



ETC3580: Advanced Statistical Modelling

Week 8: Hierarchical, longitudinal
and non-Gaussian mixed effect
models

Outline

- 1 Hierarchical Linear Models
- 2 Longitudinal data
- 3 Generalized Linear Mixed Models

Nested effects

Levels of one factor vary only within levels of another factor

- Workers within job locations
- Units within campus

Be careful: nested levels with the same labels are not the same thing.

Crossed effects

- Any non-nested effects are “crossed”.
- That is, every level of one factor can potentially interact with every level of another factor.
- Incomplete crossing occurs when not all combinations of factors exist in the data.

Multilevel models

- Models with nested (hierarchical) structure.
- Commonly used in psychology, education, and other social sciences where survey data is naturally clustered hierarchically.

Junior School Project (1988)

Variables: student, class, school, gender, social, raven, math, english, year

Nesting: school:class:student

Other variables crossed.

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Longitudinal data

- Repeated measurements on each unit taken over time.
- Called “panel data” in econometrics. Called “longitudinal data” in every other discipline.
- Individuals treated as random effects
- Additional complexity of autocorrelation to address
- Differs from time series in having many units (e.g., people) but often not many observations per person.
- i.e., Longitudinal data has large N , small T ; Time series data has small N , large T .

Longitudinal data

For unit (individual) i , \mathbf{y}_i is a T -vector such that

$$\mathbf{y}_i | \gamma_i \sim N(\mathbf{X}_i \boldsymbol{\beta} + \gamma_i, \sigma^2 \boldsymbol{\Lambda}_i)$$

- $\gamma_i \sim N(0, \sigma^2 \mathbf{D})$ is effect of i th unit
- \mathbf{X}_i contains predictors for fixed effects
- $\boldsymbol{\Lambda}_i$ handles autocorrelations within units
- $\mathbf{y}_i \sim N(\mathbf{X}_i \boldsymbol{\beta}, \boldsymbol{\Sigma}_i)$ where $\boldsymbol{\Sigma}_i = \sigma^2(\boldsymbol{\Lambda}_i + \mathbf{D})$
- Assume individuals are independent, and random effects and errors are uncorrelated.

Longitudinal data

Combining individuals (assuming independence):

$$\mathbf{y} = \begin{bmatrix} \mathbf{y}_1 \\ \vdots \\ \mathbf{y}_N \end{bmatrix} \quad \mathbf{X} = \begin{bmatrix} \mathbf{X}_1 \\ \vdots \\ \mathbf{X}_N \end{bmatrix}$$

$$\Sigma = \text{diag}(\Sigma_1, \Sigma_2, \dots, \Sigma_N),$$

$$\mathbf{y} \sim N(\mathbf{X}\beta, \Sigma)$$

Longitudinal data

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- Only additional complication is choosing correlation structure
- Other random effects can be added; then γ_i becomes a vector.

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Generalized Linear Mixed Models

- Combine GLMs with random effects
- y_i from exponential family distribution $f(y_i, \theta_i, \phi)$
- $E(y_i) = \mu_i$
- Link function g : $g(\mu_i) = \mathbf{x}_i' \boldsymbol{\beta} + \mathbf{z}_i' \boldsymbol{\gamma}$
- $\boldsymbol{\beta}$ are fixed effects; $\boldsymbol{\gamma}$ are random effects.
- $\boldsymbol{\gamma} \sim N(\mathbf{0}, \mathbf{D})$ with density $h(\boldsymbol{\gamma}|\mathbf{D})$

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Likelihood

$$L(\boldsymbol{\beta}, \phi, \mathbf{D}) = \prod_{i=1}^n \int f(y_i | \boldsymbol{\beta}, \phi, \boldsymbol{\gamma}) h(\boldsymbol{\gamma} | \mathbf{D})$$

- Can only solve integrals if f and h both normal

Numerical integration of likelihood

Likelihood

$$L(\beta, \phi, \mathbf{D}) = \prod_{i=1}^n \int f(y_i | \beta, \phi, \gamma) h(\gamma | \mathbf{D})$$

- Use numerical integration to approximate integrals
- More accurate than PQL
- Can be slow or impossible for complex models
- Inference will be problematic, as for MLE with LMMs

Penalized Quasi Likelihood

- 1 Transform fitted values:

$$\eta_i = g(\mu_i) = \mathbf{x}_i' \boldsymbol{\beta} + \mathbf{z}_i' \boldsymbol{\gamma}$$

- 2 Create pseudo-responses:

$$\tilde{y}_i^j = \hat{\eta}_i^j + (y_i - \hat{\mu}_i^j) \left. \frac{d\eta}{d\mu} \right|_{\hat{\eta}_i^j}$$

where j is iteration in optimization algorithm

- 3 Find $\text{Var}(\tilde{y}_i | \boldsymbol{\gamma})$

- 4 Use weighted linear mixed effects models

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- fast
- approximate inference
- biased estimates, esp. for binary data or low counts
- even worse inference than regular LMM

Bayesian methods

- Much more accurate inference
- Allow for prior information and flexibility
- Usually take more computation
- Inferential form different
- Require additional software (either INLA or STAN).