

Package ‘MetricGraph’

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Type Package

Title Random Fields on Metric Graphs

Version 1.3.0

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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 (2024) <[doi:10.3150/23-BEJ1647](https://doi.org/10.3150/23-BEJ1647)>, Bolin, Kovacs, Kumar and Simas (2023) <[doi:10.1090/mcom/3929](https://doi.org/10.1090/mcom/3929)> and Bolin, Simas and Wallin (2023) <[doi:10.48550/arXiv.2304.03190](https://doi.org/10.48550/arXiv.2304.03190)> a

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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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MetricGraph-package *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 that 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. 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.

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See Also

Useful links:

- <https://davidbolin.github.io/MetricGraph/>
- Report bugs at <https://github.com/davidbolin/MetricGraph/issues>

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,
  sd_post_re = FALSE,
  se_fit = FALSE,
  conf_int = FALSE,
  pred_int = FALSE,
  level = 0.95,
  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,
  no_nugget = FALSE,
  check_euclidean = 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.
sd_post_re	Logical indicating whether or not a .sd_post_re column should be added to the augmented output containing the posterior standard deviations of the random effects.
se_fit	Logical indicating whether or not a .se_fit column should be added to the augmented output containing the standard errors of the fitted values. If TRUE, the posterior standard deviations of the random effects will also be returned.
conf_int	Logical indicating whether or not confidence intervals for the posterior mean of the random effects should be built.
pred_int	Logical indicating whether or not prediction intervals for the fitted values should be built. If TRUE, the confidence intervals for the posterior random effects will also be built.
level	Level of confidence and prediction intervals if they are constructed.
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?
no_nugget	Should the prediction be done without nugget?
check_euclidean	Check if the graph used to compute the resistance distance has Euclidean edges? The graph used to compute the resistance distance has the observation locations as vertices.
...	Additional arguments.

Value

A `tidyr::tibble()` with columns:

- `.fitted` Fitted or predicted value.

- `.relwrconf` Lower bound of the confidence interval of the random effects, if `conf_int = TRUE`
- `.reuprconf` Upper bound of the confidence interval of the random effects, if `conf_int = TRUE`
- `.fittedlwrpred` Lower bound of the prediction interval, if `conf_int = TRUE`
- `.fitteduprpred` Upper bound of the prediction interval, if `conf_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.
- `.std_resid` The standardized residuals, that is, the ordinary residuals divided by the standard error of the fitted values (by the prediction standard error), if `se_fit = TRUE` or `pred_int = TRUE`.
- `.se_fit` Standard errors of fitted values, if `se_fit = TRUE`.
- `.sd_post_re` Standard deviation of the posterior mean of the random effects, 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

<code>model</code>	An <code>inla_metric_graph_spde</code> for which to construct or extract a mapper
<code>...</code>	Arguments passed on to other methods
<code>mapper</code>	A <code>bru_mapper.inla_metric_graph_spde</code> object
<code>input</code>	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

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

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	<i>Glance at a graph_lme object</i>
------------------	-------------------------------------

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 an 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,
  edge_weights = NULL,
  ...,
  lines = deprecated()
)
```

Arguments:

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

`V` $n \times 2$ matrix with Euclidean coordinates of the n vertices.

`E` $m \times 2$ 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.

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

... 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 <code>inla_metric_graph_spde</code> object built with the <code>graph_spde()</code> function.
name	A character string with the base name of the effect.
repl	Which replicates? If there is no replicates, one can set <code>repl</code> to <code>NULL</code> . If one wants all replicates, then one sets to <code>repl</code> to <code>.all</code> .
group	Which groups? If there is no groups, one can set <code>group</code> to <code>NULL</code> . If one wants all groups, then one sets to <code>group</code> to <code>.all</code> .
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 <code>tidyr::tibble</code> ?
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 <code>only_pred</code> 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 <code>only_pred</code> is TRUE.
loc	[Deprecated] Use <code>loc_name</code> instead.

Value

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

graph_lgcp	<i>Simulation of log-Gaussian Cox processes driven by Whittle-Matérn fields on metric graphs</i>
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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 <code>metric_graph</code> 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",
  possible_methods = c("Nelder-Mead", "L-BFGS-B"),
  model_options = list(),
  BC = 0,
  previous_fit = NULL,
  fix_coeff = FALSE,
  parallel = FALSE,
  n_cores = parallel::detectCores() - 1,
  optim_controls = list(),
  improve_hessian = FALSE,
  hessian_args = list(),
  check_euclidean = TRUE
)
```

Arguments

formula	Formula object describing the relation between the response variables and the fixed effects.
graph	A <code>metric_graph</code> 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 $\alpha=1$ 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 $\alpha = 1$ and 2, respectively. 'WMD1' is the directed Whittle-Matern with $\alpha=1$. There is also the option to provide it as a list containing the elements <code>type</code> , which can be <code>linearModel</code> , <code>WhittleMatern</code> , <code>graphLaplacian</code> or <code>isoCov</code> . <code>linearModel</code> 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.

<code>which_repl</code>	Vector or list containing which replicates to consider in the model. If <code>NULL</code> all replicates will be considered.
<code>optim_method</code>	The method to be used with <code>optim</code> function.
<code>possible_methods</code>	Which methods to try in case the optimization fails or the hessian is not positive definite. The options are <code>'Nelder-Mead'</code> , <code>'L-BFGS-B'</code> , <code>'BFGS'</code> , <code>'CG'</code> and <code>'SANN'</code> . By default only <code>'Nelder-Mead'</code> and <code>'L-BFGS-B'</code> are considered.
<code>model_options</code>	A list containing additional options to be used in the model. Currently, it is possible to fix parameters during the estimation or change the starting values of the parameters. The general structure of the elements of the list is <code>fix_pname</code> and <code>start_pname</code> , where <code>pname</code> stands for the name of the parameter. If <code>fix_pname</code> is not <code>NULL</code> , then the model will be fitted with the <code>pname</code> being fixed at the value that was passed. If <code>start_pname</code> is not <code>NULL</code> , the model will be fitted using the value passed as starting value for <code>pname</code> . For <code>'WM'</code> models, the possible elements of the list are: <code>fix_sigma_e</code> , <code>start_sigma_e</code> , <code>fix_nu</code> , <code>start_nu</code> , <code>fix_sigma</code> , <code>start_sigma</code> , <code>fix_range</code> , <code>start_range</code> . Alternatively, one can use <code>fix_sigma_e</code> , <code>start_sigma_e</code> , <code>fix_nu</code> , <code>start_nu</code> , <code>fix_tau</code> , <code>start_tau</code> , <code>fix_kappa</code> , <code>start_kappa</code> . For <code>'WM1'</code> , <code>'WM2'</code> , <code>'iso-Exp'</code> , <code>'GL1'</code> and <code>'GL2'</code> models, the possible elements of the list are <code>fix_sigma_e</code> , <code>start_sigma_e</code> , <code>fix_sigma</code> , <code>start_sigma</code> , <code>fix_range</code> , <code>start_range</code> . Alternatively, one can use <code>fix_sigma_e</code> , <code>start_sigma_e</code> , <code>fix_tau</code> , <code>start_tau</code> , <code>fix_kappa</code> , <code>start_kappa</code> . For <code>'isoCov'</code> models, the possible values are <code>fix_sigma_e</code> , <code>start_sigma_e</code> , <code>fix_par_vec</code> , <code>start_par_vec</code> . Observe that contrary to the

other models, for 'isoCov' models, both `fix_par_vec` and `start_par_vec` should be given as vectors of the size of the dimension of the vector for the input of the covariance function passed to the 'isoCov' model. Furthermore, for 'isoCov' models, `fix_par_vec` is a logical vector, indicating which parameters to be fixed, and the values will be kept fixed to the values given to `start_par_vec`, one can also use `fix_sigma_e` and `start_sigma_e` for controlling the std. deviation of the measurement error.

<code>BC</code>	For WhittleMatern models, decides which boundary condition to use (0,1). Here, 0 is Neumann boundary conditions and 1 specifies stationary boundary conditions.
<code>previous_fit</code>	An object of class <code>graph_lme</code> . Use the fitted coefficients as starting values.
<code>fix_coeff</code>	If using a previous fit, should all coefficients be fixed at the starting values?
<code>parallel</code>	logical. Indicating whether to use <code>optimParallel()</code> or not.
<code>n_cores</code>	Number of cores to be used if <code>parallel</code> is true.
<code>optim_controls</code>	Additional controls to be passed to <code>optim()</code> or <code>optimParallel()</code> .
<code>improve_hessian</code>	Should a more precise estimate of the hessian be obtained? Turning on might increase the overall time.
<code>hessian_args</code>	List of controls to be used if <code>improve_hessian</code> is TRUE. The list can contain the arguments to be passed to the <code>method.args</code> argument in the <code>hessian</code> function. See the help of the <code>hessian</code> function in 'numDeriv' package for details. Observe that it only accepts the "Richardson" method for now, the method "complex" is not supported.
<code>check_euclidean</code>	Check if the graph used to compute the resistance distance has Euclidean edges? The graph used to compute the resistance distance has the observation locations as vertices.

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	<i>Observation/prediction matrices for 'SPDE' models</i>
------------------	--

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,
  model_options = list(),
  rec_tau = TRUE
)
```

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?
model_options	List object containing the model options.
rec_tau	Should a starting value for the reciprocal of tau be given?

Value

A vector, c(start_sigma_e, start_sigma, start_kappa)

logo_lines	<i>Create lines for package name</i>
------------	--------------------------------------

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 <code>metric_graph</code> 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.

metric_graph	<i>Metric graph</i>
--------------	---------------------

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 an 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 i th 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$edgeweight_to_data()`
- `metric_graph$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$get_data()`
- `metric_graph$buildDirectionalConstraints()`
- `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,  
  kirchhoff_weights = NULL,  
  longlat = FALSE,  
  crs = NULL,  
  proj4string = NULL,  
  which_longlat = "sp",  
  project = FALSE,  
  project_data = FALSE,  
  which_projection = "Winkel tripel",  
  tolerance = list(vertex_vertex = 0.001, vertex_edge = 0.001, edge_edge = 0),  
  check_connected = TRUE,  
  remove_deg2 = FALSE,  
  merge_close_vertices = TRUE,  
  factor_merge_close_vertices = 1,  
  remove_circles = TRUE,
```

```

    verbose = 1,
    lines = deprecated()
)

```

Arguments:

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

V $n \times 2$ matrix with Euclidean coordinates of the n vertices.

E $m \times 2$ 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.

kirchhoff_weights If non-null, the name (or number) of the column of edge_weights that contain the Kirchhoff weights. Must be equal to 1 (or TRUE) in case edge_weights is a single number and those are the Kirchhoff weights.

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 FALSE. 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 circular 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. There are 3 levels of verbose, level 0, 1 and 2. In level 0, no messages are printed. In level 1, only messages regarding important steps are printed. Finally, in level 2, messages detailing all the steps are printed. The default is 1.

`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),
  kirchhoff_weights = NULL
)
```

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.

`kirchhoff_weights` If non-null, the name (or number) of the column of weights that contain the Kirchhoff weights. Must be equal to 1 (or `TRUE`) in case `weights` is a single number and those are the Kirchhoff weights.

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

Method `get_edge_weights()`: Gets the edge weights

Usage:

```
metric_graph$get_edge_weights(data.frame = FALSE, tibble = TRUE)
```

Arguments:

`data.frame` If the edge weights are given as vectors, should the result be returned as a `data.frame`?

tibble Should the edge weights be returned as tibble?

Returns: A vector or data.frame 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 performed. 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,
  check_euclidean = FALSE,
  include_vertices = FALSE
)
```

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.

`check_euclidean` Check if the graph used to compute the resistance distance has Euclidean edges? The graph used to compute the resistance distance has the observation locations as vertices.

`include_vertices` Should the vertices of the graph be also included in the resulting matrix when using FULL=TRUE?

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,
  check_euclidean = 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?

`check_euclidean` Check if the graph used to compute the resistance distance has Euclidean edges? The graph used to compute the resistance distance has the observation locations as vertices.

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 weighed 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 return 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(check_weights = TRUE, verbose = FALSE)
```

Arguments:

check_weights If TRUE will only prune edges with different weights.

verbose Print progress of pruning. There are 3 levels of verbose, level 0, 1 and 2. In level 0, no messages are printed. In level 1, only messages regarding important steps are printed.

Finally, in level 2, messages detailing all the steps are printed. The default is 1.

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 `edgweight_to_data()`: Turns edge weights into data on the metric graph

Usage:

```
metric_graph$edgweight_to_data(
  loc = NULL,
  mesh = FALSE,
  data_loc = FALSE,
  weight_col = NULL,
  add = TRUE,
  data_coords = c("PtE", "spatial"),
  normalized = FALSE,
  tibble = TRUE,
  verbose = 1,
  suppress_warnings = FALSE,
  return = FALSE
)
```

Arguments:

- `loc` A matrix or data.frame with two columns containing the locations to generate the data from the edge weights. If `data_coords` is 'spatial', the first column must be the x-coordinate of the data, and the second column must be the y-coordinate. If `data_coords` is 'PtE', the first column must be the edge number and the second column must be the distance on edge.
- `mesh` Should the data be generated to the mesh locations? In this case, the `loc` argument will be ignored. Observe that the metric graph must have a mesh built for one to use this option. CAUTION: To add edgweight to data to both the data locations and mesh locations, please, add at the data locations first, then to mesh locations.
- `data_loc` Should the data be generated to the data locations? In this case, the `loc` argument will be ignored. Observe that the metric graph must have data for one to use this option. CAUTION: To add edgweight to data to both the data locations and mesh locations, please, add at the data locations first, then to mesh locations.
- `weight_col` Which columns of the edge weights should be turned into data? If NULL, all columns will be turned into data.
- `add` Should the data generated be added to the metric graph internal data?
- `data_coords` To be used only if `mesh` is FALSE. 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` if TRUE, then the distances in `distance_on_edge` are assumed to be normalized to (0,1). Default FALSE.
- `tibble` Should the data be returned as a `tidyr::tibble`?
- `verbose` Print progress of the steps when adding observations. There are 3 levels of verbose, level 0, 1 and 2. In level 0, no messages are printed. In level 1, only messages regarding important steps are printed. Finally, in level 2, messages detailing all the steps are printed. The default is 1.
- `suppress_warnings` Suppress warnings related to duplicated observations?
- `return` Should the data be returned? If `return_removed` is TRUE, only the removed locations will be return (if there is any).

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$process_data(
  data = NULL,
  edge_number = "edge_number",
  distance_on_edge = "distance_on_edge",
  coord_x = "coord_x",
  coord_y = "coord_y",
  data_coords = c("PtE", "spatial"),
  group = NULL,
  group_sep = ".",
  normalized = FALSE,
  tibble = TRUE,
  duplicated_strategy = "closest",
  include_distance_to_graph = TRUE,
  only_return_removed = FALSE,
  tolerance = max(self$edge_lengths)/2,
  verbose = FALSE,
  suppress_warnings = FALSE,
  Spoints = lifecycle::deprecated()
)
```

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 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` 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.
- `tibble` Should the data be returned as a `tidyr::tibble`?
- `duplicated_strategy` Which strategy to handle observations on the same location on the metric graph (that is, if there are two or more observations projected at the same location). The options are 'closest' and 'jitter'. If 'closest', only the closest observation will be used. If 'jitter', a small perturbation will be performed on the projected observation location. The default is 'closest'.
- `include_distance_to_graph` When `data_coord` is 'spatial', should the distance of the observations to the graph be included as a column?
- `only_return_removed` Should the removed data (if it exists) when using 'closest' `duplicated_strategy` be returned instead of the processed data?
- `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.
- `suppress_warnings` Suppress warnings related to duplicated observations?
- `Spoints` **[Deprecated]** Use `data` instead.

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(
  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,
duplicated_strategy = "closest",
include_distance_to_graph = TRUE,
return_removed = TRUE,
verbose = 1,
suppress_warnings = FALSE,
Spoints = lifecycle::deprecated()
)

```

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. data can also be an sf object or a SpatialPointsDataFrame object. in which case data_coords will automatically be spatial, and there is no need to specify the coord_x or coord_y arguments.
- 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** 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.
- 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.

`duplicated_strategy` Which strategy to handle observations on the same location on the metric graph (that is, if there are two or more observations projected at the same location). The options are 'closest' and 'jitter'. If 'closest', only the closest observation will be used. If 'jitter', a small perturbation will be performed on the projected observation location. The default is 'closest'.

`include_distance_to_graph` When `data_coord` is 'spatial', should the distance of the observations to the graph be included as a column?

`return_removed` Should the removed data (if it exists) when using 'closest' `duplicated_strategy` be returned?

`verbose` Print progress of the steps when adding observations. There are 3 levels of verbose, level 0, 1 and 2. In level 0, no messages are printed. In level 1, only messages regarding important steps are printed. Finally, in level 2, messages detailing all the steps are printed. The default is 1.

`suppress_warnings` Suppress warnings related to duplicated observations?

`Spoints` **[Deprecated]** Use `data` instead.

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 containing 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 `buildDirectionalConstraints()`: Build directional ODE constraint matrix from edges.

Usage:

```
metric_graph$buildDirectionalConstraints(alpha = 1)
```

Arguments:

`alpha` how many derivatives the processes has

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 `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 $\text{deg}(v)$ 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 vertices 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 $C_{pet_{ij}} = \langle \phi_i, \psi_j \rangle$ and $G_{pet_{ij}} = \langle d\phi_i, \psi_j \rangle$, 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 $C_{ij} = \langle \phi_i, \phi_j \rangle$, the matrix G which is the stiffness matrix with elements $G_{ij} = \langle d\phi_i, d\phi_j \rangle$, the matrix B with elements $B_{ij} = \langle d\phi_i, \phi_j \rangle$, the matrix D with elements $D_{ij} = \sum_{v \in V} \phi_i(v)\phi_j(v)$, and the vector with weights $\langle \phi_i, 1 \rangle$.

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 ith row is the edge number corresponding to the ith 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,
  interactive = 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,
  edge_weight = NULL,
  edge_width_weight = NULL,
  scale_color_main = ggplot2::scale_color_viridis_c(option = "D"),
  scale_color_weights = ggplot2::scale_color_viridis_c(option = "C"),
  scale_color_degree = ggplot2::scale_color_viridis_d(option = "D"),
  add_new_scale_weights = TRUE,
  ...
)
```

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.

interactive Only works for 2d plots. If TRUE, an interactive plot will be displayed. Unfortunately, `interactive` is not compatible with `edge_weight` if `add_new_scale_weights` is TRUE.

vertex_size Size of the vertices.

vertex_color Color of vertices.

edge_width Line width for edges. If `edge_width_weight` is not NULL, this determines the maximum edge width.

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?

edge_weight Which column from edge weights to plot? If NULL edge weights are not plotted. To plot the edge weights when the metric graph `edge_weights` is a vector instead of a `data.frame`, simply set to 1. `edge_weight` is only available for 2d plots. For 3d plots with edge weights, please use the `plot_function()` method.

edge_width_weight Which column from edge weights to determine the edges widths? If NULL edge width will be determined from `edge_width`.

scale_color_main Color scale for the data to be plotted.

scale_color_weights Color scale for the edge weights. Will only be used if `add_new_scale_weights` is TRUE.

scale_color_degree Color scale for the degrees.

add_new_scale_weights Should a new color scale for the edge weights be created?

... 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,
  edge_weight = NULL,
  vertex_size = 5,
  vertex_color = "black",
  edge_width = 1,
  edge_color = "black",
  line_width = NULL,
  line_color = "rgb(0,0,200)",
  scale_color = ggplot2::scale_color_viridis_c(option = "d"),
  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`?

`edge_weight` Which column from edge weights to plot? If NULL edge weights are not plotted. To plot the edge weights when the metric graph `edge_weights` is a vector instead of a `data.frame`, simply set to 1.

`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.
 scale_color Color scale to be used for data and weights.
 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 $m \times T$ matrix where the i th column represents the function at the i th 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. Gets the edge weights data.frame If the edge weights are given as vectors, should the result be returned as a data.frame? A vector or data.frame containing the edge weights. 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,
  compute_pred_variances = FALSE,
```



```

posterior_samples = FALSE,
pred_samples = FALSE,
n_samples = 100,
edge_number = "edge_number",
distance_on_edge = "distance_on_edge",
normalized = FALSE,
no_nugget = FALSE,
return_as_list = FALSE,
return_original_order = TRUE,
check_euclidean = 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.
compute_pred_variances	Set to TRUE to compute the prediction variances. Will only be computed if newdata is NULL.
posterior_samples	If TRUE, posterior samples for the random effect will be returned.
pred_samples	If TRUE, prediction samples for the response variable will be returned. Will only be computed if newdata is NULL.
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?
no_nugget	Should the prediction be carried out without the nugget?
return_as_list	Should the means of the predictions and the posterior samples be returned as a list, with each replicate being an element?

<code>return_original_order</code>	Should the results be return in the original (input) order or in the order inside the graph?
<code>check_euclidean</code>	Check if the graph used to compute the resistance distance has Euclidean edges? The graph used to compute the resistance distance has the observation locations as vertices.
<code>...</code>	Not used.
<code>data</code>	[Deprecated] Use <code>newdata</code> 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 posterior variances of the random effects, `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 prediction 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 <code>rspde_metric_graph</code> object built with the <code>rspde.metric_graph()</code> function.
cmp	The 'inlabru' component used to fit the model.
bru_fit	A fitted model using 'inlabru' or 'INLA'.
newdata	A <code>data.frame</code> 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 <code>NULL</code> , 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 <code>PtE</code> , 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 <code>euclidean</code> , 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 prediction 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 <code>metric_graph</code> 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.graph_lme
```

Simulation of models on metric graphs

Description

The function samples a Gaussian random field based on a fitted model using `graph_lme()`.

Usage

```
## S3 method for class 'graph_lme'
simulate(
  object,
  nsim = 1,
  seed = NULL,
  sample_latent = FALSE,
  posterior = FALSE,
  which_repl = NULL,
  ...
)
```

Arguments

object	A graph_lme object
nsim	The number of simulations.
seed	an object specifying if and how the random number generator should be initialized ('seeded').
sample_latent	If FALSE, samples for the response variable will be generated. If TRUE, samples for the latent model will be generated. The default is FALSE.
posterior	Should posterior samples be generated? If FALSE, samples will be computed based on the estimated prior distribution. The default is FALSE.
which_repl	Which replicates to generate the samples. If NULL samples will be generated for all replicates. Default is NULL.
...	Currently not used.

Value

A list containing elements `samples`, `edge_number` and `distance_on_edge`. Each of them is a list, whose indexes are the replicates, and in `samples` a matrix is given with `nsim` columns, each one being a sample. `edge_number` and `distance_on_edges` contain the respective edge numbers and distances on edge for each sampled element. The locations of the samples are the location of the data in which the model was fitted.

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	<i>Covariance function for Whittle-Matérn fields</i>
-----------------	--

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 <code>metric_graph</code> 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	<i>Precision matrix for Whittle-Matérn fields</i>
----------------	---

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 <code>metric_graph</code> .
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 <code>rspde.result</code> object.
digits	Integer, used for number formatting with <code>signif()</code>
...	Currently not used.

Value

A `data.frame` containing the summary.

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