

Package: lmmix (via r-universe)

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Title Linear Mixed Models with Correlated Residuals

Version 0.4.0

Description Fits Gaussian linear mixed models by explicitly optimizing the maximum likelihood or restricted maximum likelihood criterion. Random effects and correlated residual structures can be combined in the same model. Fixed-effect inference includes Satterthwaite and Kenward-Roger denominator degrees of freedom, type III tests, likelihood-ratio model comparisons, and estimated marginal means.

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URL <https://github.com/AurelienNicosiaULaval/lmmix>,
<https://aureliennicosiaulaval.github.io/lmmix/>

BugReports <https://github.com/AurelienNicosiaULaval/lmmix/issues>

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augment.lmm	<i>Augment data with fitted values and residuals</i>
-------------	--

Description

Augment data with fitted values and residuals

Usage

```
## S3 method for class 'lmm'  
augment(x, data = NULL, newdata = NULL, ...)
```

Arguments

- x An lmm object.
- data Optional data used for augmentation. By default, excluded rows are restored when the model used `stats::na.exclude()`.
- newdata Optional new data. If supplied, it takes precedence over data.
- ... Additional arguments passed to `predict()`.

Value

A tibble with `.fitted`, `.resid`, and `.std.resid` columns.

fixef	<i>Extract fixed effects</i>
-------	------------------------------

Description

Extract fixed effects

Usage

```
fixef(object, ...)
```

Arguments

object	A fitted model.
...	Additional arguments.

glance.lmm	<i>One-row model summary for an lmm model</i>
------------	---

Description

One-row model summary for an lmm model

Usage

```
## S3 method for class 'lmm'  
glance(x, ...)
```

Arguments

x	An lmm object.
...	Additional arguments.

Value

A one-row tibble.

lmm

*Fit a Gaussian linear mixed model***Description**

`lmm()` explicitly evaluates a profiled ML or REML criterion for $V = Z G Z' + R$. It can combine random effects with an independent, compound-symmetric, AR(1), full or fixed-band Toeplitz, or unstructured residual covariance. Missing values are handled according to `na.action`.

Usage

```
lmm(
  data,
  formula,
  random = NULL,
  repeated = NULL,
  structure = c("id", "cs", "ar1", "toep", "un"),
  method = c("REML", "ML"),
  ddf = c("satterthwaite", "residual", "kenward-roger"),
  weights = NULL,
  offset = NULL,
  contrasts = NULL,
  control = lmm_control(),
  na.action = stats::na.omit
)
```

Arguments

<code>data</code>	A data frame or tibble. Placing data first makes the function pipe-friendly.
<code>formula</code>	A two-sided fixed-effects formula.
<code>random</code>	Optional one-sided random-effects formula such as <code>~ 1 subject</code> , or a list of such formulas.
<code>repeated</code>	Optional one-sided repeated-measures formula such as <code>~ time subject</code> .
<code>structure</code>	Residual covariance structure: <code>"id"</code> , <code>"cs"</code> , <code>"ar1"</code> , <code>"toep"</code> , <code>"toep(k)"</code> , or <code>"un"</code> . The <code>"toep"</code> form estimates every available Toeplitz band. The <code>"toep(k)"</code> form estimates <code>k</code> bands, including the main diagonal, and fixes longer-lag covariances to zero.
<code>method</code>	Estimation method: restricted maximum likelihood (<code>"REML"</code>) or maximum likelihood (<code>"ML"</code>).
<code>ddf</code>	Denominator degrees-of-freedom method: <code>"satterthwaite"</code> , <code>"kenward-roger"</code> , or <code>"residual"</code> .
<code>weights</code>	Optional known relative precision weights. The residual covariance is scaled on both sides by <code>diag(1 / sqrt(weights))</code> .
<code>offset</code>	Optional numeric offset added to the fixed-effect predictor. An <code>offset()</code> term in formula is also supported.

contrasts	Optional contrasts passed to <code>stats::model.matrix()</code> .
control	An object returned by <code>lmm_control()</code> .
na.action	Missing-value action: <code>stats::na.omit()</code> , <code>stats::na.exclude()</code> , or <code>stats::na.fail()</code> .

Details

The random argument accepts a grouping formula or a list of independent grouping formulas. The repeated argument accepts one ordering variable and one grouping expression. Each repeated group may have at most one observation per ordering value. The likelihood factors independent connected covariance components separately. The fitted object retains the complete marginal covariance for model methods.

Value

An object of class `lmm`. The object stores fixed and random-effect estimates, covariance components, fitted values, residuals, optimization diagnostics, the analysis data, and the model matrices.

References

- Harville, D. A. (1977). Maximum likelihood approaches to variance component estimation and to related problems. *Journal of the American Statistical Association*, 72(358), 320-338. doi:10.1080/01621459.1977.10480998
- LaMotte, L. R. (2007). A direct derivation of the REML likelihood function. *Statistical Papers*, 48(2), 321-327. doi:10.1007/s0036200603356
- Pinheiro, J. C., and Bates, D. M. (2000). *Mixed-Effects Models in S and S-PLUS*. Springer. doi:10.1007/b98882
- Kenward, M. G., and Roger, J. H. (1997). Small sample inference for fixed effects from restricted maximum likelihood. *Biometrics*, 53(3), 983-997. doi:10.2307/2533558

Examples

```
fit <- lmm(
  data = nlme::Orthodont,
  formula = distance ~ age + Sex,
  random = ~ 1 | Subject
)
summary(fit)
```

Description

Methods are provided for extracting likelihood quantities, fitted values, residuals, model matrices and formulas, as well as for prediction, type III testing and fixed-effect confidence intervals.

Usage

```
## S3 method for class 'lmm'
print(x, ...)

## S3 method for class 'lmm'
coef(object, ...)

## S3 method for class 'lmm'
vcov(object, adjusted = TRUE, ...)

## S3 method for class 'lmm'
logLik(object, ...)

## S3 method for class 'lmm'
AIC(object, ..., k = 2)

## S3 method for class 'lmm'
BIC(object, ...)

## S3 method for class 'lmm'
deviance(object, ...)

## S3 method for class 'lmm'
nobs(object, ...)

## S3 method for class 'lmm'
fitted(object, type = c("conditional", "marginal"), ...)

## S3 method for class 'lmm'
residuals(object, type = c("response", "pearson", "marginal"), ...)

## S3 method for class 'lmm'
plot(x, which = c("residuals", "qq", "fitted"), ...)

## S3 method for class 'lmm'
sigma(object, ...)

## S3 method for class 'lmm'
predict(
  object,
  newdata = NULL,
  re.form = NULL,
  allow.new.levels = FALSE,
  se.fit = FALSE,
  interval = c("none", "confidence", "prediction"),
  level = 0.95,
  na.action = stats::na.pass,
  ...)
```

```

)

## S3 method for class 'lmm'
simulate(object, nsim = 1, seed = NULL, ...)

## S3 method for class 'lmm'
update(object, formula., ..., evaluate = TRUE)

## S3 method for class 'lmm'
model.matrix(object, data = NULL, ...)

## S3 method for class 'lmm'
model.frame(formula, ...)

## S3 method for class 'lmm'
formula(x, fixed.only = TRUE, ...)

## S3 method for class 'lmm'
terms(x, ...)

## S3 method for class 'lmm'
anova(
  object,
  ...,
  type = 3,
  refit = TRUE,
  test = c("chisq", "parametric.bootstrap"),
  nsim = 199L,
  seed = NULL
)

## S3 method for class 'lmm'
confint(object, parm = names(object$coefficients), level = 0.95, ...)

```

Arguments

<code>x, object, formula</code>	An lmm object. The formula name follows the argument name of the <code>model.frame()</code> generic.
<code>...</code>	Additional fitted lmm models for likelihood-ratio comparison, or arguments passed to the corresponding method.
<code>adjusted</code>	Whether <code>vcov()</code> returns the Kenward-Roger-adjusted covariance when available.
<code>k</code>	Penalty per parameter used by <code>AIC()</code> .
<code>type</code>	For <code>fitted()</code> , either "conditional" or "marginal". For <code>residuals()</code> , one of "response", "pearson", or "marginal". For <code>anova()</code> , only type 3 is implemented.

<code>which</code>	Diagnostic plot to draw: standardized residuals against fitted values, a normal quantile-quantile plot, or observed against fitted values.
<code>newdata</code>	Optional data frame used for prediction.
<code>re.form</code>	NULL includes every empirical random-effect term, NA or ~ 0 excludes all random effects, and a random-effects formula or list of formulas selects a subset of fitted terms.
<code>allow.new.levels</code>	Whether conditional predictions may include new grouping levels. Their random contribution is zero when allowed.
<code>se.fit</code>	Whether <code>predict()</code> returns standard errors for the expected response. These standard errors use the fixed-effect covariance and condition on any empirical random effects included through <code>re.form</code> .
<code>interval</code>	Prediction interval type. "confidence" describes the expected response. "prediction" additionally includes the fitted residual variance but not uncertainty in empirical random effects.
<code>level</code>	Confidence level for fixed-effect and covariance intervals.
<code>na.action</code>	Missing-value action retained for prediction-method compatibility.
<code>nsim</code>	Number of simulations for a parametric-bootstrap comparison.
<code>seed</code>	Optional integer seed for a reproducible parametric bootstrap.
<code>formula.</code>	Optional formula update accepted by <code>update()</code> .
<code>evaluate</code>	Whether <code>update()</code> evaluates the updated call.
<code>data</code>	Optional data frame used to construct a fixed-effects model matrix.
<code>fixed.only</code>	Whether <code>formula()</code> returns only the fixed formula. If FALSE, it returns fixed, random, and repeated formulas in a list.
<code>refit</code>	Whether REML models that differ in fixed effects are refitted with ML before comparison.
<code>test</code>	Reference test for likelihood-ratio model comparisons. The default "chisq" uses the usual asymptotic chi-squared reference. The "parametric.bootstrap" option simulates under each smaller model and is appropriate when covariance parameters can lie on a boundary.
<code>parm</code>	Parameters requested from <code>confint()</code> , supplied by name or fixed effect position. Use "beta_" for every fixed effect and "theta_" for every covariance parameter.

Details

Conditional fitted values and predictions include empirical random effects. Marginal values use fixed effects only. In prediction from new data, known grouping levels use their fitted random effect. New levels are rejected by default and receive a random contribution of zero only when explicitly allowed.

`ranef()` always returns a named list with one tibble per random-effect term, including for models with a single term. It returns an empty list for marginal models. `sigma()` is defined as `sqrt(mean(diag(R)))`; it is a descriptive residual scale when residual variances differ across observations.

Value

The return value follows the corresponding base R generic.

References

Self, S. G., and Liang, K.-Y. (1987). Asymptotic properties of maximum likelihood estimators and likelihood ratio tests under nonstandard conditions. *Journal of the American Statistical Association*, 82(398), 605-610. doi:[10.1080/01621459.1987.10478472](https://doi.org/10.1080/01621459.1987.10478472)

Davison, A. C., and Hinkley, D. V. (1997). *Bootstrap Methods and Their Application*. Cambridge University Press. doi:[10.1017/CBO9780511802843](https://doi.org/10.1017/CBO9780511802843)

lmm_control	<i>Control numerical optimization for lmm()</i>
-------------	---

Description

Control numerical optimization for lmm()

Usage

```
lmm_control(
  optimizer = c("auto", "nllminb", "optim"),
  optim_method = "BFGS",
  max_iter = 1000L,
  rel_tol = 1e-08,
  x_tol = 1e-08,
  initial = NULL,
  lower = -20,
  upper = 20,
  deriv_method = "Richardson",
  max_restarts = 3L,
  restart_scale = 0.25
)
```

Arguments

optimizer	Optimizer strategy: "auto", "nllminb", or "optim".
optim_method	Method passed to <code>stats::optim()</code> when optimizer = "optim".
max_iter	Maximum number of optimizer iterations.
rel_tol	Relative convergence tolerance.
x_tol	Parameter convergence tolerance for <code>stats::nllminb()</code> .
initial	Optional numeric vector of unconstrained starting values.
lower, upper	Bounds for unconstrained covariance parameters.
deriv_method	Numerical differentiation method passed to numDeriv.

max_restarts	Maximum number of deterministic restart attempts after an unsuccessful initial fit.
restart_scale	Size of deterministic perturbations to starting values.

Value

An object of class `lmm_control`.

lsmeans	<i>Estimated marginal means for an lmm model</i>
---------	--

Description

Marginal means use equal weights over nuisance-factor levels. Numeric covariates not listed in specs are held at their observed means. Multiplicity adjustment applies to pairwise p-values. Simultaneous Bonferroni confidence intervals are used automatically when p-values are adjusted, unless `conf_adjust = "none"` is requested.

Usage

```
lsmeans(
  object,
  specs,
  pairwise = FALSE,
  at = list(),
  level = 0.95,
  adjust = "none",
  conf_adjust = c("auto", "none", "bonferroni"),
  ...
)
```

Arguments

object	An <code>lmm</code> object.
specs	Variables defining the marginal means, supplied as a character vector or one-sided formula. Use <code>pairwise ~ factor</code> to request differences.
pairwise	Whether to return pairwise differences as well as means.
at	Named list overriding reference-grid values.
level	Confidence level.
adjust	Multiplicity adjustment passed to <code>stats::p.adjust()</code> .
conf_adjust	Confidence-interval adjustment. "auto" uses Bonferroni intervals when adjust is not "none"; the alternatives are "none" and "bonferroni".
...	Reserved for future extensions.

Value

A tibble, or a list with `lsmeans` and `contrasts` tibbles when pairwise comparisons are requested.

multicentre	<i>Multi-site repeated-measures experiment</i>
-------------	--

Description

An unbalanced experiment with three drugs in three centers and three repeated measurement times. This is the multilocation repeated-measures example described by Milliken and Johnson (2009, Section 28.3).

Usage

```
multicentre
```

Format

A data frame with 153 rows and 5 variables:

Center Center identifier with levels R, S, and T.

Drug Drug identifier with levels 1, 2, and 3.

Subject Subject identifier within each center and drug.

Time Repeated-measurement occasion with levels 1, 2, and 3.

Y Continuous response, including 28 missing values.

Source

Milliken, G. A., and Johnson, D. E. (2009). *Analysis of Messy Data, Volume 1: Designed Experiments* (2nd ed.), Section 28.3. Chapman and Hall/CRC. doi:[10.1201/EBK1584883340](https://doi.org/10.1201/EBK1584883340)

ranef	<i>Extract random effects</i>
-------	-------------------------------

Description

Extract random effects

Usage

```
ranef(object, ...)
```

Arguments

object	A fitted model.
...	Additional arguments.

recover_data.lmm	<i>Support for emmeans</i>
------------------	----------------------------

Description

These methods allow `emmeans::emmeans()` to recover the fixed-effects reference grid and use model-specific Satterthwaite degrees of freedom.

Usage

```
## S3 method for class 'lmm'
recover_data(object, frame = object$model_frame, ...)

## S3 method for class 'lmm'
emm_basis(object, trms, xlev, grid, ...)
```

Arguments

<code>object</code>	An <code>lmm</code> object.
<code>frame</code>	Model frame.
<code>...</code>	Additional arguments passed by <code>emmeans</code> .
<code>trms, xlev, grid</code>	Arguments supplied by <code>emmeans</code> .

Value

An `emmeans` data-recovery object.
 A basis list used by `emmeans`.

sas_growth	<i>Repeated-measures growth example from the SAS MIXED documentation</i>
------------	--

Description

Growth measurements for 11 girls and 16 boys at ages 8, 10, 12, and 14. SAS uses these Potthoff and Roy data in Example 79.2 of the SAS/STAT 14.3 documentation for the MIXED procedure.

Usage

```
sas_growth
```

Format

A data frame with 108 rows and 4 variables:

Person Person identifier with 27 levels.

Gender Gender factor with levels F and M.

Age Age in years.

y Continuous growth response.

Source

SAS Institute Inc. (2017). *SAS/STAT 14.3 User's Guide*, Example 79.2, Repeated Measures. <https://support.sas.com/documentation/onlinedoc/stat/>

sas_line_source	<i>Line-source irrigation example from the SAS MIXED documentation</i>
-----------------	--

Description

Winter-wheat yields for three cultivars in three blocks. Each plot contains twelve subplots arranged on two sides of a line-source sprinkler. SAS uses these data in Example 79.6 of the SAS/STAT 14.3 documentation to combine three random-intercept terms with a four-band Toeplitz residual covariance.

Usage

sas_line_source

Format

A data frame with 108 rows and 6 variables:

Block Block identifier with three levels.

Cult Winter-wheat cultivar with three levels.

Sbplt Ordered subplot position from 1 to 12.

Irrig Irrigation level with six levels.

Dir Side of the sprinkler with levels North and South.

Y Continuous yield response.

Source

SAS Institute Inc. (2017). *SAS/STAT 14.3 User's Guide*, Example 79.6, Line-Source Sprinkler Irrigation. <https://support.sas.com/documentation/onlinedoc/stat/>

sas_random_coefficients

Random-coefficients example from the SAS MIXED documentation

Description

Pharmaceutical stability measurements for three batches at six shelf ages. SAS uses these simulated data in Example 79.5 of the SAS/STAT 14.3 documentation for the MIXED procedure.

Usage

sas_random_coefficients

Format

A data frame with 108 rows and 4 variables:

Batch Batch identifier with three levels.

Month Shelf age in months.

Replicate Replicate identifier within a batch and month.

Y Assay response, including 24 missing values.

Source

SAS Institute Inc. (2017). *SAS/STAT 14.3 User's Guide*, Example 79.5, Random Coefficients.
<https://support.sas.com/documentation/onlinedoc/stat/>

sas_split_plot

Split-plot example from the SAS MIXED procedure documentation

Description

A balanced split-plot experiment with four blocks, three whole-plot levels, and two subplot levels. SAS uses this data set in Example 79.1 of the SAS/STAT 14.3 documentation for the MIXED procedure.

Usage

sas_split_plot

Format

A data frame with 24 rows and 4 variables:

Block Block identifier with four levels.

A Whole-plot treatment factor with three levels.

B Subplot treatment factor with two levels.

Y Continuous response.

Source

SAS Institute Inc. (2017). *SAS/STAT 14.3 User's Guide*, Example 79.1, Split-Plot Design. <https://support.sas.com/documentation/onlinedoc/stat/>

summary.lmm

Summarize an lmm fit

Description

Summarize an lmm fit

Usage

```
## S3 method for class 'lmm'  
summary(object, level = 0.95, ...)
```

Arguments

object	An lmm object.
level	Confidence level for fixed effects.
...	Additional arguments.

Value

An object of class summary.lmm.

tidy.lmm	<i>Tidy an lmm model</i>
----------	--------------------------

Description

Tidy an lmm model

Usage

```
## S3 method for class 'lmm'
tidy(
  x,
  effects = c("fixed", "ran_pars", "all"),
  conf.int = FALSE,
  conf.level = 0.95,
  ...
)
```

Arguments

- x An lmm object.
- effects Effects to return: fixed effects, covariance parameters, or both.
- conf.int Whether to include confidence limits for fixed effects.
- conf.level Confidence level.
- ... Additional arguments.

Value

A tibble.

VarCorr	<i>Extract covariance components</i>
---------	--------------------------------------

Description

Extract covariance components

Usage

```
VarCorr(object, ...)
```

Arguments

- object A fitted model.
- ... Additional arguments.

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