

Statistical Optimality and Computational Efficiency of Nyström Kernel PCA

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Abstract

Kernel methods provide an elegant framework for developing nonlinear learning algorithms from simple linear methods. Though these methods have superior empirical performance in several real data applications, their usefulness is inhibited by the significant computational burden incurred in large sample situations. Various approximation schemes have been proposed in the literature to alleviate these computational issues, and the approximate kernel machines are shown to retain the empirical performance. However, the theoretical properties of these approximate kernel machines are less well understood. In this work, we theoretically study the trade-off between computational complexity and statistical accuracy in Nyström approximate kernel principal component analysis (KPCA), wherein we show that the Nyström approximate KPCA matches the statistical performance of (non-approximate) KPCA while remaining computationally beneficial. Additionally, we show that Nyström approximate KPCA outperforms the statistical behavior of another popular approximation scheme, the random feature approximation, when applied to KPCA.

MSC 2010 subject classification: Primary: 65R15; Secondary: 62H25, 46E22, 65F55.

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1 Introduction

Principal component analysis (PCA) (Jolliffe, 1986) is an unsupervised learning technique in which a random variable X taking values in $\mathbb{R}^d$ is projected onto the direction $\mathbf{a} \in \mathbb{R}^d$ such that $\text{Var}[\mathbf{a}^\top X]$ is maximized. Further, for some $\ell < d$, PCA may be used to find an ℓ -dimensional subspace retaining the maximum possible variance of X , making PCA a popular methodology for dimension reduction and feature extraction. This low-dimensional subspace is the ℓ -eigenspace, i.e., the span of the eigenvectors associated with the top ℓ eigenvalues of the covariance matrix $\mathbb{E}XX^\top - \mathbb{E}X\mathbb{E}X^\top$. The respective eigenvectors are referred to as the principal components of the data, and a lower-dimensional representation of the input data may be computed by projecting onto the principal components.

The principal components outputted by PCA are linearly related to the original coordinates; however, in many cases a non-linear component provides a better description of the data. Kernel PCA (KPCA) (Schölkopf et al., 1998) is a non-linear extension of PCA which maps the original

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On Statistical Surveillance Christian Sonesson, 2003 This is a Ph D dissertation The need for statistical surveillance has been noticed in many different areas Examples of applications discussed in this thesis include the detection of an increased incidence of a disease and the detection of intra uterine **Statistical Surveillance**, 2002 Statistical Methods for Healthcare Performance Monitoring Alex Bottle, Paul Aylin, 2016-08-05 Healthcare is important to everyone yet large variations in its quality have been well documented both between and within many countries With demand and expenditure rising it is more crucial than ever to know how well the healthcare system and all its components from staff member to regional network are performing This requires data which inevitably differ in form and quality It also requires statistical methods the output of which needs to be presented so that it can be understood by whoever needs it to make decisions *Statistical Methods for Healthcare Performance Monitoring* covers measuring quality types of data risk adjustment defining good and bad performance statistical monitoring presenting the results to different audiences and evaluating the monitoring system itself Using examples from around the world it brings all the issues and perspectives together in a largely non technical way for clinicians managers and methodologists *Statistical Methods for Healthcare Performance Monitoring* is aimed at statisticians and researchers who need to know how to measure and compare performance health service regulators health service managers with responsibilities for monitoring performance and quality improvement scientists including those involved in clinical audits **Stochastic Models Of Tumor Latency And Their Biostatistical Applications** Alexander D Tsodikov, Andrei Yu Yakovlev, B Asselain, 1996-03-20 This research monograph discusses newly developed mathematical models and methods that provide biologically meaningful inferences from data on cancer latency produced by follow up and discrete surveillance studies Methods for designing optimal strategies of cancer surveillance are systematically presented for the first time in this book It offers new approaches to the stochastic description of tumor latency employs biologically based models for making statistical inference from data on tumor recurrence and also discusses methods of statistical analysis of data resulting from discrete surveillance strategies It also offers insight into the role of prognostic factors based on the interpretation of their effects in terms of parameters endowed with biological meaning as well as methods for designing optimal schedules of cancer screening and surveillance Last but not least it discusses survival models allowing for cure rates and the choice of optimal treatment based on covariate information and presents numerous examples of real data analysis

Frontiers in Statistical Quality Control 13 Sven Knoth, Wolfgang Schmid, 2021-05-15 This contributed book focuses on major aspects of statistical quality control shares insights into important new developments in the field and adapts established statistical quality control methods for use in e g big data network analysis and medical applications The content is divided into two parts the first of which mainly addresses statistical process control also known as statistical process monitoring In turn the second part explores selected topics in statistical quality control including measurement uncertainty

analysis and data quality The peer reviewed contributions gathered here were originally presented at the 13th International Workshop on Intelligent Statistical Quality Control ISQC 2019 held in Hong Kong on August 12-14, 2019 Taken together they bridge the gap between theory and practice making the book of interest to both practitioners and researchers in the field of statistical quality control Optimal Sequential Surveillance for Finance, Public Health, and Other Areas Marianne Frisén, 2007 *Innovative Statistical Methods for Public Health Data* Ding-Geng (Din) Chen, Jeffrey Wilson, 2015-09-12 The book brings together experts working in public health and multi disciplinary areas to present recent issues in statistical methodological development and their applications This timely book will impact model development and data analyses of public health research across a wide spectrum of analysis Data and software used in the studies are available for the reader to replicate the models and outcomes The fifteen chapters range in focus from techniques for dealing with missing data with Bayesian estimation health surveillance and population definition and implications in applied latent class analysis to multiple comparison and meta analysis in public health data Researchers in biomedical and public health research will find this book to be a useful reference and it can be used in graduate level classes Statistical Surveillance David Bock, 2004

Medical Product Safety Evaluation Jie Chen, Joseph Heyse, Tze Leung Lai, 2018-09-03 Medical Product Safety Evaluation Biological Models and Statistical Methods presents cutting edge biological models and statistical methods that are tailored to specific objectives and data types for safety analysis and benefit risk assessment Some frequently encountered issues and challenges in the design and analysis of safety studies are discussed with illustrative applications and examples Medical Product Safety Evaluation Biological Models and Statistical Methods presents cutting edge biological models and statistical methods that are tailored to specific objectives and data types for safety analysis and benefit risk assessment Some frequently encountered issues and challenges in the design and analysis of safety studies are discussed with illustrative applications and examples The book is designed not only for biopharmaceutical professionals such as statisticians safety specialists pharmacovigilance experts and pharmacoepidemiologists who can use the book as self learning materials or in short courses or training programs but also for graduate students in statistics and biomedical data science for a one semester course Each chapter provides supplements and problems as more readings and exercises *Statistical Design, Monitoring, and Analysis of Clinical Trials* Weichung Joe Shih, Joseph Aisner, 2021-10-25 Statistical Design Monitoring and Analysis of Clinical Trials Second Edition concentrates on the biostatistics component of clinical trials This new edition is updated throughout and includes five new chapters Developed from the authors courses taught to public health and medical students residents and fellows during the past 20 years the text shows how biostatistics in clinical trials is an integration of many fundamental scientific principles and statistical methods The book begins with ethical and safety principles core trial design concepts the principles and methods of sample size and power calculation and analysis of covariance and stratified analysis It then focuses on sequential designs and methods for two stage Phase II cancer trials to Phase III group sequential trials

covering monitoring safety utility and efficacy The authors also discuss the development of sample size reestimation and adaptive group sequential procedures phase 2/3 seamless design and trials with predictive biomarkers exploit multiple testing procedures and explain the concept of estimand intercurrent events and different missing data processes and describe how to analyze incomplete data by proper multiple imputations This text reflects the academic research commercial development and public health aspects of clinical trials It gives students and practitioners a multidisciplinary understanding of the concepts and techniques involved in designing monitoring and analyzing various types of trials The book's balanced set of homework assignments and in class exercises are appropriate for students and researchers in biostatistics epidemiology medicine pharmacy and public health

Statistical Monitoring of Clinical Trials Michael A. Proschan, K. K. Gordon Lan, Janet Turk Wittes, 2006-12-31 The approach taken in this book is to studies monitored over time what the Central Limit Theorem is to studies with only one analysis Just as the Central Limit Theorem shows that test statistics involving very different types of clinical trial outcomes are asymptotically normal this book shows that the joint distribution of the test statistics at different analysis times is asymptotically multivariate normal with the correlation structure of Brownian motion the B value irrespective of the test statistic Thus this book offers statisticians an accessible incremental approach to understanding Brownian motion as related to clinical trials

Introduction to Statistical Methods for Biosurveillance Ronald D. Fricker, 2013 While the public health philosophy of the 20th Century emphasizing prevention is ideal for addressing natural disease outbreaks it is not sufficient to confront 21st Century threats where adversaries may use biological weapons agents as part of a long term campaign of aggression and terror Health care providers and public health officers are among our first lines of defense Therefore we are building on the progress of the past three years to further improve the preparedness of our public health and medical systems to address current and future BW biological warfare threats and to respond with greater speed and flexibility to multiple or repetitive attacks Homeland Security Presidential Directive 21 Bioterrorism is not a new threat in the 21st century thousands of years ago the plague and other contagious diseases were used in warfare but today the potential for catastrophic outcomes is greater than it has ever been To address this threat the medical and public health communities are putting various measures in place including systems designed to proactively monitor populations for possible disease outbreaks Provided by publisher

Introduction to Statistical Methods for Biosurveillance Ronald D. Fricker, 2013-02-25 Bioterrorism is not a new threat but in an increasingly interconnected world the potential for catastrophic outcomes is greater today than ever The medical and public health communities are establishing biosurveillance systems designed to proactively monitor populations for possible disease outbreaks as a first line of defense The ideal biosurveillance system should identify trends not visible to individual physicians and clinicians in near real time Many of these systems use statistical algorithms to look for anomalies and to trigger epidemiologic investigation quantification localization and outbreak management This book discusses the design and evaluation of statistical methods for

effective biosurveillance for readers with minimal statistical training Weaving public health and statistics together it presents basic and more advanced methods with a focus on empirically demonstrating added value Although the emphasis is on epidemiologic and syndromic surveillance the statistical methods can be applied to a broad class of public health surveillance problems **Statistical Monitoring Schemes in Healthcare** Philipp Wittenberg,2021 **Statistics in Precision**

Health Yichuan Zhao,Ding-Geng Chen,2024-07-09 This book discusses statistical methods and their innovative applications in precision health It serves as a valuable resource to foster the development of this growing field within the context of the big data era The chapters cover a wide range of topics including foundational principles statistical theories new procedures advanced methods and practical applications in precision medicine Particular attention is devoted to the interplay between precision health big data and mobile health research while also exploring precision medicine s role in clinical trials electronic health record data analysis survival analysis and genomic studies Targeted at data scientists statisticians graduate students and researchers in academia industry and government this book offers insights into the latest advances in personalized medicine using advanced statistical techniques **Statistical Methods for Dynamic Treatment Regimes** Bibhas

Chakraborty, Erica E.M. Moodie,2013-07-23 Statistical Methods for Dynamic Treatment Regimes shares state of the art of statistical methods developed to address questions of estimation and inference for dynamic treatment regimes a branch of personalized medicine This volume demonstrates these methods with their conceptual underpinnings and illustration through analysis of real and simulated data These methods are immediately applicable to the practice of personalized medicine which is a medical paradigm that emphasizes the systematic use of individual patient information to optimize patient health care This is the first single source to provide an overview of methodology and results gathered from journals proceedings and technical reports with the goal of orienting researchers to the field The first chapter establishes context for the statistical reader in the landscape of personalized medicine Readers need only have familiarity with elementary calculus linear algebra and basic large sample theory to use this text Throughout the text authors direct readers to available code or packages in different statistical languages to facilitate implementation In cases where code does not already exist the authors provide analytic approaches in sufficient detail that any researcher with knowledge of statistical programming could implement the methods from scratch This will be an important volume for a wide range of researchers including statisticians epidemiologists medical researchers and machine learning researchers interested in medical applications Advanced graduate students in statistics and biostatistics will also find material in Statistical Methods for Dynamic Treatment Regimes to be a critical part of their studies **Statistical Monitoring of Clinical Trials** Lemuel A. Moyé,2006-02-28 Statistical Monitoring of Clinical Trials Fundamentals for Investigators introduces the investigator and statistician to monitoring procedures in clinical research Clearly presenting the necessary background with limited use of mathematics this book increases the knowledge experience and intuition of investigations in the use of these important procedures now required by the many clinical

research efforts The author provides motivated clinical investigators the background correct use and interpretation of these monitoring procedures at an elementary statistical level He defines terms commonly used such as group sequential procedures and stochastic curtailment in non mathematical language and discusses the commonly used procedures of Pocock O'Brien Fleming and Lan DeMets He discusses the notions of conditional power monitoring for safety and futility and monitoring multiple endpoints in the study The use of monitoring clinical trials is introduced in the context of the evolution of clinical research and one chapter is devoted to the more recent Bayesian procedures From the reviews The author has a wealth of experience in this area and this is demonstrated throughout the text with relevant poignant examples Short Book Reviews of the ISI June 2006 *Introduction to Statistical Methods for Biosurveillance* Ronald D. Fricker, 2013 **Optimal Evaluation and Application of Statistical Procedures of Combined Results** Qihao Jiang, 1994 Statistical Surveillance, 2001

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Table of Contents On Statistical Surveillance Ibues Of Optimality And Medical Applications

1. Understanding the eBook On Statistical Surveillance Ibues Of Optimality And Medical Applications
 - The Rise of Digital Reading On Statistical Surveillance Ibues Of Optimality And Medical Applications
 - Advantages of eBooks Over Traditional Books
2. Identifying On Statistical Surveillance Ibues Of Optimality And Medical Applications
 - 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 On Statistical Surveillance Ibues Of Optimality And Medical Applications
 - User-Friendly Interface
4. Exploring eBook Recommendations from On Statistical Surveillance Ibues Of Optimality And Medical Applications
 - Personalized Recommendations

- On Statistical Surveillance Ibues Of Optimality And Medical Applications User Reviews and Ratings
- On Statistical Surveillance Ibues Of Optimality And Medical Applications and Bestseller Lists
- 5. Accessing On Statistical Surveillance Ibues Of Optimality And Medical Applications Free and Paid eBooks
 - On Statistical Surveillance Ibues Of Optimality And Medical Applications Public Domain eBooks
 - On Statistical Surveillance Ibues Of Optimality And Medical Applications eBook Subscription Services
 - On Statistical Surveillance Ibues Of Optimality And Medical Applications Budget-Friendly Options
- 6. Navigating On Statistical Surveillance Ibues Of Optimality And Medical Applications eBook Formats
 - ePub, PDF, MOBI, and More
 - On Statistical Surveillance Ibues Of Optimality And Medical Applications Compatibility with Devices
 - On Statistical Surveillance Ibues Of Optimality And Medical Applications Enhanced eBook Features
- 7. Enhancing Your Reading Experience
 - Adjustable Fonts and Text Sizes of On Statistical Surveillance Ibues Of Optimality And Medical Applications
 - Highlighting and Note-Taking On Statistical Surveillance Ibues Of Optimality And Medical Applications
 - Interactive Elements On Statistical Surveillance Ibues Of Optimality And Medical Applications
- 8. Staying Engaged with On Statistical Surveillance Ibues Of Optimality And Medical Applications
 - Joining Online Reading Communities
 - Participating in Virtual Book Clubs
 - Following Authors and Publishers On Statistical Surveillance Ibues Of Optimality And Medical Applications
- 9. Balancing eBooks and Physical Books On Statistical Surveillance Ibues Of Optimality And Medical Applications
 - Benefits of a Digital Library
 - Creating a Diverse Reading Collection On Statistical Surveillance Ibues Of Optimality And Medical Applications
- 10. Overcoming Reading Challenges
 - Dealing with Digital Eye Strain
 - Minimizing Distractions
 - Managing Screen Time
- 11. Cultivating a Reading Routine On Statistical Surveillance Ibues Of Optimality And Medical Applications
 - Setting Reading Goals On Statistical Surveillance Ibues Of Optimality And Medical Applications
 - Carving Out Dedicated Reading Time
- 12. Sourcing Reliable Information of On Statistical Surveillance Ibues Of Optimality And Medical Applications
 - Fact-Checking eBook Content of On Statistical Surveillance Ibues Of Optimality And Medical Applications

- 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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