Package 'MetricGraph'

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Type Package

Title Random Fields on Metric Graphs

Version 1.2.0

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Description Facilitates creation and manipulation of metric graphs, such as street or river networks. Further facilitates operations and visualizations of data on metric graphs, and the creation of a large class of random fields and stochastic partial differential equations on such spaces. These random fields can be used for simulation, prediction and inference. In particular, linear mixed effects models including random field components can be fitted to data based on computationally efficient sparse matrix representations. Interfaces to the R packages 'INLA' and 'inlabru' are also provided, which facilitate working with Bayesian statistical models on metric graphs. The main references for the methods are Bolin, Simas and Wallin (2022) <doi:10.48550/arXiv.2205.06163>, Bolin, Kovacs, Kumar and Simas (2023) <doi:10.48550/arXiv.2302.03995> and Bolin, Simas and Wallin (2023) <doi:10.48550/arXiv.2304.03

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Imports stats, ggplot2, igraph, sf, viridis, rSPDE (>= 2.3.3), Matrix, methods, Rcpp (>= 1.0.5), R6, lifecycle, sp, dplyr, tidyr, magrittr, broom, zoo

Suggests knitr, testthat, INLA (>= 22.12.14), inlabru, osmdata, sn, plotly, parallel, optimParallel, numDeriv

Additional_repositories https://inla.r-inla-download.org/R/testing

BugReports https://github.com/davidbolin/MetricGraph/issues

URL https://davidbolin.github.io/MetricGraph/

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LinkingTo Rcpp, RcppEigen

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Depends R (>= 3.5.0)

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R topics documented:

`augment.graph_lme` *Augment data with information from a* `graph_lme` *object*

Description

Augment accepts a model object and a dataset and adds information about each observation in the dataset. It includes predicted values in the `.fitted` column, residuals in the `.resid` column, and standard errors for the fitted values in a `.se.fit` column. It also contains the New columns always begin with a . prefix to avoid overwriting columns in the original dataset.

Usage

```
## S3 method for class 'graph_lme'
augment(
  x,
  newdata = NULL,
  which_repl = NULL,
  se_fit = FALSE,
  conf_int = FALSE,
  pred_int = FALSE,
  level = 0.95,
  n_samples = 100,
  edge_number = "edge_number",
  distance_on_edge = "distance_on_edge",
  coord_x = "coord_x",
  coord_y = "coord_y",
  data_coords = c("PtE", "spatial"),
  normalized = FALSE,
  ...
)
```

Arguments

`x`	A `graph_lme` object.
`newdata`	A `data.frame` or a `list` containing the covariates, the edge number and the distance on edge for the locations to obtain the prediction. If `NULL`, the fitted values will be given for the original locations where the model was fitted.

which_repl	Which replicates to obtain the prediction. If NULL predictions will be obtained for all replicates. Default is NULL.
se_fit	Logical indicating whether or not a .se.fit column should be added to the augmented output. If TRUE, it only returns a non-NA value if type of prediction is 'link'.
conf_int	Logical indicating whether or not confidence intervals for the fitted variable should be built.
pred_int	Logical indicating whether or not prediction intervals for future observations should be built.
level	Level of confidence and prediction intervals if they are constructed.
n_samples	Number of samples when computing prediction intervals.
edge_number	Name of the variable that contains the edge number, the default is edge_number.
distance_on_edge	Name of the variable that contains the distance on edge, the default is distance_on_edge.
coord_x	Column (or entry on the list) of the data that contains the x coordinate. If not supplied, the column with name "coord_x" will be chosen. Will not be used if Spoints is not NULL or if data_coords is PtE.
coord_y	Column (or entry on the list) of the data that contains the y coordinate. If not supplied, the column with name "coord_x" will be chosen. Will not be used if Spoints is not NULL or if data_coords is PtE.
data_coords	To be used only if Spoints is NULL. It decides which coordinate system to use. If PtE, the user must provide edge_number and distance_on_edge, otherwise if spatial, the user must provide coord_x and coord_y.
normalized	Are the distances on edges normalized?
...	Additional arguments.

Value

A tidyr::tibble() with columns:

- .fitted Fitted or predicted value.
- .fittedlwrconf Lower bound of the confidence interval, if conf_int = TRUE
- .fitteduprconf Upper bound of the confidence interval, if conf_int = TRUE
- .fittedlwrpred Lower bound of the prediction interval, if pred_int = TRUE
- .fitteduprpred Upper bound of the prediction interval, if pred_int = TRUE
- .fixed Prediction of the fixed effects.
- .random Prediction of the random effects.
- .resid The ordinary residuals, that is, the difference between observed and fitted values.
- .se_fit Standard errors of fitted values, if se_fit = TRUE.

See Also

glance.graph_lme

bru_mapper.inla_metric_graph_spde *Metric graph 'inlabru' mapper*

Description

Metric graph 'inlabru' mapper

Usage

```
bru_get_mapper.inla_metric_graph_spde(model, ...)

ibm_n.bru_mapper_inla_metric_graph_spde(mapper, ...)

ibm_values.bru_mapper_inla_metric_graph_spde(mapper, ...)

ibm_jacobian.bru_mapper_inla_metric_graph_spde(mapper, input, ...)
```

Arguments

model	An inla_metric_graph_spde for which to construct or extract a mapper
...	Arguments passed on to other methods
mapper	A bru_mapper.inla_metric_graph_spde object
input	The values for which to produce a mapping matrix

drop_na.metric_graph_data *A version of* tidyr::drop_na() *function for datasets on metric graphs*

Description

Applies tidyr::drop_na() function for datasets obtained from a metric graph object.

Usage

```
## S3 method for class 'metric_graph_data'
drop_na(data, ...)
```

Arguments

data	The data list or tidyr::tibble obtained from a metric graph object.
...	Additional parameters to be passed to tidyr::drop_na().

Value

A tidyr::tibble with the resulting selected columns.

exp_covariance *Exponential covariance function*

Description

Evaluates the exponential covariance function

$$C(h) = \sigma^2 \exp\{-kappah\}$$

Usage

```
exp_covariance(h, theta)
```

Arguments

h	Distances to evaluate the covariance function at.
theta	A vector c(sigma, kappa), where sigma is the standard deviation and kappa is a range-like parameter.

Value

A vector with the values of the covariance function.

filter.metric_graph_data *A version of* dplyr::filter() *function for datasets on metric graphs*

Description

Applies dplyr::filter() function for datasets obtained from a metric graph object.

Usage

```
## S3 method for class 'metric_graph_data'
filter(.data, ...)
```

Arguments

.data	The data list or tidyr::tibble obtained from a metric graph object.
...	Additional parameters to be passed to dplyr::filter().

Value

A tidyr::tibble with the resulting selected columns.

gg_df.metric_graph_spde_result *Data frame for metric_graph_spde_result objects to be used in 'ggplot2'*

Description

Returns a 'ggplot2'-friendly data-frame with the marginal posterior densities.

Usage

```
## S3 method for class 'metric_graph_spde_result'
gg_df(
  result,
  parameter = result$params,
  transform = TRUE,
  restrict_x_axis = parameter,
 restrict_quantiles = list(sigma = c(0, 1), range = c(0, 1), kappa = c(0, 1), sigma =
    c(0, 1)),
  ...
)
```

Arguments

result	A metric_graph_spde_result object.
parameter	Vector. Which parameters to get the posterior density in the data.frame? The options are sigma, range or kappa.
transform	Should the posterior density be given in the original scale?
restrict_x_axis	Variables to restrict the range of x axis based on quantiles.
restrict_quantiles	List of quantiles to restrict x axis.
...	Not being used.

Value

A data.frame containing the posterior densities.

`glance.graph_lme` *Glance at a* `graph_lme` *object*

Description

Glance accepts a `graph_lme` object and returns a `tidyr::tibble()` with exactly one row of model summaries. The summaries are the square root of the estimated variance of the measurement error, residual degrees of freedom, AIC, BIC, log-likelihood, the type of latent model used in the fit and the total number of observations.

Usage

```
## S3 method for class 'graph_lme'
glance(x, ...)
```

Arguments

`x`	A `graph_lme` object.
`...`	Additional arguments. Currently not used.

Value

A `tidyr::tibble()` with exactly one row and columns:

- `nobs` Number of observations used.
- `sigma` the square root of the estimated residual variance
- `logLik` The log-likelihood of the model.
- `AIC` Akaike's Information Criterion for the model.
- `BIC` Bayesian Information Criterion for the model.
- `deviance` Deviance of the model.
- `df.residual` Residual degrees of freedom.
- `model.type` Type of latent model fitted.

See Also

augment.graph_lme

graph_bru_process_data

Prepare data frames or data lists to be used with 'inlabru' in metric graphs

Description

Prepare data frames or data lists to be used with 'inlabru' in metric graphs

Usage

```
graph_bru_process_data(
  data,
  edge_number = "edge_number",
  distance_on_edge = "distance_on_edge",
  loc = "loc"
)
```

Arguments

data	A `data.frame` or a `list` containing the covariates, the edge number and the distance on edge for the locations to obtain the prediction.
edge_number	Name of the variable that contains the edge number, the default is `edge_number`.
distance_on_edge	Name of the variable that contains the distance on edge, the default is `distance_on_edge`.
loc	character. Name of the locations to be used in 'inlabru' component.

Value

A list containing the processed data to be used in a user-friendly manner by 'inlabru'.

graph_components

Connected components of metric graph

Description

Class representing connected components of a metric graph.

Details

A list of `metric_graph` objects (representing the different connected components in the full graph) created from vertex and edge matrices, or from an sp::SpatialLines object where each line is representing and edge. For more details, see the vignette: `vignette("metric_graph", package = "MetricGraph")`

Value

Object of R6Class for creating metric graph components.

Public fields

graphs List of the graphs representing the connected components.

n The number of graphs.

sizes Number of vertices for each of the graphs.

lengths Total edge lengths for each of the graphs. Create metric graphs for connected components

Methods

Public methods:

- graph_components$new()
- graph_components$get_largest()
- graph_components$plot()
- graph_components$clone()

Method new():

Usage:

```
graph_components$new(
  edges = NULL,
  V = NULL,
  E = NULL,
  by_length = TRUE,
  ...,
  lines = deprecated()
)
```

Arguments:

edges A list containing coordinates as m x 2 matrices (that is, of matrix type) or m x 2 data frames (data.frame type) of sequence of points connected by straightlines. Alternatively, you can also prove an object of type SpatialLinesDataFrame or SpatialLines (from sp package) or MULTILINESTRING (from sf package).

V n x 2 matrix with Euclidean coordinates of the n vertices.

E m x 2 matrix where each row represents an edge.

by_length Sort the components by total edge length? If FALSE, the components are sorted by the number of vertices.

... Additional arguments used when specifying the graphs

lines **[Deprecated]** Use edges instead.

vertex_unit The unit in which the vertices are specified. The options are 'degrees' (the great circle distance in km), 'km', 'm' and 'miles'. The default is NULL, which means no unit. However, if you set length_unit, you need to set vertex_unit.

length_unit The unit in which the lengths will be computed. The options are 'km', 'm' and 'miles'. The default is vertex_unit. Observe that if vertex_unit is NULL, length_unit can only be NULL. If vertex_unit is 'degrees', then the default value for length_unit is 'km'.

longlat If TRUE, then it is assumed that the coordinates are given. in Longitude/Latitude and that distances should be computed in meters. It takes precedence over vertex_unit and length_unit, and is equivalent to vertex_unit = 'degrees' and length_unit = 'm'.

tolerance Vertices that are closer than this number are merged when constructing the graph (default = 1e-10). If longlat = TRUE, the tolerance is given in km.

Returns: A graph_components object.

Method get_largest(): Returns the largest component in the graph.

Usage:

```
graph_components$get_largest()
```

Returns: A metric_graph object.

Method plot(): Plots all components.

Usage:

```
graph_components$plot(edge_colors = NULL, vertex_colors = NULL, ...)
```

Arguments:

edge_colors A 3 x nc matrix with RGB values for the edge colors to be used when plotting each graph.

vertex_colors A 3 x nc matrix with RGB values for the edge colors to be used when plotting each graph.

... Additional arguments for plotting the individual graphs.

Returns: A ggplot object.

Method clone(): The objects of this class are cloneable with this method.

Usage:

```
graph_components$clone(deep = FALSE)
```

Arguments:

deep Whether to make a deep clone.

Examples

```
library(sp)
edge1 <- rbind(c(0, 0), c(1, 0))
edge2 <- rbind(c(1, 0), c(2, 0))
edge3 <- rbind(c(1, 1), c(2, 1))
edges <- list(edge1, edge2, edge3)

graphs <- graph_components$new(edges)
graphs$plot()
```

graph_data_spde *Data extraction for 'spde' models*

Description

Extracts data from metric graphs to be used by 'INLA' and 'inlabru'.

Usage

```
graph_data_spde(
  graph_spde,
  name = "field",
  repl = NULL,
  group = NULL,
  group_col = NULL,
  only_pred = FALSE,
  loc_name = NULL,
  tibble = FALSE,
  drop_na = FALSE,
  drop_all_na = TRUE,
  loc = deprecated()
)
```

Arguments

graph_spde	An inla_metric_graph_spde object built with the graph_spde() function.
name	A character string with the base name of the effect.
repl	Which replicates? If there is no replicates, one can set repl to NULL. If one wants all replicates, then one sets to repl to .all.
group	Which groups? If there is no groups, one can set group to NULL. If one wants all groups, then one sets to group to .all.
group_col	Which "column" of the data contains the group variable?
only_pred	Should only return the data.frame to the prediction data?
loc_name	Character with the name of the location variable to be used in 'inlabru' prediction.
tibble	Should the data be returned as a tidyr::tibble?
drop_na	Should the rows with at least one NA for one of the columns be removed? DEFAULT is FALSE. This option is turned to FALSE if only_pred is TRUE.
drop_all_na	Should the rows with all variables being NA be removed? DEFAULT is TRUE. This option is turned to FALSE if only_pred is TRUE.
loc	**[Deprecated]** Use loc_name instead.

Value

An 'INLA' and 'inlabru' friendly list with the data.

graph_lgcp *Simulation of log-Gaussian Cox processes driven by Whittle-Matérn fields on metric graphs*

Description

Simulation of log-Gaussian Cox processes driven by Whittle-Matérn fields on metric graphs

Usage

```
graph_lgcp(n = 1, intercept = 0, sigma, range, alpha, graph)
```

Arguments

n	Number of samples.
intercept	Mean value of the Gaussian process.
sigma	Parameter for marginal standard deviations.
range	Parameter for practical correlation range.
alpha	Smoothness parameter (1 or 2).
graph	A metric_graph object.

Value

List with Gaussian process sample and simulated points.

graph_lme *Metric graph linear mixed effects models*

Description

Fitting linear mixed effects model in metric graphs. The random effects can be Gaussian Whittle-Matern fields, discrete Gaussian Markov random fields based on the graph Laplacian, as well as Gaussian random fields with isotropic covariance functions.

Usage

```
graph_lme(
  formula,
  graph,
  model = list(type = "linearModel"),
  which_repl = NULL,
  optim_method = "L-BFGS-B",
  starting_values_latent = NULL,
  start_sigma_e = NULL,
```

```
  BC = 1,
  parallel = FALSE,
  n_cores = parallel::detectCores() - 1,
  optim_controls = list(),
  improve_hessian = FALSE,
  hessian_args = list()
)
```

Arguments

formula	Formula object describing the relation between the response variables and the fixed effects.
graph	A metric_graph object.
model	The random effects model that will be used (it also includes the option of not having any random effects). It can be either a character, whose options are 'lm', for linear models without random effects; 'WM1' and 'WM2' for Whittle-Matern models with α=1 and 2, with exact precision matrices, respectively; 'WM' for Whittle-Matern models where one also estimates the smoothness parameter via finite-element method; 'isoExp' for a model with isotropic exponential covariance; 'GL1' and 'GL2' for a SPDE model based on graph Laplacian with α = 1 and 2, respectively. There is also the option to provide it as a list containing the elements type, which can be linearModel, WhittleMatern, graphLaplacian or isoCov. linearModel corresponds to a linear model without random effects. For WhittleMatern models, that is, if the list contains type = 'WhittleMatern', one can choose between a finite element approximation of the precision matrix by adding fem = TRUE to the list, or to use the exact precision matrix (by setting fem = FALSE). If fem is FALSE, there is also the parameter alpha, to determine the order of the SPDE, which is either 1 or 2. If fem is TRUE and alpha is not specified, then the default value of alpha=1 will be used. If fem is TRUE and one does not specify alpha, it will be estimated from the data. However, if one wants to have alpha fixed to some value, the user can specify either alpha or nu in the list. See the vignettes for examples. Finally, for type 'WhittleMatern', there is an optional argument, rspde_order, that chooses the order of the rational approximation. By default rspde_order is 2. Finally, if one wants to fit a nonstationary model, then fem necessarily needs to be TRUE, and one needs to also supply the matrices B.tau and B.kappa or B.range and B.sigma. For graph-Laplacian models, the list must also contain a parameter alpha (which is 1 by default). For isoCov models, the list must contain a parameter cov_function, containing the covariance function. The function accepts a string input for the following covariance functions: 'exp_covariance', 'WM1', 'WM2', 'GL1', 'GL2'. For another covariance function, the function itself must be provided as the cov_function argument. The default is 'exp_covariance', the exponential covariance. We also have covariance-based versions of the Whittle-Matern and graph Laplacian models, however they are much slower, they are the following (string) values for 'cov_function': 'alpha1' and 'alpha2' for Whittle-Matern fields, and 'GL1' and 'GL2' for graph Laplacian models. Finally, for Whittle-Matern models, there is an additional parameter version, which can be either 1 or 2, to tell which version of the likelihood

should be used. Version is 1 by default.

`which_repl` Vector or list containing which replicates to consider in the model. If `NULL` all replicates will be considered.

`optim_method` The method to be used with `optim` function.

`starting_values_latent`
A vector containing the starting values for the latent model. If the latent model is `WhittleMatern` or `graphLaplacian`, then the starting values should be provided as a vector of the form c(sigma,kappa) or c(sigma,range) depending on the parameterization. If the model is `isoCov`, then the starting values should be provided as a vector containing the parameters of the covariance function.

`start_sigma_e` Starting value for the standard deviation of the measurament error.

`BC` For `WhittleMatern` models, decides which boundary condition to use (0,1). Here, 0 is Neumann boundary conditions and 1 specifies stationary boundary conditions.

`parallel` logical. Indicating whether to use `optimParallel()` or not.

`n_cores` Number of cores to be used if parallel is true.

`optim_controls` Additional controls to be passed to `optim()` or `optimParallel()`.

`improve_hessian`
Should a more precise estimate of the hessian be obtained? Turning on might increase the overall time.

`hessian_args` List of controls to be used if `improve_hessian` is `TRUE`. The list can contain the arguments to be passed to the `method.args` argument in the `hessian` function. See the help of the `hessian` function in 'numDeriv' package for details. Observet that it only accepts the "Richardson" method for now, the method "complex" is not supported.

Value

A list containing the fitted model.

`graph_spde` *'INLA' implementation of Whittle-Matérn fields for metric graphs*

Description

This function creates an 'INLA' object that can be used in 'INLA' or 'inlabru' to fit Whittle-Matérn fields on metric graphs.

Usage

```
graph_spde(
  graph_object,
  alpha = 1,
  stationary_endpoints = "all",
```

```
  parameterization = c("matern", "spde"),
  start_range = NULL,
  prior_range = NULL,
  start_kappa = NULL,
  start_sigma = NULL,
  prior_kappa = NULL,
  prior_sigma = NULL,
  shared_lib = "detect",
  debug = FALSE
)
```

Arguments

graph_object	A metric_graph object.
alpha	The order of the SPDE.
stationary_endpoints	Which vertices of degree 1 should contain stationary boundary conditions?
parameterization	Which parameterization to be used? The options are 'matern' (sigma and range) and 'spde' (sigma and kappa).
start_range	Starting value for range parameter.
prior_range	a list containing the elements meanlog and sdlog, that is, the mean and standard deviation of the range parameter on the log scale. Will not be used if prior.kappa is non-null.
start_kappa	Starting value for kappa.
start_sigma	Starting value for sigma.
prior_kappa	a list containing the elements meanlog and sdlog, that is, the mean and standard deviation of kappa on the log scale.
prior_sigma	a list containing the elements meanlog and sdlog, that is, the mean and standard deviation of sigma on the log scale.
shared_lib	Which shared lib to use for the cgeneric implementation? If "detect", it will check if the shared lib exists locally, in which case it will use it. Otherwise it will use 'INLA's shared library. If 'INLA', it will use the shared lib from 'INLA's installation. If 'MetricGraph', then it will use the local installation (does not work if your installation is from CRAN). Otherwise, you can directly supply the path of the .so (or .dll) file.
debug	Should debug be displayed?

Details

This function is used to construct a Matern SPDE model on a metric graph. The latent field u is the solution of the SPDE

$$(\kappa^2 - \Delta)^\alpha u = \sigma W,$$

where W is Gaussian white noise on the metric graph. This model implements exactly the cases in which $\alpha = 1$ or $\alpha = 2$. For a finite element approximation for general α we refer the reader to the 'rSPDE' package and to the Whittle–Matérn fields with general smoothness vignette.

We also have the alternative parameterization $\rho = \frac{\sqrt{8(\alpha-0.5)}}{\kappa}$, which can be interpreted as a range parameter.

Let κ_0 and σ_0 be the starting values for κ and σ, we write $\sigma = \exp\{\theta_1\}$ and $\kappa = \exp\{\theta_2\}$. We assume priors on θ_1 and θ_2 to be normally distributed with mean, respectively, $\log(\sigma_0)$ and $\log(\kappa_0)$, and variance 10. Similarly, if we let ρ_0 be the starting value for ρ, then we write $\rho = \exp\{\theta_2\}$ and assume a normal prior for θ_2, with mean $\log(\rho_0)$ and variance 10.

Value

An 'INLA' object.

`graph_spde_basis` *Observation/prediction matrices for 'SPDE' models*

Description

Constructs observation/prediction weight matrices for metric graph models.

Usage

```
graph_spde_basis(graph_spde, repl = NULL, drop_na = FALSE, drop_all_na = TRUE)
```

Arguments

`graph_spde`	An `inla_metric_graph_spde` object built with the `graph_spde()` function.
`repl`	Which replicates? If there is no replicates, or to use all replicates, one can set to `NULL`.
`drop_na`	Should the rows with at least one NA for one of the columns be removed? DEFAULT is `FALSE`.
`drop_all_na`	Should the rows with all variables being NA be removed? DEFAULT is `TRUE`.

Value

The observation matrix.

graph_spde_make_A *Deprecated - Observation/prediction matrices for 'SPDE' models*

Description

Constructs observation/prediction weight matrices for metric graph models.

Usage

```
graph_spde_make_A(graph_spde, repl = NULL)
```

Arguments

graph_spde	An inla_metric_graph_spde object built with the graph_spde() function.
repl	Which replicates? If there is no replicates, or to use all replicates, one can set to NULL.

Value

The observation matrix.

graph_starting_values *Starting values for random field models on metric graphs*

Description

Computes appropriate starting values for optimization of Gaussian random field models on metric graphs.

Usage

```
graph_starting_values(
  graph,
  model = c("alpha1", "alpha2", "isoExp", "GL1", "GL2"),
  data = TRUE,
  data_name = NULL,
  range_par = FALSE,
  nu = FALSE,
  manual_data = NULL,
  like_format = FALSE,
  log_scale = FALSE
)
```

Arguments

graph	A metric_graph object.
model	Type of model, "alpha1", "alpha2", "isoExp", "GL1", and "GL2" are supported.
data	Should the data be used to obtain improved starting values?
data_name	The name of the response variable in graph$data.
range_par	Should an initial value for range parameter be returned instead of for kappa?
nu	Should an initial value for nu be returned?
manual_data	A vector (or matrix) of response variables.
like_format	Should the starting values be returned with sigma.e as the last element? This is the format for the likelihood constructor from the 'rSPDE' package.
log_scale	Should the initial values be returned in log scale?

Value

A vector, c(start_sigma_e, start_sigma, start_kappa)

---

logo_lines *Create lines for package name*

Description

Create lines for package name

Usage

```
logo_lines()
```

Value

SpatialLines object with package name.

---

make_Q_euler *Space-time precision operator Euler discretization*

Description

The precision matrix for all vertices for space-time field

Usage

```
make_Q_euler(graph, t, kappa, rho, gamma, alpha, beta, sigma, theta = 1)
```

Arguments

graph	A metric_graph object.
t	Vector of time points.
kappa	Spatial range parameter.
rho	Drift parameter.
gamma	Temporal range parameter.
alpha	Smoothness parameter (integer) for spatial operator.
beta	Smoothness parameter (integer) for Q-Wiener process.
sigma	Variance parameter.
theta	Parameter theta for the Euler scheme.

Value

Precision matrix.

---

make_Q_spacetime *Space-time precision operator discretization*

Description

The precision matrix for all vertices for space-time field.

Usage

```
make_Q_spacetime(graph, t, kappa, rho, gamma, alpha, beta, sigma)
```

Arguments

graph	A metric_graph object.
t	Vector of time points.
kappa	Spatial range parameter.
rho	Drift parameter.
gamma	Temporal range parameter.
alpha	Smoothness parameter (integer) for spatial operator.
beta	Smoothness parameter (integer) for Q-Wiener process.
sigma	Variance parameter.

Value

Precision matrix.

MetricGraph *Gaussian processes on metric graphs*

Description

'MetricGraph' is used for creation and manipulation of metric graphs, such as street or river networks. It also has several functions thatfacilitates operations and visualizations of data on metric graphs, and the creation of a large class of random fields and stochastic partial differential equations on such spaces. The main models are the Whittle-Matérn fields, which are specified through the fractional elliptic SPDE

$$(\kappa^2 - \Delta)^{\alpha/2}(\tau u(s)) = W,$$

$\kappa, \tau > 0$ and $\alpha > 1/2$ are parameters and W is Gaussian white noise. It contains exact implementations of the above model for $\alpha = 1$ and $\alpha = 2$, and contains approximate implementations, via the finite element method, for any $\alpha > 0.5$. It also implements models based on graph Laplacians and isotropic covariance functions. Several utility functions for specifying graphs, computing likelihoods, performing prediction, simulating processes, and visualizing results on metric graphs are provided. In particular, linear mixed effects models including random field components can be fitted to data based on computationally efficient sparse matrix representations. Interfaces to the R packages 'INLA' and 'inlabru' are also provided, which facilitate working with Bayesian statistical models on metric graphs.

Details

At the heart of the package is the `R6` class `[metric_graph()]`. This is used for specifying metric graphs, and contains various utility functions which are needed for specifying Gaussian processes on such spaces.

Linear mixed effects models are provided (see `[graph_lme]`) and perform predictions (see `[predict.graph_lme]`). The package also has interfaces for 'INLA' (see `[graph_spde]`), and it this interface also works with 'inlabru'.

For a more detailed introduction to the package, see the 'MetricGraph' Vignettes.

metric_graph *Metric graph*

Description

Class representing a general metric graph.

Details

A graph object created from vertex and edge matrices, or from an `sp::SpatialLines` object where each line is representing and edge. For more details, see the vignette: `vignette("metric_graph", package = "MetricGraph")`

Value

Object of R6Class for creating metric graphs.

Public fields

`V` Matrix with positions in Euclidean space of the vertices of the graph.

`nV` The number of vertices.

`E` Matrix with the edges of the graph, where each row represents an edge, `E[i,1]` is the vertex at the start of the ith edge and `E[i,2]` is the vertex at the end of the edge.

`nE` The number of edges.

`edge_lengths` Vector with the lengths of the edges in the graph.

`C` Constraint matrix used to set Kirchhoff constraints.

`CoB` Change-of-basis object used for Kirchhoff constraints.

`PtV` Vector with the indices of the vertices which are observation locations.

`mesh` Mesh object used for plotting.

`edges` The coordinates of the edges in the graph.

`vertices` The coordinates of the vertices in the graph, along with several attributes.

`geo_dist` Geodesic distances between the vertices in the graph.

`res_dist` Resistance distances between the observation locations.

`Laplacian` The weighted graph Laplacian of the vertices in the graph. The weights are given by the edge lengths.

`characteristics` List with various characteristics of the graph.

Methods

Public methods:

- `metric_graph$new()`
- `metric_graph$set_edge_weights()`
- `metric_graph$get_edge_weights()`
- `metric_graph$get_vertices_incomp_dir()`
- `metric_graph$summary()`
- `metric_graph$print()`
- `metric_graph$compute_characteristics()`
- `metric_graph$check_euclidean()`
- `metric_graph$check_distance_consistency()`
- `metric_graph$compute_geodist()`
- `metric_graph$compute_geodist_PtE()`
- `metric_graph$compute_geodist_mesh()`
- `metric_graph$compute_resdist()`
- `metric_graph$compute_resdist_PtE()`
- `metric_graph$get_degrees()`

- metric_graph$compute_PtE_edges()
- metric_graph$compute_resdist_mesh()
- metric_graph$compute_laplacian()
- metric_graph$prune_vertices()
- metric_graph$get_groups()
- metric_graph$get_PtE()
- metric_graph$get_edge_lengths()
- metric_graph$get_locations()
- metric_graph$observation_to_vertex()
- metric_graph$get_mesh_locations()
- metric_graph$clear_observations()
- metric_graph$process_data()
- metric_graph$add_observations()
- metric_graph$mutate()
- metric_graph$drop_na()
- metric_graph$select()
- metric_graph$filter()
- metric_graph$summarise()
- metric_graph$get_data()
- metric_graph$buildC()
- metric_graph$build_mesh()
- metric_graph$compute_fem()
- metric_graph$mesh_A()
- metric_graph$fem_basis()
- metric_graph$VtEfirst()
- metric_graph$plot()
- metric_graph$plot_connections()
- metric_graph$is_tree()
- metric_graph$plot_function()
- metric_graph$plot_movie()
- metric_graph$add_mesh_observations()
- metric_graph$get_initial_graph()
- metric_graph$coordinates()
- metric_graph$clone()

Method `new()`**:** Create a new `metric_graph` object.

Usage:

```
metric_graph$new(
  edges = NULL,
  V = NULL,
  E = NULL,
  vertex_unit = NULL,
  length_unit = vertex_unit,
```

```
  edge_weights = 1,
  longlat = FALSE,
  crs = NULL,
  proj4string = NULL,
  which_longlat = "sp",
  project = TRUE,
  project_data = FALSE,
  which_projection = "Winkel tripel",
  tolerance = list(vertex_vertex = 1e-07, vertex_edge = 1e-07, edge_edge = 0),
  check_connected = TRUE,
  remove_deg2 = FALSE,
  merge_close_vertices = TRUE,
  factor_merge_close_vertices = 1,
  remove_circles = TRUE,
  verbose = FALSE,
  lines = deprecated()
)
```

Arguments:

`edges` A list containing coordinates as `m x 2` matrices (that is, of `matrix` type) or m x 2 data frames (`data.frame` type) of sequence of points connected by straightlines. Alternatively, you can also prove an object of type `SpatialLinesDataFrame` or `SpatialLines` (from `sp` package) or `MULTILINESTRING` (from `sf` package).

`V` n x 2 matrix with Euclidean coordinates of the n vertices.

`E` m x 2 matrix where each row represents one of the m edges.

`vertex_unit` The unit in which the vertices are specified. The options are 'degrees' (the great circle distance in km), 'km', 'm' and 'miles'. The default is `NULL`, which means no unit. However, if you set `length_unit`, you need to set `vertex_unit`.

`length_unit` The unit in which the lengths will be computed. The options are 'km', 'm' and 'miles'. The default is `vertex_unit`. Observe that if `vertex_unit` is `NULL`, `length_unit` can only be `NULL`. If `vertex_unit` is 'degrees', then the default value for `length_unit` is 'km'.

`edge_weights` Either a number, a numerical vector with length given by the number of edges, providing the edge weights, or a `data.frame` with the number of rows being equal to the number of edges, where each row gives a vector of weights to its corresponding edge. Can be changed by using the `set_edge_weights()` method.

`longlat` If `TRUE`, then it is assumed that the coordinates are given. in Longitude/Latitude and that distances should be computed in meters. If `TRUE` it takes precedence over `vertex_unit` and `length_unit`, and is equivalent to `vertex_unit = 'degrees'` and `length_unit = 'm'`.

`crs` Coordinate reference system to be used in case `longlat` is set to `TRUE` and `which_longlat` is `sf`. Object of class crs. The default is `sf::st_crs(4326)`.

`proj4string` Projection string of class CRS-class to be used in case `longlat` is set to `TRUE` and `which_longlat` is `sp`. The default is `sp::CRS("+proj=longlat +datum=WGS84")`.

`which_longlat` Compute the distance using which package? The options are `sp` and `sf`. The default is `sp`.

`project` If `longlat` is `TRUE` should a projection be used to compute the distances to be used for the tolerances (see `tolerance` below)? The default is `TRUE`. When `TRUE`, the construction

of the graph is faster.

`project_data` If `longlat` is `TRUE` should the vertices be project to planar coordinates? The default is `FALSE`. When `TRUE`, the construction of the graph is faster.

`which_projection` Which projection should be used in case `project` is `TRUE`? The options are `Robinson`, `Winkel tripel` or a proj4string. The default is `Winkel tripel`.

`tolerance` List that provides tolerances during the construction of the graph:

- `vertex_vertex` Vertices that are closer than this number are merged (default = 1e-7).
- `vertex_edge` If a vertex at the end of one edge is closer than this number to another edge, this vertex is connected to that edge (default = 1e-7). Previously `vertex_line`, which is now deprecated.
- `edge_edge` If two edges at some point are closer than this number, a new vertex is added at that point and the two edges are connected (default = 0).
- `vertex_line`, Deprecated. Use `vertex_edge` instead.
- `line_line`, Deprecated. Use `edge_edge` instead.

In case `longlat = TRUE`, the tolerances are given in `length_unit`.

`check_connected` If `TRUE`, it is checked whether the graph is connected and a warning is given if this is not the case.

`remove_deg2` Set to `TRUE` to remove all vertices of degree 2 in the initialization. Default is `FALSE`.

`merge_close_vertices` should an additional step to merge close vertices be done?

`factor_merge_close_vertices` Which factor to be multiplied by tolerance `vertex_vertex` when merging close vertices at the additional step?

`remove_circles` All circlular edges with a length smaller than this number are removed. If `TRUE`, the `vertex_vertex` tolerance will be used. If `FALSE`, no circles will be removed.

`verbose` Print progress of graph creation.

`lines` **[Deprecated]** Use `edges` instead.

Details: A graph object can be initialized in two ways. The first method is to specify V and E. In this case, all edges are assumed to be straight lines. The second option is to specify the graph via the `lines` input. In this case, the vertices are set by the end points of the lines. Thus, if two lines are intersecting somewhere else, this will not be viewed as a vertex.

Returns: A `metric_graph` object.

Method `set_edge_weights()`**:** Sets the edge weights

Usage:

```
metric_graph$set_edge_weights(weights = rep(1, self$nE))
```

Arguments:

`weights` Either a number, a numerical vector with length given by the number of edges, providing the edge weights, or a `data.frame` with the number of rows being equal to the number of edges, where each row gives a vector of weights to its corresponding edge.

Returns: No return value. Called for its side effects.

Method `get_edge_weights()`**:** Gets the edge weights

Usage:

```
metric_graph$get_edge_weights()
```

Returns: A vector containing the edge weights.

Method `get_vertices_incomp_dir()`**:** Gets vertices with incompatible directions

Usage:

```
metric_graph$get_vertices_incomp_dir()
```

Returns: A vector containing the vertices with incompatible directions.

Method `summary()`**:** Prints a summary of various informations of the graph

Usage:

```
metric_graph$summary(
  messages = FALSE,
  compute_characteristics = TRUE,
  check_euclidean = TRUE,
  check_distance_consistency = TRUE
)
```

Arguments:

`messages` Should message explaining how to build the results be given for missing quantities?

`compute_characteristics` Should the characteristics of the graph be computed?

`check_euclidean` Check if the graph has Euclidean edges?

`check_distance_consistency` Check the distance consistency assumption?

Returns: No return value. Called for its side effects.

Method `print()`**:** Prints various characteristics of the graph

Usage:

```
metric_graph$print()
```

Returns: No return value. Called for its side effects.

Method `compute_characteristics()`**:** Computes various characteristics of the graph

Usage:

```
metric_graph$compute_characteristics(check_euclidean = FALSE)
```

Arguments:

`check_euclidean` Also check if the graph has Euclidean edges? This essentially means that the distance consistency check will also be perfomed. If the graph does not have Euclidean edges due to another reason rather than the distance consistency, then it will already be indicated that the graph does not have Euclidean edges.

Returns: No return value. Called for its side effects. The computed characteristics are stored in the `characteristics` element of the `metric_graph` object.

Method `check_euclidean()`**:** Check if the graph has Euclidean edges.

Usage:

```
metric_graph$check_euclidean()
```

Returns: Returns `TRUE` if the graph has Euclidean edges, or `FALSE` otherwise. The result is stored in the `characteristics` element of the `metric_graph` object. The result is displayed when the graph is printed.

Method `check_distance_consistency()`**:** Checks distance consistency of the graph.

Usage:

```
metric_graph$check_distance_consistency()
```

Returns: No return value. The result is stored in the `characteristics` element of the `metric_graph` object. The result is displayed when the graph is printed.

Method `compute_geodist()`**:** Computes shortest path distances between the vertices in the graph

Usage:

```
metric_graph$compute_geodist(full = FALSE, obs = TRUE, group = NULL)
```

Arguments:

`full` Should the geodesic distances be computed for all the available locations? If `FALSE`, it will be computed separately for the locations of each group.

`obs` Should the geodesic distances be computed at the observation locations?

`group` Vector or list containing which groups to compute the distance for. If `NULL`, it will be computed for all groups.

Returns: No return value. Called for its side effects. The computed geodesic distances are stored in the `geo_dist` element of the `metric_graph` object.

Method `compute_geodist_PtE()`**:** Computes shortest path distances between the vertices in the graph.

Usage:

```
metric_graph$compute_geodist_PtE(
  PtE,
  normalized = TRUE,
  include_vertices = TRUE
)
```

Arguments:

`PtE` Points to compute the metric for.

`normalized` are the locations in PtE in normalized distance?

`include_vertices` Should the original vertices be included in the distance matrix?

Returns: A matrix containing the geodesic distances.

Method `compute_geodist_mesh()`**:** Computes shortest path distances between the vertices in the mesh.

Usage:

```
metric_graph$compute_geodist_mesh()
```

Returns: No return value. Called for its side effects. The geodesic distances on the mesh are stored in `mesh$geo_dist` in the `metric_graph` object.

Method `compute_resdist()`**:** Computes the resistance distance between the observation locations.

Usage:

```
metric_graph$compute_resdist(full = FALSE, obs = TRUE, group = NULL)
```

Arguments:

`full` Should the resistance distances be computed for all the available locations. If `FALSE`, it will be computed separately for the locations of each group.

`obs` Should the resistance distances be computed at the observation locations?

`group` Vector or list containing which groups to compute the distance for. If `NULL`, it will be computed for all groups.

Returns: No return value. Called for its side effects. The geodesic distances are stored in the `res_dist` element of the `metric_graph` object.

Method `compute_resdist_PtE()`**:** Computes the resistance distance between the observation locations.

Usage:

```
metric_graph$compute_resdist_PtE(
  PtE,
  normalized = TRUE,
  include_vertices = FALSE
)
```

Arguments:

`PtE` Points to compute the metric for.

`normalized` Are the locations in PtE in normalized distance?

`include_vertices` Should the original vertices be included in the Laplacian matrix?

Returns: A matrix containing the resistance distances.

Method `get_degrees()`**:** Returns the degrees of the vertices in the metric graph.

Usage:

```
metric_graph$get_degrees(which = "degree")
```

Arguments:

`which` If "degree", returns the degree of the vertex. If "indegree", returns the indegree, and if "outdegree", it returns the outdegree.

Returns: A vector containing the degrees of the vertices.

Method `compute_PtE_edges()`**:** Computes the relative positions of the coordinates of the edges and save it as an attribute to each edge. This improves the quality of plots obtained by the `plot_function()` method, however it might be costly to compute.

Usage:

```
metric_graph$compute_PtE_edges()
```

Returns: No return value, called for its side effects.

Method `compute_resdist_mesh()`**:** Computes the resistance metric between the vertices in the mesh.

Usage:

```
metric_graph$compute_resdist_mesh()
```

Returns: No return value. Called for its side effects. The geodesic distances on the mesh are stored in the `mesh$res_dist` element in the `metric_graph` object.

Method `compute_laplacian()`**:** Computes the weigthed graph Laplacian for the graph.

Usage:

```
metric_graph$compute_laplacian(full = FALSE, obs = TRUE, group = NULL)
```

Arguments:

`full` Should the resistance distances be computed for all the available locations. If `FALSE`, it will be computed separately for the locations of each group.

`obs` Should the resistance distances be computed at the observation locations? It will only compute for locations in which there is at least one observations that is not NA.

`group` Vector or list containing which groups to compute the Laplacian for. If `NULL`, it will be computed for all groups.

Returns: No reutrn value. Called for its side effects. The Laplacian is stored in the `Laplacian` element in the `metric_graph` object.

Method `prune_vertices()`**:** Removes vertices of degree 2 from the metric graph.

Usage:

```
metric_graph$prune_vertices(verbose = FALSE)
```

Arguments:

`verbose` Show progress? Default is `FALSE`.

Details: Vertices of degree 2 are removed as long as the corresponding edges that would be merged are compatible in terms of direction.

Returns: No return value. Called for its side effects.

Method `get_groups()`**:** Gets the groups from the data.

Usage:

```
metric_graph$get_groups(get_cols = FALSE)
```

Arguments:

`get_cols` Should the names of the columns that created the group variable be returned?

Returns: A vector containing the available groups in the internal data.

Method `get_PtE()`**:** Gets PtE from the data.

Usage:

```
metric_graph$get_PtE()
```

Arguments:

`group` For which group, should the PtE be returned? `NULL` means that all PtEs available will be returned.

`include_group` Should the group be included as a column? If `TRUE`, the PtEs for each group will be concatenated, otherwise a single matrix containing the unique PtEs will be returned.

Returns: A matrix with two columns, where the first column contains the edge number and the second column contains the distance on edge of the observation locations.

Method `get_edge_lengths()`**:** Gets the edge lengths with the corresponding unit.

Usage:

```
metric_graph$get_edge_lengths(unit = NULL)
```

Arguments:

`unit` If non-NULL, changes from `length_unit` from the graph construction to `unit`.

Returns: a vector with the length unit (if the graph was constructed with a length unit).

Method `get_locations()`**:** Gets the spatial locations from the data.

Usage:

```
metric_graph$get_locations()
```

Returns: A `data.frame` object with observation locations. If `longlat = TRUE`, the column names are lon and lat, otherwise the column names are x and y.

Method `observation_to_vertex()`**:** Adds observation locations as vertices in the graph.

Usage:

```
metric_graph$observation_to_vertex(tolerance = 1e-15, mesh_warning = TRUE)
```

Arguments:

`tolerance` Observations locations are merged to a single vertex if they are closer than this number (given in relative edge distance between 0 and 1). The default is `1e-15`.

`mesh_warning` Display a warning if the graph structure change and the metric graph has a mesh object.

`share_weights` Should the same weight be shared among the split edges? If `FALSE`, the weights will be removed, and a common weight given by 1 will be given.

Returns: No return value. Called for its side effects.

Method `get_mesh_locations()`**:** Returns a list or a matrix with the mesh locations.

Usage:

```
metric_graph$get_mesh_locations(bru = FALSE, loc = NULL, normalized = TRUE)
```

Arguments:

`bru` Should an 'inlabru'-friendly list be returned?

`loc` If `bru` is set to `TRUE`, the name of the location variable. The default name is 'loc'.

`normalized` If TRUE, then the distances in `distance_on_edge` are assumed to be normalized to (0,1). Default TRUE.

Returns: A list or a matrix containing the mesh locations.

Method `clear_observations()`**:** Clear all observations from the `metric_graph` object.

Usage:

```
metric_graph$clear_observations()
```

Returns: No return value. Called for its side effects.

Method `process_data()`**:** Process data to the metric graph data format.

Usage:

```
metric_graph$process_data(
  Spoints = NULL,
  data = NULL,
  edge_number = "edge_number",
  distance_on_edge = "distance_on_edge",
  coord_x = "coord_x",
  coord_y = "coord_y",
  data_coords = c("PtE", "spatial"),
  group = NULL,
  group_sep = ".",
  normalized = FALSE,
  tibble = TRUE,
  tolerance = max(self$edge_lengths)/2,
  verbose = FALSE
)
```

Arguments:

`Spoints` `SpatialPoints` or `SpatialPointsDataFrame` containing the observations. It may include the coordinates of the observations only, or the coordinates as well as the observations.

`data` A `data.frame` or named list containing the observations. In case of groups, the data.frames for the groups should be stacked vertically, with a column indicating the index of the group. If `data` is not `NULL`, it takes priority over any eventual data in `Spoints`.

`edge_number` Column (or entry on the list) of the `data` that contains the edge numbers. If not supplied, the column with name "edge_number" will be chosen. Will not be used if `Spoints` is not `NULL`.

`distance_on_edge` Column (or entry on the list) of the `data` that contains the edge numbers. If not supplied, the column with name "distance_on_edge" will be chosen. Will not be used if `Spoints` is not `NULL`.

`coord_x` Column (or entry on the list) of the `data` that contains the x coordinate. If not supplied, the column with name "coord_x" will be chosen. Will not be used if `Spoints` is not `NULL` or if `data_coords` is `PtE`.

`coord_y` Column (or entry on the list) of the `data` that contains the y coordinate. If not supplied, the column with name "coord_x" will be chosen. Will not be used if `Spoints` is not `NULL` or if `data_coords` is `PtE`.

`data_coords` To be used only if `Spoints` is `NULL`. It decides which coordinate system to use. If `PtE`, the user must provide `edge_number` and `distance_on_edge`, otherwise if `spatial`, the user must provide `coord_x` and `coord_y`. The option `euclidean` is **[Deprecated]**. Use `spatial` instead.

`group` Vector. If the data is grouped (for example measured at different time points), this argument specifies the columns (or entries on the list) in which the group variables are stored. It will be stored as a single column `.group` with the combined entries.

`group_sep` separator character for creating the new group variable when grouping two or more variables.

`normalized` if TRUE, then the distances in `distance_on_edge` are assumed to be normalized to (0,1). Default FALSE. Will not be used if `Spoints` is not `NULL`.

`tibble` Should the data be returned as a `tidyr::tibble`?

`tolerance` Parameter to control a warning when adding observations. If the distance of some location and the closest point on the graph is greater than the tolerance, the function will display a warning. This helps detecting mistakes on the input locations when adding new data.

`verbose` If `TRUE`, report steps and times.

Returns: No return value. Called for its side effects. The observations are stored in the `data` element of the `metric_graph` object.

Method `add_observations()`**:** Add observations to the metric graph.

Usage:

```
metric_graph$add_observations(
  Spoints = NULL,
  data = NULL,
  edge_number = "edge_number",
  distance_on_edge = "distance_on_edge",
  coord_x = "coord_x",
  coord_y = "coord_y",
  data_coords = c("PtE", "spatial"),
  group = NULL,
  group_sep = ".",
  normalized = FALSE,
  clear_obs = FALSE,
  tibble = FALSE,
  tolerance = max(self$edge_lengths)/2,
  verbose = FALSE
)
```

Arguments:

`Spoints` `SpatialPoints` or `SpatialPointsDataFrame` containing the observations. It may include the coordinates of the observations only, or the coordinates as well as the observations.

`data` A `data.frame` or named list containing the observations. In case of groups, the data.frames for the groups should be stacked vertically, with a column indicating the index of the group. If `data` is not `NULL`, it takes priority over any eventual data in `Spoints`.

`edge_number` Column (or entry on the list) of the `data` that contains the edge numbers. If not supplied, the column with name "edge_number" will be chosen. Will not be used if `Spoints` is not `NULL`.

`distance_on_edge` Column (or entry on the list) of the `data` that contains the edge numbers. If not supplied, the column with name "distance_on_edge" will be chosen. Will not be used if `Spoints` is not `NULL`.

`coord_x` Column (or entry on the list) of the `data` that contains the x coordinate. If not supplied, the column with name "coord_x" will be chosen. Will not be used if `Spoints` is not `NULL` or if `data_coords` is `PtE`.

`coord_y` Column (or entry on the list) of the `data` that contains the y coordinate. If not supplied, the column with name "coord_x" will be chosen. Will not be used if `Spoints` is not `NULL` or if `data_coords` is `PtE`.

`data_coords` To be used only if `Spoints` is `NULL`. It decides which coordinate system to use. If `PtE`, the user must provide `edge_number` and `distance_on_edge`, otherwise if `spatial`,

the user must provide coord_x and coord_y. The option euclidean is **[Deprecated]**. Use spatial instead.

group Vector. If the data is grouped (for example measured at different time points), this argument specifies the columns (or entries on the list) in which the group variables are stored. It will be stored as a single column .group with the combined entries.

group_sep separator character for creating the new group variable when grouping two or more variables.

normalized if TRUE, then the distances in distance_on_edge are assumed to be normalized to (0,1). Default FALSE. Will not be used if Spoints is not NULL.

clear_obs Should the existing observations be removed before adding the data?

tibble Should the data be returned as a tidyr::tibble?

tolerance Parameter to control a warning when adding observations. If the distance of some location and the closest point on the graph is greater than the tolerance, the function will display a warning. This helps detecting mistakes on the input locations when adding new data.

verbose If TRUE, report steps and times.

Returns: No return value. Called for its side effects. The observations are stored in the data element of the metric_graph object.

Method `mutate()`**:** Use dplyr::mutate function on the internal metric graph data object.

Usage:

```
metric_graph$mutate(..., .drop_na = FALSE, .drop_all_na = TRUE)
```

Arguments:

... Arguments to be passed to dplyr::mutate().

.drop_na Should the rows with at least one NA for one of the columns be removed? DEFAULT is FALSE.

.drop_all_na Should the rows with all variables being NA be removed? DEFAULT is TRUE.

Details: A wrapper to use dplyr::mutate() within the internal metric graph data object.

Returns: A tidyr::tibble object containing the resulting data list after the mutate.

Method `drop_na()`**:** Use tidyr::drop_na() function on the internal metric graph data object.

Usage:

```
metric_graph$drop_na(...)
```

Arguments:

... Arguments to be passed to tidyr::drop_na().

Details: A wrapper to use dplyr::drop_na() within the internal metric graph data object.

Returns: A tidyr::tibble object containing the resulting data list after the drop_na.

Method `select()`**:** Use dplyr::select function on the internal metric graph data object.

Usage:

```
metric_graph$select(..., .drop_na = FALSE, .drop_all_na = TRUE)
```

Arguments:

... Arguments to be passed to dplyr::select().

.drop_na Should the rows with at least one NA for one of the columns be removed? DEFAULT is FALSE.

.drop_all_na Should the rows with all variables being NA be removed? DEFAULT is TRUE.

Details: A wrapper to use dplyr::select() within the internal metric graph data object. Observe that it is a bit different from directly using dplyr::select() since it does not allow to remove the internal positions that are needed for the metric_graph methods to work.

Returns: A tidyr::tibble object containing the resulting data list after the selection.

Method filter()**:** Use dplyr::filter function on the internal metric graph data object.

Usage:

```
metric_graph$filter(..., .drop_na = FALSE, .drop_all_na = TRUE)
```

Arguments:

... Arguments to be passed to dplyr::filter().

.drop_na Should the rows with at least one NA for one of the columns be removed? DEFAULT is FALSE.

.drop_all_na Should the rows with all variables being NA be removed? DEFAULT is TRUE.

Details: A wrapper to use dplyr::filter() within the internal metric graph data object.

Returns: A tidyr::tibble object containing the resulting data list after the filter.

Method summarise()**:** Use dplyr::summarise function on the internal metric graph data object grouped by the spatial locations and the internal group variable.

Usage:

```
metric_graph$summarise(
  ...,
  .include_graph_groups = FALSE,
  .groups = NULL,
  .drop_na = FALSE,
  .drop_all_na = TRUE
)
```

Arguments:

... Arguments to be passed to dplyr::summarise().

.include_graph_groups Should the internal graph groups be included in the grouping variables? The default is FALSE. This means that, when summarising, the data will be grouped by the internal group variable together with the spatial locations.

.groups A vector of strings containing the names of the columns to be additionally grouped, when computing the summaries. The default is NULL.

.drop_na Should the rows with at least one NA for one of the columns be removed? DEFAULT is FALSE.

.drop_all_na Should the rows with all variables being NA be removed? DEFAULT is TRUE.

Details: A wrapper to use dplyr::summarise() within the internal metric graph data object grouped by manually inserted groups (optional), the internal group variable (optional) and the spatial locations. Observe that if the integral group variable was not used as a grouping variable for the summarise, a new column, called .group, will be added, with the same value 1 for all rows.

Returns: A `tidyr::tibble` object containing the resulting data list after the summarise.

Method `get_data()`**:** Return the internal data with the option to filter by groups.

Usage:

```
metric_graph$get_data(
  group = NULL,
  tibble = TRUE,
  drop_na = FALSE,
  drop_all_na = TRUE
)
```

Arguments:

`group` A vector contaning which groups should be returned? The default is `NULL`, which gives the result for the all groups.

`tibble` Should the data be returned as a `tidyr::tibble`?

`drop_na` Should the rows with at least one NA for one of the columns be removed? DEFAULT is `FALSE`.

`drop_all_na` Should the rows with all variables being NA be removed? DEFAULT is `TRUE`.

Method `buildC()`**:** Build Kirchoff constraint matrix from edges.

Usage:

```
metric_graph$buildC(alpha = 2, edge_constraint = FALSE)
```

Arguments:

`alpha` the type of constraint (currently only supports 2)

`edge_constraint` if TRUE, add constraints on vertices of degree 1

Details: Currently not implemented for circles (edges that start and end in the same vertex)

Returns: No return value. Called for its side effects.

Method `build_mesh()`**:** Builds mesh object for graph.

Usage:

```
metric_graph$build_mesh(
  h = NULL,
  n = NULL,
  continuous = TRUE,
  continuous.outs = FALSE,
  continuous.deg2 = FALSE
)
```

Arguments:

`h` Maximum distance between mesh nodes (should be provided if n is not provided).

`n` Maximum number of nodes per edge (should be provided if h is not provided).

`continuous` If `TRUE` (default), the mesh contains only one node per vertex. If `FALSE`, each vertex v is split into deg(v) disconnected nodes to allow for the creation of discontinuities at the vertices.

`continuous.outs` If `continuous` = `FALSE` and `continuous.outs` = `TRUE`, continuity is assumed for the outgoing edges from each vertex.

`continuous.deg2` If `TRUE`, continuity is assumed at degree 2 vertices.

Details: The mesh is a list with the objects:

- `PtE` The mesh locations excluding the original vertices;
- `V` The verties of the mesh;
- `E` The edges of the mesh;
- `n_e` The number of vertices in the mesh per original edge in the graph;
- `h_e` The mesh width per edge in the graph;
- `ind` The indices of the vertices in the mesh;
- `VtE` All mesh locations including the original vertices.

Returns: No return value. Called for its side effects. The mesh is stored in the `mesh` element of the `metric_graph` object.

Method `compute_fem()`**:** Build mass and stiffness matrices for given mesh object.

Usage:

```
metric_graph$compute_fem(petrov = FALSE)
```

Arguments:

`petrov` Compute Petrov-Galerkin matrices? (default `FALSE`). These are defined as $Cpet_{ij} =< \phi_i, \psi_j >$ and $Gpet_{ij} =< d\phi_i, \psi_j >$, where ψ_i are piecewise constant basis functions on the edges of the mesh.

Details: The function builds: The matrix `C` which is the mass matrix with elements $C_{ij} =< \phi_i, \phi_j >$, the matrix `G` which is the stiffness matrix with elements $G_{ij} =< d\phi_i, d\phi_j >$, the matrix `B` with elements $B_{ij} =< d\phi_i, \phi_j >$, the matrix `D` with elements $D_{ij} = \sum_{v \in V} \phi_i(v)\phi_j(v)$, and the vector with weights $< \phi_i, 1 >$.

Returns: No return value. Called for its side effects. The finite element matrices `C`, `G` and `B` are stored in the `mesh` element in the `metric_graph` object. If `petrov=TRUE`, the corresponding Petrov-Galerkin matrices are stored in `Cpet` and `Gpet`.

Method `mesh_A()`**:** Deprecated - Computes observation matrix for mesh.

[Deprecated] in favour of `metric_graph$fem_basis()`.

Usage:

```
metric_graph$mesh_A(PtE)
```

Arguments:

`PtE` Locations given as (edge number in graph, normalized location on edge)

Details: For n locations and a mesh with m nodes, `A` is an n x m matrix with elements $A_{ij} = \phi_j(s_i)$.

Returns: The observation matrix.

Method `fem_basis()`**:** Computes observation matrix for mesh.

Usage:

```
metric_graph$fem_basis(PtE)
```

Arguments:

`PtE` Locations given as (edge number in graph, normalized location on edge)

Details: For n locations and a mesh with m nodes, `A` is an n x m matrix with elements $A_{ij} = \phi_j(s_i)$.

Returns: The observation matrix.

Method `VtEfirst()`**:** Find one edge corresponding to each vertex.

Usage:

```
metric_graph$VtEfirst()
```

Returns: A nV x 2 matrix the first element of the `i`th row is the edge number corresponding to the `i`th vertex and the second value is 0 if the vertex is at the start of the edge and 1 if the vertex is at the end of the edge.

Method `plot()`**:** Plots the metric graph.

Usage:

```
metric_graph$plot(
  data = NULL,
  newdata = NULL,
  group = 1,
  plotly = FALSE,
  vertex_size = 3,
  vertex_color = "black",
  edge_width = 0.3,
  edge_color = "black",
  data_size = 1,
  support_width = 0.5,
  support_color = "gray",
  mesh = FALSE,
  X = NULL,
  X_loc = NULL,
  p = NULL,
  degree = FALSE,
  direction = FALSE,
  ...
)
```

Arguments:

`data` Which column of the data to plot? If `NULL`, no data will be plotted.

`newdata` A dataset of class `metric_graph_data`, obtained by any `get_data()`, `mutate()`, `filter()`, `summarise()`, `drop_na()` methods of metric graphs, see the vignette on data manipulation for more details.

`group` If there are groups, which group to plot? If `group` is a number, it will be the index of the group as stored internally. If `group` is a character, then the group will be chosen by its name.

`plotly` Use plot_ly for 3D plot (default `FALSE`). This option requires the 'plotly' package.

`vertex_size` Size of the vertices.

`vertex_color` Color of vertices.

`edge_width` Line width for edges.

`edge_color` Color of edges.

data_size Size of markers for data.

support_width For 3D plot, width of support lines.

support_color For 3D plot, color of support lines.

mesh Plot the mesh locations?

X Additional values to plot.

X_loc Locations of the additional values in the format (edge, normalized distance on edge).

p Existing objects obtained from 'ggplot2' or 'plotly' to add the graph to

degree Show the degrees of the vertices?

direction Show the direction of the edges?

... Additional arguments to pass to ggplot() or plot_ly()

Returns: A plot_ly (if plotly = TRUE) or ggplot object.

Method plot_connections(): Plots the connections in the graph

Usage:

```
metric_graph$plot_connections()
```

Returns: No return value. Called for its side effects.

Method is_tree(): Checks if the graph is a tree (without considering directions)

Usage:

```
metric_graph$is_tree()
```

Returns: TRUE if the graph is a tree and FALSE otherwise.

Method plot_function(): Plots continuous function on the graph.

Usage:

```
metric_graph$plot_function(
  data = NULL,
  newdata = NULL,
  group = 1,
  X = NULL,
  plotly = FALSE,
  improve_plot = FALSE,
  continuous = TRUE,
  vertex_size = 5,
  vertex_color = "black",
  edge_width = 1,
  edge_color = "black",
  line_width = NULL,
  line_color = "rgb(0,0,200)",
  support_width = 0.5,
  support_color = "gray",
  p = NULL,
  ...
)
```

Arguments:

data Which column of the data to plot? If NULL, no data will be plotted.

newdata A dataset of class metric_graph_data, obtained by any get_data(), mutate(), filter(), summarise(), drop_na() methods of metric graphs, see the vignette on data manipulation for more details.

group If there are groups, which group to plot? If group is a number, it will be the index of the group as stored internally. If group is a character, then the group will be chosen by its name.

X A vector with values for the function evaluated at the mesh in the graph

plotly If TRUE, then the plot is shown in 3D. This option requires the package 'plotly'.

improve_plot Should the original edge coordinates be added to the data with linearly interpolated values to improve the plot?

continuous Should continuity be assumed when the plot uses newdata?

vertex_size Size of the vertices.

vertex_color Color of vertices.

edge_width Width for edges.

edge_color For 3D plot, color of edges.

line_width For 3D plot, line width of the function curve.

line_color Color of the function curve.

support_width For 3D plot, width of support lines.

support_color For 3D plot, color of support lines.

p Previous plot to which the new plot should be added.

... Additional arguments for ggplot() or plot_ly()

Returns: Either a ggplot (if plotly = FALSE) or a plot_ly object.

Method plot_movie()**:** Plots a movie of a continuous function evolving on the graph.

Usage:

```
metric_graph$plot_movie(
  X,
  plotly = TRUE,
  vertex_size = 5,
  vertex_color = "black",
  edge_width = 1,
  edge_color = "black",
  line_width = NULL,
  line_color = "rgb(0,0,200)",
  ...
)
```

Arguments:

X A m x T matrix where the ith column represents the function at the ith time, evaluated at the mesh locations.

plotly If TRUE, then plot is shown in 3D. This option requires the package 'plotly'.

vertex_size Size of the vertices.

vertex_color Color of vertices.

edge_width Width for edges.

edge_color For 3D plot, color of edges.

`line_width` For 3D plot, line width of the function curve.

`line_color` Color of the function curve.

`...` Additional arguments for ggplot or plot_ly.

Returns: Either a `ggplot` (if `plotly=FALSE`) or a `plot_ly` object.

Method `add_mesh_observations()`**:** Add observations on mesh to the object.

Usage:

```
metric_graph$add_mesh_observations(data = NULL, group = NULL)
```

Arguments:

`data` A `data.frame` or named list containing the observations. In case of groups, the data.frames for the groups should be stacked vertically, with a column indicating the index of the group. If `data_frame` is not `NULL`, it takes priority over any eventual data in `Spoints`.

`group` If the data_frame contains groups, one must provide the column in which the group indices are stored.

Returns: No return value. Called for its side effects. The observations are stored in the `data` element in the `metric_graph` object.

Method `get_initial_graph()`**:** Returns a copy of the initial metric graph.

Usage:

```
metric_graph$get_initial_graph()
```

Returns: A `metric_graph` object.

Method `coordinates()`**:** Convert between locations on the graph and Euclidean coordinates.

Usage:

```
metric_graph$coordinates(PtE = NULL, XY = NULL, normalized = TRUE)
```

Arguments:

`PtE` Matrix with locations on the graph (edge number and normalized position on the edge).

`XY` Matrix with locations in Euclidean space

`normalized` If `TRUE`, it is assumed that the positions in `PtE` are normalized to (0,1), and the object returned if `XY` is specified contains normalized locations.

Returns: If `PtE` is specified, then a matrix with Euclidean coordinates of the locations is returned. If `XY` is provided, then a matrix with the closest locations on the graph is returned. data List containing data on the metric graph.

Method `clone()`**:** The objects of this class are cloneable with this method.

Usage:

```
metric_graph$clone(deep = FALSE)
```

Arguments:

`deep` Whether to make a deep clone.

Examples

```
edge1 <- rbind(c(0, 0), c(2, 0))
edge2 <- rbind(c(2, 0), c(1, 1))
edge3 <- rbind(c(1, 1), c(0, 0))
edges <- list(edge1, edge2, edge3)
graph <- metric_graph$new(edges)
graph$plot()
```

---

mutate.metric_graph_data

A version of `dplyr::mutate()` *function for datasets on metric graphs*

Description

Applies `dplyr::mutate()` function for datasets obtained from a metric graph object.

Usage

```
## S3 method for class 'metric_graph_data'
mutate(.data, ...)
```

Arguments

`.data`	The data list or `tidyr::tibble` obtained from a metric graph object.
`...`	Additional parameters to be passed to `dplyr::mutate()`.

Value

A `tidyr::tibble` with the resulting selected columns.

---

pems

Traffic speed data from San Jose, California

Description

Data set of traffic speed observations on highways in the city of San Jose, California.

Usage

```
pems
```

Format

pems:

A list with three elements:

edges A list object containing the coordinates of the road segments.

data Locations of the observations on the road segments as a data.frame with 325 rows and 2 columns. The first column indicates the edge number and the second column indicates the distance on edge of the position.

Y Observations of traffic speed. Consists of a vector with 325 observations.

Source

https://www.openstreetmap.org

https://github.com/spbu-math-cs/Graph-Gaussian-Processes/blob/main/examples/data/PEMS.zip

References

Chen, C., K. Petty, A. Skabardonis, P. Varaiya, and Z. Jia (2001). Freeway performance measurement system: mining loop detector data. Transportation Research Record 1748(1), 96–102.

OpenStreetMap contributors (2017). Planet dump retrieved from https://planet.osm.org. https://www.openstreetmap.org.

---

plot.graph_bru_pred *Plot of predicted values with 'inlabru'*

Description

Auxiliary function to obtain plots of the predictions of the field using 'inlabru'.

Usage

```
## S3 method for class 'graph_bru_pred'
plot(x, y = NULL, vertex_size = 0, ...)
```

Arguments

x	A predicted object obtained with the predict method.
y	Not used.
vertex_size	Size of the vertices.
...	Additional parameters to be passed to plot_function.

Value

A 'ggplot2' object.

posterior_crossvalidation *Leave-one-out crossvalidation for* graph_lme *models assuming observations at the vertices of metric graphs*

Description

Leave-one-out crossvalidation for graph_lme models assuming observations at the vertices of metric graphs

Usage

```
posterior_crossvalidation(object, factor = 1, tibble = TRUE)
```

Arguments

object	A fitted model using the graph_lme() function or a named list of fitted objects using the graph_lme() function.
factor	Which factor to multiply the scores. The default is 1.
tibble	Return the scores as a tidyr::tibble()

Value

Vector with the posterior expectations and variances as well as mean absolute error (MAE), root mean squared errors (RMSE), and three negatively oriented proper scoring rules: log-score, CRPS, and scaled CRPS.

predict.graph_lme *Prediction for a mixed effects regression model on a metric graph*

Description

Prediction for a mixed effects regression model on a metric graph

Usage

```
## S3 method for class 'graph_lme'
predict(
  object,
  newdata = NULL,
  mesh = FALSE,
  mesh_h = 0.01,
  which_repl = NULL,
  compute_variances = FALSE,
  posterior_samples = FALSE,
```

```
  n_samples = 100,
  edge_number = "edge_number",
  distance_on_edge = "distance_on_edge",
  normalized = FALSE,
  sample_latent = FALSE,
  return_as_list = FALSE,
  return_original_order = TRUE,
  ...,
  data = deprecated()
)
```

Arguments

object	The fitted object with the graph_lme() function.
newdata	A data.frame or a list containing the covariates, the edge number and the distance on edge for the locations to obtain the prediction. Observe that you should not provide the locations for each replicate. Only a single set of locations and covariates, and the predictions for the different replicates will be obtained for this same set of locations.
mesh	Obtain predictions for mesh nodes? The graph must have a mesh and should not have covariates.
mesh_h	If the graph does not have a mesh, one will be created with this value of 'h'.
which_repl	Which replicates to obtain the prediction. If NULL predictions will be obtained for all replicates. Default is NULL.
compute_variances	Set to TRUE to compute the kriging variances.
posterior_samples	If TRUE, posterior samples will be returned.
n_samples	Number of samples to be returned. Will only be used if sampling is TRUE.
edge_number	Name of the variable that contains the edge number, the default is edge_number.
distance_on_edge	Name of the variable that contains the distance on edge, the default is distance_on_edge.
normalized	Are the distances on edges normalized?
sample_latent	Do posterior samples only for the random effects?
return_as_list	Should the means of the predictions and the posterior samples be returned as a list, with each replicate being an element?
return_original_order	Should the results be return in the original (input) order or in the order inside the graph?
...	Not used.
data	**[Deprecated]** Use newdata instead.

Value

A list with elements `mean`, which contains the means of the predictions, `fe_mean`, which is the prediction for the fixed effects, `re_mean`, which is the prediction for the random effects, `variance` (if `compute_variance` is `TRUE`), which contains the variances of the predictions, `samples` (if `posterior_samples` is `TRUE`), which contains the posterior samples.

`predict.inla_metric_graph_spde` *Predict method for 'inlabru' fits on Metric Graphs*

Description

Auxiliar function to obtain predictions of the field using 'inlabru'.

Usage

```
## S3 method for class 'inla_metric_graph_spde'
predict(
  object,
  cmp,
  bru_fit,
  newdata = NULL,
  formula = NULL,
  data_coords = c("PtE", "euclidean"),
  normalized = TRUE,
  n.samples = 100,
  seed = 0L,
  probs = c(0.025, 0.5, 0.975),
  return_original_order = TRUE,
  num.threads = NULL,
  include = NULL,
  exclude = NULL,
  drop = FALSE,
  ...,
  data = deprecated()
)
```

Arguments

`object`	An `inla_metric_graph_spde` object built with the `graph_spde()` function.
`cmp`	The 'inlabru' component used to fit the model.
`bru_fit`	A fitted model using 'inlabru' or 'INLA'.
`newdata`	A data.frame of covariates needed for the prediction. The locations must be normalized PtE.

formula	A formula where the right hand side defines an R expression to evaluate for each generated sample. If NULL, the latent and hyperparameter states are returned as named list elements. See Details for more information.
data_coords	It decides which coordinate system to use. If PtE, the user must provide the locations as a data frame with the first column being the edge number and the second column as the distance on edge, otherwise if euclidean, the user must provide a data frame with the first column being the x Euclidean coordinates and the second column being the y Euclidean coordinates.
normalized	if TRUE, then the distances in distance on edge are assumed to be normalized to (0,1). Default TRUE. Will not be used if data_coords is euclidean.
n.samples	Integer setting the number of samples to draw in order to calculate the posterior statistics. The default is rather low but provides a quick approximate result.
seed	Random number generator seed passed on to inla.posterior.sample()
probs	A numeric vector of probabilities with values in the standard unit interval to be passed to stats::quantile
return_original_order	Should the predictions be returned in the original order?
num.threads	Specification of desired number of threads for parallel computations. Default NULL, leaves it up to 'INLA'. When seed != 0, overridden to "1:1"
include	Character vector of component labels that are needed by the predictor expression; Default: NULL (include all components that are not explicitly excluded)
exclude	Character vector of component labels that are not used by the predictor expression. The exclusion list is applied to the list as determined by the include parameter; Default: NULL (do not remove any components from the inclusion list)
drop	logical; If keep=FALSE, data is a SpatialDataFrame, and the prediciton summary has the same number of rows as data, then the output is a SpatialDataFrame object. Default FALSE.
...	Additional arguments passed on to inla.posterior.sample().
data	**[Deprecated]** Use newdata instead.

Value

A list with predictions.

`predict.rspde_metric_graph` *Predict method for 'inlabru' fits on Metric Graphs for 'rSPDE' models*

Description

Auxiliar function to obtain predictions of the field using 'inlabru' and 'rSPDE'.

Usage

```
## S3 method for class 'rspde_metric_graph'
predict(
  object,
  cmp,
  bru_fit,
  newdata = NULL,
  formula = NULL,
  data_coords = c("PtE", "euclidean"),
  normalized = TRUE,
  n.samples = 100,
  seed = 0L,
  probs = c(0.025, 0.5, 0.975),
  num.threads = NULL,
  include = NULL,
  exclude = NULL,
  drop = FALSE,
  ...,
  data = deprecated()
)
```

Arguments

object	An rspde_metric_graph object built with the rspde.metric_graph() function.
cmp	The 'inlabru' component used to fit the model.
bru_fit	A fitted model using 'inlabru' or 'INLA'.
newdata	A data.frame of covariates needed for the prediction. The locations must be normalized PtE.
formula	A formula where the right hand side defines an R expression to evaluate for each generated sample. If NULL, the latent and hyperparameter states are returned as named list elements. See Details for more information.
data_coords	It decides which coordinate system to use. If PtE, the user must provide the locations as a data frame with the first column being the edge number and the second column as the distance on edge, otherwise if euclidean, the user must provide a data frame with the first column being the x Euclidean coordinates and the second column being the y Euclidean coordinates.
normalized	if TRUE, then the distances in distance on edge are assumed to be normalized to (0,1). Default TRUE. Will not be used if data_coords is euclidean.
n.samples	Integer setting the number of samples to draw in order to calculate the posterior statistics. The default is rather low but provides a quick approximate result.
seed	Random number generator seed passed on to inla.posterior.sample
probs	A numeric vector of probabilities with values in the standard unit interval to be passed to stats::quantile.
num.threads	Specification of desired number of threads for parallel computations. Default NULL, leaves it up to 'INLA'. When seed != 0, overridden to "1:1"

include	Character vector of component labels that are needed by the predictor expression; Default: NULL (include all components that are not explicitly excluded)
exclude	Character vector of component labels that are not used by the predictor expression. The exclusion list is applied to the list as determined by the include parameter; Default: NULL (do not remove any components from the inclusion list)
drop	logical; If keep=FALSE, data is a SpatialDataFrame, and the prediciton summary has the same number of rows as data, then the output is a SpatialDataFrame object. Default FALSE.
...	Additional arguments passed on to inla.posterior.sample.
data	**[Deprecated]** Use newdata instead.

Value

A list with predictions.

`sample_spde` *Samples a Whittle-Matérn field on a metric graph*

Description

Obtains samples of a Whittle-Matérn field on a metric graph.

Usage

```
sample_spde(
  kappa,
  tau,
  range,
  sigma,
  sigma_e = 0,
  alpha = 1,
  graph,
  PtE = NULL,
  type = "manual",
  posterior = FALSE,
  nsim = 1,
  method = c("conditional", "Q"),
  BC = 1
)
```

Arguments

kappa	Range parameter.
tau	Precision parameter.

range	Practical correlation range parameter.
sigma	Marginal standard deviation parameter.
sigma_e	Standard deviation of the measurement noise.
alpha	Smoothness parameter.
graph	A metric_graph object.
PtE	Matrix with locations (edge, normalized distance on edge) where the samples should be generated.
type	If "manual" is set, then sampling is done at the locations specified in PtE. Set to "mesh" for simulation at mesh nodes, and to "obs" for simulation at observation locations.
posterior	Sample conditionally on the observations?
nsim	Number of samples to be generated.
method	Which method to use for the sampling? The options are "conditional" and "Q". Here, "Q" is more stable but takes longer.
BC	Boundary conditions for degree 1 vertices. BC = 0 gives Neumann boundary conditions and BC = 1 gives stationary boundary conditions.

Details

Samples a Gaussian Whittle-Matérn field on a metric graph, either from the prior or conditionally on observations

$$y_i = u(t_i) + \sigma_e e_i$$

on the graph, where e_i are independent standard Gaussian variables. The parameters for the field can either be specified in terms of tau and kappa or practical correlation range and marginal standard deviation.

Value

Matrix or vector with the samples.

---

select.metric_graph_data

A version of dplyr::select() *function for datasets on metric graphs*

Description

Selects columns on metric graphs, while keeps the spatial positions.

Usage

```
## S3 method for class 'metric_graph_data'
select(.data, ...)
```

Arguments

.data	The data list or tidyr::tibble obtained from a metric graph object.
...	Additional parameters to be passed to dplyr::select().

Value

A tidyr::tibble with the resulting selected columns.

---

simulate_spacetime *space-time simulation based on implicit Euler discretization in time*

Description

Simulation with starting value u0

Usage

```
simulate_spacetime(graph, t, kappa, rho, gamma, alpha, beta, sigma, u0, BC = 0)
```

Arguments

graph	A metric_graph object.
t	Vector of time points.
kappa	Spatial range parameter.
rho	Drift parameter.
gamma	Temporal range parameter.
alpha	Smoothness parameter (integer) for spatial operator.
beta	Smoothness parameter (integer) for Q-Wiener process.
sigma	Variance parameter.
u0	Starting value.
BC	Which boundary condition to use (0,1). Here, 0 is no adjustment on the boundary and 1 results in making the boundary condition stationary.

Value

Precision matrix.

spde_covariance *Covariance function for Whittle-Matérn fields*

Description

Computes the covariance function for a Whittle-Matérn field.

Usage

```
spde_covariance(P, kappa, tau, range, sigma, alpha, graph)
```

Arguments

P	Location (edge number and normalized location on the edge) for the location to evaluate the covariance function at.
kappa	Parameter kappa from the SPDE.
tau	Parameter tau from the SPDE.
range	Range parameter.
sigma	Standard deviation parameter.
alpha	Smoothness parameter (1 or 2).
graph	A metric_graph object.

Details

Compute the covariance function $\rho(P, s_i)$ where P is the provided location and s_i are all locations in the mesh of the graph.

Value

Vector with the covariance function evaluate at the mesh locations.

spde_metric_graph_result *Metric graph SPDE result extraction from 'INLA' estimation results*

Description

Extract field and parameter values and distributions for a metric graph spde effect from an 'INLA' result object.

Usage

```
spde_metric_graph_result(
  inla,
  name,
  metric_graph_spde,
  compute.summary = TRUE,
  n_samples = 5000,
  n_density = 1024
)
```

Arguments

inla	An 'INLA' object obtained from a call to inla().
name	A character string with the name of the 'rSPDE' effect in the model.
metric_graph_spde	The inla_metric_graph_spde object used for the random effect in the model.
compute.summary	Should the summary be computed?
n_samples	The number of samples to be used if parameterization is matern.
n_density	The number of equally spaced points to estimate the density.

Value

If the model was fitted with matern parameterization (the default), it returns a list containing:

marginals.range	Marginal densities for the range parameter.
marginals.log.range	Marginal densities for log(range).
marginals.sigma	Marginal densities for std. deviation.
marginals.log.sigma	Marginal densities for log(std. deviation).
marginals.values	Marginal densities for the field values.
summary.log.range	Summary statistics for log(range).
summary.log.sigma	Summary statistics for log(std. deviation).
summary.values	Summary statistics for the field values.

If compute.summary is TRUE, then the list will also contain

summary.kappa	Summary statistics for kappa.
summary.tau	Summary statistics for tau.

If the model was fitted with the spde parameterization, it returns a list containing:

`marginals.kappa`
: Marginal densities for kappa.

`marginals.log.kappa`
: Marginal densities for log(kappa).

`marginals.log.tau`
: Marginal densities for log(tau).

`marginals.tau`
: Marginal densities for tau.

`marginals.values`
: Marginal densities for the field values.

`summary.log.kappa`
: Summary statistics for log(kappa).

`summary.log.tau`
: Summary statistics for log(tau).

`summary.values`
: Summary statistics for the field values.

If `compute.summary` is `TRUE`, then the list will also contain

`summary.kappa`
: Summary statistics for kappa.

`summary.tau`
: Summary statistics for tau.

`spde_precision` *Precision matrix for Whittle-Matérn fields*

Description

Computes the precision matrix for all vertices for a Whittle-Matérn field.

Usage

```
spde_precision(kappa, tau, alpha, graph, BC = 1, build = TRUE)
```

Arguments

`kappa`	Range parameter.
`tau`	Precision parameter.
`alpha`	Smoothness parameter (1 or 2).
`graph`	A `metric_graph` object.
`BC`	Set boundary conditions for degree=1 vertices. BC =0 gives Neumann boundary conditions and BC=1 gives stationary boundary conditions.
`build`	If `TRUE`, the precision matrix is returned. Otherwise a list list(i,j,x, nv) is returned.

Value

Precision matrix or list.

summarise.metric_graph_data *A version of* dplyr::summarise() *function for datasets on metric graphs*

Description

Creates summaries, while keeps the spatial positions.

Usage

```
## S3 method for class 'metric_graph_data'
summarise(.data, ..., .include_graph_groups = FALSE, .groups = NULL)
```

Arguments

.data	The data list or tidyr::tibble obtained from a metric graph object.
...	Additional parameters to be passed to dplyr::summarise().
.include_graph_groups	Should the internal graph groups be included in the grouping variables? The default is FALSE. This means that, when summarising, the data will be grouped by the internal group variable together with the spatial locations.
.groups	A vector of strings containing the names of the columns to be additionally grouped, when computing the summaries. The default is NULL.

Value

A tidyr::tibble with the resulting selected columns.

summary.graph_lme *Summary Method for* graph_lme *Objects*

Description

Function providing a summary of results related to metric graph mixed effects regression models.

Usage

```
## S3 method for class 'graph_lme'
summary(object, all_times = FALSE, ...)
```

Arguments

object	an object of class graph_lme containing results from the fitted model.
all_times	Show all computed times.
...	not used.

Value

An object of class summary_graph_lme containing information about a *graph_lme* object.

---

summary.metric_graph *Summary Method for* metric_graph *Objects*

Description

Function providing a summary of several informations/characteristics of a metric graph object.

Usage

```
## S3 method for class 'metric_graph'
summary(
  object,
  messages = FALSE,
  compute_characteristics = TRUE,
  check_euclidean = TRUE,
  check_distance_consistency = TRUE,
  ...
)
```

Arguments

object	an object of class metric_graph.
messages	Should message explaining how to build the results be given for missing quantities?
compute_characteristics	Should the characteristics of the graph be computed?
check_euclidean	Check if the graph has Euclidean edges?
check_distance_consistency	Check the distance consistency assumption?#'
...	not used.

Value

An object of class summary_graph_lme containing information about a *metric_graph* object.

summary.metric_graph_spde_result *Summary for posteriors of field parameters for an* inla_rspde *model from a* rspde.result *object*

Description

Summary for posteriors of 'rSPDE' field parameters in their original scales.

Usage

```
## S3 method for class 'metric_graph_spde_result'
summary(object, digits = 6, ...)
```

Arguments

object	A rspde.result object.
digits	Integer, used for number formatting with signif()
...	Currently not used.

Value

A data.frame containing the summary.

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