Department of Statistics

Chair

- Matthew Stephens, Statistics and Human Genetics

Professors

- Yali Amit, Statistics
- Mihai Anitescu, Statistics and Argonne National Laboratory
- Guillaume Bal, Statistics and Mathematics
- Rina Foygel Barber, Statistics
- Brent Doiron, Neurobiology, Statistics, and the Grossman Center
- Chao Gao, Statistics
- Lars Peter Hansen, Economics, Statistics, and the Booth School of Business
- Gregory F. Lawler, Mathematics and Statistics
- Lek-Heng Lim, Statistics
- Mary Sara McPeek, Statistics and Human Genetics
- Per Mykland, Statistics and the Stevanovich Center
- Dan Liviu Nicolae, Statistics, Human Genetics, and Medicine
- John Reinitz, Statistics, Ecology and Evolution, and Molecular Genetics and Cell Biology
- Mary Silber, Statistics
- Matthew Stephens, Statistics and Human Genetics
- Rebecca Willett, Statistics and Computer Science
- Kirk M. Wolter, Statistics
- Wei Biao Wu, Statistics

Associate Professors

- Imre Risi Kondor, Computer Science and Statistics

Assistant Professors

- Claire Donnat, Statistics
- Jeremy Hoskins, Statistics
- Nikolaos Ignatiadis, Statistics
- Yuehaw Khoo, Statistics
- Frederic Koehler, Statistics
- Xinran Li, Statistics
- Cong Ma, Statistics
- Daniel Sanz-Alonso, Statistics
- Aaron Schein, Statistics
- Yi Sun, Statistics
- Victor Veitch, Statistics
- Jingshu Wang, Statistics

Senior Instructional Professors

- Eric Baer, Statistics
- David Biron, Statistics
- Kendra Burbank, Statistics
- Yibi Huang, Statistics
- Mei Wang, Statistics

Instructional Professors

- Fei Liu, Statistics
- Ryan McShane, Statistics
- Amy Nussbaum, Statistics
- Daniel Xiang, Statistics

Instructors

- Thuyen Dang, Statistics
- Tristan Goodwill, Statistics
- Yier Lin, Statistics
- Anjali Nair, Statistics
- Siyao Yang, Statistics
- Yuxin Zhou, Statistics

The Department of Statistics offers an exciting and revamped graduate program that prepares students for cutting-edge interdisciplinary research in a wide variety of fields. The field of statistics has become a core component of research in the biological, physical, and social sciences, as well as in traditional computer science domains such as artificial intelligence. In light of this, the Department of Statistics is currently undergoing a major expansion of approximately ten new faculty into fields of Computational and Applied Mathematics, as well as a number of faculty in Data Science. The massive increase in the data acquired, through scientific measurement on one hand and through web-based collection on the other, makes the development of statistical analysis and prediction methodologies more relevant than ever. Our graduate program aims to prepare students to address these issues through rigorous training in theory, methodology, and applications of statistics; rigorous training in scientific computation; and research projects in core methodology of statistics and computation as well as in a wide variety of interdisciplinary fields.

The Department of Statistics offers two tracks of graduate study, one leading to the Master of Science (M.S.) degree, the other to the Doctorate of Philosophy (Ph.D.). The M.S. degree is a professional degree. Students who receive this degree are prepared for nonacademic careers in which the use of advanced statistical and computational methods is of central importance. The program also prepares students for possible further graduate study.

During the first year of the Ph.D. program, students are given a thorough grounding in material that forms the foundations of modern statistics and scientific computation, including data analysis, mathematical statistics, probability theory, applied probability and modeling, and computational methods. Throughout the entire program, students attend a weekly consulting seminar where researchers from across the University come to get advice on modeling, statistical analysis, and computation. This seminar is often the source of interesting and ongoing research projects.

In the second year, students have a wide range of choices of topics they can pursue further, based on their interests, through advanced courses and reading courses with faculty. During the second year, students will typically identify their subfield of interest, take some advanced courses in the subject, and interact with the relevant faculty members. The Department maintains very strong connections to numerous other units on campus, either through joint appointments of the faculty or through ongoing collaborations. Students have easy access to faculty in other departments, which allows them to expand their interactions and develop new interdisciplinary research projects. Examples include joint projects with Human Genetics, Ecology and Evolution, Neurobiology, Chemistry, Economics, Health Studies, and Astronomy.

Programs and Requirements for the Ph.D.

The program offers four core sequences:

- Probability (STAT 30400, 38100, 38300)
- Mathematical statistics (STAT 30400, 30100, 30210)
- Applied statistics (STAT 34300, 34700, 34800)
- Computational mathematics and machine learning (STAT 30900, 31015/31020, 37710)

All students must take the applied statistics sequence and one of the two theoretical sequences: mathematical statistics or probability. At the start of their second year, the students take preliminary examinations covering the two sequences they have taken. In addition, it is highly recommended that students take a third core sequence based on their interests and in consultation with the Department Graduate Adviser (DGA). Incoming first-year students may request the DGA to take one or both of their preliminary exams. If approved, and if the student passes one or more of these, the student will then be excused from the requirement of taking the first-year courses in that subject. Incoming students are advised by the DGA until they find a faculty adviser for their Ph.D. thesis work.

In their second year, Ph.D. students typically take a number of advanced topics: courses in statistics, probability, computation, and applications. These should be selected with the dual objective of (i) acquiring a broad overview of current research areas, and (ii) settling on a particular research topic and dissertation supervisor. It is recommended that the students take at least one regular class based course each quarter. In addition, students can ask to take reading courses with faculty to learn more in depth about their fields of research. Students have considerable latitude in selecting their second-year courses, but their programs must be

approved by the Department Graduate Adviser. Students are expected to find a dissertation adviser by the end of the second year. The detailed process is listed here (https://stat.uchicago.edu/admissions/about-phd/).

The Ph.D.: Training in Teaching, Presentation, and Consulting

Part of every statistician's job is to evaluate the work of others and to communicate knowledge, experience, and insights. Every statistician is, to some extent, an educator, and the department provides graduate students with training for this aspect of their professional lives. The department expects all doctoral students, regardless of their professional objectives and sources of financial support, to take part in a graduated program of participation in some or all phases of instruction, from grading, course assisting, and conducting discussion sections, to being a lecturer with responsibility for an entire course.

Students also receive training in how to present research in short seminars in the first and second years of study. Later, students present their own work in a dissertation proposal and, eventually, in a thesis defense. The student seminars are listed here (https://stat.uchicago.edu/events/).

Ph.D. students should also participate in the department's consulting program (https://stat.uchicago.edu/about/consulting/), which is led by faculty members and exposes the students to empirical projects inside the university. Projects are carried out by groups of students under the guidance of a faculty member. The client is a researcher in an applied area, usually associated with the university. An informal seminar meets regularly over lunch to provide a forum for presenting and discussing problems, solutions, and topics in statistical consultation. Students present interesting or difficult consulting problems to the seminar as a way of stimulating wider consideration of the problem and as a means of developing familiarity with the kinds of problems and lines of attack involved. Often the client will participate in the presentation and discussion.

Programs and Requirements for the M.S. degree

The main requirements of the M.S. program are a sequence of at least nine approved courses plus a Master's paper. Students may take up to two years of courses. A detailed set of regulations can be found here (https://stat.uchicago.edu/admissions/about-ms/). (http://www.stat.uchicago.edu/students/master.shtml/) A substantial fraction of available courses are the same as for the Ph.D. degree.

Facilities

Almost all departmental activities—classes, seminars (https://stat.uchicago.edu/events/statistics-colloquium/), computation (https://www.stat.uchicago.edu/intranet/computing/index.shtml/), and student and faculty offices (https://stat.uchicago.edu/people/)–are located in Jones Laboratory (https://d3qi0qp55mx5f5.cloudfront.net/stat/docs/People/UChicago_Maps--Jones.pdf?cachebuster:32). Each student is assigned a desk in one of several offices. The major computing facilities of the department are based upon a network of PCs running mainly Linux. One computer room currently houses many of these PCs; these rooms are directly and primarily for graduate students in the Statistics Department. In addition, all student offices have limited computer facilities. For further information, consult the department's computing policies (https://www.stat.uchicago.edu/intranet/computing/policies/index.shtml/).

Statistics Throughout the University

In addition to the courses, seminars, and programs in the Department of Statistics, courses and workshops of direct interest to statisticians occur throughout the University, most notably in the programs in statistics and econometrics in the Booth School of Business (http://www.chicagobooth.edu/) and in the research programs in Public Health Sciences (http://health.bsd.uchicago.edu/), Human Genetics (http://genes.uchicago.edu/), Financial Mathematics and Econometrics (https://finmath.uchicago.edu/), Computer Science (http://www.cs.uchicago.edu/), Economics (http://economics.uchicago.edu/), and NORC (https://www.norc.org/) (formerly the National Opinion Research Center). The large number of statistics related seminars (https://stat.uchicago.edu/events/) is perhaps the best indication of the vibrancy of the statistics research community here at the University of Chicago.

Statistics Courses

STAT 30030. Statistical Theory and Methods Ia. 100 Units.
This course is the first quarter of a two-quarter sequence providing a principled development of statistical methods, including practical considerations in applying these methods to the analysis of data. The course begins with a brief review of probability and some elementary stochastic processes, such as Poisson processes, that are relevant to statistical applications. The bulk of the quarter covers principles of statistical inference from both frequentist and Bayesian points of view. Specific topics include maximum likelihood estimation, posterior distributions, confidence and credible intervals, principles of hypothesis testing, likelihood ratio tests, multinomial distributions, and chi-square tests. Additional topics may include diagnostic plots, bootstrapping, a critical comparison of Bayesian and frequentist inference, and the role of conditioning in statistical inference. Examples are drawn from the social, physical, and biological sciences. The statistical software package R will be used to analyze datasets from these fields and instruction in the use of R is part of the course.
Instructor(s): Staff Terms Offered: Autumn
Prerequisite(s): STAT 25100 or STAT 25150 or MATH 23500. This course is only open to graduate students in Statistics, Applied Mathematics, and Financial Mathematics, and to undergraduate Statistics majors, or by consent of instructor.

Note(s): Some previous experience with statistics helpful but not required. Concurrent or prior linear algebra (MATH 18600 or 19620 or 20250 or 20700 or STAT 24300 or equivalent) is recommended for students continuing to STAT 24510. Students may count either STAT 24400 or STAT 24410, but not both, toward the forty-two credits required for graduation.
Equivalent Course(s): STAT 24410

STAT 30040. Statistical Theory and Methods IIa. 100 Units.
This course is a continuation of STAT 24410. The focus is on theory and practice of linear models, including the analysis of variance, regression, correlation, and some multivariate analysis. Additional topics may include bootstrapping for regression models, nonparametric regression, and regression models with correlated errors.
Terms Offered: Winter
Prerequisite(s): STAT 24410 and linear algebra (MATH 18600 or 19620 or 20250 or 20700 or STAT 24300 or equivalent). This course is only open to graduate students in Statistics, Applied Mathematics, and Financial Mathematics, and to undergraduate Statistics majors, or by consent of instructor.
Note(s): Students may count either STAT 24500 or STAT 24510, but not both, toward the forty-two credits required for graduation.
Equivalent Course(s): STAT 24510

STAT 30100. Mathematical Statistics-1. 100 Units.
This course is part of a two-quarter sequence on the theory of statistics. Topics will include exponential, curved exponential, and location-scale families; mixtures, hierarchical, and conditional modeling including compatibility of conditional distributions; principles of estimation; identifiability, sufficiency, minimal sufficiency, ancillarity, completeness; properties of the likelihood function and likelihood-based inference, both univariate and multivariate, including examples in which the usual regularity conditions do not hold; elements of Bayesian inference and comparison with frequentist methods; and multivariate information inequality. Part of the course will be devoted to elementary asymptotic methods that are useful in the practice of statistics, including methods to derive asymptotic distributions of various estimators and test statistics, such as Pearson's chi-square, standard and nonstandard asymptotics of maximum likelihood estimators and Bayesian estimators, asymptotics of order statistics and extreme order statistics, Cramer's theorem including situations in which the second-order term is needed, and asymptotic efficiency. Other topics (e.g., methods for dependent observations) may be covered if time permits.
Instructor(s): Staff Terms Offered: Winter
Prerequisite(s): STAT 30400 or consent of instructor

STAT 30200. Mathematical Statistics-2. 100 Units.
This course continues the development of Mathematical Statistics, with an emphasis on hypothesis testing. Topics include comparison of Bayesian and frequentist hypothesis testing; admissibility of Bayes' rules; confidence and credible sets; likelihood ratio tests and their asymptotics; Bayes factors; methods for assessing predictions for normal means; shrinkage and thresholding methods; sparsity; shrinkage as an example of empirical Bayes; multiple testing and false discovery rates; Bayesian approach to multiple testing; sparse linear regressions (subset selection and LASSO, proof of estimation errors for LASSO, Bayesian perspective of sparse regressions); and Bayesian model averaging.
Instructor(s): Staff Terms Offered: Spring
Prerequisite(s): STAT 24500 or STAT 30100

STAT 30400. Distribution Theory. 100 Units.
This course is a systematic introduction to random variables and probability distributions. Topics include standard distributions (i.e. uniform, normal, beta, gamma, F, t, Cauchy, Poisson, binomial, and hypergeometric); properties of the multivariate normal distribution and joint distributions of quadratic forms of multivariate normal; moments and cumulants; characteristic functions; exponential families; modes of convergence; central limit theorem; and other asymptotic approximations.
Instructor(s): Staff Terms Offered: Autumn
Prerequisite(s): STAT 24500 or STAT 24510 and MATH 20500 or MATH 20510, or consent of instructor.

STAT 30600. Adv. Statistical Inference 1. 100 Units.
Topics covered in this course will include: Gaussian distributions; conditional distributions; maximum likelihood and REML; Laplace approximation and associated expansion; combinatorics and the partition lattice; Mobius inversion; moments, cumulants symmetric functions, and k-statistics; cluster expansions; Bartlett identities and Bartlett adjustment; random partitions, partition processes, and CRP process; Gauss-Ewens cluster process; classification models; trees rooted and unrooted; exchangeable random trees; and Cox processes used for classification.
Terms Offered: To be determined; may not offered in 2020-2021.
Prerequisite(s): Consent of instructor

STAT 30800. Advanced Statistical Inference II. 100 Units.
This course will discuss the following topics in high-dimensional statistical inference: random matrix theory and asymptotics of its eigen-decompositions, estimation and inference of high-dimensional covariance matrices, large dimensional factor models, multiple testing and false discovery control and high-dimensional semiparametrics. On the methodological side, probability inequalities, including exponential, Nagaev, and Rosenthal-type inequalities will be introduced.

Terms Offered: To be determined; may not be offered in 2020-2021.
Prerequisite(s): STAT 30400, STAT 30100, and STAT 30210, or consent of instructor

STAT 30810. High Dimensional Time Series Analysis. 100 Units.

This course will include lectures on the following topics: review of asymptotics for low dimensional time series analysis (linear and nonlinear processes; nonparametric methods; spectral and time domain approaches); covariance, precision, and spectral density matrix estimation for high dimensional time series; factor models; estimation of high dimensional vector autoregressive processes; prediction; and high dimensional central limit theorems under dependence.
Terms Offered: To be determined

STAT 30850. Multiple Testing, Modern Inference, and Replicability. 100 Units.

This course examines the problems of multiple testing and statistical inference from a modern point of view. High-dimensional data is now common in many applications across the biological, physical, and social sciences. With this increased capacity to generate and analyze data, classical statistical methods may no longer ensure the reliability or replicability of scientific discoveries. We will examine a range of modern methods that provide statistical inference tools in the context of modern large-scale data analysis. The course will have weekly assignments as well as a final project, both of which will include both theoretical and computational components.
Terms Offered: TBD
Prerequisite(s): STAT 24400 or STAT 24410. Familiarity with regression and with coding in R are recommended.
Equivalent Course(s): STAT 27850

STAT 30900. Mathematical Computation I: Matrix Computation Course. 100 Units.

This is an introductory course on numerical linear algebra, which is quite different from linear algebra. We will be much less interested in algebraic results that follow from axiomatic definitions of fields and vector spaces but much more interested in analytic results that hold only over the real and complex fields. The main objects of interest are real- or complex-valued matrices, which may come from differential operators, integral transforms, bilinear and quadratic forms, boundary and coboundary maps, Markov chains, correlations, DNA microarray measurements, movie ratings by viewers, friendship relations in social networks, etc. Numerical linear algebra provides the mathematical and algorithmic tools for analyzing these matrices. Topics covered: basic matrix decompositions LU, QR, SVD; Gaussian elimination and LU/LDU decompositions; backward error analysis, Gram-Schmidt orthogonalization and QR/complete orthogonal decompositions; solving linear systems, least squares, and total least squares problem; low-rank matrix approximations and matrix completion. We shall also include a brief overview of stationary and Krylov subspace iterative methods; eigenvalue and singular value problems; and sparse linear algebra.
Terms Offered: Autumn
Prerequisite(s): Linear algebra (STAT 24300 or equivalent) and some previous experience with statistics.
Equivalent Course(s): CMSC 37810, CAAM 30900

STAT 30960. Matrix Calculus and Matrix Analysis. 100 Units.

Just as basic real analysis concerns real-valued functions of one real variable and basic complex analysis concerns complex-valued functions of one complex variable, this class is about matrix-valued functions of one matrix variable. We will revisit the same basic concepts in real and complex analysis but now in the context of matrix analysis: continuity (standard, uniform, Lipchitz, Holder, upper/lower semicontinuity, etc), differentiability, higher-order differentiability, analyticity, integration (Bochner, contour, Cauchy, etc), interpolation, approximation, sequences, series (particularly Taylor, Fourier, Dirichlet), etc. We will also develop a corresponding matrix calculus for standard analytic functions, e.g., for differentiating functions like X^p, $\exp(X)$, $\log(X)$, $\operatorname{tr}(X^{-1})$, $\log\det(X)$, etc. In this class, we will largely concern ourselves with matrix functions originating from engineering and scientific applications. Everything that we do will ultimately be motivated by real-world problems.
Equivalent Course(s): CAAM 30960

STAT 31001. Modern Applied Optimization. 100 Units.

This course assumes no background in optimization. The focus will be on various classical and modern algorithms, with a view towards applications in finance, machine learning, and statistics. In the first half of the course we will go over classical algorithms: univariate optimization and root finding (Newton, secant, regula falsi, etc), unconstrained optimization (steepest descent, Newton, quasi-Newton, Gauss-Newton, Barzilai-Borwein, etc), constrained optimization (penalty, barrier, augmented Lagrangian, active set, etc). In the second half of the course we will cover algorithms that have become popular over the last decade: proximal algorithms, stochastic gradient descent and variants, algorithms that involve moments or momentum or mirror, etc. Applications to machine learning and statistics will include ridge/lasso/logistic regression, support vector machines with hinge/sigmoid loss, optimal experimental designs, maximum entropy, maximum likelihood, Gaussian covariance estimation, feedforward neural networks, etc. Applications in finance will include Markowitz classical portfolio optimization, portfolio optimization with diversification or loss risk constraints, bounding portfolio risks with incomplete covariance information, log optimal investment strategy, etc.
Instructor(s): Lek-Heng Lim Terms Offered: Autumn
Equivalent Course(s): FINM 34800, CAAM 31001

STAT 31015. Mathematical Computation IIA: Convex Optimization. 100 Units.
The course will cover techniques in unconstrained and constrained convex optimization and a practical introduction to convex duality. The course will focus on (1) formulating and understanding convex optimization problems and studying their properties; (2) understanding and using the dual; and (3) presenting and understanding optimization approaches, including interior point methods and first order methods for non-smooth problems. Examples will be mostly from data fitting, statistics and machine learning.
Instructor(s): Zhiyuan Li Terms Offered: Winter
Prerequisite(s): STAT 30900 or STAT 31430 or consent of instructor.
Note(s): In addition to the required prerequisites, background in analysis in R^n (at the level of MATH 20400) is recommended.
Equivalent Course(s): CAAM 31015, BUSN 36903, CMSC 35470, TTIC 31070

STAT 31020. Mathematical Computation IIB: Nonlinear Optimization. 100 Units.
This course covers the fundamentals of continuous optimization with an emphasis on algorithmic and computational issues. The course starts with the study of optimality conditions and techniques for unconstrained optimization, covering line search and trust region approaches, and addressing both factorization-based and iterative methods for solving the subproblems. The Karush-Kuhn-Tucker conditions for general constrained and nonconvex optimization are then discussed and used to define algorithms for constrained optimization including augmented Lagrangian, interior-point and (if time permits) sequential quadratic programming. Iterative methods for large sparse problems, with an emphasis on projected gradient methods, will be presented. Several substantial programming projects (using MATLAB and aiming at both data-intensive and physical sciences applications) are completed during the course.
Terms Offered: Winter
Prerequisite(s): STAT 30900 or STAT 31430 or consent of instructor.
Equivalent Course(s): CAAM 31020

STAT 31050. Applied Approximation Theory. 100 Units.
This course covers a range of introductory topics in applied approximation theory, the study of how and when functions can be approximated by linear combinations of other functions. The course will start with classical topics including polynomial and Fourier approximation and convergence, as well as more general theory on bases and approximability. We will also look at algorithms and applications in function compression, interpolation, quadrature, denoising, compressive sensing, finite-element methods, spectral methods, and iterative algorithms.
Terms Offered: Spring
Prerequisite(s): A strong background in real analysis. STAT 31210, or graduate student in Statistics or CCAM/MCAM, or consent of instructor.
Equivalent Course(s): CAAM 31050

STAT 31080. Numerical Analysis for Statistics and Applied Mathematics. 100 Units.
This is a beginning graduate course on selected numerical methods used in modern statistics and applied mathematics. Topics include fundamentals of ODEs and PDEs, quadratures, and Monte Carlo methods. Methods of analysis are introduced including error measures and different notions of numerical convergence. Newton's method, convex optimization and elements of nonconvex optimization are covered, together with implementations in selected selected software packages.
Terms Offered: To be determined
Prerequisite(s): STAT 24300 or background in linear algebra.

STAT 31100. Mathematical Computation III: Numerical Methods for PDE's. 100 Units.
The first part of this course introduces basic properties of PDE's; finite difference discretizations; and stability, consistency, convergence, and Lax's equivalence theorem. We also cover examples of finite difference schemes; simple stability analysis; convergence analysis and order of accuracy; consistency analysis and errors (i.e., dissipative and dispersive errors); and unconditional stability and implicit schemes. The second part of this course includes solution of stiff systems in 1, 2, and 3D; direct vs. iterative methods (i.e., banded and sparse LU factorizations); and Jacobi, Gauss-Seidel, multigrid, conjugate gradient, and GMRES iterations.
Terms Offered: Spring
Prerequisite(s): Some prior exposure to differential equations and linear algebra
Equivalent Course(s): CAAM 31100, MATH 38309, CMSC 37812

STAT 31110. Integral Equation Methods for PDEs. 100 Units.
Many important PDE problems can be converted into an equivalent integral equation. These integral equation formulations have a number of computationally useful properties. In particular, they make many unbounded scattering problems tractable, enable the construction of efficient solvers for domains with complex boundaries, and lead to well-conditioned linear systems. In this course, we will demonstrate how to derive integral equation formulations for a variety of standard PDE problems. We will also show how Fredholm theory can be used to prove the existence and uniqueness of solutions to these integral equations and discuss the hallmarks of a well-conditioned formulation. Examples will include the Laplace and Helmholtz equations on domains with compact boundaries, the variable coefficient Helmholtz equation, vector-valued scattering problems, and scattering problems involving unbounded interfaces.
Instructor(s): T. Goodwill Terms Offered: Winter

Equivalent Course(s): CAAM 31110

STAT 31120. Numerical Methods for Stochastic Differential Equations. 100 Units.
The numerical analysis of SDE differs significantly from that of ODE due to the peculiarities of stochastic calculus. This course starts with a brief review of stochastic calculus and stochastic differential equations, then emphasizing the numerical methods needed to solve such equations. The stochastic Taylor expansion provides the basis for the discrete-time numerical methods for differential equations. The course presents many results on high-order methods for strong sample path approximations and for weak functional approximations. To help with developing an intuitive understanding of the underlying mathematics and hand-on numerical skills, examples and exercises on PC are included.
Terms Offered: Spring
Prerequisite(s): Knowledge of ODE and SDE is essential. STAT 39000 or STAT 39010 or STAT 38510 are strongly recommended.
Equivalent Course(s): CAAM 31120

STAT 31140. Computational Imaging: Theory and Methods. 100 Units.
Computational imaging refers to the process of forming images from data where computation plays an integral role. This course will cover basic principles of computational imaging, including image denoising, regularization techniques, linear inverse problems and optimization-based solvers, and data acquisition models associated with tomography and interferometry. Specific topics may include patch-based denoising, sparse coding, total variation, dictionary learning, computational photography, compressive imaging, inpainting, and deep learning for image reconstruction.
Instructor(s): R. Willett Terms Offered: To be determined
Equivalent Course(s): CMSC 31140, CAAM 31140

STAT 31150. Inverse Problems and Data Assimilation. 100 Units.
This class provides an introduction to Bayesian Inverse Problems and Data Assimilation, emphasizing the theoretical and algorithmic inter-relations between both subjects. We will study Gaussian approximations and optimization and sampling algorithms, including a variety of Kalman-based and particle filters as well as Markov chain Monte Carlo schemes designed for high-dimensional inverse problems.
Instructor(s): D. Sanz-Alonso Terms Offered: Autumn
Prerequisite(s): Familiarity with calculus, linear algebra, and probability/statistics at the level of STAT 24400 or STAT 24410. Some knowledge of ODEs may also be helpful.
Equivalent Course(s): CAAM 31150

STAT 31151. Inverse Problems and Data Assimilation: A Machine Learning Approach. 100 Units.
This course demonstrates the potential for ideas in machine learning to impact on the fields of inverse problems and data assimilation. The course is primarily aimed at researchers in inverse problems and data assimilation interested in a succinct and mathematical presentation of various topics in machine learning as it pertains to their fields. Grading will be based on a computational project and on oral presentations of research papers.
Instructor(s): D. Sanz-Alonso Terms Offered: Autumn
Prerequisite(s): STAT 31150 or instructor consent
Equivalent Course(s): CAAM 31151

STAT 31190. Fast Algorithms. 100 Units.
This course will introduce students to several classes of computational methods broadly referred to as "fast analysis-based algorithms" which exploit information about structure and symmetry to obtain more favorable computational complexity. Examples which will be discussed are butterfly algorithms, fast multipole methods, fast direct solvers, and hierarchical matrix compression. Though many of these algorithms first arose in physical applications such as simulating the motion of stars or the propagation of light and sound, they have subsequently found many fruitful applications in signal processing and data science.
Terms Offered: Spring
Prerequisite(s): Familiarity with PDEs, analysis, and programming.
Equivalent Course(s): CAAM 31190

STAT 31200. Introduction to Stochastic Processes I. 100 Units.
This course will introduce some of the major classes of stochastic processes: Poisson processes, renewal processes, Markov chains, continuous time Markov processes, random walks, martingales, and Brownian motion. A substantial part of the course will be devoted to the study of important examples. Students will be expected to have proficiency in elementary probability theory, basic real analysis (especially sequences and series), and matrix algebra. Some familiarity with the theory of Lebesgue measure and integration would be helpful.
Instructor(s): Staff Terms Offered: To be determined
Prerequisite(s): STAT 25100 and MATH 20500; STAT 30400 or consent of instructor
Note(s): Students with credit for MATH 235 should not enroll in STAT 312.

STAT 31210. Applied Functional Analysis. 100 Units.
This course will cover classical topics of applied functional analysis: description of functional spaces such as Banach spaces and Hilbert spaces; properties of linear operators acting on such spaces, compactness and spectral decomposition of compact operators; and applications to ordinary and partial differential equations.
Terms Offered: To be determined

Equivalent Course(s): CAAM 31210

STAT 31220. Partial Differential Equations. 100 Units.
This is an introduction to the theory of partial differential equations covering representation formulas and regularity theory for elliptic, parabolic, and hyperbolic equations; the method of characteristics; variational formulations for second-order linear elliptic equations; and the calculus of variations.
Terms Offered: Winter
Equivalent Course(s): CAAM 31220

STAT 31230. Inverse Problems in Imaging. 100 Units.
This course focuses on the mathematical description of many inverse problems that appear in geophysical and medical imaging: X-ray tomography, ultrasound tomography and seismic imaging, optical and electrical tomography, as well as more recent imaging modalities such as elastography and photo-acoustic tomography. Seen as reconstructions of constitutive parameters in differential equations from redundant boundary measurements, these continuous models tell us which parameters may or may not be reconstructed, and with which stability with respect to measurement errors. Time-permitting, we will also consider general methodologies to perform such reconstructions (regularization, optimization, Bayesian framework). Some knowledge of PDE and Fourier transforms is recommended.
Terms Offered: Spring
Prerequisite(s): STAT 31220
Equivalent Course(s): CAAM 31230

STAT 31240. Variational Methods in Image Processing. 100 Units.
This course discusses mathematical models arising in image processing. Topics covered will include an overview of tools from the calculus of variations and partial differential equations, applications to the design of numerical methods for image denoising, deblurring, and segmentation, and the study of convergence properties of the associated models. Students will gain an exposure to the theoretical basis for these methods as well as their practical application in numerical computations.
Terms Offered: Spring
Equivalent Course(s): CAAM 31240

STAT 31250. Mathematical Introduction to Topological Insulators. 100 Units.
The field of topological (acoustic, electromagnetic, electronic, mechanical) insulators analyzes asymmetric transport phenomena observed along interfaces that separate insulating bulks. It finds applications in many areas of physical and materials sciences. The topological nature of the asymmetric transport ensures that it persists in the presence of perturbations of the underlying model which forms its main practical appeal. This graduate level course will present several mathematical and physically motivated tools to model and quantify asymmetric transport such as: current physical observables, elliptic (pseudo-)differential operators, spectral theory of self-adjoint operators, index theory and classification, trace-class operators, computation of bulk invariants by Chern and winding numbers, computation of interface invariants by index theory and spectral flows, bulk-edge correspondence relating bulk and interface invariants, scattering theory, and computational methods to estimate transport numerically. We will in particular focus on magnetic Schroedinger, systems of Dirac equations, and linearized fluid wave models with applications to the Integer Quantum Hall Effect, the Quantum Anomalous Hall effect, topological equatorial waves, and possibly Floquet topological insulators and bilayer graphene systems.
Terms Offered: Autumn
Note(s): While familiarity with partial differential equations and quantum mechanics is a plus, we plan to have self-contained lectures.
Equivalent Course(s): CAAM 31250

STAT 31260. Homogenization of Partial Differential Equations. 100 Units.
This course introduces common methods for establishing the macroscopic behavior of heterogeneous differential equations. It begins with a brief review of some classical results in functional analysis (weak/weak-* convergence and Sobolev spaces), followed by a discussion of several toolboxes: formal asymptotic expansion, compensated compactness, two-scale convergence, and Gamma-convergence. Along the way, the course presents surprising phenomena that have appeared in homogenization, such as strange terms, negative Poisson ratios, and nonlocal terms. If time permits, large-scale regularity by the compactness method will also be discussed.
Terms Offered: Winter
Prerequisite(s): STAT 31210 or STAT 31220 or MATH 27200 or MATH 27500 or permission of instructor.
Equivalent Course(s): CAAM 31260

STAT 31310. Foundations of Computational Dynamics. 100 Units.
This course provides an introduction to dynamical systems and ergodic theory with a view toward developing and understanding computational methods for studying and engineering complex dynamics. Some topics include hyperbolic dynamics, Oseledets theory, operator learning, and stochastic differential equations.
Terms Offered: Autumn
Prerequisite(s): Graduate student in Statistics, Computational and Applied Mathematics, or Computer Science, or consent of the instructor.
Equivalent Course(s): CAAM 31310

STAT 31390. Numerical Methods for Quantum Many-Body Physics. 100 Units.
Quantum many-body physics is at the heart of condensed matter physics, quantum chemistry, and quantum information science. This course provides a comprehensive introduction to numerical methods used in quantum many-body physics. The focus is on both conceptual understanding and practical implementation, with applications to strongly correlated electrons, quantum materials, and open quantum systems. Topics covered (tentatively) include: wave function methods, quantum Monte Carlo methods, tensor network methods and methods for simulating open quantum systems (quantum master equations, path integral approaches, diagrammatic quantum Monte Carlo). The course primarily focuses on the computational aspects of quantum many-body theory and does not require advanced knowledge of quantum physics. However, familiarity with undergraduate-level quantum mechanics (such as MATH18600) is recommended.
Equivalent Course(s): CAAM 31390

STAT 31405. Dynamical Systems with Applications. 100 Units.
This course is concerned with the analysis of nonlinear dynamical systems arising in the context of mathematical modeling. The focus is on qualitative analysis of solutions as trajectories in phase space, including the role of invariant manifolds as organizers of behavior. Local and global bifurcations, which occur as system parameters change, will be highlighted, along with other dimension reduction methods that arise when there is a natural time-scale separation. Concepts of bi-stability, spontaneous oscillations, and chaotic dynamics will be explored through investigation of conceptual mathematical models arising in the physical and biological sciences.
Instructor(s): Mary Silber Terms Offered: TBD
Prerequisite(s): MATH 27300 or (Multivariable calculus (MATH 18400 or 19520 or 20000 or 20400 or 20410 or PHYS 22100 or equivalent), AND linear algebra, including eigenvalues & eigenvectors (MATH 18600 or 19620 or 20250 or 20700 or STAT 24300)). Previous knowledge of elementary differential equations is helpful but not required.
Equivalent Course(s): CAAM 28200, CAAM 31405, STAT 28200

STAT 31410. Applied Dynamical Systems. 100 Units.
This course is an introduction to dynamical systems for analysis of nonlinear ordinary differential equations. The focus is on methods of bifurcation theory, canonical examples of forced nonlinear oscillators, fast-slow systems, and chaos. Examples will be drawn from mathematical modeling of physical and biological systems. While geometric perspectives will be emphasized, assignments will also introduce asymptotic methods for analysis and use numerical simulation as an exploratory tool. This course assumes students have a background in ordinary differential equations and linear algebra at the undergraduate level and an interest in mathematical modeling for applications.
Instructor(s): M. Silber Terms Offered: Spring
Prerequisite(s): ODEs and/or dynamical systems at an undergraduate level or consent of instructor.
Equivalent Course(s): CAAM 31410

STAT 31430. Applied Linear Algebra. 100 Units.
This course will provide a review and development of topics in linear algebra aimed toward preparing students for further graduate coursework in Computational and Applied Mathematics. Topics will include discussion of matrix factorizations (including diagonalization, the spectral theorem for normal matrices, the singular value decomposition, and the Schur and polar decompositions), and an overview of classical direct and iterative approaches to numerical methods for problems formulated in the language of linear algebra (including the conjugate gradient method). Additional topics will be included depending on student interests.
Instructor(s): E. Baer Terms Offered: Autumn
Prerequisite(s): STAT 24300 or MATH 20250 or Graduate Student in Physical Sciences Division
Equivalent Course(s): CAAM 31430

STAT 31440. Applied Analysis. 100 Units.
This course provides an overview of fundamentals of mathematical analysis with an eye towards developing the toolkit of graduate students in applied mathematics. Topics covered include metric spaces and basic topological notions, aspects of mathematical analysis in several variables, and an introduction to measure and integration.
Instructor(s): E. Baer Terms Offered: Autumn
Equivalent Course(s): CAAM 31440

STAT 31450. Applied Partial Differential Equations. 100 Units.
Partial differential equations (PDEs) are used to model applications in a wide variety of fields: fluid dynamics, optics, atomic and plasma physics, elasticity, chemical reactions, climate modeling, stock markets, etc. The study of their mathematical structure and solution methods remains at the forefront of applied mathematics. The course concentrates on deriving an important set of examples of PDEs from simple physical models, which are often closely related to those describing more complex physical systems. The course will also cover analytical methods and tools for solving these PDEs; such as separation of variables, Fourier series and transforms, Sturm-Liouville theory, and Green's functions. The course is suitable for graduate students and advanced undergraduates in science, engineering, and applied mathematics.
Terms Offered: Spring
Prerequisite(s): Instructor consent.
Equivalent Course(s): CAAM 31450

STAT 31460. Applied Fourier Analysis. 100 Units.
Decompositions of functions into frequency components via the Fourier transform, and related sparse representations, are fundamental tools in applied mathematics. These ideas have been important in applications to signal processing, imaging, and the quantitative and qualitative analysis of a broad range of mathematical models of data (including modern approaches to machine learning) and physical systems. Topics to be covered in this course include an overview of classical ideas related to Fourier series and the Fourier transform, wavelet representations of functions and the framework of multiresolution analysis, and applications throughout computational and applied mathematics.
Terms Offered: Winter
Prerequisite(s): Graduate student in the Physical Sciences Division or consent of instructor.
Equivalent Course(s): CAAM 31460

STAT 31470. Applied Complex Analysis. 100 Units.
Complex analysis is a beautiful and deep theory for the calculus of functions of complex variables. It also presents a very useful set of tools for finding exact expressions, asymptotic expansions, approximations and even numerical schemes that are useful throughout applied mathematics and engineering. In this class we will cover the basic complex analytic tools and theorems needed to explore these applications, with the goal of using what we learn to understand and solve problems involving Fourier or Laplace transforms. Depending on time, the topics in the class will include: analytic functions, series, complex integration, Cauchy's formula, the maximum-modulus theorem, residue theory, and the argument principle.
Equivalent Course(s): CAAM 31470

STAT 31511. Monte Carlo Simulation. 100 Units.
This class primarily concerns the design and analysis of Monte Carlo sampling techniques for the estimation of averages with respect to high dimensional probability distributions. Standard simulation tools such as importance sampling, Metropolis-Hastings, Langevin dynamics, and hybrid Monte Carlo will be introduced along with basic theoretical concepts regarding their convergence to equilibrium. The class will explore applications of these methods in Bayesian statistics and machine learning as well as to other simulation problems arising in the physical and biological sciences. Particular attention will be paid to the major complicating issues like conditioning (with analogies to optimization) and rare events and methods to address them.
Terms Offered: To be determined
Prerequisite(s): Multivariate calculus and linear algebra; elementary knowledge of ordinary differential equations.
Equivalent Course(s): CAAM 31511

STAT 31512. Analysis of Sampling Algorithms. 100 Units.
Graduate topics course on mathematical analysis of algorithms for sampling from high-dimensional probability distributions, with a focus on analysis of Markov-Chain Monte Carlo via functional inequalities. Possible/likely topics include recent developments such as Eldan's stochastic localization, techniques from high-dimensional expanders, spectral/entropic independence, log-concave polynomials and matroid basis exchange walk, connections to statistical physics and statistical estimation, recent progress on the KLS conjecture, etc., with a view towards current research questions in the area.
Terms Offered: Spring
Prerequisite(s): Graduate students in Statistics, Computational and Applied Math, Computer Science, or Math, or consent of instructor.

STAT 31521. Applied Stochastic Processes. 100 Units.
This course provides an introduction to continuous-time stochastic processes. We will focus on analytical and numerical techniques that are useful across a wide range of stochastic models in physics, chemistry, biology, financial mathematics, statistics, machine learning, and other fields. Topics covered will include diffusion processes, stochastic differential equations and their numerical solution, Ito and Feynman-Kac formulas, Girsanov and Lamperti transformations, forward and backward Kolmogorov equations, Karhunen-Loeve expansions, and the Langevin equation.
Terms Offered: Winter. To be determined
Prerequisite(s): Multivariate calculus and linear algebra
Equivalent Course(s): CAAM 31521

STAT 31531. Asymptotic Analysis. 100 Units.
This course in an introduction to standard methods of asymptotic analysis frequently encountered in applied mathematics. Topics will include: perturbation results for polynomial roots and eigenvalues, Laplace's method, stationary phase, steepest descent, WKB, and boundary layers. The course material will be a balance of rigorous analysis of methods and formal derivations. Tentatively, the textbook will be "Applied Asymptotic Analysis" by Peter Miller.
Instructor(s): J. Hoskins Terms Offered: Winter
Equivalent Course(s): CAAM 31531

STAT 31550. Uncertainty Quantification. 100 Units.
This course will cover mathematical, statistical, and algorithmic questions that arise at the interface of complex modeling and data processing. Emphasis will be given to characterizing and quantifying the uncertainties

inherent in the use of models and to exploring principled ways to reduce said uncertainty by the use of data. Specific topics include Bayesian inverse problems and data assimilation.
Terms Offered: To be determined
Prerequisite(s): STAT 30200 or consent of instructor

STAT 31610. Mathematical Aspects of Electronic Structure of Materials. 100 Units.
This course considers mathematical and numerical methods to approach electronic structure of materials through several hot-topic examples including topological insulators and incommensurate 2D materials in addition to classical systems such as periodic crystals. The course will begin with a discussion of the basics of quantum mechanics for those not yet familiar before moving to models designed for varying system sizes, from DFT to tight-binding. The theory and numerical tools for studying observables such as Chern numbers, conductivity, and density of states will be considered.
Equivalent Course(s): CAAM 31610

STAT 31700. Introduction to Probability Models. 100 Units.
This course introduces stochastic processes as models for a variety of phenomena in the physical and biological sciences. Following a brief review of basic concepts in probability, we introduce stochastic processes that are popular in applications in sciences (e.g., discrete time Markov chain, the Poisson process, continuous time Markov process, renewal process and Brownian motion).
Instructor(s): Staff Terms Offered: Winter
Prerequisite(s): STAT 24400 or STAT 24410 or STAT 25100 or STAT 25150
Equivalent Course(s): STAT 25300

STAT 31900. Introduction to Causal Inference. 100 Units.
This course is designed for graduate students and advanced undergraduate students from the social sciences, education, public health science, public policy, social service administration, and statistics who are involved in quantitative research and are interested in studying causality. The goal of this course is to equip students with basic knowledge of and analytic skills in causal inference. Topics for the course will include the potential outcomes framework for causal inference; experimental and observational studies; identification assumptions for causal parameters; potential pitfalls of using ANCOVA to estimate a causal effect; propensity score based methods including matching, stratification, inverse-probability-of-treatment-weighting (IPTW), marginal mean weighting through stratification (MMWS), and doubly robust estimation; the instrumental variable (IV) method; regression discontinuity design (RDD) including sharp RDD and fuzzy RDD; difference in difference (DID) and generalized DID methods for cross-section and panel data, and fixed effects model. Intermediate Statistics or equivalent such as STAT 224/PBHS 324, PP 31301, BUS 41100, or SOC 30005 is a prerequisite. This course is a prerequisite for "Advanced Topics in Causal Inference" and "Mediation, moderation, and spillover effects."
Instructor(s): G. Hong Terms Offered: Winter
Prerequisite(s): Intermediate Statistics or equivalent such as STAT 224, PBHS 324, PBPL 31301, BUS 41100, or SOCI 30005
Note(s): CHDV Distribution: M; M
Equivalent Course(s): SOCI 30315, PLSC 30102, MACS 51000, PBHS 43201, CHDV 30102, CHDV 20102, MACS 21000

STAT 32400. Probability and Statistics. 100 Units.
This is a PhD course that introduces fundamental statistical concepts for academic research in business and economics. It covers basic topics in probability and statistics, including limit theorems, principles of estimation and inference, linear and logistic regression, and causal inference. Much emphasis is put on large-sample (asymptotic) theory. Please visit Booth Course Search for the most updated information: https://intranet.chicagobooth.edu/pub/coursesearch/coursesearch
Terms Offered: Autumn
Equivalent Course(s): BUSN 41901

STAT 32900. Applied Multivariate Analysis. 100 Units.
The course will introduce the basic theory and applications for analyzing multidimensional data. Topics include multivariate distributions, Gaussian models, multivariate statistical inferences and applications, classifications, cluster analysis, and dimension reduction methods. Course content is subject to change in order to keep the contents up-to-date with new development in multivariate statistical techniques. The course is offered in alternate years by the Statistics Department (S15, S17, ...) and the Booth Business School (S16, S18, ...). When the course is offered by the Booth school, please visit the Booth portal and search via the course search tool: http://boothportal.chicagobooth.edu/portal/server.pt/community/course_search for the most up to date information.
Equivalent Course(s): BUSN 41912

STAT 32950. Multivariate Statistical Analysis: Applications and Techniques. 100 Units.
This course focuses on applications and techniques for analysis of multivariate and high dimensional data. Beginning subjects cover common multivariate techniques and dimension reduction, including principal component analysis, factor model, canonical correlation, multi-dimensional scaling, discriminant analysis, clustering, and correspondence analysis (if time permits). Further topics on statistical learning for high dimensional data and complex structures include penalized regression models (LASSO, ridge, elastic net), sparse PCA, independent component analysis, Gaussian mixture model, Expectation-Maximization methods, and

random forest. Theoretical derivations will be presented with emphasis on motivations, applications, and hands-on data analysis.
Instructor(s): M. Wang Terms Offered: Spring
Prerequisite(s): (STAT 24300 or MATH 20250) and (STAT 24500 or STAT 24510). Graduate students in Statistics or Financial Mathematics can enroll without prerequisites.
Note(s): Linear algebra at the level of STAT 24300. Knowledge of probability and statistical estimation techniques (e.g. maximum likelihood and linear regression) at the level of STAT 24400-24500.
Equivalent Course(s): STAT 24620, FINM 34700

STAT 33100. Sample Surveys. 100 Units.
This course covers random sampling methods; stratification, cluster sampling, and ratio estimation; and methods for dealing with nonresponse and partial response.
Instructor(s): K. Wolter Terms Offered: Autumn
Prerequisite(s): Consent of instructor

STAT 33400. Bayesian Statistical Inference and Machine Learning. 50 Units.
The course will develop a general approach to building models of economic and financial processes, with a focus on statistical learning techniques that scale to large data sets. We begin by introducing the key elements of a parametric statistical model: the likelihood, prior, and posterior, and show how to use them to make predictions. We shall also discuss conjugate priors and exponential families, and their applications to big data. We treat linear and generalized-linear models in some detail, including variable selection techniques, penalized regression methods such as the lasso and elastic net, and a fully Bayesian treatment of the linear model. As applications of these techniques, we shall discuss Ross' Arbitrage Pricing Theory (APT), and its applications to risk management and portfolio optimization. As extensions, we will discuss multilevel and hierarchical models, and conditional inference trees and forests. We also treat model-selection methodologies including cross-validation, AIC, and BIC and show how to apply them to all of the financial data sets presented as examples in class. Then we move on to dynamic models for time series including Markov state-space models, as special cases. As we introduce models, we will also introduce solution techniques including the Kalman filter and particle filter, the Viterbi algorithm, Metropolis-Hastings and Gibbs Sampling, and the EM algorithm.
Instructor(s): Gordon Ritter
Equivalent Course(s): FINM 33210

STAT 33500. Time-series Analysis for Forecasting and Model Building. 100 Units.
Forecasting plays an important role in business planning and decisionmaking. This Ph.D.-level course discusses time series models that have been widely used in business and economic data analysis and forecasting. Both theory and methods of the models are discussed. Real examples are used throughout the course to illustrate applications. The topics covered include: (1) stationary and unit-root non-stationary processes; (2) linear dynamic models, including Autoregressive Moving Average models; (3) model building and data analysis; (4) prediction and forecasting evaluation; (5) asymptotic theory for estimation including unit-root theory; (6) models for time varying volatility; (7) models for time varying correlation including Dynamic Conditional Correlation and time varying factor models.; (9) state-space models and Kalman filter; and (10) models for high frequency data. Course description is subject to change. Please visit the Booth portal and search via the course search tool for the most up to date information: http://boothportal.chicagobooth.edu/portal/server.pt/community /course_search/
Prerequisite(s): BUSF 41901/STAT 32400 or instructor consent.
Equivalent Course(s): BUSN 41910

STAT 33600. Time Dependent Data. 100 Units.
This course considers the modeling and analysis of data that are ordered in time. The main focus is on quantitative observations taken at evenly spaced intervals and includes both time-domain and spectral approaches.
Instructor(s): W. Wu Terms Offered: Autumn
Prerequisite(s): STAT 24500 w/B- or better or STAT 24510 w/C+ or better is required; alternatively STAT 22400 w/B- or better and exposure to multivariate calculus (MATH 16300 or MATH 16310 or MATH 18400 or MATH 19520 or MATH 20000 or MATH 20500 or MATH 20510 or MATH 20800). Graduate students in Statistics or Financial Mathematics can enroll without prerequisites. Some previous exposure to Fourier series is helpful but not required.
Equivalent Course(s): STAT 26100

STAT 33611. Gaussian Processes with Applications to Modern Statistical Problems. 100 Units.
Gaussian processes play a fundamental role in modern statistics, machine learning, and probability theory. In the first part of the course, we will cover several essential techniques related to the Gaussian distribution, including Gaussian concentration, Gaussian comparison theorems, and Poincare type inequalities. We will then detail the applications of these theoretical tools in a series of modern statistical and mathematical problems, including sharp spectral bounds of Gaussian matrices, exact characterization of the least squares estimator, and the free energy of the Sherrington-Kirkpatrick model in statistical physics.
Instructor(s): Yandi Shen Terms Offered: Winter
Prerequisite(s): Graduate student in Statistics, Computer Science, or Computational and Applied Mathematics, or consent of instructor.

STAT 33700. Multivariate Time Series Analysis. 100 Units.
This course investigates the dynamic relationships between variables. It starts with linear relationships between two variables, including distributed-lag models and detection of unidirectional dependence (Granger causality). Nonlinear and time-varying relationships are also discussed. Dynamic models discussed include vector autoregressive models, vector autoregressive moving-average models, multivariate regression models with time series errors, co-integration and error-correction models, state-space models, dynamic factor models, and multivariate volatility models such as BEKK, Dynamic conditional correlation, and copula-based models. The course also addresses impulse response function, structural specification, co-integration tests, least squares estimates, maximum likelihood estimates, principal component analysis, asymptotic principal component analysis, principal volatility components, recursive estimation, and Markov Chain Monte Carlo estimation. Empirical data analysis is an integral part of the course. Students are expected to analyze many real data sets. The main software used in the course is the MTS package in R, but students may use their own software if preferred.
Equivalent Course(s): BUSN 41914

STAT 33910. Financial Statistics: Time Series, Forecasting, Mean Reversion, and High Frequency Data. 100 Units.
This course is an introduction to the econometric analysis of high-frequency financial data. This is where the stochastic models of quantitative finance meet the reality of how the process really evolves. The course is focused on the statistical theory of how to connect the two, but there will also be some data analysis. With some additional statistical background (which can be acquired after the course), the participants will be able to read articles in the area. The statistical theory is longitudinal, and it thus complements cross-sectional calibration methods (implied volatility, etc.). The course also discusses volatility clustering and market microstructure.
Terms Offered: Winter
Prerequisite(s): Some statistics/econometrics background as in STAT 24400–24500, or FINM 33150 and FINM 33400, or equivalent, or consent of instructor.
Equivalent Course(s): FINM 33170

STAT 34300. Applied Linear Stat Methods. 100 Units.
This course introduces the theory, methods, and applications of fitting and interpreting multiple regression models. Topics include the examination of residuals, the transformation of data, strategies and criteria for the selection of a regression equation, nonlinear models, biases due to excluded variables and measurement error, and the use and interpretation of computer package regression programs. The theoretical basis of the methods, the relation to linear algebra, and the effects of violations of assumptions are studied. Techniques discussed are illustrated by examples involving both physical and social sciences data.
Terms Offered: Autumn
Prerequisite(s): Graduate student in Statistics or Financial Mathematics or instructor consent.
Note(s): Students who need it should take Linear Algebra (STAT 24300 or equivalent) concurrently.

STAT 34700. Generalized Linear Models. 100 Units.
This applied statistics course is a successor of STAT 34300 and covers the foundations of generalized linear models (GLM). We will discuss the general linear modeling idea for exponential family data and introduce specifically models for binary, multinomial, count and categorical data, and the challenges in model fitting, and inference. We will also discuss approaches that supplement the classical GLM, including quasi-likelihood for over-dispersed data, robust estimation, and penalized GLM. The course also covers related topics including mixed effect models for clustered data, the Bayesian approach of GLM, and survival analysis. This course will make a balance between practical real data analysis with examples and a deeper understanding of the models with mathematical derivations.
Instructor(s): Staff Terms Offered: Winter
Prerequisite(s): STAT 343 (or a similar-level linear regression course) or consent of instructor; comfortable with programming in R.

STAT 34800. Modern Methods in Applied Statistics. 100 Units.
This course covers latent variable models and graphical models; definitions and conditional independence properties; Markov chains, HMMs, mixture models, PCA, factor analysis, and hierarchical Bayes models; methods for estimation and probability computations (EM, variational EM, MCMC, particle filtering, and Kalman Filter); undirected graphs, Markov Random Fields, and decomposable graphs; message passing algorithms; sparse regression, Lasso, and Bayesian regression; and classification generative vs. discriminative. Applications will typically involve high-dimensional data sets, and algorithmic coding will be emphasized.
Terms Offered: Spring

STAT 34900. Data Analysis Project. 100 Units.
The first part of this class will focus on general principles of data analysis and how to report the results of an analysis, including taking account of the context of the data, making informative and clear visual displays, developing relevant statistical models and describing them clearly, and carrying out diagnostic procedures to assess the appropriateness of adopted models. The second half of the class will focus on data analysis projects. Students working on a data analysis project in another context (e.g., for consulting) may, with proper permission, use that project for this course as well. Open only to PhD students in Statistics. Instructor consent required.
Terms Offered: To be determined

Prerequisite(s): In order to register for this course, you must have taken STAT 34700 and have permission from the instructor.

STAT 35201. Introduction to Clinical Trials. 100 Units.
This course will review major components of clinical trial conduct, including the formulation of clinical hypotheses and study endpoints, trial design, development of the research protocol, trial progress monitoring, analysis, and the summary and reporting of results. Other aspects of clinical trials to be discussed include ethical and regulatory issues in human subjects research, data quality control, meta-analytic overviews and consensus in treatment strategy resulting from clinical trials, and the broader impact of clinical trials on public health.
Instructor(s): M. Polley Terms Offered: Autumn
Prerequisite(s): PBHS 32100 or STAT 22000; Introductory Statistics or Consent of Instructor
Equivalent Course(s): PBHS 32901

STAT 35410. Genomic Evolution I. 100 Units.
Canalization, a unifying biological principle first enunciated by Conrad Waddington in 1942, is an idea that has had tremendous intellectual influence on developmental biology, evolutionary biology, and mathematics. In this course we will explore canalization in all three contexts through extensive reading and discussion of both the classic and modern primary literature. We intend this exploration to raise new research problems which can be evaluated for further understanding. We encourage participants to present new ideas in this area for comment and discussion.
Instructor(s): M. Long, J. Reinitz Terms Offered: Autumn
Equivalent Course(s): ECEV 35901, EVOL 35901

STAT 35420. Stochastic Processes in Gene Regulation. 100 Units.
This didactic course covers the fundamentals of stochastic chemical processes as they arise in the study of gene regulation. The central object of study is the Chemical Master Equation and its coarse-grainings at the Langevin/Fokker-Planck, linear noise, and deterministic levels. We will consider both mathematical and computational approaches in contexts where there are both single and multiple deterministic limits.
Instructor(s): J. Reinitz Terms Offered: To be determined
Prerequisite(s): Consent of instructor.
Equivalent Course(s): MGCB 35420, CAAM 35420, ECEV 35420

STAT 35450. Fundamentals of Computational Biology: Models and Inference. 100 Units.
Covers key principles in probability and statistics that are used to model and understand biological data. There will be a strong emphasis on stochastic processes and inference in complex hierarchical statistical models. Topics will vary but the typical content would include: Likelihood-based and Bayesian inference, Poisson processes, Markov models, Hidden Markov models, Gaussian Processes, Brownian motion, Birth-death processes, the Coalescent, Graphical models, Markov processes on trees and graphs, Markov Chain Monte Carlo.
Instructor(s): J. Novembre, M. Stephens Terms Offered: Winter
Prerequisite(s): STAT 244
Equivalent Course(s): HGEN 48600

STAT 35460. Fundamentals of Computational Biology: Algorithms and Applications. 100 Units.
This course will cover principles of data structure and algorithms, with emphasis on algorithms that have broad applications in computational biology. The specific topics may include dynamic programming, algorithms for graphs, numerical optimization, finite-difference, schemes, matrix operations/factor analysis, and data management (e.g. SQL, HDF5). We will also discuss some applications of these algorithms (as well as commonly used statistical techniques) in genomics and systems biology, including genome assembly, variant calling, transcriptome inference, and so on.
Instructor(s): Xin He, Mengjie Chen Terms Offered: Spring
Equivalent Course(s): HGEN 48800

STAT 35490. Introduction to Statistical Genetics. 100 Units.
As a result of technological advances over the past few decades, there is a tremendous wealth of genetic data currently being collected. These data have the potential to shed light on the genetic factors influencing traits and diseases, as well as on questions of ancestry and population history. The aim of this course is to develop a thorough understanding of probabilistic models and statistical theory and methods underlying analysis of genetic data, focusing on problems in complex trait mapping, with some coverage of population genetics. Although the case studies are all in the area of statistical genetics, the statistical inference topics, which will include likelihood-based inference, linear mixed models, and restricted maximum likelihood, among others, are widely applicable to other areas. No biological background is needed, but a strong foundation in linear algebra, as well as probability and statistics at the level of STAT 24400-STAT 24500 or higher is assumed.
Instructor(s): M. McPeek Terms Offered: TBD
Prerequisite(s): STAT 24500 or 24510 or 30200 or consent of instructor.
Equivalent Course(s): STAT 26300

STAT 35500. Statistical Genetics. 100 Units.
This is an advanced course in statistical genetics. We will take an in-depth look at statistical methods development in recent genetics literature, with the aim of achieving a deep understanding of the modeling approaches and assumptions, statistical principles, mathematical theorems, computational issues, and data

analytic approaches underlying the methods. The goal is for the student to be able to ultimately apply the principles learned to future statistical methods development for genetic data analysis. This is a discussion course and student presentations will be required. Topics depend on the interests of the participants and will be based on recent published literature. Topics may include, but are not limited to, statistical problems in genetic association mapping, population genetics, integration of different types of genetic data, and genetic models for complex traits. The course material changes every year, and the course may be repeated for credit.
Terms Offered: To be determined
Prerequisite(s): Either HGEN 47100 or both STAT 24400 (or STAT 24410) and 24500 (or 24510). Students without these prerequisites may enroll on a P/NP basis with consent of the instructor.

STAT 35510. Statistical Algorithms for Single-Cell Omics and Related Techniques. 100 Units.
Single-cell sequencing is a revolutionary technique that allows the analysis of the genetic information within individual cells, providing unprecedented insights into cellular heterogeneity and diversity. This course aims to offer a comprehensive overview of the cutting-edge quantitative methods employed in analyzing single-cell sequencing data. Designed for graduate students with a statistical/quantitative background, the course requires no prior knowledge of biology or experience in analyzing genetics data. We will start with a gentle introduction to basic biological concepts relevant to understanding the data, coupled with a concise overview of single-cell sequencing technologies such as single-cell RNA-seq, single-cell ATAC-seq, spatial transcriptomics, CITE-seq, Perturb-seq, and more. Then, we will discuss common types of computational analyses, such as visualization, denoising, clustering, trajectory analyses, data integration, transfer learning, and the alignment of multi-omics data. A special emphasis will be placed on exploring deep learning models that have been designed for various tasks analyzing single-cell sequencing data. We will also address statistical considerations that arise, including appropriate distributional assumptions on the data, distribution-free tests, "post-estimation" inference, and causal inference.
Instructor(s): J. Wang Terms Offered: Spring
Prerequisite(s): Graduate student in Statistics, Computational and Applied Mathematics, Computer Science, or Mathematics, or consent of instructor.

STAT 35700. Epidemiologic Methods. 100 Units.
This course provides students with an in-depth understanding of epidemiologic concepts and methods. It is the second course in the epidemiology series. The focus of this course will be in practical and theoretical considerations of observational research methods; statistical methods and applications in epidemiologic studies; in-depth evaluation of bias, confounding, and interaction; and communicating epidemiologic findings. Students will also learn how to perform data analysis using classic methods.
Instructor(s): D. Huo Terms Offered: Winter
Prerequisite(s): PBHS 30910 and PBHS 32400/STAT 22400 or PBHS 32410 (taken concurrently) or applied statistics courses through multivariate regression.
Equivalent Course(s): PBHS 31001

STAT 35800. Statistical Applications. 100 Units.
This course provides a transition between statistical theory and practice. The course will cover statistical applications in medicine, mental health, environmental science, analytical chemistry, and public policy. ,Lectures are oriented around specific examples from a variety of content areas. Opportunities for the class to work on interesting applied problems presented by U of C faculty will be provided. Although an overview ,of relevant statistical theory will be presented, emphasis is on the development of statistical solutions to interesting applied problems.
Instructor(s): R. Gibbons Terms Offered: Autumn
Prerequisite(s): PBHS 32400, PBHS 32410 or equivalent, and PBHS 32600/STAT 22600 or PBHS 32700/STAT 22700 or equivalent; or consent of instructor. Knowledge of STATA and/or R highly recommended.
Equivalent Course(s): PBHS 33500, CHDV 32702

STAT 35920. Applied Bayesian Modeling and Inference. 100 Units.
Course begins with basic probability and distribution theory, and covers a wide range of topics related to Bayesian modeling, computation, and inference. Significant amount of effort will be directed to teaching students on how to build and apply hierarchical models and perform posterior inference. The first half of the course will be focused on basic theory, modeling, and computation using Markov chain Monte Carlo methods, and the second half of the course will be about advanced models and applications. Computation and application will be emphasized so that students will be able to solve real-world problems with Bayesian techniques.
Instructor(s): Y. Ji Terms Offered: Spring
Prerequisite(s): STAT 24400 and STAT 24500 or master level training in statistics.
Equivalent Course(s): PBHS 43010

STAT 36510. Random Growth Model and the Kardar-Parisi-Zhang Equation. 100 Units.
In this course, we will show how a variety of physical systems and mathematical models, including randomly growing interfaces, queueing systems, stochastic PDEs, and traffic models, all demonstrate the same universal statistical behaviors in their long-time/large-scale limit. These systems are said to lie in the Kardar-Parisi-Zhang universality class. We will also study a central object in this universality class: the Kardar-Parisi-Zhang equation. We will also study a central object in this universality class: the Kardar-Parisi-Zhang equation.
Instructor(s): Yier Lin Terms Offered: Winter

Prerequisite(s): PhD student in Statistics, Computational and Applied Mathematics, Mathematics, or Toyota Technological Institute at Chicago, or MS student in Statistics or Computational and Applied Mathematics or consent on instructor.
Note(s): Graduate or advanced undergraduate probability theory and undergraduate linear algebra and combinatorics are recommended.

STAT 36600. Decision Theory. 100 Units.
This course covers statistical decision theory with examples drawn from modern high-dimensional and nonparametric estimation. Topics that will be covered include basic information theory, decision theory, asymptotic equivalence, Gaussian sequence model, sparse regression, model selection, aggregation, and large covariance matrix estimation. Lower bound techniques such as Bayes, Le Cam, and Fano's methods will be taught.
Terms Offered: To be determined

STAT 36700. History of Statistics. 100 Units.
This course covers topics in the history of statistics, from the eleventh century to the middle of the twentieth century. We focus on the period from 1650 to 1950, with an emphasis on the mathematical developments in the theory of probability and how they came to be used in the sciences. Our goals are both to quantify uncertainty in observational data and to develop a conceptual framework for scientific theories. This course includes broad views of the development of the subject and closer looks at specific people and investigations, including reanalyses of historical data.
Instructor(s): S. Stigler Terms Offered: TBD. Not offered in 2023-2024.
Prerequisite(s): Prior statistics course
Equivalent Course(s): CHSS 32900, HIPS 25600, STAT 26700

STAT 36900. Applied Longitudinal Data Analysis. 100 Units.
Longitudinal data consist of multiple measures over time on a sample of individuals. This type of data occurs extensively in both observational and experimental biomedical and public health studies, as well as in studies in sociology and applied economics. This course will provide an introduction to the principles and methods for the analysis of longitudinal data. Whereas some supporting statistical theory will be given, emphasis will be on data analysis and interpretation of models for longitudinal data. Problems will be motivated by applications in epidemiology, clinical medicine, health services research, and disease natural history studies.
Instructor(s): D. Hedeker Terms Offered: Winter
Prerequisite(s): PBHS 32400/STAT 22400 or PBHS 32410 or equivalent, AND PBHS 32600/STAT 22600 or PBHS 32700/STAT 22700 or equivalent; or consent of instructor.
Equivalent Course(s): CHDV 32501, PBHS 33300

STAT 37201. Learning, Decisions, and Limits. 100 Units.
This is a graduate course on theory of machine learning. While ML theory has multiple branches in general, this course is designed to cover basics of online learning, along with basics of reinforcement learning. It aims to establish the foundation for students who are interested in conducting research related to online decision making, learning, and optimization. The course will introduce formal formulations for fundamental problems/models in this space, describe basic algorithmic ideas for solving these models, rigorously discuss performances of these algorithms as well as these problems' fundamental limits (e.g., minmax/lower bounds). En route, we will develop necessary toolkits for algorithm development and lower bound proofs.
Instructor(s): F. Koehler, H. Xu Terms Offered: Winter
Prerequisite(s): Requires linear algebra (at the level of CMSC 25300 or its equivalent), algorithms (CMSC 27200 or its equivalent) and probability (STAT 25100 or its equivalent). If not sure, consult with the instructor.
Equivalent Course(s): DATA 37200

STAT 37400. Nonparametric Inference. 100 Units.
Nonparametric inference is about developing statistical methods and models that make weak assumptions. A typical nonparametric approach estimates a nonlinear function from an infinite dimensional space rather than a linear model from a finite dimensional space. This course gives an introduction to nonparametric inference, with a focus on density estimation, regression, confidence sets, orthogonal functions, random processes, and kernels. The course treats nonparametric methodology and its use, together with theory that explains the statistical properties of the methods.
Instructor(s): Staff Terms Offered: Winter
Prerequisite(s): STAT 24400 or STAT 24410 w/B- or better is required; alternatively STAT 22400 w/B+ or better and exposure to multivariate calculus (MATH 16300 or MATH 16310 or MATH 18400 or MATH 19520 or MATH 20000 or MATH 20500 or MATH 20510 or MATH 20800) and linear algebra (MATH 18600 or 19620 or 20250 or 20700 or STAT 24300 or equivalent). Master's students in Statistics can enroll without prerequisites.
Equivalent Course(s): DATA 37400, STAT 27400

STAT 37411. Topological Data Analysis. 100 Units.
Topological data analysis seeks to understand and exploit topology when exploring and learning from data. This course surveys core ideas and recent developments in the field and will prepare students to use topology in data analysis tasks. The core of the course will include computation with topological spaces, the mapper algorithm, and persistent homology, and cover theoretical results, algorithms, and a variety of applications.

Additional topics from algebraic topology, metric geometry, category theory, and quiver representation theory will be developed from applied and computational perspectives.
Terms Offered: Winter
Prerequisite(s): Linear algebra, prior programming experience, exposure to graph theory/algorithms.
Equivalent Course(s): CAAM 37411

STAT 37601. Machine Learning and Large-Scale Data Analysis. 100 Units.
This course is an introduction to machine learning and the analysis of large data sets using distributed computation and storage infrastructure. Basic machine learning methodology and relevant statistical theory will be presented in lectures. Homework exercises will give students hands-on experience with the methods on different types of data. Methods include algorithms for clustering, binary classification, and hierarchical Bayesian modeling. Data types include images, archives of scientific articles, online ad clickthrough logs, and public records of the City of Chicago. Programming will be based on Python and R, but previous exposure to these languages is not assumed.
Prerequisite(s): [CMSC 25300 or CMSC 35300 or STAT 27700 or TTIC 31020] and [STAT 24400 or STAT 24410 or STAT 24500 or STAT 24510]
Note(s): The prerequisites are under review and may change.
Equivalent Course(s): CMSC 25025

STAT 37710. Machine Learning. 100 Units.
This course provides hands-on experience with a range of contemporary machine learning algorithms, as well as an introduction to the theoretical aspects of the subject. Topics covered include: the PAC framework, Bayesian learning, graphical models, clustering, dimensionality reduction, kernel methods including SVMs, matrix completion, neural networks, and an introduction to statistical learning theory.
Terms Offered: To be determined
Prerequisite(s): Must be a PhD or MS student in Statistics, Computer Science, or Computational and Applied Mathematics, and has taken any one of: CMSC 35300/STAT 27700, STAT 31430, STAT 30900, STAT 24300, STAT 24500, or STAT 24510. Or consent of the instructor.
Equivalent Course(s): CAAM 37710, CMSC 35400

STAT 37711. Foundations of Machine Learning and AI - Part I. 100 Units.
This course is an introduction to machine learning targeted at students who want a deep understanding of the subject. Topics include modern approaches to supervised learning, unsupervised learning, and the use of machine learning in estimating real-world effects. In principle, no previous exposure to machine learning is required. However, students are expected to have mathematical maturity at the level of an advanced undergraduate, including being comfortable with linear algebra, multivariate calculus, and (non-measure theoretic) statistics and probability. Assignments include programming in python (and pytorch).
Instructor(s): V. Veitch Terms Offered: Autumn
Prerequisite(s): Consent of Instructor unless graduate student in Data Science
Equivalent Course(s): CAAM 37711, DATA 37711

STAT 37781. Kernel Methods: Theory and Computation. 100 Units.
We will introduce theoretical and computational aspects of kernel regression. We will explore connections with learning theory, gaussian processes, PDEs, and operator learning, and learn to analyze and implement algorithms that use the kernel trick in data science and scientific computation.
Terms Offered: Winter
Prerequisite(s): Background in matrix computation/advanced linear algebra, probability, PDEs, and functional analysis is required.
Equivalent Course(s): CAAM 37781

STAT 37782. Algorithms for Massive Datasets. 100 Units.
This course will focus on using elements of randomness for the analysis of massive datasets. It will cover randomized algorithms for matrix (tensor) decompositions, stochastic optimization algorithms, and the interplay between randomness and sparse recovery.
Instructor(s): Y. Khoo Terms Offered: Autumn
Equivalent Course(s): CAAM 37782

STAT 37783. Solving PDEs with Machine Learning. 100 Units.
In this class, we discuss approaches based on machine learning for PDEs. We start with the solution of elliptic and parabolic PDE with machine learning. We first discuss approaches based on numerical discretization and particle methods. We then discuss how these classical approaches can also be realized by machine learning in a high-dimensional setting.
Terms Offered: Spring
Prerequisite(s): Graduate student in Statistics, Computational and Applied Mathematics, or Computer Science, or consent of instructor.
Note(s): Familiarity with numerical method/analysis and numerical linear algebra recommended.
Equivalent Course(s): CAAM 37783

STAT 37784. Representation Learning in Machine Learning. 100 Units.
This course is a seminar on representation learning in machine learning. The core questions in this are: how do machine learning systems recover the structure present in real-world data, how can we expose this recovered structure to human analysts, and how does this help us in real-world applications? In this seminar, we will read and discuss papers from the modern research literature on these subjects. Students should have previous exposure to machine learning and deep learning.
Terms Offered: TBD
Equivalent Course(s): DATA 37784

STAT 37785. Modern Approaches for Computational Quantum Problems. 100 Units.
In this class, we discuss modern approaches based on machine learning for quantum mechanical problems. We start with the solution of elliptic and parabolic PDE with machine learning and discuss their adaptation in a quantum mechanical setting. If time allows, we will talk about quantum computing methods for solving quantum mechanical problems.
Instructor(s): Y. Khoo Terms Offered: Spring
Prerequisite(s): Graduate student in Statistics or CCAM/MCAM.
Equivalent Course(s): CAAM 37785

STAT 37786. Topics in Learning Under Distribution Shifts. 100 Units.
Traditional supervised learning assumes that the training and testing distributions are the same. Such a no-distribution-shift assumption, however, is frequently violated in practice. In this course, we survey topics in machine learning in which distribution shifts naturally arise. Possible topics include supervised learning with covariate shift, off-policy evaluation in reinforcement learning, and offline reinforcement learning.
Terms Offered: Winter
Prerequisite(s): In order to register for this course, you must be a graduate student in Statistics, CAAM, or Computer Science.

STAT 37787. Trustworthy Machine Learning. 100 Units.
Machine learning systems are routinely used in safety critical situations in the real world. However, they often dramatically fail! This course covers foundational and practical concerns in building machine learning systems that can be trusted. Topics include foundational issues---when do systems generalize, and why, essential results in fairness and domain shifts, and evaluations beyond standard test/train splits. This is an intermediate level course in machine learning; students should have at least one previous course in machine learning.
Terms Offered: TBD
Prerequisite(s): STAT 27700 or STAT 37710 or consent of instructor.
Equivalent Course(s): STAT 27751, DATA 27751

STAT 37788. Machine Learning on Graphs, Groups and Manifolds. 100 Units.
In many domains, including applications of machine learning to scientific problems, social phenomena and computer vision/graphics, the data that learning algorithms operate on naturally lives on structured objects such as graphs or low dimensional manifolds. There are many connections between these cases; further, since groups capture symmetries, there are also natural connections to the theory of learning on groups and group equiviariant algorithms. This course provides a mathematical introduction to these topics both in the context of kernel based learning and neural networks. Specific topics covered include graph kernels, manifold learning, graph wavelets, graph neural networks, permutation equivariant learning, rotational equivariant networks for scientific applications and imaging, gauge equivariant networks and steerable nets.
Equivalent Course(s): CMSC 35430, CAAM 37788

STAT 37789. Topics in Machine Learning: Learning in Games. 100 Units.
Games have long been used as benchmarks in artificial intelligence, and research in game playing has closely tracked major developments in computing. Famous examples include IBM's Deep Blue and Google Deepmind's AlphaGo. Driven by advances in machine learning, recent years have seen rapid progress in the field of game playing artificial intelligences. This reading course will review the major achievements in learning in games, discuss different classes of games, and the algorithms used to select good strategies. We will introduce relevant game theory, discuss classical methods for complete information games and combinatorial games, and modern learning methods such as counterfactual regret minimization methods used in incomplete information games. We will conclude by identifying the frontiers of artificial intelligence in games. Students are expected to enter with rudimentary coding experience.
Terms Offered: Spring
Prerequisite(s): Graduate student in Statistics or Computational and Applied Mathematics or Computer Science or Toyota Technological Institute at Chicago or consent of instructor.

STAT 37790. Topics in Statistical Machine Learning. 100 Units.
Topics in Statistical Machine Learning" is a second graduate level course in machine learning, assuming students have had previous exposure to machine learning and statistical theory. The emphasis of the course is on statistical methodology, learning theory, and algorithms for large-scale, high dimensional data. The selection of topics is influenced by recent research results, and students can take the course in more than one quarter.
Terms Offered: To be determined
Equivalent Course(s): CMSC 35425

STAT 37791. Topics in Machine Learning. 100 Units.
This course covers selected topics in dimension reduction, randomized algorithm, sparsity, convex optimization, and deep learning, with a focus on scientific computing.
Terms Offered: Spring
Prerequisite(s): Enrolled PhD or MS student in Statistics or in Computational and Applied Mathematics, or consent of instructor.
Note(s): Recommended prerequisites: STAT 30900, STAT 31015, and undergraduate probability.
Equivalent Course(s): CAAM 37791

STAT 37792. Topics in Deep Learning: Generative Models. 100 Units.
This course will be a hands on exploration of various approaches to generative modeling with deep networks. Topics include variational auto encoders, flow models, GAN models, and energy models. Participation in this course requires familiarity with pytorch and a strong background in statistical modeling. The course will primarily consist of paper presentations. Each presenter would be required to report on experiments performed with the algorithm proposed in the paper, exploring strengths and weaknesses of the methods.
Instructor(s): Y. Amit Terms Offered: Autumn
Prerequisite(s): STAT 34300, STAT 34700, STAT 34800, and STAT 37601/CMSC 25025, or STAT 37710/CMSC 35400

STAT 37793. Topics in Deep Learning: Discriminative Models. 100 Units.
This course will explore modern approaches to optimization, data augmentation, and representation learning for deep neural networks from a primarily theoretical perspective. Participation will require independent investigation of theoretical papers with PyTorch as well as paper presentations.
Terms Offered: Spring
Prerequisite(s): STAT 37601 or STAT 37710 or consent of instructor.

STAT 37794. Special Topics in Machine Learning. 100 Units.
Learned emulators leverage neural networks to increase the speed of physics simulations in climate models, astrophysics, high-energy physics, and more. Recent empirical results have illustrated that these emulators can speed up traditional simulations by up to eight orders of magnitude. However, little is understood about these emulators. While it is possible that recent results are representative of what is possible in most settings, a more likely scenario is that these approaches are more effective for some simulators than others, and that learned emulators achieve strong average-case performance but fail to capture rare but important phenomena. In this graduate seminar course we will provide an overview and investigate recent literature on this topic, focusing on the following questions: 1. Introduction to learned emulators: how do they work, where have they been successful so far and what are the goals in this field? 2. Two different paradigms of learned emulation: physics vs. data driven. What are the advantages and pitfalls of each? 3. Robustness of emulation to noise: what is known so far? 4. Parameter estimation: how to handle parameter uncertainty? We will provide a list of papers covering the above topics and students will be evaluated on in-class presentations.
Instructor(s): Dana Mendelson (Math) and Rebecca Willett (CS/Stats) Terms Offered: Autumn
Prerequisite(s): Students should be familiar with a numerical programming language like Python, Julia, R, or Matlab and the content of CMSC 35400. Students should also have familiarity with the contents of MATH 27300 and MATH 27500 or similar.
Note(s): Because this is a seminar course, it will be capped at 15 students, 4 Math, 4 CS/Stats, and 7 with instructor permission.
Equivalent Course(s): CMSC 35490, MATH 37794, CAAM 37794

STAT 37795. Causal Inference with Machine Learning. 100 Units.
This is a seminar on the use of causality in building robust and trustworthy machine learning systems. Standard machine learning pipelines have a wide range of issues in practice, including reliance on apparently irrelevant features, poor performance when deployed in domains that are mismatched to their training environment, and discriminatory or unfair behavior. This course will cover the use of causality in defining, understanding, and mitigating these failure modes.
Instructor(s): V. Veitch Terms Offered: Spring
Prerequisite(s): Background in machine learning

STAT 37796. Topics in Machine Learning: Symmetries and Harmonic Analysis. 100 Units.
Many algorithms in machine learning and statistical inference have inherent symmetries. In other cases, symmetries need to be enforced on the algorithm explicitly from the outside. In both cases, a systematic study of the symmetries inevitably leads to considerations borrowed from group representation theory and harmonic analysis. In this course we will take a broad view of this topic spanning the range from the concept of exchangeability in probability and nonparametric statistics, via the implementation of symmetries in kernel methods such as Gaussian processes to the new and quickly developing field of equivariant neural networks. One area that where symmetries play a key role and we will specifically focus on is learning physical systems and developing scalable algorithms for large scale modeling for physics and chemistry. The course starts with a short introduction to representation theory and wavelets, of which no prior knowledge is required.
Instructor(s): R. Kondor Terms Offered: Autumn

STAT 37797. Topics in Mathematical Data Science: Spectral Methods and Nonconvex Optimization. 100 Units.
This is a graduate level course covering various aspects of mathematical data science, particularly for large-scale problems. We will cover the mathematical foundations of several fundamental learning and inference problems,

including clustering, ranking, sparse recovery and compressed sensing, low-rank matrix factorization, and so on. Both convex and nonconvex approaches (including spectral methods and iterative nonconvex methods) will be discussed. We will focus on designing algorithms that are effective in both theory and practice.
Terms Offered: Autumn
Prerequisite(s): Graduate student in Statistics, Computational and Applied Mathematics, or Computer Science, or consent of instructor.
Note(s): Students should have backgrounds in basic linear algebra and in basic probability (measure-theoretic probability is not needed), as well as knowledge of a programming language (e.g., MATLAB, Python, Julia) to conduct simple simulation exercises. While no specific background in optimization is required, a course such as STAT 28000 (Optimization) would be beneficial.
Equivalent Course(s): CAAM 37797

STAT 37798. Topics in Machine Learning: Scientific Computing Tools for High-Dimensional Problems. 100 Units.
This course considers computational techniques in representing and optimizing a high-dimensional probability distribution in the context of computational physics and data science applications. Computationally tractable approximations to the probability distribution based on convex relaxations, tensor-network, neural-network, mean-field, Bethe approximation, and normalizing flow will be discussed. The course aims to present a practical view on these methods and illustrate when they can be successfully deployed in specific situations.
Terms Offered: Winter
Equivalent Course(s): CAAM 37798

STAT 37799. Topics in Machine Learning: Machine Learning and Inverse Problems. 100 Units.
In many scientific and medical settings, we cannot directly observe phenomena of interest, such as images of a person's internal organs, the microscopic structure of materials or cells, or observations of distant stars and galaxies. Rather, we use MRI scanners, microscopes, and satellites to collect indirect data that require sophisticated numerical methods to interpret. This course will explore a variety of machine learning techniques for solving inverse problems, ranging from linear inverse problems to PDE parameter estimation and data assimilation.
Instructor(s): R. Willett Terms Offered: Winter
Prerequisite(s): STAT 37710/CAAM 37710/CMSC 35400 or consent of instructor.
Equivalent Course(s): CMSC 37799, CAAM 37799

STAT 37810. Statistical Computing A. 50 Units.
This course is an introduction to statistical programming in R. Students will learn how to design, write, debug and test functions by implementing several famous algorithms in statistics such as Gibbs Sampling and Expectation Maximization. A basic familiarity with R is needed, but no prior programming experience is required. The course will also introduce students to the use of version control with Git and consider the differences and similarities between R and Python.
Terms Offered: Autumn
Prerequisite(s): Instructor consent.

STAT 37815. Practical R Programming with Extensions. 100 Units.
This course covers a practical set of skills vital to modern statistics and data science in handling messy, real-world data. Throughout the course, students will practice reproducible research with version control and literate programming. They will think algorithmically with base R objects, control flow, functions, and iteration. Students will also be introduced to a variety of tidyverse data wrangling methods to import, clean, transform, join, and summarize their data. Finally, students will visualize and explore data using the grammar of graphics framework. Additional introductory topics may be discussed. No programming experience is required, although some will be helpful. This course is taught at the graduate level. Credit may not be earned for both STAT 27815 and STAT 37815.
Instructor(s): R. McShane Terms Offered: Autumn
Prerequisite(s): MS or PhD student in the Physical Sciences Division or consent of instructor.

STAT 37820. Statistical Computing B. 50 Units.
Statistical Computing B focuses on common data technology used in statistical computing and broader data science. The course takes place in the second half of the autumn quarter, after STAT 37810 (Statistical Computing A). Topics include storage and accessing of large data; basic working knowledge of relational database and its querying language SQL; introduction to distributed file system and example usage of Hadoop; Python and its applications in text analysis; access and usage of high-performance computer clusters, rudimentary parallel computing, web data access. XML and Javascript may be used occasionally. A short introduction to SAS will be given if time permits. The main computing software will be Python with some R.
Terms Offered: Autumn
Prerequisite(s): Instructor consent. STAT 37810 recommended.

STAT 37830. Scientific Computing with Python. 100 Units.
This course is an introduction to scientific computing using the Python programming language intended to prepare students for further computational work in courses, research, and industry. Students will learn to design, implement, and test code in Python. The course will draw examples from numerical and discrete algorithms commonly encountered in scientific computing with an emphasis on design and performance considerations.

Topics will include numerical linear algebra, optimization, graph theory, data analysis, and physical simulations. The course will also introduce students to a variety of practical topics such as the use of remote resources, version control with git, commonly used libraries for scientific computing and data analysis, and using and contributing to open source and collaborative projects.
Prerequisite(s): Multivariable calculus, Linear algebra, prior programming experience (not necessarily in Python).
Equivalent Course(s): CAAM 37830

STAT 38100. Measure-Theoretic Probability I. 100 Units.
This course provides a detailed, rigorous treatment of probability from the point of view of measure theory, as well as existence theorems, integration and expected values, characteristic functions, moment problems, limit laws, Radon-Nikodym derivatives, and conditional probabilities.
Terms Offered: Winter
Prerequisite(s): STAT 30400 or consent of instructor

STAT 38300. Measure-Theoretic Probability III. 100 Units.
This course continues material covered in STAT 38100, with topics that include Lp spaces, Radon-Nikodym theorem, conditional expectation, and martingale theory.
Terms Offered: Spring
Prerequisite(s): STAT 38100

STAT 38510. Brownian Motion and Stochastic Calculus. 100 Units.
This is a rigorous introduction to the mathematical theory of Brownian motion and the corresponding integration theory (stochastic integration). This is material that all analysis graduate students should learn at some point whether or not they are immediately planning to use probabilistic techniques. It is also a natural course for more advanced math students who want to broaden their mathematical education and to increase their marketability for nonacademic positions. In particular, it is one of the most fundamental mathematical tools used in financial mathematics (although we will not discuss finance in this course). This course differs from the more applied STAT 39000 in that concepts are developed precisely and rigorously.
Terms Offered: To be determined.
Note(s): Recommended prerequisites: STAT 38300; or MATH 31200, MATH 31300, and MATH 31400; or consent of instructor.
Equivalent Course(s): MATH 38511

STAT 38520. Topics in Random Matrix Theory. 100 Units.
Random matrix theory (RMT) is among the most prominent subjects in modern probability theory, with applications in a wide range of disciplines (including physics, statistics, engineering, and finance). The purpose of this course is to study a broad sample of the most prominent research programs in RMT as well as their motivating applications. Main topics will include (time permitting) the moment method in RMT and its connection to combinatorics, universality, operator limits, and matrix concentration.
Terms Offered: Winter
Prerequisite(s): PhD student in Statistics or Math or Computational and Applied Mathematics or TTIC or MS student in Statistics or Computational and Applied Mathematics. Other students may enroll with consent of instructor.
Note(s): Prerequisite notes: Graduate or advanced undergraduate probability theory and undergraduate linear algebra and combinatorics are recommended.
Equivalent Course(s): CAAM 38520

STAT 39000. Stochastic Calculus. 100 Units.
The course starts with a quick introduction to martingales in discrete time, and then Brownian motion and the Ito integral are defined carefully. The main tools of stochastic calculus (Ito's formula, Feynman-Kac formula, Girsanov theorem, etc.) are developed. The treatment includes discussions of simulation and the relationship with partial differential equations. Some applications are given to option pricing, but much more on this is done in other courses. The course ends with an introduction to jump process (Levy processes) and the corresponding integration theory. Program requirement.
Instructor(s): G. Lawler Terms Offered: Winter
Equivalent Course(s): FINM 34500

STAT 39010. Stochastic Calculus I. 50 Units.
The course starts with a quick introduction to martingales in discrete time, and then Brownian motion and the Ito integral are defined carefully. The main tools of stochastic calculus (Ito's formula, Feynman-Kac formula, Girsanov theorem, etc.) are developed. The treatment includes discussions of simulation and the relationship with partial differential equations. Some applications are given to option pricing, but much more on this is done in other courses. The course ends with an introduction to jump process (Levy processes) and the corresponding integration theory.
Terms Offered: Winter
Prerequisite(s): Consent of instructor.
Equivalent Course(s): FINM 34510

STAT 39800. Field Research. 300.00 Units.
This Summer Quarter course offers graduate students in the Statistics Department the opportunity to apply statistics knowledge that they have acquired to a real industry or business situation. During the summer quarter in which they are registered for the course, students complete a paid or unpaid internship of at least six weeks. Prior to the start of the work experience, students secure faculty consent for an independent study project to be completed during the internship quarter.
Terms Offered: Summer only
Prerequisite(s): Masters or PhD student in Statistics or Consent of instructor and faculty advisor.

STAT 39900. Masters Seminar: Statistics. 300.00 Units.
This course is for Statistics Master's students to carry out directed reading or guided work on topics related to their Master's papers.
Prerequisite(s): Masters or PhD student in Statistics

STAT 40100. Reading/Research: Statistics. 300.00 Units.
This course allows doctoral students to receive credit for advanced work related to their dissertation topics. Students register for one of the listed faculty sections with prior consent from the respective instructor. Students may work with faculty from other departments; however, they still must obtain permission from and register with one of the listed faculty members in the Department of Statistics.
Terms Offered: All quarters
Prerequisite(s): Masters or PhD student in Statistics or consent of instructor

STAT 41500-41600. High-Dimensional Statistics I-II.
These courses treat statistical problems where the number of variables is very large. Classical statistical methods and theory often fail in such settings. Modern research has begun to develop techniques that can be effective in high dimensions, and that can be understood theoretically. The first quarter introduces a range of statistical frameworks for finding low-dimensional structure in high-dimensional data, such as sparsity in regression, sparse graphical models, or low-rank structure. This quarter emphasizes methods for estimation and inference developed in these areas, along with theoretical analysis of their properties. The second quarter emphasizes foundational aspects of high-dimensional statistics, focusing on principles that are used across a range of problems and are likely to be relevant for methods developed in the future. Topics include "the curse of dimensionality," elements of random matrix theory, properties of high-dimensional covariance matrices, concentration of measure, dimensionality reduction techniques, and handling mis-specified models. The courses may be taken separately.

> **STAT 41500. High-Dimensional Statistics I. 100 Units.**
> In this course, we will consider statistical estimation with a large number of parameters. Sometimes the number of parameters may exceed the sample size. Problems such as sparse linear regression, bandable covariance matrix estimation, Gaussian graphical model, sparse PCA and CCA, and isotonic regression will be covered. Along with these specific problems, we will also cover techniques including concentration of measure, convex optimization, approximate message passing, debiasing, and statistical-computational tradeoff.
> Terms Offered: To be determined
> Prerequisite(s): STAT 30100 and STAT 30400 and STAT 31015, or consent of instructor

> **STAT 41600. High-Dimensional Statistics II. 100 Units.**
> These courses treat statistical problems where the number of variables is very large. Classical statistical methods and theory often fail in such settings. Modern research has begun to develop techniques that can be effective in high dimensions, and that can be understood theoretically. The first quarter introduces a range of statistical frameworks for finding low-dimensional structure in high-dimensional data, such as sparsity in regression, sparse graphical models, or low-rank structure. This quarter emphasizes methods for estimation and inference developed in these areas, along with theoretical analysis of their properties. The second quarter emphasizes foundational aspects of high-dimensional statistics, focusing on principles that are used across a range of problems and are likely to be relevant for methods developed in the future. Topics include "the curse of dimensionality," elements of random matrix theory, properties of high-dimensional covariance matrices, concentration of measure, dimensionality reduction techniques, and handling mis-specified models. The courses may be taken separately.
> Terms Offered: To be determined
> Prerequisite(s): STAT 30100 or STAT 30400 or STAT 31015, or consent of instructor

STAT 41510. Bayesian Nonparametrics. 100 Units.
Bayesian nonparametric methods are increasingly important tools in machine learning and statistics. We will discuss nonparametric Bayesian approaches to mixture models, latent feature models, hierarchical models, network models, and high-dimensional regression models. Topics that will be covered include Dirichlet process, Chinese restaurant process, Pitman-Yor process, Indian buffet process, Gaussian process, and their computational techniques via Gibbs sampling and variational inference. Frequentist evaluations of posterior distributions will also be discussed in nonparametric and high-dimensional settings.
Instructor(s): C. Gao Terms Offered: To be determined
Prerequisite(s): STAT 30200

STAT 41511. Topics in Robust and Semiparametric Statistics. 100 Units.
This course is about statistical estimation and inference with nuisance parameters. Examples include location estimation with unknown density, Cox proportional hazard model, low-dimensional inference in sparse regression, and robust estimation with arbitrary contamination. We will learn tangent spaces, efficient score functions, and information operators. Basic empirical process tools will also be discussed.
Terms Offered: Spring
Prerequisite(s): STAT 30100

STAT 41512. Topics in High-Dimensional Hypothesis Testing. 100 Units.
This course will discuss high-dimensional hypothesis testing problems from a minimax perspective. Topics include sparse signal detection with known and unknown nulls, changepoint detection, adaptive test for nonparametric function, sparse PCA detection with computational lower bound, and goodness-of-fit test for discrete distributions.
Terms Offered: Winter

STAT 41520. Topics in Selective Inference. 100 Units.
This course will study the problem of selective inference where we would like to provide statistical guarantees about hypotheses or parameters whose definitions are influenced by our analysis of the same data set. Performing valid inference is challenging since we must find a way to condition on the outcome of the selection process which is not always simple to characterize. The course will discuss both recent advances and open problems in this field.
Instructor(s): R. Barber Terms Offered: To be determined
Prerequisite(s): STAT 27850/30850 or STAT 30200 or consent of instructor

STAT 41521. Topics in Distribution-free Inference. 100 Units.
This course will focus on the recent field of distribution-free inference which seeks to provide verifiable statistical guarantees without assumptions on the distribution of the data. Methods in this area include holdout set methods, cross-validation type methods, and conformal prediction. The course will cover theoretical advances and practical methodologies, theoretical hardness results, and open problems in the field.
Terms Offered: Autumn
Prerequisite(s): STAT 34300 and STAT 30100

STAT 41530. Topics in Causal Inference. 100 Units.
We will start with a light and comparative introduction of two causal inference languages: the potential outcome model and the graphical representation of causal effects. In the course, we will discuss topics including confounding, instrumental variables (IV), mediation analysis, and effective treatment allocations, with their applications in genetics and epidemiological research.

STAT 41540. Topics in Advanced Bayesian Methodology. 100 Units.
This course will explore topics in advanced Bayesian methodology, particularly around modern variational inference. The course will begin with a review of "classical" variational inference in exponential family models using mean-field approximations. It will then dive into recent advances in generic and scalable VI alternatives such as variational autoencoders, amortized inference, normalizing flows, and diffusion models, among other topics. The course will run like a seminar and feature a mix of lectures and student-run paper presentations. Students will also be responsible for a final project that applies or extends the methodology covered in course to applied problems of their choosing. Prerequisites include STAT 34800 (or an equivalent course on Bayesian statistics and probabilistic graphical models) and some experience in Python is encouraged.
Instructor(s): A. Schein Terms Offered: Autumn
Prerequisite(s): STAT 34800

STAT 41541. Causal Inference in Randomized Experiments and Observational Studies. 100 Units.
This course provides an introduction to statistical causal inference, designed for graduate students with interest in causality. Our primary focus will be on the potential outcome framework for causality. The course will start with causal inference in randomized experiments and then proceed to observational studies. For randomized experiments, we will focus on randomization-based or design-based inference for various experiments, including completely randomized, stratified randomized, and rerandomized experiments. For observational studies, we will introduce popular methods for addressing observed confounding, including matching, regression, inverse propensity weighting, and their combinations. Depending on the progress of the course, we will also discuss more advanced topics such as instrumental variables, mediation analysis, interference, peer effects, etc.
Terms Offered: Winter
Prerequisite(s): PhD or MS student in Statistics, or STAT 34300 and STAT 30100, or consent of instructor.

STAT 41542. Advanced Topics in Causal Inference. 100 Units.
The course focuses on more advanced topics in causal inference, in particular progresses from recent literature. Topics include heterogeneous treatment effects, instrumental variables, double machine learning, difference-in-differences, interference, peer effects, sensitivity analysis, causal representation learning, proximal causal inference, marginal treatment effects, mediation analysis, and surrogates.

STAT 41551. Empirical Bayes. 100 Units.
In an empirical Bayes analysis, we imitate inferences made by an oracle Bayesian with extensive knowledge of the data-generating distribution. Empirical Bayes provides a principled approach for "learning from the

experience of others" and is widely used in application domains such as genomics, small-area estimation, economics, and large-scale experimentation. In this graduate topics course, we provide an overview of empirical Bayes. We revisit the original papers that introduced the core ideas and explain how empirical Bayes is applied in practice. We also develop mathematical techniques to study empirical Bayes procedures from a theoretical perspective.
Terms Offered: Winter
Prerequisite(s): STAT 30100 or consent of instructor
Equivalent Course(s): DATA 41551

STAT 41561. Statistical Optimal Transport. 100 Units.
This course provides a comprehensive introduction to statistical optimal transport (OT), a mathematical framework that has become increasingly important in statistics, machine learning, and data science. Optimal transport theory provides tools for comparing probability distributions and has found applications in generative modeling, robust statistics, and structured data analysis. Topics covered will include classical formulations of OT, such as Monge's problem and the Kantorovich relaxation, as well as key results on duality, cyclical monotonicity, and Brenier-McCann's theorem. We will explore computational foundations, including the Sinkhorn algorithm, entropic OT, and its connections to Schrödinger's bridge. The course will also examine statistical properties of OT, such as sample complexity, multidimensional ranks and quantiles, and asymptotic inference. Further topics include brief introduction to Wasserstein gradient flows, JKO schemes, and applications of gradient flows in generative models, neural networks and transformer. Weekly assignments and a final project will involve both theoretical analysis and computational implementation of OT methods.
Equivalent Course(s): CAAM 41561

STAT 42600. Theoretical Neuroscience: Statistics and Information Theory. 100 Units.
This course begins with an introduction to inference and statistical methods in data analysis. We then cover the two main sections of the course: I) Encoding and II) Decoding in single neurons and neural populations. The encoding section will cover receptive field analysis (STA, STC and non-linear methods such as maximally informative dimensions) and will explore linear-nonlinear-Poisson models of neural encoding as well as generalized linear models alongside newer population coding models. The decoding section will cover basic methods for inferring stimuli or behaviors from spike train data, including both linear and correlational approaches to population decoding. The course will use examples from real data (where appropriate) in the problem sets which students will solve using MATLAB.
Instructor(s): S. Palmer Terms Offered: Spring
Prerequisite(s): Prior exposure to basic calculus and probability theory, CPNS 35500 or instructor consent.
Equivalent Course(s): ORGB 42600, CPNS 35600

STAT 42610. Theories of Cortical Circuit Dynamics and Computation. 100 Units.
This course will present mathematical frameworks for the construction and analysis of contemporary models of cortical circuits. Topics will include: models of neuronal spiking and synaptic dynamics, balanced networks, mean field theory of cortical networks, diffusion approximation and linear response in stochastically forced neuronal networks, models of decision making and working memory, information flow in cortical networks.
Instructor(s): B. Doiron Terms Offered: Winter
Equivalent Course(s): CPNS 32610, CAAM 42610

STAT 44100. Consulting In Statistics. 300.00 Units.
This seminar course is an internal training program for graduate students in Statistics. The primary goal is to expose the students to applications that involve statistical thinking and to have hands on experience on real world data. The projects are provided by researchers from the university community. Participating students form teams to work on selected projects under faculty guidance and to present their work to all student consultants and researcher clients.

STAT 70000. Advanced Study: Statistics. 300.00 Units.
Advanced Study: Statistics

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