

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 $\mathbf{y}_i = (y_{i1}, y_{i2}, \dots, y_{im})^T$ be an $m_i \times 1$ vector representing the observed sequence of the outcome variable Y_{it} recorded at time $t = 1, 2, \dots, m_i$ for the i th subject, $i = 1, 2, \dots, n$. Also, assume that $\mathbf{X}_{ij} = (x_{i1t}, x_{i2t}, \dots, x_{ipt})$ is an $l \times p$ vector of p covariates observed at time t . Thus, \mathbf{X}_i is an $m_i \times p$ matrix of covariates corresponding to the i th subject taking the form:

$$\begin{pmatrix} \mathbf{X}_{i(1)} & \dots & \mathbf{X}_{i(1)p} \\ \vdots & \ddots & \vdots \\ \mathbf{X}_{i(m_i)} & \dots & \mathbf{X}_{i(m_i)p} \end{pmatrix}$$

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

$$y_i = \mathbf{X}_i \boldsymbol{\beta} + \epsilon_i$$

where $\boldsymbol{\beta} = (\beta_1, \dots, \beta_p)^T$ is a $p \times 1$ vector of the regression coefficients. It is usually assumed that the errors, ϵ_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} ($i = 1, \dots, n$, $t = 1, 2, \dots, m$) belongs to the exponential family. The exponential family distributions can be written in the form:

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

where $a(\cdot)$ and $b(\cdot)$ 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 $\eta_{it} = x_{it} \boldsymbol{\beta}$. 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

$$E(y_{it}) = \mu_{it} = a'(\theta_{it}) \text{ and } \text{Var}(y_{it}) = \frac{a''(\theta_{it})}{g} \quad (2)$$
$$h1 = -\frac{1}{2} (y^2 + \sigma^2 \ln(2\pi\sigma^2))$$

For the GLM, the linear combination of the parameters of interest, $\beta_1, \beta_2, \dots, \beta_p$, 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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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

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Bayesian Hierarchical Models Peter D. Congdon, 2019-09-16 An intermediate level treatment of Bayesian hierarchical models and their applications this book demonstrates the advantages of a Bayesian approach to data sets involving inferences for collections of related units or variables and in methods where parameters can be treated as random collections Through illustrative data analysis and attention to statistical computing this book facilitates practical implementation of Bayesian hierarchical methods The new edition is a revision of the book Applied Bayesian Hierarchical Methods It maintains a focus on applied modelling and data analysis but now using entirely R based Bayesian computing options It has been updated with a new chapter on regression for causal effects and one on computing options and strategies This latter chapter is particularly important due to recent advances in Bayesian computing and estimation including the development of rjags and rstan It also features updates throughout with new examples The examples exploit and illustrate the broader advantages of the R computing environment while allowing readers to explore alternative likelihood assumptions regression structures and assumptions on prior densities Features Provides a comprehensive and accessible overview of applied Bayesian hierarchical modelling Includes many real data examples to illustrate different modelling topics R code based on rjags jagsUI R2OpenBUGS and rstan is integrated into the book emphasizing implementation Software options and coding principles are introduced in new chapter on computing Programs and data sets available on the book s website

Generalized, Linear, and Mixed Models Charles E. McCulloch, Shayle R. Searle, John M. Neuhaus, 2011-09-20 An accessible and self contained introduction to statistical models now in a modernized new edition Generalized Linear and

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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

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Coverage of the prediction of realized values of random effects A discussion of the impact of computing issues on mixed models *Journal of the American Statistical Association* ,2005 Objective Bayesian Inference in General (generalized) Linear Mixed Models Using Reference Priors Xin Zhao,2005 *Panel Bias and Longitudinal Data Analysis Using Generalized Linear Mixed Models and Generalized Estimating Equations* Marie-Claire Le Lait,2012 Generalized, Linear, and Mixed Models Charles E. McCulloch,Shayle R. Searle,2001 Generalised linear models are the primary tools of statistical analysis and form the underpinning of generalised linear models This work offers detailed and unified coverage of the dichotomy of linear and generalised linear models with fixed and mixed effects A Finite Support Random-effects Distribution Approach to Generalized Linear Mixed-effects Model Kwan Moon Leung,1994 **The Dhaka University Journal of Science** ,2016

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