ASEN 5519 Autonomous Bayesian Reasoning
Spring 2025 Course Syllabus

General Information

Instructor: Prof. Nisar Ahmed (`nisar.ahmed@colorado.edu`)

Time and Location: Mon & Wed 3:00 pm - 4:15 pm, AERO N250.

Course Canvas Website: `canvas.colorado.edu` (will be used for posting all course materials and announcements)

Office Hours:

Course Textbook:

Christopher M. Bishop, *Pattern Recognition and Machine Learning*, Springer, 1st edi-tion, 2007. ISBN 978-0387310732.

Optional resources: the following texts are recommended (but not required) for a deeper treatment of the core probabilistic AI, machine learning and pattern recognition concepts to be covered in this course, as well as many other important/useful topics not covered:

David Barber, *Bayesian Reasoning and Machine Learning*, Cambridge University Press, 2012: **available free online**: http://web4.cs.ucl.ac.uk/staff/D.Barber/pmwiki/pmwiki.php?n=Brml.HomePage

Finn V. Jensen and Thomas D. Nielsen, *Bayesian Networks and Decision Graphs*, Springer, 2nd edition 2007. ISBN 978-0387682815.

Sebastian Thrun, Wolfram Burgard, and Dieter Fox, *Probabilistic Robotics*, MIT Press, 2005. ISBN 978-0262201629.

Sergios Theodoridis, *Machine Learning: A Bayesian and Optimization Perspective*, Academic Press, 1st edition, 2015. ISBN 978-0128015223.

Stuart Russell and Peter Norvig, *Artificial Intelligence: A Modern Approach*, Pearson, 3rd edition, 2009. ISBN 978-0136042594.

Course Details

Description Autonomous systems must learn and reason under uncertainty. Probabilistic models and algorithms for learning and reasoning are thus crucial for modern uncrewed and robotic systems, and are popular in many other disciplines as well. This course will introduce probabilistic machine learning and AI techniques that enable representation and quantification of, adaptation to, and reasoning under uncertainty by combining prior knowledge with information from acquired data. It will build on fundamental probability, estimation, and optimization theory, and emphasize current/future applications and questions driving academic and industrial research.

Major topics to be covered include:

- review of basic probability, statistics, and related mathematical topics;
- probabilistic graphical models and applications (hidden Markov models, Bayesian nets, Markov random fields, factor graphs, Bayesian nonparametric models such as Dirichlet and Gaussian processes);
- statistical parameter identification for pattern recognition and model learning;
- computational inference methods, including exact methods for basic probabilistic models and common approximations for complex models (Monte Carlo, variational inference);
- fully Bayesian inference and learning for sparse data and highly uncertain models;
- applications to estimation, control, robotics, AI, autonomous systems and other fields
- intro to advanced/current research topics (as time and interest permits): probabilistic deep learning and neural nets; probabilistic programming; explainable/introspective learning and AI; Planning as Inference and Active Inference for online decision making, estimation, and learning; multi-sensor/multi-agent information fusion.

While these concepts will be covered in a mathematically rigorous way, students will apply these concepts to application problems developed from their own research. Students will develop their own software that could, for instance, serve as the basis for autonomy on board an uncrewed ground robot, air vehicle, spacecraft, or other application platform/system that connects to their own research problems. Students will be expected to develop and refine their project application throughout the semester, by incorporating course material into their problem and culminating in a short final project presentation and report.

Prerequisites: Students must be comfortable with programming on their own in a technical programming language (e.g. Matlab/Octave, Python, C, C++, C#, Java, Julia, R, etc.) and at a minimum are expected to be familiar/comfortable with linear algebra and multivariate calculus. Prior exposure to or willingness to learn probability theory and statistics is also a plus!

Grading and Project Assignments Course work will largely be project-oriented. There will be no exams. Several required topical quizzes and exercises related to the lectures will be posted to ensure that students demonstrate understanding of the course material, as well as to provide periodic feedback and guidance as students try to integrate/explore concepts into their final projects. These exercises will consist of short theoretical and programming problems for toy applications, as well as questions to guide the development of final project applications. Quizzes will receive numerical scores, while all exercises will be graded on a binary 'satisfactory' (S)/'unsatsifactory' (U) scale. To receive full credit for these, students must submit and receive a 'satisfactory' grade on the exercises to be posted. Students will be allowed to resubmit 'unsatisfactory' assignments for a regrade, as long as the initial assignments are submitted in a timely manner. Exercises are expected to be posted following major lecture topic sections. The final project will be developed over the course of the semester via dedicated exercises. Students have the option of working together in groups of two (max) on the exercises and the final project if they so choose, though some level of individual contributions/work will be expected on group projects. In any case, students are highly encouraged to collaborate with one another and to constantly think about how best to connect course material to their own research.

Grading breakdown: exercises: 20%; quizzes: 20% final project: 40%; class participation: 20%. Note that any group exercise submissions and final project submissions will result in the same grade for both group members. Late submissions for quizzes and exercises and final project will not be accepted, unless the student receives permission in writing (via email) from the instructor to submit a late assignment. **Permission must be granted at least 48 hours in advance of the assignment deadline.**

Benefits and Learning Objectives This course will enable students to:

1. combine knowledge of probability and statistics with engineering/science domain knowledge to formulate mathematically sound models of uncertain systems and autonomous reasoning problems;

2. identify and design algorithms that enable autonomous learning, inference and decision making with probabilistic models, and explain their similarities/differences.

3. define, explain and demonstrate the importance of fundamental tools, including (but not limited to): probabilistic graphical models; point estimation and maximum likelihood techniques; fully Bayesian and Monte Carlo inference/learning methods; variational approximate inference; nonparametric Bayesian models including Gaussian processes and Dirichlet processes.

4. identify and explain strengths/weaknesses of state of the art autonomous Bayesian reasoning algorithms;

5. develop and implement software to simulate and evaluate the performance of autonomous agents for real-world/research applications.

Tentative Course Schedule (subject to revision)

General Policies (please read carefully)

CLASSROOM BEHAVIOR Students and faculty are responsible for maintaining an appropriate learning environment in all instructional settings, whether in person, remote,

Week(s)	Topic
1	Course intro & overview
1-3	Probability and math review, Bayes nets, basic inference problems
4-5	Dynamic Bayesian nets, Hidden Markov Models, exact inference: forward-backward, message passing
5-7	Approximate inference: Monte Carlo, Importance sampling, Particle filters
7	MRFs, FGs; Nonparametric Bayesian regression models (GPs)
8-9	Intro to parameter learning: maximum likelihood, Expectation-Maximization; model selection
10	Fully Bayesian model learning; hierarchical inference and learning; intro to Markov Chain Monte Carlo
–	SPRING BREAK
11-12	Gibbs Sampling; Laplace Approximation; Variational Bayes
13	More on nonparametric Bayes GPs, DPs, etc.
14-15	Advanced topics: inferential planning, Bayesian NNs,...; final project short talks

or online. Failure to adhere to such behavioral standards may be subject to discipline. Professional courtesy and sensitivity are especially important with respect to individuals and topics dealing with race, color, national origin, sex, pregnancy, age, disability, creed, religion, sexual orientation, gender identity, gender expression, veteran status, marital status, political affiliation, or political philosophy. For more information, see the classroom behavior policy, the Student Code of Conduct, and the Office of Institutional Equity and Compliance.

ACCOMMODATION FOR DISABILITIES, TEMPORARY MEDICAL CONDITIONS, AND MEDICAL ISOLATION If you qualify for accommodations because of a disability, please submit your accommodation letter from Disability Services to your faculty member in a timely manner so that your needs can be addressed. Disability Services determines accommodations based on documented disabilities in the academic environment. Information on requesting accommodations is located on the Disability Services website. Contact Disability Services at 303-492-8671 or dsinfo@colorado.edu for further assistance. If you have a temporary medical condition, see Temporary Medical Conditions on the Disability Services website.

If you have a temporary illness, injury or required medical isolation for which you require adjustment, please email the instructor to inform them and discuss your class related needs. Per FERPA student privacy laws, students are NOT required to state the nature of their illness when alerting the instructor. "Doctor's notes" are NOT required for classes missed due to illness; campus health services no longer provide "doctor's notes" or appointment verifications.

PREFERRED STUDENT NAMES AND PRONOUNS CU Boulder recognizes that students' legal information doesn't always align with how they identify. Students may update their preferred names and pronouns via the student portal; those preferred names and pronouns are listed on instructors' class rosters. In the absence of such updates, the name that appears on the class roster is the student's legal name.

HONOR CODE All students enrolled in a CU Boulder course are responsible for knowing and adhering to the Honor Code. Violations of the Honor Code may include but are not limited to: plagiarism (including use of paper writing services or technology [such as essay bots]), cheating, fabrication, lying, bribery, threat, unauthorized access to academic materials, clicker fraud, submitting the same or similar work in more than one course

without permission from all course instructors involved, and aiding academic dishonesty. Understanding the course's syllabus is a vital part in adhering to the Honor Code. All incidents of academic misconduct will be reported to Student Conduct & Conflict Resolution: StudentConduct colorado.edu. Students found responsible for violating the Honor Code will be assigned resolution outcomes from the Student Conduct & Conflict Resolution as well as be subject to academic sanctions from the faculty member. Visit the Honor Code website for more information on the academic integrity policy.

SEXUAL MISCONDUCT, DISCRIMINATION, HARASSMENT AND/OR RELATED RETALIATION CU Boulder is committed to fostering an inclusive and welcoming learning, working, and living environment. University policy prohibits protected-class discrimination and harassment, sexual misconduct (harassment, exploitation, and assault), intimate partner abuse (dating or domestic violence), stalking, and related retaliation by or against members of our community on- and off-campus. The Office of Institutional Equity and Compliance (OIEC) addresses these concerns, and individuals who believe they have been subjected to misconduct can contact OIEC at 303-492-2127 or email cureportcolorado.edu. Information about university policies, reporting options, and support resources can be found on the OIEC website.

Please know that faculty and graduate instructors must inform OIEC when they are made aware of incidents related to these policies regardless of when or where something occurred. This is to ensure that individuals impacted receive outreach from OIEC about resolution options and support resources. To learn more about reporting and support for a variety of concerns, visit the Don't Ignore It page.

RELIGIOUS ACCOMMODATIONS Campus policy requires faculty to provide reasonable accommodations for students who, because of religious obligations, have conflicts with scheduled exams, assignments or required attendance. Please communicate the need for a religious accommodation in a timely manner. In this class, you must notify the instructor at least 2 weeks in advance to schedule make up for completing and turning in exams and other assignments (see Course Details above). See the campus policy regarding religious observances for full details.