

MA 688-P0 ADVANCED STATISTICS SYLLABUS

Course Instructor: Keren Li, PhD
Contact Information: kli@uab.edu
Office: University Hall 4041
Office Hours: By appointment

Course Info

Meeting times: Lectures: 2:40 pm – 4:00 pm, Monday/Wednesday/Friday

Meeting location: University Hall 4002

Prerequisite: MA 585 Minimum Grade of B or MA 586 Minimum Grade of B or MA 587 Minimum Grade of B or MA 589 Minimum Grade of B or MA 685 Minimum Grade of B or MA 687 Minimum Grade of B or equivalent coursework

Credits: 3 semester hours

Recommended Textbooks:

The Elements of Statistical Learning, 2nd Edition, Hastie, Trevor, Tibshirani, Robert and Friedman, Jerome, Springer, 2009.

Computer Age Statistical Inference: Algorithms, Evidence, and Data Science, Efron, Bradley, and Trevor Hastie, Cambridge University Press, 2016.

Theoretical Statistics, R. Keener, Springer, 2010

Probabilistic Machine Learning: Advanced Topics, Kevin P. Murphy, MIT Press, 2023

Course Description

This course covers advanced statistical foundations for modern machine learning, with an emphasis on theoretical rigor, methodological understanding, and principled modeling. The course is centered on the statistical formulation of learning problems, including risk minimization, likelihood-based inference, and Bayesian methods.

Core topics include exponential families, sufficiency, likelihood and M-estimation, high-dimensional statistics, kernel and nonparametric methods, and optimization techniques for statistical learning. The course further explores ensemble methods, uncertainty quantification, and statistical inference under regularization.

A central component of the course is learning under complex data environments, including heterogeneity across data sources and distributed learning settings. Topics include domain adaptation, multi-task learning, and communication-efficient learning frameworks, with emphasis on statistical properties such as stability, consistency, and interpretability. Representative Learning will be introduced as a structured approach to distributed statistical learning.

Additional topics include a brief introduction to sequential decision making from a statistical perspective, including multi-armed bandits and off-policy evaluation.

Students will develop a strong mathematical understanding of statistical machine learning methods and apply them through theoretical analysis and computational implementation in R. The final project will involve either a theoretical study of a statistical learning method or an application to a real-world problem.

Learning Outcomes

Upon successful completion of the course, a student can

- (1) Formulate machine learning problems from a statistical perspective using risk minimization and likelihood-based frameworks.
 - (2) Analyze and apply exponential family models, generalized linear models, and M-estimation methods in machine learning.
 - (3) Understand and implement optimization algorithms and evaluate their interaction with statistical estimation.
 - (4) Develop and analyze kernel methods and nonparametric models with attention to bias-variance tradeoffs.
 - (5) Apply Bayesian methods and interpret uncertainty through posterior inference and approximation techniques.
 - (6) Analyze high-dimensional models, including regularization, sparsity, and post-selection inference.
 - (7) Evaluate learning methods under data heterogeneity and distribution shift, including domain adaptation and multi-task learning.
 - (8) Understand statistical principles in distributed learning, including communication constraints and representative-based methods.
 - (9) Interpret sequential decision problems from a statistical perspective, including bandits and off-policy evaluation.
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Course Content

Statistical Foundations of Learning: Risk minimization, empirical risk minimization, bias-variance tradeoff, generalization, and capacity control.

Likelihood-Based Methods and Generalized Models: Exponential families, sufficiency, likelihood theory, M-estimation, generalized linear models, and regularization methods including Ridge and Lasso.

Optimization for Statistical Learning: Convex optimization, gradient descent, stochastic gradient descent, proximal methods, and the interaction between optimization error and statistical error.

Kernel and Nonparametric Methods: Reproducing kernel Hilbert spaces, representer theorem, kernel ridge regression, support vector machines, smoothing splines, and bias-variance tradeoffs in nonparametric models.

Bayesian Machine Learning: Bayesian inference, posterior analysis, variational inference, Markov chain Monte Carlo methods, and interpretation of uncertainty.

Ensemble Methods: Boosting, stagewise additive modeling, random forests, and variance reduction techniques.

High-Dimensional Statistics: Sparsity, regularization, oracle properties, debiased estimation, post-selection inference, and multiple testing.

Learning Under Data Heterogeneity: Types of heterogeneity ($P(X)$, $P(Y)$, $P(Y|X)$, $P(X|Y)$), domain adaptation, multi-task learning, and generalization under distribution shift.

Distributed and Communication-Efficient Learning: Distributed learning frameworks, communication constraints, federated learning, and Representative Learning for structured data summarization.

Sequential Decision Making (Statistical Perspective): Multi-armed bandits, exploration–exploitation tradeoff, off-policy evaluation, and doubly robust estimation.

Final Project: Students will complete a project involving either theoretical analysis or applied study of a statistical machine learning method, culminating in a written report and presentation.

Course Grade

Your grade in the course is determined by the points earned throughout the semester.

Homework Assignments: (40% total)

Final Project: (50%)

- Draft (10%)
- Final Report (30%)
- Presentation (10%)

Attendance and Participation: (10%)

Bonus Reflection Assignment: (5%)

Points earned	Grade
85-100+	A
75-84	B
65-74	C
50-64	D
0-49	F

Course Policies

Make-up: No late assignment will be accepted, and no make-up presentations will be given without a valid excuse.

Group: Homework is to be completed in (fixed) groups of 1-2 students each. Everyone in the group will get the same score.

Add/Drop and Course Withdrawal: Drop/Add: Deadlines for adding, dropping, or withdrawing from a course and for paying tuition are published in the Academic Calendar available online. Review the Institutional Refund Policy for information on refunds for dropped courses. It is the students responsibility to initiate add/drop procedures. Students may drop and add courses online after they have registered and until the drop/add deadline online using BlazerNET. Withdrawal: To avoid academic penalty, a student must withdraw from a course by the withdrawal deadline shown in the academic calendar and receive a grade of W (withdrawn). Failure to attend class does not constitute a formal drop or withdrawal. The official course withdrawal must be completed online in BlazerNET.

Divisive Concepts: All University faculty, instructors and teaching staff have the academic freedom to explore, discuss, and provide instruction on a wide range of topics in an academic setting. This class may present difficult, objectionable, or controversial topics for consideration, but will do so through an objective, scholarly lens designed to encourage critical thinking. Though students may be asked to share their personal views in the academic setting, no student will ever be required to assent or agree with any concept considered "divisive" under Alabama law, nor penalized for refusing to support or endorse such a concept. All students are strongly encouraged to think independently and analytically about all material presented in class and may express their views in a time, place, and manner, consistent with class organization and structure, and in accordance with the University's commitment to free and open thought, inquiry, and expressions.

Shared Values Statement: Collaboration, integrity, respect, and excellence are core values of our institution and affirm what it means to be a UAB community member. A key foundation of UAB is diversity. At UAB, everybody counts every day. UAB is committed to fostering a respectful, accessible and open campus environment. We value every member of our campus and the richly different perspectives, characteristics and life experiences that contribute to UAB's unique environment. UAB values and cultivates access, engagement and opportunity in our research, learning, clinical, and work environments. Our CAS aims to create an open and welcoming environment and to support the success of all UAB community members.

Academic Integrity Code: Your success while at UAB and after graduation is valued by the University. To gain and grow in the knowledge and skills needed for your future career, it is vital that you complete your own work in your courses and in your research. The purpose of the Academic Integrity Code is to support our academic mission and to maintain and promote academic integrity. All students in attendance at UAB are expected to pursue all academic endeavors with integrity, honor, and professionalism and to observe standards of conduct appropriate to a community of scholars. Please be sure you understand the different forms of "academic misconduct" covered by the code. See what UAB students say about academic integrity and review the FAQs about the code for details on the Student Academic Integrity webpage.

Artificial Intelligence Use: Academic misconduct is present in an academic work wherever AI assistance has been used when unauthorized, or when authorized, has not been disclosed as required. Such behavior is considered deceit and a violation of UABs shared commitment to truth and academic integrity. Deceit constitutes academic misconduct and is subject to review according to UABs Academic Integrity Code.

Student Conduct Code: The purpose of the University of Alabama at Birmingham (University) student conduct process is to support the vision, mission, and shared values of the University and the tenets of the Universitys creed, The Blazer Way. Through a student-focused and learning-centered lens, the process strives to uphold individual and community standards; foster an environment of personal accountability for decisions; promote personal growth and development of life skills; and care for the well-being, health, safety, and property of all members of the University community. The Student Conduct Code (Code) describes the standards of behavior for all students and student organizations and outlines students rights and the process for adjudicating alleged violations. It is set forth in writing in order to give general notice of non-academic prohibited conduct. The Code should be read broadly and is not designed to define non-academic conduct in exhaustive terms. All students and student organizations are expected to conduct themselves in accordance with the Code. The current version of the Code, which may be revised periodically, is available from the Office of Community Standards & Student Accountability.

Intellectual Property: My lectures and course materials, including PowerPoint presentations, quizzes, exams, outlines, and similar materials, are protected by copyright. You may take notes and make copies of course materials for your own use. You may not and may not allow others to reproduce or distribute lecture notes and course materials publicly, whether or not a fee is charged, without my expressed written consent.

Disability support Services (DSS): UAB is committed to providing an accessible learning experience for all students. If you are a student with a disability that qualifies under Americans with Disabilities Act (ADA) and Section 504 of the Rehabilitation Act, and you require accommodations, please contact Disability Support Services for information on accommodations, registration and procedures. If you are registered with Disability Support Services, please contact DSS to discuss accommodations that may be necessary in this

course. Disability Support Services can be reached at 934-4205 or www.uab.edu/dss or in the Hill Center Suite 409.

Title IX Statement: UAB is committed to providing an environment that is free from sexual misconduct, which includes gender-based assault, harassment, exploitation, dating and domestic violence, stalking, as well as discrimination based on sex, sexual orientation, gender identity, and gender expression. If you have experienced any of the aforementioned conduct we encourage you to report the incident. For more information about Title IX, policy, reporting, protections, resources and supports, please visit <http://www.uab.edu/titleix> for UAB's Title IX Policy, UAB's Equal Opportunity, Anti Harassment Policy and Duty to Report and Non-Retaliation Policy.

Violence Prevention and Response Policy: The University of Alabama at Birmingham (UAB) is committed to maintaining a safe and secure educational environment and workplace, one which seeks to ensure the well-being and safety of faculty and staff, employees, students and visitors. Violence and threatened violence are prohibited by UAB. Each member of the UAB community has the responsibility to understand, prevent and respond appropriately to campus/workplace violence. View the Violence Prevention and Response Policy.

Technology: General and course-specific technical skills learners must have to succeed in

- Using the learning management system
- Using email with attachments
- Creating and submitting files in commonly used word processing program formats
- Downloading and installing software
- Using spreadsheet programs
- Using presentation and graphics programs
- Using apps in digital devices
- Using web conferencing tools and software

Digital information literacy skills are as follows:

- Using online libraries and databases to locate and gather appropriate information
- Using computer networks to locate and store files or data
- Using online search tools for specific academic purposes, including the ability to use search criteria, keywords, and filters
- Analyzing digital information for credibility, currency, and bias (e.g., disinformation, misinformation)
- Properly citing information sources
- Preparing a presentation of research findings

Access technical support and view privacy policies and accessibility statements for Canvas and other technologies on the Student Academic Technologies website. Additionally, view information about the Minimum System Requirements and Technical Skills.

Student Academic and Support Services:

- One Stop Student Services provides a single point of professional integrated service to students. The One Stop serves students who need assistance with academic records, financial aid, registration, student accounting, ONE card, and other related topics.
- Student Assistance and Support provides individualized assistance to promote student safety and well-being, collaboration and resilience, personal accountability, and self-advocacy. The Care Team consults and collaborates with campus partners to balance the needs of individual students with those of the overall

campus community. The UAB Care Team helps find solutions for students experiencing academic, social, and crisis situations including mental health concerns.

- Disability Support Services assists students with in reaching accommodations for their educational experiences at UAB that ensure that they have equal access to programs, services, and activities at UAB.
- The Vulcan Materials Academic Success Center provides tutoring, supplemental instruction, and other services that encourage goal achievement and degree completion.
- The University Writing Center offers free writing assistance for all UAB students. Get help at any stage of the writing process and with any type of writing. Students may meet with a tutor in person or via Zoom. Students may also upload a paper for feedback (called eTutoring in the online system). During in-person and Zoom sessions, tutors can help you understand your assignment, develop and organize your ideas, use and cite sources, revise and edit your draft, and more. When you upload a draft for eTutoring, tutors can provide feedback on both big-picture issues and detail-oriented concerns; please note that you must upload a draft and assignment sheet to use eTutoring. To make an appointment or get more information, please see the UWC website, email writingcenter@uab.edu, or call 205-996-7178. Follow the UWC on Facebook, Instagram, and LinkedIn for daily news and quick writing tips.
- UAB Student Health Services delivers comprehensive, high quality, confidential, primary healthcare to students. Student Health provides testing services and vaccination clinics.
- Student Counseling Services offers students a safe place to discuss and resolve issues that interfere with personal and academic goals. UAB has created a new app (available in the App Store and Google Play) called B Well, that is designed to easily access resources on mobile devices and build a self-care plan. Kognito is a free, interactive simulation-based platform designed to help you talk with someone when you are worried about your mental health.
- UAB Blazer Kitchen at the Hill Student Center provides food and basic supplies for any UAB student in need through in-person or online shopping. Students who can are also able to donate food and supplies to assist their peers. To get more information, call 205-975-9509, email studentoutreach@uab.edu, or visit Student Assistance & Support website.
- eLearning and Professional Studies provides numerous academic technologies and learning resources for students whose learning may be affected by COVID. The following are the various websites describing additional student academic and technology resources:
 - UAB Policies for Students
 - Student Academic and Support Services
 - Technology Resources