Package ‘svylme’

May 9, 2026

Title Linear Mixed Models for Complex Survey Data

Version 1.5-1

Description Linear mixed models for complex survey data, by pairwise composite likelihood, as described in Lumley & Huang (2023) <doi:10.48550/arXiv.2311.13048>. Supports nested and crossed random effects, and correlated random effects as in genetic models. Allows for multistage sampling and for other designs where pairwise sampling probabilities are specified or can be calculated.

Imports minqa, Matrix, lme4, methods, utils, stats

Depends survey, R (>= 3.5.0)

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NeedsCompilation no

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Repository CRAN

Date/Publication 2024-02-06 16:40:02 UTC

Contents

boot2lme 2
milk_subset 4
nzmaths 5
pisa 7
svy2lme 8
svy2relmer 11

Index **13**

`boot2lme` *Resampling variances for svy2lme*

Description

Computes variance estimates for the weighted-pairwise-likelihood linear mixed models fitted by `svy2lme` using replicate weights. The replicate weights for a pair are obtained by dividing by the sampling weight and then multiplying by the replicate weight. There will be a warning if the ratio of replicate weight to sampling weight differs for observations in the same pair.

Usage

```
boot2lme(model, rdesign,  verbose = FALSE)
## S3 method for class 'boot2lme'
vcov(object,
   parameter=c("beta", "theta","s2", "relSD" ,"SD","relVar","fullVar"),
   ...)
```

Arguments

`model`	A model returned by `svy2lme` with the `devfun=TRUE` option
`rdesign`	replicate-weights design corresponding to the design used to fit the model, see example
`verbose`	print progess information?
`object`	returned by `boot2lme`
`...`	for method compatibility
`parameter`	Variance matrix for: regression parameters, relative variance parameters on Cholesky square root scale, residual variance, relative standard errors of random effects, standard errors of random effects, entire relative variance matrix, entire variance matrix

Details

The variance is estimated from the replicates `thetastar` and original point estimate `theta` as `scale*sum(rscales* (thetastar-theta)^2)`.

Value

For `boot2lme`, an object of class `boot2lme` with components

`theta`	replicates of variance parameters (on Cholesky square root scale)
`beta`	replicates of regression parameters
`D`	replicates of relative variance matrix
`scale, rscales`	from the input
`formula`	model formula from the input

For the `vcov` method, a variance matrix.

Examples

```
data(api, package="survey")

# two-stage cluster sample
dclus2<-svydesign(id=~dnum+snum, fpc=~fpc1+fpc2, data=apiclus2)

m0<-svy2lme(api00~(1|dnum)+ell+mobility, design=dclus2,return.devfun=TRUE)
jkdes<-as.svrepdesign(dclus2, type="mrb")
jkvar<-boot2lme(m0,jkdes)

SE(jkvar, "beta")
SE(jkvar, "SD")
SE(jkvar,"s2")


m1<-svy2lme(api00~(1|dnum)+ell+mobility,
design=dclus2,return.devfun=TRUE, all.pairs=TRUE, subtract.margins=TRUE)
jk1var<-boot2lme(m1,jkdes)

SE(jk1var, "beta")
SE(jk1var, "SD")



##takes a few minutes
data(pisa)

pisa$w_condstuwt<-with(pisa, w_fstuwt/wnrschbw)
pisa$id_student<-1:nrow(pisa)

dpisa<-survey::svydesign(id=~id_school+id_student, weight=~wnrschbw+w_condstuwt, data=pisa)

m<-svy2lme(isei~(1+female|id_school)+female+high_school+college+one_for+both_for+test_lang,
design=dpisa, return.devfun=TRUE,method="nested")

bpisa<-as.svrepdesign(dpisa, type="bootstrap", replicates=100)

b<-boot2lme(m, bpisa, verbose=TRUE)
str(b)

vcov(b,"beta")
vcov(b,"s2")

## SE() inherits the parameter= argument
SE(b,"beta")
SE(b,"theta")
SE(b,"SD")
```

`milk_subset` *Milk production (subset)*

Description

A subset of a dataset from the `pedigreemm` package, created as an example for the `lme4qtl` package. The original data had records of the milk production of 3397 lactations from first through fifty parity Holsteins. These were 1,359 cows, daughters of 38 sires in 57 herds. The data was downloaded from the USDA internet site. All lactation records represent cows with at least 100 days in milk, with an average of 347 days. Milk yield ranged from 4,065 to 19,345 kg estimated for 305 days, averaging 11,636 kg. There were 1,314, 1,006, 640, 334 and 103 records were from first thorough fifth lactation animals. The subset is of cows from 3 sires.

Usage

```
data("milk_subset")
```

Format

A data frame with 316 observations on the following 13 variables.

`id` numeric identifier of cow

`lact` number of lactation for which production is measured

`herd` a factor indicating the herd

`sire` a factor indicating the sire

`dim` number of days in milk for that lactation

`milk` milk production estimated at 305 days

`fat` fat production estimated at 305 days

`prot` protein production estimated at 305 days

`scs` the somatic cell score

`sdMilk` `milk` scaled by cow-specific standard deviation

`herd_id` a character vector indicating the herd

`one` a vector of 1s for convenience in weighting

`one2` another vector of 1s for convenience in weighting

Details

This data example gives noticeably different results for full likelihood and pairwise likelihood because the model is misspecified. The best fitting linear model for the large herd 89 is different, and that herd gets relatively more weight in the pairwise analysis (because it has more pairs).

Source

Constructed at `https://github.com/variani/lme4qtl/blob/master/vignettes/pedigreemm.Rmd`

References

2010. A.I. Vazquez, D.M. Bates, G.J.M. Rosa, D. Gianola and K.A. Weigel. Technical Note: An R package for fitting generalized linear mixed models in animal breeding. Journal of Animal Science, 88:497-504.

Examples

```
data(milk_subset)
herd_des<- svydesign(id = ~herd + id, prob = ~one + one2, data = milk_subset)
lm(sdMilk ~ lact + log(dim),data=milk_subset,subset=herd==89)
lm(sdMilk ~ lact + log(dim),data=milk_subset,subset=herd!=89)
svy2lme(sdMilk ~ lact + log(dim) + (1|herd), design=herd_des,method="nested")
svy2lme(sdMilk ~ lact + log(dim) + (1|herd), design=herd_des,method="general")

## pairwise result is closer to herd 89 than to remainder
lme4::lmer(sdMilk ~ lact + log(dim) + (1|herd), data=milk_subset)
svy2relmer(sdMilk ~ lact + log(dim) + (1|id) + (1|herd), design=herd_des,
    relmat = list(id = A_gen))

## compare to all pairs
svy2lme(sdMilk ~ lact + log(dim) + (1|herd),
design=herd_des,method="general", all.pairs=TRUE)
svy2lme(sdMilk ~ lact + log(dim) + (1|herd),
design=herd_des,method="general", all.pairs=TRUE, subtract.margins=TRUE)
```

`nzmaths` *Maths Performance Data from the PISA 2012 survey in New Zealand*

Description

Data on maths performance, gender, some problem-solving variables and some school resource variables.

Usage

```
data("nzmaths")
```

Format

A data frame with 4291 observations on the following 26 variables.

`SCHOOLID`	School ID
`CNT`	Country id: a factor with levels `New Zealand`
`STRATUM`	a factor with levels `NZL0101` `NZL0102` `NZL0202` `NZL0203`
`OECD`	Is the country in the OECD?
`STIDSTD`	Student ID

`ST04Q01`	Gender: a factor with levels `Female` `Male`
`ST14Q02`	Mother has university qualifications `No` `Yes`
`ST18Q02`	Father has university qualifications `No` `Yes`
`MATHEFF`	Mathematics Self-Efficacy: numeric vector
`OPENPS`	Mathematics Self-Efficacy: numeric vector
`PV1MATH`,`PV2MATH`,`PV3MATH`,`PV4MATH`,`PV5MATH`	'Plausible values' (multiple imputations) for maths performance
`W_FSTUWT`	Design weight for student
`SC35Q02`	Proportion of maths teachers with professional development in maths in past year
`PCGIRLS`	Proportion of girls at the school
`PROPMA5A`	Proportion of maths teachers with ISCED 5A (math major)
`ABGMATH`	Does the school group maths students: a factor with levels `No ability grouping between any classes` `One of these forms of ability grouping between classes for s` `One of these forms of ability grouping for all classes`
`SMRATIO`	Number of students per maths teacher
`W_FSCHWT`	Design weight for school
`condwt`	Design weight for student given school

Source

A subset extracted from the `PISA2012lite` R package, `https://github.com/pbiecek/PISA2012lite`

References

OECD (2013) PISA 2012 Assessment and Analytical Framework: Mathematics, Reading, Science, Problem Solving and Financial Literacy. OECD Publishing.

Examples

```
data(nzmaths)

oo<-options(survey.lonely.psu="average") ## only one PSU in one of the strata

des<-svydesign(id=~SCHOOLID+STIDSTD, strata=~STRATUM, nest=TRUE,
weights=~W_FSCHWT+condwt, data=nzmaths)

## This example works, but it takes more than five seconds to run, so it
## has been commented out
## m1<-svy2lme(PV1MATH~ (1+ ST04Q01 |SCHOOLID)+ST04Q01*(PCGIRLS+SMRATIO)+MATHEFF+OPENPS, design=des)

options(oo)
```

`pisa` *Data from the PISA international school survey*

Description

Data from the PISA survey of schools, obtained from Stata, who obtained it from Rabe-Hesketh & Skrondal.

Usage

```
data("pisa")
```

Format

A data frame with 2069 observations on the following 11 variables.

`female`	1 for female
`isei`	socioeconomic index
`w_fstuwt`	student sampling weight (total)
`wnrschbw`	school sampling weight
`high_school`	1 if highest level of parents' education is high school
`college`	1 if highest level of parents' education is college/uni
`one_for`	1 if one parent is foreign-born
`both_for`	1 if both parents are foreign-born
`test_lang`	1 if the test language is spoken at home
`pass_read`	1 if the student passed a reading proficiency test
`id_school`	school (sampling unit) identifier

Source

Data downloaded from `https://www.stata-press.com/data/r15/pisa2000.dta`

References

Rabe-Hesketh, S., and A. Skrondal. 2006. Multilevel modelling of complex survey data.Journal of the Royal Statistical Society, Series A. 169: 805-827

Examples

```
data(pisa)

## This model doesn't make a lot of sense, but it's the one in the
## Stata documentation because the outcome variable is numeric.

pisa$w_condstuwt<-with(pisa, w_fstuwt/wnrschbw)
```

```
pisa$id_student<-1:nrow(pisa)

dpisa<-survey::svydesign(id=~id_school+id_student, weight=~wnrschbw+w_condstuwt, data=pisa)


svy2lme(isei~(1|id_school)+female+high_school+college+one_for+both_for+test_lang,
design=dpisa)
```

---

svy2lme *Linear mixed models by pairwise likelihood*

Description

Fits linear mixed models to survey data by maximimising the profile pairwise composite likelihood.

Usage

```
svy2lme(formula, design, sterr=TRUE,  return.devfun=FALSE,
method=c("general","nested"), all.pairs=FALSE, subtract.margins=FALSE)
## S3 method for class 'svy2lme'
coef(object,...,random=FALSE)
```

Arguments

`formula`	Model formula as in the `lme4` package
`design`	A survey design object produced by `survey::svydesign`. The pairwise weights will be computed from this design, which must have separate probabilities or weights for each stage of sampling.
`sterr`	Estimate standard errors for fixed effects? Set to `FALSE` for greater speed when using resampling to get standard errors. Also, a PPS-without-replacement survey design can't get sandwich standard errors (because fourth-order sampling probabilities would be needed)
`return.devfun`	If `TRUE`, return the deviance function as a component of the object. This will increase the memory use substantially, but allows for bootstrapping.
`method`	`"nested"` requires the model clusters to have a single grouping variable that is the same as the primary sampling unit. It's faster.
`all.pairs`	Only with `method="general"`, use all pairs rather than just correlated pairs?
`subtract.margins`	If `TRUE` and `all.pairs=TRUE`, compute with all pairs by the faster algorithm involving subtraction from the marginal likelihood
`object`	`svy2lme` object
`...`	for method compatibility
`random`	if `TRUE`, the variance components rather than the fixed effects

Details

The population pairwise likelihood would be the sum of the loglikelihoods for a pair of observations, taken over all pairs of observations from the same cluster. This is estimated by taking a weighted sum over pairs in the sample, with the weights being the reciprocals of pairwise sampling probabilities. The advantage over standard weighted pseudolikelihoods is that there is no large-cluster assumption needed and no rescaling of weights. The disadvantage is some loss of efficiency and simpler point estimation.

With `method="nested"` we have the method of Yi et al (2016). Using `method="general"` relaxes the conditions on the design and model.

The code uses `lme4::lmer` to parse the formula and produce starting values, profiles out the fixed effects and residual variance, and then uses `minqa::bobyqa` to maximise the resulting profile deviance.

As with `lme4::lmer`, the default is to estimate the correlations of the random effects, since there is typically no reason to assume these are zero. You can force two random effects to be independent by entering them in separate terms, eg `(1|g)+(-1+x|g)` in the model formula asks for a random intercept and a random slope with no random intercept, which will be uncorrelated.

The internal parametrisation of the variance components uses the Cholesky decomposition of the relative variance matrix (the variance matrix divided by the residual variance), as in `lme4::lmer`. The component `object$s2` contains the estimated residual variance and the component `object$opt$par` contains the elements of the Cholesky factor in column-major order, omitting any elements that are forced to be zero by requiring indepedent random effects.

Standard errors of the fixed effects are currently estimated using a "with replacement" approximation, valid when the sampling fraction is small and superpopulation (model, process) inference is intended. Tthe influence functions are added up within cluster, centered within strata, the residuals added up within strata, and then the crossproduct is taken within each stratum. The stratum variance is scaled by `ni/(ni-1)` where `ni` is the number of PSUs in the stratum, and then added up across strata. When the sampling and model structure are the same, this is the estimator of Yi et al, but it also allows for there to be sampling stages before the stages that are modelled, and for the model and sampling structures to be different.

The `return.devfun=TRUE` option is useful if you want to examine objects that aren't returned as part of the output. For example, `get("ij", environment(object$devfun))` is the set of pairs used in computation.

Value

`svy2lme` returns an object with `print`, `coef`, and `vcov` methods.

The `coef` method with `random=TRUE` returns a two-element list: the first element is the estimated residual variance, the second is the matrix of estimated variances and covariances of the random effects.

Author(s)

Thomas Lumley

References

J.N.K. Rao, François Verret and Mike A. Hidiroglou "A weighted composite likelihood approach to inference for two-level models from survey data" Survey Methodology, December 2013 Vol. 39, No. 2, pp. 263-282

Grace Y. Yi , J. N. K. Rao and Haocheng Li "A WEIGHTED COMPOSITE LIKELIHOOD APPROACH FOR ANALYSIS OF SURVEY DATA UNDER TWO-LEVEL MODELS" Statistica Sinica Vol. 26, No. 2 (April 2016), pp. 569-587

Examples

```
data(api, package="survey")

# one-stage cluster sample
dclus1<-svydesign(id=~dnum, weights=~pw, data=apiclus1, fpc=~fpc)
# two-stage cluster sample
dclus2<-svydesign(id=~dnum+snum, fpc=~fpc1+fpc2, data=apiclus2)

svy2lme(api00~(1|dnum)+ell+mobility+api99, design=dclus1)
svy2lme(api00~(1|dnum)+ell+mobility+api99, design=dclus2)
svy2lme(api00~(1|dnum)+ell+mobility+api99, design=dclus2,method="nested")

lme4::lmer(api00~(1|dnum)+ell+mobility+api99, data=apipop)

## Simulated

set.seed(2000-2-29)

df<-data.frame(x=rnorm(1000*20),g=rep(1:1000,each=20), t=rep(1:20,1000), id=1:20000)
df$u<-with(df, rnorm(1000)[g])

df$y<-with(df, x+u+rnorm(1000,s=2))

## oversample extreme `u` to bias random-intercept variance
pg<-exp(abs(df$u/2)-2.2)[df$t==1]

in1<-rbinom(1000,1,pg)==1
in2<-rep(1:5, length(in1))

sdf<-subset(df, (g %in% (1:1000)[in1]) & (t %in% in2))

p1<-rep(pg[in1],each=5)
N2<-rep(20,nrow(sdf))

## Population values
lme4::lmer(y~x+(1|g), data=df)

## Naive estimator: higher intercept variance
lme4::lmer(y~x+(1|g), data=sdf)

##pairwise estimator
sdf$w1<-1/p1
```

```
sdf$w2<-20/5

design<-survey::svydesign(id=~g+id, data=sdf, weights=~w1+w2)
pair<-svy2lme(y~x+(1|g),design=design,method="nested")
pair

pair_g<-svy2lme(y~x+(1|g),design=design,method="general")
pair_g

all.equal(coef(pair), coef(pair_g))
all.equal(SE(pair), SE(pair_g))
```

`svy2relmer` *Linear mixed models with correlated random effects*

Description

Fits linear mixed models by maximising the profile pairwise composite likelihood. Allows for correlated random effects, eg, for genetic relatedness (QTL) models

Usage

```
svy2relmer(formula, design, sterr=TRUE, return.devfun=FALSE, relmat=NULL,
 all.pairs=FALSE, subtract.margins=FALSE )
```

Arguments

`formula`	Model formula as in the `lme4` package, or with terms like `(1|id)` for correlated random effects together with the `relmat` argument.
`design`	A survey design object produced by `survey::svydesign`. The pairwise weights will be computed from this design, which must have separate probabilities or weights for each stage of sampling.
`sterr`	Estimate standard errors for fixed effects? Set to `FALSE` for greater speed when using resampling to get standard errors.
`return.devfun`	If `TRUE`, return the deviance function as a component of the object. This will increase the memory use substantially, but allows for bootstrapping.
`relmat`	Specifies a list of relatedness matrices that corresponds to one or more random-effect groupings (eg `(1|id)` in the `formula` together with `relmat=list(id=Phi)` implies a covariance matrix of `Phi` for the random effects before scaling). See Details and the vignettes.
`all.pairs`	Use all pairs rather than just correlated pairs?
`subtract.margins`	If `TRUE` and `all.pairs=TRUE`, compute with all pairs by the faster algorithm involving subtraction from the marginal likelihood

Details

This function is very similar to `svy2lme` and only the differences are described here.

Formula parsing and starting values use code based on the `lme4qtl` package.

In `svy2lme` and `lme4::lmer`, the model is based on independent standard Normal random effects that are transformed to give random coefficients that might be correlated within observation but are either identical or independent between observations. In this function, the basic random effects in a term are multiplied by a square root of the `relmat` matrix for that term, giving basic random effects whose covariance between observations proportional to the `relmat` matrix. For example, in a quantitative trait locus model in genetics, the matrix would be a genetic relatedness matrix.

The `relmat` matrices must have dimnames for matching to the id variable. It is permissible for the `relmat` matrices to be larger than necessary – eg, containing related units that are not in the sample – since the dimnames will be used to select the relevant submatrix.

There can be only one random-effect term for each `relmat` term. If you need more, make a copy of the term with a different name.

The `return.devfun=TRUE` option is useful if you want to examine objects that aren't returned as part of the output. For example, `get("ij", environment(object$devfun))` is the set of pairs used in computation.

Value

`svy2relmer` returns an object with `print`, `coef`, and `vcov` methods.

Author(s)

Thomas Lumley

References

Ziyatdinov, A., Vázquez-Santiago, M., Brunel, H. et al. lme4qtl: linear mixed models with flexible covariance structure for genetic studies of related individuals. BMC Bioinformatics 19, 68 (2018). https://bmcbioinformatics.biomedcentral.com/articles/10.1186/s12859-018-2057-x

Examples

```
data(milk_subset)
herd_des<- svydesign(id = ~herd + id, prob = ~one + one2, data = milk_subset)

svy2lme(sdMilk ~ lact + log(dim) + (1|herd), design=herd_des, method="general")

svy2relmer(sdMilk ~ lact + log(dim) + (1|id) + (1|herd), design=herd_des,
    relmat = list(id = A_gen))
```

Index

∗ **datasets**
    milk_subset, 4
    nzmaths, 5
    pisa, 7
∗ **regression**
    boot2lme, 2
    svy2lme, 8
    svy2relmer, 11
∗ **survey**
    boot2lme, 2
    svy2lme, 8
    svy2relmer, 11

A_gen *(*milk_subset*)*, 4

boot2lme, 2

coef.svy2lme *(*svy2lme*)*, 8

milk_subset, 4

nzmaths, 5

pisa, 7

svy2lme, 2, 8, *12*
svy2relmer, 11

vcov.boot2lme *(*boot2lme*)*, 2