

Package ‘blavaan’

January 19, 2024

Title Bayesian Latent Variable Analysis

Version 0.5-3

Description Fit a variety of Bayesian latent variable models, including confirmatory factor analysis, structural equation models, and latent growth curve models. References: Merkle & Rosseel (2018) <[doi:10.18637/jss.v085.i04](https://doi.org/10.18637/jss.v085.i04)>; Merkle et al. (2021) <[doi:10.18637/jss.v100.i06](https://doi.org/10.18637/jss.v100.i06)>.

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ByteCompile true

Depends R(>= 3.5.0), methods, Rcpp(>= 0.12.15)

Imports stats, utils, graphics, lavaan(>= 0.6-17), coda, mnormt, nonnest2(>= 0.5-5), loo(>= 2.0), rstan(>= 2.26.0), rstantools(>= 1.5.0), RcppParallel (>= 5.0.1), bayesplot, Matrix, future.apply, tmvnsim

LinkingTo StanHeaders (>= 2.26.0), rstan (>= 2.26.0), BH (>= 1.69.0), Rcpp (>= 0.12.15), RcppEigen (>= 0.3.3.4.0), RcppParallel (>= 5.0.1)

Suggests runjags(>= 2.0.4-3), modeest(>= 2.3.3), rjags, cmdstanr, semTools, tinytest

SystemRequirements GNU make

NeedsCompilation yes

URL <https://ecmerkle.github.io/blavaan/>,
<https://github.com/ecmerkle/blavaan>

BugReports <https://github.com/ecmerkle/blavaan/issues>

Additional_repositories <https://mc-stan.org/r-packages/>

Config/Needs/website brms

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Repository CRAN

Date/Publication 2024-01-19 22:50:02 UTC

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bcfa

Fit Confirmatory Factor Analysis Models

Description

Fit a Confirmatory Factor Analysis (CFA) model.

Usage

```
bcfa(..., cp = "srs",
      dp = NULL, n.chains = 3, burnin, sample,
      adapt, mcmcfile = FALSE, mcmcextra = list(), inits = "simple",
      convergence = "manual", target = "stan", save.lvs = FALSE,
      wiggle = NULL, wiggle.sd = 0.1, prisamp = FALSE, jags.ic = FALSE,
      seed = NULL, bcontrol = list())
```

Arguments

...	Default lavaan arguments. See lavaan .
cp	Handling of prior distributions on covariance parameters: possible values are "srs" (default) or "fa". Option "fa" is only available for target="jags".
dp	Default prior distributions on different types of parameters, typically the result of a call to <code>dpriors()</code> . See the <code>dpriors()</code> help file for more information.
n.chains	Number of desired MCMC chains.
burnin	Number of burnin/warmup iterations (not including the adaptive iterations, for target="jags"). Defaults to 4000 or target="jags" and 500 for Stan targets.
sample	The total number of samples to take after burnin. Defaults to 10000 for target="jags" and 1000 for Stan targets.
adapt	For target="jags", the number of adaptive iterations to use at the start of sampling. Defaults to 1000.
mcmcfile	If TRUE, the JAGS/Stan model will be written to file (in the <code>lavExport</code> directory). Can also supply a character string, which serves as the name of the directory to which files will be written.
mcmcextra	A list with potential names <code>syntax</code> (unavailable for target="stan"), <code>monitor</code> , <code>data</code> , and <code>l1nsamp</code> . The <code>syntax</code> object is a text string containing extra code to insert in the JAGS/Stan model syntax. The <code>data</code> object is a list of extra data to send to the JAGS/Stan model. If <code>moment_match_k_threshold</code> is specified within data the looic of the model will be calculated using moment matching. The <code>monitor</code> object is a character vector containing extra JAGS/Stan parameters to monitor. The <code>l1nsamp</code> object is only relevant to models with ordinal variables, and specifies the number of samples that should be drawn to approximate the model log-likelihood (larger numbers imply higher accuracy and longer time). This log-likelihood is specifically used to compute information criteria.
inits	If it is a character string, the options are currently "simple" (default), "Mplus", "prior", or "jags". In the first two cases, parameter values are set as though they will be estimated via ML (see lavaan). The starting parameter value for each chain is then perturbed from the original values through the addition of random uniform noise. If "prior" is used, the starting parameter values are obtained based on the prior distributions (while also trying to ensure that the starting values will not crash the model estimation). If "jags", no starting values are specified and JAGS will choose values on its own (and this will probably crash Stan targets). You can also supply a list of starting values for each chain, where the list format can be obtained from, e.g., <code>blavInspect(fit, "inits")</code> . Finally, you can specify starting values in a similar way to <code>lavaan</code> , using the <code>lavaan start</code> argument (see the <code>lavaan</code> documentation for all the options there). In this case, you should also set <code>inits="simple"</code> , and be aware that the same starting values will be used for each chain.
convergence	Useful only for target="jags". If "auto", parameters are sampled until convergence is achieved (via <code>autorun.jags()</code>). In this case, the arguments <code>burnin</code> and <code>sample</code> are passed to <code>autorun.jags()</code> as <code>startburnin</code> and <code>startsample</code> , respectively. Otherwise, parameters are sampled as specified by the user (or by the <code>run.jags</code> defaults).

target	Desired MCMC sampling, with "stan" (pre-compiled marginal approach) as default. Also available is "vb", which calls the rstan function vb(). Other options include "jags", "stancond", and "stanclassic", which sample latent variables and provide some greater functionality (because syntax is written "on the fly"). But they are slower and less efficient.
save.lvs	Should sampled latent variables (factor scores) be saved? Logical; defaults to FALSE
wiggle	Labels of equality-constrained parameters that should be "approximately" equal. Can also be "intercepts", "loadings", "regressions", "means".
wiggle.sd	The prior sd (of normal distribution) to be used in approximate equality constraints. Can be one value, or (for target="stan") a numeric vector of values that is the same length as wiggle.
prisamp	Should samples be drawn from the prior, instead of the posterior (target="stan" only)? Logical; defaults to FALSE
jags.ic	Should DIC be computed the JAGS way, in addition to the BUGS way? Logical; defaults to FALSE
seed	A vector of length n.chains (for target "jags") or an integer (for target "stan") containing random seeds for the MCMC run. If NULL, seeds will be chosen randomly.
bcontrol	A list containing additional parameters passed to run.jags (or autorun.jags) or stan. See the manpage of those functions for an overview of the additional parameters that can be set.

Details

The bcfa function is a wrapper for the more general [blavaan](#) function, using the following default [lavaan](#) 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

- Edgar C. Merkle, Ellen Fitzsimmons, James Uanhero, & Ben Goodrich (2021). Efficient Bayesian Structural Equation Modeling in Stan. *Journal of Statistical Software*, 100(6), 1-22. URL <http://www.jstatsoft.org/v100/i06/>.
- Edgar C. Merkle & Yves Rosseel (2018). blavaan: Bayesian Structural Equation Models via Parameter Expansion. *Journal of Statistical Software*, 85(4), 1-30. URL <http://www.jstatsoft.org/v85/i04/>.
- 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

[blavaan](#)

Examples

```
## Not run:
# The Holzinger and Swineford (1939) example
HS.model <- ' visual  =~ x1 + x2 + x3
             textual =~ x4 + x5 + x6
             speed   =~ x7 + x8 + x9 '

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

## End(Not run)
```

 bgrowth

Fit Growth Curve Models

Description

Fit a Growth Curve model.

Usage

```
bgrowth(..., cp = "srs", dp = NULL, n.chains = 3,
         burnin, sample, adapt, mcmcfile = FALSE, mcmextra = list(),
         inits = "simple", convergence = "manual", target = "stan",
         save.lvs = FALSE, wiggle = NULL, wiggle.sd = 0.1, prisamp = FALSE,
         jags.ic = FALSE, seed = NULL, bcontrol = list())
```

Arguments

...	Default lavaan arguments. See lavaan .
cp	Handling of prior distributions on covariance parameters: possible values are "srs" (default) or "fa". Option "fa" is only available for target="jags".
dp	Default prior distributions on different types of parameters, typically the result of a call to dpriors(). See the dpriors() help file for more information.
n.chains	Number of desired MCMC chains.
burnin	Number of burnin/warmup iterations (not including the adaptive iterations, for target="jags"). Defaults to 4000 or target="jags" and 500 for Stan targets.
sample	The total number of samples to take after burnin. Defaults to 10000 for target="jags" and 1000 for Stan targets.
adapt	For target="jags", the number of adaptive iterations to use at the start of sampling. Defaults to 1000.
mcmcfile	If TRUE, the JAGS/Stan model will be written to file (in the lavExport directory). Can also supply a character string, which serves as the name of the directory to which files will be written.

mcmcextra	A list with potential names syntax (unavailable for target="stan"), monitor, data, and llnsamp. The syntax object is a text string containing extra code to insert in the JAGS/Stan model syntax. The data object is a list of extra data to send to the JAGS/Stan model. If moment_match_k_threshold is specified within data the looic of the model will be calculated using moment matching. The monitor object is a character vector containing extra JAGS/Stan parameters to monitor. The llnsamp object is only relevant to models with ordinal variables, and specifies the number of samples that should be drawn to approximate the model log-likelihood (larger numbers imply higher accuracy and longer time). This log-likelihood is specifically used to compute information criteria.
inits	If it is a character string, the options are currently "simple" (default), "Mplus", "prior", or "jags". In the first two cases, parameter values are set as though they will be estimated via ML (see lavaan). The starting parameter value for each chain is then perturbed from the original values through the addition of random uniform noise. If "prior" is used, the starting parameter values are obtained based on the prior distributions (while also trying to ensure that the starting values will not crash the model estimation). If "jags", no starting values are specified and JAGS will choose values on its own (and this will probably crash Stan targets). You can also supply a list of starting values for each chain, where the list format can be obtained from, e.g., <code>blavInspect(fit, "inits")</code> . Finally, you can specify starting values in a similar way to lavaan, using the lavaan start argument (see the lavaan documentation for all the options there). In this case, you should also set inits="simple", and be aware that the same starting values will be used for each chain.
convergence	Useful only for target="jags". If "auto", parameters are sampled until convergence is achieved (via <code>autorun.jags()</code>). In this case, the arguments burnin and sample are passed to <code>autorun.jags()</code> as <code>startburnin</code> and <code>startsample</code> , respectively. Otherwise, parameters are sampled as specified by the user (or by the <code>run.jags</code> defaults).
target	Desired MCMC sampling, with "stan" (pre-compiled marginal approach) as default. Also available is "vb", which calls the <code>rstan</code> function <code>vb()</code> . Other options include "jags", "stancond", and "stanclassic", which sample latent variables and provide some greater functionality (because syntax is written "on the fly"). But they are slower and less efficient.
save.lvs	Should sampled latent variables (factor scores) be saved? Logical; defaults to FALSE
wiggle	Labels of equality-constrained parameters that should be "approximately" equal. Can also be "intercepts", "loadings", "regressions", "means".
wiggle.sd	The prior sd (of normal distribution) to be used in approximate equality constraints. Can be one value, or (for target="stan") a numeric vector of values that is the same length as wiggle.
prisamp	Should samples be drawn from the prior, instead of the posterior (target="stan" only)? Logical; defaults to FALSE
jags.ic	Should DIC be computed the JAGS way, in addition to the BUGS way? Logical; defaults to FALSE

seed	A vector of length <code>n.chains</code> (for target "jags") or an integer (for target "stan") containing random seeds for the MCMC run. If NULL, seeds will be chosen randomly.
bcontrol	A list containing additional parameters passed to <code>run.jags</code> (or <code>autorun.jags</code>) or <code>stan</code> . See the manpage of those functions for an overview of the additional parameters that can be set.

Details

The `bgrowth` function is a wrapper for the more general `blavaan` function, using the following default `lavaan` 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 `blavaan`, for which several methods are available, including a summary method.

References

- Edgar C. Merkle, Ellen Fitzsimmons, James Uanhero, & Ben Goodrich (2021). Efficient Bayesian Structural Equation Modeling in Stan. *Journal of Statistical Software*, 100(6), 1-22. URL <http://www.jstatsoft.org/v100/i06/>.
- Edgar C. Merkle & Yves Rosseel (2018). `blavaan`: Bayesian Structural Equation Models via Parameter Expansion. *Journal of Statistical Software*, 85(4), 1-30. URL <http://www.jstatsoft.org/v85/i04/>.
- 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

[blavaan](#)

Examples

```
## Not run:
## 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 <- bgrowth(model.syntax, data=Demo.growth)
summary(fit)

## End(Not run)
```

blavaan

Fit a Bayesian Latent Variable Model

Description

Fit a Bayesian latent variable model.

Usage

```
blavaan(..., cp = "srs",
        dp = NULL, n.chains = 3, burnin, sample,
        adapt, mcmcfile = FALSE, mcmcextra = list(), inits = "simple",
        convergence = "manual", target = "stan", save.lvs = FALSE,
        wiggle = NULL, wiggle.sd = 0.1, prisamp = FALSE, jags.ic = FALSE,
        seed = NULL, bcontrol = list())
```

Arguments

...	Default lavaan arguments. See lavaan .
cp	Handling of prior distributions on covariance parameters: possible values are "srs" (default) or "fa". Option "fa" is only available for target="jags".
dp	Default prior distributions on different types of parameters, typically the result of a call to dpriors(). See the dpriors() help file for more information.
n.chains	Number of desired MCMC chains.
burnin	Number of burnin/warmup iterations (not including the adaptive iterations, for target="jags"). Defaults to 4000 or target="jags" and 500 for Stan targets.
sample	The total number of samples to take after burnin. Defaults to 10000 for target="jags" and 1000 for Stan targets.
adapt	For target="jags", the number of adaptive iterations to use at the start of sampling. Defaults to 1000.
mcmcfile	If TRUE, the JAGS/Stan model and data will be written to files (in the lavExport directory). Can also supply a character string, which serves as the name of the directory to which files will be written.
mcmcextra	A list with potential names syntax (unavailable for target="stan"), monitor, data, and llnsamp. The syntax object is a text string containing extra code to insert in the JAGS/Stan model syntax. The data object is a list of extra data to send to the JAGS/Stan model. If moment_match_k_threshold is specified within data the looic of the model will be calculated using moment matching. The monitor object is a character vector containing extra JAGS/Stan parameters

	to monitor. The <code>llnsamp</code> object is only relevant to models with ordinal variables, and specifies the number of samples that should be drawn to approximate the model log-likelihood (larger numbers imply higher accuracy and longer time). This log-likelihood is specifically used to compute information criteria.
<code>inits</code>	If it is a character string, the options are currently "simple" (default), "Mplus", "prior", or "jags". In the first two cases, parameter values are set as though they will be estimated via ML (see lavaan). The starting parameter value for each chain is then perturbed from the original values through the addition of random uniform noise. If "prior" is used, the starting parameter values are obtained based on the prior distributions (while also trying to ensure that the starting values will not crash the model estimation). If "jags", no starting values are specified and JAGS will choose values on its own (and this will probably crash Stan targets). You can also supply a list of starting values for each chain, where the list format can be obtained from, e.g., <code>blavInspect(fit, "inits")</code> . Finally, you can specify starting values in a similar way to <code>lavaan</code> , using the <code>lavaan start</code> argument (see the <code>lavaan</code> documentation for all the options there). In this case, you should also set <code>inits="simple"</code> , and be aware that the same starting values will be used for each chain.
<code>convergence</code>	Useful only for <code>target="jags"</code> . If "auto", parameters are sampled until convergence is achieved (via <code>autorun.jags()</code>). In this case, the arguments <code>burnin</code> and <code>sample</code> are passed to <code>autorun.jags()</code> as <code>startburnin</code> and <code>startsample</code> , respectively. Otherwise, parameters are sampled as specified by the user (or by the <code>run.jags</code> defaults).
<code>target</code>	Desired MCMC sampling, with "stan" (pre-compiled marginal approach) as default. Also available is "vb", which calls the <code>rstan</code> function <code>vb()</code> . Other options include "jags", "stancond", and "stanclassic", which sample latent variables and provide some greater functionality (because syntax is written "on the fly"). But they are slower and less efficient.
<code>save.lvs</code>	Should sampled latent variables (factor scores) be saved? Logical; defaults to FALSE
<code>wiggle</code>	Labels of equality-constrained parameters that should be "approximately" equal. Can also be "intercepts", "loadings", "regressions", "means".
<code>wiggle.sd</code>	The prior sd (of normal distribution) to be used in approximate equality constraints. Can be one value, or (for <code>target="stan"</code>) a numeric vector of values that is the same length as <code>wiggle</code> .
<code>prisamp</code>	Should samples be drawn from the prior, instead of the posterior (<code>target="stan"</code> only)? Logical; defaults to FALSE
<code>jags.ic</code>	Should DIC be computed the JAGS way, in addition to the BUGS way? Logical; defaults to FALSE
<code>seed</code>	A vector of length <code>n.chains</code> (for <code>target "jags"</code>) or an integer (for <code>target "stan"</code>) containing random seeds for the MCMC run. If NULL, seeds will be chosen randomly.
<code>bcontrol</code>	A list containing additional parameters passed to <code>run.jags</code> (or <code>autorun.jags</code>) or <code>stan</code> . See the manpage of those functions for an overview of the additional parameters that can be set.

Value

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

References

- Edgar C. Merkle, Ellen Fitzsimmons, James Uanhero, & Ben Goodrich (2021). Efficient Bayesian Structural Equation Modeling in Stan. *Journal of Statistical Software*, 100(6), 1-22. URL <http://www.jstatsoft.org/v100/i06/>.
- Edgar C. Merkle & Yves Rosseel (2018). blavaan: Bayesian Structural Equation Models via Parameter Expansion. *Journal of Statistical Software*, 85(4), 1-30. URL <http://www.jstatsoft.org/v85/i04/>.
- 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

[bcfa](#), [bsem](#), [bgrowth](#)

Examples

```
## Not run:
# The Holzinger and Swineford (1939) example
HS.model <- ' visual  =~ x1 + x2 + x3
             textual =~ x4 + x5 + x6
             speed   =~ x7 + x8 + x9 '

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

summary(fit)
coef(fit)

## End(Not run)
```

blavaan-class

Class For Representing A (Fitted) Bayesian Latent Variable Model

Description

The `blavaan` class contains the `lavaan` class, representing a (fitted) Bayesian 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 [bcfa](#), [bsem](#), [bgrowth](#) or [blavaan](#) functions.

Slots

- version:** The lavaan package version used to create this objects
- 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’.
- pta:** Named list containing parameter table attributes.
- 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. No longer used.
- boot:** List. Unused for Bayesian models.
- optim:** List. Information about the optimization.
- loglik:** List. Information about the loglikelihood of the model (if maximum likelihood was used).
- implied:** List. Model implied statistics.
- vcov:** List. Information about the variance matrix (vcov) of the model parameters.
- test:** List. Different test statistics.
- h1:** List. Information about the unrestricted h1 model (if available).
- baseline:** List. Information about a baseline model (often the independence model) (if available).
- external:** List. Includes Stan or JAGS objects used for MCMC.

Methods

- coef** signature(object = "blavaan", 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="user", all parameters listed in the parameter table are returned, including constrained and fixed parameters.
- vcov** signature(object = "lavaan"): returns the covariance matrix of the estimated parameters.
- show** signature(object = "blavaan"): Print a short summary of the model fit
- summary** signature(object = "blavaan", header = TRUE, fit.measures = FALSE, estimates = TRUE, ci = TRUE, standardized = FALSE, rsquare = FALSE, std.nox = FALSE, psrf = TRUE, neff = FALSE, postmedian = FALSE, postmode = FALSE, priors = TRUE, bf = FALSE, nd = 3L): Print a nice summary of the model estimates. If header = TRUE, the header section (including fit measures) is printed. If fit.measures = TRUE, additional fit measures are added to the header section. If estimates = TRUE, print the parameter estimates section. If ci = TRUE, add confidence intervals to the parameter estimates section. If standardized = TRUE, the standardized solution is also printed. Note that *SEs* and tests are still based on unstandardized estimates. Use [standardizedSolution](#) to obtain *SEs* and test statistics for standardized

estimates. If `rsquare=TRUE`, the R-Square values for the dependent variables in the model are printed. If `std.nox = TRUE`, the `std.all` column contains the `std.nox` column from the `parameterEstimates()` output. If `psrf = TRUE`, potential scale reduction factors (Rhats) are printed. If `neff = TRUE`, effective sample sizes are printed. If `postmedian` or `postmode` are `TRUE`, posterior medians or modes are printed instead of posterior means. If `priors = TRUE`, parameter prior distributions are printed. If `bf = TRUE`, Savage-Dickey approximations of the Bayes factor are printed for certain parameters. Nothing is returned (use `lavInspect` or another extractor function to extract information from a fitted model).

References

- Edgar C. Merkle, Ellen Fitzsimmons, James Uanhero, & Ben Goodrich (2021). Efficient Bayesian Structural Equation Modeling in Stan. *Journal of Statistical Software*, 100(6), 1-22. URL <http://www.jstatsoft.org/v100/i06/>.
- Edgar C. Merkle & Yves Rosseel (2018). blavaan: Bayesian Structural Equation Models via Parameter Expansion. *Journal of Statistical Software*, 85(4), 1-30. URL <http://www.jstatsoft.org/v85/i04/>.
- 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

[bcfa](#), [bsem](#), [bgrowth](#), [fitMeasures](#)

Examples

```
## Not run:
HS.model <- ' visual  =~ x1 + x2 + x3
             textual  =~ x4 + x5 + x6
             speed    =~ x7 + x8 + x9 '

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

summary(fit, standardized=TRUE, fit.measures=TRUE, rsquare=TRUE)
coef(fit)

## End(Not run)
```

blavCompare

Bayesian model comparisons

Description

Bayesian model comparisons, including WAIC, LOO, and Bayes factor approximation.

Usage

```
blavCompare(object1, object2, ...)
```

Arguments

object1	An object of class blavaan.
object2	A second object of class blavaan.
...	Other arguments to loo().

Details

This function computes Bayesian model comparison metrics, including a Bayes factor approximation, WAIC, and LOOIC.

The log-Bayes factor of the two models is based on the Laplace approximation to each model's marginal log-likelihood.

The WAIC and LOOIC metrics come from the loo package. The ELPD difference and SE specifically come from loo::loo_compare().

Value

A list containing separate results for log-Bayes factor, WAIC, LOOIC, and differences between WAIC and LOOIC.

References

Raftery, A. E. (1993). Bayesian model selection in structural equation models. In K. A. Bollen & J. S. Long (Eds.), *Testing structural equation models* (pp. 163-180). Beverly Hills, CA: Sage.

Vehtari A., Gelman A., Gabry J. (2017). Practical Bayesian model evaluation using leave-one-out cross-validation and WAIC. *Statistics and Computing*, 27, 1413-1432.

Examples

```
## Not run:
hsm1 <- ' visual  =~ x1 + x2 + x3 + x4
        textual =~ x4 + x5 + x6
        speed   =~ x7 + x8 + x9 '

fit1 <- bcfa(hsm1, data=HolzingerSwineford1939)

hsm2 <- ' visual  =~ x1 + x2 + x3
        textual =~ x4 + x5 + x6 + x7
        speed   =~ x7 + x8 + x9 '

fit2 <- bcfa(hsm2, data=HolzingerSwineford1939)

blavCompare(fit1, fit2)

## End(Not run)
```

blavFitIndices

*SEM Fit Indices for Bayesian SEM***Description**

This function provides a posterior distribution of some χ^2 -based fit indices to assess the global fit of a latent variable model.

Usage

```
blavFitIndices(object, thin = 1L, pD = c("loo", "waic", "dic"),
               rescale = c("devM", "ppmc", "mcmc"),
               fit.measures = "all", baseline.model = NULL)

## S4 method for signature 'blavFitIndices'
## S4 method for signature 'blavFitIndices'
summary(object, ...)

## S3 method for class 'bfi'
summary(object, central.tendency = c("mean", "median", "mode"),
        hpd = TRUE, prob = .90)
```

Arguments

object	An object of class <code>blavaan</code> .
thin	Optional integer indicating how much to thin each chain. Default is 1L, indicating not to thin the chains.
pD	character indicating from which information criterion returned by <code>fitMeasures(object)</code> to use the estimated number of parameters. The default is from the leave-one-out information criterion (LOO-IC), which is most highly recommended by Vehtari et al. (2017).
rescale	character indicating the method used to calculate fit indices. If <code>rescale = "devM"</code> (default), the Bayesian analog of the χ^2 statistic (the deviance evaluated at the posterior mean of the model parameters) is approximated by rescaling the deviance at each iteration by subtracting the estimated number of parameters. If <code>rescale = "PPMC"</code> , the deviance at each iteration is rescaled by subtracting the deviance of data simulated from the posterior predictive distribution (as in posterior predictive model checking; see Hoofs et al., 2017). If <code>rescale = "MCMC"</code> , the fit measures are simply calculated using <code>fitMeasures</code> at each iteration of the Markov chain(s), based on the model-implied moments at that iteration (NOT advised when the model includes informative priors, in which case the model's estimated pD will deviate from the number of parameters used to calculate df in <code>fitMeasures</code>).
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. If <code>rescale = "devM"</code> or "PPMC", the currently available indices are "BRMSEA",

"BGammaHat", "adjBGammaHat", "BMc", "BCFI", "BTLI", or "BNFI". If rescale = "MCMC", the user may request any indices returned by `fitMeasures` for objects of class `lavaan`.

`baseline.model` If not NULL, an object of class `blavaan`, representing a user-specified baseline model. If a `baseline.model` is provided, incremental fit indices (BCFI, BTLI, or BNFI) can be requested in `fit.measures`. Ignored if `rescale = "MCMC"`.

... Additional arguments to the summary method:

`central.tendency` Takes values "mean", "median", "mode", indicating which statistics should be used to characterize the location of the posterior distribution. By default, all 3 statistics are returned. The posterior mean is labeled EAP for *expected a posteriori* estimate, and the mode is labeled MAP for *modal a posteriori* estimate.

`hpd` A logical indicating whether to calculate the highest posterior density (HPD) credible interval for each fit index (defaults to TRUE).

`prob` The "confidence" level of the credible interval(s) (defaults to 0.9).

Value

An S4 object of class `blavFitIndices` consisting of 2 slots:

`@details` A list containing the choices made by the user (or defaults; e.g., which values of `pD` and `rescale` were set), as well as the posterior distribution of the χ^2 (deviance) statistic (rescaled, if `rescale = "devM"` or "PPMC").

`@indices` A list containing the posterior distribution of each requested `fit.measure`.

The `summary()` method returns a `data.frame` containing one row for each requested `fit.measure`, and columns containing the specified measure(s) of `central.tendency`, the posterior *SD*, and (if requested) the HPD credible-interval limits.

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Terrence D. Jorgensen (University of Amsterdam; <TJorgensen314@gmail.com>)

References

`rescale = "PPMC"` based on:

Hoofs, H., van de Schoot, R., Jansen, N. W., & Kant, I. (2017). Evaluating model fit in Bayesian confirmatory factor analysis with large samples: Simulation study introducing the BRMSEA. *Educational and Psychological Measurement*. doi:10.1177/0013164417709314

`rescale = "devM"` based on:

Garnier-Villarreal, M., & Jorgensen, T. D. (2020). Adapting Fit Indices for Bayesian Structural Equation Modeling: Comparison to Maximum Likelihood. *Psychological Methods*, 25(1), 46–70. <https://doi.org/dx.doi.org/10.1037/met0000224> (See also <https://osf.io/afkcw/>)

Other references:

Vehtari, A., Gelman, A., & Gabry, J. (2017). Practical Bayesian model evaluation using leave-one-out cross-validation and WAIC. *Statistics and Computing*, 27(5), 1413–1432. doi:10.1007/s11222-016-9696-4

Examples

```

## Not run:
HS.model <- ' visual  =~ x1 + x2 + x3
             textual =~ x4 + x5 + x6
             speed   =~ x7 + x8 + x9 '
## fit target model
fit1 <- bcfa(HS.model, data = HolzingerSwineford1939,
            n.chains = 2, burnin = 1000, sample = 1000)

## fit null model to calculate CFI, TLI, and NFI
null.model <- c(paste0("x", 1:9, " ~~ x", 1:9), paste0("x", 1:9, " ~ 1"))
fit0 <- bcfa(null.model, data = HolzingerSwineford1939,
            n.chains = 2, burnin = 1000, sample = 1000)

## calculate posterior distributions of fit indices

## The default method mimics fit indices derived from ML estimation
ML <- blavFitIndices(fit1, baseline.model = fit0)
ML
summary(ML)

## other options:

## - use Hoofs et al.'s (2017) PPMC-based method
## - use the estimated number of parameters from WAIC instead of LOO-IC
PPMC <- blavFitIndices(fit1, baseline.model = fit0,
                    pD = "waic", rescale = "PPMC")
## issues a warning about using rescale="PPMC" with N < 1000 (see Hoofs et al.)

## - specify only the desired measures of central tendency
## - specify a different "confidence" level for the credible intervals
summary(PPMC, central.tendency = c("mean","mode"), prob = .95)

## Access the posterior distributions for further investigation
head(distML <- data.frame(ML@indices))

## For example, diagnostic plots using the bayesplot package:

## distinguish chains
nChains <- blavInspect(fit1, "n.chains")
distML$Chain <- rep(1:nChains, each = nrow(distML) / nChains)

library(bayesplot)
mcmc_pairs(distML, pars = c("BRMSEA", "BMc", "BGammaHat", "BCFI", "BTLI"),
          diag_fun = "hist")
## Indices are highly correlated across iterations in both chains

## Compare to PPMC method
distPPMC <- data.frame(PPMC@indices)
distPPMC$Chain <- rep(1:nChains, each = nrow(distPPMC) / nChains)

```



```

mcmc_pairs(distPPMC, pars = c("BRMSEA", "BMc", "BGammaHat", "BCFI", "BTLI"),
           diag_fun = "dens")
## nonlinear relation between BRMSEA, related to the floor effect of BRMSEA
## that Hoofs et al. found for larger (12-indicator) models

## End(Not run)

```

blavInspect

Inspect or Extract Information from a Fitted blavaan Object

Description

The `blavInspect()` and `blavTech()` functions can be used to inspect/extract information that is stored inside (or can be computed from) a fitted `blavaan` object. This is similar to `lavaan`'s `lavInspect()` function.

Usage

```
blavInspect(blavobject, what, ...)
```

```
blavTech(blavobject, what, ...)
```

Arguments

<code>blavobject</code>	An object of class <code>blavaan</code> .
<code>what</code>	Character. What needs to be inspected/extracted? See Details for Bayes-specific options, and see lavaan 's <code>lavInspect()</code> for additional options. Note: the <code>what</code> argument is not case-sensitive (everything is converted to lower case.)
<code>...</code>	<code>lavaan</code> arguments supplied to <code>lavInspect()</code> ; see lavaan .

Details

Below is a list of Bayesian-specific values for the `what` argument; additional values can be found in the `lavInspect()` documentation.

`"start"`: A list of starting values for each chain, unless `inits="jags"` is used during model estimation. Aliases: `"starting.values"`, `"inits"`.

`"rhat"`: Each parameter's potential scale reduction factor for convergence assessment. Can also use `"psrf"` instead of `"rhat"`

`"ac.10"`: Each parameter's estimated lag-10 autocorrelation.

`"neff"`: Each parameters effective sample size, taking into account autocorrelation.

`"mcmc"`: An object of class `mcmc` containing the individual parameter draws from the MCMC run. Aliases: `"draws"`, `"samples"`.

`"mobj"`: The underlying `run.jags` or `stan` object that resulted from the MCMC run.

`"n.chains"`: The number of chains sampled.

"cp": The approach used for estimating covariance parameters ("srs" or "fa"); these are only relevant if using JAGS.

"dp": Default prior distributions used for each type of model parameter.

"postmode": Estimated posterior mode of each free parameter.

"postmean": Estimated posterior mean of each free parameter.

"postmedian": Estimated posterior median of each free parameter.

"lvs": An object of class mcmc containing latent variable (factor score) draws. In two-level models, use level = 1 or level = 2 to specify which factor scores you want.

"lvmeans": A matrix of mean factor scores (rows are observations, columns are variables). Use the additional level argument in the same way.

"hpd": HPD interval of each free parameter. In this case, the prob argument can be used to specify a number in (0,1) reflecting the desired percentage of the interval.

See Also

[lavInspect](#), [bcfa](#), [bsem](#), [bgrowth](#)

Examples

```
## Not run:
# The Holzinger and Swineford (1939) example
HS.model <- ' visual  =~ x1 + x2 + x3
             textual =~ x4 + x5 + x6
             speed   =~ x7 + x8 + x9 '

fit <- bcfa(HS.model, data = HolzingerSwineford1939,
            bcontrol = list(method = "rjparallel"))

# extract information
blavInspect(fit, "psrf")
blavInspect(fit, "hpd", prob = .9)

## End(Not run)
```

blavPredict	<i>Predict the values of latent variables, observed variables, and missing variables.</i>
-------------	---

Description

The purpose of the blavPredict() function is to compute various types of model predictions, conditioned on observed data. This differs somewhat from lavPredict() in lavaan.

Usage

```
blavPredict(object, newdata = NULL, type = "lv", level = 1L)
```

Arguments

object	An object of class <code>blavaan</code> .
newdata	Currently unused. (An optional <code>data.frame</code> , containing the same variables as the <code>data.frame</code> used when fitting the model in object.)
type	A character string. If "lv", estimated values for the latent variables in the model are computed. If "ov" or "yhat", predicted means for the observed variables in the model are computed. If "ypred" or "ydist", predicted values for the observed variables (including residual noise) are computed. If "ymis" or "ovmis", model predicted values ("imputations") for the missing data are computed. See details for further information.
level	For type = "lv", used to specify whether one desires the level 1 latent variables or level 2 latent variables.

Details

The `predict()` function calls the `blavPredict()` function with its default options.

Below, we provide more information about each type option. Most options only work for `target="stan"`, and "number of samples" is defined as the number of posterior samples across all chains.

`type="lv"`: The posterior distribution of latent variables conditioned on observed variables. Returns a list with "number of samples" entries, where each entry is a matrix where rows are observations and columns are latent variables.

`type="yhat"`: The posterior expected value of observed variables conditioned on the sampled latent variables. Returns a list with "number of samples" entries, where each entry is a matrix where rows are observations and columns are observed variables.

`type="ypred"`: The posterior predictive distribution of observed variables conditioned on the sampled latent variables (including residual variances). Returns a list with "number of samples" entries, where each entry is a data frame where rows are observations and columns are observed variables.

`type="ymis"`: The posterior predictive distribution of missing values conditioned on observed variables. Returns a matrix with "number of samples" rows and "number of missing variables" columns.

See Also

Users may also wish to generate the posterior predictive distribution of observed data, not conditioned on the latent variables; this would often be viewed as data from new clusters (people) that were not observed in the original dataset. For that, see `postdata()`.

Examples

```
## Not run:
data(HolzingerSwineford1939)

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

fit <- bcfa(HS.model, data = HolzingerSwineford1939, save.lvs = TRUE)
```

```

lapply(blavPredict(fit)[1:2], head) # first 6 rows of first 10 posterior samples
head(blavPredict(fit, type = "yhat")[[1]]) # top of first posterior sample

## multigroup models return a list of factor scores (one per group)
mgfit <- bcfa(HS.model, data = HolzingerSwineford1939, group = "school",
             group.equal = c("loadings","intercepts"), save.lvs = TRUE)

lapply(blavPredict(fit)[1:2], head)
head(blavPredict(fit, type = "ypred")[[1]])

## End(Not run)

```

blav_internal	<i>blavaan internal functions</i>
---------------	-----------------------------------

Description

Internal functions related to Bayesian model estimation. Not to be called by the user.

bsem	<i>Fit Structural Equation Models</i>
------	---------------------------------------

Description

Fit a Structural Equation Model (SEM).

Usage

```

bsem(..., cp = "srs",
      dp = NULL, n.chains = 3, burnin, sample,
      adapt, mcmcfile = FALSE, mcmcextra = list(), inits = "simple",
      convergence = "manual", target = "stan", save.lvs = FALSE,
      wiggle = NULL, wiggle.sd = 0.1, prisamp = FALSE, jags.ic = FALSE,
      seed = NULL, bcontrol = list())

```

Arguments

...	Default lavaan arguments. See lavaan .
cp	Handling of prior distributions on covariance parameters: possible values are "srs" (default) or "fa". Option "fa" is only available for target="jags".
dp	Default prior distributions on different types of parameters, typically the result of a call to dpriors(). See the dpriors() help file for more information.
n.chains	Number of desired MCMC chains.
burnin	Number of burnin/warmup iterations (not including the adaptive iterations, for target="jags"). Defaults to 4000 or target="jags" and 500 for Stan targets.

sample	The total number of samples to take after burnin. Defaults to 10000 for target="jags" and 1000 for Stan targets.
adapt	For target="jags", the number of adaptive iterations to use at the start of sampling. Defaults to 1000.
mcmcfile	If TRUE, the JAGS/Stan model will be written to file (in the lavExport directory). Can also supply a character string, which serves as the name of the directory to which files will be written.
mcmcextra	A list with potential names syntax (unavailable for target="stan"), monitor, data, and llnsamp. The syntax object is a text string containing extra code to insert in the JAGS/Stan model syntax. The data object is a list of extra data to send to the JAGS/Stan model. If moment_match_k_threshold is specified within data the looic of the model will be calculated using moment matching. The monitor object is a character vector containing extra JAGS/Stan parameters to monitor. The llnsamp object is only relevant to models with ordinal variables, and specifies the number of samples that should be drawn to approximate the model log-likelihood (larger numbers imply higher accuracy and longer time). This log-likelihood is specifically used to compute information criteria.
inits	If it is a character string, the options are currently "simple" (default), "Mplus", "prior", or "jags". In the first two cases, parameter values are set as though they will be estimated via ML (see lavaan). The starting parameter value for each chain is then perturbed from the original values through the addition of random uniform noise. If "prior" is used, the starting parameter values are obtained based on the prior distributions (while also trying to ensure that the starting values will not crash the model estimation). If "jags", no starting values are specified and JAGS will choose values on its own (and this will probably crash Stan targets). You can also supply a list of starting values for each chain, where the list format can be obtained from, e.g., <code>blavInspect(fit, "inits")</code> . Finally, you can specify starting values in a similar way to lavaan, using the lavaan <code>start</code> argument (see the lavaan documentation for all the options there). In this case, you should also set <code>inits="simple"</code> , and be aware that the same starting values will be used for each chain.
convergence	Useful only for target="jags". If "auto", parameters are sampled until convergence is achieved (via <code>autorun.jags()</code>). In this case, the arguments <code>burnin</code> and <code>sample</code> are passed to <code>autorun.jags()</code> as <code>startburnin</code> and <code>startsample</code> , respectively. Otherwise, parameters are sampled as specified by the user (or by the <code>run.jags</code> defaults).
target	Desired MCMC sampling, with "stan" (pre-compiled marginal approach) as default. Also available is "vb", which calls the <code>rstan</code> function <code>vb()</code> . Other options include "jags", "stancond", and "stanclassic", which sample latent variables and provide some greater functionality (because syntax is written "on the fly"). But they are slower and less efficient.
save.lvs	Should sampled latent variables (factor scores) be saved? Logical; defaults to FALSE
wiggle	Labels of equality-constrained parameters that should be "approximately" equal. Can also be "intercepts", "loadings", "regressions", "means".

wiggle.sd	The prior sd (of normal distribution) to be used in approximate equality constraints. Can be one value, or (for target="stan") a numeric vector of values that is the same length as wiggle.
prisamp	Should samples be drawn from the prior, instead of the posterior (target="stan" only)? Logical; defaults to FALSE
jags.ic	Should DIC be computed the JAGS way, in addition to the BUGS way? Logical; defaults to FALSE
seed	A vector of length n.chains (for target "jags") or an integer (for target "stan") containing random seeds for the MCMC run. If NULL, seeds will be chosen randomly.
bcontrol	A list containing additional parameters passed to run.jags (or autorun.jags) or stan. See the manpage of those functions for an overview of the additional parameters that can be set.

Details

The bsem function is a wrapper for the more general [blavaan](#) function, using the following default [lavaan](#) 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

- Edgar C. Merkle, Ellen Fitzsimmons, James Uanhoru, & Ben Goodrich (2021). Efficient Bayesian Structural Equation Modeling in Stan. *Journal of Statistical Software*, 100(6), 1-22. URL <http://www.jstatsoft.org/v100/i06/>.
- Edgar C. Merkle & Yves Rosseel (2018). blavaan: Bayesian Structural Equation Models via Parameter Expansion. *Journal of Statistical Software*, 85(4), 1-30. URL <http://www.jstatsoft.org/v85/i04/>.
- 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

[blavaan](#)

Examples

```
## Not run:
## 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
,

## unique priors for mv intercepts
fit <- bsem(model, data=PoliticalDemocracy,
           dp=dpriors(nu="normal(5,10)"))
summary(fit)

## End(Not run)

```

dpriors

Specify Default Prior Distributions

Description

Specify "default" prior distributions for classes of model parameters.

Usage

```
dpriors(..., target = "stan")
```

Arguments

...	Parameter names paired with desired priors (see example below).
target	Are the priors for jags, stan (default), or stanclassic?

Details

The prior distributions always use JAGS/Stan syntax and parameterizations. For example, the normal distribution in JAGS is parameterized via the precision, whereas the normal distribution in Stan is parameterized via the standard deviation.

User-specified prior distributions for specific parameters (using the `prior()` operator within the model syntax) always override prior distributions set using `dpriors()`.

The parameter names are:

- nu: Observed variable intercept parameters.
- alpha: Latent variable intercept parameters.
- lambda: Loading parameters.

- beta: Regression parameters.
- itheta: Observed variable precision parameters.
- ipsi: Latent variable precision parameters.
- rho: Correlation parameters (associated with covariance parameters).
- ibpsi: Inverse covariance matrix of blocks of latent variables (used for target="jags").
- tau: Threshold parameters (ordinal data only).
- delta: Delta parameters (ordinal data only).

Value

A character vector containing the prior distribution for each type of parameter.

References

- Edgar C. Merkle, Ellen Fitzsimmons, James Uanhoru, & Ben Goodrich (2021). Efficient Bayesian Structural Equation Modeling in Stan. *Journal of Statistical Software*, 100(6), 1-22. URL <http://www.jstatsoft.org/v100/i06/>.
- Edgar C. Merkle & Yves Rosseel (2018). blavaan: Bayesian Structural Equation Models via Parameter Expansion. *Journal of Statistical Software*, 85(4), 1-30. URL <http://www.jstatsoft.org/v85/i04/>.

See Also

[bcfa](#), [bsem](#), [bgrowth](#)

Examples

```
dpriors(nu = "normal(0,10)", lambda = "normal(0,1)", rho = "beta(3,3)")
```

plot.blavaan

blavaan Diagnostic Plots

Description

Convenience functions to create plots of blavaan objects, via the bayesplot package.

Usage

```
## S3 method for class 'blavaan'
plot(x, pars = NULL, plot.type = "trace", showplot = TRUE, ...)
```


Arguments

<code>x</code>	An object of class <code>blavaan</code> .
<code>pars</code>	Parameter numbers to plot, where the numbers correspond to the order of parameters as reported by <code>coef()</code> (also as shown in the 'free' column of the <code>parTable</code>). If no numbers are provided, all free parameters will be plotted.
<code>plot.type</code>	The type of plot desired. This should be the name of a MCMC function, without the <code>mcmc_</code> prefix.
<code>showplot</code>	Should the plot be sent to the graphic device? Defaults to <code>TRUE</code> .
<code>...</code>	Other arguments sent to the <code>bayesplot</code> function.

Details

In previous versions of `blavaan`, the plotting functionality was handled separately for JAGS and for Stan (using plot functionality in packages `runjags` and `rstan`, respectively). For uniformity, all plotting functionality is now handled by `bayesplot`. If users desire additional functionality that is not immediately available, they can extract the matrix of MCMC draws via `as.matrix(blavInspect(x, 'mcmc'))`.

Value

An invisible `ggplot` object that, if desired, can be further customized.

Examples

```
## Not run:
HS.model <- ' visual  =~ x1 + x2 + x3
             textual =~ x4 + x5 + x6
             speed   =~ x7 + x8 + x9 '

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

# trace plots of free loadings
plot(fit, pars = 1:6)

## End(Not run)
```

Description

This function allows users to conduct a posterior predictive model check to assess the global or local fit of a latent variable model using any discrepancy function that can be applied to a [lavaan](#) model.

Usage

```
ppmc(object, thin = 1, fit.measures = c("srmr","chisq"), discFUN = NULL,
      conditional = FALSE)

## S4 method for signature 'blavPPMC'
summary(object, ...)

## S3 method for class 'ppmc'
summary(object, discFUN, dist = c("obs","sim"),
        central.tendency = c("mean","median","mode"),
        hpd = TRUE, prob = .95, to.data.frame = FALSE, diag = TRUE,
        sort.by = NULL, decreasing = FALSE)

## S3 method for class 'blavPPMC'
plot(x, ..., discFUN, element, central.tendency = "",
     hpd = TRUE, prob = .95, nd = 3)

## S3 method for class 'blavPPMC'
hist(x, ..., discFUN, element, hpd = TRUE, prob = .95,
     printLegend = TRUE, legendArgs = list(x = "topleft"),
     densityArgs = list(), nd = 3)

## S3 method for class 'blavPPMC'
pairs(x, discFUN, horInd = 1:DIM, verInd = 1:DIM,
     printLegend = FALSE, ...)
```

Arguments

<code>object, x</code>	An object of class <code>blavaan</code> .
<code>thin</code>	Optional integer indicating how much to thin each chain. Default is 1L, indicating not to thin the chains in object.
<code>fit.measures</code>	character vector indicating the names of global discrepancy measures returned by <code>fitMeasures</code> . Ignored unless <code>discFUN</code> is NULL, but users may include <code>fitMeasures</code> in the list of discrepancy functions in <code>discFUN</code> . For ordinal models, the "log1" or "chisq" computations are done via <code>lavaan</code> .
<code>discFUN</code>	function, or a list of functions, that can be called on an object of class <code>lavaan</code> . Each function must return an object whose <code>mode</code> is numeric, but may be a vector, matrix, or multidimensional array. In the summary and plot methods, <code>discFUN</code> is a character indicating which discrepancy function to summarize.
<code>conditional</code>	logical indicating whether or not, during artificial data generation, we should condition on the estimated latent variables. Requires the model to be estimated with <code>save.lvs = TRUE</code> .
<code>element</code>	numeric or character indicating the index (in each dimension of the <code>discFUN</code> output, if multiple) to plot.

horInd,verInd	Similar to <code>element</code> , but a numeric or character vector indicating the indices of a matrix to plot in a scatterplot matrix. If <code>horInd==verInd</code> , histograms will be plotted in the upper triangle.
dist	character indicating whether to summarize the distribution of <code>discFUN</code> on either the observed or simulated data.
central.tendency	character indicating which statistics should be used to characterize the location of the posterior (predictive) distribution. By default, all 3 statistics are returned for the summary method, but none for the plot method. The posterior mean is labeled EAP for <i>expected a posteriori</i> estimate, and the mode is labeled MAP for <i>modal a posteriori</i> estimate.
hpd	logical indicating whether to calculate the highest posterior density (HPD) credible interval for <code>discFUN</code> .
prob	The "confidence" level of the credible interval(s).
nd	The number of digits to print in the scatterplot.
to.data.frame	logical indicating whether the summary of a symmetric 2-dimensional matrix returned by <code>discFUN</code> should have its unique elements stored in rows of a <code>data.frame</code> that can be sorted for convenience of identifying large discrepancies. If <code>discFUN</code> returns an asymmetric 2-dimensional matrix, the list of matrices returned by the summary can also be converted to a <code>data.frame</code> .
diag	Passed to <code>lower.tri</code> if <code>to.data.frame=TRUE</code> .
sort.by	character. If summary returns a <code>data.frame</code> , it can be sorted by this column name using <code>order</code> . Note that if <code>discFUN</code> returns an asymmetric 2-dimensional matrix, each <code>data.frame</code> in the returned list will be sorted independently, so the rows are unlikely to be consistent across summary statistics.
decreasing	Passed to <code>order</code> if <code>!is.null(sort.by)</code> .
...	Additional graphical parameters to be passed to <code>plot.default</code> .
printLegend	logical. If TRUE (default), a legend will be printed with the histogram
legendArgs	list of arguments passed to the <code>legend</code> function. The default argument is a list placing the legend at the top-left of the figure.
densityArgs	list of arguments passed to the <code>density</code> function, used to obtain densities for the <code>hist</code> method.

Value

An S4 object of class `blavPPMC` consisting of 5 list slots:

@discFUN	The user-supplied <code>discFUN</code> , or the call to <code>fitMeasures</code> that returns <code>fit.measures</code> .
@dims	The dimensions of the object returned by each <code>discFUN</code> .
@PPP	The posterior predictive p value for each <code>discFUN</code> element.
@obsDist	The posterior distribution of realize values of <code>discFUN</code> applied to observed data.
@simDist	The posterior predictive distribution of values of <code>discFUN</code> applied to data simulated from the posterior samples.

The `summary()` method returns a numeric vector if `discFUN` returns a scalar, a data.frame with one discrepancy function per row if `discFUN` returns a numeric vector, and a list with one summary statistic per element if `discFUN` returns a matrix or multidimensional array.

The `plot` and `pairs` methods invisibly return NULL, printing a plot (or scatterplot matrix) to the current device.

The `hist` method invisibly returns a list or arguments that can be passed to the function for which the list element is named. Users can edit the arguments in the list to customize their histograms.

Author(s)

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References

Levy, R. (2011). Bayesian data-model fit assessment for structural equation modeling. *Structural Equation Modeling*, 18(4), 663–685. doi:10.1080/10705511.2011.607723

Examples

```
## Not run:
HS.model <- ' visual  =~ x1 + x2 + x3
             textual =~ x4 + x5 + x6
             speed   =~ x7 + x8 + x9 '

## fit single-group model
fit <- bcfa(HS.model, data = HolzingerSwineford1939,
           n.chains = 2, burnin = 1000, sample = 500)

## fit multigroup model
fitg <- bcfa(HS.model, data = HolzingerSwineford1939,
            n.chains = 2, burnin = 1000, sample = 500, group = "school")

## Use fit.measures as a shortcut for global fitMeasures only
## - Note that indices calculated from the "df" are only appropriate under
## noninformative priors, such that pD approximates the number of estimated
## parameters counted under ML estimation; incremental fit indices
## introduce further complications)

AFIs <- ppmc(fit, thin = 10, fit.measures = c("srmr", "chisq", "rmsea", "cfi"))
summary(AFIs) # summarize the whole vector in a data.frame
hist(AFIs, element = "rmsea") # only plot one discrepancy function at a time
plot(AFIs, element = "srmr")

## define a list of custom discrepancy functions
## - (global) fit measures
## - (local) standardized residuals

discFUN <- list(global = function(fit) {
  fitMeasures(fit, fit.measures = c("cfi", "rmsea", "srmr", "chisq"))
},
std.cov.resid = function(fit) lavResiduals(fit, zstat = FALSE,
```

```

summary = FALSE)$cov,
std.mean.resid = function(fit) lavResiduals(fit, zstat = FALSE,
summary = FALSE)$mean)

out1g <- ppmc(fit, discFUN = discFUN)

## summarize first discrepancy by default (fit indices)
summary(out1g)
## some model-implied correlations look systematically over/underestimated
summary(out1g, discFUN = "std.cov.resid", central.tendency = "EAP")
hist(out1g, discFUN = "std.cov.resid", element = c(1, 7))
plot(out1g, discFUN = "std.cov.resid", element = c("x1", "x7"))
## For ease of investigation, optionally export summary as a data.frame,
## sorted by size of average residual
summary(out1g, discFUN = "std.cov.resid", central.tendency = "EAP",
to.data.frame = TRUE, sort.by = "EAP")
## or sorted by size of PPP
summary(out1g, discFUN = "std.cov.resid", central.tendency = "EAP",
to.data.frame = TRUE, sort.by = "PPP_sim_LessThan_obs")

## define a list of custom discrepancy functions for multiple groups
## (return each group's numeric output using a different function)

disc2g <- list(global = function(fit) {
fitMeasures(fit, fit.measures = c("cfi", "rmsea", "mfi", "srmr", "chisq"))
},
cor.resid1 = function(fit) lavResiduals(fit, zstat = FALSE,
type = "cor.bollen",
summary = FALSE)[[1]]$cov,
cor.resid2 = function(fit) lavResiduals(fit, zstat = FALSE,
type = "cor.bollen",
summary = FALSE)[[2]]$cov)

out2g <- ppmc(fitg, discFUN = disc2g, thin = 2)
## some residuals look like a bigger problem in one group than another
pairs(out2g, discFUN = "cor.resid1", horInd = 1:3, verInd = 7:9) # group 1
pairs(out2g, discFUN = "cor.resid2", horInd = 1:3, verInd = 7:9) # group 2

## print all to file: must be a LARGE picture. First group 1 ...
png("cor.resid1.png", width = 1600, height = 1200)
pairs(out2g, discFUN = "cor.resid1")
dev.off()
## ... then group 2
png("cor.resid2.png", width = 1600, height = 1200)
pairs(out2g, discFUN = "cor.resid2")
dev.off()

## End(Not run)

```

Description

Standardized posterior distribution of a latent variable model.

Usage

```
standardizedPosterior(object, ...)
```

Arguments

`object` An object of class `blavaan`.
`...` Additional arguments passed to `lavaan`'s `standardizedSolution()`

Value

A matrix containing standardized posterior draws, where rows are draws and columns are parameters.

Note

The only allowed `standardizedSolution()` arguments are `type`, `cov.std`, `remove.eq`, `remove.ineq`, and `remove.def`. Other arguments are not immediately suited to posterior distributions.

Examples

```
## Not run:
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 <- bsem(model, data=PoliticalDemocracy,
            dp=dpriors(nu="dnorm(5,1e-2)"),
            bcontrol=list(method="rjparallel"))

standardizedPosterior(fit)

## End(Not run)
```

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