

# STAT 695 — Bayesian Data Analysis

Fall 2020

CRN: 18484

Lectures: Tuesday & Thursday / 10:30 - 11:45 AM / RAWLS 1011

Credit Hours: 3

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**Course Website:** Brightspace (<https://purdue.brightspace.com/d2l/login>)

**Piazza:** ([piazza.com/purdue/fall2020/stat695](https://piazza.com/purdue/fall2020/stat695))

**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 fundamentals 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.

## Learning Outcomes:

- 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 [virtual Statistical Software Help Desk](#).
- Discuss what is learned in lectures 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 (8-25-2020):** Overview of Bayesian statistics and R.
  - **Handout (Due 8-27-2020):** Background survey.
  - **Lecture 2 (8-27-2019):** 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 9-10-2020):** Problems based on Chapters 1 – 3 of BDA.
- **Week 2:** Standard parametric models (Chapters 2 – 3 of BDA).
  - **Lecture 3 (9-1-2020):** Normal Data and the general exponential family.
  - **Lecture 4 (9-3-2020):** The Multivariate Normal distribution.
- **Week 3:** Linear regression (Chapter 14 of BDA).
  - **Lecture 5 (9-8-2020):** Bayesian analysis of classical regression.
  - **Lecture 6 (9-10-2020):** Ridge and Lasso regression.
  - **Homework 2 (Due 9-24-2020):** Problems based on Chapters 3, 5, and 14 of BDA.
- **Week 4:** Hierarchical models (Chapter 5 of BDA).
  - **Lecture 7 (9-15-2020):** Exchangeability and setting up hierarchical models. Computation with hierarchical models.
  - **Lecture 8 (9-17-2020):** The hierarchical Normal model.
- **Week 5:** Model checking and improvement (Chapters 6 and 7 of BDA).
  - **Lecture 9 (9-22-2020):** Posterior predictive checks.
  - **Lecture 10 (9-24-2020):** Evaluating and comparing models.
  - **Homework 3 (Due 10-15-2020):** 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 (9-29-2020):** Overview of deterministic and Monte Carlo approximations of posterior distributions. Rejection and importance sampling.
  - **Lecture 12 (10-1-2020):** An introduction to Markov Chain Monte Carlo and the Metropolis-Hastings algorithm.
  - **Project Description: Due 10-8-2020.**
- **Week 7:** Continuation of Bayesian computation (Chapter 11 of BDA).
  - **Lecture 13 (10-6-2020):** The Gibbs sampler.
  - **Lecture 14 (10-8-2020):** MCMC practicalities and advanced techniques.
- **Week 8:** Advanced MCMC algorithms (Chapter 12 of BDA).
  - **Lecture 15 (10-13-2020):** Data augmentation, annealing/tempering, and slice sampling.
  - **Lecture 16 (10-15-2020):** Sequential Monte Carlo and particle filtering.
  - **Homework 4 (Due 10-29-2020):** Problems based on Chapters 11 and 12 of BDA.
- **Week 9:** Hamiltonian Monte Carlo and its applications (Chapters 12 and 16 of BDA).
  - **Lecture 17 (10-20-2020):** Hamiltonian Monte Carlo.
  - **Lecture 18 (10-22-2020):** Applications of Hamiltonian Monte Carlo for logistic regression.
- **Week 10:** Applications of MCMC (Chapters 15 and 22 of BDA).
  - **Lecture 19 (10-27-2020):** Finite mixture models.
  - **Lecture 20 (10-29-2020):** Approximations based on posterior modes.
  - **Homework 5 (Due 11-12-2020):** Problems based on Chapters 12, 15, 16, and 22 of BDA.
- **Week 11:** Modal and distributional approximations (Chapter 13 of BDA).
  - **Lecture 21 (11-3-2020):** The EM (meta) algorithm.
  - **Lecture 22 (11-5-2020):** Hierarchical linear models.
- **Week 12:** Continuation of modal and distributional approximations (Chapter 13 of BDA).
  - **Lecture 23 (11-10-2020):** Variational inference.
  - **Lecture 24 (11-12-2020):** Applications of variational inference.
  - **Homework 6 (Due 11-24-2020):** Problems based on Chapters 8, 13, and 18 of BDA.
  - **Project Progress Report: Due 12-3-2020.**
- **Week 13:** Gaussian and Dirichlet process models (Chapters 21 and 23 of BDA).
  - **Lecture 25 (11-17-2020):** Gaussian processes and a taste of Bayesian nonparametrics.
  - **Lecture 26 (11-19-2020):** Dirichlet processes and a taste of Bayesian nonparametrics.
- **Week 14:** Causal inference (Chapter 8 of BDA).

- **Lecture 27 (11-24-2020):** An introduction to the Rubin Causal Model and noncompliance.
- **Thanksgiving Break (11-26-2020):** No class.
- **Week 15:** Project Progress Reports
  - **Lecture 28 (12-1-2020):** Bayesian data analysis for experiments in the presence of noncompliance [Webex Meeting].
  - **Lecture 29 (12-3-2020):** Presentations on progress of projects [Webex Meeting].
- **Week 16:** Project presentations [Webex Meeting].

### Course Work and Requirements:

	Percentage of Grade
Homework	50%
Group Project	50%

- *Homework* will generally be posted on Brightspace on a Thursday, and due approximately 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 at [shiny.rstudio.com/articles/rmarkdown.html](https://shiny.rstudio.com/articles/rmarkdown.html). You may discuss problems with other students, but you *must* write your own solution independently, and you *must* provide the names of students that you had significant discussions with. Homework will be e-mailed to the instructors.
- *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

**Academic Guidance in the Event a Student is Quarantined/Isolated:** If you become quarantined or isolated at any point in time during the semester, in addition to support from the Protect Purdue Health Center, you will also have access to an Academic Case Manager who can provide you academic support during this time. Your Academic Case Manager can be reached at [acmq@purdue.edu](mailto:acmq@purdue.edu) and will provide you with general guidelines/resources for communicating with your instructors, be available for academic support, and offer suggestions for how to be successful when learning remotely. Importantly, if you find yourself too sick to progress in the course, notify your academic case manager and notify the instructors via e-mail. We will make arrangements based on your particular situation. The office of the Dean of Students ([odos@purdue.edu](mailto:odos@purdue.edu)) is also available to support you should this situation occur.

**Protect Purdue:** The [Protect Purdue Plan](#), which includes the [Protect Purdue Pledge](#), is campus policy and as such all members of the Purdue community must comply with the required health and safety guidelines. Required behaviors in this class include: staying home and contacting the Protect Purdue Health Center (765-496-INFO) if you feel ill or know you have been exposed to the virus, wearing a mask [in classrooms and campus building](#), at all times (e.g., no eating/drinking in the classroom), disinfecting desk/workspace prior to and after use, maintaining proper social distancing with peers and instructors (including when entering/exiting classrooms), refraining from moving furniture, avoiding shared use of personal items, maintaining robust hygiene (e.g., handwashing, disposal of tissues) prior to, during and after class, and following all safety directions from the instructor.

Students who are not engaging in these behaviors (e.g., wearing a mask) will be offered the opportunity to comply. If non-compliance continues, possible results include instructors asking the student to leave class and instructors dismissing the whole class. Students who do not comply with the required health behaviors are violating the University Code of Conduct and will be reported to the Dean of Students Office with sanctions ranging from educational requirements to dismissal from the university.

Any student who has substantial reason to believe that another person in a campus room (e.g., classroom) is threatening the safety of others by not complying (e.g., not wearing a mask) may leave the room without consequence. The student is encouraged to report the behavior to and discuss next steps with their instructor. Students also have the option of reporting the behavior to the [Office of the Student Rights and Responsibilities](#). See also [Purdue University Bill of Student Rights](#).

**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 instructors.

**Re-grading:** All grade disputes are to be written and submitted *directly* to either Dr. Sabbaghi or Dr. 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 given 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. You should stay home and contact the Protect Purdue Health Center (765-496-INFO) if you feel ill, have any symptoms associated with COVID-19, or suspect that you have been exposed to the virus. In the current context of COVID-19, in-person attendance will not be a factor in the final grades, but you still need to inform the instructors of any conflict that can be anticipated and will affect the submission of an assignment or the ability to take an exam. Only the instructors can excuse you from a course requirement or responsibility.

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, by phone, through Brightspace, 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, quarantine, or isolation, you or your representative should contact the Office of the Dean of Students via e-mail or phone at 765-494-1747. 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. The course Brightspace includes a link on Attendance and Grief Absence policies under the University Policies menu.

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

[www.purdue.edu/advocacy/students/absences.html](http://www.purdue.edu/advocacy/students/absences.html) and

[www.purdue.edu/studentregulations/regulations\\_procedures/classes.html](http://www.purdue.edu/studentregulations/regulations_procedures/classes.html).

**Instructors:** 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 find yourself beginning to feel some stress, anxiety, and/or feeling slightly overwhelmed, try [Well-Track](#). Sign in and find information and tools at your fingertips, available to you at any time. If you need support and information about options and resources, please see the [Office of the Dean of Students](#) for drop-in hours (Monday - Friday, 8:00 AM - 5:00 PM). If you're struggling and need mental health services: 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 mental health support, services are available. For help, such individuals should contact [Counseling and Psychological Services \(CAPS\)](#) at 765-494-6995 during and after hours, on weekends and holidays, or by going to the CAPS office of the second floor of the Purdue University Student Health Center (PUSH) during business hours. If you find yourself struggling to find a healthy balance between academics, social life, stress, etc. sign up for free one-on-one virtual or in-person sessions with a [Purdue Wellness Coach at RecWell](#). Student coaches can help you navigate through barriers and challenges toward your goals throughout the semester. Sign up is completely free and can be done on BoilerConnect. If you have any questions, please contact Purdue Wellness at [evans240@purdue.edu](mailto:evans240@purdue.edu).

**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.

**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](mailto:integrity@purdue.edu), calling 765-494-8778, or contacting the Office of the Dean of Students ([www.purdue.edu/odos](http://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. More details are available on the course Brightspace table of contents, under University Policies.**

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](http://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.

**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.

Purdue University strives to make learning experiences as accessible as possible. If you anticipate or experience physical or academic behaviors based on disability, you are welcome to let the instructors know so that they can discuss options. You are also encouraged to contact the disability resource center at [drc@purdue.edu](mailto:drc@purdue.edu) or by phone 765-494-1247. If you have a disability that requires special academic accommodation, please make an appointment to speak with the instructors 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 ([www.purdue.edu/drc](http://www.purdue.edu/drc)) of an impairment/condition that may require accommodations and/or classroom modifications. More details are available on the course Brightspace page under Accessibility Information.

**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. More details are available on the course Brightspace table of contents, under University Policies. Purdue University's nondiscrimination policy can be found at [www.purdue.edu/purdue/ea\\_eou\\_statement.php](http://www.purdue.edu/purdue/ea_eou_statement.php).

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](http://www.purdue.edu/report-hate) to submit a complaint to the Office of Institutional Equity. Information may be reported anonymously.