whether the dissertation and defense are both satisfactory.

Specific degree requirements, including those listed above, are described in detail in the Graduate Student Handbook for the Ph.D. Program, available on the department's web site. The listing of graduate courses is constantly under review. Graduate students will automatically receive new listings. Since some courses are taught on an "on demand" basis, course prerequisites for each of the four concentrations are considered guidelines with courses roughly equivalent accepted as prerequisites, subject to approval of the Graduate Studies Committee and the student's Doctoral Advising Committee.

A student will be placed on academic probation if a minimum 3.00 grade point average is not maintained in all work taken in the degree program. A grade of C or less in one graduate-level course will cause a student to be placed on academic probation and will elicit a critical review of the student's program by the Graduate Studies Committee.

The Graduate College requires a minimum of 50 percent of the total credits required to complete the doctoral degree, exclusive of transferred credits and/or the dissertation, must be earned at UNLV after admission to a graduate degree program.

Mathematical Sciences

MAT 701-702 **3 credits each**
Foundations of Mathematics III and IV
Selection from the following topics: model theory, recursive function theory, set theory, mathematics of metamathematics. Prerequisite: MAT 652.

MAT 703-704 **3 credits each**
Abstract Algebra III and IV
Detailed study of the following algebraic structures: groups, rings and ideals, fields, modules, and Galois theory. Prerequisite: A year of undergraduate abstract algebra or consent of instructor.

MAT 707-708 **3 credits each**
Real Analysis I and II
Theory of measure, integration and differentiation: Banach spaces; Hilbert spaces; spaces of continuous functions. Prerequisite: MAT 658.

MAT 709-710 **3 credits each**
Complex Function Theory I and II
Analytic functions, conformal mappings, Cauchy's theorem, power series, Laurent series, the Riemann mapping theorem, harmonic functions, subharmonic functions, canonical mappings of multiply connected regions, analytic continuation. Prerequisite: MAT 657 or MAT 659 or equivalent.

MAT 711 **3 credits**
Survey of Mathematical Problems I
Selected topics from logical reasoning, probability, combinatorics, graph theory, codes, number theory, constructibility, game theory, limits, functions, set theory and foundations, and plane geometry. Problem solving and techniques of proof emphasized throughout. Connections made between the mathematics of this course and secondary education mathematics. Prerequisites: Graduate standing and consent of instructor.

MAT 712 **3 credits**
Survey of Mathematical Problems II
Continuation of topics listed for MAT 711 with emphasis on problem solving and techniques of proof. Again, connections made between the mathematical content of this course and mathematical content for secondary education. Prerequisites: MAT 711 or consent of instructor.

MAT 714 **3 credits**
History of Mathematics
Historical development of mathematics from primitive origins to the present time. Lives of many mathematicians and their contributions to the development of mathematics. Prerequisites: Graduate standing and consent of instructor.

MAT 716 **3 credits**
Integrative Mathematical Topics
Survey of mathematical topics in an integrative manner. The topics may cover theory and applications in long stretches including probability and statistics; combinatorics, number theory and algebra; geometry and topology; ODE and PDE; computation and numerical analysis; Real and complex analysis. Prerequisites: At least nine credits at 600-level as required in Requirement #1.

MAT 717 **3 credits**
Analytical Solution Methods for Partial Differential Equations, I
Covers the basic theory and methods for solving linear partial differential equations. Emphasis on introducing various techniques to obtain analytical solutions of linear partial differential equations. Techniques include: Method of separation of variables; Fourier transform method; Laplace transform method; Green's function method, etc. Prerequisites: MAT 487/687, or MAT 458/658, or consent of instructor.

MAT 718 **3 credits**
Analytical Solution Methods for Partial Differential Equations, II
Covers the basic theory and methods for solving nonlinear partial differential equations. Emphasise on introducing various techniques to obtain analytical solutions. Techniques include: Generalized method of characteristics, method of shock wave solution, method of travelling wave solution, perturbation method, method of similarity solution, etc. Prerequisites: MAT 487/687, or MAT 717, or consent of instructor.

MAT 723 **3 credits**
Advanced Ordinary Differential Equations I
Functional analysis; Frechet calculus; existence and uniqueness theorems for initial and boundary value problems; qualitative properties of solutions, particularly of linear equations. Prerequisite: MAT 671-672 or MAT 673-674.

MAT 724 **3 credits**
Advanced Ordinary Differential Equations II
Topics to be selected from the following: Sturm-Liouville theory, stability theory, perturbation theory, numerical methods, the theory of invariant imbedding and functional differential equations. Prerequisite: MAT 723.

MAT 725 **3 credits**
Mathematics for Operations Research I
Theory of stochastic processes, theory of queues, Markov processes, non-Markov processes, Markov chains, applications. Prerequisite: MAT 661.

MAT 726 **3 credits**
Mathematics for Operations Research II
Linear and non-linear programming, dynamic programming, Lagrange multiplier and duality theorems, control theory and optimal control, applications of programming. Prerequisites: MAT 671 and 673.

MAT 729 **3 credits**
Partial Differential Equations I
Linear and nonlinear first order PDEs. Heat, wave and Laplace equations. Classical representation formulas in one and more dimensions. Properties of solutions: maximum principles, energy methods, uniqueness and regularity considerations. Prerequisites: MAT 687 or MAT 717.

MAT 730 **3 credits**
Partial Differential Equations II
Develops a functional analytical framework which will give students a deeper understanding of the subject matter. Topics include Sobolev and Holder spaces, embedding inequalities, weak solutions, regularity and maximum principles. Prerequisites: MAT 708 and MAT 729, or consent of instructor.

MAT 731 **3 credits**
Mathematical Modeling
Process and techniques of mathematical modeling with an emphasis on differential equations based models, though other models may also be considered. Applications selected from physical, biological and social sciences. Modeling projects based on student interests. Symbolic computation software. Prerequisites: MAT 687 or MAT 717 or consent of instructor.

MAT 733-734 **3 credits each**
Topology
Selected topics from algebraic and point-set topology with emphasis on algebraic topology. Prerequisite: MAT 684 or consent of instructor.

MAT 740 **3 credits**
Mathematical Wave Propagation Theory and Application I
Review of linear wave equations, techniques of linear and non-linear modeling of natural occurrences and their role in understanding mathematical inversion, mathematical foundation of dyadic wave propagation, introduction to asymptotic analysis and boundary layer theory, application to problems for waves propagating in the atmosphere, ocean and space. Prerequisites: MAT 717 or MAT 729 or consent of instructor.

MAT 741 **3 credits**
Mathematical Wave Propagation Theory and Application II
The generalized tensor wave nature of matter, advanced mathematical methods of non-linear and quantum optics. Earth quake dynamics, elastic waves and cracks propagation with applications from earth system and space science. Prerequisites: MAT 718 and MAT 740 or consent of instructor.

MAT 751 **3 credits**
Topics in Foundations of Mathematics
May be repeated for credit with the consent of the mathematics department. Except under special circumstances, total credits limited to six credits. Prerequisite: MAT 701-702.

MAT 753-754 **3 credits each**
Homological Algebra
Modules, categories and factors, tensors, Hom, Tor, Ext, the dimensions of rings and modules, derived factors, cohomology of groups and algebras. Prerequisite: MAT 703-704 or consent of instructor.

MAT 755 **3 credits**
Topics in Algebra
May be repeated for credit with the consent of the mathematics department. Except under special circumstances, total credits limited to six. Prerequisite: MAT 703-704 or consent of instructor.

MAT 756 **3 credits**
Arithmetic on Elliptic Curves
The group structure of elliptic curves over the reals, complex numbers, the rationals, number fields, and finite fields; Bezout's theorem and its applications; profective geometry; genus; Mordell's theorem; points of finite order; and heights. Additional topics may include complex multiplication; modular forms; and factoring using elliptic curves. Prerequisites: MAT 653 and 654, or equivalent.

MAT 757 **3 credits**
Topics in Analysis
May be repeated for credit with the consent of the mathematics department. Except under special circumstances, total credits limited to six. Prerequisite: MAT 707-708 or consent of instructor.

MAT 760 **3 credits**
Mathematical Scattering Theory and Applications I
Scalar, vector, and tensor scattering with diverse techniques applied to earth system and space science. General Reciprocity Relations Corresponding to Different Directions of Incidence, Dyadic Scattering Theory, Two-Space Scattering Formalism of Victor Twersky, and Applications to Earth and Space Related Problems. Prerequisites: MAT 717 or MAT 729 or consent of instructor.

MAT 761 **3 credits**
Mathematical Scattering Theory and Applications II
Advanced statistical mechanics and spatial statistics in relation to Twersky scattering with applications from earth system and space science. Calculation of bulk propagation parameters using both configurational and ensemble average in addition to spatial average. Application of Twersky multiple two-Space Scattering formalism to space and earth related problems. Prerequisites: MAT 760 or consent of instructor.

MAT 765-766 **3 credits each**
Advanced Numerical Analysis
Numerical solution of ordinary and partial differential equations; advanced programming techniques; experiments with the computer. Topics selected by instructor. Three hours lecture, two hours laboratory. Prerequisite: MAT 666.

MAT 767 **3 credits**
Topics in Numerical Analysis
Topics selected by the instructor. May be repeated for credit with the consent of the mathematics department. Except under special circumstances, total credits limited to six. Prerequisite: MAT 765-766.

MAT 771-772 **3 credits each**
Applied Analysis I and II
Functional analysis in Banach spaces and Hilbert spaces, with emphasis on computational applications. Theoretical topics to be selected from: linear functionals and operators, fixed point theorems, iterative methods, elementary spectral theory. Applications to be selected from: finite element methods, finite difference methods, approximation and interpolation, optimization algorithms. Prerequisites: Graduate standing and consent of instructor.

MAT 775 **3 credits**
Calculus of Variations
Variation of functionals, Euler-Lagrange equation, general variations, broken extremals, Weierstrass-Erdmann conditions, canonical forms, Noether's theorem, Hamilton-Jacobi equations, Legendre's condition, conjugate points, fields, E-function, sufficient conditions for extrema, Pontryagin's principle, introduction to linear and non-linear optimal control theory. Prerequisite: MATH 428 or 658 or consent of instructor.

MAT 777 **3 credits**
Application of High-Performance Computing Methods in Science and Engineering
(Same as ME 777.) Application of high performance computing systems to science and engineering, models for numerically intensive problem solving, high performance numerical algorithms, FORTRAN 90 and high-performance FORTRAN. Prerequisites: Knowledge of UNIX, FORTRAN, and previous course on numerical methods. Graduate standing.

MAT 783 **3 credits**
Topics in Topology
May be repeated for credit with the consent of the mathematics department. Except under special circumstances, total credits limited to six. Prerequisite: Consent of instructor.

MAT 789 **3 credits**
Topics in Advanced Mathematics
Graduate-level course in some field of mathematics, at advanced level, depending upon the current interest of the staff and the students. May be repeated to a maximum of six credits.

MAT 790 **1-3 credits**
Independent Study
Library work and reports on topics of mathematical interest. May be repeated for credit with the consent of the mathematics department. Except under special circumstances, total credits will be limited to six.

MAT 791 **1-6 credits**
Thesis
May be repeated but only six credits will be applied to the student's program. S/F grading only.

MAT 792 **1 credit**
Research Seminar
Oral presentation of assigned articles. May be repeated to a maximum of four credits.

MAT 793 **1-3 credits**
Teaching Concentration Professional Paper Research
Individual research towards an applied professional paper under the direction of a faculty member. May be repeated any number of times, but no more than three credits will count towards degree requirements. S/F grading only. Prerequisite: Consent of instructor.

Statistics

STA 713 **3 credits**
Experimental Design
Fundamental principles of analysis of variance; one-way, two-way, and higher order designs; nested designs; randomized blocks; split plot designs; Latin squares; multiple comparisons; analysis of covariance. Prerequisites: MATH 181 or consent of instructor and one of the following: STA 161, STA 411, STA 691.

STA 715 **3 credits**
Multivariate Statistical Methods
Multivariate techniques with emphasis on application. Topics include multivariate analysis of variance, discriminant analysis, canonical correlation and independence, principal component analysis, factor analysis, cluster analysis and analysis of repeated measurements. Prerequisites: MATH 181 or consent of instructor and one of the following: STA 161, STAT 411, STA 691.

STA 731 **3 credits**
Probability Theory and Its Applications
Topics include: set theory, limits of sets, probability space, random variables, measurability, independence, expectation, probability inequalities, convergence, laws of large numbers, central limit theorem, moment generating functions, characteristic functions, large deviation theory, martingale theory, random walk. Prerequisite: MAT 657.

STA 751 **3 credits**
Spatial Statistics
Stochastic process, first and second order stationarity, intrinsic hypothesis, models of spatial dependence, different forms of Kriging— Ordinary Kriging, Universal Kriging, Probability Kriging, bicubic splines, conditional simulation. Prerequisites: Graduate standing and consent of instructor.

STA 755 **3 credits**
Stochastic Modeling I
Probability theory, Markov chains in discrete and continuous time, the Poisson process, renewal theory, queueing theory, reliability theory, martingales, stationary processes, statistical inference for stochastic processes, and simulation techniques. Prerequisite: STAT 411.

STA 756 **3 credits**
Stochastic Modeling II
Probability theory, Markov chains in discrete and continuous time, the Poisson process, renewal theory, queueing theory, reliability theory, martingales, stationary processes, statistical inference for stochastic process, and simulation techniques. Prerequisite: STA 755

STA 761-762 **3 credits each**
Analysis of Variance
Special topics in matrix theory; noncentral chi-square, F, and t; the multivariate normal distribution; Cochran's theorem; point and interval estimation; one-, two-, three-, higher-way layouts; Latin squares, incomplete blocks and nested designs, analysis of covariance; random effects models; mixed models; randomization models. Prerequisite: MAT 661.

STA 763-764 **3 credits each**
Regression and Multivariate Analysis
Fitting a straight line, matrix theory, examining residuals, selecting the "best" fit, multiple regression, non-linear regressions, multivariate normal, estimation, classification, variance-covariance matrix, testing sets of variates, principal components, canonical correlation, distribution of characteristic roots. Prerequisite: STA 667.

STA 765 **3 credits**
Statistical Decision Theory
Introduction to decision theory, decision rules, loss functions, risk functions, decision principles, utility theory, prior information and subjective probability, noninformative priors, the posterior distribution, conjugate families, predictive distribution, Bayesian estimators, generalized Bayes estimators, credible regions, hypothesis testing, admissibility of Bayes rules, robustness of Bayes rules, minimax analysis, invariance, Bayesian sequential analysis. Prerequisite: STA 667 or consent of instructor.

STA 767 **3 credits**
Mathematical Statistics I
Basic probability theory, conditional probability, independence, random variables, probability distribution functions, distribution functions, transformations, function of random variables, expectations, moment generating functions, discrete and continuous distributions, exponential family, joint distribution, marginal distribution, modes of convergence, limiting distribution, random sample, sampling distribution, principle of data reduction. Prerequisite: STA 667 or consent of instructor.

STA 768 **3 credits**
Mathematical Statistics II
Random sample, sampling theory, point estimation, sufficiency, likelihood, method of moment, maximum likelihood estimator, Bayes estimator, unbiasedness, optimality, decision theory, hypothesis testing, likelihood ratio tests, Bayes test, most powerful test, set estimation, evaluating interval estimators, sequential estimation, asymptotics, robustness, linear models. Prerequisite: STA 767.

STA 769 **3 credits**
Environmental Statistics II: Multivariate Methods
Testing for multivariate normality, data dependent transformations for multivariate normality, tests for outliers for multivariate data, multivariate control charts, exploratory data analysis of multivariate data using principal components, cluster analysis, factor analysis, and multivariate calibration problems. Prerequisite: STA 669.

STA 789 **3 credits**
Topics in Advanced Statistics
Graduate-level course in some field of statistics, depending upon the current interest of the faculty and the students. May be repeated to a maximum of six credits.

STA 790 **1-3 credits**
Independent Study
Library research and reports on topics of statistical interest. May be repeated to a maximum of six credits with consent of the department.

STA 791 **3-6 credits**
Thesis
May be repeated but only six credits applied to the student's program. S/F grading only.

STA 792 **1 credit**
Research Seminar
Oral presentation of assigned articles. May be repeated to a maximum of four credits.

STA 793 **1-3 credits**
Techniques of Statistical Consulting
Seminar series and practicum covering technical and non-technical aspects of statistical consulting, including skills for effective communication with clients, report writing, issues in sampling and design of experiments, and other statistical tools commonly used in a consulting setting. May be repeated to a maximum of six credits.

The following courses, when taught by a member of the graduate faculty, may be applied to a graduate program. For listings and course descriptions of 600-level courses, please consult the current *Undergraduate Catalog* under the corresponding 400 number. The 600-level MAT and STA courses that are normally available for graduate credit are those numbered 650 or higher; the exceptions are MAT 680, which may be counted for graduate credit in an education degree program, and STA 691, STA 693, and STA 695, which may be counted for graduate credit in a biological sciences program.

MAT 651-652	Foundations of Mathematics I and II
MAT 653	Abstract Algebra I
MAT 654	Abstract Algebra II
MAT 655	Elementary Theory of Numbers I
MAT 656	Elementary Theory of Numbers II
MAT 657-658	Introduction to Real Analysis I and II
MAT 659	Elementary Complex Analysis
MAT 661	Probability Theory
MAT 662	Stochastic Processes
MAT 663	Advanced Matrix Theory and Applications
MAT 665-666	Numerical Analysis I and II
MAT 668	Applied Finite Element Analysis
MAT 669	Combinatorics I
MAT 670	Combinatorics II
MAT 680	College Geometry
MAT 683-684	General Topology I and II
MAT 687	Introduction to Partial Differential Equations
MAT 689	Advanced Mathematical Topics
MAT 690	Independent Study
STA 663	Applied Statistics for Engineers
STA 667	Introduction to Mathematical Statistics
STA 669	Environmental Statistics I: Univariate Methods
STA 689	Advanced Statistics Topics
STA 690	Independent Study
STA 691-692	Statistics for Scientists I and II
STA 693	Applied Regression Analysis
STA 695	Nonparametic Statistics