Generalized Linear Mixed Models for Longitudinal Data

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Abstract The study of longitudinal data plays a significant role in medicine, epidemiology and social sciences. Typically, the interest is in the dependence of an outcome variable on the covariates. The Generalized Linear Models (GLMs) were proposed to unify the regression approach for a wide variety of discrete and continuous longitudinal data. The responses (outcomes) in longitudinal data are usually correlated. Hence, we need to use an extension of the GLMs that account for such correlation. This can be done by inclusion of random effects in the linear predictor; that is the Generalized Linear Mixed Models (GLMMs) (also called random effects models). The maximum likelihood estimates (MLE) are obtained for the regression parameters of a logit model, when the traditional assumption of normal random effects is relaxed. In this case a more convenient distribution, such as the lognormal distribution, is used. However, adding non-normal random effects to the GLMM considerably complicates the likelihood estimation. So, the direct numerical evaluation techniques (such as Newton - Raphson) become analytically and computationally tedious. To overcome such problems, we propose and develop a Monte Carlo EM (MCEM) algorithm, to obtain the maximum likelihood estimates. The proposed method is illustrated using a simulated data.

Keywords Generalized Linear Mixed Models, Logistic Regression, Longitudinal Data, Monte Carlo EM Algorithm, Random Effects Model

1. Introduction

Longitudinal data consist of repeated observations, for the same subject, of an outcome variable. There may be a set of covariates for each subjects. Let $y_i = (y_{i1}, y_{i2}, \ldots, y_{im_i})^T$ be an $m_i \times 1$ vector representing the observed sequence of the outcome variable Y_{it} recorded at time $t = 1, 2, \ldots, m_i$, for the ith subject, $i = 1, 2, \ldots, n$. Also, assume that $\mathbf{x}_{ij} = (x_{it1}, x_{it2}, \ldots, x_{itp})$ is an $l \times p$ vector of p covariates observed at time t. Thus, X_i is an $m_i \times p$ matrix of covariates corresponding to the ith subject taking the form:

$$\begin{pmatrix} x_{i11} & \cdots & x_{i1p} \\ \vdots & \ddots & \vdots \\ x_{im_i 1} & \cdots & x_{im_i p} \end{pmatrix}.$$

For simplicity we can assume that $m_i = m$.

The primary focus is on the dependence of the outcome on the covariates[3,5]. In other words, we are usually interested in the inference about the regression coefficients, in the usual linear models of the form

$$Y_i = X_i \beta + e_i,$$

where $\beta = (\beta_1, \ldots, \beta_p)^T$ is a $p \times 1$ vector of the regression coefficients. It is usually assumed that the errors, e_i, are independent and identically normally distributed. Therefore, these models are not used in situations when response variables have distributions other than the normal, or even when they are qualitative rather than quantitative. Examples include binary longitudinal data.

To solve this problem, Reference[18] introduce the generalized linear models (GLM) as a unified framework to model all types of longitudinal data[13, 15, 24]. These models assume that the distribution of Y_{it} ($i = 1, \ldots, n$, $t = 1, 2, \ldots, m$) belongs to the exponential family. The exponential family distributions can be written in the form:

$$f(y_{it}, \theta_{it}) = e^{\{(y_{it}\theta_{it} - a(\theta_{it}))/\phi + b(y_{it},\phi)\}}, \quad (1)$$

where $a(.)$ and $b(.)$ are specific functions defined according to the underlying distribution of the exponential family. Some examples of univariate distributions are given in Table (1). The parameters $\theta_{it} = h(\eta_{it})$ and $\eta_{it} = x_{it}\beta$. Also ϕ is the scale parameter and it is treated as a nuisance parameter when the main interest is in the regression coefficients[13]. The distribution in Equation (1) is the canonical form and θ_{it} is called the natural parameter of the distribution.

The first two moments of y_{it} in Equation (1) are given by

$$E(y_{it}) = \mu_{it} = a'(\theta_{it}) \text{ and } Var(y_{it}) = \frac{a''(\theta_{it})}{\phi} \quad (2)$$

$$b1 = -\tfrac{1}{2}(y^2 + \sigma^{-2}\ln(2\pi\sigma^2))$$

For the GLM, the linear combination of the parameters of interest, $\beta_1, \beta_2, \ldots, \beta_p$, are equal to some function of the expected value of y_{it} (μ_{it}), i. e., $g(\mu_{it}) = \eta_{it}$ where g is a monotone and differentiable function called the link function. From Equation (1) and Equation (2), we can write the inverse of the link function as $g^{-1} = a' \circ h$. Note that a link function in which $\theta_{it} = \eta_{it}$ (e.g., h is the identity function)

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Hongmei Yang

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Variable Selection Procedures for Generalized Linear Mixed Models in Longitudinal Data Analysis ,2004 Model selection is important for longitudinal data analysis But up to date little work has been done on variable selection for generalized linear mixed models GLMM In this paper we propose and study a class of variable selection methods Full likelihood FL approach is proposed for simultaneous model selection and parameter estimation Due to the intensive computation involved in FL approach Penalized Quasi Likelihood PQL procedure is developed so that model selection in GLMMs can proceed in the framework of linear mixed models Since the PQL approach will produce biased parameter estimates for sparse binary longitudinal data Two stage Penalized Quasi Likelihood approach TPQL is proposed to bias correct PQL in terms of estimation use PQL to do model selection at the first stage and existing software to do parameter estimation at the second stage Marginal approach for some special types of data is also developed A robust estimator of standard error for the fitted parameters is derived based on a sandwich formula A bias correction is proposed to improve the estimation accuracy of PQL for binary data The sampling performance of four proposed procedures is evaluated through extensive simulations and their application to real data analysis In terms of model selection all of them perform closely As for parameter estimation FL AML and TPQL yield similar results Compared with FL the other procedures greatly reduce computational load The proposed procedures can be extended to longitudinal data analysis involving missing data and the shrinkage penalty based approach allows them to work even when the number of observations n is less than the number of parameters d   Models for Discrete Longitudinal Data Geert Molenberghs,Geert Verbeke,2006-01-28 The linear mixed model has become the main parametric tool for the analysis of continuous longitudinal data as the authors discussed in their 2000 book Without putting too much emphasis on software the book shows how the different approaches can be implemented within the SAS software package The authors received the American Statistical Association s Excellence in Continuing Education Award based on short courses on longitudinal and incomplete data at the Joint Statistical Meetings of 2002 and 2004   *Linear and Generalized Linear Mixed Models and Their Applications* Jiming Jiang,Thuan Nguyen,2021-03-22 This book covers two major classes of mixed effects models linear mixed models and generalized linear mixed models It presents an up to date account of theory and methods in analysis of these models as well as their applications in various fields The book offers a systematic approach to inference about non Gaussian linear mixed models Furthermore it includes recently developed methods such as mixed model diagnostics mixed model selection and jackknife method in the context of mixed models The book is aimed at students researchers and other practitioners who are interested in using mixed models for statistical data analysis   **Variable Selection Procedures for Generalized Linear Mixed Models in Longitudinal Data Analysis** Hongmei Yang,2007 Keywords variance component Laplace approximation generalized linear mixed model quasi likelihood generalized estimation equation approximate marginal likelihood SCAD

Computational and Methodological Statistics and Biostatistics Andriëtte Bekker,(Din) Ding-Geng Chen,Johannes T. Ferreira,2020-08-10 In the statistical domain certain topics have received considerable attention during the last decade or so necessitated by the growth and evolution of data and theoretical challenges This growth has invariably been accompanied by computational advancement which has presented end users as well as researchers with the necessary opportunities to handle data and implement modelling solutions for statistical purposes Showcasing the interplay among a variety of disciplines this book offers pioneering theoretical and applied solutions to practice oriented problems As a carefully curated collection of prominent international thought leaders it fosters collaboration between statisticians and biostatisticians and provides an array of thought processes and tools to its readers The book thereby creates an understanding and appreciation of recent developments as well as an implementation of these contributions within the broader framework of both academia and industry Computational and Methodological Statistics and Biostatistics is composed of three main themes Recent developments in theory and applications of statistical distributions Recent developments in supervised and unsupervised modelling Recent developments in biostatistics and also features programming code and accompanying algorithms to enable readers to replicate and implement methodologies Therefore this monograph provides a concise point of reference for a variety of current trends and topics within the statistical domain With interdisciplinary appeal it will be useful to researchers graduate students and practitioners in statistics biostatistics clinical methodology geology data science and actuarial science amongst others *Springer Handbook of Engineering Statistics* Hoang Pham,2006 In today s global and highly competitive environment continuous improvement in the processes and products of any field of engineering is essential for survival This book gathers together the full range of statistical techniques required by engineers from all fields It will assist them to gain sensible statistical feedback on how their processes or products are functioning and to give them realistic predictions of how these could be improved The handbook will be essential reading for all engineers and engineering connected managers who are serious about keeping their methods and products at the cutting edge of quality and competitiveness Epidemiology and Medical Statistics ,2007-11-21 This volume representing a compilation of authoritative reviews on a multitude of uses of statistics in epidemiology and medical statistics written by internationally renowned experts is addressed to statisticians working in biomedical and epidemiological fields who use statistical and quantitative methods in their work While the use of statistics in these fields has a long and rich history explosive growth of science in general and clinical and epidemiological sciences in particular have gone through a see of change spawning the development of new methods and innovative adaptations of standard methods Since the literature is highly scattered the Editors have undertaken this humble exercise to document a representative collection of topics of broad interest to diverse users The volume spans a cross section of standard topics oriented toward users in the current evolving field as well as special topics in much need which have more recent origins This volume was prepared especially keeping the applied statisticians in mind emphasizing applications

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Mixed Models Second Edition provides an up to date treatment of the essential techniques for developing and applying a wide variety of statistical models The book presents thorough and unified coverage of the theory behind generalized linear and mixed models and highlights their similarities and differences in various construction application and computational aspects A clear introduction to the basic ideas of fixed effects models random effects models and mixed models is maintained throughout and each chapter illustrates how these models are applicable in a wide array of contexts In addition a discussion of general methods for the analysis of such models is presented with an emphasis on the method of maximum likelihood for the estimation of parameters The authors also provide comprehensive coverage of the latest statistical models for correlated non normally distributed data Thoroughly updated to reflect the latest developments in the field the Second Edition features A new chapter that covers omitted covariates incorrect random effects distribution correlation of covariates and random effects and robust variance estimation A new chapter that treats shared random effects models latent class models and properties of models A revised chapter on longitudinal data which now includes a discussion of generalized linear models modern advances in longitudinal data analysis and the use between and within covariate decompositions Expanded coverage of marginal versus conditional models Numerous new and updated examples With its accessible style and wealth of illustrative exercises Generalized Linear and Mixed Models Second Edition is an ideal book for courses on generalized linear and mixed models at the upper undergraduate and beginning graduate levels It also serves as a valuable reference for applied statisticians industrial practitioners and researchers **Measurement Error in Nonlinear Models** Raymond J. Carroll,David Ruppert,Leonard A. Stefanski,Ciprian M. Crainiceanu,2006-06-21 It s been over a decade since the first edition of Measurement Error in Nonlinear Models splashed onto the scene and research in the field has certainly not cooled in the interim In fact quite the opposite has occurred As a result Measurement Error in Nonlinear Models A Modern Perspective Second Edition has been revamped and ex   Model Diagnostics for Generalized Linear Mixed Models Zhonghua Gu,2008   Generalized Linear Mixed Models Charles E. McCulloch,2003 Wiley Series in Probability and Statistics A modern perspective on mixed models The availability of powerful computing methods in recent decades has thrust linear and nonlinear mixed models into the mainstream of statistical application This volume offers a modern perspective on generalized linear and mixed models presenting a unified and accessible treatment of the newest statistical methods for analyzing correlated nonnormally distributed data As a follow up to Searle s classic Linear Models and Variance Components by Searle Casella and McCulloch this new work progresses from the basic one way classification to generalized linear mixed models A variety of statistical methods are explained and illustrated with an emphasis on maximum likelihood and restricted maximum likelihood An invaluable resource for applied statisticians and industrial practitioners as well as students interested in the latest results Generalized Linear and Mixed Models features A review of the basics of linear models and linear mixed models Descriptions of models for nonnormal data including generalized linear and nonlinear models Analysis and illustration of

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