Package 'SpatialTools'

January 20, 2025

Type Package

Title Tools for Spatial Data Analysis

Version 1.0.5

Author Joshua French <joshua.french@ucdenver.edu>

Maintainer Joshua French <joshua.french@ucdenver.edu>

Depends R (>= 3.0.2)

Imports spBayes (>= 0.3.0), Rcpp

LinkingTo Rcpp (>= 0.9.10), RcppArmadillo (>= 0.3.0)

Description Tools for spatial data analysis. Emphasis on kriging. Provides functions for prediction and simulation. Intended to be relatively straightforward, fast, and flexible.

License GPL (>= 2)

Encoding UTF-8

LazyData true

NeedsCompilation yes

Repository CRAN

Date/Publication 2023-07-18 20:50:02 UTC

Contents

`coincident` *Determine coincident coordinates*

Description

`coincident` takes the coordinate matrices `coords1` and `coords2` and returns the indices of the coincident coordinates of the two matrices.

Usage

```
coincident(coords1, coords2)
```

Arguments

`coords1`	An $n1 \times 2$ numeric matrix of coordinates.
`coords2`	An $n2 \times 2$ numeric matrix of coordinates.

Details

This function calls a compiled `C++` program created using the Rcpp package. This (may) result in a significant speedup over pure R code since the search algorithm involves loops. We assume that there are no duplicate coordinates in `coords1` and `coords2`, respectively. In other words, each row of `coords1` is unique and each row of `coords2` is unique. There is at most 1 row of `coords1` that will match with a row in `coords2`.

Value

Returns a matrix with the indices of the coincident locations. Specifically, an $r \times 2$ matrix will be returned, with r being the number of coordinates in `coords1` coinciding with coordinates in `coords2`. If row `i` of the matrix is c(2, 5), then the `i`th set of coincident locations is between the 2nd row of `coords1` and the 5th row of `coords2`. If there are no coincident locations, then a matrix of size 0×2 is returned.

Author(s)

Joshua French

Examples

```
#Generate two sets of coordinates
loc1 <- as.matrix(expand.grid(seq(0, 1, len = 25), seq(0, 1, len = 25)))
loc2 <- as.matrix(expand.grid(seq(0, 1, len = 101), seq(0, 1, len = 101)))
coincident(loc1, loc2)
```

`cov.sp` *Calculates spatial covariance*

Description

Calculates spatial covariance matrix of the observed responses, and possibly, the responses to be predicted. If `pcoords` is not provided, then only `V`, the covariance matrix of the observed responses will be returned. If `pcoords` is provided, then `Vp` and `Vop` (the covariance matrix for predicted responses and between observed and predicted responses, respectively) will also be returned.

Usage

```
cov.sp(coords, sp.type = "exponential",
sp.par = stop("specify sp.par argument"),
error.var = 0, smoothness = 0.5, finescale.var = 0,
pcoords = NULL, D = NULL, Dp = NULL, Dop = NULL)
```

Arguments

`coords`	A numeric matrix of size $n \times d$ containing the observed data locations.
`sp.type`	A character vector specifying the spatial covariance type. Valid types are currently exponential, gaussian, matern, matern2, and spherical.
`sp.par`	A vector of length 2 specifying the scale and strength of dependence of the covariance function. The first element is the variance of the underlying spatial process (also known as the hidden or latent spatial process). This value is also called the partial sill. The second element is the strength of dependence between responses.
`error.var`	A non-negative number indicating the variance of the error term.
`smoothness`	A positive number indicating the variance of the error term.
`finescale.var`	A non-negative positive number indicating the finescale variability. The is also called the microscale variance
`pcoords`	A numeric matrix of size $np \times d$ containing the locations of the responses to be predicted.
`D`	The Euclidean distance matrix for the `coords` matrix. Must be of size $n \times n$.
`Dp`	The Eucliean distance matrix for the `pcoords` matrix. Must be of size $np \times np$.
`Dop`	The Euclidean intersite distance matrix between the locations in `coords` and the locations in `pcoords`. Must be of size $n \times np$.

Details

The spatial covariance functions are parameterized in a manner consistent with the `cov.spatial` function in the `geoR` package. The `matern2` covariance function is an alternative covariance function suggested by Handcock and Wallis (1994). The benefit of this parameterization is that the range parameter is that it allows the effective range to be less dependent on the smoothness parameter.

The `D`, `Dp`, and `Dop` arguments are supplied to decrease the number of necessary computations needed when performing repetitive analysis or simulations. It is probably in the user's interest to not supply these arguments unless the duration of analysis is an important consideration. Note that these arguments override the information given in `coords` and `pcoords`, i.e., if dist1(coords) != D, then D is used in subsequent calculations, etc. This could create problems.

Value

Returns a list with the following elements:

`V`	The covariance matrix for the observed responses. Will be of size $n \times n$.
`Vp`	The covariance matrix for the predicted responses. Only returned if `pcoords` is supplied. Will be of size $np \times np$.
`Vp`	The covariance matrix between the observed responses and the predicted responses. Only returned if `pcoords` is supplied. Will be of size $n \times np$.

Author(s)

Joshua French

References

M.S. Handcock, J.R. Wallis. An approach to statistical spatial-temporal modeling of meteorological fields (with discussion). Journal of the American Statistical Association, 89 (1994), pp. 368–390.

See Also

`simple.cov.sp`

Examples

```
coords <- matrix(rnorm(30), ncol = 3)
cov.sp(coords = coords, sp.type = "exponential", sp.par = c(2, 1),
    error.var = 1)
```

cov.st *Calculates spatio-temporal covariance*

Description

Calculates spatial covariance matrix of the observed responses, and possibly, the responses to be predicted. If pcoords is not provided, then only V, the covariance matrix of the observed responses will be returned. If pcoords is provided, then Vp and Vop (the covariance matrix for predicted responses and between observed and predicted responses, respectively) will also be returned.

Usage

```
cov.st(coords, time, sp.type = "exponential",
    sp.par = stop("specify sp.par argument"),
      error.var = 0, smoothness = 0.5, finescale.var = 0,
    t.type = "ar1", t.par = .5,
    pcoords = NULL, ptime = NULL,
    D = NULL, Dp = NULL, Dop = NULL,
    T = NULL, Tp = NULL, Top = NULL)
```

Arguments

coords	A numeric matrix of size $n \times d$ containing the observed data locations.
time	A numeric matrix of size $n \times 1$ containing the times at which the data was observed.
sp.type	A character vector specifying the spatial covariance type. Valid types are currently exponential, gaussian, matern, and spherical.
sp.par	A vector of length 2 specifying the scale and dependence of the covariance function. The first element refers to the variance of the hidden process (sometimes this is called the partial sill) while the second elements determines the strength of dependence between locations.
error.var	A non-negative number indicating the variance of the error term.
smoothness	A positive number indicating the variance of the error term.
finescale.var	A non-negative positive number indicating the finescale variability. The is also called the microscale variance
t.type	A character vector indicating the temporal dependance structure. Currently, only "ar1" is implemented.
t.par	A numeric vector of length 1 indicating the strength of temporal dependence.
pcoords	A numeric matrix of size $np \times d$ containing the locations of the responses to be predicted
ptime	A numeric matrix of size $np \times 1$ containing the times at which the responses are to be predicted.
D	The Euclidean distance matrix for the coords matrix. Must be of size $n \times n$.

Dp	The Eucliean distance matrix for the pcoords matrix. Must be of size $np \times np$.
Dop	The Eucliean intersite distance matrix between the locations in coords and the locations in pcoords. Must be of size $n \times np$.
T	The Euclidean distance matrix for the time matrix. Must be of size $n \times n$.
Tp	The Eucliean distance matrix for the ptime matrix. Must be of size $np \times np$.
Top	The Eucliean intertime distance matrix between the times in time and ptime. Must be of size $n \times np$.

Details

At this point, this function only implements a separable spatio-temporal covariance funcation. If h is the distance between two sites, and t is the temporal lag between the times when the associated responses were observed, then the covariance function $C(h,t) = Cs(h) \times Ct(t)$ where Cs is a spatial covariance function corresponding to the exponential, matern, gaussian, or spherical and Ct is the temporal covariance function corresponding to an ar1 process with $Ct(t) = \phi^t$.

The D, Dp, Dop, T, Tp, Top arguments are supplied to decrease the number of necessary computations needed when performing repetitive analysis or simulations. It is probably in the user's interest to not supply these arguments unless the duration of analysis is an important consideration. Note that these arguments override the information given in coords, pcoords, time, and prime, i.e., if dist1(coords) != D, then D is used in subsequent calculations, etc. This could create problems.

Value

Returns a list with the following elements:

V	The covariance matrix for the observed responses.
Vp	The covariance matrix for the predicted responses. Only returned if pcoords is supplied.
Vp	The covariance matrix between the observed responses and the predicted responses. Only returned if pcoords is supplied. Will be of size $n \times np$

Author(s)

Joshua French

See Also

simple.cov.sp

Examples

```
coords <- matrix(rnorm(30), ncol = 3)
pcoords <- matrix(rnorm(90), ncol = 3)
time <- 1:10
ptime <- 1:30
cov.st(coords = coords, time = time, sp.type = "exponential",
    sp.par = c(2, 1), error.var = 1, t.type = "ar1", t.par = .5,
    pcoords = pcoords, ptime = ptime)
```

`decomp.cov` *Calculates decomposition of covariance matrix*

Description

Calculates a decomposition of the provided covariance matrix, `V`, using the chosen method.

Usage

```
decomp.cov(V, method = "eigen")
```

Arguments

`V`	A (symmetric, positive-definite) covariance matrix.
`method`	A character vector specifying the method used to decompose `V`. Options are "eigen", "chol", or "svd" (Eigen decomposition, Cholesky decomposition, or Singular value decomposition, respectively).

Details

The matrix `V` is assumed to be symmetric and positive definite. Symmetry is checked, but the positive definiteness of the matrix is not. Returns a decomposition matrix `U` such that `V = U %*% t(U)`.

Value

Returns a decomposition matrix `U` such that `V = U %*% t(U)`.

Author(s)

Joshua French

See Also

`cov.sp`

Examples

```
data(toydata)
U <- decomp.cov(toydata$V, method = "chol")
#range(toydata$V - U %*% t(U))
```

dist1 — *Calculate Euclidean distance matrix for a matrix of coordinates*

Description

`dist1` takes a matrix of coordinates and returns the Euclidean distance matrix of the coordinates. It does this using a compiled `C` program, so it is faster than the builtin R `dist` function.

Usage

```
dist1(coords)
```

Arguments

`coords`	An $nr \times nc$ numeric matrix of coordinates.

Value

An $nr \times nr$ matrix of Euclidean distances.

Author(s)

Joshua French

See Also

dist, dist2

Examples

```
x <- matrix(rnorm(30), ncol = 3)
dist1(x)
```

dist2 — *Calculate Euclidean distance matrix between coordinates of two matrices*

Description

`dist2` takes the matrices of coordinates `coords1` and `coords2` and returns the inter-Euclidean distances between coordinates.

Usage

```
dist2(coords1, coords2)
```

Arguments

coords1	An $nr1 \times nc1$ numeric matrix of coordinates.
coords2	An $nr2 \times nc2$ numeric matrix of coordinates.

Value

An $nr1 \times nr2$ matrix of Euclidean distances.

Author(s)

Joshua French

See Also

dist, dist1

Examples

```
x1 <- matrix(rnorm(30), ncol = 3)
x2 <- matrix(rnorm(60), ncol = 3)
dist2(x1, x2)
```

---

get.contours *Extracts coordinates from contourLines function*

Description

Takes contours of contourLines function and extracts the associated coordinates.

Usage

```
get.contours(x)
```

Arguments

x	A list returned by the contourLines function.

Value

Returns a 2-column matrix containing the coordinates making up the contours in contours.list.

Author(s)

Joshua French

See Also

contourLines, contour

Examples

```
data(volcano)
x <- 10*1:nrow(volcano)
y <- 10*1:ncol(volcano)
cL <- contourLines(x, y, volcano)
out <- get.contours(cL)
```

---

krige.ok *Performs Ordinary Kriging*

Description

Performs Ordinary Kriging using y, the $n \times 1$ matrix of observed responses, V, the (positive definite) covariance matrix of the observed responses, Vp, the $np \times np$ covariance matrix of the responses to be predicted, and Vop, the $n \times np$ matrix of covariances between the observed responses and the responses to be predicted.

Usage

```
krige.ok(y, V, Vp, Vop, nsim = 0, Ve.diag = NULL, method = "eigen")
```

Arguments

y	The vector of observed responses. Should be a matrix of size $n \times 1$ or a vector of length n.
V	The covariance matrix of the observed responses. The size is $n \times n$.
Vp	The covariance matrix of the responses to be predicted. The size is $np \times np$.
Vop	The cross-covariance between the observed responses and the responses to be predicted. The size is $n \times np$
nsim	The number of simulated data sets to sample from the conditional predictive distribution.
Ve.diag	A vector of length n specifying the measure error variances of the observed data. Only needed if nsim > 0.
method	The method for decomposing V in conditional simulation. Default is "eigen", for the Eigen decomposition. Alternatives are "chol" (Cholesky) and "svd" (Singular Value Decomposition).

Details

It is assumed that there are n observed data values and that we wish to make predictions at np locations.

If doing conditional simulation, the Cholesky decomposition should not work when there are coincident locations between the observed data locations and the predicted data locations. Both the Eigen and Singular Value Decompositions should work.

If user specifies nsim to be a positive integer, then nsim conditional realizations of the predictive distribution will be generated. If this is less than 1, then no conditional simulation is done. If nsim is a positive integer, then Ve.diag must also be supplied. Ve.diag is should be a vector of length n specifying the measurement error variances of the observed data. This information is only used for conditional simulation, so this argument is only needed when nsim > 0. When conditional simulation is desired, then the argument method can be to specify the method used to decompose V. Options are "eigen", "chol", or "svd" (Eigen decomposition, Cholesky decomposition, or Singular value decomposition, respectively). This information is only used for conditional simulation, so this argument is only applicable when nsim > 0.

Value

The function returns a list containing the following objects:

pred	A vector of length np containing the predicted responses.
mspe	A vector of length np containing the mean-square prediction error of the predicted responses.
coeff	A vector of length k containing the estimated regression coefficients.
vcov.coeff	A $k \times k$ matrix containing the (estimated) covariance matrix of estimated the regression coefficients.
simulations	An $n \times nsim$ matrix containing the nsim realizations of the conditional realizations. Each column of the matrix represents a realization of the conditional normal distribution.

If nsim > 0, this list has class "krigeConditionalSample".

Author(s)

Joshua French

References

Statistical Methods for Spatial Data Analysis, Schabenberger and Gotway (2003). See p. 226-228.

Examples

```
# create observed and predicted coordinates
ocoords <- matrix(runif(100), ncol = 2)
pcoords <- matrix(runif(200), ncol = 2)

# include some observed locations in the predicted coordinates
acoords <- rbind(ocoords, pcoords)

# create covariance matrix
C3 <- cov.sp(coords = ocoords, sp.type = "matern", sp.par = c(2, 1), smoothness = 1,
finescale = 0, error = 0.5, pcoords = acoords)

# generate data with error
y <- rmvnorm(nsim = 1, mu = rep(2, 50), V = C3$V) + rnorm(50, sd = sqrt(.5))
```

```
# use universal kriging to make predictions.  Do not do conditional simulation
krige.obj <- krige.ok(as.vector(y), V = C3$V, Vp = C3$Vp, Vop = C3$Vop,
nsim = 0)

#Do conditional simulation
krige.obj2 <- krige.ok(as.vector(y), V = C3$V, Vp = C3$Vp, Vop = C3$Vop,
nsim = 100, Ve.diag = rep(.5, 50), method = "eigen")
```

`krige.sk` *Performs simple kriging*

Description

Performs simple kriging using `y`, a vector of length n, `V`, the (positive definite) covariance matrix of the observed responses, `Vp`, the $np \times np$ covariance matrix of the responses to be predicted, `Vop`, the $n \times np$ matrix of covariances between the observed responses and the responses to be predicted, and `m`, a numeric vector of length 1 identifying the value of the mean for each response.

Usage

```
krige.sk(y, V, Vp, Vop, m = 0, nsim = 0, Ve.diag = NULL, method = "eigen")
```

Arguments

`y`	The vector of observed responses. Should be a matrix of size $n \times 1$ or a vector of length n.
`V`	The covariance matrix of the observed responses. The size is $n \times n$.
`Vp`	The covariance matrix of the responses to be predicted. The size is $np \times np$
`Vop`	The cross-covariance between the observed responses and the responses to be predicted. The size is $n \times np$.
`m`	A numeric vector of length 1 giving the mean of each response.
`nsim`	The number of simulated data sets to sample from the conditional predictive distribution.
`Ve.diag`	A vector of length n specifying the measure error variances of the observed data. Only needed if `nsim` > 0.
`method`	The method for decomposing `V` in conditional simulation. Default is "eigen", for the Eigen decomposition. Alternatives are "chol" (Cholesky) and "svd" (Singular Value Decomposition).

Details

It is assumed that there are n observed data values and that we wish to make predictions at np locations. The mean is subtracted from each value of y before determining the kriging weights, and then the mean is added onto the predicted response.

If doing conditional simulation, the Cholesky decomposition should not work when there are coincident locations between the observed data locations and the predicted data locations. Both the Eigen and Singular Value Decompositions should work.

If user specifies nsim to be a positive integer, then nsim conditional realizations of the predictive distribution will be generated. If this is less than 1, then no conditional simulation is done. If nsim is a positive integer, then Ve.diag must also be supplied. Ve.diag is should be a vector of length n specifying the measurement error variances of the observed data. This information is only used for conditional simulation, so this argument is only needed when nsim > 0. When conditional simulation is desired, then the argument method can be to specify the method used to decompose V. Options are "eigen", "chol", or "svd" (Eigen decomposition, Cholesky decomposition, or Singular value decomposition, respectively). This information is only used for conditional simulation, so this argument is only applicable when nsim > 0.

Value

The function returns a list containing the following objects:

pred	A vector of length np containing the predicted responses.
mspe	A vector of length np containing the mean-square prediction error of the predicted responses.
simulations	An $n \times nsim$ matrix containing the nsim realizations of the conditional realizations. Each column of the matrix represents a realization of the conditional normal distribution.
mean	The mean value (m) originally provided to the function

. If nsim > 0, this list has class "krigeConditionalSample".

Author(s)

Joshua French

References

Statistical Methods for Spatial Data Analysis, Schabenberger and Gotway (2003). See p. 226-228.

Examples

```
data(toydata)
y <- as.vector(toydata$y)
V <- toydata$V
Vp <- toydata$Vp
Vop <- toydata$Vop
krige.sk(y, V, Vp, Vop, m = 2)
```

krige.uk *Performs universal kriging*

Description

Performs universal kriging using X, the $n \times k$ design matrix for the regression coefficients of the observed data, y, the $n \times 1$ matrix of observed responses, V, the (positive definite) covariance matrix of the observed responses, Xp, the $np \times k$ design matrix of the responses to be predicted, Vp, the $np \times np$ covariance matrix of the responses to be predicted, and Vop, the $n \times np$ matrix of covariances between the observed responses and the responses to be predicted. If user specifies nsim to be a positive integer, then nsim conditional realizations of the predictive distribution will be generated.

Usage

```
krige.uk(y, V, Vp, Vop, X, Xp, nsim = 0, Ve.diag = NULL, method = "eigen")
```

Arguments

y	The vector of observed responses. Should be a matrix of size $n \times 1$ or a vector of length n.
V	The covariance matrix of the observed responses. The size is $n \times n$.
Vp	The covariance matrix of the responses to be predicted. The size is $np \times np$
Vop	The cross-covariance between the observed responses and the responses to be predicted. The size is $n \times np$
X	The design matrix of the observed data. The size is $n \times k$
Xp	The design matrix of the responses to be predicted. The size is $np \times k$
.	
nsim	The number of simulated data sets to sample from the conditional predictive distribution.
Ve.diag	A vector of length n specifying the measure error variances of the observed data.
method	The method for decomposing V in conditional simulation. Default is "eigen", for the Eigen decomposition. Alternatives are "chol" (Cholesky) and "svd" (Singular Value Decomposition).

Details

It is assumed that there are n observed data values and that we wish to make predictions at np locations. We assume that there are k regression coefficients (including the intercept). Both X and Xp should contain a column of 1's if an intercept is desired.

If doing conditional simulation, the Cholesky decomposition should not work when there are coincident locations between the observed data locations and the predicted data locations. Both the Eigen and Singular Value Decompositions should work.

If user specifies nsim to be a positive integer, then nsim conditional realizations of the predictive distribution will be generated. If this is less than 1, then no conditional simulation is done. If

nsim is a positive integer, then Ve.diag must also be supplied. Ve.diag is should be a vector of length n specifying the measurement error variances of the observed data. This information is only used for conditional simulation, so this argument is only needed when nsim > 0. When conditional simulation is desired, then the argument method can be to specify the method used to decompose V. Options are "eigen", "chol", or "svd" (Eigen decomposition, Cholesky decomposition, or Singular value decomposition, respectively). This information is only used for conditional simulation, so this argument is only applicable when nsim > 0.

Value

The function returns a list containing the following objects:

pred	A vector of length np containing the predicted responses.
mspe	A vector of length np containing the mean-square prediction error of the predicted responses.
coeff	A vector of length k containing the estimated regression coefficients.
vcov.coeff	A $k \times k$ matrix containing the (estimated) covariance matrix of estimated the regression coefficients.
sim	An $n \times nsim$ matrix containing the nsim realizations of the conditional realizations. Each column of the matrix represents a realization of the conditional normal distribution.

If nsim > 0, this list has class "krigeConditionalSample".

Author(s)

Joshua French

References

Statistical Methods for Spatial Data Analysis, Schabenberger and Gotway (2003). See p. 241-243.

Examples

```
# create observed and predicted coordinates
ocoords <- matrix(runif(100), ncol = 2)
pcoords <- matrix(runif(200), ncol = 2)

# include some observed locations in the predicted coordinates
acoords <- rbind(ocoords, pcoords)

# create design matrices
X <- as.matrix(cbind(1, ocoords))
Xa <- as.matrix(cbind(1, acoords))

# create covariance matrix
C3 <- cov.sp(coords = ocoords, sp.type = "matern", sp.par = c(2, 1), smoothness = 1,
finescale = 0, error = 0.5, pcoords = acoords)

# set values of regression coefficients
```

```
coeff <- matrix(c(1, 2, 3), nrow = 1)

# generate data with error
y <- rmvnorm(nsim = 1, mu = tcrossprod(X, coeff), V = C3$V) + rnorm(50, sd = sqrt(.5))

# use universal kriging to make predictions.  Do not do
# conditional simulation
krige.obj <- krige.uk(as.vector(y), V = C3$V, Vp = C3$Vp, Vop = C3$Vop,
X = X, Xp = Xa, nsim = 0)

#Do kriging with conditional simulation
krige.obj2 <- krige.uk(as.vector(y), V = C3$V, Vp = C3$Vp, Vop = C3$Vop,
X = X, Xp = Xa, nsim = 100,
Ve.diag = rep(.5, 50), method = "eigen")
```

`maxlik.cov.sp` *Determines maximum likelihood estimates of covariance parameters*

Description

Estimates covariance parameters of spatial covariance functions using maximum likelihood or restricted maximum likelihood. See `cov.sp` for more details of covariance functions to be estimated.

Usage

```
maxlik.cov.sp(X, y, coords, sp.type = "exponential",
    range.par = stop("specify range.par argument"),
    error.ratio = stop("specify error.ratio argument"),
    smoothness = 0.5,
    D = NULL, reml = TRUE, lower = NULL, upper = NULL,
    control = list(trace = TRUE), optimizer="nlminb")
```

Arguments

`X`	A numeric matrix of size $n \times k$ containing the design matrix of the data locations.
`y`	A vector of length n containing the observed responses.
`coords`	A numeric matrix of size $n \times d$ containing the locations of the observed responses.
`sp.type`	A character vector specifying the spatial covariance type. Valid types are currently exponential, gaussian, matern, and spherical.
`range.par`	An initial guess for the spatial dependence parameter.
`error.ratio`	A value non-negative value indicating the ratio `error.var/sp.par[1]`.
`smoothness`	A positive number indicating the smoothness of the matern covariance function, if applicable.
`D`	The Euclidean distance matrix for the coords matrix. Must be of size $n \times n$.

reml	A boolean value indicating whether restricted maximum likelihood estimation should be used. Defaults to TRUE.
lower	A vector giving lower bounds for the covariance parameters sp.par[2], error.ratio, and smoothness (when the model is matern). Order matters! If not given defaults to an upper bound of Inf for sp.par[2], 1 for error.ratio, and 10 for smoothness.
upper	A vector giving upper bounds for the covariance parameters sp.par[2], error.ratio, and smoothness (when the model is matern). Order matters! If not given defaults to an upper bound of Inf for sp.par[2], 1 for error.ratio, and 10 for smoothness.
control	A list giving tuning parameters for the nlminb function. See nlminb for more details.
optimizer	A vector describing the optimization function to use for the optimization. Currently, only nlminb is an acceptable value.

Details

When doing the numerical optimizaiton, the covariance function is reparameterized slightly to speedup computation. Specifically, the variance parameter for the process of interest,sp.par[1], is profiled out, and the error.var parameter is parameterized as sp.par[1] * error.ratio, where error.ratio = error.var/sp.par[1].

Value

Returns a list with the following elements:

sp.type	The covariance form used.
sp.par	A vector containing the estimated variance of the hidden process and the spatial dependence.
error.var	The estimated error variance.
smoothness	The smoothness of the matern covariance function.
par	The final values of the optimization parameters. Note that these will not necessarily match sp.par, error.var, and smoothness because of the reparameterization.
convergence	Convergence message from nlminb.
message	Message from nlminb.
iterations	Number of iterations for optimization to converge.
evaluations	Evaluations from nlminb.

Author(s)

Joshua French

See Also

cov.st

Examples

```
#generate 20 random (x, y) coordinates
coords <- matrix(rnorm(20), ncol = 2)

#create design matrix
X <- cbind(1, coords)

#create mean for observed data to be generated
mu <- X %*% c(1, 2, 3)

#generate covariance matrix
V <- exp(-dist1(coords))

#generate observe data
y <- rmvnorm(mu = mu, V = V)

#find maximum likelihood estimates of covariance parameters
maxlik.cov.sp(X = X, y = y, coords = coords,
    sp.type = "exponential", range.par = 1, error.ratio = 0,
    reml = TRUE)
```

`maxlik.cov.st` *Determines maximum likelihood estimates of covariance parameters*

Description

Estimates covariance parameters of spatio-temporal covariance functions using maximum likelihood or restricted maximum likelihood. See `cov.st` for more details of covariance functions to be estimated. The covariance function is reparameterized slightly to speedup computation. Specifically, the variance parameter for the hidden process, sp.par[1], is profiled out and the error.var parameter is parameterized as sp.par[1] * error.ratio.

Usage

```
maxlik.cov.st(X, y, coords, time, sp.type = "exponential",
    range.par = stop("specify range.par argument"),
    error.ratio = stop("specify error.ratio argument"),
    smoothness = 0.5, t.type = "ar1", t.par = .5, D = NULL, T = NULL,
    reml = TRUE, lower = NULL, upper = NULL, control = list(trace = TRUE),
    optimizer="nlminb")
```

Arguments

`X`	A numeric matrix of size $n \times k$ containing the design matrix of the data locations.
`y`	A vector of length n containing the observed responses.
`coords`	A numeric matrix of size $n \times d$ containing the locations of the observed responses.

time	A numeric vector of length n containing the time at which the responses were observed.
sp.type	A character vector specifying the spatial covariance type. Valid types are currently exponential, gaussian, matern, and spherical.
range.par	An initial guess for the spatial dependence parameter.
error.ratio	A value non-negative value indicating the ratio error.var/sp.par[1].
smoothness	A positive number indicating the variance of the error term.
t.type	A character vector indicating the spatial covariance type. Only ar1 is currently available.
t.par	A value specifying the temporal dependence parameter of the ar1 process.
D	The Euclidean distance matrix for the coords matrix. Must be of size $n \times n$.
T	The Euclidean distance matrix for the time matrix. Must be of size $n \times n$.
reml	A boolean value indicating whether restricted maximum likelihood estimation should be used. Defaults to TRUE.
lower	A vector giving lower bounds for the covariance parameters sp.par[2], error.ratio, and smoothness (when the model is matern). Order matters! If not given defaults to a lower bound of .001 for sp.par[2], 0 for error.ratio, and .001 for smoothness.
upper	A vector giving upper bounds for the covariance parameters sp.par[2], error.ratio, and smoothness (when the model is matern). Order matters! If not given defaults to an upper bound of Inf for sp.par[2], 1 for error.ratio, and 10 for smoothness.
control	A list giving tuning parameters for the nlminb function. See nlminb for more details.
optimizer	A vector describing the optimization function to use for the optimization. Currently, only nlminb is an acceptable value.

Details

When doing the numerical optimization, the covariance function is reparameterized slightly to speedup computation. Specifically, the variance parameter for the process of interest,sp.par[1], is profiled out, and the error.var parameter is parameterized as sp.par[1] * error.ratio, where error.ratio = error.var/sp.par[1].

Value

Returns a list with the following elements:

sp.type	The covariance form used.
sp.par	A vector containing the estimated variance of the hidden process and the spatial dependence.
error.var	The estimated error variance.
smoothness	The smoothness of the matern covariance function.

par	The final values of the optimization parameters. Note that these will not necessarily match sp.par, error.var, and smoothness because of the reparameterization.
convergence	Convergence message from nlminb.
message	Message from nlminb.
iterations	Number of iterations for optimization to converge.
evaluations	Evaluations from nlminb.

Author(s)

Joshua French

See Also

cov.st

Examples

```
#Generate locations and observed times
coords <- matrix(rnorm(40), ncol = 2)
time <- rep(1:2, each = 10)

#Calculate distance matrix for time vector
T <- dist1(matrix(time))

#create design matrix
X <- cbind(1, coords)

#create mean for observed data to be generated
mu <- X %*% c(1, 2, 3)

#generate covariance matrix for spatio-temporal data
V <- exp(-dist1(coords)) * .25^T

#generate observe data
y <- rmvnorm(mu = mu, V = V)

maxlik.cov.st(X = X, y = y, coords = coords, time = time,
    sp.type = "exponential", range.par = 1, error.ratio = 0,
    t.type = "ar1", t.par = .5, reml = TRUE)
```

---

plot.contourLines *Plot contour lines*

Description

Plot contour lines from list produced by contourLines function.

Usage

```
## S3 method for class 'contourLines'
plot(x, begin=1, end = length(x), add = FALSE, ...)
```

Arguments

x	The list of contour lines (created by contourLines) you want to plot.
begin	Beginning position in list of contour lines you want to plot.
end	Ending position in list of contour lines you want to plot.
add	A boolean value indicating whether the contour lines should be added to an existing plot (add = TRUE) or should be plotted on a new plot (add = FALSE).
...	Additional arguments that will be passed to the plot or lines function.

Value

This function does not return anything; it only creates a new plot or modifies an existing plot.

Author(s)

Joshua French

Examples

```
data(volcano)
x <- 10*1:nrow(volcano)
y <- 10*1:ncol(volcano)
cL <- contourLines(x, y, volcano)
plot.contourLines(cL)
```

---

rcondnorm *Generate from conditional normal distribution*

Description

Generates realizations from a multivariate normal distribution conditional on observed data vector

Usage

```
rcondnorm(nsim = 1, y, mu, mup, V, Vp, Vop, method = "eigen")
```

Arguments

nsim	An integer indicating the number of realizations from the distribution.
y	A vector of length n contained the observed data.
mu	The mean vector of the observed data. Should be a vector of length n.
mup	The mean vector of the responses to be generated. Should be a vector of length np.
V	The covariance matrix of the observed data. The matrix should be symmetric and positive definite. The size must be $ntimesn$.
Vp	The covariance matrix of the responses to be generated. The matrix should be symmetric and positive definite. The size must be $nptimesnp$.
Vop	The cross-covariance matrix between the observed data and the responses to be generated. The size must be $ntimesnp$.
method	The method for performing a decomposition of the covariance matrix. Possible values are "eigen", "chol", and "svd", Eigen value decomposition, Cholesky decomposition, or Singular Value Decomposoition, respectively.

Value

An $np \times nsim$ matrix containing the nsim realizations of the conditional normal distribution. Each column of the matrix represents a realization of the multivariate normal distribution.

Author(s)

Joshua French

See Also

rmvnorm

Examples

```
n <- 100
np <- 100

mu <- rep(1, 100)
mup <- rep(2, 100)

coords <- matrix(runif(2 * n), ncol = 2)
pcoords <- matrix(runif(2 * np), ncol = 2)

myV <- cov.sp(coords, sp.type = "exponential", c(1, 2), error.var = 1, pcoords = pcoords)

y <- rmvnorm(1, mu = mu, V = myV$V)

rcondnorm(3, y = y, mu = mu, mup = mup, V = myV$V, Vp = myV$Vp, Vop = myV$Vop, method = "chol")
```

rmvnorm *Generates realizations from a multivariate normal distribution*

Description

Generates realizations from a multivariate normal distribution.

Usage

```
rmvnorm(nsim = 1, mu, V, method = "eigen")
```

Arguments

nsim	An integer indicating the number of realizations from the distribution.
mu	A vector of length n containing the mean values of the multivariate normal distribution.
V	The covariance matrix of the multivariate normal distribution. The matrix should be symmetric and positive definite. The size must be $ntimesn$.
method	The method for performing a decomposition of the covariance matrix. Possible values are "eigen", "chol", and "svd", Eigen value decomposition, Cholesky decomposition, or Singular Value Decomposoition, respectively.

Value

An $n \times nsim$ matrix containing the nsim realizations of the multivariate normal distribution. Each column of the matrix represents a realization of the multivariate normal distribution.

Author(s)

Joshua French

See Also

rmvnorm

Examples

```
n <- 20
mu <- 1:n
V <- exp(-dist1(matrix(rnorm(n))))
rmvnorm(nsim = 100, mu = mu, V = V, method = "eigen")
```

simple.cov.sp *Calculates spatial covariance based on distance matrix*

Description

Calculates a spatial covariance using a (Euclidean) distance matrix D. Not intended to be used directly by user (though it may be helpful to some). It is strongly recommended that you use the cov.sp function. No argument or error checking is provided for this function.

Usage

```
simple.cov.sp(D, sp.type, sp.par, error.var, smoothness, finescale.var)
```

Arguments

D	A distance matrix between locations
sp.type	A character vector specifying the spatial covariance type. Valid types are currently exponential, gaussian, matern, and spherical.
sp.par	A vector of length 2 specifying the scale and dependence of the covariance function. The first element refers to the variance of the hidden process (sometimes this is called the partial sill) while the second elements determines the strength of dependence between locations.
error.var	A non-negative number indicating the variance of the error term.
smoothness	A positive number indicating the variance of the error term.
finescale.var	A non-negative positive number indicating the finescale variability. The is also called the microscale variance

Value

Returns a covariance matrix.

Author(s)

Joshua French

See Also

~ cov.sp

Examples

```
coords <- matrix(rnorm(30), ncol = 3)
D <- dist1(coords)
simple.cov.sp(D = D, sp.type = "exponential", sp.par = c(2, 1),
error.var = 1, smoothness = 0.5, finescale.var = 0)
```

simple.cov.time *Calculates temporal covariance based on distance matrix*

Description

Calculates a temporal covariance using a (Euclidean) distance matrix `T`. Not intended to be used directly by user (though it may be helpful to some). It is used in the `covets` function. No argument or error checking is provided for this function.

Usage

```
simple.cov.time(T, t.type, t.par)
```

Arguments

`T`	A distance matrix.
`t.type`	A character vector specifying the temporal covariance type. Only "ar1" is currently implemented.
`t.par`	A vector of length 1 specifying the strength of dependence of the covariance function.

Value

Returns a covariance matrix.

Author(s)

Joshua French

See Also

~ `cov.st`

Examples

```
T <- dist1(matrix(1:10))
simple.cov.time(T = T, t.type = "ar1", t.par = .5)
```

spLMPredictJoint *Returns posterior predictive sample from spLM object*

Description

The function spLMPredictJoint collects posterior predictive samples for a set of new locations given a spLM object from the spBayes package.

Usage

```
spLMPredictJoint(sp.obj, pred.coords, pred.covars, start = 1,
 end = nrow(sp.obj$p.theta.samples), thin = 1, verbose = TRUE, n.report = 100,
  noisy = FALSE, method = "eigen")
```

Arguments

sp.obj	An spLM object returned by the spLM function in the spBayes package.
pred.coords	An $np \times 2$ matrix of np prediction location coordinates in R^2 (e.g., easting and northing). The first column is assumed to be easting coordinates and the second column northing coordinates.
pred.covars	An $n \times p$ matrix of covariates matrix associated with the new locations.
start	Specifies the first sample included in the composition sampling.
end	Specifies the last sample included in the composition. The default is to use all posterior samples in sp.obj.
thin	A sample thinning factor. The default of 1 considers all samples between start and end. For example, if thin = 10 then 1 in 10 samples are considered between start and end.
verbose	If TRUE, model specification and progress of the sampler is printed to the screen. Otherwise, nothing is printed to the screen.
n.report	The interval to report sampling progress.
noisy	If TRUE, then the posterior sample for the response is for the signal + error noise. The default, FALSE, assumes the user wants the error-free process.
method	Method used to decompose covariance matrix. Options are "chol", "eigen", and "svd" for the Cholesky, Eigen, and singular value decomposition approaches, respectively.

Details

This function samples from the joint posterior predictive distribution of a Bayesian spatial linear model. Specifically, it is intended to be similar to the spPredict function in the spBayes except that it samples from the joint distribution instead of the marginal distribution. However, it will only work for spLM objects and should have the same limitations as the spLM and spPredict functions. Note that the spRecover function is called internally to recover the posterior samples form the posterior distribution of the spatial model.

Value

The function returns a $np \times B$ matrix of posterior predictive samples, where B is the number of posterior samples. The class is jointPredicitveSample.

Author(s)

Joshua French

See Also

spLM, spPredict, spRecover

Examples

```
# Set parameters
n <- 100
np <- 12
n.samples <- 10
burnin.start <- .5 * n.samples + 1
sigmasq <- 1
tausq <- 0.0
phi <- 1
cov.model <- "exponential"
n.report <- 5

# Generate coordinates
coords <- matrix(runif(2 * n), ncol = 2);
pcoords <- as.matrix(expand.grid(seq(0, 1, len = 12), seq(0, 1, len = 12)))

# Construct design matrices
X <- as.matrix(cbind(1, coords))
Xp <- cbind(1, pcoords)

# Specify priors
starting <- list("phi" = phi, "sigma.sq"= sigmasq, "tau.sq" = tausq)
tuning <- list("phi"=0.1, "sigma.sq"=0.1, "tau.sq"=0.1)
priors.1 <- list("beta.Norm"=list(c(1, 2, 1), diag(100, 3)),
                     "phi.Unif"=c(0.00001, 10), "sigma.sq.IG"=c(1, 1))

# Generate data
B <- rnorm(3, c(1, 2, 1), sd = 10)
phi <- runif(1, 0, 10)
sigmasq <- 1/rgamma(1, 1, 1)
V <- simple.cov.sp(D = dist1(coords), cov.model, c(sigmasq, 1/phi), error.var = tausq,
smoothness = nu, finescale.var = 0)
y <- X %*% B + rmvnorm(1, rep(0, n), V) + rnorm(n, 0, sqrt(tausq))

# Create spLM object
library(spBayes)
m1 <- spBayes::spLM(y ~ X - 1, coords = coords, starting = starting,
tuning = tuning, priors = priors.1, cov.model = cov.model,
n.samples = n.samples, verbose = FALSE, n.report = n.report)
```

```
# Sample from joint posterior predictive distribution
y1 <- spLMPredictJoint(m1, pred.coords = pcoords, pred.covars = Xp,
start = burnin.start, verbose = FALSE, method = "chol")
```

---

toydata *A toy data set for use in examples.*

Description

A list containing X, a 50 x 3 design matrix, y, a vector of length 50 of observed responses, V, a 50 x 50 covariance matrix for the observed data, Xp, a 121 x 3 design matrix for the predicted responses, Vp, the 121 x 121 covariance matrix of the predicted responses, Vop, the 50 x 121 covariance matrix between the observed responses and the predicted responses, coords, a 50 x 2 matrix containing the sites of the 50 observed responses, and pcoords, a 121 x 2 matrix containing the 121 sites for the predicted responses (a 11 x 11 regular grid over the domain [0, 1]x[0, 1]).

Usage

```
data(toydata)
```

Author(s)

Joshua French

Examples

```
data(toydata)
```

Index