OR 664 / SYST 664 / CSI 674

Bayesian Inference and Decision Theory

Spring Semester, 2020
ENGR 1107 and Online
Monday 4:30-7:10 PM

The objective of this course is to introduce students to Bayesian inference and decision making and to provide practical experience in applications from information technology and engineering. Students will learn the fundamentals of the Bayesian theory of inference, including probability as a representation for degrees of belief, the likelihood principle, the use of Bayes Rule to revise beliefs based on evidence, conjugate prior distributions for common statistical models, and methods for approximating the posterior distribution. Graphical models are introduced for representing complex probability and decision models by specifying modular components. An overview is given of expected utility and decision theory. Students apply the methods to a variety of practical problems. Modern Bayesian computational methods are introduced.

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Prerequisites:
OR 542 or STAT 544 or STAT 554 or equivalent (a strong grounding in probability with calculus; skill in elementary data analysis; basic programming skills)

Textbook

Primary text (required): This book, published in 2009, provides about the right level of coverage and is an up-to-date treatment. *An electronic edition of this book is available to George Mason University students and faculty from the university library*. Computer code is available at the link below for most of the examples in the book.

Hoff, Peter D., *A First Course in Bayesian Statistical Methods*. Springer, 2009.

Secondary text (required): This recently published book was written primarily for social scientists. It is accessible, well-written, and gives a comprehensive treatment beginning from the very basics through sophisticated hierarchical Bayesian models. *An electronic edition of this book is available to George Mason University students and faculty from the university library*. Computer code is available at the github site for most of the examples in the book.

Kruschke, John, *Doing Bayesian Data Analysis: A Tutorial with R and Bugs* *(now with JAGS!).* Academic Press, 2011.

Reference text (recommended): This comprehensive text has become the standard reference in Bayesian statistical methods. The hyperlink below contains reviews, exercises, data sets and software.

Gelman, A., Carlin, J., Stern, H., Dunson, D. B., Vehtari, A. and Rubin, D., *Bayesian Data Analysis* (3rd edition). CRC Press, 2013.

Supplemental text (recommended): This recently published book provides comprehensive coverage of computational Bayesian statistics with a focus on conducting Bayesian analyses of real data sets. The range of topics covered is much more extensive than the Hoff text, and will serve as a useful supplement for readers interested in Bayesian treatment of topics not covered in this course, such as generalized linear models, capture-recapture experiments, time series and image analysis. R code and a solution manual are available.

Marin, Jean-Michel and Robert, Christian, *Bayesian Essentials with R* (2nd edition). Springer, 2014.

Alternate text: The text by Peter Lee is accessible and may be helpful as an alternative treatment. Again, the hyperlink contains additional information, including exercises, solutions, errata and software.

Lee, Peter, *Bayesian Statistics: An Introduction* (4th edition), Wiley, 2012.

Software

- Many of the homework and exam exercises can be managed with a full-featured spreadsheet package such as Microsoft Excel. Many others, especially later in the semester, will require more power (see below).
- We will use R, a powerful (free) statistical graphics and computing language, and JAGS, an open-source, cross-platform engine for Bayesian data analysis that can be accessed from within R. Many of the exercises will require programming in R. RStudio is an integrated development environment for R.

Prerequisites

- The formal listed prerequisite is OR 542 or STAT 544 or STAT 554 or equivalent.
- The real prerequisites are:
  - Experience with elementary data analysis such as scatterplots, histograms, hypothesis tests, confidence intervals, and simple linear regression.
  - A calculus-based probability course - elementary probability theory, discrete and continuous probability distributions, probability mass and probability density functions, cumulative distribution functions, common parametric models such as the normal, binomial and Poisson distributions.
  - Experience with a high-level programming language. We will use R, a programming language for data analysis, and JAGS, a language for specifying and performing inference with Bayesian models.
  - Comfort with mathematical notation. We will not do proofs, but you will be expected to be comfortable following and doing mathematical derivations.

Requirements

Grades will be based on the following:

Homework assignments 30%

Midterm exam (take-home) 35%

Final exam (take-home) 35%

Homework problems will be due one week from the day they are assigned. Eight to ten assignments will be given during the semester. Students are encouraged to work together on homework exercises, but solutions must be written up individually. Exams will be take-home and will be similar to the homework problems. Students are expected to work by themselves on the exams.

Policies and Resources

Schedule

The topics are listed below, along with readings from the Hoff text. The take-home midterm exam will be posted by March 2 and will be due on Monday, March 23. The exam will include all material covered prior to spring break. The final exam will be due on Monday, May 11 at 11:59 PM. The final exam will be cumulative.

Unit 1	A Brief Tour of Bayesian Inference and Decision Theory	Week 1	Hoff, Chapter 1
Unit 2	Random variables, Parametric Models and Inference from Observation	Weeks 2-3	Hoff, Chapter 2
Unit 3	Bayesian Inference with Conjugate Pairs: Single Parameter Models	Weeks 3-5	Hoff, Chapter 3
Unit 4	Monte Carlo Approximation	Weeks 5-6	Hoff, Chapter 4
Unit 5	The Normal Model	Week 6-7	Hoff, Chapter 5
Unit 6	Gibbs Sampling	Week 8-9	Hoff, Chapter 6
Unit 7	Hierarchical Bayesian Models	Week 10-11	Hoff, Chapter 8
Unit 8	Bayesian Regression	Week 12	Hoff, Chapter 9
Unit 9	Additional Monte Carlo Methods	Week 13	Hoff, Chapter 9, readings
Unit 10	Hypothesis Tests, Bayes Factors and Bayesian Model Averaging	Week 14	Hoff, Chapter 10