

# Package ‘blavaan’

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**Title** Bayesian Latent Variable Analysis

**Version** 0.3-6

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

**License** GPL (>= 3)

**ByteCompile** true

**Depends** R(>= 3.5.0), methods, lavaan(>= 0.6-4), Rcpp(>= 0.12.15)

**Imports** stats, utils, graphics, MCMCpack, coda, mnormt, nonnest2(>= 0.5-2), loo(>= 2.0), rstan(>= 2.19.2), rstantools(>= 1.5.0)

**LinkingTo** StanHeaders (>= 2.18.1), rstan (>= 2.19.2), BH (>= 1.69.0), Rcpp (>= 0.12.15), RcppEigen (>= 0.3.3.4.0)

**Suggests** runjags(>= 2.0.4-2), modeest, rjags, semTools, parallel, testthat(>= 2.0.0)

**SystemRequirements** GNU make

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bcfa	<i>Fit Confirmatory Factor Analysis Models</i>
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## 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 = "prior",
      convergence = "manual", target = "stan", save.lvs = FALSE,
      jags.ic = FALSE, seed = NULL, bcontrol = list())
```

## Arguments

...	Default lavaan arguments. See <a href="#">lavaan</a> .
cp	Handling of prior distributions on covariance parameters: possible values are "srs" or "fa". Option "srs" is more flexible and better from a theoretical standpoint, but it is also slower.
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 iterations, NOT including the adaptive iterations.
sample	The total number of samples to take after burnin.
adapt	The number of adaptive iterations to use at the start of the simulation.
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> and <code>monitor</code> . The <code>syntax</code> object is a text string containing extra code to insert in the JAGS/Stan model syntax, and the <code>monitor</code> object is a character vector containing extra JAGS/Stan parameters to sample.

<code>inits</code>	If it is a character string, the options are currently "simple", "Mplus", "prior" (default), and "jags". In the first two cases, parameter values are set as though they will be estimated via ML (see <a href="#">lavaan</a> ). The starting parameter value for each chain is then perturbed from the original values through the addition of 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. If <code>start</code> is a fitted object of class <a href="#">lavaan</a> , the estimated values of the corresponding parameters will be extracted, then perturbed in the manner described above. If it is a model list, for example the output of the <code>parameterEstimates()</code> function, the values of the <code>est</code> or <code>start</code> or <code>ustart</code> column (whichever is found first) will be extracted.
<code>convergence</code>	If "auto", parameters will be 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 package, with "stan" (pre-compiled) as default. Other options include "jags" and "stanclassic", which provide greater functionality than "stan" but is much slower.
<code>save.lvs</code>	Should sample latent variables (factor scores) be saved? 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 target "jags") or an integer (for target "stan") 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.

### 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

- 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/>.
- 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**[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 = "prior", convergence = "manual", target = "stan",
save.lvs = FALSE, jags.ic = FALSE, seed = NULL, bcontrol = list())
```

**Arguments**

...	Default lavaan arguments. See <a href="#">lavaan</a> .
cp	Handling of prior distributions on covariance parameters: possible values are "srs" or "fa". Option "srs" is more flexible and better from a theoretical standpoint, but it is also slower.
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 iterations, NOT including the adaptive iterations.
sample	The total number of samples to take after burnin.
adapt	The number of adaptive iterations to use at the start of the simulation.
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 syntax and monitor. The syntax object is a text string containing extra code to insert in the JAGS/Stan model syntax, and the monitor object is a character vector containing extra JAGS/Stan parameters to sample.
inits	If it is a character string, the options are currently "simple", "Mplus", "prior" (default), and "jags". In the first two cases, parameter values are set as though they will be estimated via ML (see <a href="#">lavaan</a> ). The starting parameter value for each chain is then perturbed from the original values through the addition of 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. If start is a fitted object of class <a href="#">lavaan</a> , the estimated values of the corresponding parameters will be extracted, then perturbed in the manner described above. If it is a model list, for example the output of the parameterEstimates() function, the values of the est or start or ustart column (whichever is found first) will be extracted.
convergence	If "auto", parameters will be sampled until convergence is achieved (via autorun.jags). In this case, the arguments burnin and sample are passed to autorun.jags as startburnin and startsample, respectively. Otherwise, parameters are sampled as specified by the user (or by the run.jags defaults).
target	Desired MCMC package, with "stan" (pre-compiled) as default. Other options include "jags" and "stanclassic", which provide greater functionality than "stan" but is much slower.
save.lvs	Should sample latent variables (factor scores) be saved? 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 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

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/>.

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

[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 = "prior",
  convergence = "manual", target = "stan", save.lvs = FALSE,
  jags.ic = FALSE, seed = NULL, bcontrol = list())
```

**Arguments**

...	Default lavaan arguments. See <a href="#">lavaan</a> .
cp	Handling of prior distributions on covariance parameters: possible values are "srs" or "fa". Option "srs" is more flexible and better from a theoretical standpoint, but it is also slower.
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 iterations, NOT including the adaptive iterations.
sample	The total number of samples to take after burnin.
adapt	The number of adaptive iterations to use at the start of the simulation.
mcmcfile	If TRUE, the JAGS/Stan model and data will be written to files (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> and <code>monitor</code> . The <code>syntax</code> object is a text string containing extra code to insert in the JAGS/Stan model syntax, and the <code>monitor</code> object is a character vector containing extra JAGS/Stan parameters to sample.
inits	If it is a character string, the options are currently "simple", "Mplus", "prior" (default), or "jags". In the first two cases, parameter values are set as though they will be estimated via ML (see <a href="#">lavaan</a> ). 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. If <code>start</code> is a fitted object of class <a href="#">lavaan</a> , the estimated values of the corresponding parameters will be extracted, then perturbed in the manner described above. If it is a model list, for example the output of the <code>parameterEstimates()</code> function, the values of the <code>est</code> or <code>start</code> or <code>ustart</code> column (whichever is found first) will be extracted.
convergence	If "auto", parameters will be 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 package, with "stan" (pre-compiled) as default. Other options include "jags" and "stanclassic", which provide greater functionality than "stan" but is much slower.
save.lvs	Should sample latent variables (factor scores) be saved? 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 `run.jags` (or `autorun.jags`) or `stan`. 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

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/>.

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

```
## 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)
```

---

`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 (unused for now).

**Details**

This function approximates the log-Bayes factor of two candidate models using the Laplace approximation to each model's marginal log-likelihood.

**Value**

The log-Bayes factor approximation, along with each model's approximate marginal log-likelihood.

**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.

**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  $\chi^2$ -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, 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 $\chi^2$ 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 <code>rescale = "MCMC"</code> , the user may request any indices returned by <code>fitMeasures</code> for objects of class <code>lavaan</code> .
baseline.model	If not NULL, an object of class <code>blavaan</code> , representing a user-specified baseline model. If a <code>baseline.model</code> is provided, incremental fit indices (BCFI, BTLI, or BNFI) can be requested in <code>fit.measures</code> . Ignored if <code>rescale = "MCMC"</code> .
central.tendency	character 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 <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 each fit index.

prob            The "confidence" level of the credible interval(s).

### 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  $\chi^2$  (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.

### Author(s)

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### 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-Villareal, M., & Jorgensen, T. D. (in press). Adapting fit indices for Bayesian SEM: Comparison to maximum likelihood. *Psychological Methods*. doi: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, cp = "fa",
            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, cp = "fa",
            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)

```

## 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 <code>lavaan</code> '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>	Default <code>lavaan</code> arguments supplied to <code>lavInspect()</code> ; see <code>lavaan</code> .

## 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"`.

`"psrf"`: Each parameter's Gelman-Rubin PSRF (potential scale reduction factor) for convergence assessment.

`"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"`.

`"mcoobj"`: 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"`).

`"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.

`"lvmeans"`: A matrix of mean factor scores (rows are observations, columns are variables).

`"hpd"`: HPD interval of each free parameter. In this case, an additional argument `level` can be supplied to specify a number in (0,1) reflecting the 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,
           jagcontrol=list(method="rjparallel"))

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

## End(Not run)
```

---

blav\_internal

*blavaan internal functions*

---

**Description**

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

---

bsem

*Fit Structural Equation Models*

---

**Description**

Fit a Structural Equation Model (SEM).

**Usage**

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

**Arguments**

...	Default lavaan arguments. See <a href="#">lavaan</a> .
cp	Handling of prior distributions on covariance parameters: possible values are "srs" or "fa". Option "srs" is more flexible and better from a theoretical standpoint, but it is also slower.
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 iterations, NOT including the adaptive iterations.
sample	The total number of samples to take after burnin.
adapt	The number of adaptive iterations to use at the start of the simulation.
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> and <code>monitor</code> . The <code>syntax</code> object is a text string containing extra code to insert in the JAGS/Stan model syntax, and the <code>monitor</code> object is a character vector containing extra JAGS/Stan parameters to sample.
inits	If it is a character string, the options are currently "simple", "Mplus", "prior" (default), and "jags". In the first two cases, parameter values are set as though they will be estimated via ML (see <a href="#">lavaan</a> ). The starting parameter value for each chain is then perturbed from the original values through the addition of 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. If <code>start</code> is a fitted object of class <a href="#">lavaan</a> , the estimated values of the corresponding parameters will be extracted, then perturbed in the manner described above. If it is a model list, for example the output of the <code>parameterEstimates()</code> function, the values of the <code>est</code> or <code>start</code> or <code>ustart</code> column (whichever is found first) will be extracted.
convergence	If "auto", parameters will be 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 package, with "stan" (pre-compiled) as default. Other options include "jags" and "stanclassic", which provide greater functionality than "stan" but is much slower.
save.lvs	Should sample latent variables (factor scores) be saved? 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 `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

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/>.

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

[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; parallel chains
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 & 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)")
```

---

ppmc

*Posterior Predictive Model Checks*

---

## 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)

## S4 method for signature 'blavPPMC'
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> . If the first measure is either "logl" or "chisq", only the $\chi^2$ fit statistic's posterior (predictive) distributions will be returned.
<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>element</code>	numeric or character indicating the index (in each dimension of the <code>discFUN</code> output, if multiple) to plot.
<code>horInd, verInd</code>	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.
<code>dist</code>	character indicating whether to summarize the distribution of <code>discFUN</code> on either the observed or simulated data.
<code>central.tendency</code>	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.
<code>hpd</code>	logical indicating whether to calculate the highest posterior density (HPD) credible interval for <code>discFUN</code> .
<code>prob</code>	The "confidence" level of the credible interval(s).
<code>nd</code>	The number of digits to print in the scatterplot.
<code>to.data.frame</code>	logical indicating whether the summary of a 2-dimensional matrix returned by <code>discFUN</code> should have its unique elements stored in rows of a data.frame that can be sorted for convenience of identifying large discrepancies.
<code>diag</code>	Passed to <code>lower.tri</code> if <code>to.data.frame=TRUE</code> .
<code>sort.by</code>	character. If summary returns a data.frame, it can be sorted by this column name using <code>order</code> .
<code>decreasing</code>	Passed to <code>order</code> if <code>!is.null(sort.by)</code> .
<code>...</code>	Additional graphical parameters to be passed to <code>plot.default</code> .
<code>printLegend</code>	logical. If TRUE (default), a legend will be printed with the histogram
<code>legendArgs</code>	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.
<code>densityArgs</code>	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:

<code>@discFUN</code>	The user-supplied <code>discFUN</code> , or the call to <code>fitMeasures</code> that returns <code>fit.measures</code> .
<code>@dims</code>	The dimensions of the object returned by each <code>discFUN</code> .
<code>@PPP</code>	The posterior predictive $p$ value for each <code>discFUN</code> element.
<code>@obsDist</code>	The posterior distribution of realize values of <code>discFUN</code> applied to observed data.
<code>@simDist</code>	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, cp = "fa",
           target = "jags", bcontrol = list(method = "rjparallel"),
           n.chains = 2, burnin = 1000, sample = 500)
## fit multigroup model
fitg <- bcfa(HS.model, data = HolzingerSwineford1939, cp = "fa",
            target = "jags", bcontrol = list(method = "rjparallel"),
            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)

```

---

standardizedPosterior *Standardized Posterior*

---

### Description

Standardized posterior distribution of a latent variable model.

### Usage

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

### Arguments

object	An object of class <code>blavaan</code> .
...	Additional arguments passed to <code>lavaan</code> 's <code>standardizedSolution()</code>

### 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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