# DS 6014: Bayesian Machine Learning

Donald E. Brown
102 Olsson Hall and Dell-2
brown@virginia.edu

August 18, 2022

*Teaching Assistant:* Hossein Kaviani Hameani hk3sku@virginia.edu

*Course Description:* Bayesian approaches explicitly account for the uncertainty present in most machine learning problems. This uncertainty derives from both randomness in observational processes, as well as, incompleteness in problem understanding. This course focuses on building models from data that provide both predictions and also quantify the uncertainty in these predictions. Students will learn how to think probabilistically and apply this understanding to problems in variety of areas. Course topics include: Bayesian supervised learning; the expectation maximization algorithm; Gaussian processes, variational approximation; Markov chain Monte Carlo; and Bayesian graphical models.

*Prerequisites:* This course will be mathematical. You should have a good grasp of multivariate calculus and linear algebra. A previous course in statistics covering multiple linear regression, and programming with familiarity in either python or R are also required.

*Learning Objectives:* Upon successful completion of this course, you will be able to:

1. Apply the appropriate probabilistic technique to use based on the characteristics of the problem.
2. Demonstrate the ability to convert actual data science problems from different domains into formal, mathematical representations.
3. Demonstrate the ability to apply appropriate analytical or computational solutions to obtain solutions to real problems.
4. Use results from current applied technical papers and video presentations to understand the latest methods and newest discoveries in Bayesian machine learning.

*Delivery Mode:* Active learning in classroom meetings

*Textbooks:*

Barber, David, *Bayesian Reasoning and Machine Learning*, Cambridge University Press: New York, 2012.

Bishop, Christopher, *Pattern Recognition and Machine Learning*, Springer, 2006.

Robert, Christian, *The Bayesian Choice: From Decision-Theoretic Foundations to Computational Implementation*, Springer 2017.

Theodoridas, Sergios *Machine Learning: A Bayesian and Optimization Perspective*, Elsevier, 2015

*Other relevant texts:*

DeGroot, Morris, *Optimal Statistical Decisions*, McGraw-Hill, New York, 1970.

Gelman, Andrew, John B. Carlin, Hal S. Stern, and Donald B Rubin, *Bayesian Data Analysis*, Chapman & Hall/CRC: Boca Raton, Fl USA, 2014

Kruske, John K., *Doing Bayesian Data Analysis: A Tutorial with R, JAGS, and Stan*, Academic Press: London 2015.

Martin, Osvaldo, *Bayesian Analysis with Python*, 2nd ed., Packt: Birmingham, UK, 2018.

*Course Topics:*

- Probability Review
- Bayesian Modeling
- Bayesian Graphical Models
- Kernel methods and Gaussian proceesses
- Sampling and Markov Chain Monte Carlo
- Variational Inference

*Student Performance Evaluation and Assessment:*

*Homework:*

There are five homework exercises spread throughout the course that illustrate the concepts of Bayesian machine learning and provide the opportunity to demonstrate understanding of class material.

These assignments will include both analytical problem solving and data analysis. For both parts your answers should be written out. Show results with tables and graphs and explain them in the text. When required submit your code in python using a jupyter notebook.

Most homework will be done individually, but there may be some assignments to be done in groups assigned by the instructor.

You may discuss the assignments with others in the class, **but you must do your own work and all writing must be your own.**

You will be required to submit an honor pledge with each homework (see below).

*Project:* The goal of the project is for you to apply Bayesian machine learning to a real dataset in an advanced way. This means that the project should show you can apply probabilistic reasoning to a non-trivial problem of your choosing. I will grade the assignment based on the approach you use and your demonstration of your understanding of probabilistic modeling and not on the comparative performance of different techniques.

You will work on this project in groups of two or three people of your choosing. If you want to work alone or with a group of four, you will need my permission.

You must submit a project proposal. This proposal should be no more than one page and describe the problem, data, and approach. If your project uses material from later in the course you will need to read ahead. I will provide feedback on your proposal.

You will give a presentation of your project which should briefly describe the problem, your approach, and your results. Everyone in a group must present. You will be expected to answer questions on your project.

You will submit a written report containing the problem description, approach, results and conclusions and recommendations. The report should be no more than four pages excluding references.

You may discuss the project with others in the class, **but you must do your own work and all writing must be your own or that of your group.**

*Quizzes:* The course has two graded exams: one midterm and one final. These exams will contain short answer questions and be closed book. Many of the class sessions will include ungraded quizzes and some of these questions will be examples of what to expect on the graded quizzes.

*Class Participation:* You may earn a few extra points for class participation, which includes asking and answering questions, as well as, helping others answer questions.

*Honor Policy:*

For homework reports and the project you may consult others in the class. However, the work you submit must be your own. You may not copy the work of anyone else. Cited material must be properly referenced in your reports. If you have questions, consult the course instructor or teaching assistant.

***If you cheat or copy from someone else on a graded quiz or exam, or copy someone else's work in a homework report or***

***project report without citation then you will fail the course regardless of your grade on other assessed material.***

Every homework, project, and the exams must include acknowledgment that you abided by the honor code. Failure to include this acknowledgment will mean that your submission will not be graded.

*Grading Distribution:*

| | |
|---|---|
| Homework | 35% |
| Midterm and Final | 11% and 22%, respectively |
| Project Presentation | 16% |
| Project Report | 16% |
| Class Participation | up to 5 additional points on your class grade |

*Diversity and Inclusion:*

My expectation is that we all contribute to an inclusive and respectful classroom culture that reflects the School of Data Science's commitment to being a space in which you can find true belonging and a sense of shared community. The diversity (referring to the multiple ways that we identify ourselves, including but not limited to race, color, national origin, language, sex, disability, age, sexual orientation, gender identity, religion, creed, ancestry, belief, veteran status, or genetic information) of our classroom is a strength. You are expected to respectfully embrace the opportunity to engage, collaborate, and learn with/from a diverse team of classmates. Additionally, I will note that it is possible that, even though our course material is primarily scientific in nature, there may be covert biases in the material due to the lens with which it was written. I welcome feedback and suggestions to improve upon the inclusivity of the material. We are all responsible for ensuring that our actions/experience align with our stated values. Please consider yourselves to be my accountability partners in creating an inclusive environment that supports a diversity of perspectives, do not hesitate to reach out if you have concerns, ideas, or questions about your experience. If you find yourself in need of additional support, please consider the following resources:

- SDS Associate Dean for DEI, Siri Russell ssr5v@virginia.edu
- *UVA Just Report It*
- Student Disability Access Center 434-243-5180

*Students with Disabilities:*

One of my goals in this class it to create a learning environment that is as accessible as possible to all students. If you anticipate any issues related to the format, materials, or requirements of this course, please meet with me outside of class so that we may discuss potential options. Students with disabilities may wish to contact the Student Disability Access Center (SDAC) to discuss a range of options to removing barriers to learning,

including official accommodations. Please visit their *website* to view information on their services and apply on-line. If you have already met with SDAC and been approved for accommodations, please send me the letter and schedule an appointment with me so that we can discuss the implementation of the plan.

*Sexual Misconduct Prevention:*

The University of Virginia is dedicated to providing a safe and equitable learning environment for all students. To that end, it is vital that you know two values that I and the University hold as critically important:

1. Power-based personal misconduct will not be tolerated.
2. Everyone has a responsibility to do their part to maintain a safe community on Grounds.

If you or someone you know has been affected by power-based personal misconduct, more information can be found on the UVA Sexual Misconduct *website* that describes reporting options and resources available - As your professor and as a person, know that I care about you and your well-being and stand ready to provide support and resources as I can. As a faculty member, I am a responsible employee, which means that I am required by University policy and federal law to report what you tell me to the University's Title IX Coordinator. The Title IX Coordinator's job is to ensure that the reporting student receives the resources and support that they need, while also reviewing the information presented to determine whether further action is necessary to ensure survivor safety and the safety of the University community. If you would rather keep this information confidential, there are Confidential Employees you can talk to on Grounds that you can contact at this *page*. The worst possible situation would be for you or your friend to remain silent when there are so many here willing and able to help.

*Religious Accommodations for Students*

In accordance with the University's policy I will try to reasonably accommodate students so that they do not experience an adverse academic consequence when sincerely held religious beliefs or observances conflict with academic requirements of this course. Students who wish to request academic accommodation for a religious observance should submit their request in writing directly to me. Students may contact EOCR at uvaeocr@virginia.edu or (434) 924-3200 if they have any questions regarding this policy, which is set forth in the Academic Accommodation for Religious Observances section of PROV-008: Teaching Courses for Academic Credit, the Undergraduate Record, and the Graduate Record.