Package ‘ftsspec’

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Title Spectral Density Estimation and Comparison for Functional Time Series

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Description Functions for estimating spectral density operator of functional time series (FTS) and comparing the spectral density operator of two functional time series, in a way that allows detection of differences of the spectral density operator in frequencies and along the curve length.

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`Epanechnikov_kernel` *The Epanechnikov weight function, with support in* $[-1, 1]$

Description

The Epanechnikov weight function, with support in $[-1, 1]$

Usage

```
Epanechnikov_kernel(x)
```

Arguments

`x`	argument at which the function is evaluated

`ftsspec` *ftsspec: collection of functions for estimating spectral density operator of functional time series (FTS) and comparing the spectral density operator of two functional time series, in a way that allows detection of differences of the spectral density operator in frequencies and along the curve length.*

Description

ftsspec: collection of functions for estimating spectral density operator of functional time series (FTS) and comparing the spectral density operator of two functional time series, in a way that allows detection of differences of the spectral density operator in frequencies and along the curve length.

References

Tavakoli, Shahin and Panaretos, Victor M. "Detecting and Localizing Differences in Functional Time Series Dynamics: A Case Study in Molecular Biophysics", 2014, under revision

Generate_filterMA *Generate the Filter of a multivariate MA process*

Description

Generate the Filter of a multivariate MA process

Usage

```
Generate_filterMA(d.ts, d.n, MA.len = 3, ma.scale = rep(1, MA.len),
  a.smooth.coef = 0, seed = 1)
```

Arguments

d.ts	dimension of the (output) time series
d.n	dimension of the noise that is filtered
MA.len	Length of the filter. Set to 3 by default.
ma.scale	scaling factor of each lag matrix. See details.
a.smooth.coef	A coefficient to shrink coefficients of filter. Set to 0 by default.
seed	The random seed used to generate the filter. Set to 1 by default.

Value

A `d.ts x d.n x MA.len` array

Details

Generates a filter (i.e. a `d.ts x d.n x MA.len` array) for a moving average process. The entries of the filter are generate randomly, but can be reproduced by specifying the random seed seed.

The `ma.scale` parameter should be a vector of length `MA.len`, and corresponds to a scaling factor applied to each lag of the filter of the MA process that is generated.

Examples

```
ma.scale1=c(-1.4,2.3,-2)
a1=Generate_filterMA(10, 10, MA.len=3, ma.scale=ma.scale1, seed=10)
str(a1)
rm(a1)
```

Get_noise_sd — *Get the square root of the covariance matrix associated to a noise type*

Description

Get the square root of the covariance matrix associated to a noise type

Usage

```
Get_noise_sd(noise.type, d.n)
```

Arguments

noise.type	the type of noise that is driving the MA process. See Details section.
d.n	dimension of the noise that is filtered

lines.SampleSpecDiffFreq — *Plotting function for* SampleSpecDiffFreq *class*

Description

Plotting function for SampleSpecDiffFreq class

Usage

```
## S3 method for class 'SampleSpecDiffFreq'
lines(x, method = NA, Kmax = 4, pch = 20,
  ...)
```

Arguments

x	object of the class SampleSpecDiffFreq
method	method used to adjust p-values
Kmax	maximum number of levels K for which the pvalues are plotted (used only if autok==0)
pch	the plot character to be used
...	additional parameters to be passed to plot()

See Also

Spec_compare_localize_freq

`Marginal_basis_pval` *Compute the marginal p-values at each basis coefficients of for testing the equality of two spectral density kernels*

Description

Compute the marginal p-values at each basis coefficients of for testing the equality of two spectral density kernels

Usage

```
Marginal_basis_pval(spec1, spec2, m, kappa.square, is.pi.multiple)
```

Arguments

`spec1`	The two sample spectral densities (at the same frequency ω) to be compared.
`spec2`	The two sample spectral densities (at the same frequency ω) to be compared.
`m`	The number of Fourier frequencies over which the periodogram operator was smoothed.
`kappa.square`	the L2-norm of the weight function used to estimate the spectral density operator
`is.pi.multiple`	A logical variable, to specify if $\omega = 0, \pi$ or not.

`plot.SampleSpec` *Plotting method for object inheriting from class* `SampleSpec`

Description

Plotting method for object inheriting from class `SampleSpec`

Usage

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

Arguments

`x`	An object of the class `SampleSpec`
`...`	additional parameters to be passed to plot()

plot.SampleSpecDiffFreq

Plotting function for `SampleSpecDiffFreq` *class*

Description

Plotting function for `SampleSpecDiffFreq` class

Usage

```
## S3 method for class 'SampleSpecDiffFreq'
plot(x, method = NA, Kmax = 4, pch = 20, ...)
```

Arguments

`x`	object of the class `SampleSpecDiffFreq`
`method`	method used to adjust p-values
`Kmax`	maximum number of levels K for which the pvalues are plotted (used only if autok==0)
`pch`	the plot character to be used
`...`	additional parameters to be passed to plot()

See Also

`Spec_compare_localize_freq`

plot.SampleSpecDiffFreqCurvelength

Plotting method for class `SampleSpecDiffFreqCurvelength`

Description

Plotting method for class `SampleSpecDiffFreqCurvelength`

Usage

```
## S3 method for class 'SampleSpecDiffFreqCurvelength'
plot(x, ncolumns = 3, ...)
```

Arguments

`x`	Object of the class `SampleSpecDiffFreqCurvelength`
`ncolumns`	number of columns for the plots
`...`	additional parameters to be passed to `plot()`

`plot.SpecMA` *Plotting method for object inheriting from class* `SpecMA`

Description

Plotting method for object inheriting from class `SpecMA`

Usage

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

Arguments

`x`	A object of the class `SpecMA`
`...`	additional parameters to be passed to plot()

`print.SampleSpecDiffFreqCurvelength` *Printing method for class* `SampleSpecDiffFreqCurvelength`

Description

Printing method for class `SampleSpecDiffFreqCurvelength`

Usage

```
## S3 method for class 'SampleSpecDiffFreqCurvelength'
print(x, ...)
```

Arguments

`x`	Object of the class `SampleSpecDiffFreqCurvelength`
`...`	Additional arguments for print

PvalAdjust — *Generic function to adjust pvalues*

Description

Generic function to adjust pvalues

function to adjust pvalues for class SampleSpecDiffFreq

Usage

```
PvalAdjust(sample.spec.diff, method)

## S3 method for class 'SampleSpecDiffFreq'
PvalAdjust(sample.spec.diff, method)
```

Arguments

sample.spec.diff	Object of the class SampleSpecDiffFreq
method	method used to adjust p-values

See Also

Spec_compare_localize_freq

Simulate_new_MA — *Simulate a new Moving Average (MA) vector time series and return the time series*

Description

Simulate a new Moving Average (MA) vector time series and return the time series

Usage

```
Simulate_new_MA(a, T.len, noise.type, DEBUG = FALSE)
```

Arguments

a	Array, returned by Generate_filterMA, containing the filter of the MA process
T.len	Numeric, the length of the time series to generate
noise.type	the type of noise that is driving the MA process. See Details section.
DEBUG	Logical, for outputting information on the progress of the function

Value

A `T.len x dim(a)[1]` matrix, where each column corresponds to a coordinate of the vector time series

Details

The function simulates a moving average process of dimension `dim(a)[1]`, defined by

$$X[t,] = a[,,1]*epsilon[,t-1]+a[,,2]*epsilon[,t-2]+...+a[,,dim(a)[3]]*epsilon[t-dim(a)[3]]$$

`noise.type` specifies the nature and internal correlation of the noise that is driving the MA process. It can take the values

`white-noise` the noise is Gaussian with covariance matrix identity

`white-noise` the noise is Gaussian with diagonal covariance matrix, whose j-th diagonal entry is $((j-0.5)*pi)^(-1)$

`studentk` the coordinates of the noise are independent and have a student t distribution with 'k' degrees of freedom, standardized to have variance 1

Examples

```
ma.scale1=c(-1.4,2.3,-2)
a1=Generate_filterMA(6, 6, MA.len=3, ma.scale=ma.scale1)
X=Simulate_new_MA(a1, T.len=512, noise.type='wiener')
plot.ts(X)
```

Spec   *Compute Spectral Density of Functional Time Series*

Description

This function estimates the spectral density operator of a Functional Time Series (FTS)

Usage

```
Spec(X, W = Epanechnikov_kernel, B.T = (dim(X)[1])^(-1/5),
  only.diag = FALSE, trace = FALSE, demean = TRUE, subgrid = FALSE,
  subgrid.density = 10, verbose = 0,
  subgrid.density.relative.to.bandwidth = TRUE)
```

Arguments

`X`	A $T \times nbasis$ matrix of containing the coordinates of the FTS expressed in a basis. Each row corresponds to a time point, and each column corresponds to the coefficient of the corresponding basis function of the FTS.
`W`	The weight function used to smooth the periodogram operator. Set by default to be the Epanechnikov kernel

B.T	The bandwidth of frequencies over which the periodogram operator is smoothed. If B.T=0, the periodogram operator is returned.
only.diag	A logical variable to choose if the function only computes the marginal spectral density of each basis coordinate (only.diag=TRUE). only.diag=FALSE by default, the full spectral density operator is computed .
trace	A logical variable to choose if only the trace of the spectral density operator is computed. trace=FALSE by default.
demean	A logical variable to choose if the FTS is centered before computing its spectral density operator.
subgrid	A logical variable to choose if the spectral density operator is only returned for a subgrid of the Fourier frequencies, which can be useful in large datasets to reduce memory usage. subgrid=FALSE by default.
subgrid.density	Only used if subgrid=TRUE. Specifies the approximate number of frequencies within the bandwidth over which the periodogram operator is smoothed.
verbose	A variable to show the progress of the computations. By default, verbose=0.
subgrid.density.relative.to.bandwidth	logical parameter to specify if subgrid.density is specified relative to the bandwidth parameter B.T

Value

A list containing the following elements:

spec The estimated spectral density operator. The first dimension corresponds to the different frequencies over which the spectral density operators are estimated.

omega The frequencies over which the spectral density is estimated.

m The number of Fourier frequencies over which the periodogram operator was smoothed.

bw The equivalent Bandwidth used in the weight function W(), as defined in Bloomfield (1976, p.201).

weight The weight function used to smooth the periodogram operator.

kappa.square The L2 norm of the weight function W.

References

spec.pgram function of R.

Bloomfield, P. (1976) "Fourier Analysis of Time Series: An Introduction", Wiley.

Panaretos, V. M. and Tavakoli, S., "Fourier Analysis of Functional Time Series", Ann. Statist. Volume 41, Number 2 (2013), 568-603.

Examples

```
ma.scale1=c(-1.4,2.3,-2)
a1=Generate_filterMA(10, 10, MA.len=3, ma.scale=ma.scale1)
X=Simulate_new_MA(a1, T.len=512, noise.type='wiener')
ans=Spec(X, trace=FALSE, only.diag=FALSE)
```

```
plot(ans)
plot(Spec(X, trace=FALSE, only.diag=FALSE, subgrid=TRUE, subgrid.density=10,
subgrid.density.relative.to.bandwidth=FALSE))
rm(ans)
```

SpecMA *'Spectral density operator of a MA vector process' Object*

Description

'Spectral density operator of a MA vector process' Object

Usage

```
SpecMA(a, nfreq = 2^9, noise.type)
```

Arguments

a	the filter of the moving average
nfreq	the number of frequencies between 0 and pi at which the spectral density has to be computed
noise.type	the type of noise that is driving the MA process. See Simulate_new_MA

Examples

```
ma.scale1=c(-1.4,2.3,-2)
a1=Generate_filterMA(6, 6, MA.len=3, ma.scale=ma.scale1)
a1.spec=SpecMA(a1, nfreq=512, noise.type='wiener')
plot(a1.spec)
rm(a1, a1.spec)
```

Spec_compare_fixed_freq *Test if two spectral density operators at some fixed frequency are equal.*

Description

A test for the null hypothesis that two spectral density operators (at the same frequency ω) are equal, using a pseudo-AIC criterion for the choice of the truncation parameter. (used in Spec_compare_localize_freq)

Usage

```
Spec_compare_fixed_freq(spec1, spec2, is.pi.multiple, m, kappa.square,
  autok = 2, K.fixed = NA)
```

Arguments

spec1,spec2	The two sample spectral densities (at the same frequency ω) to be compared.
is.pi.multiple	A logical variable, to specify if $\omega = 0, \pi$ or not.
m	The number of Fourier frequencies over which the periodogram operator was smoothed.
kappa.square	the L2-norm of the weight function used to estimate the spectral density operator
autok	A variable used to specify if (and which) pseudo-AIC criterion is used to select the truncation parameter K.
K.fixed	The value of K used if `autok=0`.

References

Tavakoli, Shahin and Panaretos, Victor M. "Detecting and Localizing Differences in Functional Time Series Dynamics: A Case Study in Molecular Biophysics", 2014, under revision

Panaretos, Victor M., David Kraus, and John H. Maddocks. "Second-order comparison of Gaussian random functions and the geometry of DNA minicircles." Journal of the American Statistical Association 105.490 (2010): 670-682.

See Also

Spec_compare_localize_freq

Examples

```
ma.scale2=ma.scale1=c(-1.4,2.3,-2)
ma.scale2[3] = ma.scale1[3]+.3
a1=Generate_filterMA(10, 10, MA.len=3, ma.scale=ma.scale1)
a2=Generate_filterMA(10, 10, MA.len=3, ma.scale=ma.scale2)
X=Simulate_new_MA(a1, T.len=512, noise.type='wiener')
Y=Simulate_new_MA(a2, T.len=512, noise.type='wiener')
spec.X = Spec(X)
spec.Y = Spec(Y)
Spec_compare_fixed_freq(spec.X$spec[1,,], spec.Y$spec[1,,],
is.pi.multiple=TRUE, spec.X$m, spec.X$kappa.square)
```

Spec_compare_localize_freq

Compare the spectral density operator of two Functional Time Series and localize frequencies at which they differ.

Description

Compare the spectral density operator of two Functional Time Series and localize frequencies at which they differ.

Usage

```
Spec_compare_localize_freq(X, Y, B.T = (dim(X)[1])^(-1/5), W, autok = 2,
  subgrid.density, verbose = 0, demean = FALSE, K.fixed = NA,
  subgrid.density.relative.to.bandwidth)
```

Arguments

`X,Y`	The $T \times nbasis$ matrices of containing the coordinates, expressed in some functional basis, of the two FTS that to be compared. expressed in a basis.
`B.T`	The bandwidth of frequencies over which the periodogram operator is smoothed. If `B.T=0`, the periodogram operator is returned.
`W`	The weight function used to smooth the periodogram operator. Set by default to be the Epanechnikov kernel
`autok`	A variable used to specify if (and which) pseudo-AIC criterion is used to select the truncation parameter K.
`subgrid.density`	Only used if `subgrid=TRUE`. Specifies the approximate number of frequencies within the bandwidth over which the periodogram operator is smoothed.
`verbose`	A variable to show the progress of the computations. By default, `verbose=0`.
`demean`	A logical variable to choose if the FTS is centered before computing its spectral density operator.
`K.fixed`	The value of K used if `autok=0`.
`subgrid.density.relative.to.bandwidth`	logical parameter to specify if `subgrid.density` is specified relative to the bandwidth parameter `B.T`

Details

`X,Y` must be of equal size $T.len \times d$, where T.len is the length of the time series, and d is the number of basis functions. Each row corresponds to a time point, and each column corresponds to the coefficient of the corresponding basis function of the FTS.

`autok=0` returns the p-values for $K = 1, \ldots,$ `K.fixed`. `autok=1` uses the `AIC` criterion of Tavakoli \& Panaretos (2015), which is a generalization of the pseudo-AIC introduced in Panaretos et al (2010). `autok=2` uses the `AIC*` criterion of Tavakoli \& Panaretos (2015), which is an extension of the `AIC` criterion that takes into account the difficulty associated with the estimation of eigenvalues of a compact operator.

References

Tavakoli, Shahin and Panaretos, Victor M. "Detecting and Localizing Differences in Functional Time Series Dynamics: A Case Study in Molecular Biophysics", 2014, under revision

Panaretos, Victor M., David Kraus, and John H. Maddocks. "Second-order comparison of Gaussian random functions and the geometry of DNA minicircles." Journal of the American Statistical Association 105.490 (2010): 670-682.

Examples

```
ma.scale2=ma.scale1=c(-1.4,2.3,-2)
ma.scale2[3] = ma.scale1[3]+.0
a1=Generate_filterMA(10, 10, MA.len=3, ma.scale=ma.scale1)
a2=Generate_filterMA(10, 10, MA.len=3, ma.scale=ma.scale2)
X=Simulate_new_MA(a1, T.len=512, noise.type='wiener')
Y=Simulate_new_MA(a2, T.len=512, noise.type='wiener')
ans0=Spec_compare_localize_freq(X, Y, W=Epanechnikov_kernel, autok=2,
subgrid.density=10, verbose=0, demean=FALSE,
subgrid.density.relative.to.bandwidth=TRUE)
plot(ans0)
plot(ans0, method='fdr')
PvalAdjust(ans0, method='fdr') ## print FDR adjusted p-values
abline(h=.05, lty=3)
ans0=Spec_compare_localize_freq(X, Y, W=Epanechnikov_kernel, autok=0,
subgrid.density=10, verbose=0, demean=FALSE,
subgrid.density.relative.to.bandwidth=TRUE, K.fixed=4) ## fixed values of K
plot(ans0)
plot(ans0, 'fdr')
plot(ans0, 'holm')
PvalAdjust(ans0, method='fdr')
rm(ans0)
```

Spec_compare_localize_freq_curvelength

Compare the spectral density operator of two Functional Time Series and localize frequencies at which they differ, and (spatial) regions where they differ

---

Description

Compare the spectral density operator of two Functional Time Series and localize frequencies at which they differ, and (spatial) regions where they differ

Usage

```
Spec_compare_localize_freq_curvelength(X, Y, B.T = (dim(X)[1])^(-1/5), W,
  alpha = 0.05, accept = 0, reject = 1, verbose = 0, demean = FALSE)
```

Arguments

X	The $T \times nbasis$ matrices of containing the coordinates, expressed in some functional basis, of the two FTS that to be compared. expressed in a basis.
Y	The $T \times nbasis$ matrices of containing the coordinates, expressed in some functional basis, of the two FTS that to be compared. expressed in a basis.
B.T	The bandwidth of frequencies over which the periodogram operator is smoothed. If `B.T=0`, the periodogram operator is returned.

W	The weight function used to smooth the periodogram operator. Set by default to be the Epanechnikov kernel
alpha	level for the test
accept,reject	values for accepted, rejected regions
verbose	A variable to show the progress of the computations. By default, verbose=0.
demean	A logical variable to choose if the FTS is centered before computing its spectral density operator.

Examples

```
ma.scale2=ma.scale1=c(-1.4,2.3,-2)
ma.scale2[3] = ma.scale1[3]+.4
a1=Generate_filterMA(10, 10, MA.len=3, ma.scale=ma.scale1)
a2=Generate_filterMA(10, 10, MA.len=3, ma.scale=ma.scale2)
X=Simulate_new_MA(a1, T.len=2^9, noise.type='wiener')
Y=Simulate_new_MA(a2, T.len=2^9, noise.type='wiener')
ans0=Spec_compare_localize_freq_curvelength(X, Y, W=Epanechnikov_kernel, alpha=.01, demean=TRUE)
print(ans0)
plot(ans0)
rm(ma.scale1, ma.scale2, a1, a2, X, Y, ans0)
```

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