Go Forth and Propagate: Book Recommendations for Learning and Teaching Bayesian Statistics

As published in Benchmarks RSS Matters, September 2011
http://web3.unt.edu/benchmarks/issues/2011/09/rss-matters

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If you've read more than a couple of these *RSS Matters* articles, then you have likely noticed we, rather unapologetically, advocate two things frequently; 1.) using the **R**[1] statistical programming language environment, and 2.) using the Bayesian statistical paradigm. The current article recommends some books (not just textbooks) which can be used to hoist oneself into the wonderful world of Bayes. This article was motivated by the publication of a few books this year (2011) which offer some unique insights and benefits to those seeking to understand (and teach) Bayesian statistical inference.

There have always been Bayesian materials available of course, dating back to the Reverend Thomas Bayes himself (1701 - 1761), and to some extent Pierre-Simon Laplace (1749 - 1849). During most of the 20th century, the frequentist perspective has dominated and as a result, there were relatively few Bayesian texts published. The Bayesian texts published during this time were often obscure and not widely distributed (e.g., Jeffreys, 1939; 1948). These texts kept Bayes alive and offered invaluable resources for those who happen to need them for practical problem solving and inferential decision making (e.g., Stone, 1975). However, beginning with the last two or so decades of the 20th century, the advent of relatively cheap but substantial computing power has allowed a resurgence of the Bayesian perspective. It seems inevitable that the Bayesian perspective will supplant the frequentist perspective as the most used statistical paradigm in the near future. For that reason, it seems equally appropriate that we should be advocating the adoption of the Bayesian perspective to professional researchers and instructors at both the graduate and undergraduate levels. In order to facilitate that adoption, it is often necessary and convenient to have a few texts which can be used as instructional materials – both for researchers and instructors, as well as the students enrolled in statistics classes. Below, we begin by offering some recommendations for a couple of recent books which describe the history and philosophical underpinnings of the Bayesian perspective. Then, we recommend some books which are general treatments of Bayesian statistical analysis. Next, we recommend books we have come across which offer more domain or field specific treatments of the Bayesian perspective.

History and Philosophy

One of the books which was published this year which also motivated this article and composition of the listing(s) below was McGrayne's (2011) book discussing the history, application, spread and future prospects of Bayesianism. It is important to note that McGrayne's book is not a textbook and does not attempt to *teach* Bayesian inferential techniques. Rather, McGrayne offers a very thorough, informative, and often entertaining (in our humble opinion) discussion of the Bayesian perspective. The book discusses how Bayesianism developed, was dismissed as not terribly useful (without computers capable of making the necessary and intensive computations), and it's sporadic but extremely important applications during World War II, as well as its recent resurgence. As mentioned, McGrayne's book is not a textbook, but it is strongly recommended as it provides the theoretical underpinnings of the Bayesian perspective and shows how Bayesianism has been applied to *real world* inferential / statistical problems - often with great success.

Bayesianism is sometimes considered a learning strategy as it is much better suited to the (empirical) accumulation of knowledge than the traditional frequentist perspective. Williamson's (2010) book covers Bayesianism from a philosophical and epistemological approach, discussing the philosophy of science

[1] `http://cran.r-project.org/index.html`

implications of, and justifications for, the Bayesian perspective. Williamson's book deals with empirical theory building, based on probabilities, as well as the notion of priors and the researcher's (agent's) ability to use them to empirically express uncertainty.

General Introductions to Bayesian Statistics

The books in this section offer a general introduction to Bayesianism, without field or domain specific applcations; although they all have application examples, the books are not tailored to fit into a specific field (e.g., biology, political science, etc.). Generally, these books are written by individuals who work as applied statisticians, either as faculty or as researchers (i.e. they do not tend to be theoretical statisticians). The purpose of such books is to introduce the Bayesian perspective to individuals who are interested in statistics; primarily students, at the undergraduate and graduate level.

Berry (1996) was one of the earlier texts (of those mentioned here) to be used as a statistics course textbook and although it is a bit dated now, it offers a very familiar structure to those who have been exposed to traditional applied statistics textbooks. The book briefly advocates Bayesianism by pointing out its advantages over the frequentist perspective. Berry's book is designed to be an undergraduate textbook and begins with chapters which reflect that audience. The initial chapters cover topics such as; Statistics and the Scientific Method, Displaying and Summarizing Data, Designing Experiments, and Probability. Only then does the book progress to Bayes Rule. The book is fairly limited in its reach, with the last few chapters covering Comparisons of Two or More Means, Data Transformations and Nonparametric Methods, and Regression Analysis. The limited reach is a benefit; because, it allows each chapter to progress at a gradual pace which facilitates thorough coverage of each chapter's content. Also, as stated in the book itself, use of a computer is not necessary with the book. However, a 3.5" disk containing some Minitab program codes, as well as all the necessary data files, is included.

Bolstad (2004) is a book which is similar to Berry (1996) from above, in that Bolstad is targeting undergraduate students in a first course of statistics. Bolstad is, clearly; updated, and uses both Minitab and the R statistical programming environment, but like Berry in that both books rely primarily on hand calculation for examples (end of chapter exercises are designed to be done with a computer). One advantage to Bolstad is that his book contains some comparisons between frequentist and Bayesian results / inferences.

Hoff (2009) represents a relatively common style of book which is intended for graduate students of the first or second year. Hoff's book begins with some introduction to Bayesianism and probability, and then transitions into more practical applications – with one-parameter models appearing in Chapter 3. The book utilizes the R statistical programming environment and covers topics such as the Monte Carlo method, Gibbs sampling, multivariate analysis, and hierarchical modeling. Linear mixed effects models and latent variable modeling round out the book in the last few chapters. Other similar texts designed for graduate students in a first course of statistics are available; such as Ghosh, Delampady, and Samanta (2006) as well as Marin and Robert (2007).

Congdon (2006) offers a more narrowly focused approach, specifically toward Bayesian statistical modeling. This book is geared toward more advanced learners (not just students) and assumes more in the way of statistical knowledge than the books mentioned above. The book utilizes the WinBUGS software and at nearly 600 pages and 15 chapters it provides a fairly exhaustive review of modeling techniques in order to allow the research to fit the model most appropriate to the data. Congdon (2005) also has a Bayesian text specifically for the treatment of categorical data. Both books offer chapters on such important, but often not covered, topics as dealing with missing data.

A book which offers a relatively gentle introduction to Bayesian statistics comes from Lee (2004).

Lee covers some common Bayesian analysis techniques while using examples from a variety of fields (e.g. biology, political science, etc.). Because of the varied examples, the book is accessible for a variety of audiences / readers. Lee uses primarily the R statistical programming language environment (as well as some WinBUGS) and maintains a website[2] in support of the book.

Albert (2007) offers an extremely useful book simply titled *Bayesian Computation in R*. As the title suggests, the Albert book is not a textbook *per se*, rather it is more like a reference book, in that it offers a tutorial style for applying Bayesian methods in the R statistical programming language environment. For those unaccustomed to R, the first chapter offers a brief introduction to the software and provides references for other sources specific to the use of R. Chapter 2 provides an introduction/overview of the Bayesian perspective and subsequent chapters focus on types of Bayesian analysis (e.g. one-parameter models, Markov Chain Monte Carlo [MCMC] methods, regression models, hierarchical models, etc.). An additional benefit to using Albert's book is the R package he created and maintains for the book, `LearnBayes`[3].

For those seeking a more technical exploration of the *nuts and bolts* of Bayesian inference, see Tanner (1996) which provides derivations and formulaic presentations of most algorithms used to construct posterior distributions and likelihood functions. It is not for the faint of heart; or more precisely, it is not for the faint of math.

Biology, Ecology, Genetics, and Medicine

It seems as though the bio-oriented fields have embraced Bayesianism more so than some other fields. As such, there are several Bayesian texts available which are directed toward researchers and students in biology based fields.

Perhaps the most comprehensive of the bio-based books mentioned here is Sorensen and Gianola (2002), which covers a variety of inferential methods and is tailored for the study of genetics. Sorensen and Gianola do not recommend (or use) a specific statistical software and instead show all the elaborate formulas or mathematical and algebraic proofs (i.e. "giving step-by-step derivations and fully worked-out examples" p.vi). As such the authors recommend "some mathematical and statistical prerequisitesin order to be able to extract maximum benefit from the material presented in this book" (p. vi). The benefit of this approach is that each chapter is lengthy and covers each topic extensively; leading to a rather substantial volume of 758 pages. Another bio-oriented text which focuses on genetics is *Bayesian Analysis of Gene Expression* (Mallick, Gold, & Baladandayuthapani; 2009). Mallick et al. also do not advocate or use particular statistical software, but they do cover such topics as False Discovery Rate and clustered data analysis.

Woodworth (2004) offers what might be considered a less intimidating treatment of Bayesian statistics for the bio-oriented researcher. Woodworth's book utilizes SAS, WinBugs, and MS Excel; and although the book is not as extensive as Sorensen and Gianola (2002), it does offer some additional benefits. First, there is a companion website[4] which contains data sets and computer codes, as well as sample exams and computer exercises. Second, it does not assume as much prior knowledge of statistics.

Another highly recommended book is Bolker's (2008) text, *Ecological Models and Data in R*. Bolker offers one of the most down-to-Earth introductions to Bayesianism we have come across. Another positive of the Bolker book is the treatment of frequentist methods, as well as maximum likelihood methods, even though the text focuses primarily on Bayesian methods. The book covers a range of topics from the simple

[2] `http://www-users.york.ac.uk/~pml1/bayes/book.htm`
[3] `http://cran.r-project.org/web/packages/LearnBayes/index.html`
[4] `http://www.stat.uiowa.edu/~gwoodwor/BBIText/Index.html`

to the complex, and as the title suggests, it uses the R statistical programming language environment. Bolker also maintains a website[5] for the book which contains exercises, data, and R code.

Link and Barker (2010) also offer an introduction to Bayesian statistics from the ecological perspective. Link and Barker also use the R statistical programming language environment and BUGS. They maintain a website[6] for the book which includes code, data, and errata. The book assumes some (limited) prior knowledge of statistics. Still, the book represents a very gentle introduction to the Bayesian analysis of ecological data types and methods; including Closed-Population Mark-Recapture Models (Chapter 9), Latent Multinomial Models (Chapter 10), Open Population Models (Chapter 11), Individual Fitness (Chapter 12), and Autoregressive Smoothing (Chapter 13).

Other examples of bio-oriented Bayesian statistical texts are relatively plentiful. One such example is *Bayesian Biostatistics and Diagnostic Medicine* (Broemeling, 2007), which uses WinBUGS and Minitab and is primarily directed at research into diagnostic testing accuracy, agreement, and treatment efficacy. Another narrowly focused text, within the bio-oriented arena is *Bayesian Adaptive Methods for Clinical Trials* (Berry, Carlin, Lee, & Muller; 2011). As one of the books published this year, this book presents some of the more modern approaches to Bayesian analysis, thanks in large part to the constantly advancing progress made with the R statistical programming language environment; which the book uses along with WinBUGS. Finally, Day, Ghosh, and Mallick (2011) offer a book with a wider bio-oriented audience in mind. As an edited book, each chapter presents a different group of authors' take on a specific topic. The topics/chapters are each thorough in their treatment of the topic they cover and each is approached from a strong biological perspective. The focus of the book is on Bayesian modeling and therefore it is recommended for an audience with some previous statistical background.

Political Science

One author well known in Bayesian statistical circles, as well as the R community, is Andrew Gelman of Columbia University. Gelman and colleagues have published several books and articles related to Bayesian analysis and he (Gelman) maintains a very active blog dedicated to (primarily) "Statistical Modeling, Causal Inference, and Social Science"[7]. In terms of book recommendations, there are three which will be strongly recommended here; regardless if the reader is interested in political science. First, one of the most frequently used/cited texts for Bayesian statistics is simply *Bayesian Data Analysis* (2nd ed.; Gelman, Carlin, Stern, & Rubin; 2004). This book is very useful for a variety of reasons, primarily because it covers such a *variety* of topics well. The first sentence of the Preface gives one an idea of the multifaceted nature of this book: "this book is intended to have three roles and to serve three associated audiences: an introductory text on Bayesian inference starting from first principles, a graduate text on effective current approaches to Bayesian modeling and computation in statistics and related fields, and a handbook of Bayesian methods in applied statistics for general users of and researchers in applied statistics" (Gelman et al., p. xix). As the authors advise, this book has many intended purposes and can be used as a reference text; or using select chapters, as a text for either an advanced undergraduate class or a graduate class. In short, there is very little lacking from this book and researchers would likely find it very useful regardless of field or study design.

Second, Gelman and Meng (2004) is an edited book which contains a great deal of practically useful techniques for *Applied Bayesian Modeling and Causal Inference from Incomplete-Data Perspectives*. As the title suggests, this resource is directed toward modeling situations in which, as is often the case, miss-

[5] `http://www.math.mcmaster.ca/~bolker/emdbook/index.html`
[6] `http://www.maramatanga.com/LinkandBarkerBook/Book.php`
[7] `http://andrewgelman.com/`

ing or messy data is at hand. The text has four sections with the first generally addressing observational studies, quasi-experimental designs, and 'broken' experiments. Topics such as propensity score analysis, stratification, and sensitivity are covered in the chapters of section two; while section three covers modeling and section four covers applied Bayesian inference methods. Although this book is listed here in the political science section of this article, it should be noted that each chapter is written by a separate group of authors and often the chapters approach a topic from a specific field other than political science.

Third, Gelman and Hall's (2007) text is recommended not only as a general regression and linear modeling text, but also as a Bayesian approach to those subjects. The book offers a comprehensive review of linear and generalized linear modeling techniques from a Bayesian perspective. Like most published materials Gelman is a part of, it uses the R statistical programming language environment (and BUGS). The book is broken down into 5 parts (1A, 1B, 2A, 2B, & 3); single-level regression, working with regression inferences, multilevel regression, fitting multilevel models, and from data collection to model understanding to model checking. Multiple chapters flesh out each part of the book, allowing the reader to grasp concepts and application.

Education, Psychology, and Sociology

This section is directed toward what are typically lumped together as the 'social sciences'; meaning psychology, education, and sociology. However, they are distinguished here from political science and economics, which are also considered social sciences, but have specific books available for their respective fields. One of the books which was recently published and motivated this article was Kruschke (2011). Kruschke's *Doing Bayesian Data Analysis* is clearly directed toward an audience of education, psychology, and sociology instructors and their students. Instructors who have experience teaching statistics in these fields will recognize the general structure of the book as similar to countless (traditional frequentist) books designed for students of these disciplines. The book primarily uses the R statistical programming environment, but also uses BUGS, and is written with special care to be as easily digestible by a wide audience which may or may not have previous experience with statistics. Those familiar with traditional frequentist methods will find useful the author's direct referencing of those familiar methods when discussing their respective Bayesian counterparts (e.g., simple linear regression with its Bayesian counterpart covered in Chapter 16, t-test for two independent means and oneway ANOVA with their Bayesian counterparts covered in Chapter 18, etc.). The text covers essential components such as Bayes rule, power and sample size considerations, Markov Chain Monte Carlo (MCMC) methods, and writing up Bayesian results; as well as advanced subjects such as hierarchical models and generalized linear models. Kruschke also maintains a rather extensive website[8] for the book.

Another similar text which has as its audience the social science crowd is Lynch's (2007) *Introduction to Applied Bayesian Statistics and Estimation for Social Scientists*. The Lynch text is not as thorough as the Kruschke (2011) book mentioned above, but it too uses primarily the R statistical programming language environment and seeks to provide a basic introduction to applied Bayesian analysis for social sciences. Familiar key analyses covered include linear regression, generalized linear models, hierarchical models, and multivariate regression models. Throughout the text, as in Kruschke, mention is made of the traditional frequentist connection to the analysis covered, which makes both books very accessible to the newcomer to Bayesianism.

A third book aimed at introducing social scientists to the Bayesian perspective is Jackman's (2009) *Bayesian Analysis for the Social Sciences*. Jackman is a political scientist, but the book is listed here as it appears to have more in common with those directly above. Again, this text uses the R statistical program-

[8] `http://www.indiana.edu/~kruschke/DoingBayesianDataAnalysis/`

ming language environment, and WinBUGS, and contains social science specific examples in great detail. The text has essentially three parts; Part one introduces the Bayesian perspective and principles, Part two covers simulations with Monte Carlo methods, Markov chains, and the combination of the two (each with a chapter), and Part three covers advanced topics such as hierarchical models, binomial response models, and multinomial response models. Jackman also maintains a website[9] dedicated to the book and class he teaches with it.

Econometrics

Econometrics as a field also has a variety of books which expound the Bayesian perspective. Koop (2003) offers a gentle introduction which is directed at the econometric audience. As stated in the preface, the book requires only a single course in calculus for the reader to benefit. Koop, understandably, focuses primarily on various forms of regression analysis; but, also covers topics such as time series, tobit and probit models; as well as Bayesian model averaging. The book recommends MATLAB and at the end of each chapter there are theoretical exercises and computer exercises.

Koop and colleagues (Koop, Poirier, & Tobias, 2007) also published a thorough volume of exercises which covers a great deal of research and analysis situations. Koop et al. is not necessarily a workbook per se, but offers a description, an exercise, and then a solution for each topic covered. The topics range from simple topics such as 'Conjugate normal analysis with known mean and unknown variance' (in Chapter 2) to more complex topics such as; asymptotic Bayes (Chapter 9), hierarchical models (Chapter 12), latent variable models (Chapter 14), mixture models (Chapter 15), and Bayesian model averaging (Chapter16). Again, this book recommends and uses MATLAB.

Similar to Koop et al., (2007) is the book by Geweke (2005), which offers a technical introduction to Bayesian econometrics. The Geweke book is similar to Koop and colleagues in that it offers a vast array of well described and detailed examples. Also like Koop and colleagues, the Geweke book uses a combination of software, primarily MATLAB, but also the Bayesian Analysis Computation and Communication (BACC) extension; as well as Splus and the R statistical programming language environment. Like other books mentioned above, the Geweke book assumes some exposure to statistics and calculus as it is aimed at professional researchers and graduate students.

Lancaster (2004) offers *An Introduction to Modern Bayesian Econometrics* which is designed for professional applied econometricians and advanced graduate students. Lancaster uses BUGS, Splus and the R statistical programming language environment. Lancaster covers basics of Bayesianism (prior, likelihood, posterior, model comparison, etc.), linear and nonlinear regression models, observational data studies, panel data studies, and time series. Thoughtful examples and exercises are given with plenty of code so that the reader may replicate what is in the text.

Marketing and Forensic Science

Rossi, Allenby, and McCulloch (2005) are direct in stating that their book is aimed particularly at marketing professionals and graduate students. Their book uses the R statistical programming language environment and specifically the package `bayesm`[10] which they developed in support of the book. The book is essentially two books, with the first half focused on basic Bayesian concepts, Markov chain Monte Carlo (MCMC) methods, models for discrete data, hierarchical models, model selection and decision

[9] `http://jackman.stanford.edu/mcmc/`

[10] `http://cran.r-project.org/web/packages/bayesm/index.html`

theory, and dependent error models. The second half of the book provides a series of very detailed case study examples (with R code and data available in the `bayesm` package); each of which focus on a realistic marketing study situation. The book also contains two appendices; the first covers hierarchical Bayesian modeling in R and the second provides documentation for installing and using the `bayesm` package.

Taroni, Bozza, Biedermann, Garbolino, and Aitken (2010) seek to introduce Bayesian inferential procedures to the forensic sciences and decision analysis. Taroni et al. make clear they are advocating the adoption of Bayesian methods for criminologists, forensic scientists, and those interested in decision analysis (e.g., court decisions). The book is divided into two parts, the first focuses on basic concepts and principles; while the second focuses on practical applications. The book uses the R statistical programming language environment to explore point estimation, interval estimation, hypothesis testing, sampling analysis, and classification. Although the Taroni et al. book does not cover a wide variety of Bayesian methods, it is significant as one of the first texts to address forensic sciences with the Bayesian perspective.

Conclusions

It should be noted that many more books are available for learning and teaching Bayesian statistics, only a few have been mentioned here. It was hoped that in producing such an annotated bibliography; professional researchers, faculty, and students would be motivated to find at least two books to begin implementing Bayesian methods – either in their own research or in their own classes. The phrase 'two books' is necessitated by the opinion that the McGrayne (2011) text is considered essential for anyone interested in Bayesian methods. Although we have tried to provide books from most academic and professional fields, we acknowledge that inevitably some fields were not represented by the books listed. However, the section on *General Introductions to Bayesian Statistics* provides recommended books which are applicable regardless of field. Having stated that, we encourage anyone who has suggestions for fields not represented to email those suggestions to this article's author. A copy of the reference list is (and will continue to be) maintained on the Research and Statistical Support's Do-It-Yourself Introduction to R website[11] in the Bayesian section (Module 10). If suggested recommendations are received, they will be reviewed, and if approved, added to that list[12].

Until next time, I'll be tapping my foot for 20, Miles [13].

This article was last updated on September 16, 2011.

This document was created using LaTeX

[11] `http://www.unt.edu/rss/class/Jon/R_SC/`
[12] `http://www.unt.edu/rss/class/Jon/R_SC/Module10/BayesBooks.pdf`
[13] Miles Dewey Davis III (May 26, 1926 - *September* 28, 1991)

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