Package 'NetworkChange'

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Title Bayesian Package for Network Changepoint Analysis

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Depends R (>= 3.5.0), MCMCpack, ggplot2

Imports Rmpfr, abind, mvtnorm, tidyr, igraph, qgraph, network, stats, MASS, methods, RColorBrewer, ggrepel, rlang, GGally, patchwork, viridis

Description
Network changepoint analysis for undirected network data. The package implements a hidden Markov network change point model (Park and Sohn (2020)). Functions for break number detection using the approximate marginal likelihood and WAIC are also provided. This version includes performance optimizations with vectorized MCMC operations and modern ggplot2-based visualizations with colorblind-friendly palettes.

License GPL-3

NeedsCompilation no

RoxygenNote 7.3.3

Encoding UTF-8

Suggests sna, lifecycle

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Repository CRAN

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Contents

`BreakDiagnostic` *Detect a break number using different metrics*

Description

Detect a break number using different metrics

Usage

```
BreakDiagnostic(
  Y,
  R = 2,
  mcmc = 100,
  burnin = 100,
  verbose = 100,
```

```
  thin = 1,
  UL.Normal = "Orthonormal",
  v0 = NULL,
  v1 = NULL,
  break.upper = 3,
  a = 1,
  b = 1
)
```

Arguments

Y	Reponse tensor
R	Dimension of latent space. The default is 2.
mcmc	The number of MCMC iterations after burnin.
burnin	The number of burn-in iterations for the sampler.
verbose	A switch which determines whether or not the progress of the sampler is printed to the screen. If verbose is greater than 0 the iteration number, the β vector, and the error variance are printed to the screen every verboseth iteration.
thin	The thinning interval used in the simulation. The number of MCMC iterations must be divisible by this value.
UL.Normal	Transformation of sampled U. Users can choose "NULL", "Normal" or "Orthonormal." "NULL" is no normalization. "Normal" is the standard normalization. "Orthonormal" is the Gram-Schmidt orthgonalization. Default is "NULL."
v0	$v_0/2$ is the shape parameter for the inverse Gamma prior on variance parameters for V. If v0 = NULL, a value is computed from a test run of NetworkStatic.
v1	$v_1/2$ is the scale parameter for the inverse Gamma prior on variance parameters for V. If v1 = NULL, a value is computed from a test run of NetworkStatic.
break.upper	Upper threshold for break number detection. The default is break.upper = 3.
a	a is the shape1 beta prior for transition probabilities. By default, the expected duration is computed and corresponding a and b values are assigned. The expected duration is the sample period divided by the number of states.
b	b is the shape2 beta prior for transition probabilities. By default, the expected duration is computed and corresponding a and b values are assigned. The expected duration is the sample period divided by the number of states.

References

Jong Hee Park and Yunkyun Sohn. 2020. "Detecting Structural Change in Longitudinal Network Data." *Bayesian Analysis*. Vol.15, No.1, pp.133-157.

Examples

```
## Not run:
set.seed(19333)
## Generate an array (15 by 15 by 20) with a block merging transition
Y <- MakeBlockNetworkChange(n=5, T=20, type ="merge")
```

```
## Fit 3 models (no break, one break, and two break) for break number detection
detect <- BreakDiagnostic(Y, R=2, break.upper = 2)

## Look at the graph
detect[[1]]; print(detect[[2]])


## End(Not run)
```

`BreakPointLoss` *Compute the Average Loss of Hidden State Changes from Expected Break Points*

Description

Compute the Average Loss of Hidden State Changes from Expected Break Points

Usage

```
BreakPointLoss(model.list, waic = FALSE, display = TRUE)
```

Arguments

`model.list`	MCMC output objects. These have to be of class `mcmc` and have a `logmarglike` attribute. In what follows, we let `M` denote the total number of models to be compared.
`waic`	If `waic` is TRUE, `waic`(Watanabe information criterion) will be reported.
`display`	If `display` is TRUE, a plot of `ave.loss` will be produced.
	`BreakPointLoss`. ave.loss, logmarglike, State, Tau, Tau.samp

Value

`BreakPointLoss` returns five objects. They are: `ave.loss` the expected loss for each model computed by the mean sqaured distance of hidden state changes from the expected break points. `logmarglike` the natural log of the marginal likelihood for each model; `State` sampled state vectors; `Tau` expected break points for each model; and `Tau.samp` sampled break points from hidden state draws.

References

Jong Hee Park and Yunkyun Sohn. 2020. "Detecting Structural Change in Longitudinal Network Data." *Bayesian Analysis*. Vol.15, No.1, pp.133-157.

Examples

```
## Not run:
set.seed(1973)
## Generate an array (30 by 30 by 40) with block transitions
from 2 blocks to 3 blocks
Y <- MakeBlockNetworkChange(n=10, T=40, type ="split")
G <- 100 ## Small mcmc scans to save time

## Fit multiple models for break number detection using Bayesian model comparison
out0 <- NetworkStatic(Y, R=2, mcmc=G, burnin=G, verbose=G, Waic=TRUE)
out1 <- NetworkChange(Y, R=2, m=1, mcmc=G, burnin=G, verbose=G, Waic=TRUE)
out2 <- NetworkChange(Y, R=2, m=2, mcmc=G, burnin=G, verbose=G, Waic=TRUE)
out3 <- NetworkChange(Y, R=2, m=3, mcmc=G, burnin=G, verbose=G, Waic=TRUE)

## The most probable model given break number 0 to 3 and data is out1 according to WAIC
out <- BreakPointLoss(out0, out1, out2, out3, waic=TRUE)

print(out[["ave.loss"]])

## End(Not run)
```

`drawPostAnalysis` *Plot of latent node cluster*

Description

Plot latent node cluster using ggplot2. Uses tidyr for data reshaping and viridis for colorblind-friendly palettes.

Usage

```
drawPostAnalysis(
  mcmcout,
  Y,
  point.cex = 3,
  text.cex = 3,
  segment.size = 0.1,
  n.cluster = NULL,
  start = 1,
  frequency = 1
)
```

Arguments

`mcmcout`	NetworkChange output
`Y`	Input raw data

point.cex	node point size. Default is 3.
text.cex	node label size. Default is 3.
segment.size	segment size. Default is 0.1.
n.cluster	number of cluster. Default is 3.
start	start of ts object
frequency	frequency of ts object

Value

A plot object

References

Jong Hee Park and Yunkyun Sohn. 2020. "Detecting Structural Change in Longitudinal Network Data." *Bayesian Analysis*. Vol.15, No.1, pp.133-157.

Examples

```
## Not run:
set.seed(1973)
## generate an array with two constant blocks
data(MajorAlly)
Y <- MajorAlly
fit <- NetworkChange(newY, R=2, m=2, mcmc=G, initial.s = initial.s,
       burnin=G, verbose=0, v0=v0, v1=v1)
drawPostAnalysis(fit, Y, n.cluster=c(4, 4, 3))

## End(Not run)
```

---

drawRegimeRaw *Plot of network by hidden regime*

Description

Plot latent node cluster

Usage

```
drawRegimeRaw(mcmcout, Y)
```

Arguments

mcmcout	NetworkChange output
Y	Input raw data

Value

A plot object

References

Jong Hee Park and Yunkyun Sohn. 2020. "Detecting Structural Change in Longitudinal Network Data." *Bayesian Analysis*. Vol.15, No.1, pp.133-157.

Examples

```
## Not run:
set.seed(1973)
## generate an array with two constant blocks
data(MajorAlly)
Y <- MajorAlly
fit <- NetworkChange(newY, R=2, m=2, mcmc=G, initial.s = initial.s,
       burnin=G, verbose=0, v0=v0, v1=v1)
drawRegimeRaw(fit, newY)

## End(Not run)
```

---

kmeansU *K-mean clustering of latent node positions*

Description

K-mean clustering of latent node positions

Usage

```
kmeansU(out, R = 2, n.cluster = 3, layer = 1, main = "")
```

Arguments

out	Output of networkchange objects.
R	Number of latent space dimensions
n.cluster	Number of latent cluster
layer	Layer id for the cluster analysis
main	Title

Value

A plot object

Examples

```
## Not run: set.seed(1973)
## generate an array with two constant blocks
Y <- MakeBlockNetworkChange(n=10, shape=10, T=10, type ="constant")
out0 <- NetworkStatic(Y, R=2, mcmc=10, burnin=10,
verbose=10, UL.Normal = "Orthonormal")
## latent node positions
kmeansU(out0)

## End(Not run)
```

`MajorAlly` *Major Power Alliance Network (1816 - 2012)*

Description

This dataframe contains major power alliance network data from 1816 to 2012 (2 year interval).

Format

The dataframe has contains data for major power alliance network data from 1816 to 2012. Major power definition is the COW data set, which incldues USA, UK, France, Germany (West Germany during 1954-1989), Austria, Italy, Russia, China, and Japan. In this data set, a defense pact (Type I), which is the highest level of military commitment, is coded as 1, and 0 otherwise.

Source

Correlates of War Project. 2017. "State System Membership List, v2016." Online, https://correlatesofwar.org/. Gibler, Douglas M. 2009. *International military alliances, 1648-2008.* CQ Press.

`MakeBlockNetworkChange`

Build a synthetic block-structured temporal data with breaks

Description

MakeBlockNetworkChange generates a block-structured temporal data with breaks.

Usage

```
MakeBlockNetworkChange(
  n = 10,
  break.point = 0.5,
  base.prob = 0.05,
  block.prob = 0.5,
  shape = 1,
  T = 40,
  break.point1 = 0.25,
  break.point2 = 0.75,
  type = "merge"
)
```

Arguments

n	The number of nodes within a block. The total number of nodes is n*block.number.
break.point	The point of break. 0 indicates the beginning, 0.5 indicates the middle, and 1 indicates the end.
base.prob	The probability of link among non-block members.
block.prob	The probability of link among within-block members.
shape	The speed of breaks. The larger shape is, the faster the transition is. shape > 0 and shape < 8.
T	The length of time.
break.point1	The point of the first break in "merge-split" or "split-merge". Any number between 0 and 0.5 can be chosen. For example, 0 indicates #' the beginning, 0.25 indicates the 1/4th point, and 0.5 indicates the half point.
break.point2	The point of the second breakin "merge-split" or "split-merge". Any number between 0.5 and 1 can be chosen. For example, 0.5 indicates the beginning, 0.75 indicates the 3/4th point, and 1 indicates the end point.
type	The type of network changes. Options are "constant", "merge", "split", "merge-split", "split-merge." If "constant" is chosen, the number of breaks is zero. If "merge" or "split" is chosen, the number of breaks is one. If either "merge-split" or "split-merge" is chosen, the number of breaks is two.

Value

output An output of MakeBlockNetworkChange contains a symmetric block-structured temporal network data set with breaks.

`MarginalCompare` *Compare Log Marginal Likelihood*

Description

Compare Log Marginal Likelihood

Usage

```
MarginalCompare(outlist)
```

Arguments

`outlist`	List of NetworkChange objects

Value

A matrix of log marginal likelihoods.

References

Siddhartha Chib. 1995. "Marginal Likelihood from the Gibbs Output." *Journal of the American Statistical Association*. 90: 1313-1321.

Jong Hee Park and Yunkyun Sohn. 2020. "Detecting Structural Change in Longitudinal Network Data." *Bayesian Analysis*. Vol.15, No.1, pp.133-157.

Sumio Watanabe. 2010. "Asymptotic equivalence of Bayes cross validation and widely applicable information criterion in singular learning theory." *Journal of Machine Learning Research*. 11: 3571-3594.

See Also

`WaicCompare`

`multiplot` *Printing multiple ggplots in one file (DEPRECATED)*

Description

[Deprecated]

This function has been deprecated in favor of `patchwork::wrap_plots()`. Please use `patchwork::wrap_plots(plotlist, ncol = cols)` instead.

Usage

```
multiplot(..., plotlist = NULL, cols = 1, layout = NULL)
```

Arguments

...	A list of ggplot objects separated by commas.
plotlist	A list of ggplot objects
cols	The number of columns.
layout	A matrix specifying the layout. If present, 'cols' is ignored.

Value

A plot object

NetworkChange *Changepoint analysis of a degree-corrected multilinear tensor model*

Description

NetworkChange implements Bayesian multiple changepoint models to network time series data using a degree-corrected multilinear tensor decomposition method

Usage

```
NetworkChange(
  Y,
  R = 2,
  m = 1,
  initial.s = NULL,
  mcmc = 100,
  burnin = 100,
  verbose = 0,
  thin = 1,
  reduce.mcmc = NULL,
  degree.normal = "eigen",
  UL.Normal = "Orthonormal",
  DIC = FALSE,
  Waic = FALSE,
  marginal = FALSE,
  plotUU = FALSE,
  plotZ = FALSE,
  constant = FALSE,
  b0 = 0,
  B0 = 1,
  c0 = NULL,
  d0 = NULL,
  u0 = NULL,
  u1 = NULL,
  v0 = NULL,
  v1 = NULL,
```

```
  a = NULL,
  b = NULL
)
```

Arguments

Y	Reponse tensor
R	Dimension of latent space. The default is 2.
m	Number of change point. If m = 0 is specified, the result should be the same as NetworkStatic.
initial.s	The starting value of latent state vector. The default is sampling from equal probabilities for all states.
mcmc	The number of MCMC iterations after burnin.
burnin	The number of burn-in iterations for the sampler.
verbose	A switch which determines whether or not the progress of the sampler is printed to the screen. If verbose is greater than 0 the iteration number, the β vector, and the error variance are printed to the screen every verboseth iteration.
thin	The thinning interval used in the simulation. The number of MCMC iterations must be divisible by this value.
reduce.mcmc	The number of reduced MCMC iterations for marginal likelihood computations. If reduce.mcmc = NULL, mcmc/thin is used.
degree.normal	A null model for degree correction. Users can choose "NULL", "eigen" or "Lsym." "NULL" is no degree correction. "eigen" is a principal eigen-matrix consisting of the first eigenvalue and the corresponding eigenvector. " Lsym" is a modularity matrix. Default is "eigen."
UL.Normal	Transformation of sampled U. Users can choose "NULL", "Normal" or "Orthonormal." "NULL" is no normalization. "Normal" is the standard normalization. "Orthonormal" is the Gram-Schmidt orthgonalization. Default is "NULL."
DIC	If DIC = TRUE, the deviation information criterion is computed.
Waic	If Waic = TRUE, the Watanabe information criterion is computed.
marginal	If marginal = TRUE, the log marignal likelihood is computed using the method of Chib (1995).
plotUU	If plotUU = TRUE and verbose > 0, then the plot of the latent space will be printed to the screen at every verboseth iteration. The default is plotUU = FALSE.
plotZ	If plotZ = TRUE and verbose > 0, then the plot of the degree-corrected input matrix will be printed to the screen with the sampled mean values at every verboseth iteration. The default is plotUU = FALSE.
constant	If constant = TRUE, constant parameter is sampled and saved in the output as attribute bmat. Default is constant = FALSE.
b0	The prior mean of β. This must be a scalar. The default value is 0.
B0	The prior variance of β. This must be a scalar. The default value is 1.
c0	= 0.1

d0	= 0.1
u0	$u_0/2$ is the shape parameter for the inverse Gamma prior on variance parameters for U. The default is 10.
u1	$u_1/2$ is the scale parameter for the inverse Gamma prior on variance parameters for U. The default is 1.
v0	$v_0/2$ is the shape parameter for the inverse Gamma prior on variance parameters for V. The default is 10.
v1	$v_1/2$ is the scale parameter for the inverse Gamma prior on variance parameters for V. The default is the time length of Y.
a	a is the shape1 beta prior for transition probabilities. By default, the expected duration is computed and corresponding a and b values are assigned. The expected duration is the sample period divided by the number of states.
b	b is the shape2 beta prior for transition probabilities. By default, the expected duration is computed and corresponding a and b values are assigned. The expected duration is the sample period divided by the number of states.

Value

An mcmc object that contains the posterior sample. This object can be summarized by functions provided by the coda package. The object contains an attribute `Waic.out` that contains results of WAIC and the log-marginal likelihood of the model (`logmarglike`). The object also contains an attribute `prob.state` storage matrix that contains the probability of $state_i$ for each period

References

Jong Hee Park and Yunkyun Sohn. 2020. "Detecting Structural Change in Longitudinal Network Data." *Bayesian Analysis*. Vol.15, No.1, pp.133-157.

Peter D. Hoff 2011. "Hierarchical Multilinear Models for Multiway Data." *Computational Statistics & Data Analysis*. 55: 530-543.

Siddhartha Chib. 1998. "Estimation and comparison of multiple change-point models." *Journal of Econometrics*. 86: 221-241.

See Also

NetworkStatic

Examples

```
## Not run:
set.seed(1973)
\## Generate an array (30 by 30 by 40) with block transitions
from 2 blocks to 3 blocks
Y <- MakeBlockNetworkChange(n=10, T=40, type ="split")
G <- 100 ## Small mcmc scans to save time

\## Fit multiple models for break number detection using Bayesian model comparison
out0 <- NetworkStatic(Y, R=2, mcmc=G, burnin=G, verbose=G, Waic=TRUE)
out1 <- NetworkChange(Y, R=2, m=1, mcmc=G, burnin=G, verbose=G, Waic=TRUE)
```

```
out2 <- NetworkChange(Y, R=2, m=2, mcmc=G, burnin=G, verbose=G, Waic=TRUE)
out3 <- NetworkChange(Y, R=2, m=3, mcmc=G, burnin=G, verbose=G, Waic=TRUE)
outlist <- list(out0, out1, out2, out3)

\## The most probable model given break number 0 to 3 and data is out1 according to WAIC
WaicCompare(outlist)

plotU(out1)

plotV(out1)

## End(Not run)
```

NetworkChangeRobust *Changepoint analysis of a degree-corrected multilinear tensor model with t-distributed error*

Description

NetworkChangeRobust implements Bayesian multiple changepoint models to network time series data using a degree-corrected multilinear tensor decomposition method with t-distributed error

Usage

```
NetworkChangeRobust(
  Y,
  R = 2,
  m = 1,
  initial.s = NULL,
  mcmc = 100,
  burnin = 100,
  verbose = 0,
  thin = 1,
  degree.normal = "eigen",
  UL.Normal = "Orthonormal",
  plotUU = FALSE,
  plotZ = FALSE,
  b0 = 0,
  B0 = 1,
  c0 = NULL,
  d0 = NULL,
  n0 = 2,
  m0 = 2,
  u0 = NULL,
  u1 = NULL,
  v0 = NULL,
  v1 = NULL,
  a = NULL,
```

```
  b = NULL
)
```

Arguments

Y	Reponse tensor
R	Dimension of latent space. The default is 2.
m	Number of change point. If m = 0 is specified, the result should be the same as NetworkStatic.
initial.s	The starting value of latent state vector. The default is sampling from equal probabilities for all states.
mcmc	The number of MCMC iterations after burnin.
burnin	The number of burn-in iterations for the sampler.
verbose	A switch which determines whether or not the progress of the sampler is printed to the screen. If verbose is greater than 0 the iteration number, the β vector, and the error variance are printed to the screen every verboseth iteration.
thin	The thinning interval used in the simulation. The number of MCMC iterations must be divisible by this value.
degree.normal	A null model for degree correction. Users can choose "NULL", "eigen" or "Lsym." "NULL" is no degree correction. "eigen" is a principal eigen-matrix consisting of the first eigenvalue and the corresponding eigenvector. " Lsym" is a modularity matrix. Default is "eigen."
UL.Normal	Transformation of sampled U. Users can choose "NULL", "Normal" or "Orthonormal." "NULL" is no normalization. "Normal" is the standard normalization. "Orthonormal" is the Gram-Schmidt orthgonalization. Default is "NULL."
plotUU	If plotUU = TRUE and verbose > 0, then the plot of the latent space will be printed to the screen at every verboseth iteration. The default is plotUU = FALSE.
plotZ	If plotZ = TRUE and verbose > 0, then the plot of the degree-corrected input matrix will be printed to the screen with the sampled mean values at every verboseth iteration. The default is plotUU = FALSE.
b0	The prior mean of β. This must be a scalar. The default value is 0.
B0	The prior variance of β. This must be a scalar. The default value is 1.
c0	= 0.1 The shape parameter of inverse gamma prior for σ^2.
d0	= 0.1 The rate parameter of inverse gamma prior for σ^2.
n0	= 0.1 The shape parameter of inverse gamma prior for γ of Student-t distribution.
m0	= 0.1 The rate parameter of inverse gamma prior for γ of Student-t distribution.
u0	$u_0/2$ is the shape parameter for the inverse Gamma prior on variance parameters for U. The default is 10.
u1	$u_1/2$ is the scale parameter for the inverse Gamma prior on variance parameters for U. The default is 1.
v0	$v_0/2$ is the shape parameter for the inverse Gamma prior on variance parameters for V. The default is 10.

v1 $v_1/2$ is the scale parameter for the inverse Gamma prior on variance parameters for V. The default is the time length of Y.

a a is the shape1 beta prior for transition probabilities. By default, the expected duration is computed and corresponding a and b values are assigned. The expected duration is the sample period divided by the number of states.

b b is the shape2 beta prior for transition probabilities. By default, the expected duration is computed and corresponding a and b values are assigned. The expected duration is the sample period divided by the number of states.

Value

An mcmc object that contains the posterior sample. This object can be summarized by functions provided by the coda package. The object contains an attribute `Waic.out` that contains results of WAIC and the log-marginal likelihood of the model (`logmarglike`). The object also contains an attribute `prob.state` storage matrix that contains the probability of $state_i$ for each period

References

Jong Hee Park and Yunkyun Sohn. 2020. "Detecting Structural Change in Longitudinal Network Data." *Bayesian Analysis*. Vol.15, No.1, pp.133-157.

Peter D. Hoff 2011. "Hierarchical Multilinear Models for Multiway Data." *Computational Statistics & Data Analysis*. 55: 530-543.

Siddhartha Chib. 1998. "Estimation and comparison of multiple change-point models." *Journal of Econometrics*. 86: 221-241.

Sumio Watanabe. 2010. "Asymptotic equivalence of Bayes cross validation and widely applicable information criterion in singular learning theory." *Journal of Machine Learning Research*. 11: 3571-3594. Siddhartha Chib. 1995. “Marginal Likelihood from the Gibbs Output.” *Journal of the American Statistical Association*. 90: 1313-1321.

See Also

NetworkStatic

Examples

```
## Not run:
set.seed(1973)
## Generate an array (30 by 30 by 40) with block transitions
from 2 blocks to 3 blocks
Y <- MakeBlockNetworkChange(n=10, T=40, type ="split")
G <- 100 ## only 100 mcmc scans to save time
## Fit models
out1 <- NetworkChangeRobust(Y, R=2, m=1, mcmc=G, burnin=G, verbose=G)
## plot latent node positions
plotU(out1)
## plot layer-specific network generation rules
plotV(out1)

## End(Not run)
```

NetworkStatic *Degree-corrected multilinear tensor model*

Description

NetworkStatic implements a degree-corrected Bayesian multilinear tensor decomposition method

Usage

```
NetworkStatic(
  Y,
  R = 2,
  mcmc = 100,
  burnin = 100,
  verbose = 0,
  thin = 1,
  reduce.mcmc = NULL,
  degree.normal = "eigen",
  UL.Normal = "Orthonormal",
  plotUU = FALSE,
  plotZ = FALSE,
  constant = FALSE,
  b0 = 0,
  B0 = 1,
  c0 = NULL,
  d0 = NULL,
  u0 = NULL,
  u1 = NULL,
  v0 = NULL,
  v1 = NULL,
  marginal = FALSE,
  DIC = FALSE,
  Waic = FALSE
)
```

Arguments

Y	Reponse tensor
R	Dimension of latent space. The default is 2.
mcmc	The number of MCMC iterations after burnin.
burnin	The number of burn-in iterations for the sampler.
verbose	A switch which determines whether or not the progress of the sampler is printed to the screen. If verbose is greater than 0 the iteration number, the β vector, and the error variance are printed to the screen every verboseth iteration.
thin	The thinning interval used in the simulation. The number of MCMC iterations must be divisible by this value.

`reduce.mcmc` The number of reduced MCMC iterations for marginal likelihood computations. If `reduce.mcmc = NULL`, `mcmc/thin` is used.

`degree.normal` A null model for degree correction. Users can choose "NULL", "eigen" or "Lsym." "NULL" is no degree correction. "eigen" is a principal eigen-matrix consisting of the first eigenvalue and the corresponding eigenvector. " Lsym" is a modularity matrix. Default is "eigen."

`UL.Normal` Transformation of sampled U. Users can choose "NULL", "Normal" or "Orthonormal." "NULL" is no normalization. "Normal" is the standard normalization. "Orthonormal" is the Gram-Schmidt orthgonalization. Default is "NULL."

`plotUU` If `plotUU = TRUE` and `verbose > 0`, then the plot of the latent space will be printed to the screen at every `verbose`th iteration. The default is `plotUU = FALSE`.

`plotZ` If `plotZ = TRUE` and `verbose > 0`, then the plot of the degree-corrected input matrix will be printed to the screen with the sampled mean values at every `verbose`th iteration. The default is `plotUU = FALSE`.

`constant` If `constant = TRUE`, constant parameter is sampled and saved in the output as attribute `bmat`. Default is `constant = FALSE`.

`b0` The prior mean of β. This must be a scalar. The default value is 0.

`B0` The prior variance of β. This must be a scalar. The default value is 1.

`c0` = 0.1

`d0` = 0.1

`u0` $u_0/2$ is the shape parameter for the inverse Gamma prior on variance parameters for U. The default is 10.

`u1` $u_1/2$ is the scale parameter for the inverse Gamma prior on variance parameters for U. The default is 1.

`v0` $v_0/2$ is the shape parameter for the inverse Gamma prior on variance parameters for V. The default is 10.

`v1` $v_1/2$ is the scale parameter for the inverse Gamma prior on variance parameters for V. The default is the time length of Y.

`marginal` If `marginal = TRUE`, the log marignal likelihood is computed using the method of Chib (1995).

`DIC` If `DIC = TRUE`, the deviation information criterion is computed.

`Waic` If `Waic = TRUE`, the Watanabe information criterion is computed.

Value

An mcmc object that contains the posterior sample. This object can be summarized by functions provided by the coda package. The object contains an attribute `Waic.out` that contains results of WAIC and the log-marginal likelihood of the model (`logmarglike`).

References

Jong Hee Park and Yunkyun Sohn. 2020. "Detecting Structural Change in Longitudinal Network Data." *Bayesian Analysis*. Vol.15, No.1, pp.133-157.

Peter D. Hoff 2011. "Hierarchical Multilinear Models for Multiway Data." *Computational Statistics & Data Analysis*. 55: 530-543.

Sumio Watanabe. 2010. "Asymptotic equivalence of Bayes cross validation and widely applicable information criterion in singular learning theory." *Journal of Machine Learning Research*. 11: 3571-3594. Siddhartha Chib. 1995. "Marginal Likelihood from the Gibbs Output." *Journal of the American Statistical Association*. 90: 1313-1321.

See Also

NetworkChange

Examples

```
## Not run:
set.seed(1973)

\## generate an array with three constant blocks
Y <- MakeBlockNetworkChange(n=10, shape=10, T=10, type ="constant")
G <- 100 ## Small mcmc scans to save time
out0 <- NetworkStatic(Y, R=2, mcmc=G, burnin=G, verbose=G)

\## recovered latent blocks
Kmeans(out0, n.cluster=3, main="Recovered Blocks")

\## contour plot of latent node positions
plotContour(out0)

\## plot latent node positions
plotU(out0)

\## plot layer-specific network connection rules
plotV(out0)

## End(Not run)
```

---

plotContour *Contour plot of latent node positions*

Description

Draw a contour plot of latent node positions. Uses colorblind-friendly viridis palette by default.

Usage

```
plotContour(OUT, main = "", k = 8, my.cols = viridis::viridis(k))
```

Arguments

OUT	Output of networkchange objects.
main	The title of plot
k	The number of levels (nlevels in contour ()).
my.cols	Color scale. Defaults to viridis palette. Can also use brewer.pal() from RColorBrewer.

Value

A plot object

Examples

```
   ## Not run: set.seed(1973)
   \## generate an array with two constant blocks
   Y <- MakeBlockNetworkChange(n=10, shape=10, T=40, type ="constant")
   out0 <- NetworkStatic(Y, R=2, mcmc=10, burnin=10,
   verbose=10, UL.Normal = "Orthonormal")
   \## contour plot of latent node positions
   plotContour(out0)

## End(Not run)
```

---

plotnetarray *Plot of network array data*

Description

Plot network array data using ggplot2 and patchwork for layout.

Usage

```
plotnetarray(
  Y,
  n.graph = 4,
  node.size = 2,
  node.color = "brown",
  edge.alpha = 0.5,
  edge.size = 0.2,
  edge.color = "grey"
)
```

Arguments

Y	network array data
n.graph	number of subgraphs. Default is 4.
node.size	node size. Default is 2.
node.color	node color. Default is "brown."
edge.alpha	transparency of edge. Default is 0.5.
edge.size	edge size. Default is 0.2.
edge.color	edge color. Default is "grey."

Value

A patchwork plot object

References

Jong Hee Park and Yunkyun Sohn. 2020. "Detecting Structural Change in Longitudinal Network Data." *Bayesian Analysis*. Vol.15, No.1, pp.133-157.

Examples

```
## Not run:
set.seed(1973)
## generate an array with two constant blocks
Y <- MakeBlockNetworkChange(n=10, shape=1, T=20, type ="split")
plotnetarray(Y)

## End(Not run)
```

---

plotU *Plot of latent node positions*

Description

Plot latent node positions using ggplot2 with patchwork for multi-panel layouts. Uses colorblind-friendly palettes and cross-platform compatible fonts.

Usage

```
plotU(OUT, Time = NULL, names = NULL, main = NULL, label.prob = 0.9)
```

Arguments

OUT	Output of networkchange objects.
Time	Starting of the time period. If NULL, 1.
names	Node names. If NULL, use natural numbers.
main	The title of plot
label.prob	Label print threshold. 0.9 is the default.

Value

A plot object

Examples

```
## Not run:
set.seed(1973)
\## generate an array with two constant blocks
Y <- MakeBlockNetworkChange(n=10, shape=10, T=40, type ="constant")
out0 <- NetworkStatic(Y, R=2, mcmc=10, burnin=10,
verbose=10, UL.Normal = "Orthonormal")
\## latent node positions
plotU(out0)

## End(Not run)
```

---

plotV *Plot of layer-specific network generation rules.*

Description

Plot layer-specific network generation rules using ggplot2. Uses colorblind-friendly viridis palette for publication-quality output.

Usage

```
plotV(OUT, main = "", point_size = 3, line_size = 1)
```

Arguments

OUT	Output of networkchange objects.
main	The title of plot
point_size	Point size (default: 3)
line_size	Line width (default: 1)

Value

A ggplot2 plot object

Examples

```
## Not run: set.seed(1973)
\## generate an array with two constant blocks
Y <- MakeBlockNetworkChange(n=10, shape=10, T=40, type ="constant")
out0 <- NetworkStatic(Y, R=2, mcmc=10, burnin=10,
verbose=10, UL.Normal = "Orthonormal")
\## latent node positions
plotV(out0)
```

```
## End(Not run)
```

`PostwarAlly` *Postwar Alliance Network (1846 - 2012)*

Description

This dataframe contains postwar alliance network data from 1946 to 2012 (2 year interval).

Format

The dataframe has contains data for postwar alliance network data from 1946 to 2012 with 2 year interval. After removing disconnected components, 104 countries are included. In this data set, a defense pact (Type I), which is the highest level of military commitment, is coded as 1, and 0 otherwise.

Source

Correlates of War Project. 2017. "State System Membership List, v2016." Online, https://correlatesofwar.org/. Gibler, Douglas M. 2009. *International military alliances, 1648-2008.* CQ Press.

`scale_color_networkchange`
NetworkChange Discrete Color Scale

Description

Colorblind-friendly discrete color scale using viridis palette.

Usage

```
scale_color_networkchange(..., option = "D")
```

Arguments

`...`	Additional arguments passed to scale_color_viridis_d
`option`	Viridis palette option: "D" (default), "A", "B", "C", "E"

Value

A ggplot2 color scale

scale_color_networkchange_c

NetworkChange Continuous Color Scale

Description

Colorblind-friendly continuous color scale using viridis palette.

Usage

```
scale_color_networkchange_c(..., option = "D")
```

Arguments

...	Additional arguments passed to scale_color_viridis_c
option	Viridis palette option: "D" (default), "A", "B", "C", "E"

Value

A ggplot2 color scale

scale_fill_networkchange

NetworkChange Discrete Fill Scale

Description

Colorblind-friendly discrete fill scale using viridis palette.

Usage

```
scale_fill_networkchange(..., option = "D")
```

Arguments

...	Additional arguments passed to scale_fill_viridis_d
option	Viridis palette option: "D" (default), "A", "B", "C", "E"

Value

A ggplot2 fill scale

startS *Sample a starting value of hidden states*

Description

Sample a starting value of hidden states

Usage

```
startS(Z, Time, m, initial.U, V, s2, R)
```

Arguments

Z	Degree-corrected network array data
Time	The length of time.
m	The number of breaks
initial.U	Initialized U matrix.
V	Initialized V matrix.
s2	Initialized error variance
R	The dimensionality of latent space

Value

A state vector

startUV *Starting values of U and V*

Description

Initialize starting values of U and V

Usage

```
startUV(Z, R, K)
```

Arguments

Z	Degree-corrected network array data.
R	The dimensionality of latent space.
K	The dimensionality of Z.

Value

A list of U and V

theme_networkchange *NetworkChange ggplot2 Theme*

Description

A consistent theme for all NetworkChange visualizations. Based on theme_minimal with customizations for publication-quality output.

Usage

```
theme_networkchange(base_size = 11, base_family = "")
```

Arguments

base_size	Base font size (default: 11)
base_family	Base font family (default: "" for system default)

Value

A ggplot2 theme object

Examples

```
## Not run:
library(ggplot2)
ggplot(mtcars, aes(mpg, wt)) + geom_point() + theme_networkchange()

## End(Not run)
```

ULUstateSample *Hidden State Sampler*

Description

Sample hidden states from hidden Markov multilinear model. Uses vectorized operations for improved performance.

Usage

```
ULUstateSample(m, s, ZMUt, s2, P, SOS.random)
```

Arguments

m	The number of break
s	Latent state vector
ZMUt	Z - MU
s2	error variance
P	Transition matrix
SOS.random	single observation state random perturbation

Value

A list of a state vector, state probabilities, and SOS.random.

ULUstateSample.mpfr *Hidden State Sampler with precision*

Description

Sample hidden states from hidden Markov multilinear model with precision using Rmpfr package. Uses vectorized operations for improved performance.

Usage

```
ULUstateSample.mpfr(m, s, ZMUt, s2, P, SOS.random)
```

Arguments

m	The number of break
s	Latent state vector
ZMUt	Z - MU
s2	error variance
P	Transition matrix
SOS.random	single observation state random perturbation

Value

A list of a state vector, state probabilities, and SOS.random.

updateb *Update time-constant regression parameters*

Description

Update time-constant regression parameters

Usage

```
updateb(Z, MU, s2, XtX, b0, B0)
```

Arguments

Z	Degree corrected response tensor
MU	Mean array
s2	Error variance
XtX	X'X
b0	Prior mean of beta
B0	Prior variance of beta

Value

A vector of regression parameters

updatebm *Update regime-changing regression parameters*

Description

Update regime-changing beta

Usage

```
updatebm(ns, K, s, s2, B0, p, ZU)
```

Arguments

ns	The number of hidden states
K	The dimensionality of Z
s	Latent state vector
s2	The variance of error
B0	The prior variance of beta
p	The rank of X
ZU	Z - ULU

Value

A vector of regime-changing regression parameters

`updateP` *Update transition matrix*

Description

Update transition matrix

Usage

```
updateP(s, ns, P, A0)
```

Arguments

`s`	Latent state vector
`ns`	The number of hidden states
`P`	Transition matrix
`A0`	Prior of transition matrix

Value

A transtion matrix

`updateS` *Update latent states*

Description

Update latent states

Usage

```
updateS(
  iter,
  s,
  V,
  m,
  Zb,
  Zt,
  Time,
  MU.state,
  P,
  s2,
  N.upper.tri,
  random.perturb
)
```

Arguments

iter	iteration number
s	the most recent latent states
V	Network generation rules
m	The number of breaks
Zb	Z - b
Zt	Z stacked by time
Time	The length of time
MU.state	UVU for each state
P	Transition matrix
s2	error variance
N.upper.tri	The number of upper triangular elements
random.perturb	If random.perturb = TRUE and a single state observation is found, the latent state is randomly selected by equal weights.

Value

A list of vectors containing latent states and their probabilities

---

updates2m *Update regime-specific variance*

Description

Update regime-specific variance parameter

Usage

```
updates2m(ns, Zm, MU, c0, d0, Km)
```

Arguments

ns	The number of hidden states
Zm	The regime-specific holder of Z - beta
MU	The mean array.
c0	Scalar shape parameter
d0	Scalar scale parameter
Km	Regime-specific dimensions

Value

A scalar for a regime-specific variance

updateU *Update time-constant latent node positions*

Description

Update time-constant latent node positions using optimized matrix operations. Pre-computes invariant quantities outside the node loop for better performance.

Usage

```
updateU(K, U, V, R, Zb, s2, eU, iVU)
```

Arguments

K	The dimensionality of Z
U	The most recent draw of latent node positions
V	Layer-specific network generation rule
R	The dimensionality of latent space
Zb	Z - beta
s2	error variance
eU	The mean of U
iVU	The variance of U

Value

A matrix of time-constant latent node positions

updateUm *Regime-specific latent node positions*

Description

Update regime-specific latent node positions using optimized matrix operations. Pre-computes invariant quantities outside the node loop for better performance.

Usage

```
updateUm(ns, U, V, R, Zm, Km, ej, s2, eU, iVU, UL.Normal)
```

Arguments

ns	The number of latent states
U	THe latent node positions
V	Layer-specific network generation rule.
R	The dimensionality of latent space
Zm	Regim-specific Z - beta
Km	The dimension of regime-specific Z.
ej	Regime indicator.
s2	The variance of error.
eU	The regim-specific mean of U.
iVU	The regim-specific variance of U.
UL.Normal	Normalization method for U. "Normal" or "Orthonormal" are supported.

Value

A matrix of regime-specific latent node positions

---

updateV *Update layer specific network generation rules*

Description

Update layer specific network generation rules using optimized matrix operations. Eliminates redundant array permutations for better performance.

Usage

```
updateV(Zb, U, R, K, s2, eV, iVV, UTA)
```

Arguments

Zb	Z - beta.
U	The latent node positions.
R	The dimension of latent space.
K	The dimension of Z.
s2	The variance of error.
eV	The mean of V.
iVV	The variance of V.
UTA	Indicator of upper triangular array

Value

A matrix of layer specific network generation rules

`updateVm` *Update V from a change-point network process*

Description

Update layer specific network generation rules from a change-point network process. Uses optimized matrix operations and eliminates redundant array permutations.

Usage

```
updateVm(ns, U, V, Zm, Km, R, s2, eV, iVV, UTA)
```

Arguments

`ns`	The number of hidden regimes.
`U`	The latent node positions.
`V`	The layer-specific network generation rule.
`Zm`	The holder of Z - beta.
`Km`	The dimension of regime-specific Z.
`R`	The dimension of latent space.
`s2`	The variance of error.
`eV`	The mean of V
`iVV`	The variance of V
`UTA`	Indicator of upper triangular array

Value

A matrix of regime-specific layer specific network generation rules

---

`WaicCompare` *Compare WAIC*

Description

Compare Widely Applicable Information Criterion

Usage

```
WaicCompare(outlist)
```

Arguments

`outlist`	List of NetworkChange objects

Value

Results of WAIC computation

A matrix of log marginal likelihoods.

References

Sumio Watanabe. 2010. "Asymptotic equivalence of Bayes cross validation and widely applicable information criterion in singular learning theory." *Journal of Machine Learning Research*. 11: 3571-3594.

Andrew Gelman, Jessica Hwang, and Aki Vehtari. 2014. "Understanding predictive information criteria for Bayesian models." *Statistics and Computing*. 24(6):997-1016.

Jong Hee Park and Yunkyun Sohn. 2020. "Detecting Structural Change in Longitudinal Network Data." *Bayesian Analysis*. Vol.15, No.1, pp.133-157.

See Also

MarginalCompare

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