

# Package ‘bootnet’

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**Type** Package

**Title** Bootstrap Methods for Various Network Estimation Routines

**Version** 0.3

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**Depends** ggplot2, R (>= 3.0.0)

**Imports** methods, IsingFit, qgraph, dplyr (>= 0.3.0.2), gtools,  
corpcor, IsingSampler, mvtnorm, abind, Matrix, parallel, huge,  
parcor

**Suggests** psych

**Description** Bootstrap methods to assess accuracy and stability of estimated network structures and centrality indices. Allows for flexible specification of any undirected network estimation procedure in R, and offers default sets for 'qgraph', 'IsingFit', 'IsingSampler', 'glasso', 'huge' and 'parcor' packages.

**License** GPL-2

**NeedsCompilation** no

**Repository** CRAN

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anRpackage-package      *Bootstrap Methods for Various Network Estimation Routines*

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**Description**

Bootstrap standard errors on various network estimation routines, such as EBICglasso from the qgraph package and IsingFit from the IsingFit package. See [bootnet](#)

**Details**

Package: bootnet  
Type: Package  
Version: 0.1  
Date: 2015-03-01  
License: GPL-2

**Author(s)**

Sacha Epskamp

Maintainer: Sacha Epskamp <mail@sachaepskamp.com>

**See Also**

[bootnet](#)

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binarize      *Binarizes a dataset*

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**Description**

This function will transform data into binary data (0,1). If the data is already binary, this function does nothing.

**Usage**

```
binarize(x, split = "median", na.rm = TRUE, removeNArows = TRUE)
```

**Arguments**

x	A data frame or matrix
split	Either a function to split on (as character or as function) or a vector. e.g., split = "mean" will split every variable on the mean of that variable, split=2 will make every value above 2 a 1 and every value below 2 a 0 and a vector of the same length as each variable in the dataset will use those elements to split.
na.rm	The na.rm argument used in the split function.
removeNArows	Logical, should rows with NA be removed?

**Value**

A binarized data frame

**Author(s)**

Sacha Epskamp <mail@sachaepskamp.com>

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 bootnet

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*Bootstrapped network estimation*


---

**Description**

This function can be used to bootstrap network estimation methods so that the spread of parameter and centrality estimates can be assessed. Most important methods are type = 'nonparametric' for the non-parametric bootstrap and type = 'case' for the case-dropping bootstrap. See also Epskamp, Borsboom and Fried (2016) for more details.

**Usage**

```
bootnet(data, nBoots = 1000, default = c("none", "EBICglasso",
    "pcor", "IsingFit", "IsingLL"), type =
    c("nonparametric", "parametric", "node", "person",
    "jackknife", "case"), nCores = 1, statistics = c("edge"
    , "strength", "closeness", "betweenness"), model = c("detect",
    "GGM", "Ising"), prepFun, prepArgs, estFun, estArgs,
    graphFun, graphArgs, intFun, intArgs, verbose = TRUE,
    labels, alpha = 1, subNodes = 2:(ncol(data) - 1),
    subPersons = round(seq(0.25, 0.95, length = 10) *
    nrow(data)), computeCentrality = TRUE, propBoot = 1,
    replacement = TRUE, graph, sampleSize, intercepts)
```

**Arguments**

data	A data frame or matrix containing the raw data. Must be numeric, integer or ordered factors.
nBoots	Number of bootstraps
default	A string indicating the method to use. See documentation at <a href="#">estimateNetwork</a> .
type	The kind of bootstrap method to use.
nCores	Number of cores to use in computing results. Set to 1 to not use parallel computing.
statistics	Vector indicating which statistics to store. Can contain "edge", "strength", "closeness", "betweenness", "length" and "distance". By default, length and distance are not stored.
model	The modeling framework to use. Automatically detects if data is binary or not.
prepFun	See documentation at <a href="#">estimateNetwork</a> .
prepArgs	See documentation at <a href="#">estimateNetwork</a> .
estFun	See documentation at <a href="#">estimateNetwork</a> .
estArgs	See documentation at <a href="#">estimateNetwork</a> .
graphFun	See documentation at <a href="#">estimateNetwork</a> .
graphArgs	See documentation at <a href="#">estimateNetwork</a> .
intFun	See documentation at <a href="#">estimateNetwork</a> .
intArgs	See documentation at <a href="#">estimateNetwork</a> .
verbose	Logical. Should progress of the function be printed to the console?
labels	A character vector containing the node labels. If omitted the column names of the data are used.
alpha	The centrality tuning parameter as used in <a href="#">centrality</a> .
subNodes	Range of nodes to sample in node-drop bootstrap
subPersons	Range of persons to sample in person-drop bootstrap
computeCentrality	Logical, should centrality be computed?
propBoot	Proportion of persons to sample in bootstraps. Set to lower than 1 for m out of n bootstrap
replacement	Logical, should replacement be used in bootstrap sampling?
graph	A given network structure to use in parametric bootstrap.
sampleSize	The samplesize to use in parametric bootstrap.
intercepts	Intercepts to use in parametric bootstrap.

**Value**

A bootnet object with the following elements:

sampleTable	A data frame containing all estimated values on the real sample.
bootTable	A data frame containing all estimated values on all bootstrapped samples.
sample	A bootnetResult object with plot and print method containing the estimated network of the real sample.
boots	A list of bootnetResult objects containing the raw bootstrap results.

**Author(s)**

Sacha Epskamp <mail@sachaepskamp.com>

**References**

Epskamp, S., Borsboom, D., & Fried, E. I. (2016). Estimating psychological networks and their accuracy: a tutorial paper. arXiv preprint, arXiv:1604.08462.

**See Also**

[estimateNetwork](#), [differenceTest](#), [corStability](#), [plot.bootnet](#), [summary.bootnet](#)

**Examples**

```
# BFI Extraversion data from psych package:
library("psych")
data(bfi)
bfiSub <- bfi[,1:25]

# Estimate network:
Network <- estimateNetwork(bfiSub, default = "EBICglasso")

# Centrality indices:
library("qgraph")
centralityPlot(Network)

## Not run:
# Estimated network:
plot(Network, layout = 'spring')

### Non-parametric bootstrap ###
# Bootstrap 1000 values, using 8 cores:
Results1 <- bootnet(Network, nBoots = 1000, nCores = 8)

# Plot bootstrapped edge CIs:
plot(Results1, labels = FALSE, order = "sample")

# Plot significant differences (alpha = 0.05) of edges:
plot(Results1, "edge", plot = "difference", onlyNonZero = TRUE,
     order = "sample")

# Plot significant differences (alpha = 0.05) of node strength:
plot(Results1, "strength", plot = "difference")

# Test for difference in strength between node "A1" and "C2":
differenceTest(Results, "A1", "C2", "strength")

### Case-drop bootstrap ###
# Bootstrap 1000 values, using 8 cores:
Results2 <- bootnet(Network, nBoots = 1000, nCores = 8,
                   type = "case")
```

```
# Plot centrality stability:
plot(Results2)

# Compute CS-coefficients:
corStability(Results2)

## End(Not run)
```

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corStability	<i>Correlation stability coefficient</i>
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### Description

This coefficient denotes the estimated maximum number of cases that can be dropped from the data to retain, with 95% probability, a correlation of at least 0.7 (default) between statistics based on the original network and statistics computed with less cases. This coefficient should not be below 0.25 and is preferably above 0.5. See also Epskamp, Borsboom and Fried (2016) for more details.

### Usage

```
corStability(x, cor = 0.7, statistics = c("strength", "closeness", "betweenness"))
```

### Arguments

x	Output of <a href="#">bootnet</a> . Must be case-drop bootstrap.
cor	The correlation level to test at.
statistics	The statistic(s) to test for.

### Author(s)

Sacha Epskamp <[mail@sachaepskamp.com](mailto:mail@sachaepskamp.com)>

### References

Epskamp, S., Borsboom, D., & Fried, E. I. (2016). Estimating psychological networks and their accuracy: a tutorial paper. arXiv preprint, arXiv:1604.08462.

### See Also

[bootnet](#)

## Examples

```
## Not run:
# BFI Extraversion data from psych package:
library("psych")
data(bfi)
bfiSub <- bfi[,1:25]

# Estimate network:
Network <- estimateNetwork(bfiSub, default = "EBICglasso")

# Bootstrap 1000 values, using 8 cores:
# Bootstrap 1000 values, using 8 cores:
Results2 <- bootnet(Network, nBoots = 1000, nCores = 8,
                    type = "case")

# Compute CS-coefficients:
corStability(Results2)

## End(Not run)
```

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differenceTest	<i>Bootstrapped difference test</i>
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## Description

This function computes the bootstrapped difference test for edge-weights and centrality indices. A confidence interval is constructed on the difference of two values, and the test is deemed significant if zero is not in this confidence interval. See also Epskamp, Borsboom and Fried (2016) for more details.

## Usage

```
differenceTest(bootobject, x, y, measure = c("strength", "closeness", "betweenness"),
              alpha = 0.05, x2, y2, verbose = TRUE)
```

## Arguments

bootobject	Output of <code>bootnet</code> . Must be nonparametric or parametric bootstrap.
x	A character string indicating the ID of a node or an edge, or a number indicating the node or edge. For an edge, can be e.g., "1--2" or "x = 1, x2 = 2".
y	A character string indicating the ID of a node or an edge, or a number indicating the node or edge. For an edge, can be e.g., "1--2" or "y = 1, y2 = 2".
measure	Measure to test. Can be "strength", "closeness", "betweenness", "edge" or "distance".
alpha	Significance level to test at. Note that the actual significance level is influenced by the number of bootstrap samples, and is returned in a message.
x2	Second node in an edge. optional.

y2                    Second node in an edge. optional.  
 verbose             Logical, should the message indicating actual significance level be printed?

**Author(s)**

Sacha Epskamp <mail@sachaepskamp.com>

**References**

Epskamp, S., Borsboom, D., & Fried, E. I. (2016). Estimating psychological networks and their accuracy: a tutorial paper. arXiv preprint, arXiv:1604.08462.

**See Also**

[bootnet](#)

**Examples**

```
## Not run:
# BFI Extraversion data from psych package:
library("psych")
data(bfi)
bfiSub <- bfi[,1:25]

# Estimate network:
Network <- estimateNetwork(bfiSub, default = "EBICglasso")

# Bootstrap 1000 values, using 8 cores:
Results1 <- bootnet(Network, nBoots = 1000, nCores = 8)

# Test for difference in strength between node "A1" and "C2":
differenceTest(Results, "A1", "C2", "strength")

# Test for difference between edge N1--N2 and N3--N4:
differenceTest(Results, "N1--N2", "N3--N4", "edge")

# Alternative:
differenceTest(Results, x = "N1", x2 = "N2", y = "N3",
              y2 = "N4", measure = "edge")

## End(Not run)
```

---

estimateNetwork

*Estimate a network structure*

---

**Description**

This function allows for flexible estimation of a network structure using various R packages and model frameworks. This is typically done by using one of the default sets. See details for manual specification. See also Epskamp, Borsboom and Fried (2016) for more details.



**Usage**

```
estimateNetwork(data, default = c("none", "EBICglasso", "pcor", "IsingFit", "IsingLL",
  "huge", "adalasso"), prepFun, prepArgs, estFun, estArgs,
  graphFun, graphArgs, intFun, intArgs, labels, verbose = TRUE)
```

**Arguments**

data	A data frame or matrix containing the raw data. Must be numeric, integer or ordered factors.
default	A string indicating the method to use. Specifying a default sets default values to prepFun, prepArgs, estFun, estArgs, graphFun, graphArgs, intFun and intArgs. Setting a default can be omitted but that does require specifying all above mentioned arguments. Current options are: <p>"EBICglasso" Gaussian Markov random field estimation using graphical LASSO and extended Bayesian information criterion to select optimal regularization parameter. Using <a href="#">EBICglasso</a> from the qgraph package.</p> <p>"IsingFit" Ising model estimation using LASSO regularized nodewise logistic regression and extended Bayesian information criterion to select optimal regularization parameter. Using <a href="#">IsingFit</a> from the IsingFit package.</p> <p>"pcor" Partial correlation network (non-regularized Gaussian Markov random field), using <a href="#">cor2pcor</a> from the corpcor package.</p> <p>adalasso Uses the <a href="#">adalasso.net</a> from the parcor package.</p> <p>huge Uses EBIC model selection of GGM networks estimated via the glasso algorithm as implemented in the huge package (as opposed to glasso and qgraph packages used in default = "EBICglasso"). Uses nonparanormal transformation in preparing the data and does not use polychoric correlations.</p> <p>See details section for a more detailed description.</p>
prepFun	A function that takes as input the raw data and returns whatever the estimation function needs (as first argument). Typically this function is used to correlate or binarize the data. Defaults to <a href="#">identity</a> if omitted and default is not set.
prepArgs	A list with arguments for prepFun. Defaults to <code>list()</code> if omitted and default is not set.
estFun	A function that takes as input the prepared raw data and estimates a network.
estArgs	A list with arguments for estArgs
graphFun	A function that takes the result of estFun and extracts the estimated weights matrix. Defaults to <a href="#">identity</a> if omitted and default is not set.
graphArgs	A list with arguments for graphFun. Defaults to <code>list()</code> if omitted and default is not set.
intFun	A function that takes the result of estFun and extracts the estimated intercepts. Defaults to <code>null</code> if omitted and default is not set.
intArgs	A list with arguments for intFun. Defaults to <code>list()</code> if omitted and default is not set.

labels	A character vector containing the node labels. If omitted the column names of the data are used.
verbose	Logical, currently only used when default = "EBICglasso" in the cor_auto function.

## Details

The user can manually set the estimation method of the PMRF in bootnet using a set of arguments to the bootnet function. First, the method of preprocessing the data must be defined via the prepFun argument, which must be assigned a function that takes a dataset as input and returns the viable input for the network estimator. The argument prepArgs can be specified a list of arguments to the prepFun function. Data preprocessing typically means correlating the data for the GGM or binarizing it for the Ising model (to this end bootnet provides a binarize function). Next, we estimate the network. To do so, we assign the estFun argument, a function that takes whatever the output of prepFun was and estimates a network. The estArgs argument can be used to assign a list of additional arguments to the function used in estFun. Finally, we need to extract the weights matrix and intercepts. Assigning functions to the graphFun and intFun arguments respectively can do this. An example of how these commands work together to estimate a network using default = "EBICglasso" is shown below:

```
estimateNetwork(Data,prepFun = cor_auto,prepArgs = list(verbose = FALSE),estFun = qgraph::EBICglasso
```

The following defaults can be used:

default = "EBICglasso" **prepFun** cor\_auto from the qgraph package

**prepArgs** list(verbose=TRUE) for estimating a network and list(verbose=FALSE) for bootstrap samples.

**estFun** EBICglasso from the qgraph package

**estArgs** list(n = nrow(data), returnAllResults = TRUE)

**graphFun** function(x)x[['optnet']]

**graphArgs** list()

**intFun** null

**intArgs** list()

default = "IsingFit" **prepFun** binarize

**prepArgs** list()

**estFun** IsingFit from the IsingFit package

**estArgs** list(plot = FALSE, progress = FALSE)

**graphFun** function(x)x[['weiadj']]

**graphArgs** list()

**intFun** function(x)x[['thresholds']]

**intArgs** list()

default = "pcor" **prepFun** cor\_auto from the qgraph package

**prepArgs** list()

**estFun** cor2pcor from the corpcor package

**estArgs** list()

**graphFun** identity

**graphArgs** list()

```

intFun null
intArgs list()
default = "adalasso" prepFun identity
prepArgs list()
estFun adalasso.net from the parcor package
estArgs list()
graphFun function(x)as.matrix(Matrix::forceSymmetric(x$pcor.adalasso))
graphArgs list()
intFun null
intArgs list()
default = "huge" prepFun function(x)huge.npn(na.omit(as.matrix(x)),verbose = FALSE),
  using huge.npn from the huge package
prepArgs list()
estFun function(x)huge::huge.select(huge::huge(x,method = "glasso",verbose=FALSE), criterion = "
  using the huge package
estArgs list()
graphFun as.matrix(qgraph::wi2net(as.matrix(x$opt.icov))), using the huge pack-
  age
graphArgs list()
intFun null
intArgs list()

```

**Value**

A `bootnetResult` object with the following elements:

<code>graph</code>	The weights matrix of the network
<code>intercepts</code>	The intercepts
<code>results</code>	The results of the estimation procedure
<code>labels</code>	A vector with node labels
<code>nNodes</code>	Number of nodes in the network
<code>nPerson</code>	Number of persons in the network
<code>input</code>	Input used, including the result of the default set used

**Author(s)**

Sacha Epskamp <[mail@sachaepskamp.com](mailto:mail@sachaepskamp.com)>

**References**

Epskamp, S., Borsboom, D., & Fried, E. I. (2016). Estimating psychological networks and their accuracy: a tutorial paper. arXiv preprint, arXiv:1604.08462.

**See Also**

[bootnet](#)

**Examples**

```
# BFI Extraversion data from psych package:
library("psych")
data(bfi)
bfiSub <- bfi[,1:25]

# Estimate network:
Network <- estimateNetwork(bfiSub, default = "EBICglasso")

# Some pointers:
print(Network)

# Estimated network:
plot(Network, layout = 'spring')

## Not run:
# Centrality indices:
library("qgraph")
centralityPlot(Network)

## End(Not run)
```

---

null

*Returns NULL*

---

**Description**

This function simply returns NULL.

**Usage**

```
null(...)
```

**Arguments**

... Anything

**Author(s)**

Sacha Epskamp <mail@sachaepskamp.com>

**Examples**

```
null("Not NULL")
```

plot.bootnet

*Plots bootnet results***Description**

This function can be used to plot bootnet results by plotting all bootstrapped statistics as line or by plotting confidence intervals.

**Usage**

```
## S3 method for class 'bootnet'
plot(x, statistics,
     plot, CIstyle = c("default", "SE", "quantiles"),
     rank = FALSE, sampleColor = "darkred", samplelwd = 1, bootColor = "black",
     bootAlpha = 0.01, bootlwd = 0.9, areaAlpha = 0.1,
     order = c("id", "sample", "mean"), decreasing = TRUE, perNode = FALSE,
     legendNcol = 2, labels=TRUE, legend = TRUE, subsetRange = c(100,0),
     area = !perNode, alpha = 0.05, onlyNonZero = FALSE, differenceShowValue,
     differenceEdgeColor = TRUE, verbose = TRUE,...)
```

**Arguments**

x	A bootnet object
statistics	The types of statistics to plot. c("intercept", "strength", "closeness", "betweenness") plots all nodewise statistics whereas c("edge", "distance") plots all pairwise statistics. Defaults to "edge" for regular bootstrap and c("strength", "closeness", "betweenness") for node and person drop bootstrap.
plot	Character string indicating what to plot. Can be "area" to produce a graph with the area indicating the confidence region, or "difference" producing a plot showing significant differences. Other options are "line" and "interval", which are currently unstable and not recommended to use.
CIstyle	Style of CIs to construct. "SE" shows the sample statistic plus and minus two times the standard deviation of bootstraps, and "quantiles" the area between the 2.5th and 97.5th quantile. Defaults to "SE" for strength and betweenness and "quantiles" otherwise
rank	Logical, should plots show rank of statistics instead of statistics?
sampleColor	Color of the original sample line
samplelwd	Line width of the original sample line
bootColor	Color of the bootstrap lines
bootAlpha	Alpha of the bootstrap lines
bootlwd	Line width of the bootstrap lines
areaAlpha	Alpha of the area

order	String indicating how to order nodes. "id" will order nodes based on their name, "mean" will order nodes based on the average bootstrapped value of the first statistic in <code>statistics</code> , and "sample" will order the nodes as done in "mean" but orders ties based on their sample value.
decreasing	Logical indicating if the ordering is decreasing or increasing.
perNode	Logical, should centrality estimates per node be plotted instead of correlation with original parameter. Only used in node and person drop bootstrap.
legendNcol	Number of columns in the legend if <code>perNode = TRUE</code> .
labels	Logical, should labels be plotted?
legend	Logical, should the legend be plotted?
subsetRange	Range in percentages of the x-axis in node and person drop plots.
area	Logical, should the confidence area be plotted?
alpha	Significance level used in <code>plot = "difference"</code> .
onlyNonZero	Logical used when <code>plot = "difference"</code> , <code>statistics = "edge"</code> , should only edges be included that were nonzero in the estimated network structure?
differenceShowValue	Logical used when <code>plot = "difference"</code> . Should values be shown in the diagonal of the difference plot?
differenceEdgeColor	Logical used when <code>plot = "difference"</code> , <code>statistics = "edge"</code> . Should diagonal blocks be colored according to default edge colors?
verbose	Should expected alpha be printed?
...	Not used.

**Value**

A `ggplot2` object.

**Author(s)**

Sacha Epskamp <mail@sachaepskamp.com>

---

plot.bootnetResult      *Plot method for bootnetResult objects*

---

**Description**

Plots the graph using the `qgraph` package and the `qgraph` function. Defined as `qgraph::qgraph(x[['graph']], labels=x[`

**Usage**

```
## S3 method for class 'bootnetResult'
plot(x, ...)
```

### Arguments

x                    A bootnetResult object  
...                  Arguments sent to [qgraph](#).

### Author(s)

Sacha Epskamp <[mail@sachaepskamp.com](mailto:mail@sachaepskamp.com)>

---

print.bootnet                    *Print method for bootnet and bootnetResult objects*

---

### Description

Prints a short overview of the results of [bootnet](#)

### Usage

```
## S3 method for class 'bootnet'  
print(x, ...)  
## S3 method for class 'bootnetResult'  
print(x, ...)  
## S3 method for class 'bootnetResult'  
summary(object, ...)
```

### Arguments

x                    A bootnet or bootnetResult object  
object              A bootnetResult object  
...                  Not used.

### Author(s)

Sacha Epskamp <[mail@sachaepskamp.com](mailto:mail@sachaepskamp.com)>

---

summary.bootnet      *Summarize bootnet results*

---

**Description**

Creates a data frame (wrapped as `tbl_df`) containing summarized results of the bootstraps.

**Usage**

```
## S3 method for class 'bootnet'  
summary(object, statistics = c("edge", "intercept", "strength",  
                              "closeness", "betweenness", "distance"), perNode = FALSE,  
        rank = FALSE, ...)
```

**Arguments**

object	A bootnet object
statistics	The types of statistics to include in the summary table
perNode	Logical, should centrality estimates per node be plotted instead of correlation with original parameter. Only used in node and person drop bootstrap.
rank	Logical, should plots show rank of statistics instead of statistics?
...	Not used.

**Value**

A `tbl_df` (data frame) containing summarized statistics.

**Author(s)**

Sacha Epskamp <mail@sachaepskamp.com>



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