Department of Mathematics and Statistics

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Norfolk, VA 23529
757-683-3882
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Gordon Melrose, Chair
Ruhai Zhou, Graduate Program Director
N. Rao Chaganty, Statistics Program Director

Graduate Study in Computational and Applied Mathematics

The master’s and doctoral programs in computational and applied mathematics offered by the Department of Mathematics and Statistics are designed to produce applied mathematicians and statisticians who can meet the growing demand for analytical and computational skills in traditional scientific and multi-disciplinary fields. Students in the program can choose to pursue an option in either applied mathematics, statistics, or biostatistics.

Applied mathematics is the application of mathematics to the solution of non-mathematical problems. Such problems may originate in math-oriented fields (physics, chemistry, and engineering) as well as in such areas such as geology, oceanography, meteorology, biology, ecology, environmental health, economics, actuarial science, business (operations and market research), banking, and medicine. Students will learn to use methods of applied mathematics, probability, statistics, biostatistics, numerical analysis, and scientific computing in seeking solutions to such problems. For work in computational and applied mathematics, training in an additional field of application is a necessity.

The desire and ability to use mathematics to bring together various disciplines is the unique characteristic of an applied mathematician. Not only has mathematical modeling and solving of societal and scientific problems increased the demand for applied mathematicians, but the flexibility and breadth of knowledge inherent in this discipline make it attractive for those who do not want to become irreversibly specialized.

Old Dominion University is one of the few American institutions offering a program expressly in applied mathematics. There are approximately 22 graduate program faculty members in the Department of Mathematics and Statistics, and current enrollment in the program is about 50 students. Areas of faculty research include analytical and numerical modeling in oceanography and meteorology, computational fluid dynamics and stability theory, elasticity and fracture mechanics, combustion theory, magnetohydrodynamics, mathematical biology, numerical analysis and approximation, optimization, applied probability, statistical inference, reliability, multivariate statistics, generalized linear models, estimating equations, biostatistics, nonparametric statistics, bioinformatics, and high performance computing.

Facilities within the metropolitan area include the NASA/Langley Research Center, the Virginia Modeling, Analysis and Simulation Center (VMASC), and the Eastern Virginia Medical School.

Program Financial Aid. Graduate assistantships in the Department of Mathematics and Statistics offer stipends ranging from $16,000 to $18,000. The level of award is determined on the basis of previous experience and performance as a graduate assistant and on the student’s academic achievement and potential in applied mathematics or statistics. In addition, a number of teaching and research positions are available for financial support of graduate assistants during the summer months (June and July).

Writing Proficiency. All students in the graduate program are expected to demonstrate an acceptable level of writing ability. Students needing help to remedy their writing deficiencies will be referred to the Writing Center for diagnosis and assistance. All M.S. candidates will enroll in one of the MATH 632, STAT 632, and BDA 632 for a master’s project.

Master of Science - Computational and Applied Mathematics

Admission

An applicant to the master’s program in computational and applied mathematics should have a bachelor’s degree in mathematics, statistics, computer science, or an application area with a strong mathematics component (e.g., physics or engineering). Undergraduate mathematics preparation should include course work in linear algebra, advanced calculus, differential equations, probability, and numerical methods. Undergraduate averages of 2.80 overall (4.00 scale) and 3.00 in the major and related mathematics courses are required.

A student who does not fully meet all requirements for admission as a regular graduate student may be allowed, with permission of the program director, to enroll as a provisional graduate student. Students lacking adequate preparation will be required to make up their deficiencies by taking appropriate undergraduate courses in addition to those specified for the master’s program.

A formal application form, official transcripts, and two letters of recommendation should be forwarded to the Office of Admissions. It is recommended that applicants supply Graduate Record Examination aptitude scores.

The following material should be mailed directly to the director of the graduate program in computational and applied mathematics, Department of Mathematics and Statistics: a list of all mathematics courses taken and other programs closely allied to the applicant’s primary interests in applied math or statistics along with the texts used (titles and authors), chapters studied or topics covered, and grades. This information should be enclosed with the financial aid application (if the applicant is submitting one).

Students may enroll in the program on either a full-time or part-time basis. Courses are offered on a regular basis during the late afternoon and early evening hours which allows part-time students to obtain master’s degrees or post-master’s graduate credit.

Requirements

The M.S. candidate must complete a minimum of 36 normal credit hours of course work designed to fulfill an option in either applied mathematics, statistics or biostatistics. Each option includes 18 credit hours of Core Courses. With approval of the graduate program director, up to six of the 36 credits may be chosen from a field of application (e.g. oceanography, ecosystem analysis, computer science, economics, health sciences, operations research, physics and engineering mechanics) in which the student applies analytical and numerical techniques to another discipline. All programs of study must be approved by the graduate program director, and substitutions may be made only with his or her approval.

Master’s Project Requirement

The M.S. candidate will be assigned to a faculty advisor for a master’s project. Each student will enroll in MATH 632, STAT 632 and BDA 632 to complete his/her project. The master’s project is designed not only to broaden students’ analytical competency but also to enhance students’ writing and reporting skills on a technical subject.

Colloquium Requirement

In order to develop an appreciation for the breadth of contemporary research in applied mathematics and statistics, all M.S. candidates will attend at least 80% and succinctly summarize and evaluate in writing at least eight professional seminars given by research faculty or external seminar visitors. The Richard F. Barry Colloquium Series is run by the department throughout the academic year. The department also conducts seminars jointly with other departments.
Concentrations

• Applied Mathematics: Students electing the concentration in Applied Mathematics will pursue course work in advanced mathematical analysis, differential equations, numerical methods, transform methods and data science. They will take electives in other methods of applied mathematics, or in an application area. A Master’s Project will bring them in contact with the research frontier.

• Statistics: Students electing the concentration in Statistics will pursue course work in mathematical statistics, advanced regression analysis including responses surfaces, factorial designs, time series, advanced statistical computing. They will take electives in other areas of statistics and biostatistics. A Modeling Project involving statistical analysis of real-life data is required.

• Biostatistics Concentration: Students electing the concentration in Biostatistics will pursue course work in mathematical statistics, and biostatistical methods including survival analysis, clinical trials, categorical and longitudinal data analysis. They will take electives in other areas of statistics and biostatistics. A Modeling Project involving statistical analysis of biomedical or health care data is required.

• Mathematics of Data Science: Students electing the concentration in Mathematics of Data Science will pursue course work in data science including mathematical statistics, regression and time series analysis, mathematical foundation of machine learning and genome data science. A Master’s Project will bring them in contact to the real world applications.

Course Requirements

Common Core Courses

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
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<tbody>
<tr>
<td>BDA 501</td>
<td>Programming Languages for Data Science</td>
</tr>
<tr>
<td>BDA 511</td>
<td>Introduction to Machine Learning</td>
</tr>
<tr>
<td>BDA 531</td>
<td>Modern Statistical Methods for Big Data Analytics</td>
</tr>
<tr>
<td>MATH 616</td>
<td>Computational Linear Algebra</td>
</tr>
<tr>
<td>STAT 625</td>
<td>Mathematical Statistics I</td>
</tr>
<tr>
<td>MATH 632</td>
<td>Master’s Project</td>
</tr>
<tr>
<td>or BDA 632</td>
<td>Master’s Project</td>
</tr>
<tr>
<td>or STAT 632</td>
<td>Computational Data Analytics Project</td>
</tr>
</tbody>
</table>

Select one of the following concentrations

Applied Mathematics Concentration (18 additional hours from the following list.)

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATH 617</td>
<td>Measure and Integration</td>
</tr>
<tr>
<td>MATH 618</td>
<td>Applied Functional Analysis</td>
</tr>
<tr>
<td>MATH 622</td>
<td>Numerical Solutions to Differential Equations</td>
</tr>
<tr>
<td>or MATH 721</td>
<td>Advanced Applied Numerical Methods I</td>
</tr>
<tr>
<td>MATH 637</td>
<td>Tensor Calculus and Differential Geometry</td>
</tr>
<tr>
<td>MATH 691</td>
<td>Engineering Analysis I</td>
</tr>
<tr>
<td>MATH 692</td>
<td>Engineering Analysis II</td>
</tr>
<tr>
<td>BDA 620</td>
<td>Large-Scale Optimization</td>
</tr>
</tbody>
</table>

Statistics Concentration (18 additional hours from the following list.)

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
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</thead>
<tbody>
<tr>
<td>STAT 626</td>
<td>Mathematical Statistics II</td>
</tr>
<tr>
<td>STAT 637</td>
<td>Advanced Regression and Time Series</td>
</tr>
<tr>
<td>STAT 638</td>
<td>Advanced Design and Analysis of Experiments</td>
</tr>
<tr>
<td>STAT 730</td>
<td>Multivariate Statistics</td>
</tr>
<tr>
<td>STAT 740</td>
<td>Clinical Trials</td>
</tr>
<tr>
<td>STAT 747</td>
<td>Advanced Analysis of Longitudinal Data</td>
</tr>
<tr>
<td>STAT 749</td>
<td>Advanced Nonparametric Statistics</td>
</tr>
<tr>
<td>STAT 750</td>
<td>Advanced Categorical Data Analysis</td>
</tr>
<tr>
<td>BDA 640</td>
<td>Genomic Data Science</td>
</tr>
<tr>
<td>BDA 721</td>
<td>High-Dimensional Statistics</td>
</tr>
</tbody>
</table>

Biostatistics Concentration (18 additional hours from the following list.)

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
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</thead>
<tbody>
<tr>
<td>STAT 626</td>
<td>Mathematical Statistics II</td>
</tr>
<tr>
<td>STAT 740</td>
<td>Clinical Trials</td>
</tr>
<tr>
<td>STAT 747</td>
<td>Advanced Analysis of Longitudinal Data</td>
</tr>
<tr>
<td>STAT 750</td>
<td>Advanced Categorical Data Analysis</td>
</tr>
<tr>
<td>BDA 640</td>
<td>Genomic Data Science</td>
</tr>
<tr>
<td>BDA 721</td>
<td>High-Dimensional Statistics</td>
</tr>
</tbody>
</table>

Graduate Certificate in Modeling and Simulation for Mathematics and Statistics

The Department of Mathematics and Statistics at Old Dominion University plays an integral part in the University’s campus-wide initiative to promote its research in Modeling and Simulation. The Department offers a Graduate Certificate in Modeling and Simulation for Mathematics and Statistics. In order to obtain this certificate, a student must complete four graduate courses that include MSIM 601 (Introduction to Modeling and Simulation). MSIM 601 is offered by the Department of Engineering Management and System Engineering. Students may select three of three other simulation courses from the following Modeling and Simulation courses.

Modeling and Simulation courses in Computational Mathematics

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>MSIM 601</td>
<td>Introduction to Modeling and Simulation</td>
</tr>
<tr>
<td>MATH 508</td>
<td>Applied Numerical Methods I</td>
</tr>
<tr>
<td>MATH 509</td>
<td>Applied Numerical Methods II</td>
</tr>
<tr>
<td>MATH 622</td>
<td>Numerical Solutions to Differential Equations</td>
</tr>
<tr>
<td>MATH 632</td>
<td>Master’s Project</td>
</tr>
<tr>
<td>MATH 721/821</td>
<td>Advanced Applied Numerical Methods I</td>
</tr>
<tr>
<td>MATH 722/822</td>
<td>Advanced Applied Numerical Methods II</td>
</tr>
</tbody>
</table>

Total Hours 12

Modeling and Simulation courses in Statistics

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>MSIM 601</td>
<td>Introduction to Modeling and Simulation</td>
</tr>
<tr>
<td>STAT 535</td>
<td>Design and Analysis of Experiments</td>
</tr>
<tr>
<td>STAT 537</td>
<td>Applied Regression and Time Series Analysis</td>
</tr>
<tr>
<td>STAT 560</td>
<td>Statistical Simulation/Programming Using Statistical Software Packages</td>
</tr>
<tr>
<td>STAT 597/697</td>
<td>Topics in Statistics</td>
</tr>
<tr>
<td>STAT 630</td>
<td>Time Series Models</td>
</tr>
<tr>
<td>STAT 632</td>
<td>Master’s Project</td>
</tr>
<tr>
<td>STAT 640</td>
<td>Survival Analysis</td>
</tr>
</tbody>
</table>

Total Hours 12
Doctor of Philosophy - Computational and Applied Mathematics

Admission

Applicants who appear to be qualified for study at an advanced graduate level may be admitted to the doctoral program in computational and applied mathematics. These will be students with very strong backgrounds in mathematics, statistics, computer science, or application areas with a mathematics component (e.g., physics or engineering).

Students may be admitted directly to the Ph.D. program with either a bachelor’s or a master’s degree. A grade point average of 3.00 (4.00 scale) in the major and related mathematics courses is required.

Students are required to submit three letters of recommendation, and GRE aptitude scores, if the student will not have completed a master’s degree in mathematics, statistics, computer science, or application areas with a mathematics component (e.g., physics or engineering).

Requirements

A minimum of 78 credit hours beyond the bachelor’s degree and 48 hours beyond the master’s degree is required. Each student will be assigned an Advisory Committee, and together they will plan a complete program of course work designed to meet the student’s objectives and to fulfill a concentration in applied mathematics, statistics or biostatistics. The student is strongly encouraged to select courses in more than one of these concentration areas and in a field of application whenever such courses contribute appropriately to his or her program. Each program, however, must be directed and approved by the student’s Advisory committee. A student receiving a grade of C+ or lower in any graduate course may be dismissed from the program. The four concentrations offered under the PhD Program in Computational and Applied Mathematics are Applied Mathematics, Statistics, Biostatistics and Mathematics of Data Science:

- **Applied Mathematics Concentration**: Students electing the concentration in Applied Mathematics will pursue course work in advanced mathematical analysis, differential equations, numerical methods, transform methods, and data science. They will take electives in other methods of applied mathematics, or in an application area. A PhD thesis project will bring them in contact with the research frontier.

- **Statistics Concentration**: Students electing the concentration in Statistics will pursue course work in mathematical statistics, advanced regression analysis including responses surfaces, factorial designs, time series, advanced statistical computing. They will take electives in other areas of statistics and biostatistics. A PhD thesis project involving statistical analysis of real-life data is required.

- **Biostatistics Concentration**: Students electing the concentration in Biostatistics will pursue course work in mathematical statistics, and biostatistical methods including survival analysis, clinical trials, categorical and longitudinal data analysis. They will take electives in other areas of statistics and biostatistics. A PhD thesis project involving statistical analysis of biomedical or health care data is required.

- **Mathematics of Data Science Concentration**: Students electing the concentration in Mathematics of Data Science will pursue course work in the mathematical and statistical analysis of computational data science, including advanced machine learning, linear models, multivariate statistics, high dimensional statistics and applied functional data analytics. A PhD thesis project will bring them in contact with the research frontier.

Course Requirements

**Common core courses with 6 credits of Research**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATH 617</td>
<td>Measure and Integration</td>
</tr>
<tr>
<td>STAT 626</td>
<td>Mathematical Statistics II</td>
</tr>
<tr>
<td>MATH 898</td>
<td>Research</td>
</tr>
<tr>
<td>or STAT 898</td>
<td>Research</td>
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</tbody>
</table>

**Dissertation credits**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATH 899</td>
<td>Dissertation</td>
</tr>
<tr>
<td>or STAT 899</td>
<td>Dissertation</td>
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<table>
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<tr>
<th>Total Hours</th>
<th>18</th>
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<table>
<thead>
<tr>
<th>Select one of the following concentrations</th>
<th>18</th>
</tr>
</thead>
<tbody>
<tr>
<td>Applied Mathematics (Students must select, in consultation with their advisor, 18 credits of graduate courses from this list and approved substitutes.)</td>
<td></td>
</tr>
<tr>
<td>MATH 605 Complex Variables I</td>
<td></td>
</tr>
<tr>
<td>MATH 618 Applied Functional Analysis</td>
<td></td>
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<tr>
<td>MATH 622 Numerical Solutions to Differential Equations</td>
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<tr>
<td>MATH 637 Tensor Calculus and Differential Geometry</td>
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<tr>
<td>MATH 638 Mathematical Theories of Continua</td>
<td></td>
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<tr>
<td>MATH 693 Engineering Analysis III</td>
<td></td>
</tr>
<tr>
<td>MATH 801 Asymptotic and Perturbation Methods</td>
<td></td>
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<tr>
<td>&amp; MATH 802 and Integral Equations</td>
<td></td>
</tr>
<tr>
<td>MATH 821 Advanced Applied Numerical Methods I</td>
<td></td>
</tr>
<tr>
<td>&amp; MATH 822 and Advanced Applied Numerical Methods II</td>
<td></td>
</tr>
<tr>
<td>MATH 803 Advanced Applied Mathematics I</td>
<td></td>
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<tr>
<td>or MATH 825 Computational Fluid Dynamics</td>
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<tr>
<td>BDA 845 Transform Methods for Data Science</td>
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<table>
<thead>
<tr>
<th>Statistics (Students must select, in consultation with their advisor, 18 credits of graduate courses from this list and approved substitutes.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>STAT 630 Time Series Models</td>
</tr>
<tr>
<td>STAT 640 Survival Analysis</td>
</tr>
<tr>
<td>STAT 825 Linear Statistical Models</td>
</tr>
<tr>
<td>STAT 827 Advanced Statistical Inference I</td>
</tr>
<tr>
<td>STAT 828 Advanced Statistical Inference II</td>
</tr>
<tr>
<td>STAT 830 Multivariate Statistics</td>
</tr>
<tr>
<td>STAT 847 Advanced Analysis of Longitudinal Data</td>
</tr>
<tr>
<td>STAT 849 Advanced Nonparametric Statistics</td>
</tr>
<tr>
<td>STAT 850 Advanced Categorical Data Analysis</td>
</tr>
<tr>
<td>BDA 821 High-Dimensional Statistics</td>
</tr>
<tr>
<td>BDA 831 Applied Functional Data Analysis</td>
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</tbody>
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<thead>
<tr>
<th>Biostatistics (Students must select, in consultation with their advisor, 18 credits of graduate courses from this list and approved substitutes.)</th>
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<tbody>
<tr>
<td>STAT 825 Linear Statistical Models</td>
</tr>
<tr>
<td>STAT 827 Advanced Statistical Inference I</td>
</tr>
<tr>
<td>STAT 828 Advanced Statistical Inference II</td>
</tr>
<tr>
<td>STAT 830 Multivariate Statistics</td>
</tr>
<tr>
<td>STAT 840 Advanced Clinical Trials</td>
</tr>
<tr>
<td>STAT 849 Advanced Nonparametric Statistics</td>
</tr>
<tr>
<td>BDA 640 Genomic Data Science</td>
</tr>
<tr>
<td>BDA 821 High-Dimensional Statistics</td>
</tr>
<tr>
<td>BDA 831 Applied Functional Data Analysis</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Mathematics of Data Science (Students must select, in consultation with their advisor, 18 credits of graduate courses from this list and approved substitutes.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BDA 611 Mathematical Foundations of Machine Learning</td>
</tr>
<tr>
<td>BDA 620 Large-Scale Optimization</td>
</tr>
<tr>
<td>BDA 640 Genomic Data Science</td>
</tr>
<tr>
<td>BDA 821 High-Dimensional Statistics</td>
</tr>
<tr>
<td>BDA 831 Applied Functional Data Analysis</td>
</tr>
<tr>
<td>BDA 845 Transform Methods for Data Science</td>
</tr>
<tr>
<td>MATH 618 Applied Functional Analysis</td>
</tr>
<tr>
<td>MATH 820 Advanced Applied Functional Analysis</td>
</tr>
<tr>
<td>STAT 825 Linear Statistical Models</td>
</tr>
<tr>
<td>STAT 830 Multivariate Statistics</td>
</tr>
</tbody>
</table>

| Total Hours | 48 |
Colloquium Requirement

In order to develop an appreciation for the breadth of contemporary research in applied mathematics and statistics, all Ph.D. candidates will attend at least 80% and succinctly summarize and evaluate in writing at least 16 professional seminars given by research faculty or external seminar visitors. The Richard F. Barry Colloquium Series is run by the department throughout the academic year. The department also conducts seminars jointly with other departments.

Foreign Language

A foreign language is not required.

Residency Requirement

An essential feature of doctoral study is the provision of total concentration on the field of study for significant periods of time. Students who wish to pursue a part of their doctoral study on a part-time basis may do so, but all doctoral students shall spend at least two academic years engaged in full-time graduate study.

Admission to Candidacy Examination

At the end of the core mathematics or statistics course work and prior to selecting a dissertation advisor, the student must pass an Admission to Candidacy Examination designed to test scholarly competence and knowledge and to give the examiners a basis for constructive recommendations on subsequent study. The written portion of this examination will be based upon an examination syllabus that will be provided to each student. The outcome of this examination will be reported to the vice provost for graduate studies and research as passed, failed, additional work to be completed, or to be re-examined. In the event of a re-examination, the outcome must be reported as passed or failed. This decision is final. The examination must be passed at least eight months prior to the granting of the degree.

Dissertation

A doctoral dissertation representing an achievement in research and a significant contribution to the field is required. Students must register for MATH 898 or MATH 899 each semester in which they are doing substantial work on their dissertations. A minimum of 24 hours of such research credit is required.

Defense of Dissertation

This examination will be oral and must be completed at least four weeks before the date on which the degree is to be conferred. The dissertation committee members must have the completed dissertation at least two weeks before the date of the oral examination. Under normal circumstances, it is expected that the student will have had a research paper accepted for publication prior to the dissertation defense.

BIG DATA ANALYTICS Courses

BDA 501. Programming Languages for Data Science. 3 Credits.

An introductory course on programming languages and tools which are relevant to data analytics. Each language or tool is introduced as a separate module and incorporates applications in mathematics and statistics. Examples of included programming languages and tools are MATLAB, Python, R and SAS. Additional languages and tools may be covered based on current trends in data analytics. Students will complete hands-on programming assignments throughout the course. Prerequisites: MATH 312, MATH 316 and STAT 330 or STAT 331.

BDA 511. Introduction to Machine Learning. 3 Credits.

An introductory course on machine learning. Machine Learning is the science of discovering pattern and structure and making predictions in data sets. It lies at the interface of mathematics, statistics and computer science. The course gives an elementary summary of modern machine learning tools. Topics include regression, classification, regularization, resampling methods, and unsupervised learning. Students enrolled are expected to have some ability to write computer programs, some knowledge of probability, statistics and linear algebra. Prerequisites: MATH 312, MATH 316, and STAT 330 or STAT 331.

BDA 531. Modern Statistical Methods for Big Data Analytics. 3 Credits.

The statistical perspective of data mining is emphasized for majority of the course. Both applied aspects (programming, problem solving, and data analysis) and theoretical concepts (learning, understanding, and evaluating methodologies) of data mining will be covered. Topics include Regularization and Kernel Smoothing Methods, Tree-based Methods, Neural Networks and optional topics such as deep learning. Prerequisites: BDA 511 and STAT 505.

BDA 532. Introduction to Optimization and Inverse Problems. 3 Credits.

Topics considered include the solution of non-smooth optimization problems arising in data science, including unconstrained and constrained optimization problems, Lagrange multiplier methods, inequality constraints, Kuhn-Tucker conditions, and applications. Also considered are linear and nonlinear inverse problems, regularization of ill-posed problem including singular value decomposition, and Tikhonov regularization methods and sparse regularization methods, inverse eigenvalue problems and applications such as compressed sensing, image reconstruction and machine learning. Prerequisites: MATH 307, MATH 312 and MATH 316.

BDA 611. Mathematical Foundations of Machine Learning. 3 Credits.

This course will introduce mathematical foundations of machine learning theory and algorithms. Topics include statistical learning theory, kernel methods and generative models. Some modern machine learning methods such as dictionary learning, deep learning, online learning, and reinforcement learning may also be included, time permitting. Students enrolled are expected to have some knowledge of linear algebra, optimization, probability, and analysis. Prerequisites: BDA 511, MATH 518 and STAT 531.

BDA 620. Large-Scale Optimization. 3 Credits.

This course will introduce optimization methods for large-scale problems by exploiting special structures including convexity and sparsity. Topics include introduction to convexity, gradient-related methods, dual methods, sparse optimization methods and nonconvex optimization methods. Students enrolled are expected to have some knowledge of linear algebra, optimization, probability, and analysis. Prerequisites: MATH 518 and STAT 531.

BDA 632. Computational Data Analytics Project. 3 Credits.

Under the guidance of a faculty member in the Department of Mathematics and Statistics, the student will undertake a significant computational data analysis problem. A written report and/or public presentation of results will be required. Prerequisites: Permission of graduate program director.

BDA 640. Genomic Data Science. 3 Credits.

Introductory discussion on central dogma of molecular biology, concepts of transcription, translation, gene regulation, and the need for high throughput methods. Other topics covered are Introduction to R and Bioconductor, Advanced microarray data analysis, NGS data analysis using edgeR in Bioconductor, Network Biology, sequence pathwayinformatics, SNPs, GWAS,informatics for genome variants. Prerequisites: BDA 511, BDA 531, and STAT 505.

BDA 721. High-Dimensional Statistics. 3 Credits.

Techniques for obtaining basic tail bounds and concentration inequalities, uniform laws of large numbers, Rademacher complexity of a set, covering and packing in metric spaces, and metric entropy. Also, high dimensional random matrices described in a non-asymptotic framework, with a focus on the estimation of sparse and structured covariance matrix, are studied. The sparse linear regression models and the principal component analysis in the unstructured and sparse setting will be covered. Pre- or corequisite: STAT 727, STAT 728, MATH 616, and MATH 618.

BDA 731. Applied Functional Data Analysis. 3 Credits.

An introduction to the statistical analysis of sample curves or functions. Topics include smoothing, registration, functional principal component analysis, scalar-on-function regression, and functional response models. All these techniques will be applied using the statistical software R. Prerequisites: STAT 725 or STAT 825.
BDA 745. Transform Methods for Data Science. 3 Credits.
Various transform methods from the data domain to coefficients of the data in certain discrete bases are studied. Transforms studied include FFT, DCT, wavelet transforms and framelet transform. Both theory and applications of these transforms are covered. Prerequisites: MATH 518 and MATH 616.

BDA 821. High-Dimensional Statistics. 3 Credits.
Techniques for obtaining basic tail bounds and concentration inequalities, uniform laws of large numbers, Rademacher complexity of a set, covering and packing in metric spaces, and metric entropy. Also, high dimensional random matrices described in a non-asymptotic framework, with a focus on the estimation of sparse and structured covariance matrix are studied. The sparse linear regression models and the principal component analysis in the unstructured and sparse setting will be covered. Prerequisites: STAT 727, STAT 728, MATH 616, and MATH 618.

BDA 831. Applied Functional Data Analysis. 3 Credits.
An introduction to the statistical analysis of sample curves or functions. Topics include smoothing, registration, functional principal component analysis, scalar-on-function regression, functional response models. All these techniques will be applied using the statistical software R. Prerequisites: STAT 725 or STAT 825.

BDA 845. Transform Methods for Data Science. 3 Credits.
Various transform methods from the data domain to coefficients of the data in certain discrete bases are studied. Transforms studied include FFT, DCT, wavelet transforms and framelet transform. Both theory and applications of these transforms are covered. Prerequisites: MATH 518 and MATH 616.

MATH 518. Intermediate Real Analysis I. 3 Credits.
A rigorous course in classical real analysis. Topics include the topology of Euclidean n-space, properties of vector valued functions of several variables such as limits, continuity, differentiability and integrability, pointwise and uniform convergence of sequences and series of functions; Fourier series.

MATH 519. Intermediate Real Analysis II. 3 Credits.
A rigorous course in classical real analysis. Topics include the topology of Euclidean n-space, properties of vector valued functions of several variables such as limits, continuity, differentiability and integrability, pointwise and uniform convergence of sequences and series of functions; Fourier series. Prerequisite: A grade of C or better in MATH 517.

MATH 520. Applied Mathematics I: Biomathematics. 3 Credits.
An introduction to current developments in the mathematical investigation of biological problems. Topics include scaling systems of differential equations, stability, perturbation methods, bifurcation phenomena and wave propagation. Applications are chosen from interacting populations, transport and reaction diffusion kinetics, transmission of nerve impulses, and cardiovascular modeling.

MATH 521. Applied Mathematics II: Mathematical Modeling. 3 Credits.
A one semester course in formulating, evaluating and validating mathematical models of physical phenomena. Models of traffic flow, mechanical vibrations, combustion, quantum mechanics, wave propagation or other fields of applied mathematics will be examined. Techniques learned in previous courses are used to simplify, analyze and solve these models. New methods introduced include phase-plane analysis, characteristics, calculus of variations and perturbation methods.

MATH 522. Applied Complex Variables. 3 Credits.
Not available to students with credit in MATH 692. Topics include complex numbers, analytical functions and their properties, derivatives, integrals, series representations, residues and conformal mappings. Applications of the calculus of residues and mapping techniques to the solution of boundary value problems in physics and engineering.

MATH 527. Applied Mathematics III: Elasticity. 3 Credits.
An introduction to the mathematical theory of linear and non-linear elastic continua. Topics include vectors, tensors, deformation, stress, nonlinear constitutive theory, exact solutions, infinitesimal theory, antiplane strain, plane strain, plane stress, extension, torsion, bending and elastic wave propagation.

MATH 528. Applied Mathematics IV: Fluid Mechanics. 3 Credits.
A mathematical investigation of the differential equations governing fluid flow with an emphasis on steady state incompressible flows. The Navier-Stokes equations are derived and some exact solutions are presented including the potential flow solutions. Topics therefore include classical ideal fluid flow and its complex variable representation, various approximations to the Navier-Stokes equations, boundary layer theory, and also surface and internal gravity wave motion, aspects of hydrodynamic stability theory and convection. Other topics may be introduced by the instructor. Corequisite: MATH 501.

MATH 547. Mathematics in Nature. 3 Credits.
A calculus and differential equations based description of many patterns observable in the natural world including wave motion in the air, oceans, rivers, and puddles; rainbows, halos and other meteorological phenomena; arrangement of leaves, petals and branches; height of trees; river meanders; animal and insect markings; mudcracks; spider webs; and others. Partial differential equations will be discussed as needed but a knowledge of ordinary differential equations will be assumed.

MATH 596. Topics in Mathematics. 1-3 Credits.
Study of selected topics. Prerequisite: permission of the instructor.

MATH 598. Tutorial Work in Special Topics in Mathematics. 1-3 Credits.
Independent study under the direction of an instructor including library research and reports. Prerequisite: permission of the instructor.

MATH 605. Complex Variables I. 3 Credits.
An advanced course in complex analysis. Prerequisites: MATH 501, MATH 518 and MATH 522.
MATH 615. Advanced Calculus for Teachers. 3 Credits.
An introduction to real analysis. Topics include the field and order axioms, completeness of the real line, theory of sequences, limits of function, continuity, differentiability, sequences and series of functions, uniform convergence. Prerequisites: MATH 212.

MATH 616. Computational Linear Algebra. 3 Credits.
Topics include singular value decomposition, sparse systems, Krylov subspace methods, large sparse eigenvalue problems and iterative methods. This course also covers applications of computational linear algebra in the areas of image compression, data processing and principal component analysis. Prerequisites: MATH 312 and MATH 316.

MATH 617. Measure and Integration. 3 Credits.
An introduction to measure theory and integration theory with special emphasis on Lebesgue measure and the Lebesgue integral including Fatou's Lemma, the Monotone Convergence Theorem and the Dominated Convergence Theorem. Prerequisite: MATH 518.

MATH 618. Applied Functional Analysis. 3 Credits.
Topics include orthogonal projections to subspaces, duality, the Hahn-Banach theorem and the Banach-Steinhaus theorem, L2-spaces and convolution operators, fixed point theory, construction of Hilbert spaces, approximation procedures in Hilbert spaces, and spectral theory. Prerequisites: MATH 617.

MATH 620. Optimization Techniques. 3 Credits.
Theory and computational algorithms for the optimization of constrained linear and nonlinear systems or for locating the maximum of a constrained nonlinear function. Applications to problems in economics, operations research and systems theory. Prerequisites: MATH 312 and MATH 316.

MATH 622. Numerical Solutions to Differential Equations. 3 Credits.
An in-depth study of the numerical solution to ordinary and partial differential equations. Topics include linear multi-step methods, Runge-Kutta methods, stiff differential equations, collocation methods, and strong and weak stability analysis for ODEs. For PDEs, finite difference methods are examined. Prerequisites: MATH 509.

MATH 632. Master's Project. 3 Credits.
Under the guidance of a faculty member in the Department of Mathematics and Statistics, the student will undertake a significant data analysis problem in a scientific setting outside the department. A written report and/or public presentation of results will be required. Prerequisite: permission of graduate program director.

MATH 637. Tensor Calculus and Differential Geometry. 3 Credits.
Topics include metric spaces, bilinear and quadratic forms, tensors, point manifolds, theory of curves, geodesic differentiation, theory of surfaces, curvature of general manifolds, integrability. Prerequisites: MATH 517.

MATH 638. Mathematical Theories of Continua. 3 Credits.
Topics include deformation, motion, stress, conservation laws, and constitutive theories. Prerequisites: MATH 501 and MATH 637.

MATH 691. Engineering Analysis I. 3 Credits.
Not available to students with credit in MATH 501. Separation of variable techniques, Sturm-Liouville systems, generalized Fourier series, orthogonal functions of the trigonometric, Legendre and Bessel type, boundary value problems associated with the wave equation and the heat conduction equation in various coordinate systems, applications to physics and engineering.

MATH 692. Engineering Analysis II. 3 Credits.
Not available to students with credit in MATH 522. Topics include complex numbers, analytical functions and their properties, derivatives, integrals, series representations, residues and conformal mappings. Applications of the calculus of residues and mapping techniques to the solution of boundary value problems in physics and engineering. Prerequisites: MATH 312.

MATH 693. Engineering Analysis III. 3 Credits.
Advanced topics in the theory and application of ordinary differential equations, distributions, Green's functions, classification of partial differential equations, initial-value problems, eigenfunction expansions for boundary-value problems, selected special functions, singular perturbation theory for differential equations. Prerequisites: MATH 501 or MATH 691.

MATH 695. Seminar in Mathematics. 1-3 Credits.
Seminar in advanced topics. Prerequisites: permission of the instructor.

MATH 696. Topics in Mathematics. 1-3 Credits.
Advanced study of selected topics. Prerequisites: permission of the instructor.

MATH 697. Topics in Mathematics. 1-3 Credits.
Advanced study of selected topics.

MATH 698. Research. 3 Credits.

MATH 699. Thesis. 3 Credits.

MATH 702. Integral Equations. 3 Credits.

MATH 720. Advanced Applied Functional Analysis. 3 Credits.
In the first half of this course, several concepts in the classical functional analysis are studied. Topics include Banach Spaces, the dual space, the Baire category theorem, the adjoint operator, weak convergence, spectral theory and compact operators. In the second half, at the instructor's discretion, special topics are studied. Possible topics include ill-posed problems, inverse scattering theory, the regular Sturm-Liouville problem and the Dirichlet problem for Laplace's equation. Prerequisites: MATH 617 and MATH 618.

MATH 721. Advanced Applied Numerical Methods I. 3 Credits.
Numerical solutions of partial differential equations and integral equations. For PDEs, the finite difference method, the finite element method and the boundary element method are studied. A priori and a posteriori error estimates are examined. For integral equations, topics include Galerkin methods, collocation methods, and the Petrov-Galerkin method. Prerequisites: MATH 501, MATH 508 and MATH 509.

MATH 722. Advanced Applied Numerical Methods II. 3 Credits.
Numerical solutions of partial differential equations and integral equations. For PDEs, the finite difference method, the finite element method and the boundary element method are studied. A priori and a posteriori error estimates are examined. For integral equations, topics include Galerkin methods, collocation methods, and the Petrov-Galerkin method. Prerequisites: MATH 501, MATH 508 and MATH 509.

MATH 725. Computational Fluid Dynamics. 3 Credits.
An introduction to the theory of finite volume methods for scalar and vector conservation laws and the Euler and Navier-Stokes equations. Topics include weak solutions, characteristics, Rankine-Hugoniot conditions, energy and entropy inequalities, Riemann solvers, and numerical methods for compressible and incompressible flows including MUSCL and total variation diminishing (TVD) schemes. Prerequisites: MATH 501, MATH 508 and MATH 509.

MATH 745. Advanced Applied Functional Analysis. 3 Credits.
Use of integral transforms for students of applied mathematics, physics and engineering. Integral transforms studied are Laplace, Fourier, Hankel, finite Z-transforms and other special transforms. Prerequisites: MATH 691 and MATH 692.

MATH 750. Calculus of Variations. 3 Credits.
Maximum and minimum techniques in calculus and dynamic programming. Derivation of Euler-Lagrange equations for a variety of conditions, formulation of extremum problems with side conditions for ordinary and partial differential equations. Application to dynamics, elasticity, heat and mass transfer, energy principles and finite element techniques. Prerequisites: MATH 691 and MATH 692.
MATH 755. Introduction to Kinetic Theory and Mesoscopic Methods for Computational Mechanics I. 3 Credits.
The goal of this course is to provide an introduction to kinetic theory and nonequilibrium statistical mechanics, which bridges the microscopic theories and the macroscopic continuum theories of flows. Topics include the molecular dynamics of N particles, Hamiltonian equation, Liouville equation, Boltzmann equation, binary collision, linearized collision operator and its eigen theory, the H-theorem and irreversibility, calculation of the transport coefficients. Prerequisites: MATH 501 or MATH 691 or permission of the instructor.

MATH 756. Introduction to Kinetic Theory and Mesoscopic Methods for Computational Mechanics II. 3 Credits.
This is the second part of the study of the interaction between kinetic theory and nonequilibrium statistical mechanics. Models of Boltzmann equation and numerical techniques for hydrodynamic equations (Euler and Navier-Stokes equations) and the Boltzmann equation are studied. Topics include Non-normal and moment method, Maxwell's moment method, BGK model equation, gas mixtures and transport phenomena in mixtures, the Wang-Chang-Uhlenbeck equation, Enskog equation for dense gases, the lattice Boltzmann equation for incompressible flows, the gas-kINETic scheme for compressible flows and the Direct Simulation Monte Carlo (DSMC) method. Prerequisites: MATH 755/MATH 855.

MATH 771. Scientific Computing in Applied Mathematics. 3 Credits.
Numerical methods for algebraic systems, partial differential equations, integral equations, optimization, Monte Carlo method, and statistics, with emphasis on computational performance using modern programming languages such as Fortran 90 or C/C++ and modern computer architecture. Basic techniques of parallel computing using MPI (Message Passing Interface), openMP, or other distributed/multicore computing platforms. Common tools in scientific computing, such as Unix shell commands, debuggers, version control systems, scientific libraries, graphics and visualization, will also be introduced. Prerequisites: MATH 501, MATH 508 and MATH 509.

MATH 795. Seminar in Mathematics. 1-3 Credits.
Seminar in advanced topics. Prerequisites: permission of the instructor.

MATH 796. Topics in Mathematics. 1-3 Credits.
Advanced study of selected topics. Prerequisites: permission of the instructor.

MATH 797. Topics in Mathematics. 1-3 Credits.
Advanced study of selected topics. Prerequisites: permission of instructor.

MATH 801. Asymptotic and Perturbation Methods. 3 Credits.
Asymptotic and perturbation methods are developed and used to solve linear and nonlinear differential equations. Included are analyses of Duffing's Equation, Van der Pol's Equation, and Mathieu's Equation. Singular perturbation theory and the Method of Matched Asymptotic Expansions are used to solve equations with boundary layer type solutions. Asymptotic expansions of integrals using Laplace's Method, Method of Steepest Descent and Method of Stationary Phase are developed. Applications from all areas of applied mathematics are given. Prerequisites: MATH 693.

MATH 802. Integral Equations. 3 Credits.

MATH 803. Advanced Applied Mathematics I. 3 Credits.
Advanced techniques of mathematics applied to specific topics of physical interest. Examples could include high activation energy asymptotics applied to combustion, singular integral equations applied to fracture mechanics, or bifurcation theory applied to non-linear phenomena such as transition to turbulence, phase transitions and hydrodynamic stability. Prerequisites: MATH 702.

MATH 804. Advanced Applied Mathematics II. 3 Credits.
Advanced techniques of mathematics applied to specific topics of physical interest. Examples could include high activation energy asymptotics applied to combustion, singular integral equations applied to fracture mechanics, or bifurcation theory applied to non-linear phenomena such as transition to turbulence, phase transitions and hydrodynamic stability. Prerequisites: MATH 702.

MATH 817. Mathematical Analysis III. 3 Credits.
Topics in mathematical analysis. Measure and integration; classical Banach spaces; operators on linear spaces; Fourier series and integrals. Prerequisites: MATH 617 and MATH 618.

MATH 820. Advanced Applied Functional Analysis. 3 Credits.
In the first half of this course, several concepts in the classical functional analysis are studied. Topics include Banach Spaces, the dual spaces, the Baire category theorem, the adjoint operator, weak convergence, spectral theory and compact operators. In the second half, at the instructor's discretion, special topics are studied. Possible topics include ill-posed problems, inverse scattering theory, the regular Sturm-Liouville problem and the Dirichlet problem for Laplace's equation. Prerequisites: MATH 617 and MATH 618.

MATH 821. Advanced Applied Numerical Methods I. 3 Credits.
Numerical solutions of partial differential equations and integral equations. For PDEs, the finite difference method, the finite element method and the boundary element method are studied. A priori and a posteriori error estimates are examined. For integral equations, topics include Galerkin methods, collocation methods, and the Petrov-Galerkin method. Prerequisites: MATH 501, MATH 508 and MATH 509.

MATH 822. Advanced Applied Numerical Methods II. 3 Credits.
Numerical solutions of partial differential equations and integral equations. For PDEs, the finite difference method, the finite element method and the boundary element method are studied. A priori and a posteriori error estimates are examined. For integral equations, topics include Galerkin methods, collocation methods, and the Petrov-Galerkin method. Prerequisites: MATH 821.

MATH 823. Approximation and Optimization I. 3 Credits.
Introductory and advanced topics representing current research in approximation and optimization techniques for various application problems. Topics include recent developments in algorithms, their analysis, and applications such as data fitting and pattern separation. Prerequisites: permission of the graduate program director.

MATH 825. Computational Fluid Dynamics. 3 Credits.
An introduction to the theory of finite volume methods for scalar and vector conservation laws and the Euler and Navier-Stokes equations. Topics include weak solutions, characteristics, Rankine-Hugoniot conditions, energy and entropy inequalities, Riemann solvers, and numerical methods for compressible and incompressible flows including MUSCL and total variation diminishing (TVD) schemes. Prerequisites: MATH 501, MATH 508 and MATH 509.

MATH 845. Transform Methods. 3 Credits.
Use of integral transforms for students of applied mathematics, physics and engineering. Integral transforms studied are Laplace, Fourier, Hankel, finite Z-transforms and other special transforms. Prerequisites: MATH 691 and MATH 692.

MATH 850. Calculus of Variations. 3 Credits.
Maximum and minimum techniques in calculus and dynamic programming. Derivation of Euler-Lagrange equations for a variety of conditions, formulation of extremum problems with side conditions for ordinary and partial differential equations. Application to dynamics, elasticity, heat and mass transfer, energy principles and finite element techniques. Prerequisites: MATH 691 and MATH 692.
MATH 855. Introduction to Kinetic Theory and Mesoscopic Methods for Computational Mechanics I. 3 Credits.
The goal of this course is to provide an introduction to kinetic theory and nonequilibrium statistical mechanics, which bridges the microscopic theories and the macroscopic continuum theories of flows. Topics include the molecular dynamics of N particles, Hamiltonian equation, Liouville equation, Boltzmann equation, binary collision, linearized collision operator and its eigen theory, the H-theorem and irreversibility, calculation of the transport coefficients. Prerequisites: MATH 501 or MATH 691 or permission of the instructor.

MATH 856. Introduction to Kinetic Theory and Mesoscopic Methods for Computational Mechanics II. 3 Credits.
This is the second part of the study of the interaction between kinetic theory and nonequilibrium statistical mechanics. Models of Boltzmann equation and numerical techniques for hydrodynamic equations (Euler and Navier-Stokes equations) and the Boltzmann equation are studied. Topics include Non-normal and moment method, Maxwell’s moment method, BGK model equation, gas mixtures and transport phenomena in mixtures, the Wang-Chang-Uhlenbeck equation, Enskog equation for dense gases, the lattice Boltzmann equation for incompressible flows, the gas-kinetic scheme for compressible flows and the Direct Simulation Monte Carlo (DSMC) method. Prerequisites: MATH 755/MATH 855.

MATH 871. Scientific Computing in Applied Mathematics. 3 Credits.
Numerical methods for algebraic systems, partial differential equations, integral equations, optimization, Monte Carlo method, and statistics, with emphasis on computational performance using modern programming languages such as Fortran 90 or C/C++ and modern computer architecture. Basic techniques of parallel computing using MPI (Message Passing Interface), openMP, or other distributed/multicore computing platforms. Common tools in scientific computing, such as Unix shell commands, debuggers, version control systems, scientific libraries, graphics and visualization, will also be introduced. Prerequisites: MATH 501, MATH 508 and MATH 509.

MATH 895. Seminar in Mathematics. 1-3 Credits.
Seminar in advanced topics. Prerequisite: permission of the instructor.

MATH 896. Topics in Mathematics. 1-3 Credits.
Advanced study of selected topics. Prerequisite: permission of the instructor.

MATH 897. Topics in Mathematics. 1-3 Credits.
Advanced study of selected topics.

MATH 898. Research. 1-9 Credits.

MATH 899. Dissertation. 1-9 Credits.

MATH 999. Doctoral Graduate Credit. 1 Credit.
This course is a pass/fail course doctoral students may take to maintain active status after successfully passing the candidacy examination. All doctoral students are required to be registered for at least one graduate credit hour every semester until their graduation.

STATISTICS Courses

STAT 505. Introduction to Data Handling. 3 Credits.
Use of SAS and R to handle data sets. Topics for SAS include data input, creating permanent data sets, merging data sets, creating new variables, sorting, printing, charting, formatting, IML programming, macro programming, and an overview of proc SQL and other statistical procedures. Topics for R include data structure, control structure, writing functions, and graphics. Prerequisites: A grade of C or better in STAT 130M or equivalent, and a grade of C or better in MATH 316 or equivalent, or permission of the instructor.

STAT 531. Theory of Statistics. 3 Credits.
Topics include point and interval estimation, tests of hypotheses, introduction to linear models, likelihood techniques, and regression and correlation analysis. Prerequisites: A grade of C or better in STAT 331 or permission of the instructor.

STAT 532. Sampling Theory. 3 Credits.
Sampling from finite populations is discussed. Topics such as simple random sampling, stratified random sampling and ratio and regression estimation are included. Also discussed are aspects of systematic sampling, cluster sampling, and multi-stage sampling. Prerequisites: A grade of C or better in STAT 431/STAT 531.

STAT 535. Design and Analysis of Experiments. 3 Credits.
Topics include introduction to design of experiments, analysis of variance with a single factor, power and OC curves, and two factors with interactions, random effects models, randomized blocks, Latin square and related designs, introduction to factorial and 2k factorial designs. Statistical software will be used to analyze real life data. Prerequisites: STAT 431/STAT 531 or STAT 437/STAT 537. Pre- or corequisite: STAT 405/STAT 505.

STAT 537. Applied Regression and Time Series Analysis. 3 Credits.
Topics include introduction to regression and model building, simple linear regression, multiple regression, logistic regression, and simple time series, residual analysis, selection of variables, model adequacy checking, regression on dummy variables, analysis of covariance, regression analysis of time series data, and applications of these techniques to real life data using statistical software. Prerequisites: A grade of C or better in STAT 531. Pre- or corequisite: STAT 405 or STAT 505.

STAT 540. Clinical Trials. 3 Credits.
This course will introduce basic statistical concepts and methods used in clinical trials. Topics include trial designs, including parallel, group allocation, cross-over, and factorial designs; randomization; sample size and power calculation; survival analysis; and monitoring of trials for safety and efficacy. Prerequisites: A grade of C or better in STAT 431 or STAT 531.

STAT 542. Environmental Statistics. 3 Credits.
Topics include nonlinear and generalized linear models, quantitative risk assessment, analysis of stimulus-response and spatially correlated data, methods of combining data from several independent studies. Regression settings are emphasized where one or more predictor variables are used to make inferences on an outcome variable of interest. Applications include modeling growth inhibition of organisms exposed to environmental toxins, spatial associations of like species, risk estimation, and spatial prediction. SAS is used extensively in the course. Prerequisites: A grade of C or better in STAT 431 or STAT 531; STAT 437 or STAT 537 recommended.

STAT 547. Analysis of Longitudinal Data. 3 Credits.
This course introduces statistical methods for analyzing multivariate and longitudinal data. Topics include multivariate normal distribution, covariance modeling, multivariate linear models, principal components, analysis of continuous response repeated measures, and models for discrete longitudinal data. Emphasis will be on the applications to the biological and health sciences and the use of the statistical software. Prerequisites: A grade of C or better in STAT 431 or STAT 531. Pre- or corequisite: STAT 405 OR STAT 505.

STAT 549. Nonparametric Statistics. 3 Credits.
Topics include the theory and applications of binomial tests and rank tests, including the tests of McNemar, Mann-Whitney, Friedman, Kruskal-Wallis, and Smirnov. Prerequisites: A grade of C or better in STAT 330 or STAT 331 or departmental permission.

STAT 550. Categorical Data Analysis. 3 Credits.
Topics include types of categorical data, relative risk and odds ratio measures for 2 x 2 tables, the chi-square and Mantel-Haenszel tests, Fisher's exact test, analysis of sets of 2 x 2 tables using Cochran-Mantel-Haenszel methodology, analysis of I x J and sets of I x J tables for both nominal and ordinal data, logistic regression including the logit and probit models. Emphasis will be on the application of these statistical tools to data related to the health and social sciences. Interpretation of computer output will be stressed. Prerequisites: A grade of C or better in STAT 431 or STAT 531. Pre- or corequisite: STAT 405 or STAT 505.
STAT 560. Statistical Simulation/Programming Using Statistical Software Packages. 3 Credits.
This course is a data-based tour of advanced statistical techniques using software packages, exploring a catalog of data sets (simulated or otherwise) spanning a variety of fields and applications, including data suitable for regression, ANOVA, time series modeling, longitudinal data analysis and multivariate techniques. Approaches will include parametric, nonparametric, simulation, and bootstrapping. SAS and R (S-plus) will be used extensively, with some other specialized products. For writing actual (not packaged) code, PROC IML and R will be used. This is a finishing course for applied statisticians, highly recommended for students planning a career in statistical programming and simulation. Prerequisites: A grade of C or better in STAT 505 and two of STAT 535, STAT 537, STAT 547 and STAT 550.

STAT 597. Topics in Statistics. 1-3 Credits.
The advanced study of selected topics. Prerequisites: permission of the instructor.

STAT 603. Statistical/Probability Models for Data Science and Analytics. 3 Credits.
This course will serve as an introduction for modeling data using probability and statistical methods. Topics include basic concepts of probability, Bayes theorem, frequently-occurring discrete and continuous probability distributions, as well as how to simulate data from these distributions. Basic properties of the probability distributions will be discussed, which will provide an insight into the use of these distributions in data science. The course will also cover bivariate and conditional distributions, linear correlation and statistical inference concepts that include likelihood, parameter estimation, and goodness of fit. Prerequisite: STAT 330 or equivalent or permission of the instructor.

STAT 604. Statistical Tools for Data Science and Analytics. 3 Credits.
This course will cover statistical tools for data exploration. Topics taught include descriptive statistics, correlation, confidence intervals, linear and logistic regressions, t-test for one and two samples, and analysis of variance. For analyzing categorical data, students will study contingency tables, odds ratios for measuring association, and chi-square tests for testing independence. The course will also introduce principal components and clustering methods to analyze multivariate data. R and/or Python software for computing various statistics for real data analysis will be used. Prerequisite: STAT 603 or equivalent or permission of the instructor.

STAT 613. Applied Statistical Methods I. 3 Credits.
Intended for graduate students in all academic disciplines; not available for credit to graduate students in the Department of Mathematics and Statistics. Topics include descriptive statistics, probability computations, estimation, hypothesis testing, linear regression, analysis of variance and categorical data analysis. Emphasis will be on statistical analysis of data arising in a research setting. The rationale for selecting methods to address research questions will be emphasized. Examples will be given from the health sciences, social sciences, engineering, education and other application areas. Prerequisites: A grade of C or better in STAT 130M or STAT 330 or MATH 211 or permission of the instructor.

STAT 625. Mathematical Statistics I. 3 Credits.
An introduction to probability. Topics include axiomatic foundations of probability, conditional probability, Bayes formula, random variables, density and mass functions, stochastic independence, expectation, moment generating functions, transformations, common families of distributions, multiple random variables, covariance and correlation, multivariate distributions, convergence concepts, law of large numbers, limit theorems. Prerequisites: A grade of C+ or better in STAT 531.

STAT 626. Mathematical Statistics II. 3 Credits.
An introduction to statistical inference. Principles of data reduction, sufficiency, completeness, ancillary, likelihood principle, point estimation, method of moments, maximum likelihood and Bayes estimation, Cramer-Rao inequality, hypothesis testing, likelihood ratio tests, Bayesian tests, most powerful tests, Neyman-Pearson Lemma, interval estimates, pivotal quantities, asymptotic evaluations, consistency and asymptotic relative efficiency. Prerequisites: A grade of C+ or better in STAT 625.

STAT 630. Time Series Models. 3 Credits.
This course examines the principles and concepts of time series and forecasting. Study includes theory, methods, and model parameter estimation taking into account correlation and autocorrelation structures with data applications from pollution, economics, seasonal trends, and the stock market. Notions of autoregressive, moving, average, stationary and nonstationary ARIMA models will be discussed. The multivariate version and state-space models will also be introduced. Simulation of time series data will be discussed in depth. Prerequisites: STAT 626, STAT 505, and STAT 537.

STAT 632. Master’s Project. 3 Credits.
Under the guidance of a faculty member in the Department of Mathematics and Statistics, the student will undertake a significant data analysis problem in a scientific setting outside the department. A written report and/or public presentation of results will be required. Prerequisites: permission of graduate program director.

STAT 635. Statistical Consulting. 3 Credits.
This course is intended to teach statistical consulting techniques to graduate students in statistics. Students are expected to work on statistical consulting problems brought by faculty and graduate students in various fields. Prerequisites: STAT 626.

STAT 637. Advanced Regression and Time Series. 3 Credits.
Topics include theory of least squares regression, multiple linear regression (including its matrix formulation), transformations and weighting, diagnostics for leverage and influence, polynomial and indicator regression model, multi-collinearity, variable selection and model building, validation of regression models, introduction to nonlinear regression, robust regression, regression for time series data, and applications of these techniques using statistical software. Prerequisites: STAT 437/STAT 537. Pre- or corequisite: STAT 405/STAT 505.

STAT 638. Advanced Design and Analysis of Experiments. 3 Credits.
Topics include blocking and confounding in factorial designs, power, balanced incomplete block designs, fractional factorial designs, factors with mixed levels, response surface methods and designs, Latin and Graeco-Latin square designs, optimality criterion, examples of optimal designs, experiments with random factors, nested and split-plot designs, analysis of covariance, robust designs. Statistical software will be used to analyze real life data. Prerequisites: STAT 435/STAT 535 or STAT 437/STAT 537 or STAT 637.

STAT 640. Survival Analysis. 3 Credits.
This course will introduce basic concepts and methods for analyzing survival time data obtained from following individuals until the occurrence of an event or their loss to follow-up. It will cover nonparametric, semiparametric, and parametric models and two-sample test techniques. It will demonstrate mathematical and graphical methods for evaluating the goodness of fit and introduce the concept of dependent censoring/competing risk. Both SAS and R software will be used to analyze survival data. Prerequisites: STAT 626.

STAT 667. Cooperative Education. 1-3 Credits.
Student participation for credit based on academic relevance of the work experience, criteria, and evaluative procedures as formally determined by the department and the cooperative education program prior to the semester in which the work experience is to take place.

STAT 697. Topics in Statistics. 1-3 Credits.
Advanced study of selected topics. Prerequisites: permission of the instructor.

STAT 725. Linear Statistical Models. 3 Credits.
Topics include the multivariate normal distribution, distributions of quadratic forms, the general linear model, estimability, the Gauss-Markov theorem and general linear hypotheses, analysis of variance (ANOVA) and covariance (ANCOVA) with special attention to unbalanced data, and analysis of mixed effects and variance components models including repeated measures and split-plot designs. Prerequisites: STAT 626.
Topics to be covered include introduction to measure theoretic probability, properties of group and exponential families, sufficiency, unbiasedness, equivariance, properties of estimators, large sample theory, maximum likelihood estimation, EM algorithm, information inequality, asymptotic optimality. Prerequisites: A grade of C+ or higher in MATH 517 and STAT 626.

Topics to be covered include convergence concepts, limit theorems, large sample theory, asymptotic distributions, decision theory, minimax, admissibility, Bayes estimates, generalized Neyman-Pearson Lemma, uniformly most powerful tests, unbiased tests, invariant tests, and Bayesian tests. Prerequisites: A grade of C+ or higher in STAT 727 or STAT 827.

Topics include the multivariate normal distribution, graphical display of multivariate data and tests for normality, Hotelling’s T2, multivariate analysis of variance (MANOVA) and regression, profile analysis, growth curve models, canonical correlation analysis, principal components, factor models, clustering, and discriminant analysis. All methods are implemented using the SAS statistical software. Prerequisites: STAT 537 or STAT 725/STAT 825.

This course will discuss sequential and adaptive designs for clinical trials; the statistical properties and challenges these designs engender; and the advantages and disadvantages of utilizing sequential and adaptive designs compared to a standard, fixed-sample design. Prerequisites: STAT 440 or STAT 540.

Topics include general linear models, weighted least squares (WLS), maximum likelihood (ML), restricted maximum likelihood (REML) methods of estimation, analysis of continuous response repeated measures data, parametric models for covariance structure, generalized estimating equations (GEE) for discrete longitudinal data, marginal, random effects, and transition models. Limitations of existing approaches will be discussed. Emphasis will be on the application of these tools to data related to the biological and health sciences. Methods will be implemented using statistical software. Prerequisites: STAT 447/STAT 547.

Topics include multivariate permutation tests, multivariate rank tests, permutation and rank tests for censored data, bootstrap methods, permutation and rank tests for the analysis of multifactor experiments, and nonparametric smoothing methods. Prerequisites: STAT 449/STAT 549.

This course will cover statistical models and methods appropriate for analyzing categorical responses, contingency tables, Pearson Chi-square test, Fisher’s Exact test, Mantel-Haenszel test, Cochran-Armitage trend test, independence and conditional independence, Simpson’s paradox, generalized linear models, logistic and Poisson regression models, matched paired studies, McNemar test, conditional logistic regression model and random effects logistic model for data from matched paired studies, models for multinomial data. Prerequisites: STAT 450/STAT 550.

Seminar. Prerequisite: permission of the instructor.

Advanced study of selected topics. Prerequisites: Permission of the instructor.

Topics to be covered include introduction to measure theoretic probability, properties of group and exponential families, sufficiency, unbiasedness, equivariance, properties of estimators, large sample theory, maximum likelihood estimation, EM algorithm, information inequality, asymptotic optimality. Prerequisites: A grade of C+ or higher in MATH 517 and STAT 626.

Topics to be covered include convergence concepts, limit theorems, large sample theory, asymptotic distributions, decision theory, minimax, admissibility, Bayes estimates, generalized Neyman-Pearson Lemma, uniformly most powerful tests, unbiased tests, invariant tests, and Bayesian tests. Prerequisites: A grade of C+ or higher in STAT 727 or STAT 827.

Topics include the multivariate normal distribution, graphical display of multivariate data and tests for normality, Hotelling’s T2, multivariate analysis of variance (MANOVA) and regression, profile analysis, growth curve models, canonical correlation analysis, principal components, factor models, clustering, and discriminant analysis. All methods are implemented using the SAS statistical software. Prerequisites: STAT 537 or STAT 725/STAT 825.

This course will discuss sequential and adaptive designs for clinical trials; the statistical properties and challenges these designs engender; and the advantages and disadvantages of utilizing sequential and adaptive designs compared to a standard, fixed-sample design. Prerequisites: STAT 440/STAT 540.

Topics include general linear models, weighted least squares (WLS), maximum likelihood (ML), restricted maximum likelihood (REML) methods of estimation, analysis of continuous response repeated measures data, parametric models for covariance structure, generalized estimating equations (GEE) for discrete longitudinal data, marginal, random effects, and transition models. Limitations of existing approaches will be discussed. Emphasis will be on the application of these tools to data related to the biological and health sciences. Methods will be implemented using statistical software. Prerequisites: STAT 447/STAT 547.

Topics include multivariate permutation tests, multivariate rank tests, permutation and rank tests for censored data, bootstrap methods, permutation and rank tests for the analysis of multifactor experiments, and nonparametric smoothing methods. Prerequisites: STAT 449/STAT 549.

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Seminar. Prerequisite: permission of the instructor.

Seminar. Prerequisite: permission of the instructor.

This course is a pass/fail course doctoral students may take to maintain active status after successfully passing the candidacy examination. All doctoral students are required to be registered for at least one graduate credit hour every semester until their graduation.