Package ‘VLTimeCausality’

May 28, 2024

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

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### 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

```r
## 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

Description

followingRelation is a function that infers whether \( Y \) follows \( X \).

Usage

\[
\text{followingRelation}(Y, X, \text{timeLagWindow}, \text{lagWindow} = 0.2)
\]

Arguments

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

Value

This function returns a list of following relation variables below.

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

Examples

\[
\text{# Generate simulation data}
\text{TS <- SimpleSimulationVLTimeseries()}
\text{# Run the function}
\text{out<-followingRelation}(Y=TS$Y,X=TS$X)
\]
**GrangerFunc**

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

**Usage**

```r
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 whether $X$ Granger-causes $Y$.

- ftest F-statistic of Granger causality.
- 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 $\geq$ gamma.
MultipleSimulationVLtimeseries

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)

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

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

multipleVLGrangerFunc

Description

multipleVLGrangerFunc is a function that infers Variable-lag Granger Causality of all pairwise of \( m \) time series \( TS[,1], \ldots TS[,m] \).

Usage

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

Arguments

<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>TS</td>
<td>is a numerical time series of effect where ( TS[t,k] ) is an element at time ( t ) of ( k )th time series.</td>
</tr>
<tr>
<td>maxLag</td>
<td>is a maximum possible time delay. The default is 0.2*length(Y).</td>
</tr>
<tr>
<td>alpha</td>
<td>is a significance level of F-test to determine whether ( X ) Granger-causes ( Y ). The default is 0.05.</td>
</tr>
<tr>
<td>gamma</td>
<td>is a parameter to determine whether ( X ) Granger-causes ( Y ) using BIC difference ratio. The default is 0.3.</td>
</tr>
</tbody>
</table>
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 a list of an adjacency matrix of causality where adjMat[i,j] is true if TS[,i] causes TS[,j].

Examples

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

multipleVLTransferEntropy

Description

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

Usage

```r
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 \(k\)th 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 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 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**

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

**Description**

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

**Usage**

```r
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`.

---

**SimpleSimulationVLtimeseries**

*SimpleSimulationVLtimeseries*
expflag is the flag to set the relation between $Y[i+\text{lag}]$ and $X[i]$. If it is false, $Y, X$ have 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

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

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

```r
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

```r
# Load example data
z<-1:20
z[2:5]<-NA
z<-TSNANNearestNeighborPropagation(z)
```
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.
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.
VL Transfer Entropy

XgCsY: The flag is true if X Granger-causes Y using BIC difference ratio where BICDiffRatio \( \geq \) gamma.

XgCsY_ftest: The flag is true if X Granger-causes Y using f-test where p.val \( \geq \) alpha.

XgCsY_BIC: The flag is true if X Granger-causes Y using BIC where BIC_H0 \( \geq \) 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.

dollOut: is a list of variables from function followingRelation.

BICDiffRatio: Bayesian Information Criterion difference ratio: \( \frac{(\text{BIC}_\text{H0}-\text{BIC}_\text{H1})}{\text{BIC}_\text{H0}} \).

Examples

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

Description

VL Transfer Entropy 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).
**VLTransferEntropy**

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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