STAT 695 — Bayesian Data Analysis

Fall 2017

Credit Hours: 3

Lectures: Tuesday & Thursday / 9:00 - 10:15 AM / GRIS 126

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Course Website: Blackboard (`mycourses.purdue.edu`)

Required Textbook: Gelman A., Carlin J.B., Stern H.S., Dunson D.B., Vehtari A., Rubin D.B. (2013). *Bayesian Data Analysis* (3rd ed.). Chapman and Hall/CRC. ISBN 978-1439840955.

Supplementary Textbooks: Bishop C.M. (2006). *Pattern Recognition and Machine Learning*. Springer-Verlag. ISBN 978-0387310732.

Christensen R., Johnson W., Branscum A., Hanson T.E. (2010). *Bayesian Ideas and Data Analysis: An Introduction for Scientists and Statisticians*. Chapman and Hall/CRC. ISBN 978-1439803547.

Carlin B.P., Louis T.A. (2008). *Bayesian Methods for Data Analysis* (3rd ed.). Chapman and Hall/CRC. ISBN 978-1584886976.

Course Description: Bayesian data analysis refers to practical inferential methods that use probability models for both observable and unobservable quantities. The flexibility and generality of these methods allow them to address complex real-life problems that are not amenable to other techniques. This course will provide a pragmatic introduction to Bayesian data analysis and its powerful applications. Topics include: the basics of Bayesian inference for single and multiparameter models, regression, hierarchical models, model checking, approximation of a posterior distribution by iterative and non-iterative sampling methods, and Bayesian nonparametrics. Specific topics and the course outline are subject to change as the semester progresses. All topics will be motivated by problems from the physical, life, social, and management sciences. Conceptual understanding and inference via computer simulation will be emphasized throughout the course.

Course/Learning Objectives:

- Acquire fluency in the principles and techniques of Bayesian data analysis.

- Apply Bayesian methodology to solve real-life problems.
- Utilize `R` for Bayesian computation, visualization, and analysis of data.
  - `R` is freely available for download here. Free manuals are available here.
  - Assistance for `R` is available at the help desk in MATH G175.
- Discuss what is learned in lecture and assignments through an oral presentation and written report.

Prerequisites: Introductory graduate-level courses in probability and statistics, such as STAT 516 and 517, and familiarity with computing. Students should have some programming experience using a language such as `R`, Python, or MATLAB. The ability to write, debug, and execute programs in at least one of the above languages is required. Advanced graduate-level statistics courses, such as STAT 519, STAT 525, STAT 528, and STAT 532 are strongly recommended.

Course Outline:

- **Week 1**: Introduction to Bayesian inference and `R` (Chapters 1 – 3 of BDA).
  - **Lecture 1 (8-22-2017)**: Overview of Bayesian statistics and `R`.
  - **Handout (Due 8-24-2017)**: Background survey.
  - **Lecture 2 (8-24-2017)**: Bayesian inference from Binomial and Multinomial data. Elicitation of prior knowledge from a subject-matter expert. Analytic, discrete approximation, and Monte Carlo posterior calculation methods.
  - **Homework 1 (Due 9-7-2017)**: Problems based on Chapters 1 – 3 of BDA.
- **Week 2**: Standard parametric models (Chapters 2 – 3 of BDA).
  - **Lecture 3 (8-29-2017)**: Normal Data and the general exponential family.
  - **Lecture 4 (8-31-2017)**: Multivariate Normal distribution.
- **Week 3**: Linear regression (Chapter 14 of BDA).
  - **Lecture 5 (9-5-2017)**: Bayesian analysis of classical regression.
  - **Lecture 6 (9-7-2017)**: Ridge and Lasso regression.
  - **Homework 2 (Due 9-21-2017)**: Problems based on Chapters 3, 5, and 14 of BDA.
- **Week 4**: Hierarchical models (Chapter 5 of BDA).
  - **Lecture 7 (9-12-2017)**: Exchangeability and setting up hierarchical models. Computation with hierarchical models.
  - **Lecture 8 (9-14-2017)**: Hierarchical Normal model.
- **Week 5**: Model checking and improvement (Chapters 6 and 7 of BDA).
  - **Lecture 9 (9-19-2017)**: Posterior predictive checks.
  - **Lecture 10 (9-21-2017)**: Evaluating and comparing models.
  - **Homework 3 (Due 10-12-2017)**: Problems based on Chapters 6, 7, 10, and 11 of BDA.
- **Week 6**: Introduction to Bayesian computation (Chapters 10 and 11 of BDA).
  - **Lecture 11 (9-26-2017)**: Overview of deterministic and Monte Carlo approximations of posterior distributions. Rejection and importance sampling.

  - **Lecture 12 (9-28-2017)**: An introduction to Markov Chain Monte Carlo and the Metropolis-Hastings algorithm.
  - **Project Description: Due 10-5-2017**.
- **Week 7**: Bayesian computation (cont'd) (Chapter 11 of BDA).
  - **Lecture 13 (10-3-2017)**: The Gibbs sampler.
  - **Lecture 14 (10-5-2017)**: MCMC practicalities and advanced techniques.
- **Week 8**: Advanced MCMC algorithms (Chapter 12 of BDA).
  - **October Break (10-10-2017)**: No class.
  - **Lecture 15 (10-12-2017)**: Data augmentation, annealing/tempering, and slice sampling.
  - **Homework 4 (Due 10-26-2017)**: Problems based on Chapters 11 and 12 of BDA.
- **Week 9**: Hamiltonian Monte Carlo and its applications (Chapters 12 and 16 of BDA).
  - **Lecture 16 (10-17-2017)**: Hamiltonian Monte Carlo.
  - **Lecture 17 (10-19-2017)**: Applications of Hamiltonian Monte Carlo for logistic regression.
- **Week 10**: Applications of MCMC (Chapters 15 and 22 of BDA).
  - **Lecture 18 (10-24-2017)**: **Cancelled -** Hierarchical linear models.
  - **Lecture 19 (10-26-2017)**: Finite mixture models.
  - **Homework 5 (Due 11-9-2017)**: Problems based on Chapters 12, 15, 16, and 22 of BDA.
- **Week 11**: Modal and distributional approximations (Chapter 13 of BDA).
  - **Lecture 20 (10-31-2017)**: Approximations based on posterior modes.
  - **Lecture 21 (11-2-2017)**: The EM (meta) algorithm.
- **Week 12**: Modal and distributional approximations (cont'd) (Chapter 13 of BDA).
  - **Lecture 22 (11-7-2017)**: Variational inference.
  - **Lecture 23 (11-9-2017)**: Applications of variational inference.
  - **Homework 6 (Due 11-30-2017)**: Problems based on Chapter 8, 13, and 18 of BDA.
  - **Project Progress Report: Due 11-16-2017**.
- **Week 13**: Gaussian process models (Chapter 21 of BDA).
  - **Lecture 24 (11-14-2017)**: Gaussian processes and a taste of Bayesian nonparametrics.
  - **Lecture 25 (11-16-2017)**: Presentations on progress of projects.
- **Week 14**: Dirichlet process models (Chapter 23 of BDA).
  - **Lecture 26 (11-21-2017)**: Dirichlet processes and a taste of Bayesian nonparametrics.
  - **Thanksgiving Break (11-23-2017)**: No class.
- **Week 15**: Causal inference (Chapter 8 of BDA).

  - **Lecture 27 (11-28-2017)**: An introduction to the Rubin Causal Model and noncompliance.
  - **Lecture 28 (11-30-2017)**: Bayesian data analysis for experiments in the presence of noncompliance.
- **Week 16**: Review, and open problems in Bayesian data analysis.
- **Week 17**: Project presentations.

Course Work and Requirements:

	Percentage of Grade
Homework	50%
Group Project	50%

- *Homework* will generally be posted on a Thursday, and due two or three weeks later (**before lecture begins**). No late homework will be accepted. There will be 6 homework assignments accounting for 50% of your course grade. The lowest homework score will be dropped. R Markdown should be used for homework submission. A short tutorial can be found here: `http://tinyurl.com/gqyoaxm`. You may discuss problems with other students, but you *must* write your own solution independently, and *must* provide the names of students that you had significant discussions with.
- *Group projects* will be due at the end of the semester. Specific details on the project will be given in a separate handout.

For both your homework and group projects, please note the Purdue Honors Pledge: "As a Boilermaker pursuing academic excellence, I pledge to be honest and true in all that I do. Accountable together - we are Purdue."

Course Policies

Addressing Questions via E-mail: Please feel free to e-mail questions to the instructors, but reserve those that involve extensive computation or mathematical expressions for office hours. If your question involves programming, please be sure to e-mail a minimal working example of your code to the instructors.

Incompletes: Incompletes will only be given under emergency circumstances, e.g., a serious auto accident, death of family member, etc. (see the grief absence policy for further information). Incompletes will not be given to students failing the course.

Grading: The grading scale is predetermined so as to eliminate competition with other students, and to ensure that you always know your grade in the class. Your grade is based upon *your* performance only. Grades will not be curved.

Grade	Numerical range
A	90.00-100.00
B	80.00-89.99
C	70.00-79.99
D	60.00-69.99
F	0.00-59.99

Evaluation: Student feedback is essential for any course to be successful. Feedback questionnaires will be included in each assignment. These evaluations should be taken seriously, and will be addressed directly by the instructor.

Re-grading: All grade disputes are to be made on paper, and submitted *directly* to either Professor Sabbaghi or Professor Rao. Discussions or arguments for re-grades will *not* be done in person. A student has until one week after receiving his/her grade to dispute the grade (in writing). Handling re-grades in this manner eliminates the "end of the semester" digging for points.

When disputing a grade, you should state the question, the dispute, and the number of points you feel you should have received for the question. If you do not state the number of points you think are reasonable for the re-grade, zero points will be give as the re-grade. Please note that when you ask for a question to be re-graded, the entire assignment may be re-graded, and there is a possibility of losing points.

Dropping the Course: The instructors reserve the right to *not* sign anyone out of the course once the deadline for dropping without the instructors signature has passed. Please take care to pay attention to these dates.

Attendance and Participation: Students: You are expected to attend lectures. You are expected to arrive on time, or before. You are expected to stay until the end of lecture unless you have asked in advance to leave early. You are expected to be prepared and participate. On the rare occasion that a student is extremely close to the cut-off value between letter grades, attendance and class participation may help.

When conflicts or absences can be anticipated, such as for many University sponsored activities and religious observations, you should inform the instructors of the situation as far in advance as possible. For unanticipated or emergency absences when advance notification is not possible, you should contact the instructors as soon as possible by e-mail, or the Department of Statistics main office. When you are unable to make direct contact with the instructors and unable to leave word with the Department of Statistics because of circumstances beyond your control, and in cases of bereavement, you or your representative should contact the Office of the Dean of Students. The instructors will try to accommodate you either by excusing you or by allowing you an extension when possible. Ultimately, you are responsible for all required coursework and bear full responsibility for any academic consequences that may result due to your absence.

Links to the complete attendance policy and implications can be found at

www.purdue.edu/advocacy/students/absences.html and
www.purdue.edu/studentregulations/regulations_procedures/classes.html.

Professors: You can expect that we will attend lectures. We will arrive in the lecture room prior to the start of lecture, and will end lecture on time. You can expect that we will be prepared for lecture, try our best to convey the information for the course, and show respect for all students.

If we are unable to attend lecture you will know in advance, and we will either cancel class or provide a guest instructor. We will be present for our office hours, and available for scheduled appointments.

The amount of material covered in each lecture is governed by the speed with which we complete the material. Every group of students is different, and we would rather teach the material well (and have you learn it) than speed through the topics for the purpose of covering a preset number of topics. Accordingly, the course outline is subject to change as the course progresses.

Grief Absence Policy for Students: Purdue University recognizes that a time of bereavement is very difficult for a student. The University therefore provides the following rights to students facing the loss of a family member through the Grief Absence Policy for Students (GAPS). Students will be excused for funeral leave and given the opportunity to earn equivalent credit and to demonstrate evidence of meeting the learning outcomes for missed assignments or assessments in the event of the death of a member of the student's family.

Counseling and Psychological Services Information: Purdue University is committed to advancing the mental health and well-being of its students. If you or someone you know is feeling overwhelmed, depressed, and/or in need of support, services are available. For help, such individuals should contact Counseling and Psychological Services (CAPS) at 765-494-6995 and www.purdue.edu/caps/ during and after hours, on weekends and holidays, or through its counselors physically located in the Purdue University Student Health Center (PUSH) during business hours.

University Emergency Information: A safety briefing will be conducted on the first day of class. In the event of a major campus emergency or temporary suspension of classes, course requirements, deadlines and grading percentages are subject to changes that may be necessitated by a revised semester calendar or other circumstances beyond the instructors' control. You can get information about changes in this course by means of the course web page, or contacting the instructors via e-mail or phone. You are expected to read your Purdue e-mail on a frequent basis.

Violent Behavior Policy: Purdue University is committed to providing a safe and secure campus environment for members of the university community. Purdue strives to create an educational environment for students and a work environment for employees that promote educational and career goals. Violent behavior impedes such goals. Therefore, violent behavior is prohibited in or on any University Facility or while participating in any university activity. See the following website for more details: www.purdue.edu/policies/pages/facilities_lands/i_2_3.shtml.

Academic Dishonesty: Purdue prohibits "dishonesty in connection with any University activity. Cheating, plagiarism, or knowingly furnishing false information to the University are examples of dishonesty." [Part 5, Section III-B-2-a, University Regulations] Furthermore, the University Senate has stipulated that "the commitment of acts of cheating, lying, and deceit in any of their diverse forms (such as the use of substitutes for taking examinations, the use of illegal cribs, plagiarism, and copying during examinations) is dishonest and must not be tolerated. Moreover, knowingly to aid and abet, directly or indirectly, other parties in committing dishonest acts is in itself dishonest." [University Senate Document 72-18, December 15, 1972].

Academic integrity is one of the highest values that Purdue University holds. You are encouraged to alert university officials to potential breeches

of this value by either e-mailing integrity@purdue.edu, calling 765-494-8778, or contacting the Office of the Dean of Students (www.purdue.edu/odos). While information may be submitted anonymously, the more information that is submitted provides the greatest opportunity for the university to investigate the concern. Bonus points will be given to students who report instances of cheating.

Incidents of academic misconduct in this course will be addressed by the course instructor and referred to the Office of Student Rights and Responsibilities (OSRR, www.purdue.edu/odos/osrr/) for review at the university level. Any violation of course policies as it relates to academic integrity will result minimally in a failing or zero grade for that particular assignment, and at the instructor's discretion may result in a failing grade for the course. In addition, all incidents of academic misconduct will be forwarded to OSRR, where university penalties, including removal from the university, may be considered. Use of instructor solution manuals or related resources will not be tolerated.

For more information, please refer to Purdue's student guide for academic integrity (www.purdue.edu/odos/osrr/academic-integrity-brochure).

Use of Copyrighted Materials: Among the materials that may be protected by copyright law are the lectures, notes, and other material presented in class or as part of the course. Always assume the materials presented by the instructors are protected by copyright unless the instructors have stated otherwise. Students enrolled in, and authorized visitors to, Purdue University courses are permitted to take notes, which they may use for individual/group study or for other non-commercial purposes reasonably arising from enrollment in the course or the University generally.

Notes taken in class are, however, generally considered to be "derivative works" of the instructors' presentations and materials, and they are thus subject to the instructors' copyright in such presentations and materials. No individual is permitted to sell or otherwise barter notes, either to other students or to any commercial concern, for a course without the express written permission of the course instructor. To obtain permission to sell or barter notes, the individual wishing to sell or barter the notes must be registered in the course or must be an approved visitor to the class. Course instructors may choose to grant or not grant such permission at their own discretion, and may require a review of the notes prior to their being sold or bartered. If they do grant such permission, they may revoke it at any time, if they so choose.

Students with Disabilities: Purdue University is required to respond to the needs of the students with disabilities as outlined in both the Rehabilitation Act of 1973 and the Americans with Disabilities Act of 1990 through the provision of auxiliary aids and services that allow a student with a disability to fully access and participate in the programs, services, and activities at Purdue University.

If you have a disability that requires special academic accommodation, please make an appointment to speak with the instructor within the first three (3) weeks of the semester in order to discuss any adjustments. It is important to talk about this at the beginning of the semester. It is the student's responsibility to notify the Disability Resource Center (http://www.purdue.edu/drc) of an impairment/condition that may

require accommodations and/or classroom modifications.

Nondiscrimination: Purdue University is committed to maintaining a community that recognizes and values the inherent worth and dignity of every person; fosters tolerance, sensitivity, understanding, and mutual respect among its members; and encourages each individual to strive to reach his or her own potential. In pursuit of its goal of academic excellence, the University seeks to develop and nurture diversity. The University believes that diversity among its many members strengthens the institution, stimulates creativity, promotes the exchange of ideas, and enriches campus life. Purdue University's nondiscrimination policy can be found at www.purdue.edu/purdue/ea_eou_statement.html.

Purdue University prohibits discrimination against any member of the University community on the basis of race, religion, color, sex, age, national origin or ancestry, genetic information, marital status, parental status, sexual orientation, gender identity and expression, disability, or status as a veteran. The University will conduct its programs, services and activities consistent with applicable federal, state and local laws, regulations and orders and in conformance with the procedures and limitations as set forth in Executive Memorandum No. D-1, which provides specific contractual rights and remedies. Any student who believes they have been discriminated against may visit www.purdue.edu/report-hate to submit a complaint to the Office of Institutional Equity. Information may be reported anonymously.