Many fields of science are transitioning from null hypothesis significance testing (NHST) to Bayesian data analysis. Bayesian analysis provides rich information about the relative credibilities of all candidate parameter values for any descriptive model of the data, without reference to \( p \) values. Bayesian analysis applies flexibly and seamlessly to complex hierarchical models and realistic data structures, including small samples, large samples, unbalanced designs, missing data, censored data, outliers, etc. Bayesian analysis software is flexible and can be used for a wide variety of data-analytic models. (More about why to go Bayesian is described below.) This course shows you how to do Bayesian data analysis, hands on, with free software called R and JAGS. The course will use new programs and examples.

This course is offered through the Inter-university Consortium for Political and Social Research (ICPSR) Summer Program, at the University of Michigan in Ann Arbor. Registration is required and links are provided below.

**Course Objectives:** You will learn

- the rich information provided by Bayesian analysis and how it differs from traditional (Frequentist) statistical analysis
- the concepts of Bayesian reasoning along with the easy math and intuitions for Bayes' rule
- the concepts and hands-on use of modern algorithms ("Markov chain Monte Carlo") that achieve Bayesian analysis for realistic applications
- how to use the *free* software R and JAGS for Bayesian analysis, with many programs created by the instructor, readily useable and adaptable for your research applications
- an extensive array of applications, including comparison of two groups, ANOVA-like designs, linear regression, logistic regression, ordinal regression, etc. Also numerous variations for robustness to outliers, non-normally distributed noise,
heterogenous variances, censored data, non-linear trends, auto-regressive models, etc. See more details in the list of topics, below.

Course Audience: The intended audience is advanced students, faculty, and other researchers, from all disciplines, who want a ground-floor introduction to doing Bayesian data analysis.

Course Prerequisites: No specific mathematical expertise is presumed. In particular, no matrix algebra is used in the course. Some previous familiarity with statistical methods such as a t-test or linear regression can be helpful, as is some previous experience with programming in any computer language, but these are not critical.

Course Topics: (Exact content, ordering, and durations may change.)

Day 1:

- Overview / Preview:
  - Bayesian reasoning generally. (See this introductory chapter.)
  - Robust Bayesian estimation of difference of means. Software: R, JAGS, etc.
  - NHST t test: Perfidious p values and the con game of confidence intervals.
- Bayes' rule, grid approximation, and R. Example: Estimating the bias of a coin.
- Markov Chain Monte Carlo and JAGS. Example: Estimating parameters of a normal distribution.
- HDI, ROPE, decision rules, and null values.

Day 2:

- Hierarchical models: Example of means at individual and group levels. Shrinkage.
- Examples with beta distributions: therapeutic touch, baseball, meta-analysis of extrasensory perception.
- The generalized linear model.
- Simple linear regression. Exponential regression. Sinusoidal regression, with autoregression component.
- How to modify a program in JAGS & rjags for a different model.
- Robust regression for accommodating outliers, for all the models above and below.
- Multiple linear regression.
- Logistic regression.
- Ordinal regression.
- Hierarchical regression models: Estimating regression parameters at multiple levels simultaneously.

Day 3:

- Hierarchical model for shrinkage of regression coefficients in multiple regression.
• Variable selection in multiple linear regression.
• Model comparison as hierarchical model. The Bayes factor. Doing it in JAGS.
• Two Bayesian ways to assess null values: Estimation vs model comparison.
  Day 4:
• Bayesian hierarchical oneway "ANOVA". Multiple comparisons and shrinkage.
• Example with unequal variances ("heteroscedasticity").
• Bayesian hierarchical two way "ANOVA" with interaction. Interaction contrasts.
• Split plot design.
• Log-linear models and chi-square test.
  Additional topics as time permits:
• Power: Probability of achieving the goals of research. Applied to Bayesian estimation of two groups.
• Sequential testing.
• The goal of achieving precision, instead of rejecting/accepting a null value.
• How to report a Bayesian analysis.
• Advanced topics as audience interest suggests:
  o Censored data in JAGS.
  o Mixture of normals.
  o Other data distributions in JAGS using Bernoulli 1's trick.
  o Stan and Hamiltonian Monte Carlo.
Who is the instructor?

John Kruschke is eight-time winner of Teaching Excellence Recognition Awards from Indiana University, where he is Professor of Psychological and Brain Sciences, and Adjunct Professor of Statistics. He has written an acclaimed introductory textbook on Bayesian data analysis and many tutorial articles. He has given numerous popular workshops on Bayesian methods. His research interests include the science of moral judgment and Bayesian data analysis. He received the Troland Research Award from the National Academy of Sciences, and the Remak Distinguished Scholar Award from Indiana University. He has been on the editorial boards of several scientific journals, including Psychological Review, the Journal of Experimental Psychology: General, the Journal of Mathematical Psychology, and others.

Highly recommended textbook:

Doing Bayesian Data Analysis, 2nd Edition: A Tutorial with R, JAGS, and Stan. The book is a genuinely accessible, tutorial introduction to doing Bayesian data analysis. The software used in the course accompanies the book, and many topics in the course are based on the book. (The course uses the 2nd edition, not the 1st edition.) Further information about the book can be found here.
Register with the ICPSR summer program.

This course is offered as part of the ICPSR Summer Program in Quantitative Methods of Social Research, so you must register to attend. People who are not on the official roster will not be admitted to the classroom. Registration information is at this link. Registration fees are the standard amounts set by ICPSR. The instructor has no control over fees. Please check this ICPSR web page for information about whether your institution is a member of ICPSR.
Install software before arriving.

It is important to bring a notebook computer to the course, so you can run the programs and see how their output corresponds with the presentation material. Please install the software before arriving at the course. The software and programs are occasionally updated, so please check here a week before the course to be sure you have the most recent versions. For complete installation instructions, please refer to this web page.
Group 1 Mean
mean = 102

Group 2 Mean
mean = 101

Group 1 Std. Dev.
mode = 1.95

Group 2 Std. Dev.
mode = 0.981
A posterior probability distribution for parameters that describe two groups, showing complete distributions of the difference of means (right middle), the difference of standard deviations, the effect size (right bottom), and posterior predictive check (right upper).

**Why go Bayesian?**

Sciences from astronomy to zoology are changing from null-hypothesis significance testing to Bayesian data analysis, because Bayesian analysis provides richer information with great flexibility and without need for $p$ values. Read more:

- An introductory chapter that explains the two foundational concepts of Bayesian data analysis.
- An article that shows the rich information provided by Bayesian estimation in the context of analyzing data from two groups: Kruschke, J. K. (2013). Bayesian estimation supersedes the $t$ test.* Journal of Experimental Psychology: General, 142(2), 573-603. More info, including links to videos, is here.
- An article that explains two Bayesian methods to assess null values, and which one is typically more informative: Kruschke, J. K. (2011). Bayesian assessment of null values via parameter estimation and model comparison.* Perspectives on Psychological Science, 6(3), 299-312.
- An article that emphasizes that Bayesian data analysis is appropriate regardless of the status of Bayesian models of cognition: Kruschke, J. K. (2010). What to believe: Bayesian methods for data analysis.* Trends in Cognitive Sciences, 14(7), 293-300.

*Your click on this link constitutes your request to the author for a personal copy of the article exclusively for individual research.
Data analysis: Model and its parameters merely describe trends in data. The parameters need not refer to anything in the process that generated the data.

Psychometric model: Model and its parameters describe trends in behavioral data, and parameters refer to mental constructs. But there need not be anything Bayesian that generated the behavioral data.

Bayesian data analysis is not Bayesian modeling of cognition.

Data analysis involves "generic" descriptive models (such as linear regression) without any necessary interpretation as cognitive computation. The rational way to estimate parameters in descriptive models is Bayesian, regardless of whether or not Bayesian models of mind are viable. The concepts and methods of Bayesian data analysis transfer to other Bayesian models, including Bayesian models of cognition. Read more at this blog entry.