



Robust Bayesian functional principal component analysis

Jiarui Zhang¹ · Jiguo Cao¹ · Liangliang Wang¹

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Abstract

We develop a robust Bayesian functional principal component analysis (RB-FPCA) method that utilizes the skew elliptical class of distributions to model functional data, which are observed over a continuous domain. This approach effectively captures the primary sources of variation among curves, even in the presence of outliers, and provides a more robust and accurate estimation of the covariance function and principal components. The proposed method can also handle sparse functional data, where only a few observations per curve are available. We employ annealed sequential Monte Carlo for posterior inference, which offers several advantages over conventional Markov chain Monte Carlo algorithms. To evaluate the performance of our proposed model, we conduct simulation studies, comparing it with well-known frequentist and conventional Bayesian methods. The results show that our method outperforms existing approaches in the presence of outliers and performs competitively in outlier-free datasets. Finally, we demonstrate the effectiveness of our method by applying it to environmental and biological data to identify outlying functional observations. The implementation of our proposed method and applications are available at <https://github.com/SFU-Stat-ML/RBFPCA>.

Keywords Functional data analysis · Robust estimation · Sparse functional data · Multivariate skew elliptical distribution · Model comparison · Outlier detection

1 Introduction

The development of modern technology has resulted in the continuous recording of data during a given period in many scientific fields, such as neuroscience, biology, and environmental science. These data can be categorized as functional data (Ramsay and Silverman 2005b; Ferraty and Vieu 2006; Horváth and Kokoszka 2012; Hsing and Eubank 2015), which are usually observed over time, space or any other continuous domain. For instance, Fig. 1 displays two examples of functional data. Figure 1a shows a collection of densely observed trajectories from the Hawaii Ocean Oxygen dataset (HOT-DOGS 2022), wherein certain outlying trajectories have been highlighted. Figure 1b presents one illustration of

sparse function data from the CD4 dataset (Zeger and Diggle 1994), with only a few observations per curve. Both datasets have a few curves demonstrating unusual patterns in contrast to the rest.

Functional principal component analysis (FPCA) plays a crucial role in functional data analysis (FDA) as a dimension reduction technique. FPCA can be viewed as an exploratory analysis tool to discover the hidden structure of the data by capturing the optimal low-dimensional representation and the major source of variations among curves. FPCA can also be used to help reconstruct partially observed functions or used as a preprocessing step for regression analysis (Reiss et al. 2017) or clustering tasks (Margaritella et al. 2021). The frequentist analysis of FPCA is a mature field. Numerous works have been proposed to explore fully or densely observed function data (Dauxois et al. 1982; Rice and Silverman 1991; Cardot 2000; Hall and Hosseini-Nasab 2006). Studies of the FPCA approach for sparsely observed data, a more challenging situation, can also be seen in James et al. (2000), Yao et al. (2005), and Paul and Peng (2009). Wang et al. (2016) provided a detailed review of methods, open questions and applications of FPCA.

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Robust Bayesian Analysis

Michael Brown



Robust Bayesian Analysis:

Robust Bayesian Analysis David Rios Insua, Fabrizio Ruggeri, 2012-12-06 Robust Bayesian analysis aims at overcoming the traditional objection to Bayesian analysis of its dependence on subjective inputs mainly the prior and the loss Its purpose is the determination of the impact of the inputs to a Bayesian analysis the prior the loss and the model on its output when the inputs range in certain classes If the impact is considerable there is sensitivity and we should attempt to further refine the information the incumbent classes available perhaps through additional constraints on and or obtaining additional data if the impact is not important robustness holds and no further analysis and refinement would be required Robust Bayesian analysis has been widely accepted by Bayesian statisticians for a while it was even a main research topic in the field However to a great extent their impact is yet to be seen in applied settings This volume therefore presents an overview of the current state of robust Bayesian methods and their applications and identifies topics of further interest in the area The papers in the volume are divided into nine parts covering the main aspects of the field The first one provides an overview of Bayesian robustness at a non technical level The paper in Part II concerns foundational aspects and describes decision theoretical axiomatisations leading to the robust Bayesian paradigm motivating reasons for which robust analysis is practically unavoidable within Bayesian analysis *Bayesian Robustness* James O. Berger, 1996 **Robust Bayesian Analysis** J. O. Berger, 1987 Robust Bayesian Analysis Yuanzhang Li, 1990 An Introduction to Bayesian Analysis Jayanta K. Ghosh, Mohan Delampady, Tapas Samanta, 2007-07-03 Though there are many recent additions to graduate level introductory books on Bayesian analysis none has quite our blend of theory methods and applications We believe a beginning graduate student taking a Bayesian course or just trying to find out what it means to be a Bayesian ought to have some familiarity with all three aspects More specialization can come later Each of us has taught a course like this at Indian Statistical Institute or Purdue In fact at least partly the book grew out of those courses We would also like to refer to the review Ghosh and Samanta 2002b that first made us think of writing a book The book contains somewhat more material than can be covered in a single semester We have done this intentionally so that an instructor has some choice as to what to cover as well as which of the three aspects to emphasize Such a choice is essential for the instructor The topics include several results or methods that have not appeared in a graduate text before In fact the book can be used also as a second course in Bayesian analysis if the instructor supplies more details Chapter 1 provides a quick review of classical statistical inference Some knowledge of this is assumed when we compare different paradigms Following this an introduction to Bayesian inference is given in Chapter 2 emphasizing the need for the Bayesian approach to statistics *Discussion of 'An Overview of Robust Bayesian Analysis' by James Berger* *Self Contained: Original Discussion Not Included* A. DasGupta, 1994 Robust Bayesian Analysis of Selection Models M. J. Bayarri, J. Berger, 1993 **Global Robust Bayesian Analysis in Large Models** Paul Ho, 2020 Decision Theory and Bayesian Analysis Mr. Rohit Manglik, 2024-04-14 EduGorilla Publication is a trusted name in the

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Robust Bayesian Analysis for Econometrics Raffaella Giacomini, Toru Kitagawa, Matthew Read, 2021 We review the literature on robust Bayesian analysis as a tool for global sensitivity analysis and for statistical decision making under ambiguity We discuss the methods proposed in the literature including the different ways of constructing the set of priors that are the key input of the robust Bayesian analysis We consider both a general set up for Bayesian statistical decisions and inference and the special case of set identified structural models We provide new results that can be used to derive and compute the set of posterior moments for sensitivity analysis and to compute the optimal statistical decision under multiple priors The paper ends with a self contained discussion of three different approaches to robust Bayesian inference for set identified structural vector autoregressions including details about numerical implementation and an empirical illustration

Robust Bayesian Analysis of the Binomial Empirical Bayes Problem S. Sivaganesan, J. Berger, 1990 Robust Bayesian Analysis Given Priors on Partition Sets Cinzia Carota, Fabrizio Ruggeri, 1993 Robust Bayesian Analysis of the Binomial Empirical Bayes Problem S. Sivaganesan, James O. Berger, 1992

The Robust Bayesian Analysis of Bayesian Networks J. Q. Smith, A. R. Daneshkhan, University of Sheffield. Department of Probability and Statistics, 2005 Robust Bayesian Analysis of Heavy-tailed Stochastic Volatility Models Using Scale Mixtures of Normal Distributions C. A. Abanto-Valle, 2008 Robust Statistics, Data Analysis, and Computer Intensive Methods Helmut Rieder, 2012-12-06 To celebrate Peter Huber's 60th birthday in 1994 our university had invited for a festive occasion in the afternoon of Thursday June 9 The invitation to honour this outstanding personality was followed by about fifty colleagues and former students from mainly all over the world Others who could not attend sent their congratulations by mail and e mail P Bickel It's hard to imagine that Peter turned 60 After a welcome address by Adalbert Kerber dean the following lectures were delivered Volker Strassen Konstanz Almost Sure Primes and Cryptography an Introduction Frank Hampel Zurich On the Philosophical Foundations of Statistics 1 Andreas Buja Murray Hill Projections and Sections High Dimensional Graphics for Data Analysis The distinguished speakers lauded Peter Huber a hard and fair mathematician a cooperative and stimulating colleague and an inspiring and helpful teacher The Festkolloquium was surrounded with a musical program by the University's Brass Ensemble The subsequent Workshop Robust Statistics Data Analysis and Computer Intensive Methods in Schloss Thurnau Friday until Sunday June 9-12 was organized about the areas in statistics that Peter Huber himself has markedly shaped In the time since the conference most of the contributions could be edited for this volume a late birthday present that may give a new impetus to further research in these fields

Robust Bayesian Analysis, an Interactive Approach Brunero Liseo, 1994 Bayesian Thinking, Modeling and Computation, 2005-11-29 This volume describes how to develop Bayesian thinking modelling and computation both from philosophical

methodological and application point of view It further describes parametric and nonparametric Bayesian methods for modelling and how to use modern computational methods to summarize inferences using simulation The book covers wide range of topics including objective and subjective Bayesian inferences with a variety of applications in modelling categorical survival spatial spatiotemporal Epidemiological software reliability small area and micro array data The book concludes with a chapter on how to teach Bayesian thoughts to nonstatisticians Critical thinking on causal effects Objective Bayesian philosophy Nonparametric Bayesian methodology Simulation based computing techniques Bioinformatics and Biostatistics

Statistical Decision Theory and Bayesian Analysis James O. Berger, 2013-03-14 In this new edition the author has added substantial material on Bayesian analysis including lengthy new sections on such important topics as empirical and hierarchical Bayes analysis Bayesian calculation Bayesian communication and group decision making With these changes the book can be used as a self contained introduction to Bayesian analysis In addition much of the decision theoretic portion of the text was updated including new sections covering such modern topics as minimax multivariate Stein estimation

Bayesian Analysis in Statistics and Econometrics Donald A. Berry, Kathryn M. Chaloner, John K. Geweke, 1996 This book is a definitive work that captures the current state of knowledge of Bayesian Analysis in Statistics and Econometrics and attempts to move it forward It covers such topics as foundations forecasting inferential matters regression computation and applications

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Table of Contents Robust Bayesian Analysis

1. Understanding the eBook Robust Bayesian Analysis
 - The Rise of Digital Reading Robust Bayesian Analysis
 - Advantages of eBooks Over Traditional Books
2. Identifying Robust Bayesian Analysis
 - Exploring Different Genres
 - Considering Fiction vs. Non-Fiction
 - Determining Your Reading Goals
3. Choosing the Right eBook Platform
 - Popular eBook Platforms
 - Features to Look for in an Robust Bayesian Analysis
 - User-Friendly Interface
4. Exploring eBook Recommendations from Robust Bayesian Analysis
 - Personalized Recommendations
 - Robust Bayesian Analysis User Reviews and Ratings
 - Robust Bayesian Analysis and Bestseller Lists
5. Accessing Robust Bayesian Analysis Free and Paid eBooks
 - Robust Bayesian Analysis Public Domain eBooks
 - Robust Bayesian Analysis eBook Subscription Services
 - Robust Bayesian Analysis Budget-Friendly Options

6. Navigating Robust Bayesian Analysis eBook Formats
 - ePub, PDF, MOBI, and More
 - Robust Bayesian Analysis Compatibility with Devices
 - Robust Bayesian Analysis Enhanced eBook Features
7. Enhancing Your Reading Experience
 - Adjustable Fonts and Text Sizes of Robust Bayesian Analysis
 - Highlighting and Note-Taking Robust Bayesian Analysis
 - Interactive Elements Robust Bayesian Analysis
8. Staying Engaged with Robust Bayesian Analysis
 - Joining Online Reading Communities
 - Participating in Virtual Book Clubs
 - Following Authors and Publishers Robust Bayesian Analysis
9. Balancing eBooks and Physical Books Robust Bayesian Analysis
 - Benefits of a Digital Library
 - Creating a Diverse Reading Collection Robust Bayesian Analysis
10. Overcoming Reading Challenges
 - Dealing with Digital Eye Strain
 - Minimizing Distractions
 - Managing Screen Time
11. Cultivating a Reading Routine Robust Bayesian Analysis
 - Setting Reading Goals Robust Bayesian Analysis
 - Carving Out Dedicated Reading Time
12. Sourcing Reliable Information of Robust Bayesian Analysis
 - Fact-Checking eBook Content of Robust Bayesian Analysis
 - Distinguishing Credible Sources
13. Promoting Lifelong Learning
 - Utilizing eBooks for Skill Development
 - Exploring Educational eBooks
14. Embracing eBook Trends
 - Integration of Multimedia Elements

- Interactive and Gamified eBooks

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