Package 'MRFA'

January 20, 2025

Type Package

Title Fitting and Predicting Large-Scale Nonlinear Regression Problems using Multi-Resolution Functional ANOVA (MRFA) Approach

Version 0.6

Date 2023-11-01

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Description Performs the MRFA approach proposed by Sung et al. (2020) <doi:10.1080/01621459.2019.1595630> to fit and predict nonlinear regression problems, particularly for large-scale and high-dimensional problems. The application includes deterministic or stochastic computer experiments, spatial datasets, and so on.

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RoxygenNote 7.2.3

Depends R (>= 2.14.1)

Imports fields, glmnet, grplasso, methods, plyr, randtoolbox, foreach, stats, graphics, utils

NeedsCompilation no

Repository CRAN

Date/Publication 2023-11-10 19:43:20 UTC

Contents

`aic.MRFA` *Extract AIC from a Fitted Multiresolution Functional ANOVA (MRFA) Model*

Description

The function extracts Akaike information criterion (AIC) from a fitted MRFA model.

Usage

```
aic.MRFA(fit)
```

Arguments

`fit`	a class MRFA object estimated by `MRFA_fit`.

Value

a vector with length `length(lambda)` returing AICs.

Author(s)

Chih-Li Sung <iamdfchile@gmail.com>

See Also

`predict.MRFA` for prediction of the MRFA model.

Examples

```
## Not run:

#####             Testing function: GRAMACY & LEE (2009) function            #####
#####   Thanks to Sonja Surjanovic and Derek Bingham, Simon Fraser University #####
grlee09 <- function(xx)
{
  x1 <- xx[1]
  x2 <- xx[2]
  x3 <- xx[3]
  x4 <- xx[4]
  x5 <- xx[5]
  x6 <- xx[6]

  term1 <- exp(sin((0.9*(x1+0.48))^10))
  term2 <- x2 * x3
  term3 <- x4

  y <- term1 + term2 + term3
  return(y)
}
```

```
library(MRFA)
#####   Training data and testing data   #####
set.seed(2)
n <- 100; n_rep <- 3; n_new <- 50; d <- 6
X.train <- matrix(runif(d*n), ncol = d)
X.train <- matrix(rep(X.train, each = n_rep), ncol = d)
Y.train <- apply(X.train, 1, grlee09)
Y.train <- Y.train + rnorm(n*n_rep, 0, 0.05)
X.test <- matrix(runif(d*n_new), ncol = d)
Y.test <- apply(X.test, 1, grlee09)

#####   Fitting    #####
MRFA_model <- MRFA_fit(X.train, Y.train)
print(aic.MRFA(MRFA_model))
print(bic.MRFA(MRFA_model))

#####   Prediction : AIC and BIC  ######
lambda.aic <- MRFA_model$lambda[which.min(aic.MRFA(MRFA_model))]
Y.pred <- predict(MRFA_model, X.test, lambda = lambda.aic)$y_hat
print(sqrt(mean((Y.test - Y.pred)^2)))

lambda.bic <- MRFA_model$lambda[which.min(bic.MRFA(MRFA_model))]
Y.pred <- predict(MRFA_model, X.test, lambda = lambda.bic)$y_hat
print(sqrt(mean((Y.test - Y.pred)^2)))

## End(Not run)
```

`bic.MRFA` *Extract BIC from a Multiresolution Functional ANOVA (MRFA) Model*

Description

The function extracts Bayesian information criterion (BIC) from a fitted MRFA model.

Usage

```
bic.MRFA(fit)
```

Arguments

`fit`	a class MRFA object estimated by `MRFA_fit`.

Value

a vector with length `length(lambda)` returing BICs.

Author(s)

Chih-Li Sung <iamdfchile@gmail.com>

See Also

predict.MRFA for prediction of the MRFA model.

Examples

```
## Not run:

#####             Testing function: GRAMACY & LEE (2009) function             #####
#####   Thanks to Sonja Surjanovic and Derek Bingham, Simon Fraser University #####
grlee09 <- function(xx)
{
  x1 <- xx[1]
  x2 <- xx[2]
  x3 <- xx[3]
  x4 <- xx[4]
  x5 <- xx[5]
  x6 <- xx[6]

  term1 <- exp(sin((0.9*(x1+0.48))^10))
  term2 <- x2 * x3
  term3 <- x4

  y <- term1 + term2 + term3
  return(y)
}

library(MRFA)
#####   Training data and testing data   #####
set.seed(2)
n <- 100; n_rep <- 3; n_new <- 50; d <- 6
X.train <- matrix(runif(d*n), ncol = d)
X.train <- matrix(rep(X.train, each = n_rep), ncol = d)
Y.train <- apply(X.train, 1, grlee09)
Y.train <- Y.train + rnorm(n*n_rep, 0, 0.05)
X.test <- matrix(runif(d*n_new), ncol = d)
Y.test <- apply(X.test, 1, grlee09)

#####   Fitting    #####
MRFA_model <- MRFA_fit(X.train, Y.train)
print(aic.MRFA(MRFA_model))
print(bic.MRFA(MRFA_model))

#####   Prediction : AIC and BIC  ######
lambda.aic <- MRFA_model$lambda[which.min(aic.MRFA(MRFA_model))]
Y.pred <- predict(MRFA_model, X.test, lambda = lambda.aic)$y_hat
print(sqrt(mean((Y.test - Y.pred)^2)))

lambda.bic <- MRFA_model$lambda[which.min(bic.MRFA(MRFA_model))]
Y.pred <- predict(MRFA_model, X.test, lambda = lambda.bic)$y_hat
print(sqrt(mean((Y.test - Y.pred)^2)))

## End(Not run)
```

`confidence.MRFA` *Confidence Interval for Multiresolution Functional ANOVA (MRFA) Model*

Description

The function computes the confidence intervals of predicted responses (only works for linear regression model).

Usage

```
confidence.MRFA(
  object,
  xnew,
  X,
  lambda = object$lambda,
  conf.level = 0.95,
  var.estimation = c("rss", "cv", "posthoc")[1],
  w.estimation = c("cv", "nugget")[1],
  K = 5,
  nugget = 1e-06,
  parallel = FALSE,
  verbose = FALSE
)
```

Arguments

`object`	a class MRFA object estimated by `MRFA_fit`.
`xnew`	a testing matrix with dimension `n_new` by `d` in which each row corresponds to a predictive location.
`X`	input for `MRFA_fit`.
`lambda`	a value. The default is `min(object$lambda)`.
`conf.level`	a value specifying confidence level of the confidence interval. The default is 0.95.
`var.estimation`	a character string specifying the estimation method for variance. "rss" specifies residual sum of squares, "cv" specifies a cross-validation method with `K` fold, and "posthoc" specifies a post-hoc estimation method. The default is "rss".
`w.estimation`	a character string specifying the estimation method for weights w. "cv" specifies a cross-validation method with `K` fold, and "nugget" specifies a least square error method with nugget=`nugget`. The default is "cv".
`K`	a positive integer specifying the number of folds.
`nugget`	a value specifying the nugget value for `w.estimation`. The default is 1e-6. It only works when `w.estimation="nugget"`.
`parallel`	logical. If `TRUE`, apply function in parallel using parallel backend provided by foreach.
`verbose`	logical. If `TRUE`, additional diagnostics are printed.

Details

When The details about `var.estimation` and `w.estimation` can be seen in Sung et al. (2017+).

Value

`lower bound`	a vector with length `n_new` displaying lower bound of predicted responses at locations `xnew`.
`upper bound`	a vector with length `n_new` displaying upper bound of predicted responses at locations `xnew`.
`conf.level`	as above.

Author(s)

Chih-Li Sung <iamdfchile@gmail.com>

See Also

`MRFA_fit` for fitting of a multi-resolution functional ANOVA model; `predict.MRFA` for prediction of a multi-resolution functional ANOVA model.

Examples

```
## Not run:

#####             Testing function: OTL circuit function                     #####
#####   Thanks to Sonja Surjanovic and Derek Bingham, Simon Fraser University #####
otlcircuit <- function(xx)
{
  Rb1  <- 50   + xx[1] * 100
  Rb2  <- 25   + xx[2] * 45
  Rf   <- 0.5  + xx[3] * 2.5
  Rc1  <- 1.2  + xx[4] * 1.3
  Rc2  <- 0.25 + xx[5] * 0.95
  beta <- 50   + xx[6] * 250

  Vb1 <- 12*Rb2 / (Rb1+Rb2)
  term1a <- (Vb1+0.74) * beta * (Rc2+9)
  term1b <- beta*(Rc2+9) + Rf
  term1 <- term1a / term1b

  term2a <- 11.35 * Rf
  term2b <- beta*(Rc2+9) + Rf
  term2 <- term2a / term2b

  term3a <- 0.74 * Rf * beta * (Rc2+9)
  term3b <- (beta*(Rc2+9)+Rf) * Rc1
  term3 <- term3a / term3b

  Vm <- term1 + term2 + term3
  return(Vm)
}
```

```
library(MRFA)
#####   training data and testing data   #############
set.seed(2)
n <- 100; n_new <- 10; d <- 6
X.train <- matrix(runif(d*n), ncol = d)
Y.train <- apply(X.train, 1, otlcircuit)
X.test <- matrix(runif(d*n_new), ncol = d)
Y.test <- apply(X.test, 1, otlcircuit)

#####   Fitting    #####
MRFA_model <- MRFA_fit(X.train, Y.train)

#####   Prediction   ######
Y.pred <- predict(MRFA_model, X.test, lambda = min(MRFA_model$lambda))$y_hat
print(sqrt(mean((Y.test - Y.pred)^2)))

### confidence interval ###
conf.interval <- confidence.MRFA(MRFA_model, X.test, X.train, lambda = min(MRFA_model$lambda))
print(conf.interval)

## End(Not run)
```

`cv.MRFA` *Compute K-fold cross-validated error for Multi-Resolution Functional ANOVA (MRFA) Model*

Description

Computes the K-fold cross validated mean squared prediction error for multiresolution functional ANOVA model.

Usage

```
cv.MRFA(
  X,
  Y,
  order = 10,
  level = 10,
  lambda = exp(seq(log(500), log(0.001), by = -0.01)),
  K = 10,
  plot.it = TRUE,
  parallel = FALSE,
  verbose = FALSE,
  ...
)
```

Arguments

X	input for MRFA_fit.
Y	input for MRFA_fit.
order	input for MRFA_fit.
level	input for MRFA_fit.
lambda	lambda values at which CV curve should be computed.
K	a positive integer specifying the number of folds.
plot.it	logical. If TRUE, a CV curve will be shown. The default is TRUE.
parallel	logical. If TRUE, apply cross-validation function in parallel using parallel back-end provided by foreach. The default is FALSE.
verbose	logical. If TRUE, additional diagnostics are printed. The default is FALSE.
...	additional arguments to MRFA_fit.

Value

lambda	lambda values at which CV curve is computed.
cv	the CV curve at each value of lambda.
cv.error	the standard error of the CV curve

Author(s)

Chih-Li Sung <iamdfchile@gmail.com>

See Also

MRFA_fit for fitting a multiresolution functional ANOVA model.

Examples

```
## Not run:

#####             Testing function: GRAMACY & LEE (2009) function             #####
#####   Thanks to Sonja Surjanovic and Derek Bingham, Simon Fraser University #####
grlee09 <- function(xx)
{
  x1 <- xx[1]
  x2 <- xx[2]
  x3 <- xx[3]
  x4 <- xx[4]
  x5 <- xx[5]
  x6 <- xx[6]

  term1 <- exp(sin((0.9*(x1+0.48))^10))
  term2 <- x2 * x3
  term3 <- x4

  y <- term1 + term2 + term3
```

```
  return(y)
}

library(MRFA)
#####   Training data and testing data   #####
set.seed(2)
n <- 100; n_rep <- 3; n_new <- 50; d <- 6
X.train <- matrix(runif(d*n), ncol = d)
X.train <- matrix(rep(X.train, each = n_rep), ncol = d)
Y.train <- apply(X.train, 1, grlee09)
Y.train <- Y.train + rnorm(n*n_rep, 0, 0.05)
X.test <- matrix(runif(d*n_new), ncol = d)
Y.test <- apply(X.test, 1, grlee09)

#####   Fitting    #####
MRFA_model <- MRFA_fit(X.train, Y.train)

#####   Computes the K-fold cross validated   #####
cv.out <- cv.MRFA(X.train, Y.train, K = 5, lambda = seq(0.01,3,0.1))

#####   Prediction : CV  ######
lambda_cv <- cv.out$lambda[which.min(cv.out$cv)]
Y.pred <- predict(MRFA_model, X.test, lambda = lambda_cv)$y_hat
print(sqrt(mean((Y.test - Y.pred)^2)))

## End(Not run)
```

MRFA_fit *Fit a Multi-Resolution Functional ANOVA (MRFA) Model*

Description

The function performs the multi-resolution functional ANOVA (MRFA) approach.

Usage

```
MRFA_fit(
  X,
  Y,
  weights = rep(1, length(Y)),
  order = 10,
  level = 10,
  lambda.min = 1e-05,
  converge.tol = 1e-10,
  nvar.max = min(3 * length(Y), 3000),
  k = 2,
  pen.norm = c("2", "N")[1],
  model = LinReg(),
  standardize.d = TRUE,
```

```
  center = TRUE,
  standardize = TRUE,
  parallel = FALSE,
  verbose = TRUE
)
```

Arguments

X	a design matrix with dimension n by d.
Y	a response vector of size n.
weights	a vector of observation weights.
order	a positive integer specifying the highest order of interactions that can be entertained in the model. The default is 10.
level	a positive integer specifying the highest resolution level that can be entertained in the model. The default is 10.
lambda.min	a positive value specifying the minimum penalty value to be performed before the convergence criterion is met.
converge.tol	convergence tolerance. It converges when relative difference with respect to function value (penalized likelihood) is smaller than the tolerance. The default is 1e-10.
nvar.max	maximum number of non-zero variables.
k	a positive integer specifying the order of Wendland covariance function. The default is 2.
pen.norm	a character string specifying the type of penalty norm for group lasso to be computed. "2" or 2 specifies 2-norm, and "N" specifies native norm. The default is "2".
model	an object of class specifying other models. LinReg() (default) fits a linear regression, LogReg() fits a logistic regression, and PoissReg() fits a Poisson regression.
standardize.d	logical. If TRUE, the columns of the design matrix will be standardized into [0,1].
center	logical. If TRUE, the columns of the model matrix will be centered (except a possible intercept column).
standardize	logical. If TRUE, the model matrix will be blockwise orthonormalized.
parallel	logical. If TRUE, apply function in parallel in ldply using parallel backend provided by foreach.
verbose	logical. If TRUE, additional diagnostics are printed.

Details

A multi-resolution functional ANOVA (MRFA) model targets a low resolution representation of a low order functional ANOVA, with respect to strong effect heredity, to form an accurate emulator in a large-scale and high dimensional problem. This function fits an MRFA model using a modified group lasso algrithm. One can consider the loss function

$$\frac{1}{n}\sum_{i=1}^{n}\left(y_i-\sum_{|u|=1}^{D_{\max}}\sum_{r=1}^{R_{\max}}\sum_{k=1}^{n_u(r)}\beta_u^{rk}\varphi_u^{rk}(x_{iu})\right)^2+\lambda\sum_{|u|=1}^{D_{\max}}\sum_{r=1}^{R_{\max}}\sqrt{N_u(r)\sum_{v\subseteq u}\sum_{s\leq r}\sum_{k=1}^{n_v(s)}(\beta_v^{sk})^2},$$

where $\varphi_u^{rk}(x_{iu})$ is the basis function with resolution level r and with dimension $u \subset \{1, 2, \ldots, d\}$, and $D_{\max}$ and $R_{\max}$ respectively are the maximal orders of functional ANOVA and multi-resolution level, which are indicated by `order` and `level`.

The group lasso path along the penalty parameter λ is given by the function, where the $\lambda_{\max}$ is automatically given and $\lambda_{\min}$ is given by users, which is indicated by `lambda.min`. The group lasso algrithm is implemented via the modifications to the source code of the `grplasso` package (Meier, 2015).

`lambda.min`, `converge.tol` and `nvar.max` are the options for stopping the fitting process. Smaller `lambda.min`, or smaller `converge.tol`, or larger `nvar.max` yields more accurate results, paricularly for deterministic computer experiments. `pen.norm` specifies the type of penalty norm in the loss function. `model` specifies the response type, which can be non-continuous response, in the case the loss function is replaced by negative log-likelihood function. More details can be seen in Sung et al. (2017+).

Value

An MRFA object is returned, for which `aic.MRFA`, `bic.MRFA` and `predict` methods exist.

Author(s)

Chih-Li Sung <iamdfchile@gmail.com>

See Also

`predict.MRFA` for prediction of the MRFA model.

Examples

```
## Not run:

#####             Testing function: OTL circuit function                    #####
#####  Thanks to Sonja Surjanovic and Derek Bingham, Simon Fraser University #####
otlcircuit <- function(xx)
{
  Rb1  <- 50   + xx[1] * 100
  Rb2  <- 25   + xx[2] * 45
  Rf   <- 0.5  + xx[3] * 2.5
  Rc1  <- 1.2  + xx[4] * 1.3
  Rc2  <- 0.25 + xx[5] * 0.95
  beta <- 50   + xx[6] * 250

  Vb1 <- 12*Rb2 / (Rb1+Rb2)
  term1a <- (Vb1+0.74) * beta * (Rc2+9)
  term1b <- beta*(Rc2+9) + Rf
  term1 <- term1a / term1b

  term2a <- 11.35 * Rf
  term2b <- beta*(Rc2+9) + Rf
  term2 <- term2a / term2b

  term3a <- 0.74 * Rf * beta * (Rc2+9)
```

```
  term3b <- (beta*(Rc2+9)+Rf) * Rc1
  term3 <- term3a / term3b

  Vm <- term1 + term2 + term3
  return(Vm)
}

library(MRFA)
#####   Training data and testing data   #####
set.seed(2)
n <- 1000; n_new <- 100; d <- 6
X.train <- matrix(runif(d*n), ncol = d)
Y.train <- apply(X.train, 1, otlcircuit)
X.test <- matrix(runif(d*n_new), ncol = d)
Y.test <- apply(X.test, 1, otlcircuit)

#####   Fitting    #####
MRFA_model <- MRFA_fit(X.train, Y.train, verbose = TRUE)

#####   Prediction   ######
Y.pred <- predict(MRFA_model, X.test, lambda = min(MRFA_model$lambda))$y_hat
print(sqrt(mean((Y.test - Y.pred)^2)))

## End(Not run)
```

`predict.MRFA` *Prediction of Multi-Resolution Functional ANOVA (MRFA) Model*

Description

The function computes the predicted responses.

Usage

```
## S3 method for class 'MRFA'
predict(object, xnew, lambda = object$lambda, parallel = FALSE, ...)
```

Arguments

`object`	a class MRFA object estimated by `MRFA_fit`.
`xnew`	a testing matrix with dimension `n_new` by `d` in which each row corresponds to a predictive location.
`lambda`	a value, or vector of values, indexing the path. The default is `object$lambda`.
`parallel`	logical. If `TRUE`, apply function in parallel in `ldply` using parallel backend provided by foreach.
`...`	for compatibility with generic method `predict`.

Value

lambda	as above.
coefficients	coefficients with respect to the basis function value.
y_hat	a matrix with dimension n_new by length(lambda) displaying predicted responses at locations xnew.

Author(s)

Chih-Li Sung <iamdfchile@gmail.com>

See Also

MRFA_fit for fitting a multiresolution functional ANOVA model.

Examples

```
## Not run:

#####             Testing function: OTL circuit function                    #####
#####  Thanks to Sonja Surjanovic and Derek Bingham, Simon Fraser University #####
otlcircuit <- function(xx)
{
  Rb1  <- 50   + xx[1] * 100
  Rb2  <- 25   + xx[2] * 45
  Rf   <- 0.5  + xx[3] * 2.5
  Rc1  <- 1.2  + xx[4] * 1.3
  Rc2  <- 0.25 + xx[5] * 0.95
  beta <- 50   + xx[6] * 250

  Vb1 <- 12*Rb2 / (Rb1+Rb2)
  term1a <- (Vb1+0.74) * beta * (Rc2+9)
  term1b <- beta*(Rc2+9) + Rf
  term1 <- term1a / term1b

  term2a <- 11.35 * Rf
  term2b <- beta*(Rc2+9) + Rf
  term2 <- term2a / term2b

  term3a <- 0.74 * Rf * beta * (Rc2+9)
  term3b <- (beta*(Rc2+9)+Rf) * Rc1
  term3 <- term3a / term3b

  Vm <- term1 + term2 + term3
  return(Vm)
}

library(MRFA)
#####   Training data and testing data   #####
set.seed(2)
n <- 1000; n_new <- 100; d <- 6
X.train <- matrix(runif(d*n), ncol = d)
```

```
Y.train <- apply(X.train, 1, otlcircuit)
X.test <- matrix(runif(d*n_new), ncol = d)
Y.test <- apply(X.test, 1, otlcircuit)

#####   Fitting    #####
MRFA_model <- MRFA_fit(X.train, Y.train, verbose = TRUE)

#####   Prediction   ######
Y.pred <- predict(MRFA_model, X.test, lambda = min(MRFA_model$lambda))$y_hat
print(sqrt(mean((Y.test - Y.pred)^2)))

## End(Not run)
```

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