Package ‘ftsa’

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Author Rob Hyndman [aut] (<https://orcid.org/0000-0002-2140-5352>),
Han Lin Shang [aut, cre, cph] (<https://orcid.org/0000-0003-1769-6430>)
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**ftsa-package**

*Functional Time Series Analysis*
Description

This package presents descriptive statistics of functional data; implements principal component regression and partial least squares regression to provide point and distributional forecasts for functional data; utilizes functional linear regression, ordinary least squares, penalized least squares, ridge regression, and moving block approaches to dynamically update point and distributional forecasts when partial data points in the most recent curve are observed; performs stationarity test for a functional time series; estimates a long-run covariance function by kernel sandwich estimator.

Author(s)

Rob J Hyndman and Han Lin Shang
Maintainer: Han Lin Shang <hanlin.shang@anu.edu.au>

References


# References in Population Studies


# References in Actuarial Studies #


# References in Finance #


```
centre
Mean function, variance function, median function, trim mean function of functional data
```

Description
Mean function, variance function, median function, trim mean function of functional data

Usage
```
centre(x, type)
```

Arguments
- `x`: An object of class `matrix`.
- `type`: Mean, variance, median or trim mean?

Value
Return mean function, variance function, median function or trim mean function.

Author(s)
Han Lin Shang
See Also

`pcscorebootstrapdata`, `mean.fts`, `median.fts`, `sd.fts`, `var.fts`

Examples

# mean function is often removed in the functional principal component analysis.
# trimmed mean function is sometimes employed for robustness in the presence of outliers.
# In calculating trimmed mean function, several functional depth measures were employed.
centre(x = ElNino.ERSST_region.Land2$y, type = "mean")
centre(x = ElNino.ERSST_region.Land2$y, type = "var")
centre(x = ElNino.ERSST_region.Land2$y, type = "median")
centre(x = ElNino.ERSST_region.Land2$y, type = "trimmed")

diff.fts  Differences of a functional time series

Description

Computes differences of a `fts` object at each variable.

Usage

```r
## S3 method for class 'fts'
diff(x, lag = 1, differences = 1, ...)
```

Arguments

- `x`  An object of class `fts`.
- `lag`  An integer indicating which lag to use.
- `differences`  An integer indicating the order of the difference.
- `...`  Other arguments.

Value

An object of class `fts`.

Author(s)

Rob J Hyndman

Examples

# ElNino is an object of sliced functional time series.
# Differencing is sometimes used to achieve stationarity.
diff(x = ElNino.ERSST_region.Land2)
Dynamic multilevel functional principal component analysis

Description

Functional principal component analysis is used to decompose multiple functional time series. This function uses a functional panel data model to reduce dimensions for multiple functional time series.

Usage

`dmfpca(y, M = NULL, J = NULL, N = NULL, tstart = 0, tlength = 1)`

Arguments

- `y`: A data matrix containing functional responses. Each row contains measurements from a function at a set of grid points, and each column contains measurements of all functions at a particular grid point.
- `M`: Number of fts objects.
- `J`: Number of functions in each object.
- `N`: Number of grid points per function.
- `tstart`: Start point of the grid points.
- `tlength`: Length of the interval that the functions are evaluated at.

Value

- `K1`: Number of components for the common time-trend.
- `K2`: Number of components for the residual component.
- `lambda1`: A vector containing all common time-trend eigenvalues in non-increasing order.
- `lambda2`: A vector containing all residual component eigenvalues in non-increasing order.
- `phi1`: A matrix containing all common time-trend eigenfunctions. Each row contains an eigenfunction evaluated at the same set of grid points as the input data. The eigenfunctions are in the same order as the corresponding eigenvalues.
- `phi2`: A matrix containing all residual component eigenfunctions. Each row contains an eigenfunction evaluated at the same set of grid points as the input data. The eigenfunctions are in the same order as the corresponding eigenvalues.
- `scores1`: A matrix containing estimated common time-trend principal component scores. Each row corresponding to the common time-trend scores for a particular subject in a cluster. The number of rows is the same as that of the input matrix `y`. Each column contains the scores for a common time-trend component for all subjects.
- `scores2`: A matrix containing estimated residual component principal component scores. Each row corresponding to the level 2 scores for a particular subject in a cluster. The number of rows is the same as that of the input matrix `y`. Each column contains the scores for a residual component for all subjects.
mu

A vector containing the overall mean function.

etta

A matrix containing the deviation from overall mean function to country specific mean function. The number of rows is the number of countries.

Author(s)

Chen Tang and Han Lin Shang

References


See Also

mftsc

Examples

```r
## The following takes about 10 seconds to run
## Not run:
y <- do.call(rbind, sim_ex_cluster)
MFPCA.sim <- dmfpca(y, M = length(sim_ex_cluster), J = nrow(sim_ex_cluster[[1]]),
                  N = ncol(sim_ex_cluster[[1]]), tlength = 1)

## End(Not run)
```

dynamic_FLR

*Dynamic updates via functional linear regression*

Description

A functional linear regression is used to address the problem of dynamic updating, when partial data in the most recent curve are observed.

Usage

dynamic_FLR(dat, newdata, holdoutdata, order_k_percent = 0.9, order_m_percent = 0.9,
            pcd_method = c("classical", "M"), robust_lambda = 2.33, bootrep = 100,
            pointfore, level = 80)
Arguments

dat  An object of class \textit{sfts}.
newdata  A data vector of newly arrived observations.
holdoutdata  A data vector of holdout sample to evaluate point forecast accuracy.
order_k_percent  Select the number of components that explains at least 90 percent of the total variation.
order_m_percent  Select the number of components that explains at least 90 percent of the total variation.
pcd_method  Method to use for principal components decomposition. Possibilities are "M", "rapca" and "classical".
robust_lambda  Tuning parameter in the two-step robust functional principal component analysis, when \texttt{pcd_method = "M"}.
bootrep  Number of bootstrap samples.
pointfore  If \texttt{pointfore = TRUE}, point forecasts are produced.
level  Nominal coverage probability.

Details

This function is designed to dynamically update point and interval forecasts, when partial data in the most recent curve are observed.

Value

update_forecast  Updated forecasts.
holdoutdata  Holdout sample.
err  Forecast errors.
order_k  Number of principal components in the first block of functions.
order_m  Number of principal components in the second block of functions.
update_comb  Bootstrapped forecasts for the dynamically updating time period.
update_comb_lb_ub  By taking corresponding quantiles, obtain lower and upper prediction bounds.
err_boot  Bootstrapped in-sample forecast error for the dynamically updating time period.

Author(s)

Han Lin Shang
References


See Also
dynupdate

Examples
dynamic_FLR_point = dynamic_FLR(dat = elNino_ERSST_region_1and2$s[,1:68],
newdata = elNino_ERSST_region_1and2$s[1:4,69],
holdoutdata = elNino_ERSST_region_1and2$s[5:12,69], pointfore = TRUE)

dynamic_FLR_interval = dynamic_FLR(dat = elNino_ERSST_region_1and2$s[,1:68],
newdata = elNino_ERSST_region_1and2$s[1:4,69],
holdoutdata = elNino_ERSST_region_1and2$s[5:12,69], pointfore = FALSE)

dynupdate

Dynamic updates via BM, OLS, RR and PLS methods

Description

Four methods, namely block moving (BM), ordinary least squares (OLS) regression, ridge regression (RR), penalized least squares (PLS) regression, were proposed to address the problem of dynamic updating, when partial data in the most recent curve are observed.

Usage
dynupdate(data, newdata = NULL, holdoutdata, method = c("ts", "block",
"ols", "pls", "ridge"), fmethod = c("arima", "ar", "ets", "ets.na",
"rwdrift", "rw"), pcdmethod = c("classical", "M", "rapca"),
ngrid = max(1000, ncol(data$s)), order = 6,
robust_lambda = 2.33, lambda = 0.01, value = FALSE, interval = FALSE, level = 80, pimethod = c("parametric", "nonparametric"), B = 1000

Arguments

data
An object of class sfts.

newdata
A data vector of newly arrived observations.

holdoutdata
A data vector of holdout sample to evaluate point forecast accuracy.

method
Forecasting methods. The latter four can dynamically update point forecasts.

fmethod
Univariate time series forecasting methods used in method = "ts" or method = "block".

pcdmethod
Method to use for principal components decomposition. Possibilities are "M", "rapca" and "classical".

ngrid
Number of grid points to use in calculations. Set to maximum of 1000 and ncol(data$y).

order
Number of principal components to fit.

robust_lambda
Tuning parameter in the two-step robust functional principal component analysis, when pcdmethod = "M".

lambda
Penalty parameter used in method = "pls" or method = "ridge".

value
When value = TRUE, returns forecasts or when value = FALSE, returns forecast errors.

interval
When interval = TRUE, produces distributional forecasts.

level
Nominal coverage probability.

pimethod
Parametric or nonparametric method to construct prediction intervals.

B
Number of bootstrap samples.

Details

This function is designed to dynamically update point and interval forecasts, when partial data in the most recent curve are observed.

If method = "classical", then standard functional principal component decomposition is used, as described by Ramsay and Dalzell (1991).

If method = "rapca", then the robust principal component algorithm of Hubert, Rousseeuw and Verboven (2002) is used.

If method = "M", then the hybrid algorithm of Hyndman and Ullah (2005) is used.

Value

forecasts
An object of class fts containing the dynamic updated point forecasts.

bootsamp
An object of class fts containing the bootstrapped point forecasts, which are updated by the PLS method.

low
An object of class fts containing the lower bound of prediction intervals.

up
An object of class fts containing the upper bound of prediction intervals.
Author(s)

Han Lin Shang

References


See Also

* ftsm, forecast.ftsm, plot.fm, residuals.fm, summary.fm*

Examples

```r
# ElNino is an object of sliced functional time series, constructed from a univariate time series.
# When we observe some newly arrived information in the most recent time period, this function
# allows us to update the point and interval forecasts for the remaining time period.
dynupdate(data = ElNino.ERSST_region_land2, newdata = ElNino.ERSST_region_land2$y[1:4,69],
          holdoutdata = ElNino.ERSST_region_land2$y[5:12,57], method = "block", interval = FALSE)
```
Description

Computes the forecast error measure.

Usage

```
error(forecast, forecastbench, true, insampletrue, method = c("me", "mpe", "mae", 
    "mse", "sse", "rmse", "mdae", "mse", "mape", "mdape", "smape", 
    "smdape", "rmspe", "rmspe", "mrae", "mdrae", "gmae", 
    "relmae", "relmse", "mase", "mdase", "rmsse"), giveall = FALSE)
```

Arguments

- `forecast`: Out-of-sample forecasted values.
- `forecastbench`: Forecasted values using a benchmark method, such as random walk.
- `true`: Out-of-sample holdout values.
- `insampletrue`: Insample values.
- `method`: Method of forecast error measure.
- `giveall`: If `giveall` = TRUE, all error measures are provided.

Details

**Bias measure:**
If `method` = "me", the forecast error measure is mean error.
If `method` = "mpe", the forecast error measure is mean percentage error.

**Forecast accuracy error measure:**
If `method` = "mae", the forecast error measure is mean absolute error.
If `method` = "mse", the forecast error measure is mean square error.
If `method` = "sse", the forecast error measure is sum square error.
If `method` = "rmse", the forecast error measure is root mean square error.
If `method` = "mdae", the forecast error measure is median absolute error.
If `method` = "mape", the forecast error measure is mean absolute percentage error.
If `method` = "mdape", the forecast error measure is median absolute percentage error.
If `method` = "rmspe", the forecast error measure is root mean square percentage error.
If `method` = "rmspe", the forecast error measure is root median square percentage error.

**Forecast accuracy symmetric error measure:**
If `method` = "smape", the forecast error measure is symmetric mean absolute percentage error.
If `method` = "smdape", the forecast error measure is symmetric median absolute percentage error.
**Forecast accuracy relative error measure:**
If method = "mrae", the forecast error measure is mean relative absolute error.
If method = "mdrae", the forecast error measure is median relative absolute error.
If method = "gmrae", the forecast error measure is geometric mean relative absolute error.
If method = "relmae", the forecast error measure is relative mean absolute error.
If method = "relmse", the forecast error measure is relative mean square error.

**Forecast accuracy scaled error measure:**
If method = "mase", the forecast error measure is mean absolute scaled error.
If method = "mdase", the forecast error measure is median absolute scaled error.
If method = "rmsse", the forecast error measure is root mean square scaled error.

**Value**
A numeric value.

**Author(s)**
Han Lin Shang

**References**

**Examples**
# Forecast error measures can be categorized into three groups: (1) scale-dependent,
# (2) scale-independent but with possible zero denominator,
# (3) scale-independent with non-zero denominator.
error(forecast = 1:2, true = 3:4, method = "mae")
error(forecast = 1:5, forecastbench = 6:10, true = 11:15, method = "mrae")
error(forecast = 1:5, forecastbench = 6:10, true = 11:15, insampletrue = 16:20,
giveall = TRUE)
**extract**

*Extract variables or observations*

**Description**

Creates subsets of a fts object.

**Usage**

```r
extract(data, direction = c("time", "x"), timeorder, xorder)
```

**Arguments**

- **data**: An object of fts.
- **direction**: In time direction or x variable direction?
- **timeorder**: Indexes of time order.
- **xorder**: Indexes of x variable order.

**Value**

When `xorder` is specified, it returns a fts object with same argument as data but with a subset of x variables.

When `timeorder` is specified, it returns a fts object with same argument as data but with a subset of time variables.

**Author(s)**

Han Lin Shang

**Examples**

```r
# ElNino is an object of class sliced functional time series.
# This function truncates the data series rowwise or columnwise.
extract(data = ElNino_ERSST_region_land2, direction = "time",
timeorder = 1980:2006)  # Last 27 curves
extract(data = ElNino_ERSST_region_land2, direction = "x",
xorder = 1:8)  # First 8 x variables
```
Description

Compute functional autocorrelation function at various lags

Usage

```r
facf(fun_data, lag_value_range = seq(0, 20, by = 1))
```

Arguments

- `fun_data`: A data matrix of dimension (n by p), where n denotes sample size; and p denotes dimensionality
- `lag_value_range`: Lag value

Details

The autocovariance at lag \( i \) is estimated by the function \( \hat{\gamma}_i(t,s) \), a functional analog of the autocorrelation is defined as

\[
\hat{\rho}_i = \frac{\| \hat{\gamma}_i \|}{\int \hat{\gamma}_i(t, t) dt}.
\]

Value

A vector of functional autocorrelation function at various lags

Author(s)

Han Lin Shang

References


Examples

```r
facf_value = facf(fun_data = t(E1Nino_ERSST_region_land2$y))
```
Functional data forecasting through functional principal component autoregression

Description
The coefficients from the fitted object are forecasted using a multivariate time-series forecasting method. The forecast coefficients are then multiplied by the functional principal components to obtain a forecast curve.

Usage
farforecast(object, h = 10, var_type = "const", Pmax_value, level = 80, PI = FALSE)

Arguments
- **object**: An object of `fds`.
- **h**: Forecast horizon.
- **var_type**: Type of multivariate time series forecasting method; see `VAR` for details.
- **Pmax_value**: Maximum order of VAR model considered.
- **level**: Nominal coverage probability of prediction error bands.
- **PI**: When `PI = TRUE`, a prediction interval will be given along with the point forecast.

Details
1. Decompose the smooth curves via a functional principal component analysis (FPCA).
2. Fit a multivariate time-series model to the principal component score matrix.
3. Forecast the principal component scores using the fitted multivariate time-series models. The order of VAR is selected optimally via an information criterion.
4. Multiply the forecast principal component scores by estimated principal components to obtain forecasts of $f_{n+h}(x)$.
5. Prediction intervals are constructed by taking quantiles of the one-step-ahead forecast errors.

Value
- **point_fore**: Point forecast
- **PI_lb**: Lower bound of a prediction interval
- **PI_ub**: Upper bound of a prediction interval

Author(s)
Han Lin Shang
References


See Also

`forecast.ftsm, forecastfpls`r

Examples

```r
sqrt_pm10 = sqrt(pm10_GR$y)
x = seq(0, 23.5, by=.5)
uni_forecast_sqrt_pm10 = forecast(fts(x, sqrt_pm10), h = 10, method = "arima")
multi_forecast_sqrt_pm10 = farforecast(object = fts(x, sqrt_pm10), h = 10, Pmax_value = 3)
par(mfrow = c(1,2))
plot(uni_forecast_sqrt_pm10, ylim = c(5.2,8.5))
plot(multi_forecast_sqrt_pm10, ylim = c(5,2,8.5))
```

---

**fbootstrap**

*Bootstrap independent and identically distributed functional data*

**Description**

Computes bootstrap or smoothed bootstrap samples based on independent and identically distributed functional data.

**Usage**

```r
fbootstrap(data, estad = func.mean, alpha = 0.05, nb = 200, suav = 0,
media.dist = FALSE, graph = FALSE, ...)
```

**Arguments**

- `data` An object of class `fds` or `fts`.
- `estad` Estimate function of interest. Default is to estimate the mean function. Other options are `func.mode` or `func.var`.
- `alpha` Significance level used in the smooth bootstrapping.
- `nb` Number of bootstrap samples.
- `suav` Smoothing parameter.
- `media.dist` Estimate mean function.
- `graph` Graphical output.
- `...` Other arguments.
Value

A list containing the following components is returned.

- `estimate` Estimate function.
- `max.dist` Max distance of bootstrap samples.
- `rep.dist` Distances of bootstrap samples.
- `resamples` Bootstrap samples.
- `center` Functional mean.

Author(s)

Han Lin Shang

References


See Also

- `pcscorebootstrapdata`

Examples

```
# Bootstrapping the distribution of a summary statistics of functional data.
fbootstrap(data = E1Nino_ERSSST_region_land2)
```
Description

The coefficients from the fitted object are forecasted using either an ARIMA model (method = "arima"), an AR model (method = "ar"), an exponential smoothing method (method = "ets"), a linear exponential smoothing method allowing missing values (method = "ets.na"), or a random walk with drift model (method = "rwdrift"). The forecast coefficients are then multiplied by the principal components to obtain a forecast curve.

Usage

```r
## S3 method for class 'ftsm'
forecast(object, h = 10, method = c("ets", "arima", "ar", "ets.na", "rwdrift", "rw", "struct", "arfima"), level = 80, jumpchoice = c("fit", "actual"), pimethod = c("parametric", "nonparametric"), B = 100, usedata = nrow(object$coeff), adjust = TRUE, model = NULL, damped = NULL, stationary = FALSE, ...)```

Arguments

- `object`: Output from `ftsm`.
- `h`: Forecast horizon.
- `method`: Univariate time series forecasting methods. Current possibilities are “ets”, “arima”, “ets.na”, “rwdrift” and “rw”.
- `level`: Coverage probability of prediction intervals.
- `jumpchoice`: Jump-off point for forecasts. Possibilities are “actual” and “fit”. If “actual”, the forecasts are bias-adjusted by the difference between the fit and the last year of observed data. Otherwise, no adjustment is used. See Booth et al. (2006) for the detail on jump-off point.
- `pimethod`: Indicates if parametric method is used to construct prediction intervals.
- `B`: Number of bootstrap samples.
- `usedata`: Number of time periods to use in forecasts. Default is to use all.
- `adjust`: If `adjust = TRUE`, adjusts the variance so that the one-step forecast variance matches the empirical one-step forecast variance.
- `model`: If the ets method is used, model allows a model specification to be passed to `ets()`.
- `damped`: If the ets method is used, damped allows the damping specification to be passed to `ets()`.
- `stationary`: If `stationary = TRUE`, method is set to method = “ar” and only stationary AR models are used.
- `...`: Other arguments passed to forecast routine.
Details

1. Obtain a smooth curve $f_t(x)$ for each $t$ using a nonparametric smoothing technique.
2. Decompose the smooth curves via a functional principal component analysis.
3. Fit a univariate time series model to each of the principal component scores.
4. Forecast the principal component scores using the fitted time series models.
5. Multiply the forecast principal component scores by fixed principal components to obtain forecasts of $f_{n+h}(x)$.
6. The estimated variances of the error terms (smoothing error and model residual error) are used to compute prediction intervals for the forecasts.

Value

List with the following components:

- **mean**: An object of class `fts` containing point forecasts.
- **lower**: An object of class `fts` containing lower bound for prediction intervals.
- **upper**: An object of class `fts` containing upper bound for prediction intervals.
- **fitted**: An object of class `fts` of one-step-ahead forecasts for historical data.
- **error**: An object of class `fts` of one-step-ahead errors for historical data.
- **coeff**: List of objects of type `forecast` containing the coefficients and their forecasts.
- **coeff.error**: One-step-ahead forecast errors for each of the coefficients.
- **var**: List containing the various components of variance: model, error, mean, total and coeff.
- **model**: Fitted `ftsm` model.
- **bootsamp**: An array of dimension $= c(p, B, h)$ containing the bootstrapped point forecasts. $p$ is the number of variables. $B$ is the number of bootstrap samples. $h$ is the forecast horizon.

Author(s)

Rob J Hyndman

References


See Also

`ftsm, forecastfplsr, plot.fts, plot.fm, residuals.fm, summary.fm`

Examples

```r
# Elnino is an object of class sliced functional time series.
# Via functional principal component decomposition, the dynamic was captured
# by a few principal components and principal component scores.
# By using an exponential smoothing method,
# the principal component scores are forecasted.
# The forecasted curves are constructed by forecasted principal components
# times fixed principal components plus the mean function.
forecast(object = ftsm(Elnino_ERSST_region_land2), h = 10, method = "ets")
forecast(object = ftsm(Elnino_ERSST_region_land2, weight = TRUE))
```

**Description**

Forecast high-dimensional functional principal component model.

**Usage**

```r
## S3 method for class 'hdfpca'
forecast(object, h = 3, level = 80, B = 50, ...)
```
Arguments

- **object**: An object of class 'hdfpca'
- **h**: Forecast horizon
- **level**: Prediction interval level, the default is 80 percent
- **B**: Number of bootstrap replications
- **...**: Other arguments passed to forecast routine.

Details

The low-dimensional factors are forecasted with autoregressive integrated moving average (ARIMA) models separately. The forecast functions are then calculated using the forecast factors. Bootstrap prediction intervals are constructed by resampling from the forecast residuals of the ARIMA models.

Value

- **forecast**: A list containing the h-step-ahead forecast functions for each population
- **upper**: Upper confidence bound for each population
- **lower**: Lower confidence bound for each population

Author(s)

Y. Gao and H. L. Shang

References


See Also

- **hdfpca, hd_data**

Examples

```r
hd_model = hdfpca(hd_data, order = 2, r = 2)
hd_model_fore = forecast.hdfpca(object = hd_model, h = 1)
```
**forecastfplsr**  
*Forecast functional time series*

**Description**

The decentralized response is forecasted by multiplying the estimated regression coefficient with the new decentralized predictor.

**Usage**

`forecastfplsr(object, components, h)`

**Arguments**

- `object`  
  An object of class `fts`.
- `components`  
  Number of optimal components.
- `h`  
  Forecast horizon.

**Value**

A `fts` class object, containing forecasts of responses.

**Author(s)**

Han Lin Shang

**References**


**See Also**

`forecast.ftsm`, `ftsm`, `plot.fm`, `plot.ftsf`, `residuals.fm`, `summary.fm`

**Examples**

```
# A set of functions are decomposed by functional partial least squares decomposition.
# By forecasting univariate partial least squares scores, the forecasted curves are
# obtained by multiplying the forecasted scores by fixed functional partial least
# squares function plus fixed mean function.
forecastfplsr(object = E1Nino_ERSST_region_land2, components = 2, h = 5)
```
**fplsr**

Functional partial least squares regression

**Description**

Fits a functional partial least squares (PLSR) model using nonlinear partial least squares (NIPALS) algorithm or simple partial least squares (SIMPLS) algorithm.

**Usage**

```r
fplsr(data, order = 6, type = c("simpls", "nipals"), unit.weights = TRUE, weight = FALSE, beta = 0.1, interval = FALSE, method = c("delta", "boota"), alpha = 0.05, B = 100, adjust = FALSE, backh = 10)
```

**Arguments**

- `data`: An object of class `fts`.
- `order`: Number of principal components to fit.
- `type`: When `type = "nipals"`, uses the NIPALS algorithm; when `type = "simpls"`, uses the SIMPLS algorithm.
- `unit.weights`: Constrains predictor loading weights to have unit norm.
- `weight`: When `weight = TRUE`, a set of geometrically decaying weights is applied to the decentralized data.
- `beta`: When `weight = TRUE`, the speed of geometric decay is governed by a weight parameter.
- `interval`: When `interval = TRUE`, produces distributional forecasts.
- `method`: Method used for computing prediction intervals.
- `alpha`: `1-alpha` gives the nominal coverage probability.
- `B`: Number of replications.
- `adjust`: When `adjust = TRUE`, an adjustment is performed.
- `backh`: When `adjust = TRUE`, an adjustment is performed by evaluating the difference between predicted and actual values in a testing set. `backh` specifies the testing set.

**Details**

**Point forecasts:**

The NIPALS function implements the orthogonal scores algorithm, as described in Martens and Naes (1989). This is one of the two classical PLSR algorithms, the other is the simple partial least squares regression in DeJong (1993). The difference between these two approaches is that the NIPALS deflates the original predictors and responses, while the SIMPLS deflates the covariance.
matrix of original predictors and responses. Thus, SIMPLS is more computationally efficient than NIPALS. In a functional data set, the functional PLSR can be performed by setting the functional responses to be 1 lag ahead of the functional predictors. This idea has been adopted from the Autoregressive Hilbertian processes of order 1 (ARH(1)) of Bosq (2000).

**Distributional forecasts:**

**Parametric method:**

Influenced by the works of Denham (1997) and Phatak et al. (1993), one way of constructing prediction intervals in the PLSR is via a local linearization method (also known as the Delta method). It can be easily understood as the first two terms in a Taylor series expansion. The variance of coefficient estimators can be approximated, from which an analytic-formula based prediction intervals are constructed.

**Nonparametric method:**

After discretizing and decentralizing functional data $f_t(x)$ and $g_s(y)$, a PLSR model with $K$ latent components is built. Then, the fit residuals $o_s(y_i)$ between $g_s(y_i)$ and $\hat{g}_s(y_i)$ are calculated as

$$o_s(y_i) = g_s(y_i) - \hat{g}_s(y_i), i = 1, ..., p.$$ 

The next step is to generate $B$ bootstrap samples $o^b_s(y_i)$ by randomly sampling with replacement from $[o_1(y_i), ..., o_n(y_i)]$. Adding bootstrapped residuals to the original response variables in order to generate new bootstrap responses,

$$g^b_s(y_i) = g_s(y_i) + o^b_s(y_i).$$

Then, the PLSR models are constructed using the centered and discretized predictors and bootstrapped responses to obtain the boostrapped regression coefficients and point forecasts, from which the empirical prediction intervals and kernel density plots are constructed.

**Value**

A list containing the following components is returned.

- $\mathbf{B}$: $(p \times m)$ matrix containing the regression coefficients. $p$ is the number of variables in the predictors and $m$ is the number of variables in the responses.
- $\mathbf{P}$: $(p \times \text{order})$ matrix containing the predictor loadings.
- $\mathbf{Q}$: $(m \times \text{order})$ matrix containing the response loadings.
- $\mathbf{T}$: $(\text{ncol(data}$y$)-1) \times \text{order}$ matrix containing the predictor scores.
- $\mathbf{R}$: $(p \times \text{order})$ matrix containing the weights used to construct the latent components of predictors.
- $\mathbf{YScores}$: $(\text{ncol(data}$y$)-1) \times \text{order}$ matrix containing the response scores.
- $\text{projection}$: $(p \times \text{order})$ projection matrix used to convert predictors to predictor scores.
- $\text{meanX}$: An object of class $\text{fts}$ containing the column means of predictors.
- $\text{meanY}$: An object of class $\text{fts}$ containing the column means of responses.
Ypred An object of class fts containing the 1-step-ahead predicted values of the responses.

fitted An object of class fts containing the fitted values.

residuals An object of class fts containing the regression residuals.

Xvar A vector with the amount of predictor variance explained by each number of component.

Xtotvar Total variance in predictors.

weight When weight = TRUE, a set of geometrically decaying weights is given. When weight = FALSE, weights are all equal 1.

x1 Time period of a fts object, which can be obtained from colnames(data$y).

y1 Variables of a fts object, which can be obtained from data$x.

ypred Returns the original functional predictors.

y Returns the original functional responses.

bootsamp Bootstrapped point forecasts.

lb Lower bound of prediction intervals.

ub Upper bound of prediction intervals.

lbadj Adjusted lower bound of prediction intervals.

ubadj Adjusted upper bound of prediction intervals.

lbadjfactor Adjusted lower bound factor, which lies generally between 0.9 and 1.1.

ubadjfactor Adjusted upper bound factor, which lies generally between 0.9 and 1.1.

Author(s)

Han Lin Shang

References


C. Preda, G. Saporta (2005) "PLS regression on a stochastic process", *Computational Statistics and Data Analysis, 48*(1), 149-158.


**See Also**

*ftsm, forecast.ftsm, plot.fm, summary.fm, residuals.fm, plot.fmres*

**Examples**

```r
# When weight = FALSE, all observations are assigned equally.
# When weight = TRUE, all observations are assigned geometrically decaying weights.
fplsr(data = ElNino.ERsst_region_land2, order = 6, type = "nipals")
fplsr(data = ElNino.ERsst_region_land2, order = 6)
fplsr(data = ElNino.ERsst_region_land2, weight = TRUE)
fplsr(data = ElNino.ERsst_region_land2, unit.weights = FALSE)
fplsr(data = ElNino.ERsst_region_land2, unit.weights = FALSE, weight = TRUE)

# The prediction intervals are calculated numerically.
fplsr(data = ElNino.ERsst_region_land2, interval = TRUE, method = "delta")

# The prediction intervals are calculated by bootstrap method.
fplsr(data = ElNino.ERsst_region_land2, interval = TRUE, method = "boota")
```

**ftsm**

* Fit functional time series model

**Description**

Fits a principal component model to a *fts* object. The function uses optimal orthonormal principal components obtained from a principal components decomposition.
Usage

```r
tfsm(y, order = 6, ngrid = max(500, ncol(y$x)), method = c("classical", "M", "rapca"), mean = TRUE, level = FALSE, lambda = 3, weight = FALSE, beta = 0.1, ...)
```

Arguments

- **y**: An object of class `fts`.
- **order**: Number of principal components to fit.
- **ngrid**: Number of grid points to use in calculations. Set to maximum of 500 and `ncol(y$x)`.
- **method**: Method to use for principal components decomposition. Possibilities are “M”, “rapca” and “classical”.
- **mean**: If `mean` = TRUE, it will estimate mean term in the model before computing basis terms. If `mean` = FALSE, the mean term is assumed to be zero.
- **level**: If `mean` = TRUE, it will include an additional (intercept) term that depends on `t` but not on `x`.
- **lambda**: Tuning parameter for robustness when `method` = "M".
- **weight**: When `weight` = TRUE, a set of geometrically decaying weights is applied to the decentralized data.
- **beta**: When `weight` = TRUE, the speed of geometric decay is governed by a weight parameter.
- **...**: Additional arguments controlling the fitting procedure.

Details

- If `method` = "classical", then standard functional principal component decomposition is used, as described by Ramsay and Dalzell (1991).
- If `method` = "rapca", then the robust principal component algorithm of Hubert, Rousseeuw and Verbouven (2002) is used.
- If `method` = "M", then the hybrid algorithm of Hyndman and Ullah (2005) is used.

Value

Object of class “ftsm” with the following components:

- **x1**: Time period of a fts object, which can be obtained from `colnames(y$x)`.
- **y1**: Variables of a fts object, which can be obtained from `y$x`.
- **y**: Original functional time series or sliced functional time series.
- **basis**: Matrix of principal components evaluated at value of `y$x` (one column for each principal component). The first column is the fitted mean or median.
- **basis2**: Matrix of principal components excluded from the selected model.
- **coeff**: Matrix of coefficients (one column for each coefficient series). The first column is all ones.
coeff2

Matrix of coefficients associated with the principal components excluded from the selected model.

fitted

An object of class fts containing the fitted values.

residuals

An object of class fts containing the regression residuals (difference between observed and fitted).

varprop

Proportion of variation explained by each principal component.

wt

Weight associated with each time period.

v

Measure of variation for each time period.

mean.se

Measure of standard error associated with the mean.

Author(s)

Rob J Hyndman

References


See Also

ftsmweightselect, forecast.ftsm, plot.fm, plot.fts, residuals.fm, summary.fm

Examples

# ElNino is an object of class sliced functional time series, constructed # from a univariate time series.
# By default, all observations are assigned with equal weighting.
ftsm(y = ElNino.ERSST_region_land2, order = 6, method = "classical", weight = FALSE)
# When weight = TRUE, geometrically decaying weights are used.
ftsm(y = ElNino.ERSST_region_land2, order = 6, method = "classical", weight = TRUE)
**ftsmiterativeforecasts**

*Forecast functional time series*

**Description**

The coefficients from the fitted object are forecasted using either an ARIMA model (`method = "arima"`), an AR model (`method = "ar"`), an exponential smoothing method (`method = "ets"`), a linear exponential smoothing method allowing missing values (`method = "ets.na"`), or a random walk with drift model (`method = "rwdrift"`). The forecast coefficients are then multiplied by the principal components to obtain a forecast curve.

**Usage**

```r
ftsmiterativeforecasts(object, components, iteration = 20)
```

**Arguments**

- `object` An object of class `fts`.
- `components` Number of principal components.
- `iteration` Number of iterative one-step-ahead forecasts.

**Details**

1. Obtain a smooth curve $f_t(x)$ for each $t$ using a nonparametric smoothing technique.
2. Decompose the smooth curves via a functional principal component analysis.
3. Fit a univariate time series model to each of the principal component scores.
4. Forecast the principal component scores using the fitted time series models.
5. Multiply the forecast principal component scores by fixed principal components to obtain forecasts of $f_{n+h}(x)$.
6. The estimated variances of the error terms (smoothing error and model residual error) are used to compute prediction intervals for the forecasts.

**Value**

List with the following components:

- `mean` An object of class `fts` containing point forecasts.
- `lower` An object of class `fts` containing lower bound for prediction intervals.
- `upper` An object of class `fts` containing upper bound for prediction intervals.
- `fitted` An object of class `fts` of one-step-ahead forecasts for historical data.
- `error` An object of class `fts` of one-step-ahead errors for historical data.
- `coeff` List of objects of type `forecast` containing the coefficients and their forecasts.
ftsmweightselect

coeff.error One-step-ahead forecast errors for each of the coefficients.
var List containing the various components of variance: model, error, mean, total and coeff.
model Fitted ftsm model.
bootsamp An array of \( \text{dim} = c(p, B, h) \) containing the bootstrapped point forecasts. \( p \) is the number of variables. \( B \) is the number of bootstrap samples. \( h \) is the forecast horizon.

Author(s)
Han Lin Shang

References

See Also
ftsm, plot.ftsf, plot.fm, residuals.fm, summary.fm

Examples

# Iterative one-step-ahead forecasts via functional principal component analysis.
ftsmiterativeforecasts(object = Australiasmoothfertility, components = 2, iteration = 5)

ftsmweightselect

Selection of the weight parameter used in the weighted functional time series model.

Description
The geometrically decaying weights are used to estimate the mean curve and functional principal components, where more weights are assigned to the more recent data than the data from the distant past.

Usage

ftsmweightselect(data, ncomp = 6, ntestyear, errorcriterion = c("mae", "mse", "mape"))
Arguments

data An object of class fts.
ncomp Number of components.
ntestyear Number of holdout observations used to assess the forecast accuracy.
errorcriterion Error measure.

Details

The data set is split into a fitting period and forecasting period. Using the data in the fitting period, we compute the one-step-ahead forecasts and calculate the forecast error. Then, we increase the fitting period by one, and carry out the same forecasting procedure until the fitting period covers entire data set. The forecast accuracy is determined by the averaged forecast error across the years in the forecasting period. By using an optimization algorithm, we select the optimal weight parameter that would result in the minimum forecast error.

Value

Optimal weight parameter.

Note

Can be computational intensive, as it takes about half-minute to compute. For example, ftsmweight-select(ElNinosmooth, ntestyear = 1).

Author(s)

Han Lin Shang

References


See Also

ftsm, forecast.ftsm

hdfpca High-dimensional functional principal component analysis

Description

Fit a high dimensional functional principal component analysis model to a multiple-population of functional time series data.
Usage

```r
hdfpca(y, order, q = sqrt(dim(y[[1]])[2]), r)
```

Arguments

- **y**: A list, where each item is a population of functional time series. Each item is a data matrix of dimension \( p \) by \( n \), where \( p \) is the number of discrete points in each function and \( n \) is the sample size.
- **order**: The number of principal component scores to retain in the first step dimension reduction.
- **q**: The tuning parameter used in the first step dimension reduction, by default it is equal to the square root of the sample size.
- **r**: The number of factors to retain in the second step dimension reduction.

Details

In the first step, dynamic functional principal component analysis is performed on each population and then in the second step, factor models are fitted to the resulting principal component scores. The high-dimensional functional time series are thus reduced to low-dimensional factors.

Value

- **y**: The input data.
- **p**: The number of discrete points in each function.
- **fitted**: A list containing the fitted functions for each population.
- **m**: The number of populations.
- **model**: Model 1 includes the first step dynamic functional principal component analysis models, model 2 includes the second step high-dimensional principal component analysis models.
- **order**: Input order.
- **r**: Input \( r \).

Author(s)

Y. Gao and H. L. Shang

References


See Also

- `forecast.hdfpca`, `hd_data`

Examples

```r
hd_model = hdfpca(hd_data, order = 2, r = 2)
```
Description

We generate $N$ populations of functional time series. For each $i \in \{1, \ldots, N\}$, the $i$th function at time $t \in \{1, \ldots, T\}$ is given by

$$X_t^{(i)}(u) = \sum_{p=1}^{2} \beta_{p,t}^{(i)} f_p(u) + \theta_t^{(i)}(u),$$

where $\theta_t^{(i)}(u) = \sum_{p=3}^{\infty} \beta_{p,t}^{(i)} g_p(u)$. Here, $\beta_{p,t}$ is an $N \times N$ matrix, and $f_p$ is an $N \times 1$ vector.

The first set of coefficients $\beta_{1,t}$ for $N$ populations are generated with $\beta_{1,t} = A_1 f_{1,t}$. Each element in the matrix $A_1$ is generated by $a_{ij} = N^{-1/4} \times b_{ij}$, where $b_{ij} \sim N(2, 4)$. The factors $f_{1,t}$ are generated using an autoregressive model of order 1, i.e., AR(1). Define the $i$th element in vector $f_{1,t}$ as $f_{1,t}^{(i)}$. Then, $f_{1,t}^{(i)}$ is generated by $f_{1,t}^{(i)} = 0.5 \times f_{1,t-1}^{(i)} + \omega_t$, where $\omega_t$ are independent $N(0, 1)$ random variables. We generate $f_{1,t}^{(i)}$ for all $i \in \{2, \ldots, N\}$ by $f_{1,t}^{(i)} = (1/N) \times g_t^{(i)}$, where $g_t^{(2)}, \ldots, g_t^{(N)}$ are also AR(1) and follow $g_t^{(i)} = 0.2 \times g_{t-1}^{(i)} + \omega_t$. It is then ensured that most of the variance of $\beta_{1,t}$ can be explained by one factor. The second coefficient $\beta_{2,t}$ are constructed the same way as $\beta_{1,t}$.

We also generate the third functional principal component scores $\beta_{3,t}$ but with small values. Moreover, $A_3$ is generated by $a_{ij} = N^{-1/4} \times b_{ij}$, where $b_{ij} \sim N(0, 0.04)$. The factors $bmf_{3,t}$ are generated as $f_{1,t}$.

The three basis functions are constructed by $\gamma_1^{(i)}(u) = \sin(2\pi u + \pi i/2)$, $\gamma_2^{(i)}(u) = \cos(2\pi u + \pi i/2)$ and $\gamma_3^{(i)}(u) = \sin(4\pi u + \pi i/2)$, where $u \in [0, 1]$. Finally, the functional time series for the $i$th population is constructed by

$$X_t^{(i)}(u) = \beta_{1,t} \gamma_1^{(i)}(u) + \beta_{2,t} \gamma_2^{(i)}(u) + \beta_{3,t} \gamma_3^{(i)}(u),$$

where $(\cdot)_i$ denotes the $i$th element of the vector.
References


See Also

hdfpca, forecast.hdfpca

Examples

data(hd_data)

---

is.fts

*Test for functional time series*

Description

Tests whether an object is of class fts.

Usage

is.fts(x)

Arguments

x

Arbitrary R object.

Author(s)

Rob J Hyndman

Examples

# check if ElNino is the class of the functional time series.

is.fts(x = ElNino_ERSST_region_1and2)
isfe.fts

Integrated Squared Forecast Error for models of various orders

Description

Computes integrated squared forecast error (ISFE) values for functional time series models of various orders.

Usage

isfe.fts(data, max.order = N - 3, N = 10, h = 5:10, method = 
c("classical", "M", "rapca"), mean = TRUE, level = FALSE, 
method = c("arima", "ar", "ets", "ets.na", "struct", "rwdrift", 
"rw", "arfima"), lambda = 3, ...)

Arguments

data An object of class fts.
max.order Maximum number of principal components to fit.
N Minimum number of functional observations to be used in fitting a model.
h Forecast horizons over which to average.
method Method to use for principal components decomposition. Possibilities are “M”, “rapca” and “classical”.
mean Indicates if mean term should be included.
level Indicates if level term should be included.
fmethod Method used for forecasting. Current possibilities are “ets”, “arima”, “ets.na”, “struct”, “rwdrift” and “rw”.
lambda Tuning parameter for robustness when method = "M".
... Additional arguments controlling the fitting procedure.

Value

Numeric matrix with (max.order+1) rows and length(h) columns containing ISFE values for models of orders 0:(max.order).

Note

This function can be very time consuming for data with large dimensionality or large sample size. By setting max.order small, computational speed can be dramatically increased.

Author(s)

Rob J Hyndman
References


See Also

`ftsm, forecast.ftsm, plot.fm, plot.fmres, summary.fm, residuals.fm`

---

**long_run_covariance_estimation**

*Estimating long-run covariance function for a functional time series*

**Description**

Bandwidth estimation in the long-run covariance function for a functional time series, using different types of kernel function

**Usage**

`long_run_covariance_estimation(dat, C0 = 3, H = 3)`

**Arguments**

- `dat` A matrix of p by n, where p denotes the number of grid points and n denotes sample size
- `C0` A tuning parameter used in the adaptive bandwidth selection algorithm of Rice
- `H` A tuning parameter used in the adaptive bandwidth selection algorithm of Rice

**Value**

An estimated covariance function of size (p by p)

**Author(s)**

Han Lin Shang

**References**


Mean functions for functional time series

Description
Computes mean of functional time series at each variable.

Usage
```r
## S3 method for class 'fts'
mean(x, method = c("coordinate", "FM", "mode", "RP", "RPD", "radius"),
     na.rm = TRUE, alpha, beta, weight, ...)
```

Arguments
- `x` An object of class `fts`.
- `method` Method for computing the mean function.
- `na.rm` A logical value indicating whether NA values should be stripped before the computation proceeds.
- `alpha` Tuning parameter when `method="radius"`. 
- `beta` Trimming percentage, by default it is 0.25, when `method="radius"`. 
- `weight` Hard thresholding or soft thresholding.
- `...` Other arguments.

Details
If `method = "coordinate"`, it computes the coordinate-wise functional mean.
If `method = "FM"`, it computes the mean of trimmed functional data ordered by the functional depth of Fraiman and Muniz (2001).
If `method = "mode"`, it computes the mean of trimmed functional data ordered by $h$-modal functional depth.
If `method = "RP"`, it computes the mean of trimmed functional data ordered by random projection depth.
If `method = "RPD"`, it computes the mean of trimmed functional data ordered by random projection derivative depth.
If `method = "radius"`, it computes the mean of trimmed functional data ordered by the notion of alpha-radius.
Value

A list containing \( x = \) variables and \( y = \) mean rates.

Author(s)

Rob J Hyndman, Han Lin Shang

References


See Also

*median.fts, var.fts, sd.fts, quantile.fts*

Examples

```r
# Calculate the mean function by the different depth measures.
mean(x = ElNino.ERSST_region_land2, method = "coordinate")
mean(x = ElNino.ERSST_region_land2, method = "FM")
mean(x = ElNino.ERSST_region_land2, method = "mode")
mean(x = ElNino.ERSST_region_land2, method = "RP")
mean(x = ElNino.ERSST_region_land2, method = "RPD")
mean(x = ElNino.ERSST_region_land2, method = "radius",
     alpha = 0.5, beta = 0.25, weight = "hard")
mean(x = ElNino.ERSST_region_land2, method = "radius",
     alpha = 0.5, beta = 0.25, weight = "soft")
```
Description

Computes median of functional time series at each variable.

Usage

```r
## S3 method for class 'fts'
median(x, na.rm, method = c("hossjerCroux", "coordinate", "FM", "mode", "RP", "RPD", "radius"), alpha, beta, weight, ...)
```

Arguments

- `x`: An object of class `fts`.
- `na.rm`: Remove any missing value.
- `method`: Method for computing median.
- `alpha`: Tuning parameter when `method = "radius"`.
- `beta`: Trimming percentage, by default it is 0.25, when `method = "radius"`.
- `weight`: Hard thresholding or soft thresholding.
- `...`: Other arguments.

Details

If `method = "coordinate"`, it computes a coordinate-wise median.

If `method = "hossjerCroux"`, it computes the L1-median using the Hossjer-Croux algorithm.

If `method = "FM"`, it computes the median of trimmed functional data ordered by the functional depth of Fraiman and Muniz (2001).

If `method = "mode"`, it computes the median of trimmed functional data ordered by h-modal functional depth.

If `method = "RP"`, it computes the median of trimmed functional data ordered by random projection depth.

If `method = "RPD"`, it computes the median of trimmed functional data ordered by random projection derivative depth.

If `method = "radius"`, it computes the mean of trimmed functional data ordered by the notion of alpha-radius.

Value

A list containing `x` = variables and `y` = median rates.
Author(s)

Rob J Hyndman, Han Lin Shang

References


See Also

*mean.fts, var.fts, sd.fts, quantile.fts*

Examples

```r
# Calculate the median function by the different depth measures.
m = ElNino.ERSST.region.land2
median(x = m, method = "hossjercroux")
m = ElNino.ERSST.region.land2
median(x = m, method = "coordinate")
m = ElNino.ERSST.region.land2
median(x = m, method = "FM")
m = ElNino.ERSST.region.land2
median(x = m, method = "mode")
m = ElNino.ERSST.region.land2
median(x = m, method = "RP")
m = ElNino.ERSST.region.land2
median(x = m, method = "RDP")
m = ElNino.ERSST.region.land2
median(x = m, method = "radius", alpha = 0.5, beta = 0.25, weight = "hard")
m = ElNino.ERSST.region.land2
median(x = m, method = "radius", alpha = 0.5, beta = 0.25, weight = "soft")
```
**Description**

Fit a multilevel functional principal component model. The function uses two-step functional principal component decompositions.

**Usage**

```r
MFDM(mort_female, mort_male, mort_ave, percent_1 = 0.95, percent_2 = 0.95, fh, 
      level = 80, alpha = 0.2, MCMCiter = 100, fmethod = c("auto_arima", "ets"), 
      BC = c(FALSE, TRUE), lambda)
```

**Arguments**

- `mort_female` Female mortality (p by n matrix), where p denotes the dimension and n denotes the sample size.
- `mort_male` Male mortality (p by n matrix).
- `mort_ave` Total mortality (p by n matrix).
- `percent_1` Cumulative percentage used for determining the number of common functional principal components.
- `percent_2` Cumulative percentage used for determining the number of sex-specific functional principal components.
- `fh` Forecast horizon.
- `level` Nominal coverage probability of a prediction interval.
- `alpha` 1 - Nominal coverage probability.
- `MCMCiter` Number of MCMC iterations.
- `fmethod` Univariate time-series forecasting method.
- `BC` If Box-Cox transformation is performed.
- `lambda` If BC = TRUE, specify a Box-Cox transformation parameter.

**Details**

The basic idea of multilevel functional data method is to decompose functions from different sub-populations into an aggregated average, a sex-specific deviation from the aggregated average, a common trend, a sex-specific trend and measurement error. The common and sex-specific trends are modelled by projecting them onto the eigenvectors of covariance operators of the aggregated and sex-specific centred stochastic process, respectively.
Clustering multiple functional time series. This function uses a functional panel data model to cluster different functional time series into subgroups.
Usage
mftsc(X, alpha)

Arguments

X A list of functional time series to be clustered for each object, it is a \( p \) by \( q \) matrix, where \( p \) denotes sample size and \( q \) denotes number of grid points within a function support.

alpha An input value for adjusted rand index to measure similarity of the memberships with last iteration, can be any value bigger than 0.9.

Value

iteration Number of iterations until convergence

membership A list of all membership matrices at each iteration

member.final Final membership

Author(s)
Chen Tang and Han Lin Shang

See Also
dmfpca

Examples

```r
## The following takes about 20 minutes to run ##
## Not run:
cluster_result <- mftsc(X = sim_ex_cluster, alpha = 0.99)
## End(Not run)
```

pcscorebootstrapdata Bootstrap independent and identically distributed functional data or functional time series

Description
Computes bootstrap or smoothed bootstrap samples based on either independent and identically distributed functional data or functional time series.

Usage

pcscorebootstrapdata(dat, bootrep, statistic, bootmethod = c("st", "sm", "mvn", "stiefel", "meboot"), smo)
Arguments

dat        An object of class matrix.
bootrep    Number of bootstrap samples.
statistic  Summary statistics.
bootmethod Bootstrap method. When bootmethod = "st", the sampling with replacement is implemented. To avoid the repeated bootstrap samples, the smoothed bootstrap method can be implemented by adding multivariate Gaussian random noise. When bootmethod = "mvn", the bootstrapped principal component scores are drawn from a multivariate Gaussian distribution with the mean and covariance matrices of the original principal component scores. When bootmethod = "stiefel", the bootstrapped principal component scores are drawn from a Stiefel manifold with the mean and covariance matrices of the original principal component scores. When bootmethod = "meboot", the bootstrapped principal component scores are drawn from a maximum entropy algorithm of Vinod (2004).
smo        Smoothing parameter.

Details

We will presume that each curve is observed on a grid of $T$ points with $0 \leq t_1 < t_2 \ldots < t_T \leq \tau$. Thus, the raw data set $(X_1, X_2, \ldots, X_n)$ of $n$ observations will consist of an $n$ by $T$ data matrix. By applying the singular value decomposition, $X_1, X_2, \ldots, X_n$ can be decomposed into $X = ULR^\top$, where the crossproduct of $U$ and $R$ is identity matrix.

Holding the mean and $L$ and $R$ fixed at their realized values, there are four re-sampling methods that differ mainly by the ways of re-sampling $U$.

(a) Obtain the re-sampled singular column matrix by randomly sampling with replacement from the original principal component scores.

(b) To avoid the appearance of repeated values in bootstrapped principal component scores, we adopt a smooth bootstrap procedure by adding a white noise component to the bootstrap.

(c) Because principal component scores follow a standard multivariate normal distribution asymptotically, we can randomly draw principal component scores from a multivariate normal distribution with mean vector and covariance matrix of original principal component scores.

(d) Because the crossproduct of $U$ is identity matrix, $U$ is considered as a point on the Stiefel manifold, that is the space of $n$ orthogonal vectors, thus we can randomly draw principal component scores from the Stiefel manifold.

Value

bootdata   Bootstrap samples. If the original data matrix is $p$ by $n$, then the bootstrapped data are $p$ by $n$ by bootrep.
meanfunction Bootstrap summary statistics. If the original data matrix is $p$ by $n$, then the bootstrapped summary statistics is $p$ by bootrep.

Author(s)

Han Lin Shang
References


D. S. Poskitt and A. Sengarapillai (2013), "Description length and dimensionality reduction in functional data analysis", Computational Statistics and Data Analysis, 58, 98-113.


See Also

fbootstrap

Examples

# Bootstrapping the distribution of a summary statistics of functional data.
boot1 = pcscorebootstrapdata(ElNino$ERSST_region_1and2$y, 400,
  "mean", bootmethod = "st")
boot2 = pcscorebootstrapdata(ElNino$ERSST_region_1and2$y, 400,
  "mean", bootmethod = "sm", smo = 0.05)
boot3 = pcscorebootstrapdata(ElNino$ERSST_region_1and2$y, 400,
  "mean", bootmethod = "mvn")
boot4 = pcscorebootstrapdata(ElNino$ERSST_region_1and2$y, 400,
  "mean", bootmethod = "stiefel")
boot5 = pcscorebootstrapdata(ElNino$ERSST_region_1and2$y, 400,
  "mean", bootmethod = "meboot")

plot.fm

Plot fitted model components for a functional model

Description

When class(x)[1] = ftsm, plot showing the principal components in the top row of plots and the coefficients in the bottom row of plots.

When class(x)[1] = fm, plot showing the predictor scores in the top row of plots and the response loadings in the bottom row of plots.

Usage

## S3 method for class 'fm'
plot(x, order, xlab1 = x$y$xname, ylab1 = "Principal component",
   xlab2 = "Time", ylab2 = "Coefficient", mean.lab = "Mean",
   level.lab = "Level", main.title = "Main effects", interaction.title
   = "Interaction", basiscol = 1, coeffcol = 1, outlier.col = 2,
   outlier.pch = 19, outlier.cex = 0.5, ...)

Arguments

- **x**: Output from `ftsm` or `fplsr`.
- **order**: Number of principal components to plot. Default is all principal components in a model.
- **xlab1**: x-axis label for principal components.
- **xlab2**: x-axis label for coefficient time series.
- **ylab1**: y-axis label for principal components.
- **ylab2**: y-axis label for coefficient time series.
- **mean.lab**: Label for mean component.
- **level.lab**: Label for level component.
- **main.title**: Title for main effects.
- **interaction.title**: Title for interaction terms.
- **basiscol**: Colors for principal components if `plot.type = "components"`.
- **coeffcol**: Colors for time series coefficients if `plot.type = "components"`.
- **outlier.col**: Colors for outlying years.
- **outlier.pch**: Plotting character for outlying years.
- **outlier.cex**: Size of plotting character for outlying years.
- ... Plotting parameters.

Value

Function produces a plot.

Author(s)

Rob J Hyndman

References


See Also

`ftsm`, `forecast.ftsm`, `residuals.fm`, `summary.fm`, `plot.fmres`, `plot.ftsf`

Examples

```r
plot(x = ftsm(y = EINino_ERSSST_region_land2))
```
plot.fmres function

Plot residuals from a fitted functional model.

Description

Functions to produce a plot of residuals from a fitted functional model.

Usage

```r
## S3 method for class 'fmres'
plot(x, type = c("image", "fts", "contour", "filled.contour", "persp"), xlab = "Year", ylab = "Age", zlab = "Residual", ...)
```

Arguments

- `x` Generated by `residuals(fit)`, where `fit` is the output from `ftsm` or `fplsr`.
- `type` Type of plot to use. Possibilities are `image`, `fts`, `contour`, `filled.contour`, and `persp`.
- `xlab` Label for x-axis.
- `ylab` Label for y-axis.
- `zlab` Label for z-axis.
- `...` Plotting parameters.

Value

Produces a plot.

Author(s)

Rob J Hyndman

See Also

`ftsm`, `forecast.ftsm`, `plot.fm`, `plot.fmres`, `residuals.fm`, `summary.fm`

Examples

# colorspace package was used to provide a more coherent color option.
plot(residuals(ftsm(y = Elnino.ERSST_region_1and2)), type = "filled.contour", xlab = "Month", ylab = "Residual sea surface temperature")
Description

Plot fitted model components for a fts object.

Usage

```r
## S3 method for class 'fts'
plot(x, plot.type = c("function", "components", "variance"),
     components, xlab1 = fit$y$xname, ylab1 = "Basis function",
     xlab2 = "Time", ylab2 = "Coefficient", mean.lab = "Mean",
     level.lab = "Level", main.title = "Main effects",
     interaction.title = "Interaction", vcol = 1:3, shadecols = 7,
     fcol = 4, basiscol = 1, coeffcol = 1, outlier.col = 2,
     outlier.pch = 19, outlier.cex = 0.5,...)
```

Arguments

- **x**: Output from `forecast.fts`
- **plot.type**: Type of plot.
- **components**: Number of principal components.
- **xlab1**: x-axis label for principal components.
- **xlab2**: x-axis label for coefficient time series.
- **ylab1**: y-axis label for principal components.
- **ylab2**: y-axis label for coefficient time series.
- **mean.lab**: Label for mean component.
- **level.lab**: Label for level component.
- **main.title**: Title for main effects.
- **interaction.title**: Title for interaction terms.
- **vcol**: Colors to use if `plot.type` = "variance".
- **shadecols**: Color for shading of prediction intervals when `plot.type` = "components".
- **fcol**: Color of point forecasts when `plot.type` = "components".
- **basiscol**: Colors for principal components if `plot.type` = "components".
- **coeffcol**: Colors for time series coefficients if `plot.type` = "components".
- **outlier.col**: Colors for outlying years.
- **outlier.pch**: Plotting character for outlying years.
- **outlier.cex**: Size of plotting character for outlying years.
- **...**: Plotting parameters.
When `plot.type = "function"`, it produces a plot of the forecast functions;
When `plot.type = "components"`, it produces a plot of the principal components and coefficients with forecasts and prediction intervals for each coefficient;
When `plot.type = "variance"`, it produces a plot of the variance components.

Value
Function produces a plot.

Author(s)
Rob J Hyndman

References

See Also
ftsmand plot.fm, plot.fmres, residuals.fm, summary.fm

Examples
```
plot(x = forecast(object = ftsm(y = ElNino_ERSST_region_land2)))
```

Description
Plot showing the basis functions in the top row of plots and the coefficients in the bottom row of plots.
Usage

```r
## S3 method for class 'ftsm'
plot(x, components, components.start = 0, xlab1 = x$y$xname, ylab1 = "Basis function",
     xlab2 = "Time", ylab2 = "Coefficient", mean.lab = "Mean",
     level.lab = "Level", main.title = "Main effects",
     interaction.title = "Interaction", basiscol = 1, coeffcol = 1,
     outlier.col = 2, outlier.pch = 19, outlier.cex = 0.5, ...)
```

Arguments

- `x` Output from `ftsm`.
- `components` Number of principal components to plot.
- `components.start` Plotting specified component.
- `xlab1` x-axis label for basis functions.
- `xlab2` x-axis label for coefficient time series.
- `ylab1` y-axis label for basis functions.
- `ylab2` y-axis label for coefficient time series.
- `mean.lab` Label for mean component.
- `level.lab` Label for level component.
- `main.title` Title for main effects.
- `interaction.title` Title for interaction terms.
- `basiscol` Colors for basis functions if plot.type="components".
- `coeffcol` Colors for time series coefficients if plot.type="components".
- `outlier.col` Colour for outlying years.
- `outlier.pch` Plotting character for outlying years.
- `outlier.cex` Size of plotting character for outlying years.
- `...` Plotting parameters.

Value

None. Function produces a plot.

Author(s)

Rob J Hyndman

References


plotfplsr

Description
Plot showing the basis functions of the predictors in the top row, followed by the basis functions of
the responses in the second row, then the coefficients in the bottom row of plots.

Usage
plotfplsr(x, xlab1 = x$ypred$xname, ylab1 = "Basis function", xlab2 = "Time",
ylab2 = "Coefficient", mean.lab = "Mean", interaction.title = "Interaction")

Arguments
x Output from fplsr.
xlab1 x-axis label for basis functions.
ylab1 y-axis label for basis functions.
xlab2 x-axis label for coefficient time series.
ylab2 y-axis label for coefficient time series.
mean.lab Label for mean component.
interaction.title Title for interaction terms.

Value
None. Function produces a plot.

Author(s)
Han Lin Shang

References
R. J. Hyndman and M. S. Ullah (2007) "Robust forecasting of mortality and fertility rates: A func-
tional data approach", Computational Statistics and Data Analysis, 51(10), 4942-4956.
R. J. Hyndman and H. L. Shang (2009) "Forecasting functional time series" (with discussion),
See Also

forecast.ftsm, ftsm, plot.fm, plot.fts, residuals.fm, summary.fm

Examples

# Fit the data by the functional partial least squares.
ausfplsr = fplsr(data = ElNino_ERSST_region_land2, order = 2)
plotfplsr(x = ausfplsr)

Data

pm_10_GR

Particulate Matter Concentrations (pm10)

Description

This data set consists of half-hourly measurement of the concentrations (measured in ug/m3) of particular matter with an aerodynamic diameter of less than 10um, abbreviated PM10, in ambient air taken in Graz-Mitte, Austria from October 1, 2010 until March 31, 2011. To stabilise the variance, a square-root transformation can be applied to the data.

Usage

data(pm_10_GR)

Details

As epidemiological and toxicological studies have pointed to negative health effects, European Union (EU) regulation sets pollution standards for the level of the concentration. Policy makers have to ensure compliance with these EU rules and need reliable statistical tools to determine, and justify the public, appropriate measures such as partial traffic regulation (see Stadlober, Hormann and Pfeiler, 2008).

Source

Thanks Professor Siegfried. Hormann for providing this data set. The original data source is http://www.umwelt.steiermark.at/cms/

References

quantile

Examples

plot(pm_10_Gr)

quantile  Quantile

Description

Generic functions for quantile.

Usage

quantile(x, ...)

Arguments

x Numeric vector whose sample quantiles are wanted, or an object of a class for which a method has been defined.
...
Arguments passed to specific methods.

Value

Refer to specific methods. For numeric vectors, see the quantile functions in the stats package.

Author(s)

Han Lin Shang

See Also

quantile.fts

quantile.fts  Quantile functions for functional time series

Description

Computes quantiles of functional time series at each variable.

Usage

## S3 method for class 'fts'
quantile(x, probs, ...)
Arguments

- **x**: An object of class `fts`.
- **probs**: Quantile percentages.
- **...**: Other arguments.

Value

Return quantiles for each variable.

Author(s)

Han Lin Shang

See Also

`meanNfts`, `medianNfts`, `varNfts`, `sdNfts`

Examples

```r
quantile(x = E1Nino_ERSST_region_land2)
```

---

**residuals.fm**

*Compute residuals from a functional model*

Description

After fitting a functional model, it is useful to inspect the residuals. This function extracts the relevant information from the fit object and puts it in a form suitable for plotting with `image`, `persp`, `contour`, `filled.contour`, etc.

Usage

```r
## S3 method for class `fm`
residuals(object, ...)
```

Arguments

- **object**: Output from `ftsm` or `fplsr`.
- **...**: Other arguments.

Value

Produces an object of class “fmres” containing the residuals from the model.

Author(s)

Rob J Hyndman
References


See Also

`ftsm`, `forecast.ftsm`, `summary.fm`, `plot.fm`, `plot.fmres`

Examples

```r
plot(residuals(object = ftsm(y = EI_Nino_ERSST_region_1and2)),
     xlab = "Year", ylab = "Month")
```

---

**sd**

*Standard deviation*

Description

Generic functions for standard deviation.

Usage

`sd(...)`

Arguments

... Argument passed to specific methods.

Details

The `sd` functions in the `stats` package are replaced by `sd.default`.

Value

Refer to specific methods. For numeric vectors, see the `sd` functions in the `stats` package.

Author(s)

Han Lin Shang
See Also

sd.fts

sd.fts  

*Standard deviation functions for functional time series*

**Description**

Computes standard deviation of functional time series at each variable.

**Usage**

```r
## S3 method for class 'fts'
sd(x, method = c("coordinate", "FM", "mode", "RP", "RPD", "radius"),
    trim = 0.25, alpha, weight,...)
```

**Arguments**

- `x` An object of class `fts`.
- `method` Method for computing median.
- `trim` Percentage of trimming.
- `alpha` Tuning parameter when `method="radius"`.
- `weight` Hard thresholding or soft thresholding.
- `...` Other arguments.

**Details**

If `method = "coordinate"`, it computes coordinate-wise standard deviation functions.

If `method = "FM"`, it computes the standard deviation functions of trimmed functional data ordered by the functional depth of Fraiman and Muniz (2001).

If `method = "mode"`, it computes the standard deviation functions of trimmed functional data ordered by h-modal functional depth.

If `method = "RP"`, it computes the standard deviation functions of trimmed functional data ordered by random projection depth.

If `method = "RPD"`, it computes the standard deviation functions of trimmed functional data ordered by random projection with derivative depth.

If `method = "radius"`, it computes the standard deviation function of trimmed functional data ordered by the notion of alpha-radius.

**Value**

A list containing `x = variables` and `y = standard deviation rates`. 
Author(s)

Han Lin Shang

References


See Also

`mean.fts, median.fts, var.fts, quantile.fts`

Examples

```r
# Frain-Muniz depth was arguably the oldest functional depth.
sd(x = ElNino.ERSST_region_land2, method = "FM")
sd(x = ElNino.ERSST_region_land2, method = "coordinate")
sd(x = ElNino.ERSST_region_land2, method = "mode")
sd(x = ElNino.ERSST_region_land2, method = "RP")
sd(x = ElNino.ERSST_region_land2, method = "RPD")
sd(x = ElNino.ERSST_region_land2, method = "radius", alpha = 0.5, weight = "hard")
sd(x = ElNino.ERSST_region_land2, method = "radius", alpha = 0.5, weight = "soft")
```
Simulated multiple sets of functional time series

Description

We generate 2 groups of \( m \) functional time series. For each \( i \) in \{1, \ldots, m\} in a given cluster \( c, c \) in \{1,2\}, the \( t \) th function, \( t \) in \{1,\ldots, T\}, is given by

\[
Y_{it}^{(c)}(x) = \mu^{(c)}(x) + \sum_{k=1}^{2} \xi_{tk}^{(c)} \rho_k^{(c)}(x) + \sum_{l=1}^{2} \zeta_{itl}^{(c)} \psi_l^{(c)}(x) + \upsilon_{it}^{(c)}(x)
\]

Usage

data("sim_ex_cluster")

Details

The mean functions for each of these two clusters are set to be \( \mu^{(1)}(x) = 2(x-0.25)^2 \) and \( \mu^{(2)}(x) = 2(x-0.4)^2 + 0.1 \).

While the variates \( \xi_{tk}^{(c)} = (\xi_{1k}^{(c)}, \xi_{2k}^{(c)}, \ldots, \xi_{Tk}^{(c)})^{\top} \) for both clusters, are generated from autoregressive of order 1 with parameter 0.7, while the variates \( \zeta_{itl}^{(c)} \) for both clusters, are generated from independent and identically distributed \( N(0,0.5) \) and \( N(0,0.25) \), respectively.

The basis functions for the common-time trend for the first cluster, \( \rho_k^{(1)}(x) \), for \( k \) in \{1,2\} are \( sqrt(2) \ast sin(\pi \ast (0 : 200/200)) \) and \( sqrt(2) \ast cos(\pi \ast (0 : 200/200)) \) respectively; and the basis functions for the common-time trend for the second cluster, \( \rho_k^{(2)}(x) \), for \( k \) in \{1,2\} are \( sqrt(2) \ast sin(2\pi \ast (0 : 200/200)) \) and \( sqrt(2) \ast cos(2\pi \ast (0 : 200/200)) \) respectively.

The basis functions for the residual for the first cluster, \( \psi_l^{(1)}(x) \), for \( l \) in \{1,2\} are \( sqrt(2) \ast sin(3\pi \ast (0 : 200/200)) \) and \( sqrt(2) \ast cos(3\pi \ast (0 : 200/200)) \) respectively; and the basis functions for the residual for the second cluster, \( \psi_l^{(2)}(x) \), for \( l \) in \{1,2\} are \( sqrt(2) \ast sin(4\pi \ast (0 : 200/200)) \) and \( sqrt(2) \ast cos(4\pi \ast (0 : 200/200)) \) respectively.

The measurement error \( \upsilon_{it} \) for each continuum \( x \) is generated from independent and identically distributed \( N(0,0.2^2) \)

Examples

data(sim_ex_cluster)
Summary for functional time series model

Description
Summarizes a basis function model fitted to a functional time series. It returns various measures of goodness-of-fit.

Usage
## S3 method for class 'fm'
summary(object, ...)

Arguments
object Output from ftsm or fplsr.
... Other arguments.

Value
None.

Author(s)
Rob J Hyndman

See Also
fts, forecast.ftsm, residuals.fm, plot.fm, plot.fmres

Examples
summary(object = ftsm(y = ElNino_ERSST_region_land2))

Testing stationarity of functional time series

Description
A hypothesis test for stationarity of functional time series.

Usage
T_stationary(sample, L = 49, J = 500, MC_rep = 1000, cumulative_var = .90,
Ker1 = FALSE, Ker2 = TRUE, h = ncol(sample)^.5, pivotal = FALSE)
Arguments

sample A matrix of discretised curves of dimension (p by n), where p represents the dimensionality and n represents sample size.

L Number of Fourier basis functions.

J Truncation level used to approximate the distribution of the squared integrals of Brownian bridges that appear in the limit distribution.

MC_rep Number of replications.

cumulative_var Amount of variance explained.

Ker1 Flat top kernel in (4.1) of Horvath et al. (2014).

Ker2 Flat top kernel in (7) of Politis (2003).

h Kernel bandwidth.

pivotal If pivotal = TRUE, a pivotal statistic is used.

Details

As in traditional (scalar and vector) time series analysis, many inferential procedures for functional time series assume stationarity. Stationarity is required for functional dynamic regression models, for bootstrap and resampling methods for functional time series and for the functional analysis of volatility.

Value

p-value When p-value is less than any level of significance, we reject the null hypothesis and conclude that the tested functional time series is not stationary.

Author(s)

Greg. Rice and Han Lin Shang

References


See Also

farforecast

Examples

result = T_stationary(sample = pm_10_GR_sqrt$y)
result_pivotal = T_stationary(sample = pm_10_GR_sqrt$y, J = 100, MC_rep = 5000, h = 20, pivotal = TRUE)
Description

Generic functions for variance.

Usage

\texttt{var(...)}

Arguments

\texttt{...} Arguments passed to specific methods.

Details

The \texttt{cor} functions in the \texttt{stats} package are replaced by \texttt{var.default}.

Value

Refer to specific methods. For numeric vectors, see the \texttt{cor} functions in the \texttt{stats} package.

Author(s)

Rob J Hyndman and Han Lin Shang

See Also

\texttt{var.fts}

Description

Computes variance functions of functional time series at each variable.
Arguments

- **x**: An object of class `fts`.
- **method**: Method for computing median.
- **trim**: Percentage of trimming.
- **alpha**: Tuning parameter when `method`="radius".
- **weight**: Hard thresholding or soft thresholding.
- **...**: Other arguments.

Details

If `method` = "coordinate", it computes coordinate-wise variance.

If `method` = "FM", it computes the variance of trimmed functional data ordered by the functional depth of Fraiman and Muniz (2001).

If `method` = "mode", it computes the variance of trimmed functional data ordered by \( h \)-modal functional depth.

If `method` = "RP", it computes the variance of trimmed functional data ordered by random projection depth.

If `method` = "RPD", it computes the variance of trimmed functional data ordered by random projection derivative depth.

If `method` = "radius", it computes the standard deviation function of trimmed functional data ordered by the notion of alpha-radius.

Value

A list containing \( x \) = variables and \( y \) = variance rates.

Author(s)

Han Lin Shang

References


& Data Analysis*, 51(2), 1063-1074.


See Also

mean.fts, median.fts, sd.fts, quantile.fts

Examples

# Fraiman-Muniz depth was arguably the oldest functional depth.
var(x = ELNino.ERSST_region_land2, method = "FM")
var(x = ELNino.ERSST_region_land2, method = "coordinate")
var(x = ELNino.ERSST_region_land2, method = "mode")
var(x = ELNino.ERSST_region_land2, method = "RP")
var(x = ELNino.ERSST_region_land2, method = "RPD")
var(x = ELNino.ERSST_region_land2, method = "radius", alpha = 0.5, weight = "hard")
var(x = ELNino.ERSST_region_land2, method = "radius", alpha = 0.5, weight = "soft")
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