Bayesian Statistics

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Sample Syllabus

Course Description

The purpose of this course is to give students a broader understanding of statistical inference, based on the logic of *Bayesian* thinking. This class provides a primer on Bayesian statistical methods, serving as a critical complement to the traditional (frequentist) approach. The content will be centered around regression analysis, so that students that have already been introduced to it may experience a smooth transition to Bayesian thinking.

Course Objectives

By the end of the course, students will be able to:

- Think critically about traditional and Bayesian inferential methods;
- Perform statistical analyses using R and Stan;
- Use modern techniques, especially Markov Chain Monte Carlo (MCMC) for posterior estimation.

Prerequisites

Introductory courses on Calculus and Probability & Statistics are strongly recommended. A course on Econometrics may also be helpful.

References

Required Textbook:

- R. McElreath (2020). *Statistical Rethinking: A Bayesian course with examples in* R *and Stan*, 2nd edition. CRC Press.

Additional References:

- E. T. Jaynes (2003). *Probability Theory: The logic of science*. Cambridge University Press.

- A. Gelman, J. Carlin, H. Stern, D. Dunson, A. Vehtari, and D. Rubin (2013). *Bayesian Data Analysis*, 3rd edition. CRC Texts in Statistical Science.
- J. Albert (2009). *Bayesian Computation with* R, 2nd edition. Springer.
- J. Kruschke (2015). *Doing Bayesian Data Analysis: A tutorial with* R, *JAGS, and Stan*, 2nd edition. Elsevier.

Required Software

- Download R: http://www.r-project.org
- Download RStudio: http://www.rstudio.com
- Download RStan: http://mc-stan.org/rstan.html

Grading

Assignments (50%) + Participation (10%) + Research Paper (40%)

Assignments

This class will have no exams, and students will be asked to complete several Problem Sets. Based on covered topics, these will ask theoretical and applied questions, so that students apply class content with artificial and real data sets. Group work is strongly recommended, but students must turn in individual sumbissions.

Class Participation

Class attendance is required, and class participation is a crucial part of class dynamics.

Research paper

Students will be asked to turn in a research paper, due the last day of class. These must be no longer than 15 pages, double spaced. Undergraduate students may work in pairs, while graduate students are required to turn in individual papers. The purpose of this assignment is to apply the concepts seen in class, performing empirical Bayesian analysis on real-world data. Further instructions will be given in class, as well as instructor guidance whenever needed. As the semester evolves, we will periodically assess some checkpoints for the paper, such as research questions, data sets, and the appropriate methods to answer these questions.

Letter Grade Distribution

- Excellent, superior performance: A (93-100%), A- (90-92.9%)
- Good performance: B+ (87-89.9%), B (83-86.9%), B- (80-82.9%)
- Standard performance: C+ (77-79.9%), C (73-76.9%), C- (70-72.9%)
- Substandard performance: D+ (67-69.9%), D (63-66.9%), D- (60-62.9%)
- Unsatisfactory performance: E (0-59.9%)

Class Policies

You can expect me to:

- Grade and provide feedback on assignments and exams within one week from the due date;
- Reply to emails/messages within 24 hours during the week and within 48 hours on weekends and holidays;
- Hold weekly in person/virtual office hours, where students can join and ask every question and talk about any issues/concerns relative to our class. For virtual cases, links for each meeting will be provided every week.

I expect students to:

- Come to class prepared, by checking out announcements, new content updates, and studying the assigned readings;
- Take the exams on the scheduled dates. No make-up exams will be allowed, except in cases of documented medical emergencies or religious circumstances;
- Respectfully participate in in-class discussions and activities;
- Immediately notify me in the event of an emergency that prevents you from doing an exam or completing the course;
- Ask questions if any expectations or assignments are unclear.

Tentative Course Outline

The course will follow 13 sections, whose readings are detailed below:

1. **Course introduction; Motivating a Bayesian approach to Statistics**

- *Required Readings*:
  - McElreath (2020), ch 1.
- *Recommended Readings*:
  - Jaynes (2003), Preface and ch. 1–3.

2. **Breaking down Bayes' theorem: Prior, likelihood, and posterior**

- *Required Readings*:
  - McElreath (2020), ch. 2.
- *Recommended Readings*:
  - Albert (2009), ch. 2.

3. **Getting closer to the posterior: Grid and quadratic approximations**

- *Required Readings*:
  - McElreath (2020), ch. 3.

4. **Bayesian regression models I: single-regressor models**

- *Required Readings*:
  - McElreath (2020), ch. 4.
- *Recommended Readings*:
  - Gelman et al. (2013), ch. 14.

5. **Bayesian regression models II: multiple-regressor models**

- *Required Readings*:
  - McElreath (2020), ch. 5.
- *Recommended Readings*:
  - Gelman et al. (2013), ch. 14.

6. **Bayesian regression models III: Interactions and *dummy* variables**

- *Required Readings*:
  - McElreath (2020), ch. 8.
- *Recommended Readings*:
  - Gelman et al. (2013), ch. 14.

7. **Markov Chain Monte Carlo (MCMC) methods I: Introduction**

- *Required Readings*:
  - McElreath (2020), ch. 9.
- *Recommended Readings*:
  - Kruschke (2015), ch. 7.

8. **Markov Chain Monte Carlo (MCMC) methods II: Hamiltonian Monte Carlo**

- *Required Readings*:
  - McElreath (2020), ch. 9.
- *Recommended Readings*:
  - Kruschke (2015), ch. 9.

9. **Markov Chain Monte Carlo (MCMC) methods III: Diagnostic tests and evaluation**

- *Required Readings*:
  - McElreath (2020), ch. 9.
- *Recommended Readings*:
  - Kruschke (2015), ch. 9.

10. **Information theory and maximum entropy distributions**

- *Required Readings*:
  - McElreath (2020), ch. 10.

11. **Limited dependent variable models**

- *Required Readings*:
  - McElreath (2020), ch. 11.

12. **Hierarchical models I: Introduction and motivation**

- *Required Readings*:
  - McElreath (2020), ch. 13.
- *Recommended Readings*:
  - Albert (2009), ch. 7

13. **Hierarchical models II: Examples**

- *Required Readings*:
  - McElreath (2020), ch. 13.
- *Recommended Readings*:
  - Albert (2009), ch. 7.

Space for University Policies and Procedures