Package 'VLTimeCausality'

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Title Variable-Lag Time Series Causality Inference Framework

Version 0.1.5

Description A framework to infer causality on a pair of time series of real numbers based on variable-lag Granger causality and transfer entropy. Typically, Granger causality and transfer entropy have an assumption of a fixed and constant time delay between the cause and effect. However, for a non-stationary time series, this assumption is not true. For example, considering two time series of velocity of person A and person B where B follows A. At some time, B stops tying his shoes, then running to catch up A. The fixed-lag assumption is not true in this case. We propose a framework that allows variable-lags between cause and effect in Granger causality and transfer entropy to allow them to deal with variable-lag non-stationary time series. Please see Chainarong Amornbunchornvej, Elena Zheleva, and Tanya Berger-Wolf (2021) <doi:10.1145/3441452> when referring to this package in publications.

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URL https://github.com/DarkEyes/VLTimeSeriesCausality

BugReports https://github.com/DarkEyes/VLTimeSeriesCausality/issues

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R topics documented:

`checkMultipleSimulationVLtimeseries` *checkMultipleSimulationVLtimeseries*

Description

checkMultipleSimulationVLtimeseries is a support function that can compare two adjacency matrices: groundtruth and inferred matrices. It re

Usage

```
checkMultipleSimulationVLtimeseries(trueAdjMat, adjMat)
```

Arguments

`trueAdjMat`	a groundtruth matrix.
`adjMat`	an inferred matrix.

Value

This function returns a list of precision `prec`, recall `rec`, and F1 score `F1` of inferred vs. groundtruth matrices.

Examples

```
## Generate simulation data
#G<-matrix(FALSE,10,10) # groundtruth
#G[1,c(4,7,8,10)]<-TRUE
#G[2,c(5,7,9,10)]<-TRUE
#G[3,c(6,8,9,10)]<-TRUE
#TS <- MultipleSimulationVLtimeseries()
#out<-multipleVLGrangerFunc(TS)
#checkMultipleSimulationVLtimeseries(trueAdjMat=G,adjMat=out$adjMat)
```

followingRelation *followingRelation*

Description

followingRelation is a function that infers whether Y follows X.

Usage

```
followingRelation(Y, X, timeLagWindow, lagWindow = 0.2)
```

Arguments

Y	is a numerical time series of a follower
X	is a numerical time series of a leader
timeLagWindow	is a maximum possible time delay in the term of time steps.
lagWindow	is a maximum possible time delay in the term of percentage of length(X). If timeLagWindow is missing, then timeLagWindow=ceiling(lagWindow*length(X)). The default is 0.2.

Value

This function returns a list of following relation variables below.

follVal	is a following-relation value s.t. if follVal is positive, then Y follows X. If follVal is negative, then X follows Y. Otherwise, if follVal is zero, there is no following relation between X,Y.
nX	is a time series that is rearranged from X by applying the lags optIndexVec in order to imitate Y.
optDelay	is the optimal time delay inferred by cross-correlation of X,Y. It is positive if Y is simply just a time-shift of X (e.g. Y[t]=X[t-optDelay]).
optCor	is the optimal correlation of Y[t]=X[t-optDelay] for all t.
optIndexVec	is a time series of optimal warping-path from DTW that is corrected by cross correlation. It is approximately that Y[t]=X[t-optIndexVec[t]]).
VLval	is a percentage of elements in optIndexVec that is not equal to optDelay.
ccfout	is an output object of ccf function.

Examples

```
# Generate simulation data
TS <- SimpleSimulationVLtimeseries()
# Run the function
out<-followingRelation(Y=TS$Y,X=TS$X)
```

GrangerFunc *GrangerFunc*

Description

GrangerFunc is a Granger Causality function. It tests whether X Granger-causes Y.

Usage

```
GrangerFunc(
  Y,
  X,
  maxLag = 1,
  alpha = 0.05,
  autoLagflag = TRUE,
  gamma = 0.5,
  family = gaussian
)
```

Arguments

Y	is a numerical time series of effect
X	is a numerical time series of cause
maxLag	is a maximum possible time delay. The default is 1.
alpha	is a significance level of F-test to determine whether X Granger-causes Y. The default is 0.05.
autoLagflag	is a flag for enabling the automatic lag inference function. The default is true. If it is set to be true, then maxLag is set automatically using cross-correlation. Otherwise, if it is set to be false, then the function takes the maxLag value to infer Granger causality.
gamma	is a parameter to determine whether X Granger-causes Y using BIC difference ratio.
family	is a parameter of family of function for Generalized Linear Models function (glm). The default is gaussian.

Value

This function returns of whether X Granger-causes Y.

ftest	F-statistic of Granger causality.
p.val	A p-value from F-test.
BIC_H0	Bayesian Information Criterion (BIC) derived from Y regressing on Y past.
BIC_H1	Bayesian Information Criterion (BIC) derived from Y regressing on Y,X past.
XgCsY	The flag is true if X Granger-causes Y using BIC difference ratio where BICDiffRatio >= gamma.

XgCsY_ftest	The flag is true if X Granger-causes Y using F-test where p.val>=alpha.
XgCsY_BIC	The flag is true if X Granger-causes Y using BIC where BIC_H0>=BIC_H1.
maxLag	A maximum possible time delay.
H0	glm object of Y regressing on Y past.
H1	glm object of Y regressing on Y,X past.
BICDiffRatio	Bayesian Information Criterion difference ratio: (BIC_H0-BIC_H1)/BIC_H0.

Examples

```
# Generate simulation data
TS <- SimpleSimulationVLtimeseries()
# Run the function
out<-GrangerFunc(Y=TS$Y,X=TS$X)
```

`MultipleSimulationVLtimeseries`

MultipleSimulationVLtimeseries

Description

MultipleSimulationVLtimeseries is a support function for generating a set of time series TS[,1],...TS[,10]. TS[,1],TS[,2],TS[,3] are causes X time series that are generated independently. The rest of time series are Y time series that are effects of some causes TS[,1],TS[,2],TS[,3]. TS[,1] causes TS[,4],TS[,7],TS[,8], and TS[,10]. TS[,2] causes TS[,5],TS[,7],TS[,9], and TS[,10]. TS[,3] causes TS[,6],TS[,8],TS[,9], and TS[,10].

Usage

```
MultipleSimulationVLtimeseries(
  n = 200,
  lag = 5,
  YstFixInx = 110,
  YfnFixInx = 170,
  XpointFixInx = 100,
  arimaFlag = TRUE,
  seedVal = -1
)
```

Arguments

n	is length of time series.
lag	is a time lag between X and Y s.t. Y[t] is approximately X[t-lag].
YstFixInx	is the starting point of variable lag part.
YfnFixInx	is the end point of variable lag part.

XpointFixInx	is a point in X s.t. Y[YstFixInx:YfnFixInx]= X[XpointFixInx] .
arimaFlag	is ARMA model flag. If it is true, then X is generated by ARMA model. If it is false, then X is generated by sampling of the standard normal distribution.
seedVal	is a seed parameter for generating random noise.

Value

This function returns a list of time series TS.

Examples

```
# Generate simulation data
TS <- MultipleSimulationVLtimeseries()
```

---

multipleVLGrangerFunc *multipleVLGrangerFunc*

Description

multipleVLGrangerFunc is a function that infers Variable-lag Granger Causality of all pairwises of m time series TS[,1],...TS[,m].

Usage

```
multipleVLGrangerFunc(
  TS,
  maxLag,
  alpha = 0.05,
  gamma = 0.3,
  autoLagflag = TRUE,
  causalFlag = 0,
  VLflag = TRUE,
  family = gaussian
)
```

Arguments

TS	is a numerical time series of effect where TS[t,k] is an element at time t of kth time series.
maxLag	is a maximum possible time delay. The default is 0.2*length(Y).
alpha	is a significance level of F-test to determine whether X Granger-causes Y. The default is 0.05.
gamma	is a parameter to determine whether X Granger-causes Y using BIC difference ratio. The default is 0.3.

autoLagflag	is a flag for enabling the automatic lag inference function. The default is true. If it is set to be true, then maxLag is set automatically using cross-correlation. Otherwise, if it is set to be false, then the function takes the maxLag value to infer Granger causality.
causalFlag	is a choice of criterion for inferring causality: causalFlag=0 for BIC difference ratio, causalFlag=1 for f-test, or causalFlag=2 for BIC.
VLflag	is a flag of Granger causality choice: either VLflag=TRUE for VL-Granger or VLflag=FALSE for Granger causality.
family	is a parameter of family of function for Generalized Linear Models function (glm). The default is gaussian.

Value

This function returns of a list of an adjacency matrix of causality where adjMat[i,j] is true if TS[,i] causes TS[,j].

Examples

```
## Generate simulation data
#TS <- MultipleSimulationVLtimeseries()
## Run the function
#out<-multipleVLGrangerFunc(TS)
```

---

multipleVLTransferEntropy

multipleVLTransferEntropy

Description

multipleVLTransferEntropy is a function that infers Variable-lag Transfer Entropy of all pairwises of m time series TS[,1],...TS[,m].

Usage

```
multipleVLTransferEntropy(
  TS,
  maxLag,
  nboot = 0,
  lx = 1,
  ly = 1,
  VLflag = TRUE,
  autoLagflag = TRUE,
  alpha = 0.05
)
```

Arguments

TS	is a numerical time series of effect where TS[t,k] is an element at time t of kth time series.
maxLag	is a maximum possible time delay. The default is 0.2*length(Y).
nboot	is a number of times of bootstrapping for RTransferEntropy::transfer_entropy() function.
lx, ly	are lag parameters of RTransferEntropy::transfer_entropy().
VLflag	is a flag of Granger causality choice: either VLflag=TRUE for VL-Granger or VLflag=FALSE for Granger causality.
autoLagflag	is a flag for enabling the automatic lag inference function. The default is true. If it is set to be true, then maxLag is set automatically using cross-correlation. Otherwise, if it is set to be false, then the function takes the maxLag value to infer Granger causality.
alpha	is a significant-level threshold for TE bootstrapping by Dimpfl and Peter (2013).

Value

This function returns of a list of an adjacency matrix of causality where adjMat[i,j] is true if TS[,i] causes TS[,j].

Examples

```
## Generate simulation data
#out1<-SimpleSimulationVLtimeseries()
#TS<-cbind(out1$X,out1$Y)
## Run the function
#out2<-multipleVLTransferEntropy(TS,maxLag=1)
```

---

plotTimeSeries *plotTimeSeries*

Description

plotTimeSeries is a function for visualizing time series

Usage

```
plotTimeSeries(X, Y, strTitle = "Time Series Plot", TSnames)
```

Arguments

X	is a 1st numerical time series
Y	is a 2nd numerical time series. If it is not supplied, the function plots only X.
strTitle	is a string of the plot title
TSnames	is a list of legend of X,Y where TSnames[1] is a legend of X and TSnames[2] is a legend of Y.

Value

This function returns an object of ggplot class.

Examples

```
# Generate simulation data
TS <- SimpleSimulationVLtimeseries()
# Run the function
plotTimeSeries(Y=TS$Y,X=TS$X)
```

`SimpleSimulationVLtimeseries` *SimpleSimulationVLtimeseries*

Description

SimpleSimulationVLtimeseries is a support function for generating time series `X,Y` where `X` VL-Granger-causes `Y`.

Usage

```
SimpleSimulationVLtimeseries(
  n = 200,
  lag = 5,
  YstFixInx = 110,
  YfnFixInx = 170,
  XpointFixInx = 100,
  arimaFlag = TRUE,
  seedVal = -1,
  expflag = FALSE,
  causalFlag = TRUE
)
```

Arguments

`n`	is length of time series.
`lag`	is a time lag between `X` and `Y` s.t. `Y[t]` is approximately `X[t-lag]`.
`YstFixInx`	is the starting point of variable lag part.
`YfnFixInx`	is the end point of variable lag part.
`XpointFixInx`	is a point in X s.t. `Y[YstFixInx:YfnFixInx]= X[XpointFixInx]` .
`arimaFlag`	is ARMA model flag. If it is true, then `X` is generated by ARMA model. If it is false, then `X` is generated by sampling of the standard normal distribution.
`seedVal`	is a seed parameter for generating random noise. If it is not -1, then the rnorm is set the random seed with `seedVal`.

expflag	is the flag to set the relation between Y[i+lag] and X[i]. If it is false Y,X has a linear relation, otherwise, they have an exponential relation.
causalFlag	is a flag. If it is true, then X causes Y. Otherwise, X,Y have no causal relation.

Value

This function returns a list of time series X,Y where X VL-Granger-causes Y.

Examples

```
# Generate simulation data
TS <- SimpleSimulationVLtimeseries()
```

TSNANNearestNeighborPropagation

TSNANNearestNeighborPropagation

Description

TSNANNearestNeighborPropagation is a function that fills NA values with nearest real values in the past (or future if the first position of time series is NA), for time series X.

Usage

```
TSNANNearestNeighborPropagation(X)
```

Arguments

X	is a T-by-D matrix numerical time series

Value

This function returns a list of following relation variables below.

Xout	is a T-by-D matrix numerical time series that all NAN have been filled with nearest real values.

Examples

```
# Load example data

z<-1:20
z[2:5]<-NA
z<-TSNANNearestNeighborPropagation(z)
```

VLGrangerFunc *VLGrangerFunc*

Description

VLGrangerFunc is a Variable-lag Granger Causality function. It tests whether X VL-Granger-causes Y.

Usage

```
VLGrangerFunc(
  Y,
  X,
  alpha = 0.05,
  maxLag,
  gamma = 0.5,
  autoLagflag = TRUE,
  family = gaussian
)
```

Arguments

Y	is a numerical time series of effect
X	is a numerical time series of cause
alpha	is a significance level of f-test to determine whether X Granger-causes Y. The default is 0.05.
maxLag	is a maximum possible time delay. The default is 0.2*length(Y).
gamma	is a parameter to determine whether X Granger-causes Y using BIC difference ratio. The default is 0.5.
autoLagflag	is a flag for enabling the automatic lag inference function. The default is true. If it is set to be true, then maxLag is set automatically using cross-correlation. Otherwise, if it is set to be false, then the function takes the maxLag value to infer Granger causality.
family	is a parameter of family of function for Generalized Linear Models function (glm). The default is gaussian.

Value

This function returns of whether X Granger-causes Y.

ftest	F-statistic of Granger causality.
p.val	A p-value from F-test.
BIC_H0	Bayesian Information Criterion (BIC) derived from Y regressing on Y past.
BIC_H1	Bayesian Information Criterion (BIC) derived from Y regressing on Y,X past.

XgCsY	The flag is true if X Granger-causes Y using BIC difference ratio where BICDiffRatio >= gamma.
XgCsY_ftest	The flag is true if X Granger-causes Y using f-test where p.val>=alpha.
XgCsY_BIC	The flag is true if X Granger-causes Y using BIC where BIC_H0>=BIC_H1.
maxLag	A maximum possible time delay.
H0	glm object of Y regressing on Y past.
H1	glm object of Y regressing on Y,X past.
follOut	is a list of variables from function followingRelation.
BICDiffRatio	Bayesian Information Criterion difference ratio: (BIC_H0-BIC_H1)/BIC_H0.

Examples

```
# Generate simulation data
TS <- SimpleSimulationVLtimeseries()
# Run the function
out<-VLGrangerFunc(Y=TS$Y,X=TS$X)
```

VLTransferEntropy *VLTransferEntropy*

Description

VLTransferEntropy is a Variable-lag Transfer Entropy function. It tests whether X VL-Transfer-Entropy-causes Y.

Usage

```
VLTransferEntropy(
  Y,
  X,
  maxLag,
  nboot = 0,
  lx = 1,
  ly = 1,
  VLflag = TRUE,
  autoLagflag = TRUE,
  alpha = 0.05
)
```

Arguments

Y	is a numerical time series of effect
X	is a numerical time series of cause
maxLag	is a maximum possible time delay. The default is 0.2*length(Y).

nboot	is a number of times of bootstrapping for RTransferEntropy::transfer_entropy() function.
lx, ly	are lag parameters of RTransferEntropy::transfer_entropy().
VLflag	is a flag of Transfer Entropy choice: either VLflag=TRUE for VL-Transfer Entropy or VLflag=FALSE for Transfer Entropy.
autoLagflag	is a flag for enabling the automatic lag inference function. The default is true. If it is set to be true, then maxLag is set automatically using cross-correlation. Otherwise, if it is set to be false, then the function takes the maxLag value to infer Granger causality.
alpha	is a significant-level threshold for TE bootstrapping by Dimpfl and Peter (2013).

Value

This function returns of whether X (VL-)Transfer-Entropy-causes Y.

TEratio	is a Transfer Entropy ratio. If it is greater than one , then X causes Y.
res	is an object of output from RTransferEntropy::transfer_entropy()
follOut	is a list of variables from function followingRelation.
XgCsY_trns	The flag is true if X (VL-)Transfer-Entropy-causes Y using Transfer Entropy ratio ratio where TEratio >1 if X causes Y. Additionally, if nboot>1, the flag is true only when pval<=alpha.
pval	It is a p-value for TE bootstrapping by Dimpfl and Peter (2013).

Examples

```
# Generate simulation data
TS <- SimpleSimulationVLtimeseries()
# Run the function
out<-VLTransferEntropy(Y=TS$Y,X=TS$X)
```

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