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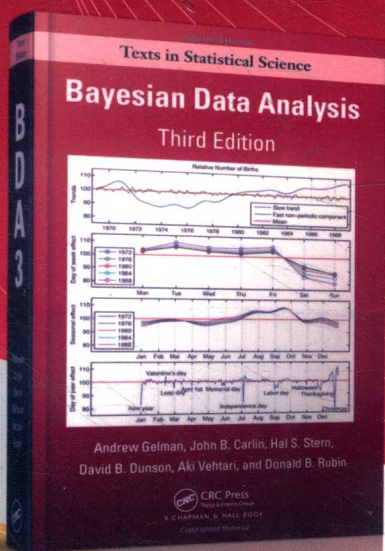
# 贝叶斯数据分析

(英文导读版·原书第3版)

## Bayesian Data Analysis

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本书是《贝叶斯数据分析》(Bayesian Data Analysis)的第3版,因在数据分析、研究解决难题方面的可读性、实用性而广受读者好评,被认为是贝叶斯方法领域的权威之作。本书作者团队中不乏有统计学界的大师,他们先以数据分析的视角讨论了一些统计学基本概念,之后再引进各种高级分析方法,秉承实用性的风格,介绍和分析了大量最新的贝叶斯方法。

全书共分为贝叶斯推断基础,贝叶斯数据分析基础,高级计算,回归模型,以及非线性和非参数模型五部分。第I部分包括:概率与推断,单参数模型,多参数模型,渐近性以及与非贝叶斯方法的关系,分层模型等内容。第II部分包括:模型核查,模型评价、对比及延伸,建模数据的收集,决策分析等内容。第III部分主要介绍贝叶斯计算入门,马尔可夫链模拟基本概念,高效计算的马尔可夫链模拟,众数和分布近似等内容。第IV部分包括:回归模型简介,分层线性模型,广义线性模型,稳健模型推断,缺失数据模型等内容。最后第V部分补充介绍了参数非线性模型,基函数模型,高斯过程模型,有限混合模型,Dirichlet过程模型等内容。全书援引大量来源于现实应用研究的真实案例,突出强调了贝叶斯推断在实际工作中的运用和价值。

本书可作为高等院校的高年级本科生以及研究生用书,也可作为统计相关科研人员的参考书。

Bayesian Data Analysis, Third Edition/Andrew Gelman, John B. Carlin, Hal S. Stern, David B. Dunson, Aki Vehtari, Donald B. Rubin /ISBN: 978-1439840955.

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# 前 言

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本书有三个定位分别服务于三类不同需求的读者：一是作为贝叶斯推断基本原理的基础性教材，二是涵盖统计学及其相关应用领域的贝叶斯建模与计算方法的研究用教材；三是作为应用统计工作者和研究者的有关贝叶斯方法的使用手册。虽然书中的前几章充满了大量介绍性文字，但它并非严格意义上的统计学初等教材。书中使用的数学基础包括：基本的概率与统计知识、初等微积分和线性代数。第1章会比较详细地回顾基础的概率论中的概念，以及一些我们假设读者已经学习过的主题项。本书实用性的定位，意味着读者应该已经具备较强的计算能力并且在处理概率论、统计、线性代数方面问题中有着丰富的经验。

如果写作本书仅仅是为了在市面上增添又一本介绍性读物，那么它的价值不外乎是为读者引入一些概念性的知识，却不能为他们将来的实际工作提供指导，事实上贝叶斯分析和非贝叶斯分析本质上是一样的，都能将分析引入胜境。另外，因为统计的本质是应用，所以我们觉得只阐述高级方法却不涉及对一些基本数据分析概念的介绍是不太妥当的；只介绍流行的贝叶斯理论却不列举一些实际应用的案例也是不完整的。为了避免主体叙述混乱，将文献注记放在每个章节之后，参考文献放在全书的末尾。

真实的统计分析案例会贯穿全书，我们这样做是希望能使本书整体的讲解都带有实用的意味。事实上，贝叶斯方法概念力求简洁，令那些处于特殊环境之中的复杂问题迎刃而解。非贝叶斯的方法虽然也曾是统计理论的主流，20世纪的大部分实践都基于这些方法，但是近几十年贝叶斯理论的重新兴起大多得益于现代计算机技术的普及和发展，而不是通常我们所认为的贝叶斯思想的理论和逻辑优势。

我们在处理贝叶斯推断时，主要注重实践而不是理论——书中引用的大量来自于我们和其他人亲身经历的实践案例可见证这一点。第1章诠释以概率论基础作为经验和度量工具的观点（具体见1.4 ~ 1.7节）。

## • 第3版的变化

本书第3版中最突出的一个特色就是增加了第20 ~ 23章——讲述非参数建模。其他的一些变化包括：第2、5章和其他地方新增了关于弱信息先验的内容；第13章增添了避免边界先验的内容；第7章更新了对交叉验证和预测信息标准的讨论；第11章讲述改进了收敛检测以及迭代模拟有效样本量的计算方法；第12、13章陈述了哈密顿蒙特卡罗方法、变分贝叶斯以及EP算法的内容；附录C给出了新修订过的代码。除此之外，本书还有一些其他的变化。

在完成第1版《贝叶斯数据分析》之后的18年里，我们处理过众多有趣的应用案例，限于篇幅，我们没能把它们都写入这一版中。一些例子收录在我们出版的《数据的回归分析与多级模型》一书和发表的一些论文中。

## • 在线资源

附加的资料,包括例子中使用的数据、章后练习的解答,以及书籍出版之后发现的一些错误,都已经发布在网站上。网址为 <http://www.stat.columbia.edu/~gelman/book/>。如有任何建议或意见可以直接发给我们。

## • 致谢

我们对许多学生、同事以及提出建议和意见的朋友们表示感谢,同时感谢公共赞助使我们的工作能够顺利完成。

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这项工作部分是由美国国家科学基金会、美国国家卫生研究院、美国教育科学研究所、美国国家安全局、美国能源部和芬兰科学院提供资助的。

另外,本书中出现的例子和文章有些是由我们自己完成,有些则由别人撰写,这些都在文献注记以及章后练习中有所标记。

最后,我们要感谢 Caroline、Nancy、Hara、Amy、Ilona,以及其他家人和朋友,感谢他们在我们的写作与修改过程中的关爱与支持。

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# Preface

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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. Although introductory in its early sections, the book is definitely not elementary in the sense of a first text in statistics. The mathematics used in our book is basic probability and statistics, elementary calculus, and linear algebra. A review of probability notation is given in Chapter 1 along with a more detailed list of topics assumed to have been studied. The practical orientation of the book means that the reader's previous experience in probability, statistics, and linear algebra should ideally have included strong computational components.

To write an introductory text alone would leave many readers with only a taste of the conceptual elements but no guidance for venturing into genuine practical applications, beyond those where Bayesian methods agree essentially with standard non-Bayesian analyses. On the other hand, we feel it would be a mistake to present the advanced methods without first introducing the basic concepts from our data-analytic perspective. Furthermore, due to the nature of applied statistics, a text on current Bayesian methodology would be incomplete without a variety of worked examples drawn from real applications. To avoid cluttering the main narrative, *there are bibliographic notes at the end of each chapter* and references at the end of the book.

Examples of real statistical analyses appear throughout the book, and we hope thereby to give an applied flavor to the entire development. Indeed, given the conceptual simplicity of the Bayesian approach, it is only in the intricacy of specific applications that novelty arises. Non-Bayesian approaches dominated statistical theory and practice for most of the last century, but the last few decades have seen a re-emergence of Bayesian methods. This has been driven more by the availability of new computational techniques than by what many would see as the theoretical and logical advantages of Bayesian thinking.

In our treatment of Bayesian inference, we focus on practice rather than philosophy. We demonstrate our attitudes via examples that have arisen in the applied research of ourselves and others. Chapter 1 presents our views on the foundations of probability as empirical and measurable; see in particular Sections 1.4–1.7.

## *Changes for the third edition*

The biggest change for this new edition is the addition of Chapters 20–23 on nonparametric modeling. Other major changes include weakly informative priors in Chapters 2, 5, and elsewhere; boundary-avoiding priors in Chapter 13; an updated discussion of cross-validation and predictive information criteria in the new Chapter 7; improved convergence monitoring and effective sample size calculations for iterative simulation in Chapter 11; presentations of Hamiltonian Monte Carlo, variational Bayes, and expectation propagation in Chapters 12 and 13; and new and revised code in Appendix C. We have made other changes throughout.

During the eighteen years since completing the first edition of *Bayesian Data Analysis*, we have worked on dozens of interesting applications which, for reasons of space, we are not able to add to this new edition. Many of these examples appear in our book, *Data Analysis*

*Using Regression and Hierarchical/Multilevel Models*, as well as in our published research articles.

### *Online information*

Additional materials, including the data used in the examples, solutions to many of the end-of-chapter exercises, and any errors found after the book goes to press, are posted at <http://www.stat.columbia.edu/~gelman/book/>. Feel free to send any comments to us directly.

### *Acknowledgments*

We thank many students, colleagues, and friends for comments and advice and also acknowledge the public funding that made much of this work possible.

In particular, we thank Stephen Ansolabehere, Adriano Azevedo, Jarrett Barber, Richard Barker, Tom Belin, Michael Betancourt, Suzette Blanchard, Rob Calver, Brad Carlin, Bob Carpenter, Alicia Carriquiry, Samantha Cook, Alex Damour, Victor De Oliveira, Vince Dorie, David Draper, John Emerson, Steve Fienberg, Alex Franks, Byron Gajewski, Yuanjun Gao, Daniel Gianola, Yuri Goegebeur, David Hammill, Chad Heilig, Matt Hoffman, Chuanpu Hu, Zaiying Huang, Shane Jensen, Yoon-Sook Jeon, Pasi Jylanki, Jay Kadane, Jouni Kerman, Gary King, Lucien Le Cam, Yew Jin Lim, Rod Little, Tom Little, Chuanhai Liu, Xuecheng Liu, Peter McCullagh, Mary Sara McPeck, Xiao-Li Meng, Baback Moghaddam, Olivier Nimeskern, Peter Norvig, Ali Rahimi, Thomas Richardson, Christian Robert, Scott Schmidler, Matt Schofield, Andrea Siegel, Sandip Sinharay, Elizabeth Stuart, Andrew Swift, Eric Tassone, Francis Tuerlinckx, Iven Van Mechelen, Amos Waterland, Rob Weiss, Lo-Hua Yuan, and Alan Zaslavsky. We especially thank John Boscardin, Jessica Hwang, Daniel Lee, Phillip Price, and Radford Neal.

This work was partially supported by research grants from the National Science Foundation, National Institutes of Health, Institute of Education Sciences, National Security Agency, Department of Energy, and Academy of Finland.

Many of our examples have appeared in books and articles written by ourselves and others, as we indicate in the bibliographic notes and exercises in the chapters where they appear.<sup>1</sup>

Finally, we thank Caroline, Nancy, Hara, Amy, Ilona, and other family and friends for their love and support during the writing and revision of this book.

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<sup>1</sup>In particular: Figures 1.3–1.5 are adapted from the *Journal of the American Statistical Association* 90 (1995), pp. 696, 702, and 703, and are reprinted with permission of the American Statistical Association. Figures 2.6 and 2.7 come from Gelman, A., and Nolan, D., *Teaching Statistics: A Bag of Tricks*, Oxford University Press (1992), pp. 14 and 15, and are reprinted with permission of Oxford University Press. Figures 19.8–19.10 come from the *Journal of the American Statistical Association* 91 (1996), pp. 1407 and 1409, and are reprinted with permission of the American Statistical Association. Table 19.1 comes from Berry, D., *Statistics: A Bayesian Perspective*, first edition, copyright 1996 Wadsworth, a part of Cengage Learning, Inc. Reproduced by permission. [www.cengage.com/permissions](http://www.cengage.com/permissions). Figures 18.1 and 18.2 come from the *Journal of the American Statistical Association* 93 (1998), pp. 851 and 853, and are reprinted with permission of the American Statistical Association. Figures 9.1–9.3 are adapted from the *Journal of Business and Economic Statistics* 21 (2003), pp. 219 and 223, and are reprinted with permission of the American Statistical Association. We thank Jack Taylor for the data used to produce Figure 23.4.



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# Part I: Fundamentals of Bayesian Inference

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Bayesian inference is the process of fitting a probability model to a set of data and summarizing the result by a probability distribution on the parameters of the model and on unobserved quantities such as predictions for new observations. In Chapters 1–3, we introduce several useful families of models and illustrate their application in the analysis of relatively simple data structures. Some mathematics arises in the analytical manipulation of the probability distributions, notably in transformation and integration in multiparameter problems. We differ somewhat from other introductions to Bayesian inference by emphasizing stochastic simulation, and the combination of mathematical analysis and simulation, as general methods for summarizing distributions. Chapter 4 outlines the fundamental connections between Bayesian and other approaches to statistical inference. The early chapters focus on simple examples to develop the basic ideas of Bayesian inference; examples in which the Bayesian approach makes a practical difference relative to more traditional approaches begin to appear in Chapter 3. The major practical advantages of the Bayesian approach appear in Chapter 5, where we introduce *hierarchical models*, which allow the parameters of a prior, or population, distribution themselves to be estimated from data.

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