Package 'lavaan'

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Title Latent Variable Analysis

Version 0.5-13

Description Fit a variety of latent variable models, including
confirmatory factor analysis, structural equation modeling and latent growth curve models.

Depends methods, R(>= 2.14.0), MASS, boot, mnormt, pbivnorm, quadprog

Imports stats4, stats, graphics

Suggests lavaan.survey, semPlot, semTools, simsem

License GPL (>= 2)

LazyData yes

URL http://lavaan.org

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NeedsCompilation no

Repository CRAN

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R topics documented:

`bootstrapLavaan` *Bootstrapping a Lavaan Model*

Description

Bootstrap the LRT, or any other statistic (or vector of statistics) you can extract from a fitted lavaan object.

Usage

```
bootstrapLavaan(object, R = 1000L, type = "ordinary", verbose = FALSE,
                FUN = "coef", warn = -1L, return.boot = FALSE,
                parallel = c("no", "multicore", "snow"),
                ncpus = 1L, cl = NULL, h0.rmsea = NULL, ...)

bootstrapLRT(h0 = NULL, h1 = NULL, R = 1000L, type="bollen.stine",
             verbose = FALSE, return.LRT = FALSE, double.bootstrap = "no",
             double.bootstrap.R = 500L, double.bootstrap.alpha = 0.05,
             warn = -1L, parallel = c("no", "multicore", "snow"),
             ncpus = 1L, cl = NULL)
```

Arguments

object	An object of class lavaan.
h0	An object of class lavaan. The restricted model.
h1	An object of class lavaan. The unrestricted model.
R	Integer. The number of bootstrap draws.
type	If "ordinary" or "nonparametric", the usual (naive) bootstrap method is used. If "bollen.stine", the data is first transformed such that the null hypothesis holds exactly in the resampling space. If "yuan", the data is first transformed by combining data and theory (model), such that the resampling space is closer to the population space. If "parametric", the parametric bootstrap approach is used; currently, this is only valid for continuous data following a multivariate normal distribution. See references for more details.
FUN	A function which when applied to the lavaan object returns a vector containing the statistic(s) of interest. The default is FUN="coef", returning the estimated values of the free parameters in the model.
...	Other named arguments for FUN which are passed unchanged each time it is called.
verbose	If TRUE, show information for each bootstrap draw.
warn	Sets the handling of warning messages. See options.
return.boot	Not used for now.
return.LRT	If TRUE, return the LRT values as an attribute to the pvalue.
parallel	The type of parallel operation to be used (if any). If missing, the default is "no".
ncpus	Integer: number of processes to be used in parallel operation: typically one would chose this to the number of available CPUs.
cl	An optional **parallel** or **snow** cluster for use if parallel = "snow". If not supplied, a cluster on the local machine is created for the duration of the bootstrapLavaan or bootstrapLRT call.
h0.rmsea	Only used if type="yuan". Allows one to do the Yuan bootstrap under the hypothesis that the population RMSEA equals a specified value.
double.bootstrap	If "standard" the genuine double bootstrap is used to compute an additional set of plug-in p-values for each boostrap sample. If "FDB", the fast double bootstrap is used to compute second level LRT-values for each bootstrap sample. If "no", no double bootstrap is used. The default is set to "FDB".
double.bootstrap.R	Integer. The number of bootstrap draws to be use for the double bootstrap.
double.bootstrap.alpha	The significance level to compute the adjusted alpha based on the plugin p-values.

Details

The FUN function can return either a scalar or a numeric vector. This function can be an existing function (for example `coef`) or can be a custom defined function. For example:

```
myFUN <- function(x) {
    # require(lavaan)
    modelImpliedCov <- fitted(x)$cov
    vech(modelImpliedCov)
}
```

If `parallel="snow"`, it is imperative that the `require(lavaan)` is included in the custom function.

Author(s)

Yves Rosseel, Leonard Vanbrabant and Ed Merkle

References

Bollen, K. and Stine, R. (1992) Bootstrapping Goodness of Fit Measures in Structural Equation Models. Sociological Methods and Research, 21, 205–229.

Yuan, K.-H., Hayashi, K., & Yanagihara, H. (2007). A class of population covariance matrices in the bootstrap approach to covariance structure analysis. Multivariate Behavioral Research, 42, 261–281.

Examples

```
# fit the Holzinger and Swineford (1939) example
HS.model <- ' visual  =~ x1 + x2 + x3
              textual =~ x4 + x5 + x6
              speed   =~ x7 + x8 + x9 '

fit <- cfa(HS.model, data=HolzingerSwineford1939, se="none")

# get the test statistic for the original sample
T.orig <- fitMeasures(fit, "chisq")

# bootstrap to get bootstrap test statistics
# we only generate 10 bootstrap sample in this example; in practice
# you may wish to use a much higher number
T.boot <- bootstrapLavaan(fit, R=10, type="bollen.stine",
                          FUN=fitMeasures, fit.measures="chisq")

# compute a bootstrap based p-value
pvalue.boot <- length(which(T.boot > T.orig))/length(T.boot)
```

cfa *Fit Confirmatory Factor Analysis Models*

Description

Fit a Confirmatory Factor Analysis (CFA) model.

Usage

```
cfa(model = NULL, data = NULL,
    meanstructure = "default", fixed.x = "default",
    orthogonal = FALSE, std.lv = FALSE, std.ov = FALSE,
    missing = "default", ordered = NULL,
    sample.cov = NULL, sample.cov.rescale = "default",
    sample.mean = NULL, sample.nobs = NULL,
    ridge = 1e-05, group = NULL,
    group.label = NULL, group.equal = "", group.partial = "",
    cluster = NULL, constraints = '',
    estimator = "default", likelihood = "default",
    information = "default", se = "default", test = "default",
    bootstrap = 1000L, mimic = "default", representation = "default",
    do.fit = TRUE, control = list(), WLS.V = NULL, NACOV = NULL,
    start = "default", verbose = FALSE, warn = TRUE, debug = FALSE)
```

Arguments

model	A description of the user-specified model. Typically, the model is described using the lavaan model syntax. See model.syntax for more information. Alternatively, a parameter table (eg. the output of the lavaanify() function) is also accepted.
data	An optional data frame containing the observed variables used in the model. If some variables are declared as ordered factors, lavaan will treat them as ordinal variables.
meanstructure	If TRUE, the means of the observed variables enter the model. If "default", the value is set based on the user-specified model, and/or the values of other arguments.
fixed.x	If TRUE, the exogenous 'x' covariates are considered fixed variables and the means, variances and covariances of these variables are fixed to their sample values. If FALSE, they are considered random, and the means, variances and covariances are free parameters. If "default", the value is set depending on the mimic option.
orthogonal	If TRUE, the exogenous latent variables are assumed to be uncorrelated.
std.lv	If TRUE, the metric of each latent variable is determined by fixing their variances to 1.0. If FALSE, the metric of each latent variable is determined by fixing the factor loading of the first indicator to 1.0.

`std.ov` If `TRUE`, all observed variables are standardized before entering the analysis.

`missing` If `"listwise"`, cases with missing values are removed listwise from the data frame before analysis. If `"direct"` or `"ml"` or `"fiml"` and the estimator is maximum likelihood, Full Information Maximum Likelihood (FIML) estimation is used using all available data in the data frame. This is only valid if the data are missing completely at random (MCAR) or missing at random (MAR). If `"default"`, the value is set depending on the estimator and the mimic option.

`ordered` Character vector. Only used if the data is in a data.frame. Treat these variables as ordered (ordinal) variables, if they are endogenous in the model. Importantly, all other variables will be treated as numeric (unless they are declared as ordered in the original data.frame.)

`sample.cov` Numeric matrix. A sample variance-covariance matrix. The rownames and/or colnames must contain the observed variable names. For a multiple group analysis, a list with a variance-covariance matrix for each group. Note that if maximum likelihood estimation is used and `likelihood="normal"`, the user provided covariance matrix is internally rescaled by multiplying it with a factor (N-1)/N, to ensure that the covariance matrix has been divided by N. This can be turned off by setting the `sample.cov.rescale` argument to `FALSE`.

`sample.cov.rescale`
If `TRUE`, the sample covariance matrix provided by the user is internally rescaled by multiplying it with a factor (N-1)/N. If `"default"`, the value is set depending on the estimator and the likelihood option: it is set to `TRUE` if maximum likelihood estimation is used and `likelihood="normal"`, and `FALSE` otherwise.

`sample.mean` A sample mean vector. For a multiple group analysis, a list with a mean vector for each group.

`sample.nobs` Number of observations if the full data frame is missing and only sample moments are given. For a multiple group analysis, a list or a vector with the number of observations for each group.

`ridge` Numeric. Small constant used for ridging. Only used if the sample covariance matrix is non positive definite.

`group` A variable name in the data frame defining the groups in a multiple group analysis.

`group.label` A character vector. The user can specify which group (or factor) levels need to be selected from the grouping variable, and in which order. If `NULL` (the default), all grouping levels are selected, in the order as they appear in the data.

`group.equal` A vector of character strings. Only used in a multiple group analysis. Can be one or more of the following: `"loadings"`, `"intercepts"`, `"means"`, `"thresholds"`, `"regressions"`, `"residuals"`, `"residual.covariances"`, `"lv.variances"` or `"lv.covariances"`, specifying the pattern of equality constraints across multiple groups.

`group.partial` A vector of character strings containing the labels of the parameters which should be free in all groups (thereby overriding the group.equal argument for some specific parameters).

`cluster` Not used yet.

constraints Additional (in)equality constraints not yet included in the model syntax. See model.syntax for more information.

estimator The estimator to be used. Can be one of the following: "ML" for maximum likelihood, "GLS" for generalized least squares, "WLS" for weighted least squares (sometimes called ADF estimation), "ULS" for unweighted least squares and "DWLS" for diagonally weighted least squares. These are the main options that affect the estimation. For convenience, the "ML" option can be extended as "MLM", "MLMV", "MLMVS", "MLF", and "MLR". The estimation will still be plain "ML", but now with robust standard errors and a robust (scaled) test statistic. For "MLM", "MLMV", "MLMVS", classic robust standard errors are used (se="robust.sem"); for "MLF", standard errors are based on first-order derivatives (se="first.order"); for "MLR", 'Huber-White' robust standard errors are used (se="robust.huber.white"). In addition, "MLM" will compute a Satorra-Bentler scaled (mean adjusted) test statistic (test="satorra.bentler") , "MLMVS" will compute a mean and variance adjusted test statistic (Satterthwaite style) (test="mean.var.adjusted"), "MLMV" will compute a mean and variance adjusted test statistic (scaled and shifted) (test="scaled.shifted"), and "MLR" will compute a test statistic which is asymptotically equivalent to the Yuan-Bentler T2-star test statistic. Analogously, the estimators "WLSM" and "WLSMV" imply the "DWLS" estimator (not the "WLS" estimator) with robust standard errors and a mean or mean and variance adjusted test statistic. Estimators "ULSM" and "ULSMV" imply the "ULS" estimator with robust standard errors and a mean or mean and variance adjusted test statistic.

likelihood Only relevant for ML estimation. If "wishart", the wishart likelihood approach is used. In this approach, the covariance matrix has been divided by N-1, and both standard errors and test statistics are based on N-1. If "normal", the normal likelihood approach is used. Here, the covariance matrix has been divided by N, and both standard errors and test statistics are based on N. If "default", it depends on the mimic option: if mimic="lavaan" or mimic="Mplus", normal likelihood is used; otherwise, wishart likelihood is used.

information If "expected", the expected information matrix is used (to compute the standard errors). If "observed", the observed information matrix is used. If "default", the value is set depending on the estimator and the mimic option.

se If "standard", conventional standard errors are computed based on inverting the (expected or observed) information matrix. If "first.order", standard errors are computed based on first-order derivatives. If "robust.sem", conventional robust standard errors are computed. If "robust.huber.white", standard errors are computed based on the 'mlr' (aka pseudo ML, Huber-White) approach. If "robust", either "robust.sem" or "robust.huber.white" is used depending on the estimator, the mimic option, and whether the data are complete or not. If "boot" or "bootstrap", bootstrap standard errors are computed using standard bootstrapping (unless Bollen-Stine bootstrapping is requested for the test statistic; in this case bootstrap standard errors are computed using model-based bootstrapping). If "none", no standard errors are computed.

test If "standard", a conventional chi-square test is computed. If "Satorra.Bentler", a Satorra-Bentler scaled test statistic is computed. If "Yuan.Bentler", a Yuan-Bentler scaled test statistic is computed. If "mean.var.adjusted" or "Satterthwaite",

a mean and variance adjusted test statistic is compute. If "scaled.shifted", an alternative mean and variance adjusted test statistic is computed (as in Mplus version 6 or higher). If "boot" or "bootstrap" or "Bollen.Stine", the Bollen-Stine bootstrap is used to compute the bootstrap probability value of the test statistic. If "default", the value depends on the values of other arguments.

bootstrap — Number of bootstrap draws, if bootstrapping is used.

mimic — If "Mplus", an attempt is made to mimic the Mplus program. If "EQS", an attempt is made to mimic the EQS program. If "default", the value is (currently) set to "lavaan", which is very close to "Mplus".

representation — If "LISREL" the classical LISREL matrix representation is used to represent the model (using the all-y variant).

do.fit — If FALSE, the model is not fit, and the current starting values of the model parameters are preserved.

control — A list containing control parameters passed to the optimizer. By default, lavaan uses "nlminb". See the manpage of nlminb for an overview of the control parameters. A different optimizer can be chosen by setting the value of optim.method. For unconstrained optimization (the model syntax does not include any "==", ">" or "<" operators), the available options are "nlminb" (the default), "BFGS" and "L-BFGS-B". See the manpage of the optim function for the control parameters of the latter two options. For constrained optimization, the only available option is "nlminb.constr".

WLS.V — A user provided weight matrix to be used by estimator "WLS"; if the estimator is "DWLS", only the diagonal of this matrix will be used. For a multiple group analysis, a list with a weight matrix for each group. The elements of the weight matrix should be in the following order (if all data is continuous): first the means (if a meanstructure is involved), then the lower triangular elements of the covariance matrix including the diagonal, ordered column by column. In the categorical case: first the thresholds (including the means for continuous variables), then the slopes (if any), the variances of continuous variables (if any), and finally the lower triangular elements of the correlation/covariance matrix excluding the diagonal, ordered column by column.

NACOV — A user provided matrix containing the elements of (N times) the asymptotic variance-covariance matrix of the sample statistics. For a multiple group analysis, a list with an asymptotic variance-covariance matrix for each group. See the WLS.V argument for information about the order of the elements.

start — If it is a character string, the two options are currently "simple" and "Mplus". In the first case, all parameter values are set to zero, except the factor loadings (set to one), the variances of latent variables (set to 0.05), and the residual variances of observed variables (set to half the observed variance). If "Mplus", we use a similar scheme, but the factor loadings are estimated using the fabin3 estimator (tsls) per factor. If start is a fitted object of class lavaan, the estimated values of the corresponding parameters will be extracted. If it is a model list, for example the output of the paramaterEstimates() function, the values of the est or start or ustart column (whichever is found first) will be extracted.

verbose — If TRUE, the function value is printed out during each iteration.

warn — If TRUE, some (possibly harmless) warnings are printed out during the iterations.

debug If TRUE, debugging information is printed out.

Details

The cfa function is a wrapper for the more general lavaan function, using the following default arguments: int.ov.free = TRUE, int.lv.free = FALSE, auto.fix.first = TRUE (unless std.lv = TRUE), auto.fix.single = TRUE, auto.var = TRUE, auto.cov.lv.x = TRUE, auto.th = TRUE, auto.delta = TRUE, and auto.cov.y = TRUE.

Value

An object of class lavaan, for which several methods are available, including a summary method.

References

Yves Rosseel (2012). lavaan: An R Package for Structural Equation Modeling. Journal of Statistical Software, 48(2), 1-36. URL http://www.jstatsoft.org/v48/i02/.

See Also

lavaan

Examples

```
## The famous Holzinger and Swineford (1939) example
HS.model <- ' visual  =~ x1 + x2 + x3
              textual =~ x4 + x5 + x6
              speed   =~ x7 + x8 + x9 '

fit <- cfa(HS.model, data=HolzingerSwineford1939)
summary(fit, fit.measures=TRUE)
```

Demo.growth *Demo dataset for a illustrating a linear growth model.*

Description

A toy dataset containing measures on 4 time points (t1,t2, t3 and t4), two predictors (x1 and x2) influencing the random intercept and slope, and a time-varying covariate (c1, c2, c3 and c4).

Usage

```
data(Demo.growth)
```

Format

A data frame of 400 observations of 10 variables.

- `t1` Measured value at time point 1
- `t2` Measured value at time point 2
- `t3` Measured value at time point 3
- `t4` Measured value at time point 4
- `x1` Predictor 1 influencing intercept and slope
- `x2` Predictor 2 influencing intercept and slope
- `c1` Time-varying covariate time point 1
- `c2` Time-varying covariate time point 2
- `c3` Time-varying covariate time point 3
- `c4` Time-varying covariate time point 4

See Also

`growth`

Examples

```
head(Demo.growth)
```

---

estfun *Extract Empirical Estimating Functions*

Description

A function for extracting the empirical estimating functions of a fitted lavaan model. This is the derivative of the objective function with respect to the parameter vector, evaluated at the observed (case-wise) data. In other words, this function returns the case-wise scores, evaluated at the fitted model parameters.

Usage

```
estfun.lavaan(object, scaling = FALSE)
```

Arguments

`object`	An object of class `lavaan`.
`scaling`	If `TRUE`, the scores are scaled to reflect the specific objective function used by lavaan. If `FALSE` (the default), the objective function is the loglikelihood function assuming multivariate normality.

Value

A n x k matrix corresponding to n observations and k parameters.

Author(s)

Ed Merkle

`FacialBurns` *Dataset for illustrating the InformativeTesting function.*

Description

A dataset from the Dutch burn center (http://www.adbc.nl). The data were used to examine psychosocial functioning in patients with facial burn wounds. Psychosocial functioning was measured by Anxiety and depression symptoms (HADS), and self-esteem (Rosenberg's self-esteem scale).

Usage

```
data(FacialBurns)
```

Format

A data frame of 77 observations of 6 variables.

`Selfesteem` Rosenberg's self-esteem scale

`HADS` Anxiety and depression scale

`Age` Age measured in years, control variable

`TBSA` Total Burned Surface Area

`RUM` Rumination, control variable

`Sex` Gender, grouping variable

Examples

```
head(FacialBurns)
```

fitMeasures *Fit Measures for a Latent Variable Model*

Description

This function computes a variety of fit measures to assess the global fit of a latent variable model.

Usage

```
fitMeasures(object, fit.measures = "all")
fitmeasures(object, fit.measures = "all")
```

Arguments

object	An object of class lavaan.
fit.measures	If "all", all fit measures available will be returned. If only a single or a few fit measures are specified by name, only those are computed and returned.

Value

A named numeric vector of fit measures.

Examples

```
HS.model <- ' visual  =~ x1 + x2 + x3
              textual =~ x4 + x5 + x6
              speed   =~ x7 + x8 + x9 '

fit <- cfa(HS.model, data=HolzingerSwineford1939)
fitMeasures(fit)
fitMeasures(fit, "cfi")
fitMeasures(fit, c("chisq", "df", "pvalue", "cfi", "rmsea"))
```

getCov *Utility Functions For Covariance Matrices*

Description

Convenience functions to deal with covariance and correlation matrices.

Usage

```
getCov(x, lower = TRUE, diagonal = TRUE, sds = NULL,
       names = paste("V", 1:nvar, sep=""))
char2num(s)
cor2cov(R, sds, names = NULL)
```

Arguments

x	The elements of the covariance matrix. Either inside a character string or as a numeric vector. In the former case, the function char2num is used to convert the numbers (inside the character string) to numeric values.
lower	Logical. If TRUE, the numeric values in x are the lower-triangular elements of the (symmetric) covariance matrix only. If FALSE, x contains the upper triangular elements only. Note we always assumed the elements are provided row-wise!
diagonal	Logical. If TRUE, the numeric values in x include the diagonal elements. If FALSE, a unit diagonal is assumed.
sds	A numeric vector containing the standard deviations to be used to scale the elements in x or the correlation matrix R into a covariance matrix.
names	The variable names of the observed variables.
s	Character string containing numeric values; comma's and semi-colons are ignored.
R	A correlation matrix, to be scaled into a covariance matrix.

Details

The getCov function is typically used to input the lower (or upper) triangular elements of a (symmetric) covariance matrix. In many examples found in handbooks, only those elements are shown. However, lavaan needs a full matrix to proceed.

The cor2cov function is the inverse of the cov2cor function, and scales a correlation matrix into a covariance matrix given the standard deviations of the variables. Optionally, variable names can be given.

Examples

```
# The classic Wheaton et. al. (1977) model
# panel data on he stability of alienation
lower <- '
 11.834,
  6.947,    9.364,
  6.819,    5.091,   12.532,
  4.783,    5.028,    7.495,    9.986,
 -3.839,   -3.889,   -3.841,   -3.625,   9.610,
-21.899,  -18.831,  -21.748,  -18.775,  35.522,  450.288 '

# convert to a full symmetric covariance matrix with names
wheaton.cov <- getCov(lower, names=c("anomia67","powerless67", "anomia71",
                                     "powerless71","education","sei"))

# the model
wheaton.model <- '
  # measurement model
    ses     =~ education + sei
    alien67 =~ anomia67 + powerless67
    alien71 =~ anomia71 + powerless71
```

```
  # equations
    alien71 ~ alien67 + ses
    alien67 ~ ses

  # correlated residuals
    anomia67 ~~ anomia71
    powerless67 ~~ powerless71
'

# fitting the model
fit <- sem(wheaton.model, sample.cov=wheaton.cov, sample.nobs=932)

# showing the results
summary(fit, standardized=TRUE)
```

---

growth *Fit Growth Curve Models*

Description

Fit a Growth Curve model.

Usage

```
growth(model = NULL, data = NULL, fixed.x = "default",
    orthogonal = FALSE, std.lv = FALSE, std.ov = FALSE,
    missing = "default", ordered = NULL,
    sample.cov = NULL, sample.cov.rescale = "default",
    sample.mean = NULL, sample.nobs = NULL,
    ridge = 1e-05, group = NULL,
    group.label = NULL, group.equal = "", group.partial = "",
    cluster = NULL, constraints = '',
    estimator = "default", likelihood = "default",
    information = "default", se = "default", test = "default",
    bootstrap = 1000L, mimic = "default", representation = "default",
    do.fit = TRUE, control = list(), WLS.V = NULL, NACOV = NULL,
    start = "default", verbose = FALSE, warn = TRUE, debug = FALSE)
```

Arguments

model	A description of the user-specified model. Typically, the model is described using the lavaan model syntax. See model.syntax for more information. Alternatively, a parameter table (eg. the output of the lavaanify() function) is also accepted.
data	An optional data frame containing the observed variables used in the model. If some variables are declared as ordered factors, lavaan will treat them as ordinal variables.

`fixed.x` If TRUE, the exogenous 'x' covariates are considered fixed variables and the means, variances and covariances of these variables are fixed to their sample values. If FALSE, they are considered random, and the means, variances and covariances are free parameters. If "default", the value is set depending on the mimic option.

`orthogonal` If TRUE, the exogenous latent variables are assumed to be uncorrelated.

`std.lv` If TRUE, the metric of each latent variable is determined by fixing their variances to 1.0. If FALSE, the metric of each latent variable is determined by fixing the factor loading of the first indicator to 1.0.

`std.ov` If TRUE, all observed variables are standardized before entering the analysis.

`missing` If "listwise", cases with missing values are removed listwise from the data frame before analysis. If "direct" or "ml" or "fiml" and the estimator is maximum likelihood, Full Information Maximum Likelihood (FIML) estimation is used using all available data in the data frame. This is only valid if the data are missing completely at random (MCAR) or missing at random (MAR). If "default", the value is set depending on the estimator and the mimic option.

`ordered` Character vector. Only used if the data is in a data.frame. Treat these variables as ordered (ordinal) variables, if they are endogenous in the model. Importantly, all other variables will be treated as numeric (unless they are declared as ordered in the original data.frame.)

`sample.cov` Numeric matrix. A sample variance-covariance matrix. The rownames and/or colnames must contain the observed variable names. For a multiple group analysis, a list with a variance-covariance matrix for each group. Note that if maximum likelihood estimation is used and `likelihood="normal"`, the user provided covariance matrix is internally rescaled by multiplying it with a factor (N-1)/N, to ensure that the covariance matrix has been divided by N. This can be turned off by setting the `sample.cov.rescale` argument to FALSE.

`sample.cov.rescale` If TRUE, the sample covariance matrix provided by the user is internally rescaled by multiplying it with a factor (N-1)/N. If "default", the value is set depending on the estimator and the likelihood option: it is set to TRUE if maximum likelihood estimation is used and `likelihood="normal"`, and FALSE otherwise.

`sample.mean` A sample mean vector. For a multiple group analysis, a list with a mean vector for each group.

`sample.nobs` Number of observations if the full data frame is missing and only sample moments are given. For a multiple group analysis, a list or a vector with the number of observations for each group.

`ridge` Numeric. Small constant used for ridging. Only used if the sample covariance matrix is non positive definite.

`group` A variable name in the data frame defining the groups in a multiple group analysis.

`group.label` A character vector. The user can specify which group (or factor) levels need to be selected from the grouping variable, and in which order. If NULL (the default), all grouping levels are selected, in the order as they appear in the data.

`group.equal` A vector of character strings. Only used in a multiple group analysis. Can be one or more of the following: `"loadings"`, `"intercepts"`, `"means"`,`"thresholds"`, `"regressions"`, `"residuals"`, `"residual.covariances"`, `"lv.variances"` or `"lv.covariances"`, specifying the pattern of equality constraints across multiple groups.

`group.partial` A vector of character strings containing the labels of the parameters which should be free in all groups (thereby overriding the group.equal argument for some specific parameters).

`cluster` Not used yet.

`constraints` Additional (in)equality constraints not yet included in the model syntax. See `model.syntax` for more information.

`estimator` The estimator to be used. Can be one of the following: `"ML"` for maximum likelihood, `"GLS"` for generalized least squares, `"WLS"` for weighted least squares (sometimes called ADF estimation), `"ULS"` for unweighted least squares and `"DWLS"` for diagonally weighted least squares. These are the main options that affect the estimation. For convenience, the `"ML"` option can be extended as `"MLM"`, `"MLMV"`, `"MLMVS"`, `"MLF"`, and `"MLR"`. The estimation will still be plain `"ML"`, but now with robust standard errors and a robust (scaled) test statistic. For `"MLM"`, `"MLMV"`, `"MLMVS"`, classic robust standard errors are used (`se="robust.sem"`); for `"MLF"`, standard errors are based on first-order derivatives (`se="first.order"`); for `"MLR"`, 'Huber-White' robust standard errors are used (`se="robust.huber.white"`). In addition, `"MLM"` will compute a Satorra-Bentler scaled (mean adjusted) test statistic (`test="satorra.bentler"`) , `"MLMVS"` will compute a mean and variance adjusted test statistic (Satterthwaite style) (`test="mean.var.adjusted"`), `"MLMV"` will compute a mean and variance adjusted test statistic (scaled and shifted) (`test="scaled.shifted"`), and `"MLR"` will compute a test statistic which is asymptotically equivalent to the Yuan-Bentler T2-star test statistic. Analogously, the estimators `"WLSM"` and `"WLSMV"` imply the `"DWLS"` estimator (not the `"WLS"` estimator) with robust standard errors and a mean or mean and variance adjusted test statistic. Estimators `"ULSM"` and `"ULSMV"` imply the `"ULS"` estimator with robust standard errors and a mean or mean and variance adjusted test statistic.

`likelihood` Only relevant for ML estimation. If `"wishart"`, the wishart likelihood approach is used. In this approach, the covariance matrix has been divided by N-1, and both standard errors and test statistics are based on N-1. If `"normal"`, the normal likelihood approach is used. Here, the covariance matrix has been divided by N, and both standard errors and test statistics are based on N. If `"default"`, it depends on the mimic option: if `mimic="lavaan"` or `mimic="Mplus"`, normal likelihood is used; otherwise, wishart likelihood is used.

`information` If `"expected"`, the expected information matrix is used (to compute the standard errors). If `"observed"`, the observed information matrix is used. If `"default"`, the value is set depending on the estimator and the mimic option.

`se` If `"standard"`, conventional standard errors are computed based on inverting the (expected or observed) information matrix. If `"first.order"`, standard errors are computed based on first-order derivatives. If `"robust.sem"`, conventional robust standard errors are computed. If `"robust.huber.white"`, standard errors are computed based on the 'mlr' (aka pseudo ML, Huber-White) ap-

proach. If "robust", either "robust.sem" or "robust.huber.white" is used depending on the estimator, the mimic option, and whether the data are complete or not. If "boot" or "bootstrap", bootstrap standard errors are computed using standard bootstrapping (unless Bollen-Stine bootstrapping is requested for the test statistic; in this case bootstrap standard errors are computed using model-based bootstrapping). If "none", no standard errors are computed.

`test` If "standard", a conventional chi-square test is computed. If "Satorra.Bentler", a Satorra-Bentler scaled test statistic is computed. If "Yuan.Bentler", a Yuan-Bentler scaled test statistic is computed. If "mean.var.adjusted" or "Satterthwaite", a mean and variance adjusted test statistic is compute. If "scaled.shifted", an alternative mean and variance adjusted test statistic is computed (as in Mplus version 6 or higher). If "boot" or "bootstrap" or "Bollen.Stine", the Bollen-Stine bootstrap is used to compute the bootstrap probability value of the test statistic. If "default", the value depends on the values of other arguments.

`bootstrap` Number of bootstrap draws, if bootstrapping is used.

`mimic` If "Mplus", an attempt is made to mimic the Mplus program. If "EQS", an attempt is made to mimic the EQS program. If "default", the value is (currently) set to to "lavaan", which is very close to"Mplus".

`representation` If "LISREL" the classical LISREL matrix representation is used to represent the model (using the all-y variant).

`WLS.V` A user provided weight matrix to be used by estimator "WLS"; if the estimator is "DWLS", only the diagonal of this matrix will be used. For a multiple group analysis, a list with a weight matrix for each group. The elements of the weight matrix should be in the following order (if all data is continuous): first the means (if a meanstructure is involved), then the lower triangular elements of the covariance matrix including the diagonal, ordered column by column. In the categorical case: first the thresholds (including the means for continuous variables), then the slopes (if any), the variances of continuous variables (if any), and finally the lower triangular elements of the correlation/covariance matrix excluding the diagonal, ordered column by column.

`NACOV` A user provided matrix containing the elements of (N times) the asymptotic variance-covariance matrix of the sample statistics. For a multiple group analysis, a list with an asymptotic variance-covariance matrix for each group. See the `WLS.V` argument for information about the order of the elements.

`start` If it is a character string, the two options are currently "simple" and "Mplus". In the first case, all parameter values are set to zero, except the factor loadings (set to one), the variances of latent variables (set to 0.05), and the residual variances of observed variables (set to half the observed variance). If "Mplus", we use a similar scheme, but the factor loadings are estimated using the fabin3 estimator (tsls) per factor. If `start` is a fitted object of class `lavaan`, the estimated values of the corresponding parameters will be extracted. If it is a model list, for example the output of the `paramaterEstimates()` function, the values of the `est` or `start` or `ustart` column (whichever is found first) will be extracted.

`do.fit` If `FALSE`, the model is not fit, and the current starting values of the model parameters are preserved.

control	A list containing control parameters passed to the optimizer. By default, lavaan uses "nlminb". See the manpage of nlminb for an overview of the control parameters. A different optimizer can be chosen by setting the value of optim.method. For unconstrained optimization (the model syntax does not include any "==", ">" or "<" operators), the available options are "nlminb" (the default), "BFGS" and "L-BFGS-B". See the manpage of the optim function for the control parameters of the latter two options. For constrained optimization, the only available option is "nlminb.constr".
verbose	If TRUE, the function value is printed out during each iteration.
warn	If TRUE, some (possibly harmless) warnings are printed out during the iterations.
debug	If TRUE, debugging information is printed out.

Details

The growth function is a wrapper for the more general lavaan function, using the following default arguments: meanstructure = TRUE, int.ov.free = FALSE, int.lv.free = TRUE, auto.fix.first = TRUE (unless std.lv = TRUE), auto.fix.single = TRUE, auto.var = TRUE, auto.cov.lv.x = TRUE, auto.th = TRUE, auto.delta = TRUE, and auto.cov.y = TRUE.

Value

An object of class lavaan, for which several methods are available, including a summary method.

References

Yves Rosseel (2012). lavaan: An R Package for Structural Equation Modeling. Journal of Statistical Software, 48(2), 1-36. URL http://www.jstatsoft.org/v48/i02/.

See Also

lavaan

Examples

```
## linear growth model with a time-varying covariate
model.syntax <- '
  # intercept and slope with fixed coefficients
    i =~ 1*t1 + 1*t2 + 1*t3 + 1*t4
    s =~ 0*t1 + 1*t2 + 2*t3 + 3*t4

  # regressions
    i ~ x1 + x2
    s ~ x1 + x2

  # time-varying covariates
    t1 ~ c1
    t2 ~ c2
    t3 ~ c3
    t4 ~ c4
'
```

```
fit <- growth(model.syntax, data=Demo.growth)
summary(fit)
```

`HolzingerSwineford1939` *Holzinger and Swineford Dataset (9 Variables)*

Description

The classic Holzinger and Swineford (1939) dataset consists of mental ability test scores of seventh- and eighth-grade children from two different schools (Pasteur and Grant-White). In the original dataset (available in the `MBESS` package), there are scores for 26 tests. However, a smaller subset with 9 variables is more widely used in the literature (for example in Joreskog's 1969 paper, which also uses the 145 subjects from the Grant-White school only).

Usage

```
data(HolzingerSwineford1939)
```

Format

A data frame with 301 observations of 15 variables.

`id` Identifier

`sex` Gender

`ageyr` Age, year part

`agemo` Age, month part

`school` School (Pasteur or Grant-White)

`grade` Grade

`x1` Visual perception

`x2` Cubes

`x3` Lozenges

`x4` Paragraph comprehension

`x5` Sentence completion

`x6` Word meaning

`x7` Speeded addition

`x8` Speeded counting of dots

`x9` Speeded discrimination straight and curved capitals

Source

This dataset was retrieved from http://web.missouri.edu/~kolenikovs/stata/hs-cfa.dta and converted to an R dataset.

References

Holzinger, K., and Swineford, F. (1939). A study in factor analysis: The stability of a bifactor solution. Supplementary Educational Monograph, no. 48. Chicago: University of Chicago Press.

Joreskog, K. G. (1969). A general approach to confirmatory maximum likelihood factor analysis. *Psychometrika*, 34, 183-202.

See Also

cfa

Examples

```
head(HolzingerSwineford1939)
```

`InformativeTesting` *Testing order Constrained Hypotheses in SEM*

Description

Testing order constrained Hypotheses in SEM

Usage

```
InformativeTesting(model = NULL, data, constraints = NULL,
                   R = NULL, type = "bollen.stine",
                   return.LRT = TRUE,
                   double.bootstrap = "FDB",
                   double.bootstrap.R = 500L,
                   double.bootstrap.alpha = 0.05,
                   parallel = c("no", "multicore", "snow"),
                   ncpus = 1L, cl = NULL, verbose = FALSE, ...)
```

Arguments

`model`	Model syntax specifying the model. See `model.syntax` for more information.
`data`	The data frame containing the observed variables being used to fit the model.
`constraints`	The imposed inequality constraints on the model.
`R`	Integer; number of bootstrap draws. If missing the default value is set to 2000. If `double.bootstrap = "standard"` the default value, if missing, is set to 1000.
`type`	If `"parametric"`, the parametric bootstrap is used. If `"bollen.stine"`, the semi-nonparametric Bollen-Stine bootstrap is used. The default is set to `"bollen.stine"`.
`return.LRT`	Logical; if `TRUE`, the function returns bootstrapped LRT-values.

`double.bootstrap`
: If `"standard"` the genuine double bootstrap is used to compute an additional set of plug-in p-values for each bootstrap sample. If `"FDB"`, the fast double bootstrap is used to compute second level LRT-values for each bootstrap sample. If `"no"`, no double bootstrap is used. The default is set to `"FDB"`.

`double.bootstrap.R`
: Integer; number of double bootstrap draws. Only used if `double.bootstrap = "standard"`. The default value is set to 500.

`double.bootstrap.alpha`
: The significance level to compute the adjusted alpha based on the plugin p-values. Only used if `double.bootstrap = "standard"`. The default value is set to 0.05.

`parallel`
: The type of parallel operation to be used (if any). If missing, the default is set "no".

`ncpus`
: Integer: number of processes to be used in parallel operation: typically one would chose this to the number of available CPUs.

`cl`
: An optional parallel or snow cluster for use if `parallel = "snow"`. If not supplied, a cluster on the local machine is created for the duration of the `InformativeTesting` call.

`verbose`
: Logical; if `TRUE`, information is shown at each bootstrap draw.

`...`
: Other named arguments from the lavaan package which are passed to the function. For example `"group"` in a multiple group model.

Value

An object of class InformativeTesting for which a plot method is available.

Author(s)

Leonard Vanbrabant

References

Van de Schoot, R., Hoijtink, H., & Dekovic, M. (2010). Testing inequality constrained hypotheses in SEM models. Structural Equation Modeling, 17, 443-463.

Van de Schoot, R., Strohmeier, D. (2011). Testing informative hypotheses in SEM increases power: An illustration contrasting classical. International Journal of Behavioral Development 35(2), 180-190.

Examples

```
## Not run:
#Multiple group model for facial burns example.

#model syntax with starting values.
burns.model <- 'Selfesteem ~ Age + c(m1, f1)*TBSA + HADS +
                            start(-.10, -.20)*TBSA
                HADS ~ Age + c(m2, f2)*TBSA + RUM +
```

```
                      start(.10, .20)*TBSA '


#constraints syntax.
burns.constraints <- 'f2 > 0  ; m1 < 0
                      m2 > 0  ; f1 < 0
                      f2 > m2 ; f1 < m1'


# we only generate 2 bootstrap samples in this example; in practice
# you may wish to use a much higher number.
example <- InformativeTesting(model = burns.model, data = FacialBurns,
                              R = 2, constraints = burns.constraints,
                              group = "Sex")

plot(example, vline = TRUE, legend = TRUE)

## End(Not run)
```

`inspectSampleCov` *Observed Variable Correlation Matrix from a Model and Data*

Description

The lavaan model syntax describes a latent variable model. Often, the user wants to see the covariance matrix generated by their model for diagnostic purposes. However, their data may have far more columns of information than what is contained in their model.

Usage

```
inspectSampleCov(model, data, ...)
```

Arguments

`model`	The model that will be fit by lavaan.
`data`	The data frame being used to fit the model.
`...`	Other arguments to `sem` for how to deal with multiple groups, missing values, etc.

Details

One must supply both a model, coded with proper `model.syntax` and a data frame from which a covariance matrix will be calculated. This function essentially calls `sem`, but doesn't fit the model, then uses `inspect` to get the sample covariance matrix and meanstructure.

See also

`sem`, `inspect`

Author(s)

Jarrett Byrnes

`lavaan` *Fit a Latent Variable Model*

Description

Fit a latent variable model.

Usage

```
lavaan(model = NULL, data = NULL,
    model.type = "sem", meanstructure = "default",
    int.ov.free = FALSE, int.lv.free = FALSE, fixed.x = "default",
    orthogonal = FALSE, std.lv = FALSE, auto.fix.first = FALSE,
    auto.fix.single = FALSE, auto.var = FALSE, auto.cov.lv.x = FALSE,
    auto.cov.y = FALSE, auto.th = FALSE, auto.delta = FALSE,
    std.ov = FALSE, missing = "default", ordered = NULL,
    sample.cov = NULL, sample.cov.rescale = "default",
    sample.mean = NULL, sample.nobs = NULL, ridge = 1e-05,
    group = NULL, group.label = NULL, group.equal = "", group.partial = "",
    cluster = NULL, constraints = "", estimator = "default",
    likelihood = "default", information = "default",
    se = "default", test = "default", bootstrap = 1000L, mimic = "default",
    representation = "default", do.fit = TRUE, control = list(),
    WLS.V = NULL, NACOV = NULL, start = "default",
    slotOptions = NULL, slotParTable = NULL,
    slotSampleStats = NULL, slotData = NULL, slotModel = NULL,
    verbose = FALSE, warn = TRUE, debug = FALSE)
```

Arguments

`model`	A description of the user-specified model. Typically, the model is described using the lavaan model syntax. See `model.syntax` for more information. Alternatively, a parameter table (eg. the output of the `lavaanify()` function) is also accepted.
`data`	An optional data frame containing the observed variables used in the model. If some variables are declared as ordered factors, lavaan will treat them as ordinal variables.
`model.type`	Set the model type: possible values are `"cfa"`, `"sem"` or `"growth"`. This may affect how starting values are computed, and may be used to alter the terminology used in the summary output, or the layout of path diagrams that are based on a fitted lavaan object.
`meanstructure`	If `TRUE`, the means of the observed variables enter the model. If `"default"`, the value is set based on the user-specified model, and/or the values of other arguments.

`int.ov.free` If `FALSE`, the intercepts of the observed variables are fixed to zero.

`int.lv.free` If `FALSE`, the intercepts of the latent variables are fixed to zero.

`fixed.x` If `TRUE`, the exogenous 'x' covariates are considered fixed variables and the means, variances and covariances of these variables are fixed to their sample values. If `FALSE`, they are considered random, and the means, variances and covariances are free parameters. If `"default"`, the value is set depending on the mimic option.

`orthogonal` If `TRUE`, the exogenous latent variables are assumed to be uncorrelated.

`std.lv` If `TRUE`, the metric of each latent variable is determined by fixing their variances to 1.0. If `FALSE`, the metric of each latent variable is determined by fixing the factor loading of the first indicator to 1.0.

`auto.fix.first` If `TRUE`, the factor loading of the first indicator is set to 1.0 for every latent variable.

`auto.fix.single` If `TRUE`, the residual variance (if included) of an observed indicator is set to zero if it is the only indicator of a latent variable.

`auto.var` If `TRUE`, the residual variances and the variances of exogenous latent variables are included in the model and set free.

`auto.cov.lv.x` If `TRUE`, the covariances of exogenous latent variables are included in the model and set free.

`auto.cov.y` If `TRUE`, the covariances of dependent variables (both observed and latent) are included in the model and set free.

`auto.th` If `TRUE`, thresholds for limited dependent variables are included in the model and set free.

`auto.delta` If `TRUE`, response scaling parameters for limited dependent variables are included in the model and set free.

`std.ov` If `TRUE`, all observed variables are standardized before entering the analysis.

`missing` If `"listwise"`, cases with missing values are removed listwise from the data frame before analysis. If `"direct"` or `"ml"` or `"fiml"` and the estimator is maximum likelihood, Full Information Maximum Likelihood (FIML) estimation is used using all available data in the data frame. This is only valid if the data are missing completely at random (MCAR) or missing at random (MAR). If `"default"`, the value is set depending on the estimator and the mimic option.

`ordered` Character vector. Only used if the data is in a data.frame. Treat these variables as ordered (ordinal) variables, if they are endogenous in the model. Importantly, all other variables will be treated as numeric (unless they are declared as ordered in the original data.frame.)

`sample.cov` Numeric matrix. A sample variance-covariance matrix. The rownames and/or colnames must contain the observed variable names. For a multiple group analysis, a list with a variance-covariance matrix for each group. Note that if maximum likelihood estimation is used and `likelihood="normal"`, the user provided covariance matrix is internally rescaled by multiplying it with a factor (N-1)/N, to ensure that the covariance matrix has been divided by N. This can be turned off by setting the `sample.cov.rescale` argument to `FALSE`.

`sample.cov.rescale`
: If `TRUE`, the sample covariance matrix provided by the user is internally rescaled by multiplying it with a factor (N-1)/N. If `"default"`, the value is set depending on the estimator and the likelihood option: it is set to `TRUE` if maximum likelihood estimation is used and `likelihood="normal"`, and `FALSE` otherwise.

`sample.mean`
: A sample mean vector. For a multiple group analysis, a list with a mean vector for each group.

`sample.nobs`
: Number of observations if the full data frame is missing and only sample moments are given. For a multiple group analysis, a list or a vector with the number of observations for each group.

`ridge`
: Numeric. Small constant used for ridging. Only used if the sample covariance matrix is non positive definite.

`group`
: A variable name in the data frame defining the groups in a multiple group analysis.

`group.label`
: A character vector. The user can specify which group (or factor) levels need to be selected from the grouping variable, and in which order. If missing, all grouping levels are selected, in the order as they appear in the data.

`group.equal`
: A vector of character strings. Only used in a multiple group analysis. Can be one or more of the following: `"loadings"`, `"intercepts"`, `"means"`,`"thresholds"`, `"regressions"`, `"residuals"`, `"residual.covariances"`, `"lv.variances"` or `"lv.covariances"`, specifying the pattern of equality constraints across multiple groups.

`group.partial`
: A vector of character strings containing the labels of the parameters which should be free in all groups (thereby overriding the group.equal argument for some specific parameters).

`cluster`
: Not used yet.

`constraints`
: Additional (in)equality constraints not yet included in the model syntax. See `model.syntax` for more information.

`estimator`
: The estimator to be used. Can be one of the following: `"ML"` for maximum likelihood, `"GLS"` for generalized least squares, `"WLS"` for weighted least squares (sometimes called ADF estimation), `"ULS"` for unweighted least squares and `"DWLS"` for diagonally weighted least squares. These are the main options that affect the estimation. For convenience, the `"ML"` option can be extended as `"MLM"`, `"MLMV"`, `"MLMVS"`, `"MLF"`, and `"MLR"`. The estimation will still be plain `"ML"`, but now with robust standard errors and a robust (scaled) test statistic. For `"MLM"`, `"MLMV"`, `"MLMVS"`, classic robust standard errors are used (`se="robust.sem"`); for `"MLF"`, standard errors are based on first-order derivatives (`se="first.order"`); for `"MLR"`, 'Huber-White' robust standard errors are used (`se="robust.huber.white"`). In addition, `"MLM"` will compute a Satorra-Bentler scaled (mean adjusted) test statistic (`test="satorra.bentler"`) , `"MLMVS"` will compute a mean and variance adjusted test statistic (Satterthwaite style) (`test="mean.var.adjusted"`), `"MLMV"` will compute a mean and variance adjusted test statistic (scaled and shifted) (`test="scaled.shifted"`), and `"MLR"` will compute a test statistic which is asymptotically equivalent to the Yuan-Bentler T2-star test statistic. Analogously, the estimators `"WLSM"` and `"WLSMV"` imply the `"DWLS"` estimator (not the `"WLS"` estimator) with robust standard errors and a mean or mean and

variance adjusted test statistic. Estimators "ULSM" and "ULSMV" imply the "ULS" estimator with robust standard errors and a mean or mean and variance adjusted test statistic.

likelihood — Only relevant for ML estimation. If "wishart", the wishart likelihood approach is used. In this approach, the covariance matrix has been divided by N-1, and both standard errors and test statistics are based on N-1. If "normal", the normal likelihood approach is used. Here, the covariance matrix has been divided by N, and both standard errors and test statistics are based on N. If "default", it depends on the mimic option: if mimic="lavaan" or mimic="Mplus", normal likelihood is used; otherwise, wishart likelihood is used.

information — If "expected", the expected information matrix is used (to compute the standard errors). If "observed", the observed information matrix is used. If "default", the value is set depending on the estimator and the mimic option.

se — If "standard", conventional standard errors are computed based on inverting the (expected or observed) information matrix. If "first.order", standard errors are computed based on first-order derivatives. If "robust.sem", conventional robust standard errors are computed. If "robust.huber.white", standard errors are computed based on the 'mlr' (aka pseudo ML, Huber-White) approach. If "robust", either "robust.sem" or "robust.huber.white" is used depending on the estimator, the mimic option, and whether the data are complete or not. If "boot" or "bootstrap", bootstrap standard errors are computed using standard bootstrapping (unless Bollen-Stine bootstrapping is requested for the test statistic; in this case bootstrap standard errors are computed using model-based bootstrapping). If "none", no standard errors are computed.

test — If "standard", a conventional chi-square test is computed. If "Satorra.Bentler", a Satorra-Bentler scaled test statistic is computed. If "Yuan.Bentler", a Yuan-Bentler scaled test statistic is computed. If "mean.var.adjusted" or "Satterthwaite", a mean and variance adjusted test statistic is compute. If "scaled.shifted", an alternative mean and variance adjusted test statistic is computed (as in Mplus version 6 or higher). If "boot" or "bootstrap" or "Bollen.Stine", the Bollen-Stine bootstrap is used to compute the bootstrap probability value of the test statistic. If "default", the value depends on the values of other arguments.

bootstrap — Number of bootstrap draws, if bootstrapping is used.

mimic — If "Mplus", an attempt is made to mimic the Mplus program. If "EQS", an attempt is made to mimic the EQS program. If "default", the value is (currently) set to to "lavaan", which is very close to"Mplus".

representation — If "LISREL" the classical LISREL matrix representation is used to represent the model (using the all-y variant).

do.fit — If FALSE, the model is not fit, and the current starting values of the model parameters are preserved.

control — A list containing control parameters passed to the optimizer. By default, lavaan uses "nlminb". See the manpage of nlminb for an overview of the control parameters. A different optimizer can be chosen by setting the value of optim.method. For unconstrained optimization (the model syntax does not include any "==", ">" or "<" operators), the available options are "nlminb" (the default), "BFGS"

and "L-BFGS-B". See the manpage of the optim function for the control parameters of the latter two options. For constrained optimization, the only available option is "nlminb.constr".

WLS.V — A user provided weight matrix to be used by estimator "WLS"; if the estimator is "DWLS", only the diagonal of this matrix will be used. For a multiple group analysis, a list with a weight matrix for each group. The elements of the weight matrix should be in the following order (if all data is continuous): first the means (if a meanstructure is involved), then the lower triangular elements of the covariance matrix including the diagonal, ordered column by column. In the categorical case: first the thresholds (including the means for continuous variables), then the slopes (if any), the variances of continuous variables (if any), and finally the lower triangular elements of the correlation/covariance matrix excluding the diagonal, ordered column by column.

NACOV — A user provided matrix containing the elements of (N times) the asymptotic variance-covariance matrix of the sample statistics. For a multiple group analysis, a list with an asymptotic variance-covariance matrix for each group. See the WLS.V argument for information about the order of the elements.

start — If it is a character string, the two options are currently "simple" and "Mplus". In the first case, all parameter values are set to zero, except the factor loadings (set to one), the variances of latent variables (set to 0.05), and the residual variances of observed variables (set to half the observed variance). If "Mplus", we use a similar scheme, but the factor loadings are estimated using the fabin3 estimator (tsls) per factor. If start is a fitted object of class lavaan, the estimated values of the corresponding parameters will be extracted. If it is a model list, for example the output of the paramaterEstimates() function, the values of the est or start or ustart column (whichever is found first) will be extracted.

slotOptions — Options slot from a fitted lavaan object. If provided, no new Options slot will be created by this call.

slotParTable — ParTable slot from a fitted lavaan object. If provided, no new ParTable slot will be created by this call.

slotSampleStats — SampleStats slot from a fitted lavaan object. If provided, no new SampleStats slot will be created by this call.

slotData — Data slot from a fitted lavaan object. If provided, no new Data slot will be created by this call.

slotModel — Model slot from a fitted lavaan object. If provided, no new Model slot will be created by this call.

verbose — If TRUE, the function value is printed out during each iteration.

warn — If TRUE, some (possibly harmless) warnings are printed out during the iterations.

debug — If TRUE, debugging information is printed out.

Value

An object of class lavaan, for which several methods are available, including a summary method.

References

Yves Rosseel (2012). lavaan: An R Package for Structural Equation Modeling. Journal of Statistical Software, 48(2), 1-36. URL http://www.jstatsoft.org/v48/i02/.

See Also

cfa, sem, growth

Examples

```
# The Holzinger and Swineford (1939) example
HS.model <- ' visual  =~ x1 + x2 + x3
              textual =~ x4 + x5 + x6
              speed   =~ x7 + x8 + x9 '

fit <- lavaan(HS.model, data=HolzingerSwineford1939,
              auto.var=TRUE, auto.fix.first=TRUE,
              auto.cov.lv.x=TRUE)
summary(fit, fit.measures=TRUE)
```

---

lavaan-class *Class For Representing A (Fitted) Latent Variable Model*

Description

The lavaan class represents a (fitted) latent variable model. It contains a description of the model as specified by the user, a summary of the data, an internal matrix representation, and if the model was fitted, the fitting results.

Objects from the Class

Objects can be created via the cfa, sem, growth or lavaan functions.

Slots

call: The function call as returned by match.call().

timing: The elapsed time (user+system) for various parts of the program as a list, including the total time.

Options: Named list of options that were provided by the user, or filled-in automatically.

ParTable: Named list describing the model parameters. Can be coerced to a data.frame. In the documentation, this is called the 'parameter table'.

Data: Object of internal class "Data": information about the data.

SampleStats: Object of internal class "SampleStats": sample statistics

Model: Object of internal class "Model": the internal (matrix) representation of the model

Cache: List using objects that we try to compute only once, and reuse many times.

Fit: Object of internal class "Fit": the results of fitting the model

Methods

coef `signature(object = "lavaan", type = "free")`: Returns the estimates of the parameters in the model as a named numeric vector. If `type="free"`, only the free parameters are returned. If `type="unco"`, both free and constrained parameters (simple equality constraints only) are returned. If `type="user"`, all parameters listed in the parameter table are returned, including constrained and fixed parameters.

fitted.values `signature(object = "lavaan")`: Returns the implied moments of the model as a list with two elements (per group): `cov` for the implied covariance matrix, and `mean` for the implied mean vector. If only the covariance matrix was analyzed, the implied mean vector will be zero.

fitted `signature(object = "lavaan")`: an alias for `fitted.values`.

residuals `signature(object = "lavaan", type="raw")`: If `type="raw"`, this function returns the raw (=unstandardized) difference between the implied moments and the observed moments as a list of two elements: `cov` for the residual covariance matrix, and `mean` for the residual mean vector. If only the covariance matrix was analyzed, the residual mean vector will be zero. If codetype="cor", the observed and model implied covariance matrix is first transformed to a correlation matrix (using `cov2cor`), before the residuals are computed. If `type="normalized"`, the residuals are normalized. If `type="standardized"`, the residuals are standardized. In the latter case, the residuals have a metric similar to z-values.

resid `signature(object = "lavaan")`: an alias for `residuals`

vcov `signature(object = "lavaan")`: returns the covariance matrix of the estimated parameters.

predict `signature(object = "lavaan")`: compute factor scores for all cases that are provided in the data frame. For complete data only.

anova `signature(object = "lavaan")`: returns model comparison statistics. See anova. At least two arguments (fitted models) are required. If the test statistic is scaled, an appropriate scaled difference test will be computed.

update `signature(object = "lavaan", model.syntax, ..., evaluate=TRUE)`: update a fitted lavaan object and evaluate it (unless `evaluate=FALSE`). Note that we use the environment that is stored within the lavaan object, which is not necessarily the parent frame.

nobs `signature(object = "lavaan")`: returns the effective number of observations used when fitting the model. In a multiple group analysis, this is the sum of all observations per group.

logLik `signature(object = "lavaan")`: returns the log-likelihood of the fitted model, if maximum likelihood estimation was used. The AIC and BIC methods automatically work via `logLik()`.

inspect `signature(object = "lavaan", what = "free")`: This is the main 'extractor' function for `lavaan` objects. It allows the user to peek into the internal representation of the model. In addition, the requested information is returned (typically as a list) and can be used for further processing. The following values for `what` are allowed (in alphabetical order):

`"coef"`: A list of model matrices containing the current values of all parameters.

`"coefficients"`: An alias for `"coef"`.

`"converged"`: Returns TRUE if the optimization routine has converged; FALSE otherwise.

`"cov.all"`: Model implied covariance matrix of both the observed and latent variables.

`"cov.lv"`: Model implied covariance matrix of the latent variables.

"cor.all": Model implied covariance matrix of both the observed and latent variables, in a correlation mectric.

"cor.lv": Model implied covariance matrix of the latent variables, in a correlation metric.

"derivatives": An alias for "dx".

"dx": A list of model matrices containing the derivatives of all parameters evaluated at the current (typically minimum) function value.

"estimates": An alias for "coef".

"est": An alias for "coef".

"free": A list of model matrices counting the free parameters in the model, typically in the same order as they are specified by the user.

"gradient": An alias for "dx".

"list": A dataframe showing the internal representation of a lavaan model. Each row corresponds to a model parameter. The columns contain all the information that lavaan stores about these parameters (for example, if it is free of fixed, the user-specified starting values, etcetera). This is called the parameter table.

"mi": A data.frame containing modification indices and expected parameter change (EPC) values, both in unstandardized and standardized metric.

"modindices": An alias for "mi".

"modification": An alias for "mi".

"modificationindices": An alias for "mi".

"modification.indices": An alias for "mi".

"nacov": N times the asymptotic variance of the model parameters.

"parameters": An alias for "coef".

"parameter.estimates": An alias for "coef".

"parameter.values": An alias for "coef".

"r2": An alias for "rsquare".

"rsquare": A named vector with the R-Square value of the dependent observed and latent variables.

"r-square": An alias for "rsquare".

"sampstat": The sample statistics used for the analysis.

"se": A list of model matrices containing the estimated standard errors for all free parameters.

"standardized": An alias for "std.coef".

"standardizedsolution": An alias for "std.coef".

"standardized.solution": An alias for "std.coef".

"standard.errors": An alias for "se".

"start": A list of model matrices containing the starting values for all parameters.

"starting.values": An alias for "start".

"std": An alias for "std.coef".

"std.coef": A data.frame containing both the raw and (completely) standardized parameter values.

"std.err": An alias for "se".

"wls.v": The weight matrix for WLS.

"x": An alias for "coef".

show `signature(object = "lavaan")`: Print a short summary of the model fit

summary `signature(object = "lavaan", standardized=FALSE, fit.measures=FALSE, rsquare=FALSE, modind`
Print a nice summary of the model estimates. If `standardized=TRUE`, the standardized solution is also printed. If `fit.measures=TRUE`, the chi-square statistic is supplemented by several fit measures. If `rsquare=TRUE`, the R-Square values for the dependent variables in the model are printed. If `modindices=TRUE`, modification indices are printed for all fixed parameters. Nothing is returned (use `inspect` or another extractor function to extract information from a fitted model).

References

Yves Rosseel (2012). lavaan: An R Package for Structural Equation Modeling. Journal of Statistical Software, 48(2), 1-36. URL http://www.jstatsoft.org/v48/i02/.

See Also

`cfa`, `sem`, `growth`, `fitMeasures`, `standardizedSolution`, `parameterEstimates`, `modindices`

Examples

```
HS.model <- ' visual  =~ x1 + x2 + x3
              textual =~ x4 + x5 + x6
              speed   =~ x7 + x8 + x9 '

fit <- cfa(HS.model, data=HolzingerSwineford1939)

summary(fit, standardized=TRUE, fit.measures=TRUE, rsquare=TRUE)
inspect(fit, "free")
inspect(fit, "start")
inspect(fit, "rsquare")
inspect(fit, "fit")
fitted.values(fit)
coef(fit)
resid(fit, type="normalized")
```

---

lavExport *lavaan Export*

Description

Export a fitted lavaan object to an external program.

Usage

```
lavExport(object, target = "lavaan", prefix = "sem", dir.name = "lavExport",
          export = TRUE)
```

Arguments

object	An object of class lavaan.
target	The target program. Current options are "lavaan" and "Mplus".
prefix	The prefix used to create the input files; the name of the input file has the pattern 'prefix dot target dot in'; the name of the data file has the pattern 'prefix dot target dot raw'.
dir.name	The directory name (including a full path) where the input files will be written.
export	If TRUE, the files are written to the output directory (dir.name). If FALSE, only the syntax is generated as a character string.

Details

This function was mainly created to quickly generate an Mplus syntax file to compare the results between Mplus and lavaan. The target "lavaan" can be useful to create a full model syntax as needed for the lavaan() function. More targets (perhaps for LISREL or EQS) will be added in future releases.

Value

If export = TRUE, a directory (called lavExport by default) will be created, typically containing a data file, and an input file so that the same analysis can be run using an external program. If export = FALSE, a character string containing the model syntax only for the target program.

See Also

lavaanify, mplus2lavaan

Examples

```
HS.model <- ' visual  =~ x1 + x2 + x3
              textual =~ x4 + x5 + x6
              speed   =~ x7 + x8 + x9 '

fit <- cfa(HS.model, data=HolzingerSwineford1939)
out <- lavExport(fit, target = "Mplus", export=FALSE)
cat(out)
```

---

lavMatrixRepresentation

lavaan matrix representation

Description

Extend the parameter table with a matrix representation.

Usage

```
lavMatrixRepresentation(partable, representation = "LISREL",
                        as.data.frame. = TRUE)
```

Arguments

partable	A lavaan parameter table (as extracted by the parTable function, or generated by the lavPartable function).
representation	The matrix representation style. Currently, only the all-y version of the LISREL representation is supported.
as.data.frame.	If TRUE, the extended parameter table is returned as a data.frame.

Value

A list or a data.frame containing the original parameter table, plus three columns: a "mat" column containing matrix names, and a "row" and "col" column for the row and column indices of the model parameters in the model matrices.

See Also

lavParTable, parTable

Examples

```
HS.model <- ' visual  =~ x1 + x2 + x3
              textual =~ x4 + x5 + x6
              speed   =~ x7 + x8 + x9 '

fit <- cfa(HS.model, data=HolzingerSwineford1939)

# extract partable (only first six columns are needed)
partable <- parTable(fit)[,1:6]

# add matrix representation
lavMatrixRepresentation(partable)
```

---

lavTables *lavaan Tables*

Description

Pairwise tables for categorical variables.

Usage

```
lavTables(object, categorical = NULL, std.resid = TRUE,
          min.std.resid = 0.0, average = FALSE, collapse = FALSE)
```

Arguments

object	Either a data.frame, or an object of class lavaan.
categorical	Only used if object is a data.frame. Specify variables that need to be treated as categorical.
std.resid	If TRUE and object is a lavaan object, add a column containing the standardized residuals per cell (see equation 35 in the reference).
min.std.resid	Numeric. If larger than zero, show only those cells which have a standardized residual larger than min.std.resid.
average	If TRUE, add columns for the average standardized residual per table (str.average), and for the number (str.nlarge) and proportion (str.plarge) of cells for which the standardized residual is larger than min.std.resid. Is set to TRUE if collapse is no longer FALSE.
collapse	Either a logical, or the string "matrix". If TRUE, only one row per table is shown. If "matrix", the output is a symmetric matrix; the elements of the matrix are the standardized residuals per pairwise table.

Value

If collapse = FALSE, a data.frame where each row corresponds to a cell of a pairwise table. If collapse = TRUE, the data.frame contains only one row per table. If collapse = "matrix", a symmetric matrix where the elements are the values for the standardized residual for each pairwise table.

References

Joreskog, K.G. & Moustaki, I. (2001). Factor analysis of ordinal variables: A comparison of three approaches. Multivariate Behavioral Research, 36, 347-387.

See Also

varTable.

Examples

```
HS9 <- HolzingerSwineford1939[,c("x1","x2","x3","x4","x5",
                                 "x6","x7","x8","x9")]
HSbinary <- as.data.frame( lapply(HS9, cut, 2, labels=FALSE) )
HS.model <- ' visual  =~ x1 + x2 + x3
              textual =~ x4 + x5 + x6
              speed   =~ x7 + x8 + x9 '

fit <- cfa(HS.model, data=HSbinary, ordered=names(HSbinary))
lavTables(fit, min.std.resid=1.0)
lavTables(fit, collapse="matrix")
```

model.syntax *The Lavaan Model Syntax*

Description

The lavaan model syntax describes a latent variable model. The function `lavaanify` turns it into a table that represents the full model as specified by the user. We refer to this table as the parameter table.

Usage

```
lavaanify(model = NULL, meanstructure = FALSE, int.ov.free = FALSE,
    int.lv.free = FALSE, orthogonal = FALSE, std.lv = FALSE,
    fixed.x = TRUE, constraints = NULL, auto = FALSE, model.type = "sem",
    auto.fix.first = FALSE, auto.fix.single = FALSE, auto.var = FALSE,
    auto.cov.lv.x = FALSE, auto.cov.y = FALSE, auto.th = FALSE,
    auto.delta = FALSE, varTable = NULL, ngroups = 1L, group.equal = NULL,
    group.partial = NULL, debug = FALSE, warn = TRUE, as.data.frame. = TRUE)

lavParTable(model = NULL, meanstructure = FALSE, int.ov.free = FALSE,
    int.lv.free = FALSE, orthogonal = FALSE, std.lv = FALSE,
    fixed.x = TRUE, constraints = NULL, auto = FALSE, model.type = "sem",
    auto.fix.first = FALSE, auto.fix.single = FALSE, auto.var = FALSE,
    auto.cov.lv.x = FALSE, auto.cov.y = FALSE, auto.th = FALSE,
    auto.delta = FALSE, varTable = NULL, ngroups = 1L, group.equal = NULL,
    group.partial = NULL, debug = FALSE, warn = TRUE, as.data.frame. = TRUE)

lavParseModelString(model.syntax = '', as.data.frame.=FALSE, warn=TRUE, debug=FALSE)

lavNames(object, type = "ov", group = NULL)
```

Arguments

`model`	A description of the user-specified model. Typically, the model is described using the lavaan model syntax; see details for more information. Alternatively, a parameter table (e.g., the output of `lavParseModelString` is also accepted.
`model.syntax`	The model syntax specifying the model. Must be a literal string.
`meanstructure`	If `TRUE`, intercepts/means will be added to the model both for both observed and latent variables.
`int.ov.free`	If `FALSE`, the intercepts of the observed variables are fixed to zero.
`int.lv.free`	If `FALSE`, the intercepts of the latent variables are fixed to zero.
`orthogonal`	If `TRUE`, the exogenous latent variables are assumed to be uncorrelated.
`std.lv`	If `TRUE`, the metric of each latent variable is determined by fixing their variances to 1.0. If `FALSE`, the metric of each latent variable is determined by fixing the factor loading of the first indicator to 1.0.

fixed.x	If TRUE, the exogenous 'x' covariates are considered fixed variables and the means, variances and covariances of these variables are fixed to their sample values. If FALSE, they are considered random, and the means, variances and covariances are free parameters.
constraints	Additional (in)equality constraints. See details for more information.
auto	If TRUE, the default values are used for the auto.* arguments, depending on the value of model.type.
model.type	Either "sem" or "growth"; only used if auto=TRUE.
auto.fix.first	If TRUE, the factor loading of the first indicator is set to 1.0 for every latent variable.
auto.fix.single	If TRUE, the residual variance (if included) of an observed indicator is set to zero if it is the only indicator of a latent variable.
auto.var	If TRUE, the residual variances and the variances of exogenous latent variables are included in the model and set free.
auto.cov.lv.x	If TRUE, the covariances of exogenous latent variables are included in the model and set free.
auto.cov.y	If TRUE, the covariances of dependent variables (both observed and latent) are included in the model and set free.
auto.th	If TRUE, thresholds for limited dependent variables are included in the model and set free.
auto.delta	If TRUE, response scaling parameters for limited dependent variables are included in the model and set free.
varTable	The variable table containing information about the observed variables in the model.
ngroups	The number of (independent) groups.
group.equal	A vector of character strings. Only used in a multiple group analysis. Can be one or more of the following: "loadings", "intercepts", "means", "regressions", "residuals" or "covariances", specifying the pattern of equality constraints across multiple groups.
group.partial	A vector of character strings containing the labels of the parameters which should be free in all groups (thereby overriding the group.equal argument for some specific parameters).
warn	If TRUE, some (possibly harmless) warnings are printed out.
as.data.frame.	If TRUE, return the list of model parameters as a data.frame.
debug	If TRUE, debugging information is printed out.
object	Either a list containing the parameter table, as returned by lavaanify or lavParseModelString, or an object of class lavaan.
type	Only used in the function lavNames. If type contains "ov", only observed variable names are returned. If type contains "lv", only latent variable names are returned. The "ov.x" and "lv.x" types return exogenous variables only. The "ov.y" and "lv.y" types return dependent variables only (in the regression sense, excluding the indicators of latent variables). The "ov.nox" type returns all observed variables, except the exogenous ones.

group — Only used in the function lavNames. If NULL, all groups (if any) are used. If an integer (vector), only names from those groups are extracted. The group numbers are found in the group column of the parameter table.

Details

The model syntax consists of one or more formula-like expressions, each one describing a specific part of the model. The model syntax can be read from a file (using readLines), or can be specified as a literal string enclosed by single quotes as in the example below.

```
myModel <- '
  # 1. latent variable definitions
    f1 =~ y1 + y2 + y3
    f2 =~ y4 + y5 + y6
    f3 =~ y7 + y8 +
          y9 + y10
    f4 =~ y11 + y12 + y13

  ! this is also a comment

  # 2. regressions
    f1 ~ f3 + f4
    f2 ~ f4
    y1 + y2 ~ x1 + x2 + x3

  # 3. (co)variances
    y1 ~~ y1
    y2 ~~ y4 + y5
    f1 ~~ f2

  # 4. intercepts
    f1 ~ 1; y5 ~ 1

  # 5. thresholds
    y11 | t1 + t2 + t3
    y12 | t1
    y13 | t1 + t2

  # 6. scaling factors
    y11 ~*~ y11
    y12 ~*~ y12
    y13 ~*~ y13

  # 7. formative factors
    f5 <~ z1 + z2 + z3 + z4
'
```

Blank lines and comments can be used in between the formulas, and formulas can be split over multiple lines. Both the sharp (#) and the exclamation (!) characters can be used to start a comment.

Multiple formulas can be placed on a single line if they are separated by a semicolon (;).

There can be seven types of formula-like expressions in the model syntax:

1. Latent variable definitions: The `"=~"` operator can be used to define (continuous) latent variables. The name of the latent variable is on the left of the `"=~"` operator, while the terms on the right, separated by `"+"` operators, are the indicators of the latent variable.
   The operator `"=~"` can be read as "is manifested by".
2. Regressions: The `"~"` operator specifies a regression. The dependent variable is on the left of a `"~"` operator and the independent variables, separated by `"+"` operators, are on the right. These regression formulas are similar to the way ordinary linear regression formulas are used in R, but they may include latent variables. Interaction terms are currently not supported.
3. Variance-covariances: The `"~~"` ('double tilde') operator specifies (residual) variances of an observed or latent variable, or a set of covariances between one variable, and several other variables (either observed or latent). Several variables, separated by `"+"` operators can appear on the right. This way, several pairwise (co)variances involving the same left-hand variable can be expressed in a single expression. The distinction between variances and residual variances is made automatically.
4. Intercepts: A special case of a regression formula can be used to specify an intercept (or a mean) of either an observed or a latent variable. The variable name is on the left of a `"~"` operator. On the right is only the number `"1"` representing the intercept. Including an intercept formula in the model automatically implies `meanstructure = TRUE`. The distinction between intercepts and means is made automatically.
5. Thresholds: The `"|"` operator can be used to define the thresholds of categorical endogenous variables (on the left hand side of the operator). By convention, the thresholds (on the right hand sided, separated by the `"+"` operator, are named `"t1"`, `"t2"`, etcetera.
6. Scaling factors: The `"~*~"` operator defines a scale factor. The variable name on the left hand side must be the same as the variable name on the right hand side. Scale factors are used in the Delta parameterization, in a multiple group analysis when factor indicators are categorical.
7. Formative factors: The `"<~"` operator can be used to define a formative factor (on the right hand side of the operator), in a similar why as a reflexive factor is defined (using the `"=~"` operator). This is just syntax sugar to define a phantom latent variable (equivalent to using `"f =~ 0"`). And in addition, the (residual) variance of the formative factor is fixed to zero.

Usually, only a single variable name appears on the left side of an operator. However, if multiple variable names are specified, separated by the `"+"` operator, the formula is repeated for each element on the left side (as for example in the third regression formula in the example above). The only exception are scaling factors, where only a single element is allowed on the left hand side.

In the right-hand side of these formula-like expressions, each element can be modified (using the `"*"` operator) by either a numeric constant, an expression resulting in a numeric constant, an expression resulting in a character vector, or one of three special functions: `start()`, `label()` and `equal()`. This provides the user with a mechanism to fix parameters, to provide alternative starting values, to label the parameters, and to define equality constraints among model parameters. All `"*"` expressions are referred to as *modifiers*. They are explained in more detail in the following sections.

Fixing parameters

It is often desirable to fix a model parameter that is otherwise (by default) free. Any parameter in a model can be fixed by using a modifier resulting in a numerical constaint. Here are some examples:

- Fixing the regression coefficient of the predictor x2:

```
y ~ x1 + 2.4*x2 + x3
```

- Specifying an orthogonal (zero) covariance between two latent variables:

```
f1 ~~ 0*f2
```

- Specifying an intercept and a linear slope in a growth model:

```
i =~ 1*y11 + 1*y12 + 1*y13 + 1*y14
s =~ 0*y11 + 1*y12 + 2*y13 + 3*y14
```

Instead of a numeric constant, one can use a mathematical function that returns a numeric constant, for example `sqrt(10)`. Multiplying with `NA` will force the corresponding parameter to be free.

Starting values

User-provided starting values can be given by using the special function `start()`, containing a numeric constant. For example:

```
y ~ x1 + start(1.0)*x2 + x3
```

Note that if a starting value is provided, the parameter is not automatically considered to be free.

Parameter labels and equality constraints

Each free parameter in a model is automatically given a name (or label). The name given to a model parameter consists of three parts, coerced to a single character vector. The first part is the name of the variable in the left-hand side of the formula where the parameter was implied. The middle part is based on the special 'operator' used in the formula. This can be either one of `"=~"`, `"~"` or `"~~"`. The third part is the name of the variable in the right-hand side of the formula where the parameter was implied, or `"1"` if it is an intercept. The three parts are pasted together in a single string. For example, the name of the fixed regression coefficient in the regression formula `y ~ x1 + 2.4*x2 + x3` is the string `"y~x2"`. The name of the parameter corresponding to the covariance between two latent variables in the formula `f1 ~~ f2` is the string `"f1~~f2"`.

Although this automatic labeling of parameters is convenient, the user may specify its own labels for specific parameters simply by pre-multiplying the corresponding term (on the right hand side of the operator only) by a character string (starting with a letter). For example, in the formula `f1 =~ x1 + x2 + mylabelx3`, the parameter corresponding with the factor loading of `x3` will be named `"mylabel"`. `"f1=~x3"`. An alternative way to specify the label is as follows: `f1 =~ x1 + x2 + label("mylabel")*x3`, where the label is the argument of special function `label()`; this can be useful if the label contains a space, or an operator (like "~").

To constrain a parameter to be equal to another target parameter, there are two ways. If you have specified your own labels, you can use the fact that *equal labels imply equal parameter values*. If you rely on automatic parameter labels, you can use the special function `equal()`. The argument of `equal()` is the (automatic or user-specified) name of the target parameter. For example, in the confirmatory factor analysis example below, the intercepts of the three indicators of each latent variable are constrained to be equal to each other. For the first three, we have used the default names. For the last three, we have provided a custom label for the `y2a` intercept.

```
model <- '
  # two latent variables with fixed loadings
    f1 =~ 1*y1a + 1*y1b + 1*y1c
    f2 =~ 1*y2a + 1*y2b + 1*y2c

  # intercepts constrained to be equal
  # using the default names
    y1a ~ 1
    y1b ~ equal("y1a~1") * 1
    y1c ~ equal("y1a~1") * 1

  # intercepts constrained to be equal
  # using a custom label
    y2a ~ int2*1
    y2b ~ int2*1
    y2c ~ int2*1
'
```

Multiple groups

In a multiple group analysis, modifiers that contain a single constant must be replaced by a vector, having the same length as the number of groups. The only exception are numerical constants (for fixing values): if you provide only a single number, the same number will be used for all groups. However, it is safer (and cleaner) to specify the same number of elements as the number of groups. For example, if there are two groups:

```
HS.model <- ' visual  =~            x1 +
                              0.5*x2 +
                         c(0.6, 0.8)*x3

              textual =~                   x4 +
                         start(c(1.2, 0.6))*x5 +
                                           x6

              speed   =~              x7 +
                                      x8 +
                         c(x9.group1,
                           x9.group2) * x9 '
```

In this example, the factor loading of the 'x2' indicator is fixed to the value 0.5 for all groups. However, the factor loadings of the 'x3' indicator are fixed to 0.6 and 0.8 for group 1 and group 2 respectively. The same logic is used for all modifiers. Note that character vectors can contain unquoted strings.

Multiple modifiers

In the model syntax, you can specify a variable more than once on the right hand side of an operator; therefore, several 'modifiers' can be applied simultaneously; for example, if you want to fix the value of a parameter and also label that parameter, you can use something like:

```
f1 =~ x1 + x2 + 4*x3 + x3.loading*x3
```

References

Yves Rosseel (2012). lavaan: An R Package for Structural Equation Modeling. Journal of Statistical Software, 48(2), 1-36. URL http://www.jstatsoft.org/v48/i02/.

`modificationIndices` *Modification Indices*

Description

Modification indices of a latent variable model.

Usage

```
modificationIndices(object, standardized = TRUE, power = FALSE,
                    delta = 0.1, alpha = 0.05, high.power = 0.75)
modindices(object, standardized = TRUE, power = FALSE,
                    delta = 0.1, alpha = 0.05, high.power = 0.75)
```

Arguments

`object`	An object of class `lavaan`.
`standardized`	If `TRUE`, two extra columns (sepc.lv and sepc.all) will contain standardized values for the epc's. In the first column (sepc.lv), standardizization is based on the variances of the (continuous) latent variables. In the second column (sepc.all), standardization is based on both the variances of both (continuous) observed and latent variables. (Residual) covariances are standardized using (residual) variances.
`power`	If `TRUE`, the (post-hoc) power is computed for each modification index, using the values of `delta` and `alpha`.
`delta`	The value of the effect size, as used in the post-hoc power computation, currently using the unstandardized metric of the epc column.
`alpha`	The significance level used for deciding if the modification index is statistically significant or not.
`high.power`	If the computed power is higher than this cutoff value, the power is considered 'high'. If not, the power is considered 'low'. This affects the values in the 'decision' column in the output.

Value

A data.frame containing modification indices and EPC's.

Examples

```
HS.model <- ' visual  =~ x1 + x2 + x3
              textual =~ x4 + x5 + x6
              speed   =~ x7 + x8 + x9 '

fit <- cfa(HS.model, data=HolzingerSwineford1939)
modindices(fit)
```

`mplus2lavaan` *mplus to lavaan converter*

Description

Read in an Mplus input file, convert it to lavaan syntax, and fit the model.

Usage

```
mplus2lavaan(inpfile)
```

Arguments

`inpfile`	The filename (including a full path) of the Mplus input file. The data (as referred to in the Mplus input file) should be in the same directory as the Mplus input file.

Value

A list with two elements: `mplus.inp` contains the input data, a title, the variable names, and the converted (lavaan) model syntax; `lav.out` contains the fitted lavaan object.

Author(s)

Michael Hallquist

See Also

`lavExport`.

Examples

```
## Not run:
out <- mplus2lavaan("ex5.1.inp")
summary(out$lav.out)

## End(Not run)
```

parameterEstimates *Parameter Estimates*

Description

Parameter estimates of a latent variable model.

Usage

```
parameterEstimates(object, ci = TRUE, level = 0.95,
                   boot.ci.type = "perc", standardized = FALSE,
                   fmi = "default")
```

Arguments

object	An object of class lavaan.
ci	If TRUE, confidence intervals are added to the output
level	The confidence level required.
boot.ci.type	If bootstrapping was used, the type of interval required. The value should be one of "norm", "basic", "perc", or "bca.simple". For the first three options, see the help page of the boot.ci function in the boot package. The "bca.simple" option produces intervals using the adjusted bootstrap percentile (BCa) method, but with no correction for acceleration (only for bias).
standardized	If TRUE, standardized estimates are added to the output
fmi	Logical. If TRUE, an extra column is added containing the fraction of missing information for each estimated parameter. If "default", the value is set to TRUE only if estimator="ML", missing="(fi)ml", and se="standard". See references for more information.

Value

A data.frame containing the estimated parameters, parameters, standard errors, z-values, and (by default) the lower and upper values of the confidence intervals. If requested, extra columns are added with standardized versions of the parameter estimates.

References

Savalei, V. & Rhemtulla, M. (2012). On obtaining estimates of the fraction of missing information from FIML. Structural Equation Modeling: A Multidisciplinary Journal, 19(3), 477-494.

Examples

```
HS.model <- ' visual  =~ x1 + x2 + x3
              textual =~ x4 + x5 + x6
              speed   =~ x7 + x8 + x9 '

fit <- cfa(HS.model, data=HolzingerSwineford1939)
parameterEstimates(fit)
```

parTable *Parameter Table*

Description

Show the parameter table of a fitted model.

Usage

```
parameterTable(object)
parTable(object)
```

Arguments

object	An object of class lavaan.

Value

A data.frame containing the model parameters. This is simply the output of the lavaanify function coerced to a data.frame (with stringsAsFactors = FALSE).

See Also

lavaanify.

Examples

```
HS.model <- ' visual  =~ x1 + x2 + x3
              textual =~ x4 + x5 + x6
              speed   =~ x7 + x8 + x9 '

fit <- cfa(HS.model, data=HolzingerSwineford1939)
parTable(fit)
```

plot.InformativeTesting *Plot output InformativeTesting()*

Description

The function plots the distributions of bootstrapped LRT values and plug-in p-values.

Usage

```
  ## S3 method for class 'InformativeTesting'
plot(x, ..., type = "all",
       main = "main", xlab = "xlabel",
       ylab = "ylabel", freq = TRUE, cex.main = 1,
       cex.lab = NULL, cex.axis = NULL, nclass = NULL,
       col = "grey", border = par("fg"), axes = TRUE,
       vline = FALSE, vline.col = c("red", "blue"), lty = c(1,2),
       lwd = 1, legend = FALSE, bty = "o", cex.legend = 0.75,
       loc.legend = "topright")
```

Arguments

x	The output of the InformativeTesting() function
...	Currently not used.
type	If "all", all available plots are plotted simultaneously. If LRT.A or LRT.B, a distribution of the first-level bootstrapped LRT values is plotted. If ppvalues.A or ppvalues.B, a distribution of the bootstrapped plug-in p-values is plotted.
main	The main title(s) for the plot(s).
xlab	A label for the x axis, default depends on input type.
ylab	A label for the y axis, default is "frequency".
freq	Logical; if TRUE, the histogram graphic is a representation of frequencies, the counts component of the result; if FALSE, probability densities, component density, are plotted (so that the histogram has a total area of one). The default is set to TRUE.
cex.main	The magnification to be used for main titles relative to the current setting of cex. The default is set to 1.
cex.lab	The magnification to be used for x and y labels relative to the current setting of cex.
cex.axis	The magnification to be used for axis annotation relative to the current setting of cex.
nclass	Integer; number of classes.
col	A colour to be used to fill the bars. The default of NULL yields unfilled bars.
border	Color for rectangle border(s). The default means par("fg").
axes	Logical; if TRUE the x and y axis are plotted.
vline	Logical; if TRUE a vertical line is drawn at the observed LRT value. If double.bootstrap = "FDB" a vertical line is drawn at the 1-p* quantile of the second-level LRT values, where p* is the first-level bootstrapped p-value
vline.col	Color(s) for the vline.LRT.
lty	The line type. Line types can either be specified as an integer (0=blank, 1=solid (default), 2=dashed, 3=dotted, 4=dotdash, 5=longdash, 6=twodash) or as one of the character strings "blank", "solid", "dashed", "dotted", "dotdash", "longdash", or "twodash", where "blank" uses 'invisible lines' (i.e., does not draw them).

lwd	The line width, a positive number, defaulting to 1.
legend	Logical; if TRUE a legend is added to the plot.
bty	A character string which determined the type of box which is drawn about plots. If bty is one of "o" (the default), "l", "7", "c", "u", or "]" the resulting box resembles the corresponding upper case letter. A value of "n" suppresses the box.
cex.legend	A numerical value giving the amount by which the legend text and symbols should be magnified relative to the default. This starts as 1 when a device is opened, and is reset when the layout is changed.
loc.legend	The location of the legend, specified by a single keyword from the list "bottomright", "bottom", "bottomleft", "left", "topleft", "top", "topright", "right" and "center".

Author(s)

Leonard Vanbrabant

`PoliticalDemocracy` *Industrialization And Political Democracy Dataset*

Description

The 'famous' Industrialization and Political Democracy dataset. This dataset is used throughout Bollen's 1989 book (see pages 12, 17, 36 in chapter 2, pages 228 and following in chapter 7, pages 321 and following in chapter 8). The dataset contains various measures of political democracy and industrialization in developing countries.

Usage

```
data(PoliticalDemocracy)
```

Format

A data frame of 75 observations of 11 variables.

- `y1` Expert ratings of the freedom of the press in 1960
- `y2` The freedom of political opposition in 1960
- `y3` The fairness of elections in 1960
- `y4` The effectiveness of the elected legislature in 1960
- `y5` Expert ratings of the freedom of the press in 1965
- `y6` The freedom of political opposition in 1965
- `y7` The fairness of elections in 1965
- `y8` The effectiveness of the elected legislature in 1965
- `x1` The gross national product (GNP) per capita in 1960
- `x2` The inanimate energy consumption per capita in 1960
- `x3` The percentage of the labor force in industry in 1960

Source

The dataset was retrieved from http://web.missouri.edu/~kolenikovs/Stat9370/democindus.txt (see discussion on SEMNET 18 Jun 2009)

References

Bollen, K. A. (1989). *Structural Equations with Latent Variables.* Wiley Series in Probability and Mathematical Statistics. New York: Wiley.

Bollen, K. A. (1979). Political democracy and the timing of development. *American Sociological Review*, 44, 572-587.

Bollen, K. A. (1980). Issues in the comparative measurement of political democracy. *American Sociological Review*, 45, 370-390.

Examples

```
head(PoliticalDemocracy)
```

---

sem *Fit Structural Equation Models*

Description

Fit a Structural Equation Model (SEM).

Usage

```
sem(model = NULL, data = NULL,
    meanstructure = "default", fixed.x = "default",
    orthogonal = FALSE, std.lv = FALSE, std.ov = FALSE,
    missing = "default", ordered = NULL,
    sample.cov = NULL, sample.cov.rescale = "default",
    sample.mean = NULL, sample.nobs = NULL,
    ridge = 1e-05, group = NULL,
    group.label = NULL, group.equal = "", group.partial = "",
    cluster = NULL, constraints = '',
    estimator = "default", likelihood = "default",
    information = "default", se = "default", test = "default",
    bootstrap = 1000L, mimic = "default", representation = "default",
    do.fit = TRUE, control = list(), WLS.V = NULL, NACOV = NULL,
    start = "default", verbose = FALSE, warn = TRUE, debug = FALSE)
```

Arguments

model	A description of the user-specified model. Typically, the model is described using the lavaan model syntax. See model.syntax for more information. Alternatively, a parameter table (eg. the output of the lavaanify() function) is also accepted.
data	An optional data frame containing the observed variables used in the model. If some variables are declared as ordered factors, lavaan will treat them as ordinal variables.
meanstructure	If TRUE, the means of the observed variables enter the model. If "default", the value is set based on the user-specified model, and/or the values of other arguments.
fixed.x	If TRUE, the exogenous 'x' covariates are considered fixed variables and the means, variances and covariances of these variables are fixed to their sample values. If FALSE, they are considered random, and the means, variances and covariances are free parameters. If "default", the value is set depending on the mimic option.
orthogonal	If TRUE, the exogenous latent variables are assumed to be uncorrelated.
std.lv	If TRUE, the metric of each latent variable is determined by fixing their variances to 1.0. If FALSE, the metric of each latent variable is determined by fixing the factor loading of the first indicator to 1.0.
std.ov	If TRUE, all observed variables are standardized before entering the analysis.
missing	If "listwise", cases with missing values are removed listwise from the data frame before analysis. If "direct" or "ml" or "fiml" and the estimator is maximum likelihood, Full Information Maximum Likelihood (FIML) estimation is used using all available data in the data frame. This is only valid if the data are missing completely at random (MCAR) or missing at random (MAR). If "default", the value is set depending on the estimator and the mimic option.
ordered	Character vector. Only used if the data is in a data.frame. Treat these variables as ordered (ordinal) variables, if they are endogenous in the model. Importantly, all other variables will be treated as numeric (unless they are declared as ordered in the original data.frame.)
sample.cov	Numeric matrix. A sample variance-covariance matrix. The rownames and/or colnames must contain the observed variable names. For a multiple group analysis, a list with a variance-covariance matrix for each group. Note that if maximum likelihood estimation is used and likelihood="normal", the user provided covariance matrix is internally rescaled by multiplying it with a factor (N-1)/N, to ensure that the covariance matrix has been divided by N. This can be turned off by setting the sample.cov.rescale argument to FALSE.
sample.cov.rescale	If TRUE, the sample covariance matrix provided by the user is internally rescaled by multiplying it with a factor (N-1)/N. If "default", the value is set depending on the estimator and the likelihood option: it is set to TRUE if maximum likelihood estimation is used and likelihood="normal", and FALSE otherwise.
sample.mean	A sample mean vector. For a multiple group analysis, a list with a mean vector for each group.

`sample.nobs` Number of observations if the full data frame is missing and only sample moments are given. For a multiple group analysis, a list or a vector with the number of observations for each group.

`ridge` Numeric. Small constant used for ridging. Only used if the sample covariance matrix is non positive definite.

`group` A variable name in the data frame defining the groups in a multiple group analysis.

`group.label` A character vector. The user can specify which group (or factor) levels need to be selected from the grouping variable, and in which order. If `NULL` (the default), all grouping levels are selected, in the order as they appear in the data.

`group.equal` A vector of character strings. Only used in a multiple group analysis. Can be one or more of the following: `"loadings"`, `"intercepts"`, `"means"`, `"thresholds"`, `"regressions"`, `"residuals"`, `"residual.covariances"`, `"lv.variances"` or `"lv.covariances"`, specifying the pattern of equality constraints across multiple groups.

`group.partial` A vector of character strings containing the labels of the parameters which should be free in all groups (thereby overriding the group.equal argument for some specific parameters).

`cluster` Not used yet.

`constraints` Additional (in)equality constraints not yet included in the model syntax. See `model.syntax` for more information.

`estimator` The estimator to be used. Can be one of the following: `"ML"` for maximum likelihood, `"GLS"` for generalized least squares, `"WLS"` for weighted least squares (sometimes called ADF estimation), `"ULS"` for unweighted least squares and `"DWLS"` for diagonally weighted least squares. These are the main options that affect the estimation. For convenience, the `"ML"` option can be extended as `"MLM"`, `"MLMV"`, `"MLMVS"`, `"MLF"`, and `"MLR"`. The estimation will still be plain `"ML"`, but now with robust standard errors and a robust (scaled) test statistic. For `"MLM"`, `"MLMV"`, `"MLMVS"`, classic robust standard errors are used (`se="robust.sem"`); for `"MLF"`, standard errors are based on first-order derivatives (`se="first.order"`); for `"MLR"`, 'Huber-White' robust standard errors are used (`se="robust.huber.white"`). In addition, `"MLM"` will compute a Satorra-Bentler scaled (mean adjusted) test statistic (`test="satorra.bentler"`) , `"MLMVS"` will compute a mean and variance adjusted test statistic (Satterthwaite style) (`test="mean.var.adjusted"`), `"MLMV"` will compute a mean and variance adjusted test statistic (scaled and shifted) (`test="scaled.shifted"`), and `"MLR"` will compute a test statistic which is asymptotically equivalent to the Yuan-Bentler T2-star test statistic. Analogously, the estimators `"WLSM"` and `"WLSMV"` imply the `"DWLS"` estimator (not the `"WLS"` estimator) with robust standard errors and a mean or mean and variance adjusted test statistic. Estimators `"ULSM"` and `"ULSMV"` imply the `"ULS"` estimator with robust standard errors and a mean or mean and variance adjusted test statistic.

`likelihood` Only relevant for ML estimation. If `"wishart"`, the wishart likelihood approach is used. In this approach, the covariance matrix has been divided by N-1, and both standard errors and test statistics are based on N-1. If `"normal"`, the normal likelihood approach is used. Here, the covariance matrix has been divided by N,

and both standard errors and test statistics are based on N. If "default", it depends on the mimic option: if mimic="lavaan" or mimic="Mplus", normal likelihood is used; otherwise, wishart likelihood is used.

information — If "expected", the expected information matrix is used (to compute the standard errors). If "observed", the observed information matrix is used. If "default", the value is set depending on the estimator and the mimic option.

se — If "standard", conventional standard errors are computed based on inverting the (expected or observed) information matrix. If "first.order", standard errors are computed based on first-order derivatives. If "robust.sem", conventional robust standard errors are computed. If "robust.huber.white", standard errors are computed based on the 'mlr' (aka pseudo ML, Huber-White) approach. If "robust", either "robust.sem" or "robust.huber.white" is used depending on the estimator, the mimic option, and whether the data are complete or not. If "boot" or "bootstrap", bootstrap standard errors are computed using standard bootstrapping (unless Bollen-Stine bootstrapping is requested for the test statistic; in this case bootstrap standard errors are computed using model-based bootstrapping). If "none", no standard errors are computed.

test — If "standard", a conventional chi-square test is computed. If "Satorra.Bentler", a Satorra-Bentler scaled test statistic is computed. If "Yuan.Bentler", a Yuan-Bentler scaled test statistic is computed. If "mean.var.adjusted" or "Satterthwaite", a mean and variance adjusted test statistic is compute. If "scaled.shifted", an alternative mean and variance adjusted test statistic is computed (as in Mplus version 6 or higher). If "boot" or "bootstrap" or "Bollen.Stine", the Bollen-Stine bootstrap is used to compute the bootstrap probability value of the test statistic. If "default", the value depends on the values of other arguments.

bootstrap — Number of bootstrap draws, if bootstrapping is used.

mimic — If "Mplus", an attempt is made to mimic the Mplus program. If "EQS", an attempt is made to mimic the EQS program. If "default", the value is (currently) set to to "lavaan", which is very close to"Mplus".

representation — If "LISREL" the classical LISREL matrix representation is used to represent the model (using the all-y variant).

do.fit — If FALSE, the model is not fit, and the current starting values of the model parameters are preserved.

control — A list containing control parameters passed to the optimizer. By default, lavaan uses "nlminb". See the manpage of nlminb for an overview of the control parameters. A different optimizer can be chosen by setting the value of optim.method. For unconstrained optimization (the model syntax does not include any "==", ">" or "<" operators), the available options are "nlminb" (the default), "BFGS" and "L-BFGS-B". See the manpage of the optim function for the control parameters of the latter two options. For constrained optimization, the only available option is "nlminb.constr".

WLS.V — A user provided weight matrix to be used by estimator "WLS"; if the estimator is "DWLS", only the diagonal of this matrix will be used. For a multiple group analysis, a list with a weight matrix for each group. The elements of the weight matrix should be in the following order (if all data is continuous): first the means (if a meanstructure is involved), then the lower triangular elements of

the covariance matrix including the diagonal, ordered column by column. In the categorical case: first the thresholds (including the means for continuous variables), then the slopes (if any), the variances of continuous variables (if any), and finally the lower triangular elements of the correlation/covariance matrix excluding the diagonal, ordered column by column.

`NACOV` A user provided matrix containing the elements of (N times) the asymptotic variance-covariance matrix of the sample statistics. For a multiple group analysis, a list with an asymptotic variance-covariance matrix for each group. See the `WLS.V` argument for information about the order of the elements.

`start` If it is a character string, the two options are currently `"simple"` and `"Mplus"`. In the first case, all parameter values are set to zero, except the factor loadings (set to one), the variances of latent variables (set to 0.05), and the residual variances of observed variables (set to half the observed variance). If `"Mplus"`, we use a similar scheme, but the factor loadings are estimated using the fabin3 estimator (tsls) per factor. If `start` is a fitted object of class `lavaan`, the estimated values of the corresponding parameters will be extracted. If it is a model list, for example the output of the `paramaterEstimates()` function, the values of the `est` or `start` or `ustart` column (whichever is found first) will be extracted.

`verbose` If `TRUE`, the function value is printed out during each iteration.

`warn` If `TRUE`, some (possibly harmless) warnings are printed out during the iterations.

`debug` If `TRUE`, debugging information is printed out.

Details

The `sem` function is a wrapper for the more general `lavaan` function, using the following default arguments: `int.ov.free = TRUE`, `int.lv.free = FALSE`, `auto.fix.first = TRUE` (unless `std.lv = TRUE`), `auto.fix.single = TRUE`, `auto.var = TRUE`, `auto.cov.lv.x = TRUE`, `auto.th = TRUE`, `auto.delta = TRUE`, and `auto.cov.y = TRUE`.

Value

An object of class `lavaan`, for which several methods are available, including a `summary` method.

References

Yves Rosseel (2012). lavaan: An R Package for Structural Equation Modeling. Journal of Statistical Software, 48(2), 1-36. URL http://www.jstatsoft.org/v48/i02/.

See Also

`lavaan`

Examples

```
## The industrialization and Political Democracy Example
## Bollen (1989), page 332
model <- '
  # latent variable definitions
```

```
     ind60 =~ x1 + x2 + x3
     dem60 =~ y1 + a*y2 + b*y3 + c*y4
     dem65 =~ y5 + a*y6 + b*y7 + c*y8

  # regressions
    dem60 ~ ind60
    dem65 ~ ind60 + dem60

  # residual correlations
    y1 ~~ y5
    y2 ~~ y4 + y6
    y3 ~~ y7
    y4 ~~ y8
    y6 ~~ y8
'

fit <- sem(model, data=PoliticalDemocracy)
summary(fit, fit.measures=TRUE)
```

`simulateData` *Simulate Data From a Lavaan Model Syntax*

Description

Simulate data starting from a lavaan model syntax.

Usage

```
simulateData(model = NULL, model.type = "sem", meanstructure = FALSE,
    int.ov.free = TRUE, int.lv.free = FALSE, fixed.x = FALSE,
    orthogonal = FALSE, std.lv = TRUE, auto.fix.first = FALSE,
    auto.fix.single = FALSE, auto.var = TRUE, auto.cov.lv.x = TRUE,
    auto.cov.y = TRUE, ..., sample.nobs = 500L, ov.var = NULL,
    group.label = paste("G", 1:ngroups, sep = ""), skewness = NULL,
    kurtosis = NULL, seed = NULL, empirical = FALSE,
    return.type = "data.frame", return.fit = FALSE,
    debug = FALSE, standardized = FALSE)
```

Arguments

`model`	A description of the user-specified model. Typically, the model is described using the lavaan model syntax. See `model.syntax` for more information. Alternatively, a parameter table (eg. the output of the `lavaanify()` function) is also accepted.
`model.type`	Set the model type: possible values are `"cfa"`, `"sem"` or `"growth"`. This may affect how starting values are computed, and may be used to alter the terminology used in the summary output, or the layout of path diagrams that are based on a fitted lavaan object.

`meanstructure` If `TRUE`, the means of the observed variables enter the model. If `"default"`, the value is set based on the user-specified model, and/or the values of other arguments.

`int.ov.free` If `FALSE`, the intercepts of the observed variables are fixed to zero.

`int.lv.free` If `FALSE`, the intercepts of the latent variables are fixed to zero.

`fixed.x` If `TRUE`, the exogenous 'x' covariates are considered fixed variables and the means, variances and covariances of these variables are fixed to their sample values. If `FALSE`, they are considered random, and the means, variances and covariances are free parameters. If `"default"`, the value is set depending on the mimic option.

`orthogonal` If `TRUE`, the exogenous latent variables are assumed to be uncorrelated.

`std.lv` If `TRUE`, the metric of each latent variable is determined by fixing their variances to 1.0. If `FALSE`, the metric of each latent variable is determined by fixing the factor loading of the first indicator to 1.0.

`auto.fix.first` If `TRUE`, the factor loading of the first indicator is set to 1.0 for every latent variable.

`auto.fix.single`
If `TRUE`, the residual variance (if included) of an observed indicator is set to zero if it is the only indicator of a latent variable.

`auto.var` If `TRUE`, the residual variances and the variances of exogenous latent variables are included in the model and set free.

`auto.cov.lv.x` If `TRUE`, the covariances of exogenous latent variables are included in the model and set free.

`auto.cov.y` If `TRUE`, the covariances of dependent variables (both observed and latent) are included in the model and set free.

`...` additional arguments passed to the `lavaan` function.

`sample.nobs` Number of observations. If a vector, multiple datasets are created. If `return.type = "matrix"` or `return.type = "cov"`, a list of `length(sample.nobs)` is returned, with either the data or covariance matrices, each one based on the number of observations as specified in `sample.nobs`. If `return.type = "data.frame"`, all datasets are merged and a `group` variable is added to mimic a multiple group dataset.

`ov.var` The user-specified variances of the observed variables.

`group.label` The group labels that should be used if multiple groups are created.

`skewness` Numeric vector. The skewness values for the observed variables. Defaults to zero.

`kurtosis` Numeric vector. The kurtosis values for the observed variables. Defaults to zero.

`seed` Set random seed.

`empirical` Logical. If `TRUE`, the implied moments (Mu and Sigma) specify the empirical not population mean and covariance matrix.

`return.type` If `"data.frame"`, a data.frame is returned. If `"matrix"`, a numeric matrix is returned (without any variable names). If `"cov"`, a covariance matrix is returned (without any variable names).

`return.fit` If `TRUE`, return the fitted model that has been used to generate the data as an attribute (called `"fit"`); this may be useful for inspection.

`debug` If `TRUE`, debugging information is displayed.

`standardized` If `TRUE`, the residual variances of the observed variables are set in such a way such that the model implied variances are unity. This allows regression coefficients and factor loadings (involving observed variables) to be specified in a standardized metric.

Details

Model parameters can be specified by fixed values in the lavaan model syntax. If no fixed values are specified, the value zero will be assumed, except for factor loadings and variances, which are set to unity by default. By default, multivariate normal data are generated. However, by providing skewness and/or kurtosis values, nonnormal multivariate data can be generated, using the Vale & Maurelli (1983) method.

Value

The generated data. Either as a data.frame (if `return.type="data.frame"`), a numeric matrix (if `return.type="matrix"`), or a covariance matrix (if `return.type="cov"`).

Examples

```
# specify population model
population.model <- ' f1 =~ x1 + 0.8*x2 + 1.2*x3
                      f2 =~ x4 + 0.5*x5 + 1.5*x6
                      f3 =~ x7 + 0.1*x8 + 0.9*x9

                      f3 ~ 0.5*f1 + 0.6*f2
                    '

# generate data
myData <- simulateData(population.model, sample.nobs=100L)

# population moments
fitted(sem(population.model))

# sample moments
round(cov(myData), 3)
round(colMeans(myData), 3)

# fit model
myModel <- ' f1 =~ x1 + x2 + x3
             f2 =~ x4 + x5 + x6
             f3 =~ x7 + x8 + x9
             f3 ~ f1 + f2 '
fit <- sem(myModel, data=myData)
summary(fit)
```

standardizedSolution *Standardized Solution*

Description

Standardized solution of a latent variable model.

Usage

```
standardizedSolution(object, type = "std.all")
```

Arguments

object	An object of class lavaan.
type	If "std.lv", the standardized estimates are on the variances of the (continuous) latent variables only. If "std.all", the standardized estimates are based on both the variances of both (continuous) observed and latent variables. If "std.nox", the standardized estimates are based on both the variances of both (continuous) observed and latent variables, but not the variances of exogenous covariates.

Value

A data.frame containing both unstandardized and standardized model parameters.

Examples

```
HS.model <- ' visual  =~ x1 + x2 + x3
              textual =~ x4 + x5 + x6
              speed   =~ x7 + x8 + x9 '

fit <- cfa(HS.model, data=HolzingerSwineford1939)
standardizedSolution(fit)
```

utils-matrix *Utility Functions For Matrices.*

Description

Utility functions to deal with (mostly symmetric) matrices.

Usage

```
vech(S, diagonal = TRUE)
vechr(S, diagonal = TRUE)
vechu(S, diagonal = TRUE)
vechru(S, diagonal = TRUE)
vech.reverse(x, diagonal = TRUE)
vechru.reverse(x, diagonal = TRUE)
vechr.reverse(x, diagonal = TRUE)
vechu.reverse(x, diagonal = TRUE)
lower2full(x, diagonal = TRUE)
upper2full(x, diagonal = TRUE)
duplicationMatrix(n = 1L)
commutationMatrix(m = 1L, n = 1L)
sqrtSymmetricMatrix(S)
```

Arguments

S	A symmetric matrix.
x	A numeric vector containing the lower triangular or upper triangular elements of a symmetric matrix, possibly including the diagonal elements.
diagonal	Logical. If TRUE, the diagonal is included. If FALSE, the diagonal is not included.
n	Integer. Dimension of the symmetric matrix, or column dimension of a non-square matrix.
m	Integer. Row dimension of a matrix.

Details

The vech function implements the vech operator (for 'half vectorization') and transforms a symmetric matrix into a vector by stacking the columns of the matrix one underneath the other, but eliminating all supradiagonal elements.

The vech.reverse function does the reverse: given the output of the vech function, it reconstructs the symmetric matrix.

The lower2full function takes the lower

The duplicationMatrix function creates a duplication matrix D: it duplicates the elements in vech(S) to create vec(S) (where S is symmetric), such that `D %*% vech(S) == vec(S)`.

The commutationMatrix function creates a commutation matrix (K): this mn x mx matrix is a permutation matrix which transforms vec(A) into vec(t(A)), such that `K %*% vec(A) == vec(t(A))`.

The sqrtSymmetricMatrix function computes the square root of a (positive definite) symmetric matrix.

References

Magnus, J. R. and H. Neudecker (1999). Matrix Differential Calculus with Applications in Statistics and Econometrics, Second Edition, John Wiley.

Examples

```
# lower.tri elements (including diagonal) of a symmetric matrix
x <- c(4,1,5,2,3,6)

# reconstruct full symmetric matrix (row-wise!)
S <- lower2full(x)

# extract the same lower.tri elements again in the same order
vechr(S)

# without diagonal elements
vechr(S, diagonal=FALSE)

# duplication matrix
nvar <- ncol(S)
vec <- as.vector
Dup <- duplicationMatrix(nvar)
Dup %*% vech(S) == vec(S) # should all be true

# commutation matrix
K <- commutationMatrix(nvar, nvar)
K %*% vec(S) == vec(t(S)) # should all be true

# take sqrt root of a symmetric matrix
S.sqrt <- sqrtSymmetricMatrix(S)
S.sqrt %*% S.sqrt
# should be equal to S again (ignoring some rounding-off errors)
```

---

varTable *Variable Table*

Description

Summary information about the variables included in either a data.frame, or a fitted lavaan object.

Usage

```
varTable(object, ov.names = names(object), ov.names.x = NULL,
    ordered = NULL, factor = NULL, as.data.frame. = TRUE)
```

Arguments

object	Either a data.frame, or an object of class lavaan.
ov.names	Only used if object is a data.frame. A character vector containing the variables that need to be summarized.
ov.names.x	Only used if object is a data.frame. A character vector containing additional variables that need to be summarized.
ordered	Character vector. Which variables should be treated as ordered factors

factor	Character vector. Which variables should be treated as (unordered) factors?
as.data.frame.	If TRUE, return the list as a data.frame.

Value

A list or data.frame containing summary information about variables in a data.frame. If object is a fitted lavaan object, it displays the summary information about the observed variables that are included in the model. The summary information includes variable type (numeric, ordered, ...), the number of non-missing values, the mean and variance for numeric variables, the number of levels of ordered variables, and the labels for ordered variables.

Examples

```
HS.model <- ' visual  =~ x1 + x2 + x3
              textual =~ x4 + x5 + x6
              speed   =~ x7 + x8 + x9 '

fit <- cfa(HS.model, data=HolzingerSwineford1939)
varTable(fit)
```

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