Package 'mlma'

July 14, 2016

Type Package

Title Multilevel Mediation Analysis

Version 4.0-1

Date 2016-7-12

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Depends R (>= 2.14.1), lme4, splines, car, gplots

Description Do multilevel mediation analysis with generalized additive multilevel models.

License GPL (>= 2)

URL http://www.r-project.org,
http://publichealth.lsuhsc.edu/Faculty_pages/qyu/index.html

NeedsCompilation no

Repository CRAN

Date/Publication 2016-07-14 00:28:34

R topics documented:

`mlma-package` *Multilevel Mediation Analysis*

Description

The package is used to do mediation analysis with generalized multilevel models.

Details

Package:	mlma
Type:	Package
Version:	1.0
Date:	2015-10-28
License:	GPL (>= 2)

"`data.org`" is used to transform the variables and organize the predictor, mediators and outcome into the format that are ready to be used for multilevel mediation analysis. "`mlma`" is for multilevel mediation analysis on the original data set. "`boot.mlma`" is a combined function that organized data set, do multilevel mediation analysis on original data sets and bootstrapping samples.

The multilevel mediation is based on the following linear multilevel additive models:

$$Y_{ij} = u^Y_{0j}(X_{.j}, \mathbf{M}_{.j}, \mathbf{Z}_{.j}) + {\boldsymbol\beta^Y_{10}}^T \mathbf{f}^Y_{10}(X_{ij} - X_{.j}) + \sum_{k=1}^{K} {\boldsymbol\beta^Y_{20k}}^T \mathbf{f}^Y_{20k}(M_{ijk} - M_{.jk}) + {\boldsymbol\beta^Y_{30}}^T (\mathbf{Z}_{ij} - \mathbf{Z}_{.j}) + r^Y_{ij},$$

where

$$u^Y_{0j}(X_{.j}, \mathbf{M}_{.j}, \mathbf{Z}_{.j}) = c^Y_{00} + {\boldsymbol\beta^Y_{01}}^T \mathbf{f}^Y_{01}(X_{.j}) + \sum_{k=1}^{K} {\boldsymbol\beta^Y_{02k}}^T \mathbf{f}^Y_{02k}(M_{.jk}) + {\boldsymbol\beta^Y_{03}}^T \mathbf{Z}_{.j} + r^Y_{0j}.$$

For $k = 1, \ldots, K$,

$$M_{.jk} = u^M_{0jk}(X_{.j}) + {\boldsymbol\beta^M_{10k}}^T \mathbf{f}^M_{10k}(X_{ij} - X_{.j}) + r^M_{ijk},$$

$$u^M_{0jk}(X_{.j}) = c^M_{00k} + {\boldsymbol\beta^M_{01k}}^T \mathbf{f}^{M1}_{01k}(X_{.j}) + r^M_{0jk}.$$

If for some k, M_k is level 2 variable,

$$M_{.jk} = c^M_{00k} + {\boldsymbol\beta^M_{01k}}^T \mathbf{f}^{M2}_{01k}(X_{.j}) + r^M_{0jk}.$$

Note that in the models, $\mathbf{f}(\cdot) = (f_1(\cdot), f_2(\cdot), \cdots, f_l(\cdot))^T$ is a set of l transformation functions on $\cdot$, with the corresponding linear coefficients vector $\boldsymbol\beta = (\beta_1, \beta_2, \cdots, \beta_l)^T$. $\mathbf{f}$ and l are known for model fitting. l may be different with $\mathbf{f}$ of different sub- and super-scripts.

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boot.mlma *Bootstrap Method for Inference on Multilevel Mediation Analysis*

Description

Bootstrap samples are selected from the original data set. The bootstrap sample has the same number of groups and in each group, the same number of observations as in the original data set. Based on each bootstrap sample, a multilevel mediation analysis is done and the results saved to make inferences on the total, direct and indirect effects.

Usage

```
boot.mlma(y, biny = FALSE, x, levelx, levely, m, l1 = NULL, l2 = NULL, c1 = NULL,
          c1r = rep(1, length(c1)), c2 = NULL, c2r = rep(1, length(c2)),
          f01y = NULL, f10y = NULL, f02ky = NULL, f20ky = NULL, f01km1 = NULL,
        f01km2 = NULL, f10km = NULL, level=1:length(y), weight = rep(1, length(x)),
          random = "(1|level)", random.m1 = NULL, intercept = TRUE,
          w2=rep(1,length(unique(level[!is.na(level)]))),
          boot = 100, seed = 1, covariates=NULL,cy1=NULL,cy2=NULL,cm=NULL,
          joint=NULL,x.new=x, m.new=m, level.new=level,weight.new=weight,
          covariates.new=covariates)
```

Arguments

y	the vector of the outcome variable.
biny	True if the outcome is binary, otherwise False. Default is False.
x	the vector of the predictive variable.
levelx	the level of x (1 or 2), 1 by default.
levely	the level of y (1 or 2), 1 by default.
m	the matrix or vector of mediators.
l1	the column numbers of level 1 continuous mediators in m.
l2	the column numbers of level 2 continuous mediators in m.
c1	the column numbers of level 1 categorical mediators in m.
c1r	the reference groups of categorical mediators specified by c1.
c2	the column numbers of level 2 categorical mediators in m.
c2r	the reference groups of categorical mediators specified by c2.
f01y	the transformation function expressions on level 2 predictive variable (x.j) in explaining y (eg, c("x^2","log(x)")).
f10y	the transformation function expressions on level 1 predictive variable (xij-x.j) in explaining y.

`f02ky` the transformation-function-expression list on level 2 mediators (m.jk) in explaining y (eg, list(2:3,c("log(x)","sqrt(x)"), "2*x")). The first item lists column numbers of the level 2 mediators in m, which needs to be transformed. By that order, each of the rest items of f01ky list the transformation functional expressions for each mediator. The mediators not specified in the list will not be transformed in any way.

`f20ky` the transformation-function-expression list on level 1 mediators (mijk-m.jk) in explaining y.The first item lists column numbers of the level 1 mediators in m, which needs to be transformed. By that order, each of the rest items of f02ky list the transformation functional expressions for each mediator. The mediators not specified in the list will not be transformed in any way.

`f01km1` the transformation-function-expression list on level 2 predictor (x.j) in explaining the level 1 mediators. The first item lists column numbers of the level 1 mediators in m, which should be explained by the transformed predictor(s). By that order, each of the rest items of f01km1 lists the transformation functional expressions for the (aggregated) level 2 predictor in explaining each mediator. The mediators not specified in the list will be explained by the original format of the level 2 predictor only.

`f01km2` the transformation-function-expression list on level 2 predictor (x.j) in explaining the level 2 mediators. The first item lists column numbers of the level 2 mediators in m, which should be explained by the transformed level 2 predictor(s). By that order, each of the rest items of f01km2 lists the transformation functional expressions for the predictor in explaining each mediator. The mediators not specified in the list will be explained by the original format of the (aggregated) level 2 predictor only.

`f10km` the transformation-function-expression list on level 1 predictor (xij-x.j) in explaining the level 1 mediators. The first item lists column numbers of the level 1 mediators in m, which should be explained by the transformed level 1 predictor(s). By that order, each of the rest items of f10km lists the transformation functional expressions for the level 1 predictor in explaining each mediator. The mediators not specified in the list will be explained by the original format of the level 1 predictor only.

`level` a vector that record the group number for each observation.

`weight` the weight of cases in groups.

`random` the random effect part for the full model. random = "(1|level)" by default.

`random.m1` the random effect part for model explaining the mediators. All other random effects are random = "(1|level)" if not specified here.

`intercept` True if fit an intercept to models, by default.

`w2` the weight for observations at level 2, which should be the same order as unique(level[!is.na(level)]).

`boot` the number of bootstrapping samples.

`seed` set seed, default is 1.

`covariates` the covariates matrix to explain the outcome, y, and/or the mediators, m.

`cy1` the column numbers of covariates that are level 1 and used to explain y.

`cy2` the column numbers of covariates that are level 2 and used to explain y.

`cm` the column numbers of covariates that are used to explain m. cm[[1]] gives the mediators (in l1, cl, l2, or c2) that can be partially explained by covariates. Each of the rest items of the cm list shows the column number(s) in covariates that should be used to explain each mediator listed in cm[[1]] and by that order.For example, joint=list(1,c("m.2","m.4")) means find the joint effects of level 1 mediators m.2 and m.4.

`joint` the list of group(s) of mediators whose joint mediation effect is of interests. joint[[1]] list the levels of mediators in each group and by the order of the list. Note that if any mediator in the group is of level 2, the level of the group should be 2.

`x.new, covariates.new, m.new, level.new, weight.new`
the settings that we want to make inferences on the mediation effects. If m.new=NULL, generate new mediators from x.new.

Details

The multilevel mediation is based on the following linear multilevel additive models:

$$Y_{ij} = u^Y_{0j}(X_{.j}, \mathbf{M}_{.j}, \mathbf{Z}_{.j}) + \boldsymbol{\beta}^{Y\,T}_{10}\mathbf{f}^Y_{10}(X_{ij} - X_{.j}) + \sum_{k=1}^{K} \boldsymbol{\beta}^{Y}_{20k}{}^{T}\mathbf{f}^Y_{20k}(M_{ijk} - M_{.jk}) + \boldsymbol{\beta}^{Y\,T}_{30}(\mathbf{Z}_{ij} - \mathbf{Z}_{.j}) + r^Y_{ij},$$

where

$$u^Y_{0j}(X_{.j}, \mathbf{M}_{.j}, \mathbf{Z}_{.j}) = c^Y_{00} + \boldsymbol{\beta}^{Y\,T}_{01}\mathbf{f}^Y_{01}(X_{.j}) + \sum_{k=1}^{K} \boldsymbol{\beta}^{Y}_{02k}{}^{T}\mathbf{f}^Y_{02k}(M_{.jk}) + \boldsymbol{\beta}^{Y\,T}_{03}\mathbf{Z}_{.j} + r^Y_{0j}.$$

For $k = 1, \ldots, K$,

$$M_{.jk} = u^M_{0jk}(X_{.j}) + \boldsymbol{\beta}^{M}_{10k}{}^{T}\mathbf{f}^M_{10k}(X_{ij} - X_{.j}) + r^M_{ijk},$$

$$u^M_{0jk}(X_{.j}) = c^M_{00k} + \boldsymbol{\beta}^{M}_{01k}{}^{T}\mathbf{f}^{M1}_{01k}(X_{.j}) + r^M_{0jk}.$$

If for some k, M_k is level 2 variable,

$$M_{.jk} = c^M_{00k} + \boldsymbol{\beta}^{M}_{01k}{}^{T}\mathbf{f}^{M2}_{01k}(X_{.j}) + r^M_{0jk}.$$

Note that in the models, $\mathbf{f}(\cdot) = (f_1(\cdot), f_2(\cdot), \cdots, f_l(\cdot))^T$ is a set of l transformation functions on $\cdot$, with the corresponding linear coefficients vector $\boldsymbol{\beta} = (\beta_1, \beta_2, \cdots, \beta_l)^T$. $\mathbf{f}$ and l are known for model fitting. l may be different with $\mathbf{f}$ of different sub- and super-scripts.

Value

Return a "mlma.boot" mode list, which include the following items:

`de1` an n by boot matrix, where each column is the level 1 direct effects from one bootstrap sampling. n is the number of observations in the original data.

`de2` an g by boot matrix, where each column is the level 2 direct effects from one bootstrap sampling. g is the number of groups in the original data.

ie1	an v1 by n*boot matrix, where each column is the level 1 indirect effects from the boot bootstrap samples for one level 1 mediator. v1 is the number of level 1 mediators.
ie1	an v2 by g*boot matrix, where each column is the level 2 indirect effects from the boot bootstrap samples for one level 2 mediator. v2 is the number of level 2 mediators.
ie12	an v1 by g*boot matrix, where each column is the aggregated level 2 indirect effects from the boot bootstrap samples for one level 1 mediator. v1 is the number of level 1 mediators.
sum.boot1	summary results of level 1 mediation effects from bootstrap sample.
sum.boot2	summary results of level 2 mediation effects from bootstrap sample.
full	an "mlma" results using the original data set.
xboot	a n*boot vector of the level 1 predictors in all boot bootstrap samples.
xjboot	a g*boot vector of the (aggregated) level 2 predictors in all boot bootstrap samples.
levelx	inherited from the same argument.
level	inherited from the same argument.

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Examples

```
data(sim.111)
temp111<-boot.mlma(y=sim.111$y, biny=FALSE, sim.111$x, levelx=1,
                   m=sim.111$m, l1=1:2, c1=3,c1r=1,
                   f01y=c("x","log(x^2)"), f10y=c("x^2","sqrt(x+6)"),
                   f20ky=list(2,c("x","x^3")), f01km1=list(2,"sqrt(x)+3"),
                   f10km=list(2,"log(x+2)"), level=sim.111$level, boot=2)

data(sim.211)
temp211<-boot.mlma(y=sim.211$y, biny=FALSE, x=sim.211$x, levelx=2, m=sim.211$m,
                   l1=2,l2=1, c1=3,c1r=1, f01y=c("x","log(x^2)"),
                   f02ky=list(1,c("x","x^2")), f20ky=list(2,c("x","x^3")),
                   f01km1=list(2,"sqrt(x)+3"), f01km2=list(1,c("x^1.2","x^2.3")),
                   level=sim.211$level, boot=2)
```

---

data.org *Transform and Organize Data for Mediation Analysis*

Description

To transform variables and generate data sets for mediation analysis.

Usage

```
data.org(x, levelx=1, levely=1, m, l1 = NULL, l2 = NULL, c1 = NULL,
         c1r = rep(1, length(c1)), c2 = NULL, c2r = rep(1, length(c2)),
         f01y = NULL, f10y = NULL, f02ky = NULL, f20ky = NULL, f01km1 = NULL,
       f01km2 = NULL, f10km = NULL, level=1:length(x), weight = rep(1, length(x)))
```

Arguments

x	the vector of the predictive variable.
levelx	the level of x (1 or 2), 1 by default.
levely	the level of y (1 or 2), 1 by default.
m	the matrix or vector of mediators.
l1	the column numbers of level 1 continuous mediators in m or the list of names of the level 1 continuous mediators.
l2	the column numbers of level 2 continuous mediators in m or the list of names of the level 2 continuous mediators.
c1	the column numbers of level 1 categorical mediators in m or the list of names of the level 1 categorical mediators.
c1r	the reference groups of categorical mediators specified by c1.
c2	the column numbers of level 2 categorical mediators in m or the list of names of the level 2 categorical mediators.
c2r	the reference groups of categorical mediators specified by c2.
f01y	the transformation function expressions on level 2 predictive variable (x.j) in explaining y (eg, c("x^2","log(x)")).
f10y	the transformation function expressions on level 1 predictive variable (xij-x.j) in explaining y.
f02ky	the transformation-function-expression list on level 2 mediators (m.jk) in explaining y (eg, list(2:3,c("log(x)","sqrt(x)"), "2*x")). The first item lists column numbers/variable names of the level 2 mediators in m, which needs to be transformed. By that order, each of the rest items of f01ky list the transformation functional expressions for each mediator. The mediators not specified in the list will not be transformed in any way.
f20ky	the transformation-function-expression list on level 1 mediators (mijk-m.jk) in explaining y.The first item lists column numbers/variable names of the level 1 mediators in m, which needs to be transformed. By that order, each of the rest items of f02ky list the transformation functional expressions for each mediator. The mediators not specified in the list will not be transformed in any way.
f01km1	the transformation-function-expression list on level 2 predictor (x.j) in explaining the level 1 mediators. The first item lists column numbers/variable names of the level 1 mediators in m, which should be explained by the transformed predictor(s). By that order, each of the rest items of f01km1 lists the transformation functional expressions for the (aggregated) level 2 predictor in explaining each mediator. The mediators not specified in the list will be explained by the original format of the level 2 predictor only.

`f01km2` the transformation-function-expression list on level 2 predictor (x.j) in explaining the level 2 mediators. The first item lists column numbers/variable names of the level 2 mediators in m, which should be explained by the transformed level 2 predictor(s). By that order, each of the rest items of f01km2 lists the transformation functional expressions for the predictor in explaining each mediator. The mediators not specified in the list will be explained by the original format of the (aggregated) level 2 predictor only.

`f10km` the transformation-function-expression list on level 1 predictor (xij-x.j) in explaining the level 1 mediators. The first item lists column numbers/variable names of the level 1 mediators in m, which should be explained by the transformed level 1 predictor(s). By that order, each of the rest items of f10km lists the transformation functional expressions for the level 1 predictor in explaining each mediator. The mediators not specified in the list will be explained by the original format of the level 1 predictor only.

`level` a vector that record the group number for each observation.

`weight` the weight of cases in groups.

Details

The arguments starting with "f" are used to specify the transformation functions of the predictor or mediators in explaining y, or the transformation functions of the predictor in explaining the mediators. If the name of the argument includes a "k", the transformation is on the mediators. If the names of the arguments end with "y", the transformation is to explain the outcome. Otherwise, the transformation is on x to predict mediators (the argument ends with "m1" or "m" (for level 1 mediator), or "m2" (for level 2 mediator)). The functions corresponds to the functions in the following multilevel additive models, reading as f+subscript+superscript. For example, f01y specifies f^Y_{01}.

$$Y_{ij} = u^Y_{0j}(X_{.j}, \mathbf{M}_{.j}, \mathbf{Z}_{.j}) + \boldsymbol{\beta}^{Y\,T}_{10}\mathbf{f}^Y_{10}(X_{ij} - X_{.j}) + \sum_{k=1}^{K} \boldsymbol{\beta}^{Y\,T}_{20k}\mathbf{f}^Y_{20k}(M_{ijk} - M_{.jk}) + \boldsymbol{\beta}^{Y\,T}_{30}(\mathbf{Z}_{ij} - \mathbf{Z}_{.j}) + r^Y_{ij},$$

where

$$u^Y_{0j}(X_{.j}, \mathbf{M}_{.j}, \mathbf{Z}_{.j}) = c^Y_{00} + \boldsymbol{\beta}^{Y\,T}_{01}\mathbf{f}^Y_{01}(X_{.j}) + \sum_{k=1}^{K} \boldsymbol{\beta}^{Y\,T}_{02k}\mathbf{f}^Y_{02k}(M_{.jk}) + \boldsymbol{\beta}^{Y\,T}_{03}\mathbf{Z}_{.j} + r^Y_{0j}.$$

For $k = 1, \ldots, K$,

$$M_{.jk} = u^M_{0jk}(X_{.j}) + \boldsymbol{\beta}^{M\,T}_{10k}\mathbf{f}^M_{10k}(X_{ij} - X_{.j}) + r^M_{ijk},$$

$$u^M_{0jk}(X_{.j}) = c^M_{00k} + \boldsymbol{\beta}^{M\,T}_{01k}\mathbf{f}^{M1}_{01k}(X_{.j}) + r^M_{0jk}.$$

If for some k, M_k is level 2 variable,

$$M_{.jk} = c^M_{00k} + \boldsymbol{\beta}^{M\,T}_{01k}\mathbf{f}^{M2}_{01k}(X_{.j}) + r^M_{0jk}.$$

The transformation function can be any function that is differentiable by the function deriv(), or the ifelse function with those functions. The transformation function can also be the ns() and bs() functions for natural and b spline basis.

Value

The function returns a list with transformed and organized data with the following items:

`x1`	the level 1 and 2 transformed predictor variable matrix in explaining y (eg, f01y(x.j) & f10y(xij-x.j)).
`l1x`	the column numbers of level 1 predictors in x1.
`l2x`	the column numbers of level 2 predictors in x1.
`m1y`	the level 1 mediator matrix in explaining y (eg, f20ky(mijk-m.jk) & mijk or binarized mijk for categorical mediators).
`m1`	a list where the first item identify column numbers of level 1 mediators in m (eg l1 and c1). For every mediator identified by m1[[1]] and by that order, each of the rest item identify the column number(s) in m1y the (transformed) value(s) of the mediator in explaining y.
`m2y`	the level 2 mediator (original or aggregated) matrix in explaining y (eg, f02ky(m.jk) & m.jk).
`m2`	a list where the first item identify column numbers of level 2 mediators in m (eg l2 and c2). For every mediator identified by m2[[1]] and by that order, each of the rest item identify the column number(s) in m2y the (transformed) value(s) of the mediator in explaining y.
`m12`	a list where the first item identify column numbers of aggregated level 2 mediators in m (eg, aggregated f20ky). For every mediator identified by m12[[1]] and by that order, each of the rest item identify the column number(s) in m2y the aggregated value(s) of the mediator in explaining y.
`xm1`	the (transformed) level 1 and level 2 predictor(s) in explaining level 1 mediators.
`fm11`	a list where the first item identify column numbers of level 1 mediators in m. For every mediator identified by fm11[[1]] and by that order, each of the rest item identify the column number(s) in xm1 the (transformed) level 1 predictor(s) in explaining the mediator.
`fm12`	a list where the first item identify column numbers of level 1 mediators in m. For every mediator identified by fm12[[1]] and by that order, each of the rest item identify the column number(s) in xm1 the (transformed/aggregated) level 2 predictor(s) in explaining the mediator.
`m.2`	a matrix of level 2 mediators (one row for each group).
`xm2`	the (transformed/aggregated) level 2 predictor(s) in explaining level 2 mediators (one row for each group).
`fm22`	a list where the first item identify column numbers of level 2 mediators in m. For every mediator identified by fm22[[1]] and by that order, each of the rest item identify the column number(s) in xm2 the (transformed) level 2 predictor(s) in explaining the mediator.
`x1.der, m2y.der, m1y.der, xm2.der, xm1.der`	the derivative of x1, m2y, m1y, xm2, and xm1 respectively.
`parameter`	The list of arguments used.

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Examples

```
data(sim.211)
example1<-data.org(x=sim.211$x, levelx=2, m=sim.211$m, l1=2,l2=1, c1=3, c1r=1,
                   f01y=c("x","log(x^2)"), f02ky=list(1,c("x","x^2")),
                   f20ky=list(2,c("x","x^3")), f01km1=list(2,"sqrt(x)+3"),
                   f01km2=list(1,c("x^1.2","x^2.3")), level=sim.211$level)

data(sim.111)
example2<-data.org(sim.111$x, levelx=1, m=sim.111$m, l1=1:2, c1=3, c1r=1,
                   f01y=c("x","log(x^2)"), f10y=c("x^2","sqrt(x+6)"),
                   f20ky=list(2,c("x","x^3")), f01km1=list(2,"sqrt(x)+3"),
                   f10km=list(2,"log(x+2)"), level=sim.111$level)
```

`mlma` *Multilevel Mediation Analysis*

Description

The function transforms the data set and does multilevel mediation analysis. The total, direct, and indirect effects will be returned as the results.

Usage

```
mlma(y, biny=FALSE, data1=NULL, x, levelx=1, levely=1, m, l1=NULL,
     l2=NULL,c1=NULL,c1r=rep(1,length(c1)), c2=NULL, c2r=rep(1,length(c2)),
     level=1:length(y),weight=rep(1,length(x)), random="(1|level)",
     random.m1=NULL,intercept=TRUE,covariates=NULL,cy1=NULL,cy2=NULL,cm=NULL,
     joint=NULL,org.data=FALSE,f01y=NULL,f10y=NULL,f02ky=NULL,f20ky=NULL,
     f01km1=NULL,f01km2=NULL,f10km=NULL)
```

Arguments

`y`	the vector of the outcome variable.
`biny`	True if the outcome is binary, otherwise False. Default is False.
`data1`	The transformed and organized data set from data.org. If the data set has not been organized, leave data1=NULL (by default), and set org.data=T with the transformation functions (f arguments). Otherwise, set data1 as the output from the data.org function and do not include the arguments: org.data and fs.
`x`	the vector of the predictive variable.
`levelx`	the level of x (1 or 2), 1 by default.
`levely`	the level of y (1 or 2), 1 by default.
`m`	the matrix or vector of mediators.

l1	the column numbers of level 1 continuous mediators in m or the list of names of the level 1 continuous mediators.
l2	the column numbers of level 2 continuous mediators in m or the list of names of the level 2 continuous mediators.
c1	the column numbers of level 1 categorical mediators in m or the list of names of the level 1 categorical mediators.
c1r	the reference groups of categorical mediators specified by c1.
c2	the column numbers of level 2 categorical mediators in m or the list of names of the level 2 categorical mediators.
c2r	the reference groups of categorical mediators specified by c2.
level	a vector that record the group number for each observation.
weight	the weight of cases in groups.
random	the random effect part for the full model. random = "(1|level)" by default.
random.m1	the random effect part for model explaining the mediators. All other random effects are random = "(1|level)" if not specified here.
intercept	True if fit an intercept to models, by default.
covariates	the covariates matrix to explain the outcome, y, and/or the mediators, m.
cy1	the column numbers of covariates that are level 1 and used to explain y.
cy2	the column numbers of covariates that are level 2 and used to explain y.
cm	the column numbers of covariates that are used to explain m. cm[[1]] gives the mediators (in l1, cl, l2, or c2) that can be partially explained by covariates. Each of the rest items of the cm list shows the column number(s) in covariates that should be used to explain each mediator listed in cm[[1]] and by that order.
joint	the list of group(s) of mediators whose joint mediation effect is of interests. joint[[1]] list the levels of mediators in each group and by the order of the list. Note that if any mediator in the group is of level 2, the level of the group should be 2.
org.data	if is TRUE, first organize the data set and do transformations using the function "data.org". In such case, need to specify the transformation function arguments.
f01y, f10y, f02ky, f20ky, f01km1, f01km2, f10km	the transformation functions as describe in the function "data.org". Need these arguments only when org.data=T.

Details

The multilevel mediation is based on the following linear multilevel additive models:

$$Y_{ij} = u_{0j}^{Y}(X_{.j}, \mathbf{M}_{.j}, \mathbf{Z}_{.j}) + \boldsymbol{\beta}_{10}^{Y\,T}\mathbf{f}_{10}^{Y}(X_{ij} - X_{.j}) + \sum_{k=1}^{K} \boldsymbol{\beta}_{20k}^{Y\,T}\mathbf{f}_{20k}^{Y}(M_{ijk} - M_{.jk}) + \boldsymbol{\beta}_{30}^{Y\,T}(\mathbf{Z}_{ij} - \mathbf{Z}_{.j}) + r_{ij}^{Y},$$

where

$$u_{0j}^{Y}(X_{.j}, \mathbf{M}_{.j}, \mathbf{Z}_{.j}) = c_{00}^{Y} + \boldsymbol{\beta}_{01}^{Y\,T}\mathbf{f}_{01}^{Y}(X_{.j}) + \sum_{k=1}^{K} \boldsymbol{\beta}_{02k}^{Y\,T}\mathbf{f}_{02k}^{Y}(M_{.jk}) + \boldsymbol{\beta}_{03}^{Y\,T}\mathbf{Z}_{.j} + r_{0j}^{Y}.$$

For $k = 1, \ldots, K$,

$$M_{.jk} = u^M_{0jk}(X_{.j}) + \boldsymbol{\beta}^{M}_{10k}{}^T \mathbf{f}^M_{10k}(X_{ij} - X_{.j}) + r^M_{ijk},$$

$$u^M_{0jk}(X_{.j}) = c^M_{00k} + \boldsymbol{\beta}^{M}_{01k}{}^T \mathbf{f}^{M1}_{01k}(X_{.j}) + r^M_{0jk}.$$

If for some k, M_k is level 2 variable,

$$M_{.jk} = c^M_{00k} + \boldsymbol{\beta}^{M}_{01k}{}^T \mathbf{f}^{M2}_{01k}(X_{.j}) + r^M_{0jk}.$$

Note that in the models, $\mathbf{f}(\cdot) = (f_1(\cdot), f_2(\cdot), \cdots, f_l(\cdot))^T$ is a set of l transformation functions on $\cdot$, with the corresponding linear coefficients vector $\boldsymbol{\beta} = (\beta_1, \beta_2, \cdots, \beta_l)^T$. $\mathbf{f}$ and l are known for model fitting. l may be different with $\mathbf{f}$ of different sub- and super-scripts.

Value

A "mlma" mode list will be returned with the following items:

`de1`	level 1 direct effect from predictor.
`de2`	level 2 direct effect from predictor.
`ie1`	level 1 indirect effect from level 1 mediator.
`ie12`	level 2 indirect effect from level 1 mediator.
`ie2`	level 2 indirect effect from level 2 mediator.
`f1`	the overall multilevel model.
`fm1`	a list, where the first item identifies the level 1 mediators, and in that order, the following items give the prediction functions of the mediators.
`fm2`	a list, where the first item identifies the level 2 mediators, and in that order, the following items give the prediction functions of the mediators.
`ie1_list`	a list, where the first item identifies the level 1 mediators, and in that order, the following items give the column(s) of the indirect effects of the mediator in ie1.
`ie2_list`	a list, where the first item identifies the level 2 mediators, and in that order, the following items give the column(s) of the indirect effects of the mediator in ie2.
`iej2_list`	a list, where the first item identifies the level 2 joint mediators, and in that order, the following items give the column(s) of the indirect effects of the mediator in cbind(ie12,ie2).
`ie12_1,ie12_2, ie1_1, ie1_2, ie2_1, ie2_2`	the first and second part of the corresponding indirect effects.
`x`	the vector of the predictive variable.
`x.j`	the vector of the aggregated variable at the higher level by the order of unique(level[!is.na(level)]).
`data1`	The results from data.org.

Author(s)

Qingzhao Yu (qyu@lsuhsc.edu), Bin Li (bli@lsu.edu).

Examples

```
data(sim.111)
data1<-data.org(x=sim.111$x, levelx=1, m=sim.111$m, l1=1:2, c1=3, c1r=1,
                f01y=c("x","log(x^2)"), f10y=c("x^2","sqrt(x+6)"),
                f20ky=list(2,c("x","x^3")), f01km1=list(2,"sqrt(x)+3"),
                f10km=list(2,"log(x+2)"), level=sim.111$level)
temp<-mlma(y=sim.111$y, biny=FALSE, data1=data1, x=sim.111$x, levelx=1, m=sim.111$m,
                l1=1:2,c1=3, c1r=1,level=sim.111$level)
#can also do the above analysis using the following code
temp<-mlma(y=sim.111$y, biny=FALSE, data1=data1, x=sim.111$x, levelx=1, m=sim.111$m,
                l1=1:2,c1=3, c1r=1,level=sim.111$level,org.data=TRUE,
                f01y=c("x","log(x^2)"), f10y=c("x^2","sqrt(x+6)"),
                f20ky=list(2,c("x","x^3")), f01km1=list(2,"sqrt(x)+3"),
                f10km=list(2,"log(x+2)"))

data(sim.211)
data1<-data.org(x=sim.211$x, levelx=2, m=sim.211$m, l1=2,l2=1, c1=3, c1r=1,
                   f01y=c("x","log(x^2)"), f02ky=list(1,c("x","x^2")),
                   f20ky=list(2,c("x","x^3")), f01km1=list(2,"sqrt(x)+3"),
                   f01km2=list(1,c("x^1.2","x^2.3")), level=sim.211$level)
temp<-mlma(y=sim.211$y, biny=FALSE, data1, x=sim.211$x, levelx=2, m=sim.211$m,
           l1=2, l2=1, c1=3, c1r=1,level=sim.211$level)
```

`plot.mlma` *Plot "mlma" Object*

Description

Plot the overall mediation effect or decomposed indirect effect from the selected mediator.

Usage

```
## S3 method for class 'mlma'
plot(x, ..., var = NULL, cate = FALSE, w2 = rep(1, length(object$de2)))
```

Arguments

`x`	an "mlma" object.
`...`	arguments to be passed to methods.
`var`	the name of the mediator that is to be plotted. If var is NULL, plot the relative mediation effects of all mediators.
`cate`	TRUE when the mediator is a categorical variable. By default is FALSE.
`w2`	the weight for observations at level 2, which should be the same order as unique(level[!is.na(level)]). The default is rep(1,length(object$de2)).

Details

Plot the relative effects of direct effects and indirect effects of mediators at level 1 (if levelx=1) and level 2 respectively if var=NULL. Otherwise, plot the indirect effect of var, the estimated differential effect of the predictor on var, and the predicted relationship between y and var at individual level and/or (aggregated) group level.

Author(s)

Qingzhao Yu (qyu@lsuhsc.edu), Bin Li (bli@lsu.edu).

Examples

```
data(sim.111)
data1<-data.org(x=sim.111$x, levelx=1, m=sim.111$m, l1=1:2, c1=3, c1r=1,
                f01y=c("x","log(x^2)"), f10y=c("x^2","sqrt(x+6)"),
                f20ky=list(2,c("x","x^3")), f01km1=list(2,"sqrt(x)+3"),
                f10km=list(2,"log(x+2)"), level=sim.111$level)
temp111<-mlma(y=sim.111$y, biny=FALSE, data1=data1, x=sim.111$x, levelx=1, m=sim.111$m,
                l1=1:2,c1=3, c1r=1,level=sim.111$level)
plot(temp111)
plot(temp111,var="m.2")
plot(temp111,var="m.3")
plot(temp111,var="m.4", cate=TRUE)

data(sim.211)
data1<-data.org(x=sim.211$x, levelx=2, m=sim.211$m, l1=2,l2=1, c1=3, c1r=1,
                   f01y=c("x","log(x^2)"), f02ky=list(1,c("x","x^2")),
                   f20ky=list(2,c("x","x^3")), f01km1=list(2,"sqrt(x)+3"),
                   f01km2=list(1,c("x^1.2","x^2.3")), level=sim.211$level)
temp211<-mlma(y=sim.211$y, biny=FALSE, data1, x=sim.211$x, levelx=2, m=sim.211$m,
           l1=2, l2=1, c1=3, c1r=1,level=sim.211$level)
plot(temp211)
plot(temp211,var="m.1")
plot(temp211,var="m.4", cate=TRUE)
plot(temp211,var="m.3")
```

`plot.mlma.boot` *Plot the "mlma.boot" Object*

Description

For the mediator identified by var, the function draws the level 1 and/or (aggregated) level 2 indirect effects versus the predictor and the confidence bands at alpha significance level. If var is NULL, draw the relative mediation effects with confidence intervals.

Usage

```
## S3 method for class 'mlma.boot'
plot(x, ..., var = NULL, alpha = 0.05, quant=FALSE)
```

Arguments

x	an "mlma" object.
...	arguments to be passed to methods.
var	the name of the mediator that is to be plotted.
alpha	the significance level at which to draw the confidence bands.
quant	if true, confidence interval is calculated using quantil when plot the relative effects. By default, the CIs are calculated using normal approximation. This argument does nothing for the CIs calculated when var is not null.

Author(s)

Qingzhao Yu (qyu@lsuhsc.edu), Bin Li (bli@lsu.edu).

Examples

```
#1-1-1 model
data(sim.111)
temp111<-boot.mlma(y=sim.111$y, biny=FALSE, sim.111$x, levelx=1,
                   m=sim.111$m, l1=1:2, c1=3,c1r=1,
                   f01y=c("x","log(x^2)"), f10y=c("x^2","sqrt(x+6)"),
                   f20ky=list(2,c("x","x^3")), f01km1=list(2,"sqrt(x)+3"),
                   f10km=list(2,"log(x+2)"), level=sim.111$level, boot=2)
plot(temp111)
plot(temp111,var="m.2")
plot(temp111,var="m.3")
plot(temp111,var="m.4")


#2-1-1 model
data(sim.211)
temp211<-boot.mlma(y=sim.211$y, biny=FALSE, x=sim.211$x, levelx=2, m=sim.211$m,
                   l1=2,l2=1, c1=3,c1r=1, f01y=c("x","log(x^2)"),
                   f02ky=list(1,c("x","x^2")), f20ky=list(2,c("x","x^3")),
                   f01km1=list(2,"sqrt(x)+3"), f01km2=list(1,c("x^1.2","x^2.3")),
                   level=sim.211$level, boot=2)
plot(temp211)
plot(temp211,var="m.1")
plot(temp211,var="m.4")
plot(temp211,var="m.3")
```

---

print.mlma *Print "mlma" Object*

Description

print the level 1 and level 2 mediation effecs from the object.

Usage

```
## S3 method for class 'mlma'
print(x, ..., w2 = rep(1, length(object$de2)))
```

Arguments

x	an "mlma" object.
...	arguments to be passed to methods.
w2	the weight for observations at level 2, which should be the same order as unique(level[!is.na(level)]). The default is rep(1,length(object$de2)).

Author(s)

Qingzhao Yu (qyu@lsuhsc.edu), Bin Li (bli@lsu.edu).

Examples

```
data(sim.111)
data1<-data.org(x=sim.111$x, levelx=1, m=sim.111$m, l1=1:2, c1=3, c1r=1,
                f01y=c("x","log(x^2)"), f10y=c("x^2","sqrt(x+6)"),
                f20ky=list(2,c("x","x^3")), f01km1=list(2,"sqrt(x)+3"),
                f10km=list(2,"log(x+2)"), level=sim.111$level)
temp111<-mlma(y=sim.111$y, biny=FALSE, data1=data1, x=sim.111$x, levelx=1, m=sim.111$m,
                l1=1:2,c1=3, c1r=1,level=sim.111$level)
print(temp111)

data(sim.211)
data1<-data.org(x=sim.211$x, levelx=2, m=sim.211$m, l1=2,l2=1, c1=3, c1r=1,
                   f01y=c("x","log(x^2)"), f02ky=list(1,c("x","x^2")),
                   f20ky=list(2,c("x","x^3")), f01km1=list(2,"sqrt(x)+3"),
                   f01km2=list(1,c("x^1.2","x^2.3")), level=sim.211$level)
temp211<-mlma(y=sim.211$y, biny=FALSE, data1, x=sim.211$x, levelx=2, m=sim.211$m,
           l1=2, l2=1, c1=3, c1r=1,level=sim.211$level)
print(temp211)
```

---

sim.111 *Simulated 1-1-1 Data set*

Description

A simulated data set, where both predictor and outcome are level 1 variables.

Usage

```
data("sim.111")
```

Format

The data set contains 10 groups, each group has 30 observations. The format is list, where there are four elements:

x: the level 1 continuous predictor.

y: the level 1 continuous outcome.

m: the matrix of mediators, where there are three level 1 mediators, where m.2 and m.3 are continuous, and m.4 is categorical with 3 levels.

level: the group level for each observation.

Examples

```
data(sim.111)
```

---

sim.211 *Simulated 2-1-1 Data*

Description

A simulated data set, where the predictor is a level 2 and the outcome is a level 1 variable.

Usage

```
data("sim.211")
```

Format

The data set contains 10 groups, each group has 30 observations. The format is list, where there are four elements:

x: the level 1 continuous predictor.

y: the level 1 continuous outcome.

m: the matrix of mediators, where there are one level 2 mediator, m.1, and two level 1 mediators, m.3 and m.4. m.4 is categorical with 3 levels.

level: the group level for each observation.

Examples

```
data(sim.211)
```

summary.mlma *Summary of "mlma" Object*

Description

This function provides ANOVA tests on the predictors and mediators in the full model and on the predictors for models in explaining each mediators.

Usage

```
## S3 method for class 'mlma'
summary(object,...,type="III")
## S3 method for class 'summary.mlma'
print(x, ...)
```

Arguments

object	an "mlma" object.
x	a summary.mlma.boot object created initially call to summary.mlma.boot.
...	arguments to be passed to methods.
type	type of test, "II", "III", 2, or 3.

Author(s)

Qingzhao Yu (qyu@lsuhsc.edu), Bin Li (bli@lsu.edu).

Examples

```
data(sim.111)
temp<-mlma(y=sim.111$y, biny=FALSE, data1=data1, x=sim.111$x, levelx=1, m=sim.111$m,
               l1=1:2,c1=3, c1r=1,level=sim.111$level,org.data=TRUE,
               f01y=c("x","log(x^2)"), f10y=c("x^2","sqrt(x+6)"),
               f20ky=list(2,c("x","x^3")), f01km1=list(2,"sqrt(x)+3"),
               f10km=list(2,"log(x+2)"))
summary(temp)
```

summary.mlma.boot *Summary of "mlma.boot" Object*

Description

This function provide summary statistics for all mediation effects.

Usage

```
## S3 method for class 'mlma.boot'
summary(object, ..., alpha = 0.05,RE=FALSE)
## S3 method for class 'summary.mlma.boot'
print(x, ...)
```

Arguments

object	an "mlma" object.
x	a summary.mlma.boot object created initially call to summary.mlma.boot.
...	arguments to be passed to methods.
alpha	the significance level at which to draw the confidence bands.
RE	if true, print the relative effects, otherwise show the mediation effects.

Author(s)

Qingzhao Yu (qyu@lsuhsc.edu), Bin Li (bli@lsu.edu).

Examples

```
#1-1-1 model
data(sim.111)
temp111<-boot.mlma(y=sim.111$y, biny=FALSE, sim.111$x, levelx=1,
                   m=sim.111$m, l1=1:2, c1=3,c1r=1,
                   f01y=c("x","log(x^2)"), f10y=c("x^2","sqrt(x+6)"),
                   f20ky=list(2,c("x","x^3")), f01km1=list(2,"sqrt(x)+3"),
                   f10km=list(2,"log(x+2)"), level=sim.111$level, boot=2)
summary(temp111)

#2-1-1 model
data(sim.211)
temp211<-boot.mlma(y=sim.211$y, biny=FALSE, x=sim.211$x, levelx=2, m=sim.211$m,
                   l1=2,l2=1, c1=3,c1r=1, f01y=c("x","log(x^2)"),
                   f02ky=list(1,c("x","x^2")), f20ky=list(2,c("x","x^3")),
                   f01km1=list(2,"sqrt(x)+3"), f01km2=list(1,c("x^1.2","x^2.3")),
                   level=sim.211$level, boot=2)
summary(temp211)
```

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