

Package ‘fmesher’

November 6, 2024

Type Package

Title Triangle Meshes and Related Geometry Tools

Version 0.2.0

Description Generate planar and spherical triangle meshes, compute finite element calculations for 1- and 2-dimensional flat and curved manifolds with associated basis function spaces, methods for lines and polygons, and transparent handling of coordinate reference systems and coordinate transformation, including 'sf' and 'sp' geometries. The core 'fmesher' library code was originally part of the 'INLA' package, and implements parts of "Triangulations and Applications" by Hjelle and Daehlen (2006) <[doi:10.1007/3-540-33261-8](https://doi.org/10.1007/3-540-33261-8)>.

Depends R (>= 4.0), methods

Imports dplyr, graphics, grDevices, lifecycle, Matrix, rlang, sf, stats, tibble, utils, withr, Rcpp

Suggests ggplot2, knitr, testthat (>= 3.0.0), terra, tidyterra, rgl, rmarkdown, sp (>= 1.6-1), splancs, gsl

URL <https://inlabru-org.github.io/fmesher/>,
<https://github.com/inlabru-org/fmesher>

BugReports <https://github.com/inlabru-org/fmesher/issues>

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 'crs.R' 'data-fmexample.R' 'diameter.R' 'evaluator.R' 'fem.R'
 'fm.R' 'fmeshers-package.R' 'fmeshers.R' 'ggplot.R'
 'integration.R' 'lattice_2d.R' 'list.R' 'local.R' 'manifold.R'
 'mapping.R' 'matern.R' 'mesh.R' 'mesh_1d.R' 'mesh_2d.R'
 'nonconvex_hull.R' 'onload.R' 'plot.R' 'segm.R' 'sf_mesh.R'
 'sf_utils.R' 'simplify.R' 'sp_mesh.R' 'split_lines.R'
 'tensor.R' 'utils.R'

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 fmesher-deprecated *Deprecated functions in fmesher*

Description

These functions still attempt to do their job, but will be removed in a future version.

Usage

```

fm_spTransform(x, ...)

## Default S3 method:
fm_spTransform(x, crs0 = NULL, crs1 = NULL, passthrough = FALSE, ...)

## S3 method for class 'SpatialPoints'
fm_spTransform(x, CRSobj, passthrough = FALSE, ...)

## S3 method for class 'SpatialPointsDataFrame'
fm_spTransform(x, CRSobj, passthrough = FALSE, ...)

## S3 method for class 'inla.mesh.lattice'
fm_spTransform(x, CRSobj, passthrough = FALSE, ...)

## S3 method for class 'inla.mesh.segment'
fm_spTransform(x, CRSobj, passthrough = FALSE, ...)

## S3 method for class 'inla.mesh'
fm_spTransform(x, CRSobj, passthrough = FALSE, ...)

fm_has_PROJ6()

fm_as_sp_crs(x, ...)

fm_sp_get_crs(x)

fm_as_inla_mesh_segment(...)

fm_as_inla_mesh(...)

fm_sp2segment(...)

```

Arguments

x	A <code>sp::Spatial</code> object
...	Potential additional arguments
crs0	The source <code>sp::CRS</code> or <code>inla.CRS</code> object

crs1	The target sp::CRS or inla.CRS object
passthrough	Default is FALSE. Setting to TRUE allows objects with no CRS information to be passed through without transformation.
CRSobj	The target sp::CRS or inla.CRS object

Details

This function is a convenience method to workaroud PROJ4/PROJ6 differences, and the lack of a crs extraction method for Spatial objects. For newer code, use `fm_crs()` instead, that returns crs objects, and use `fm_CRS()` to extract/construct/convert to old style sp: :CRS objects.

Value

A CRS object, or NULL if no valid CRS identified

An fm_seg object

An fm_mesh_2d object

Functions

- `fm_spTransform()`: **[Deprecated]** (See `fm_transform()` instead) Handle transformation of various inla objects according to coordinate reference systems of sp: :CRS or INLA: :inla.CRS class.
- `fm_spTransform(default)`: The default method handles low level transformation of raw coordinates.
- `fm_has_PROJ6()`: Old checker for PROJ6.
- `fm_as_sp_crs()`: Wrapper for `fm_CRS()` sp::Spatial and sp::CRS objects.
- `fm_sp_get_crs()`: Wrapper for CRS(projargs) (PROJ4) and CRS(wkt) for sp::Spatial objects.
- `fm_as_inla_mesh_segment()`: Conversion to inla.mesh.segment **[Deprecated]** in favour of `fm_as_seg()`.
- `fm_as_inla_mesh()`: Conversion to inla.mesh. **[Deprecated]** in favour of `fm_as_mesh_2d()`.
- `fm_sp2segment()`: **[Deprecated]** in favour of `fm_as_seg()`

Author(s)

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See Also

[fm_transform\(\)](#)

Examples

```
if (fm_safe_sp()) {
  s <- sp::SpatialPoints(matrix(1:6, 3, 2), proj4string = fm_CRS("sphere"))
  fm_CRS(s)
}
```

fmesher-print

Print objects

Description

Print objects

Usage

```
## S3 method for class 'fm_segm'
print(x, ..., digits = NULL, verbose = TRUE, newline = TRUE)

## S3 method for class 'fm_segm_list'
print(x, ..., digits = NULL, verbose = FALSE, newline = TRUE)

## S3 method for class 'fm_mesh_2d'
print(x, ..., digits = NULL, verbose = FALSE)

## S3 method for class 'fm_mesh_1d'
print(x, ..., digits = NULL, verbose = FALSE)

## S3 method for class 'fm_bbox'
print(x, ..., digits = NULL, verbose = TRUE, newline = TRUE)

## S3 method for class 'fm_tensor'
print(x, ..., digits = NULL, verbose = FALSE)

## S3 method for class 'fm_crs'
print(x, ...)

## S3 method for class 'fm_CRS'
print(x, ...)
```

Arguments

x	an object used to select a method.
...	further arguments passed to or from other methods.
digits	a positive integer indicating how many significant digits are to be used for numeric and complex x. The default, NULL, uses <code>getOption("digits")</code> .
verbose	logical
newline	logical; if TRUE (default), end the printing with <code>\n</code>

Value

The input object x

Examples

```
fm_bbox(matrix(1:6, 3, 2))
print(fm_bbox(matrix(1:6, 3, 2)), verbose = FALSE)

print(fmexample$mesh)
print(fmexample$boundary_fm)

print(fm_mesh_1d(c(1, 2, 3, 5, 7), degree = 2))
```

fmesher_bary	<i>Barycentric coordinate computation</i>
--------------	---

Description

Locate points and compute triangular barycentric coordinates

Usage

```
fmesher_bary(mesh_loc, mesh_tv, loc, options)
```

Arguments

mesh_loc	numeric matrix; mesh vertex coordinates
mesh_tv	3-column integer matrix with 0-based vertex indices for each triangle
loc	numeric matrix; coordinates of points to locate in the mesh
options	list of triangulation options

Value

A list with vector `t` and matrix `bary`

Examples

```
m <- fmesher_rcdt(list(cet_margin = 1), matrix(0, 1, 2))
b <- fmesher_bary(m$s,
                 m$tv,
                 matrix(c(0.5, 0.5), 1, 2),
                 list())
```

fmesher_fem	<i>Finite element matrix computation</i>
-------------	--

Description

Construct finite element structure matrices

Usage

```
fmesher_fem(mesh_loc, mesh_tv, fem_order_max, aniso, options)
```

Arguments

mesh_loc	numeric matrix; mesh vertex coordinates
mesh_tv	3-column integer matrix with 0-based vertex indices for each triangle
fem_order_max	integer; the highest operator order to compute
aniso	If non-NULL, a <code>list(gamma, v)</code> . Calculates anisotropic structure matrices (in addition to the regular) for γ and v for an anisotropic operator $\nabla \cdot H \nabla$, where $H = \gamma I + vv^T$. Currently (2023-08-05) the fields need to be given per vertex.
options	list of triangulation options (sphere_tolerance)

Value

A list of matrices

Examples

```
m <- fmesher_rcdt(list(cet_margin = 1), matrix(0, 1, 2))
b <- fmesher_fem(m$s, m$tv, fem_order_max = 2, aniso = NULL, options = list())
```

fmesher_globe_points	<i>Globe points</i>
----------------------	---------------------

Description

Create points on a globe

Usage

```
fmesher_globe_points(globe)
```

Arguments

globe	integer; the number of edge subdivision segments, 1 or higher.
-------	--

Value

A matrix of points on a unit radius globe

Examples

```
fmesher_globe_points(1)
```

 fmesher_rcdt

Refined Constrained Delaunay Triangulation

Description

(...)

Usage

```
fmesher_rcdt(
  options,
  loc,
  tv = NULL,
  boundary = NULL,
  interior = NULL,
  boundary_grp = NULL,
  interior_grp = NULL
)
```

Arguments

options	list of triangulation options
loc	numeric matrix; initial points to include
tv	3-column integer matrix with 0-based vertex indices for each triangle
boundary	2-column integer matrix with 0-based vertex indices for each boundary edge constraint
interior	2-column integer matrix with 0-based vertex indices for each interior edge constraint
boundary_grp	integer vector with group labels
interior_grp	integer vector with group labels

Value

A list of information objects for a generated triangulation

Examples

```
m <- fmesher_rcdt(list(cet_margin = 1), matrix(0, 1, 2))
```

fmesh_split_lines *Split lines at triangle edges*

Description

Split a sequence of line segments at triangle edges

Usage

```
fmesh_split_lines(mesh_loc, mesh_tv, loc, idx, options)
```

Arguments

mesh_loc	numeric matrix; mesh vertex coordinates
mesh_tv	3-column integer matrix with 0-based vertex indices for each triangle
loc	numeric coordinate matrix
idx	2-column integer matrix
options	list of triangulation options (sphere_tolerance)

Value

A list of line splitting information objects

See Also

[fm_split_lines\(\)](#)

Examples

```
mesh <- fm_mesh_2d(
  boundary = fm_segm(rbind(c(0,0), c(1,0), c(1,1), c(0, 1)), is.bnd = TRUE)
)
splitter <- fm_segm(rbind(c(0.8, 0.2), c(0.2, 0.8)))
segm_split <- fm_split_lines(mesh, splitter)
```

fmexample *Example mesh data*

Description

This is an example data set used for fmesher package examples.

Usage

```
fmexample
```

Format

The data is a list containing these elements:

loc: A matrix of points.

loc_sf: An sfc version of loc.

boundary_fm: A fm_segm_list of two fm_segm objects used in the mesh construction.

boundary_sf: An sfc list version of boundary.

mesh: An [fm_mesh_2d\(\)](#) object.

Source

Generated by data-raw/fmexample.R.

See Also

[fmexample_sp\(\)](#)

Examples

```
if (require(ggplot2, quietly = TRUE)) {  
  ggplot() +  
    geom_sf(data = fm_as_sfc(fmexample$mesh)) +  
    geom_sf(data = fmexample$boundary_sf[[1]], fill = "red", alpha = 0.5)  
}
```

fmexample_sp

Add sp data to fmexample

Description

Adds loc_sp and boundary_sp to [fmexample](#) for use in sp related code examples and tests.

Usage

```
fmexample_sp()
```

Value

Returns a copy of [fmexample](#) with loc_sp (SpatialPoints) and boundary_sp (SpatialPolygons) added.

Examples

```
if (fm_safe_sp()) {  
  fmexample_sp()  
}
```

`fm_as_fm`*Convert objects to fmesher objects*

Description

Used for conversion from general objects (usually `inla.mesh` and other INLA specific classes) to fmesher classes.

Usage

```
fm_as_fm(x, ...)  
  
## S3 method for class 'NULL'  
fm_as_fm(x, ...)  
  
## S3 method for class 'fm_mesh_1d'  
fm_as_fm(x, ...)  
  
## S3 method for class 'fm_mesh_2d'  
fm_as_fm(x, ...)  
  
## S3 method for class 'fm_tensor'  
fm_as_fm(x, ...)  
  
## S3 method for class 'fm_segm'  
fm_as_fm(x, ...)  
  
## S3 method for class 'fm_lattice_2d'  
fm_as_fm(x, ...)  
  
## S3 method for class 'fm_bbox'  
fm_as_fm(x, ...)  
  
## S3 method for class 'crs'  
fm_as_fm(x, ...)  
  
## S3 method for class 'CRS'  
fm_as_fm(x, ...)  
  
## S3 method for class 'fm_crs'  
fm_as_fm(x, ...)  
  
## S3 method for class 'inla.CRS'  
fm_as_fm(x, ...)  
  
## S3 method for class 'inla.mesh.1d'  
fm_as_fm(x, ...)
```

```

## S3 method for class 'inla.mesh'
fm_as_fm(x, ...)

## S3 method for class 'inla.mesh.segment'
fm_as_fm(x, ...)

## S3 method for class 'inla.mesh.lattice'
fm_as_fm(x, ...)

```

Arguments

x Object to be converted
... Arguments forwarded to submethods

Value

An object of some fm_* class

See Also

Other object creation and conversion: [fm_as_lattice_2d\(\)](#), [fm_as_mesh_1d\(\)](#), [fm_as_mesh_2d\(\)](#), [fm_as_seg\(\)](#), [fm_as_sfc\(\)](#), [fm_as_tensor\(\)](#), [fm_lattice_2d\(\)](#), [fm_mesh_1d\(\)](#), [fm_mesh_2d\(\)](#), [fm_seg\(\)](#), [fm_simplify\(\)](#), [fm_tensor\(\)](#)

Examples

```
fm_as_fm(NULL)
```

fm_as_lattice_2d *Convert objects to fm_lattice_2d*

Description

Convert objects to fm_lattice_2d

Usage

```

fm_as_lattice_2d(...)

fm_as_lattice_2d_list(x, ...)

## S3 method for class 'fm_lattice_2d'
fm_as_lattice_2d(x, ...)

## S3 method for class 'inla.mesh.lattice'
fm_as_lattice_2d(x, ...)

```

Arguments

... Arguments passed on to submethods
 x Object to be converted

Value

An fm_lattice_2d or fm_lattice_2d_list object

Functions

- fm_as_lattice_2d(): Convert an object to fm_lattice_2d.
- fm_as_lattice_2d_list(): Convert each element of a list

See Also

Other object creation and conversion: [fm_as_fm\(\)](#), [fm_as_mesh_1d\(\)](#), [fm_as_mesh_2d\(\)](#), [fm_as_segm\(\)](#), [fm_as_sfc\(\)](#), [fm_as_tensor\(\)](#), [fm_lattice_2d\(\)](#), [fm_mesh_1d\(\)](#), [fm_mesh_2d\(\)](#), [fm_segm\(\)](#), [fm_simplify\(\)](#), [fm_tensor\(\)](#)

Examples

```
str(fm_as_lattice_2d_list(list(fm_lattice_2d(), fm_lattice_2d())))
```

fm_as_mesh_1d	<i>Convert objects to fm_segm</i>
---------------	-----------------------------------

Description

Convert objects to fm_segm

Usage

```
fm_as_mesh_1d(x, ...)
```

```
fm_as_mesh_1d_list(x, ...)
```

```
## S3 method for class 'fm_mesh_1d'
```

```
fm_as_mesh_1d(x, ...)
```

```
## S3 method for class 'inla.mesh.1d'
```

```
fm_as_mesh_1d(x, ...)
```

Arguments

x Object to be converted
 ... Arguments passed on to submethods

Value

An fm_mesh_1d or fm_mesh_1d_list object

Functions

- fm_as_mesh_1d(): Convert an object to fm_mesh_1d.
- fm_as_mesh_1d_list(): Convert each element of a list

See Also

Other object creation and conversion: [fm_as_fm\(\)](#), [fm_as_lattice_2d\(\)](#), [fm_as_mesh_2d\(\)](#), [fm_as_segm\(\)](#), [fm_as_sfc\(\)](#), [fm_as_tensor\(\)](#), [fm_lattice_2d\(\)](#), [fm_mesh_1d\(\)](#), [fm_mesh_2d\(\)](#), [fm_segm\(\)](#), [fm_simplify\(\)](#), [fm_tensor\(\)](#)

Examples

```
fm_as_mesh_1d_list(list(fm_mesh_1d(1:4)))
```

<code>fm_as_mesh_2d</code>	<i>Convert objects to fm_mesh_2d</i>
----------------------------	--------------------------------------

Description

Convert objects to fm_mesh_2d

Usage

```
fm_as_mesh_2d(x, ...)

fm_as_mesh_2d_list(x, ...)

## S3 method for class 'fm_mesh_2d'
fm_as_mesh_2d(x, ...)

## S3 method for class 'inla.mesh'
fm_as_mesh_2d(x, ...)

## S3 method for class 'sfg'
fm_as_mesh_2d(x, ...)

## S3 method for class 'sfc_MULTIPOLYGON'
fm_as_mesh_2d(x, ...)

## S3 method for class 'sfc_POLYGON'
fm_as_mesh_2d(x, ...)

## S3 method for class 'sf'
fm_as_mesh_2d(x, ...)
```

Arguments

x Object to be converted
 ... Arguments passed on to submethods

Value

An fm_mesh_2d or fm_mesh_2d_list object

Functions

- fm_as_mesh_2d(): Convert an object to fm_mesh_2d.
- fm_as_mesh_2d_list(): Convert each element of a list

See Also

Other object creation and conversion: [fm_as_fm\(\)](#), [fm_as_lattice_2d\(\)](#), [fm_as_mesh_1d\(\)](#), [fm_as_segm\(\)](#), [fm_as_sfc\(\)](#), [fm_as_tensor\(\)](#), [fm_lattice_2d\(\)](#), [fm_mesh_1d\(\)](#), [fm_mesh_2d\(\)](#), [fm_segm\(\)](#), [fm_simplify\(\)](#), [fm_tensor\(\)](#)

Examples

```
fm_as_mesh_2d_list(list(fm_mesh_2d(cbind(2, 1))))
```

fm_as_segm	<i>Convert objects to fm_segm</i>
------------	-----------------------------------

Description

Convert objects to fm_segm

Usage

```
fm_as_segm(x, ...)
```

```
fm_as_segm_list(x, ...)
```

```
## S3 method for class 'fm_segm'  
fm_as_segm(x, ...)
```

```
## S3 method for class 'inla.mesh.segment'  
fm_as_segm(x, ...)
```

```
## S3 method for class 'sfg'  
fm_as_segm(x, ...)
```

```
## S3 method for class 'sfc_POINT'  
fm_as_segm(x, reverse = FALSE, grp = NULL, is.bnd = TRUE, ...)
```



```
## S3 method for class 'sfc_LINESTRING'
fm_as_segm(x, join = TRUE, grp = NULL, reverse = FALSE, ...)

## S3 method for class 'sfc_MULTILINESTRING'
fm_as_segm(x, join = TRUE, grp = NULL, reverse = FALSE, ...)

## S3 method for class 'sfc_POLYGON'
fm_as_segm(x, join = TRUE, grp = NULL, ...)

## S3 method for class 'sfc_MULTIPOLYGON'
fm_as_segm(x, join = TRUE, grp = NULL, ...)

## S3 method for class 'sfc_GEOMETRY'
fm_as_segm(x, grp = NULL, join = TRUE, ...)

## S3 method for class 'sf'
fm_as_segm(x, ...)

## S3 method for class 'matrix'
fm_as_segm(
  x,
  reverse = FALSE,
  grp = NULL,
  is.bnd = FALSE,
  crs = NULL,
  closed = FALSE,
  ...
)

## S3 method for class 'SpatialPoints'
fm_as_segm(x, reverse = FALSE, grp = NULL, is.bnd = TRUE, closed = FALSE, ...)

## S3 method for class 'SpatialPointsDataFrame'
fm_as_segm(x, ...)

## S3 method for class 'Line'
fm_as_segm(x, reverse = FALSE, grp = NULL, crs = NULL, ...)

## S3 method for class 'Lines'
fm_as_segm(x, join = TRUE, grp = NULL, crs = NULL, ...)

## S3 method for class 'SpatialLines'
fm_as_segm(x, join = TRUE, grp = NULL, ...)

## S3 method for class 'SpatialLinesDataFrame'
fm_as_segm(x, ...)
```

```
## S3 method for class 'SpatialPolygons'
fm_as_segm(x, join = TRUE, grp = NULL, ...)

## S3 method for class 'SpatialPolygonsDataFrame'
fm_as_segm(x, ...)

## S3 method for class 'Polygons'
fm_as_segm(x, join = TRUE, crs = NULL, grp = NULL, ...)

## S3 method for class 'Polygon'
fm_as_segm(x, crs = NULL, ...)
```

Arguments

x	Object to be converted.
...	Arguments passed on to submethods
reverse	logical; When TRUE, reverse the order of the input points. Default FALSE
grp	if non-null, should be an integer vector of grouping labels for one for each segment. Default NULL
is.bnd	logical; if TRUE, set the boundary flag for the segments. Default TRUE
join	logical; if TRUE, join input segments with common vertices. Default TRUE
crs	A crs object
closed	logical; whether to treat a point sequence as a closed polygon. Default: FALSE

Value

An `fm_segm` or `fm_segm_list` object

Functions

- `fm_as_segm()`: Convert an object to `fm_segm`.
- `fm_as_segm_list()`: Convert each element, making a `fm_segm_list` object

See Also

[c.fm_segm\(\)](#), [c.fm_segm_list\(\)](#), [\[.fm_segm_list\(\)](#)

Other object creation and conversion: [fm_as_fm\(\)](#), [fm_as_lattice_2d\(\)](#), [fm_as_mesh_1d\(\)](#), [fm_as_mesh_2d\(\)](#), [fm_as_sfc\(\)](#), [fm_as_tensor\(\)](#), [fm_lattice_2d\(\)](#), [fm_mesh_1d\(\)](#), [fm_mesh_2d\(\)](#), [fm_segm\(\)](#), [fm_simplify\(\)](#), [fm_tensor\(\)](#)

Examples

```
fm_as_segm_list(list(
  fm_segm(fmexample$mesh),
  fm_segm(fmexample$mesh, boundary = FALSE)
))
```

```
(segm <- fm_segm(fmexample$mesh, boundary = FALSE))
(segm_sfc <- fm_as_sfc(segm))
(fm_as_segm(segm_sfc))
```

fm_as_sfc

Conversion methods from mesh related objects to sfc

Description

Conversion methods from mesh related objects to sfc

Usage

```
fm_as_sfc(x, ...)

## S3 method for class 'fm_mesh_2d'
fm_as_sfc(x, ..., format = NULL, multi = FALSE)

## S3 method for class 'fm_segm'
fm_as_sfc(x, ..., multi = FALSE)

## S3 method for class 'sfc'
fm_as_sfc(x, ...)

## S3 method for class 'sf'
fm_as_sfc(x, ...)

## S3 method for class 'inla.mesh'
fm_as_sfc(x, ...)

## S3 method for class 'inla.mesh.segment'
fm_as_sfc(x, ..., multi = FALSE)
```

Arguments

x	An object to be coerced/transformed/converted into another class
...	Arguments passed on to other methods
format	One of "mesh", "int", "bnd", or "loc". Default "mesh".
multi	logical; if TRUE, attempt to a sfc_MULTIPOLYGON/LINESTRING/POINT, otherwise a set of sfc_POLYGON/LINESTRING/POINT. Default FALSE

Value

- fm_as_sfc: An sfc_MULTIPOLYGON/LINESTRING/POINT or sfc_POLYGON/LINESTRING/POINT object

Methods (by class)

- `fm_as_sfc(fm_mesh_2d)`: **[Experimental]**
- `fm_as_sfc(fm_seg)`: **[Experimental]**
- `fm_as_sfc(inla.mesh)`: **[Deprecated]** since `inla.mesh` is deprecated. See `fm_as_sfc.fm_mesh_2d` instead.
- `fm_as_sfc(inla.mesh.segment)`: **[Deprecated]** since `inla.mesh.segment` is deprecated. See `fm_as_sfc.fm_seg` instead.

See Also

Other object creation and conversion: `fm_as_fm()`, `fm_as_lattice_2d()`, `fm_as_mesh_1d()`, `fm_as_mesh_2d()`, `fm_as_seg()`, `fm_as_tensor()`, `fm_lattice_2d()`, `fm_mesh_1d()`, `fm_mesh_2d()`, `fm_seg()`, `fm_simplify()`, `fm_tensor()`

Examples

```
fm_as_sfc(fmexample$mesh)
fm_as_sfc(fmexample$mesh, multi = TRUE)
fm_as_sfc(fmexample$mesh, format = "loc")

# Boundary edge conversion currently only supports (multi)linestring output,
# and does not convert to polygons.
suppressWarnings(
  fm_as_sfc(fmexample$mesh, format = "bnd")
)
```

fm_as_tensor

Convert objects to fm_tensor

Description

Convert objects to `fm_tensor`

Usage

```
fm_as_tensor(x, ...)

fm_as_tensor_list(x, ...)

## S3 method for class 'fm_tensor'
fm_as_tensor(x, ...)
```

Arguments

`x` Object to be converted
`...` Arguments passed on to submethods

Value

An fm_tensor object

Functions

- `fm_as_tensor()`: Convert an object to fm_tensor.
- `fm_as_tensor_list()`: Convert each element of a list

See Also

Other object creation and conversion: `fm_as_fm()`, `fm_as_lattice_2d()`, `fm_as_mesh_1d()`, `fm_as_mesh_2d()`, `fm_as_segm()`, `fm_as_sfc()`, `fm_lattice_2d()`, `fm_mesh_1d()`, `fm_mesh_2d()`, `fm_segm()`, `fm_simplify()`, `fm_tensor()`

Examples

```
fm_as_tensor_list(list(fm_tensor(list())))
```

fm_bary

Compute barycentric coordinates

Description

Identify knot intervals or triangles and compute barycentric coordinates

Usage

```
fm_bary(mesh, loc, ...)

## S3 method for class 'fm_mesh_1d'
fm_bary(mesh, loc, method = c("linear", "nearest"), restricted = FALSE, ...)

## S3 method for class 'fm_mesh_2d'
fm_bary(mesh, loc, crs = NULL, ..., max_batch_size = NULL)

## S3 method for class 'inla.mesh'
fm_bary(mesh, ...)

## S3 method for class 'inla.mesh.1d'
fm_bary(mesh, ...)
```

Arguments

mesh	fm_mesh_1d or fm_mesh_2d object
loc	Points for which to identify the containing interval/triangle, and corresponding barycentric coordinates. May be a vector (for 1d) or a matrix of raw coordinates, sf, or sp point information (for 2d).
...	Arguments forwarded to sub-methods.
method	character; method for defining the barycentric coordinates, "linear" (default) or "nearest"
restricted	logical, used for method="linear". If FALSE (default), points outside the mesh interval will be given barycentric weights less than 0 and greater than 1, according to linear extrapolation. If TRUE, the barycentric weights are clamped to the (0, 1) interval.
crs	Optional crs information for loc
max_batch_size	integer; maximum number of points to process in a single batch. This speeds up calculations by avoiding repeated large internal memory allocations and data copies. The default, NULL, uses max_batch_size = 2e5L, chosen based on empirical time measurements to give an approximately optimal runtime.

Value

A list with elements `t`; either

- vector of triangle indices (triangle meshes),
- matrix of interval knot indices (1D meshes), or
- matrix of lower left box indices (2D lattices),

and `bary`, a matrix of barycentric coordinates.

Methods (by class)

- `fm_bary(fm_mesh_1d)`: Return a list with elements `t` (start and endpoint knot indices) and `bary` (barycentric coordinates), both 2-column matrices.
For method = "nearest", `t[,1]` contains the index of the nearest mesh knot, and each row of `bary` contains `c(1, 0)`.
- `fm_bary(fm_mesh_2d)`: A list with elements `t` (vector of triangle indices) and `bary` (3-column matrix of barycentric coordinates). Points that were not found give NA entries in `t` and `bary`.

Examples

```
str(fm_bary(fmexample$mesh, fmexample$loc_sf))
str(fm_bary(fm_mesh_1d(1:4), seq(0, 5, by = 0.5)))
```

fm_basis

*Compute mapping matrix between mesh function space and points***Description**

Computes the basis mapping matrix between a function space on a mesh, and locations.

Usage

```
fm_basis(x, ..., full = FALSE)

## Default S3 method:
fm_basis(x, ..., full = FALSE)

## S3 method for class 'fm_mesh_1d'
fm_basis(x, loc, weights = NULL, derivatives = NULL, ..., full = FALSE)

## S3 method for class 'fm_mesh_2d'
fm_basis(x, loc, weights = NULL, derivatives = NULL, ..., full = FALSE)

## S3 method for class 'inla.mesh.1d'
fm_basis(x, ...)

## S3 method for class 'inla.mesh'
fm_basis(x, ...)

## S3 method for class 'fm_evaluator'
fm_basis(x, ..., full = FALSE)

## S3 method for class 'fm_basis'
fm_basis(x, ..., full = FALSE)

## S3 method for class 'fm_tensor'
fm_basis(x, loc, weights = NULL, ..., full = FALSE)
```

Arguments

x	<code>fm_tensor()</code> object
...	Passed on to submethods
full	logical; if TRUE, return a <code>fm_basis</code> object, containing at least a projection matrix A and logical vector <code>ok</code> indicating which evaluations are valid. If FALSE, return only the projection matrix A. Default is FALSE.
loc	A location/value information object (vector, matrix, <code>sf</code> , etc, depending on the class of <code>x</code>)
weights	Optional weight vector to apply (from the left, one weight for each row of the basis matrix)

derivatives If non-NULL and logical, include derivative matrices in the output. Forces full = TRUE.

Value

A sparseMatrix object (if full = FALSE), or a fm_basis object (if full = TRUE or isTRUE(derivatives)). The fm_basis object contains at least the projection matrix A and logical vector ok; $u(\text{loc}_i) = \sum_j A_{ij} w_i$

Methods (by class)

- fm_basis(fm_mesh_1d): The fm_basis object contains additional derivative weight matrices, d1A and d2A, $du/dx(\text{loc}_i) = \sum_j dx_{ij} w_i$.
- fm_basis(fm_mesh_2d): If derivatives=TRUE, additional derivative weight matrices are included in the full=TRUE output: Derivative weight matrices dx, dy, dz; $du/dx(\text{loc}_i) = \sum_j dx_{ij} w_i$, etc.

See Also

[fm_raw_basis\(\)](#)

Examples

```
# Compute basis mapping matrix
str(fm_basis(fmexample$mesh, fmexample$loc))
print(fm_basis(fmexample$mesh, fmexample$loc), full = TRUE)
```

fm_bbox

Bounding box class

Description

Simple class for handling bounding box information

Usage

```
fm_bbox(...)

## S3 method for class 'list'
fm_bbox(x, ...)

## S3 method for class 'NULL'
fm_bbox(...)

## S3 method for class 'numeric'
fm_bbox(x, ...)

## S3 method for class 'matrix'
fm_bbox(x, ...)
```



```
## S3 method for class 'Matrix'
fm_bbox(x, ...)

## S3 method for class 'fm_bbox'
fm_bbox(x, ...)

## S3 method for class 'fm_mesh_1d'
fm_bbox(x, ...)

## S3 method for class 'fm_mesh_2d'
fm_bbox(x, ...)

## S3 method for class 'fm_segm'
fm_bbox(x, ...)

## S3 method for class 'fm_lattice_2d'
fm_bbox(x, ...)

## S3 method for class 'fm_tensor'
fm_bbox(x, ...)

## S3 method for class 'sf'
fm_bbox(x, ...)

## S3 method for class 'sfg'
fm_bbox(x, ...)

## S3 method for class 'sfc'
fm_bbox(x, ...)

## S3 method for class 'bbox'
fm_bbox(x, ...)

## S3 method for class 'inla.mesh'
fm_bbox(x, ...)

## S3 method for class 'inla.mesh.segment'
fm_bbox(x, ...)

fm_as_bbox(x, ...)

## S3 method for class 'fm_bbox'
x[i]

## S3 method for class 'fm_bbox'
c(..., .join = FALSE)
```

Arguments

...	Passed on to sub-methods
x	fm_bbox object from which to extract element(s)
i	indices specifying elements to extract
.join	logical; if TRUE, concatenate the bounding boxes into a single multi-dimensional bounding box. Default is FALSE.

Value

For `c.fm_bbox()`, a `fm_bbox_list` object if `join = FALSE` (the default) or an `fm_bbox` object if `join = TRUE`.

Methods (by class)

- `fm_bbox(list)`: Construct a bounding box from precomputed interval information, stored as a list of 2-vector ranges, `list(xlim, ylim, ...)`.

Methods (by generic)

- `[:`: Extract sub-list
- `c(fm_bbox)`: The ... arguments should be `fm_bbox` objects, or coercible with `fm_as_bbox(list(...))`.

Examples

```
fm_bbox(matrix(1:6, 3, 2))
m <- c(A = fm_bbox(cbind(1, 2)), B = fm_bbox(cbind(3, 4)))
str(m)
str(m[2])
```

fm_block

Blockwise aggregation matrices

Description

Creates an aggregation matrix for blockwise aggregation, with optional weighting.

Usage

```
fm_block(
  block = NULL,
  weights = NULL,
  log_weights = NULL,
  rescale = FALSE,
  n_block = NULL
)
```

```
fm_block_eval(  
    block = NULL,  
    weights = NULL,  
    log_weights = NULL,  
    rescale = FALSE,  
    n_block = NULL,  
    values = NULL  
)  
  
fm_block_logsumexp_eval(  
    block = NULL,  
    weights = NULL,  
    log_weights = NULL,  
    rescale = FALSE,  
    n_block = NULL,  
    values = NULL,  
    log = TRUE  
)  
  
fm_block_weights(  
    block = NULL,  
    weights = NULL,  
    log_weights = NULL,  
    rescale = FALSE,  
    n_block = NULL  
)  
  
fm_block_log_weights(  
    block = NULL,  
    weights = NULL,  
    log_weights = NULL,  
    rescale = FALSE,  
    n_block = NULL  
)  
  
fm_block_log_shift(block = NULL, log_weights = NULL, n_block = NULL)  
  
fm_block_prep(  
    block = NULL,  
    log_weights = NULL,  
    weights = NULL,  
    n_block = NULL,  
    values = NULL,  
    n_values = NULL,  
    force_log = FALSE  
)
```

Arguments

block	integer vector; block information. If NULL, <code>rep(1L, block_len)</code> is used, where <code>block_len</code> is determined by <code>length(log_weights)</code> or <code>length(weights)</code> . A single scalar is also repeated to a vector of corresponding length to the weights.
weights	Optional weight vector
log_weights	Optional <code>log(weights)</code> vector. Overrides <code>weights</code> when non-NULL.
rescale	logical; If TRUE, normalise the weights by <code>sum(weights)</code> or <code>sum(exp(log_weights))</code> within each block. Default: FALSE
n_block	integer; The number of conceptual blocks. Only needs to be specified if it's larger than <code>max(block)</code> , or to keep the output of consistent size for different inputs.
values	Vector to be blockwise aggregated
log	If TRUE (default), return log-sum-exp. If FALSE, return sum-exp.
n_values	When supplied, used instead of <code>length(values)</code> to determine the value vector input length.
force_log	When FALSE (default), passes either <code>weights</code> and <code>log_weights</code> on, if provided, with <code>log_weights</code> taking precedence. If TRUE, forces the computation of <code>log_weights</code> , whether given in the input or not.

Value

A (sparse) matrix

Functions

- `fm_block()`: A (sparse) matrix of size `n_block` times `length(block)`.
- `fm_block_eval()`: Evaluate aggregation. More efficient alternative to `as.vector(fm_block(...)) %*% values`.
- `fm_block_logsumexp_eval()`: Evaluate log-sum-exp aggregation. More efficient and numerically stable alternative to `log(as.vector(fm_block(...)) %*% exp(values))`.
- `fm_block_weights()`: Computes (optionally) blockwise renormalised weights
- `fm_block_log_weights()`: Computes (optionally) blockwise renormalised log-weights
- `fm_block_log_shift()`: Computes shifts for stable blocked log-sum-exp. To compute $\log(\sum_{i; \text{block}_i = k} \exp(v_i) w_i)$ for each block `k`, first compute combined values and weights, and a shift:

```
w_values <- values + fm_block_log_weights(block, log_weights = log_weights)
shift <- fm_block_log_shift(block, log_weights = w_values)
```

Then aggregate the values within each block:

```
agg <- aggregate(exp(w_values - shift[block]),
                 by = list(block = block),
                 \ (x) log(sum(x)))
agg$x <- agg$x + shift[agg$block]
```

The implementation uses a faster method:

```

as.vector(
  Matrix::sparseMatrix(
    i = block,
    j = rep(1L, length(block)),
    x = exp(w_values - shift[block]),
    dims = c(n_block, 1))
) + shift

```

- `fm_block_prep()`: Helper function for preparing `block`, `weights`, and `log_weights`, `n_block` inputs.

Examples

```

block <- rep(1:2, 3:2)
fm_block(block)
fm_block(block, rescale = TRUE)
fm_block(block, log_weights = -2:2, rescale = TRUE)
fm_block_eval(
  block,
  weights = 1:5,
  rescale = TRUE,
  values = 11:15
)
fm_block_logsumexp_eval(
  block,
  weights = 1:5,
  rescale = TRUE,
  values = log(11:15),
  log = FALSE
)

```

fm_centroids

Extract triangle centroids from an fm_mesh_2d

Description

Computes the centroids of the triangles of an `fm_mesh_2d()` object.

Usage

```
fm_centroids(x, format = NULL)
```

Arguments

<code>x</code>	An <code>fm_mesh_2d</code> or <code>inla.mesh</code> object.
<code>format</code>	character; "sf", "df", "sp"

Value

An `sf`, `data.frame`, or `SpatialPointsDataFrame` object, with the vertex coordinates, and a `.triangle` column with the triangle indices.

Author(s)

Finn Lindgren <finn.lindgren@gmail.com>

See Also

[fm_vertices\(\)](#)

Examples

```
if (require("ggplot2", quietly = TRUE)) {
  vrt <- fm_centroids(fmexample$mesh, format = "sf")
  ggplot() +
    geom_sf(data = fm_as_sfc(fmexample$mesh)) +
    geom_sf(data = vrt, color = "red")
}
```

fm_contains

Check which mesh triangles are inside a polygon

Description

Wrapper for the `sf::st_contains()` (previously `sp::over()`) method to find triangle centroids or vertices inside `sf` or `sp` polygon objects

Usage

```
fm_contains(x, y, ...)

## S3 method for class 'Spatial'
fm_contains(x, y, ...)

## S3 method for class 'sf'
fm_contains(x, y, ...)

## S3 method for class 'sfc'
fm_contains(x, y, ..., type = c("centroid", "vertex"))
```

Arguments

x	geometry (typically an sf or sp::SpatialPolygons object) for the queries
y	an fm_mesh_2d() or inla.mesh object
...	Passed on to other methods
type	the query type; either 'centroid' (default, for triangle centroids), or 'vertex' (for mesh vertices)

Value

List of vectors of triangle indices (when type is 'centroid') or vertex indices (when type is 'vertex'). The list has one entry per row of the sf object. Use unlist(fm_contains(...)) if the combined union is needed.

Author(s)

Haakon Bakka, <bakka@r-inla.org>, and Finn Lindgren <finn.lindgren@gmail.com>

Examples

```

if (TRUE &&
    fm_safe_sp()) {
  # Create a polygon and a mesh
  obj <- sp::SpatialPolygons(
    list(sp::Polygons(
      list(sp::Polygon(rbind(
        c(0, 0),
        c(50, 0),
        c(50, 50),
        c(0, 50)
      ))),
      ID = 1
    )),
    proj4string = fm_CRS("longlat_globe")
  )
  mesh <- fm_rcdt_2d_inla(globe = 2, crs = fm_crs("sphere"))

  ## 3 vertices found in the polygon
  fm_contains(obj, mesh, type = "vertex")

  ## 3 triangles found in the polygon
  fm_contains(obj, mesh)

  ## Multiple transformations can lead to slightly different results
  ## due to edge cases:
  ## 4 triangles found in the polygon
  fm_contains(
    obj,
    fm_transform(mesh, crs = fm_crs("mollweide_norm"))
  )
}

```

`fm_CRS`*Create a coordinate reference system object*

Description

Creates either a CRS object or an `inla.CRS` object, describing a coordinate reference system

Usage

```
fm_CRS(x, oblique = NULL, ...)

## S3 method for class 'fm_CRS'
is.na(x)

## S3 method for class 'crs'
fm_CRS(x, oblique = NULL, ...)

## S3 method for class 'fm_crs'
fm_CRS(x, oblique = NULL, ...)

## S3 method for class 'Spatial'
fm_CRS(x, oblique = NULL, ...)

## S3 method for class 'fm_CRS'
fm_CRS(x, oblique = NULL, ...)

## S3 method for class 'SpatVector'
fm_CRS(x, oblique = NULL, ...)

## S3 method for class 'SpatRaster'
fm_CRS(x, oblique = NULL, ...)

## S3 method for class 'sf'
fm_CRS(x, oblique = NULL, ...)

## S3 method for class 'sfc'
fm_CRS(x, oblique = NULL, ...)

## S3 method for class 'sfg'
fm_CRS(x, oblique = NULL, ...)

## S3 method for class 'fm_mesh_2d'
fm_CRS(x, oblique = NULL, ...)

## S3 method for class 'fm_lattice'
fm_CRS(x, oblique = NULL, ...)
```



```

## S3 method for class 'fm_segm'
fm_CRS(x, oblique = NULL, ...)

## S3 method for class 'matrix'
fm_CRS(x, oblique = NULL, ...)

## S3 method for class 'CRS'
fm_CRS(x, oblique = NULL, ...)

## Default S3 method:
fm_CRS(
  x,
  oblique = NULL,
  projargs = NULL,
  doCheckCRSArgs = NULL,
  args = NULL,
  SRS_string = NULL,
  ...
)

## S3 method for class 'inla.CRS'
is.na(x)

## S3 method for class 'inla.CRS'
fm_CRS(x, oblique = NULL, ...)

## S3 method for class 'inla.mesh'
fm_CRS(x, oblique = NULL, ...)

## S3 method for class 'inla.mesh.lattice'
fm_CRS(x, oblique = NULL, ...)

## S3 method for class 'inla.mesh.segment'
fm_CRS(x, oblique = NULL, ...)

```

Arguments

x	Object to convert to CRS or to extract CRS information from.
oblique	Vector of length at most 4 of rotation angles (in degrees) for an oblique projection, all values defaulting to zero. The values indicate (longitude, latitude, orientation, orbit), as explained in the Details section for fm_crs() .
...	Additional parameters, passed on to sub-methods.
projargs	Either 1) a projection argument string suitable as input to <code>sp::CRS</code> , or 2) an existing CRS object, or 3) a shortcut reference string to a predefined projection; run <code>names(fm_wkt_predef())</code> for valid predefined projections. (<code>projargs</code> is a compatibility parameter that can be used for the default <code>fm_CRS()</code> method)
doCheckCRSArgs	ignored.

args	An optional list of name/value pairs to add to and/or override the PROJ4 arguments in projargs. name=value is converted to "+name=value", and name=NA is converted to "+name".
SRS_string	a WKT2 string defining the coordinate system; see sp::CRS. This takes precedence over projargs.

Details

The first two elements of the oblique vector are the (longitude, latitude) coordinates for the oblique centre point. The third value (orientation) is a counterclockwise rotation angle for an observer looking at the centre point from outside the sphere. The fourth value is the quasi-longitude (orbit angle) for a rotation along the oblique observers equator.

Simple oblique: `oblique=c(0, 45)`

Polar: `oblique=c(0, 90)`

Quasi-transversal: `oblique=c(0, 0, 90)`

Satellite orbit viewpoint: `oblique=c(lon0-time*v1, 0, orbitangle, orbit0+time*v2)`, where `lon0` is the longitude at which a satellite orbit crosses the equator at `time=0`, when the satellite is at an angle `orbit0` further along in its orbit. The orbital angle relative to the equatorial plane is `orbitangle`, and `v1` and `v2` are the angular velocities of the planet and the satellite, respectively. Note that "forward" from the satellite's point of view is "to the right" in the projection.

When `oblique[2]` or `oblique[3]` are non-zero, the resulting projection is only correct for perfect spheres.

Value

Either an `sp::CRS` object or an `inla.CRS` object, depending on if the coordinate reference system described by the parameters can be expressed with a pure `sp::CRS` object or not.

An S3 `inla.CRS` object is a list, usually (but not necessarily) containing at least one element:

`crs` The basic `sp::CRS` object

Functions

- `is.na(fm_CRS)`: Check if a `fm_CRS` has NA `crs` information and NA obliqueness
- `is.na(inla.CRS)`: Check if a `inla.CRS` has NA `crs` information and NA obliqueness

Author(s)

Finn Lindgren <finn.lindgren@gmail.com>

See Also

[fm_crs\(\)](#), [sp::CRS\(\)](#), [fm_crs_wkt](#), [fm_sp_get_crs\(\)](#), [fm_crs_is_identical\(\)](#)

Examples

```

if (fm_safe_sp()) {
  crs1 <- fm_CRS("longlat_globe")
  crs2 <- fm_CRS("lambert_globe")
  crs3 <- fm_CRS("mollweide_norm")
  crs4 <- fm_CRS("hammer_globe")
  crs5 <- fm_CRS("sphere")
  crs6 <- fm_CRS("globe")
}

```

fm_crs

Obtain coordinate reference system object

Description

Obtain an `sf::crs` or `fm_crs` object from a spatial object, or convert crs information to construct a new `sf::crs` object.

Usage

```
fm_crs(x, oblique = NULL, ..., crsonly = deprecated())
```

```
fm_crs_oblique(x)
```

```
## S3 method for class 'fm_crs'
st_crs(x, ...)
```

```
## S3 method for class 'fm_crs'
x$name
```

```
## Default S3 method:
fm_crs(x, oblique = NULL, ...)
```

```
## S3 method for class 'crs'
fm_crs(x, oblique = NULL, ...)
```

```
## S3 method for class 'fm_crs'
fm_crs(x, oblique = NULL, ...)
```

```
## S3 method for class 'fm_CRS'
fm_crs(x, oblique = NULL, ...)
```

```
## S3 method for class 'character'
fm_crs(x, oblique = NULL, ...)
```

```
## S3 method for class 'Spatial'
fm_crs(x, oblique = NULL, ...)
```

```
## S3 method for class 'SpatVector'
fm_crs(x, oblique = NULL, ...)

## S3 method for class 'SpatRaster'
fm_crs(x, oblique = NULL, ...)

## S3 method for class 'sf'
fm_crs(x, oblique = NULL, ...)

## S3 method for class 'sfc'
fm_crs(x, oblique = NULL, ...)

## S3 method for class 'sfg'
fm_crs(x, oblique = NULL, ...)

## S3 method for class 'fm_mesh_2d'
fm_crs(x, oblique = NULL, ...)

## S3 method for class 'fm_lattice_2d'
fm_crs(x, oblique = NULL, ...)

## S3 method for class 'fm_seg'
fm_crs(x, oblique = NULL, ...)

## S3 method for class 'fm_list'
fm_crs(x, oblique = NULL, ...)

## S3 method for class 'matrix'
fm_crs(x, oblique = NULL, ...)

## S3 method for class 'fm_list'
fm_CRS(x, oblique = NULL, ...)

fm_wkt_predef()

## S3 method for class 'inla.CRS'
fm_crs(x, oblique = NULL, ...)

## S3 method for class 'inla.mesh'
fm_crs(x, oblique = NULL, ...)

## S3 method for class 'inla.mesh.lattice'
fm_crs(x, oblique = NULL, ...)

## S3 method for class 'inla.mesh.segment'
fm_crs(x, oblique = NULL, ...)
```

Arguments

x	Object to convert to crs or to extract crs information from. If character, a string suitable for <code>sf::st_crs(x)</code> , or the name of a predefined wkt string from <code>"names(fm_wkt_predef())"</code> .
oblique	Numeric vector of length at most 4 of rotation angles (in degrees) for an oblique projection, all values defaulting to zero. The values indicate (longitude, latitude, orientation, orbit), as explained in the Details section below. When oblique is non-NULL, used to override the obliqueness parameters of a <code>fm_crs</code> object. When NA, remove obliqueness from the object, resulting in a return class of <code>sf::st_crs()</code> . When NULL, pass through any oblique information in the object, returning an <code>fm_crs()</code> object if needed.
...	Additional parameters. Not currently in use.
crsonly	[Deprecated] logical; if TRUE, remove oblique information from <code>fm_crs</code> objects and return a plain <code>crs</code> object instead. For <code>crsonly = TRUE</code> , use <code>oblique = NA</code> instead. For <code>crsonly = FALSE</code> , use default, NULL, or non-NA oblique.
name	element name

Details

The first two elements of the oblique vector are the (longitude, latitude) coordinates for the oblique centre point. The third value (orientation) is a counter-clockwise rotation angle for an observer looking at the centre point from outside the sphere. The fourth value is the quasi-longitude (orbit angle) for a rotation along the oblique observers equator.

Simple oblique: `oblique=c(0, 45)`

Polar: `oblique=c(0, 90)`

Quasi-transversal: `oblique=c(0, 0, 90)`

Satellite orbit viewpoint: `oblique=c(lon0-time*v1, 0, orbitangle, orbit0+time*v2)`, where `lon0` is the longitude at which a satellite orbit crosses the equator at `time=0`, when the satellite is at an angle `orbit0` further along in its orbit. The orbital angle relative to the equatorial plane is `orbitangle`, and `v1` and `v2` are the angular velocities of the planet and the satellite, respectively. Note that "forward" from the satellite's point of view is "to the right" in the projection.

When `oblique[2]` or `oblique[3]` are non-zero, the resulting projection is only correct for perfect spheres.

Value

Either an `sf::crs` object or an `fm_crs` object, depending on if the coordinate reference system described by the parameters can be expressed with a pure `crs` object or not.

A `crs` object (`sf::st_crs()`) or a `fm_crs` object. An S3 `fm_crs` object is a list with elements `crs` and `oblique`.

`fm_wkt_predef` returns a WKT2 string defining a projection

Methods (by class)

- `fm_crs(fm_list)`: returns a list of 'crs' objects, one for each list element

Methods (by generic)

- `st_crs(fm_crs)`: `st_crs(x, ...)` is equivalent to `fm_crs(x, ... oblique = NA)` when `x` is a `fm_crs` object.
- `$`: For a `fm_crs` object `x`, `x$name` calls the accessor method for the `crs` object inside it. If name is "crs", the internal `crs` object itself is returned. If name is "oblique", the internal oblique angle parameter vector is returned.

Functions

- `fm_crs_oblique()`: Return NA for object with no oblique information, and otherwise a length 4 numeric vector.
- `fm_CRS(fm_list)`: returns a list of 'CRS' objects, one for each list element

Author(s)

Finn Lindgren <finn.lindgren@gmail.com>

See Also

[sf::st_crs\(\)](#), [fm_crs_wkt](#)
[fm_crs_is_null](#)
[fm_crs<-\(\)](#), [fm_crs_oblique<-\(\)](#)

Examples

```
crs1 <- fm_crs("longlat_globe")
crs2 <- fm_crs("lambert_globe")
crs3 <- fm_crs("mollweide_norm")
crs4 <- fm_crs("hammer_globe")
crs5 <- fm_crs("sphere")
crs6 <- fm_crs("globe")
names(fm_wkt_predef())
```

fm_crs<-

Assignment operators for crs information objects

Description

Assigns new crs information.

Usage

```
fm_crs(x) <- value

fm_crs_oblique(x) <- value

## S3 replacement method for class 'NULL'
fm_crs(x) <- value

## S3 replacement method for class 'NULL'
fm_crs_oblique(x) <- value

## S3 replacement method for class 'fm_seg'
fm_crs(x) <- value

## S3 replacement method for class 'fm_list'
fm_crs(x) <- value

## S3 replacement method for class 'fm_mesh_2d'
fm_crs(x) <- value

## S3 replacement method for class 'fm_lattice_2d'
fm_crs(x) <- value

## S3 replacement method for class 'sf'
fm_crs(x) <- value

## S3 replacement method for class 'sfg'
fm_crs(x) <- value

## S3 replacement method for class 'sfc'
fm_crs(x) <- value

## S3 replacement method for class 'Spatial'
fm_crs(x) <- value

## S3 replacement method for class 'crs'
fm_crs_oblique(x) <- value

## S3 replacement method for class 'CRS'
fm_crs_oblique(x) <- value

## S3 replacement method for class 'fm_CRS'
fm_crs_oblique(x) <- value

## S3 replacement method for class 'fm_crs'
fm_crs_oblique(x) <- value

## S3 replacement method for class 'fm_seg'
```

```

fm_crs_oblique(x) <- value

## S3 replacement method for class 'fm_mesh_2d'
fm_crs_oblique(x) <- value

## S3 replacement method for class 'fm_lattice_2d'
fm_crs_oblique(x) <- value

## S3 replacement method for class 'inla.CRS'
fm_crs_oblique(x) <- value

```

Arguments

x	Object to assign crs information to
value	For <code>fm_crs<-()</code> , object supported by <code>fm_crs(value)</code> . For <code>fm_crs_oblique<-()</code> , NA or a numeric vector, see the oblique argument for <code>fm_crs()</code> . For assignment, NULL is treated as NA.

Value

The modified object

Functions

- `fm_crs(x) <- value`: Automatically converts the input value with `fm_crs(value)`, `fm_crs(value, oblique = NA)`, `fm_CRS(value)`, or `fm_CRS(value, oblique = NA)`, depending on the type of `x`.
- `fm_crs_oblique(x) <- value`: Assigns new oblique information.

See Also

[fm_crs\(\)](#)

Examples

```

x <- fm_segm()
fm_crs(x) <- fm_crs("+proj=longlat")
fm_crs(x)$proj4string

```

`fm_crs_is_identical` *Check if two CRS objects are identical*

Description

Check if two CRS objects are identical

Usage

```
fm_crs_is_identical(crs0, crs1, crsonly = FALSE)
```

```
fm_identical_CRS(crs0, crs1, crsonly = FALSE)
```

Arguments

`crs0, crs1` Two `sf::crs`, `sp::CRS`, `fm_crs` or `inla.CRS` objects to be compared.

`crsonly` logical. If TRUE and any of `crs0` and `crs1` are `fm_crs` or `inla.CRS` objects, extract and compare only the `sf::crs` or `sp::CRS` aspects. Default: FALSE

Value

logical, indicating if the two crs objects are identical in the specified sense (see the `crsonly` argument)

Functions

- `fm_identical_CRS()`: **[Deprecated]** by `fm_crs_is_identical()`.

See Also

[fm_crs\(\)](#), [fm_CRS\(\)](#), [fm_crs_is_null\(\)](#)

Examples

```
crs0 <- crs1 <- fm_crs("longlat_globe")
fm_crs_oblique(crs1) <- c(0, 90)
print(c(
  fm_crs_is_identical(crs0, crs0),
  fm_crs_is_identical(crs0, crs1),
  fm_crs_is_identical(crs0, crs1, crsonly = TRUE)
))
```

<code>fm_crs_is_null</code>	<i>Check if a crs is NULL or NA</i>
-----------------------------	-------------------------------------

Description

Methods of checking whether various kinds of CRS objects are NULL or NA. Logically equivalent to either `is.na(fm_crs(x))` or `is.na(fm_crs(x, oblique = NA))`, but with a short-cut pre-check for `is.null(x)`.

Usage

```
fm_crs_is_null(x, crsonly = FALSE)
```

```
## S3 method for class 'fm_crs'
is.na(x)
```

Arguments

x	An object supported by <code>fm_crs(x)</code>
crsonly	For crs objects with extended functionality, such as <code>fm_crs()</code> objects with oblique information, <code>crsonly = TRUE</code> only checks the plain CRS part.

Value

logical

Functions

- `fm_crs_is_null()`: Check if an object is or has NULL or NA CRS information. If not NULL, `is.na(fm_crs(x))` is returned. This allows the input to be e.g. a proj4string or epsg number, since the default `fm_crs()` method passes its argument on to `sf::st_crs()`.
- `is.na(fm_crs)`: Check if a `fm_crs` has NA crs information and NA obliqueness

See Also

[fm_crs\(\)](#), [fm_CRS\(\)](#), [fm_crs_is_identical\(\)](#)

Examples

```
fm_crs_is_null(NULL)
fm_crs_is_null(27700)
fm_crs_is_null(fm_crs())
fm_crs_is_null(fm_crs(27700))
fm_crs_is_null(fm_crs(oblique = c(1, 2, 3, 4)))
fm_crs_is_null(fm_crs(oblique = c(1, 2, 3, 4)), crsonly = TRUE)
fm_crs_is_null(fm_crs(27700, oblique = c(1, 2, 3, 4)))
fm_crs_is_null(fm_crs(27700, oblique = c(1, 2, 3, 4)), crsonly = TRUE)
```

fm_crs_plot

Plot CRS and fm_crs objects

Description

[Experimental] Plot the outline of a crs or `fm_crs()` projection, with optional graticules (transformed parallels and meridians) and Tissot indicatrices.

Usage

```
fm_crs_plot(
  x,
  xlim = NULL,
  ylim = NULL,
  outline = TRUE,
```

```

    graticule = c(15, 15, 45),
    tissot = c(30, 30, 30),
    asp = 1,
    add = FALSE,
    eps = 0.05,
    ...
)

fm_crs_graticule(
  x,
  by = c(15, 15, 45),
  add = FALSE,
  do.plot = TRUE,
  eps = 0.05,
  ...
)

fm_crs_tissot(
  x,
  by = c(30, 30, 30),
  add = FALSE,
  do.plot = TRUE,
  eps = 0.05,
  diff.eps = 0.01,
  ...
)

```

Arguments

x	A crs or <code>fm_crs()</code> object.
xlim	Optional x-axis limits.
ylim	Optional y-axis limits.
outline	Logical, if TRUE, draw the outline of the projection.
graticule	Vector of length at most 3, to plot meridians with spacing <code>graticule[1]</code> degrees and parallels with spacing <code>graticule[2]</code> degrees. <code>graticule[3]</code> optionally specifies the spacing above and below the first and last parallel. When <code>graticule[1]==0</code> no meridians are drawn, and when <code>graticule[2]==0</code> no parallels are drawn. Use <code>graticule=NULL</code> to skip drawing a graticule.
tissot	Vector of length at most 3, to plot Tissot's indicatrices with spacing <code>tissot[1]</code> degrees and parallels with spacing <code>tissot[2]</code> degrees. <code>tissot[3]</code> specifies a scaling factor. Use <code>tissot=NULL</code> to skip drawing a Tissot's indicatrices.
asp	The aspect ratio for the plot, default 1.
add	If TRUE, add the projection plot to an existing plot.
eps	Clipping tolerance for rudimentary boundary clipping
...	Additional arguments passed on to the internal calls to plot and lines.

by	The spacing between (long, lat, long_at_poles) graticules/indicatrices, see the graticule and tissot arguments.
do.plot	logical; If TRUE, do plotting
diff.eps	Pre-scaling

Value

NULL, invisibly

Functions

- `fm_crs_graticule()`: **[Experimental]** Constructs graticule information for a given CRS or `fm_crs()` and optionally plots the graticules. Returns a list with two elements, meridians and parallels, which are `SpatialLines` objects.
- `fm_crs_tissot()`: **[Experimental]** Constructs Tissot indicatrix information for a given CRS or `fm_crs()` and optionally plots the indicatrices. Returns a list with one element, `tissot`, which is a `SpatialLines` object.

Author(s)

Finn Lindgren finn.lindgren@gmail.com

See Also

[fm_crs\(\)](#)

Examples

```
if (require("sf") && require("sp")) {
  for (projtype in c(
    "longlat_norm",
    "lambert_norm",
    "mollweide_norm",
    "hammer_norm"
  )) {
    fm_crs_plot(fm_crs(projtype), main = projtype)
  }
}
```

```
if (require("sf") && require("sp")) {
  oblique <- c(0, 45, 45, 0)
  for (projtype in c(
    "longlat_norm",
    "lambert_norm",
    "mollweide_norm",
    "hammer_norm"
  )) {
    fm_crs_plot(
      fm_crs(projtype, oblique = oblique),
      main = paste("oblique", projtype)
    )
  }
}
```

```
}  
}
```

fm_crs_wkt

Handling CRS/WKT

Description

Get and set CRS object or WKT string properties.

Usage

```
fm_wkt_is_geocent(wkt)  
  
fm_crs_is_geocent(crs)  
  
fm_wkt_get_ellipsoid_radius(wkt)  
  
fm_crs_get_ellipsoid_radius(crs)  
  
fm_ellipsoid_radius(x)  
  
## Default S3 method:  
fm_ellipsoid_radius(x)  
  
## S3 method for class 'character'  
fm_ellipsoid_radius(x)  
  
fm_wkt_set_ellipsoid_radius(wkt, radius)  
  
fm_ellipsoid_radius(x) <- value  
  
## S3 replacement method for class 'character'  
fm_ellipsoid_radius(x) <- value  
  
## S3 replacement method for class 'CRS'  
fm_ellipsoid_radius(x) <- value  
  
## S3 replacement method for class 'fm_CRS'  
fm_ellipsoid_radius(x) <- value  
  
## S3 replacement method for class 'crs'  
fm_ellipsoid_radius(x) <- value  
  
## S3 replacement method for class 'fm_crs'  
fm_ellipsoid_radius(x) <- value
```

```
fm_crs_set_ellipsoid_radius(crs, radius)

fm_wkt_unit_params()

fm_wkt_get_lengthunit(wkt)

fm_wkt_set_lengthunit(wkt, unit, params = NULL)

fm_crs_get_lengthunit(crs)

fm_crs_set_lengthunit(crs, unit)

fm_length_unit(x)

## Default S3 method:
fm_length_unit(x)

## S3 method for class 'character'
fm_length_unit(x)

fm_length_unit(x) <- value

## S3 replacement method for class 'character'
fm_length_unit(x) <- value

## S3 replacement method for class 'CRS'
fm_length_unit(x) <- value

## S3 replacement method for class 'fm_CRS'
fm_length_unit(x) <- value

## S3 replacement method for class 'crs'
fm_length_unit(x) <- value

## S3 replacement method for class 'fm_crs'
fm_length_unit(x) <- value

fm_wkt(crs)

fm_proj4string(crs)

fm_crs_get_wkt(crs)

fm_wkt_tree_projection_type(wt)

fm_wkt_projection_type(wkt)
```

```

fm_crs_projection_type(crs)

fm_crs_bounds(crs, warn.unknown = FALSE)

## S3 replacement method for class 'inla.CRS'
fm_ellipsoid_radius(x) <- value

## S3 replacement method for class 'inla.CRS'
fm_length_unit(x) <- value

```

Arguments

wkt	A WKT2 character string
crs	An <code>sf::crs</code> , <code>sp::CRS</code> , <code>fm_crs</code> or <code>inla.CRS</code> object
x	crs object to extract value from or assign values in
radius	numeric; The new radius value
value	Value to assign
unit	character, name of a unit. Supported names are "metre", "kilometre", and the aliases "meter", "m", "International metre", "kilometer", and "km", as defined by <code>fm_wkt_unit_params</code> or the <code>params</code> argument. (For legacy PROJ4 use, only "m" and "km" are supported)
params	Length unit definitions, in the list format produced by <code>fm_wkt_unit_params()</code> , Default: NULL, which invokes <code>fm_wkt_unit_params()</code>
wt	A parsed wkt tree, see <code>fm_wkt_as_wkt_tree()</code>
warn.unknown	logical, default FALSE. Produce warning if the shape of the projection bounds is unknown.

Value

For `fm_wkt_unit_params`, a list of named unit definitions

For `fm_wkt_get_lengthunit`, a list of length units used in the wkt string, excluding the ellipsoid radius unit.

For `fm_wkt_set_lengthunit`, a WKT2 string with altered length units. Note that the length unit for the ellipsoid radius is unchanged.

For `fm_crs_get_lengthunit`, a list of length units used in the wkt string, excluding the ellipsoid radius unit. (For legacy PROJ4 code, the raw units from the proj4string are returned, if present.)

For `fm_length_unit<-`, a crs object with altered length units. Note that the length unit for the ellipsoid radius is unchanged.

Functions

- `fm_wkt()`: Returns a WKT2 string, for any input supported by `fm_crs()`.
- `fm_proj4string()`: Returns a proj4 string, for any input supported by `fm_crs()`.
- `fm_crs_get_wkt()`: **[Deprecated]** Use `fm_wkt()` instead.

- `fm_wkt_tree_projection_type()`: Returns "longlat", "lambert", "mollweide", "hammer", "tmerc", or NULL
- `fm_wkt_projection_type()`: See `fm_wkt_tree_projection_type`
- `fm_crs_projection_type()`: See `fm_wkt_tree_projection_type`
- `fm_crs_bounds()`: Returns bounds information for a projection, as a list with elements type ("rectangle" or "ellipse"), xlim, ylim, and polygon.

Author(s)

Finn Lindgren <finn.lindgren@gmail.com>

See Also

[fm_crs\(\)](#)

Examples

```
c1 <- fm_crs("globe")
fm_crs_get_lengthunit(c1)
c2 <- fm_crs_set_lengthunit(c1, "m")
fm_crs_get_lengthunit(c2)
```

fm_detect_manifold *Detect manifold type*

Description

Detect if a 2d object is on "R2", "S2", or "M2"

Usage

```
fm_detect_manifold(x)

fm_crs_detect_manifold(x)

## S3 method for class 'crs'
fm_detect_manifold(x)

## S3 method for class 'CRS'
fm_detect_manifold(x)

## S3 method for class 'numeric'
fm_detect_manifold(x)

## S3 method for class 'matrix'
fm_detect_manifold(x)
```



```
## S3 method for class 'fm_mesh_2d'
fm_detect_manifold(x)
```

Arguments

x Object to investigate

Value

A string containing the detected manifold classification

Functions

- `fm_crs_detect_manifold()`: Detect if a crs is on "R2" or "S2" (if `fm_crs_is_geocent(crs)` is TRUE). Returns `NA_character_` if the crs is NULL or NA.

Examples

```
fm_detect_manifold(1:4)
fm_detect_manifold(rbind(c(1, 0, 0), c(0, 1, 0), c(1, 1, 0)))
fm_detect_manifold(rbind(c(1, 0, 0), c(0, 1, 0), c(0, 0, 1)))
```

<code>fm_diameter</code>	<i>Diameter bound for a geometric object</i>
--------------------------	--

Description

Find an upper bound to the convex hull of a point set

Usage

```
fm_diameter(x, ...)
```

```
## S3 method for class 'matrix'
fm_diameter(x, manifold = NULL, ...)
```

```
## S3 method for class 'sf'
fm_diameter(x, ...)
```

```
## S3 method for class 'sfg'
fm_diameter(x, ...)
```

```
## S3 method for class 'sfc'
fm_diameter(x, ...)
```

```
## S3 method for class 'fm_lattice_2d'
```

```

fm_diameter(x, ...)

## S3 method for class 'fm_seg'
fm_diameter(x, ...)

## S3 method for class 'fm_mesh_2d'
fm_diameter(x, ...)

## S3 method for class 'fm_mesh_1d'
fm_diameter(x, ...)

## S3 method for class 'inla.mesh.1d'
fm_diameter(x, ...)

## S3 method for class 'inla.mesh.segment'
fm_diameter(x, ...)

## S3 method for class 'inla.mesh.lattice'
fm_diameter(x, ...)

## S3 method for class 'inla.mesh'
fm_diameter(x, ...)

```

Arguments

x	A point set as an $n \times d$ matrix, or an fm_mesh_2d/1d/sf related object.
...	Additional parameters passed on to the submethods.
manifold	Character string specifying the manifold type. Default is to treat the point set with Euclidean R^d metrics. Use manifold="S2" for great circle distances on the unit sphere (this is set automatically for fm_fmsh_2d objects).

Value

A scalar, upper bound for the diameter of the convex hull of the point set.

Author(s)

Finn Lindgren finn.lindgren@gmail.com

Examples

```
fm_diameter(matrix(c(0, 1, 1, 0, 0, 0, 1, 1), 4, 2))
```

fm_dof	<i>Function spece degrees of freedom</i>
--------	--

Description

Obtain the degrees of freedom of a function space, i.e. the number of basis functions it uses.

Usage

```
fm_dof(x)

## S3 method for class 'fm_mesh_1d'
fm_dof(x)

## S3 method for class 'fm_mesh_2d'
fm_dof(x)

## S3 method for class 'fm_tensor'
fm_dof(x)
```

Arguments

x A function space object, such as [fm_mesh_1d\(\)](#) or [fm_mesh_2d\(\)](#)

Value

An integer

Examples

```
fm_dof(fmexample$mesh)
```

fm_evaluate	<i>Methods for projecting to/from mesh objects</i>
-------------	--

Description

Calculate evaluation information and/or evaluate a function defined on a mesh or function space.

Usage

```

fm_evaluate(...)

## Default S3 method:
fm_evaluate(mesh, field, ...)

## S3 method for class 'fm_evaluator'
fm_evaluate(projector, field, ...)

## S3 method for class 'fm_basis'
fm_evaluate(basis, field, ...)

fm_evaluator(...)

## Default S3 method:
fm_evaluator(...)

## S3 method for class 'fm_mesh_2d'
fm_evaluator(mesh, loc = NULL, lattice = NULL, crs = NULL, ...)

## S3 method for class 'fm_mesh_1d'
fm_evaluator(mesh, loc = NULL, xlim = mesh$interval, dims = 100, ...)

fm_evaluator_lattice(
  mesh,
  xlim = NULL,
  ylim = NULL,
  dims = c(100, 100),
  projection = NULL,
  crs = NULL,
  ...
)

## S3 method for class 'inla.mesh'
fm_evaluator(mesh, ...)

## S3 method for class 'inla.mesh.1d'
fm_evaluator(mesh, ...)

```

Arguments

...	Additional arguments passed on to methods.
mesh	An <code>inla.mesh</code> or <code>inla.mesh.1d</code> object.
field	Basis function weights, one per mesh basis function, describing the function to be evaluated at the projection locations
projector	An <code>fm_evaluator</code> object.
basis	An <code>fm_basis</code> object.

loc	Projection locations. Can be a matrix, SpatialPoints, SpatialPointsDataFrame, sf, sfc, or sfg object.
lattice	An <code>fm_lattice_2d()</code> object.
crs	An optional CRS or inla.CRS object associated with loc and/or lattice.
xlim	X-axis limits for a lattice. For R2 meshes, defaults to covering the domain.
dims	Lattice dimensions.
ylim	Y-axis limits for a lattice. For R2 meshes, defaults to covering the domain.
projection	One of <code>c("default", "longlat", "longsinlat", "mollweide")</code> .

Value

A vector or matrix of the evaluated function

An `fm_evaluator` object

Methods (by class)

- `fm_evaluate(default)`: The default method calls `proj = fm_evaluator(mesh, ...)`, followed by `fm_evaluate(proj, field)`.

Functions

- `fm_evaluate()`: Returns the field function evaluated at the locations determined by an `fm_evaluator` object. `fm_evaluate(mesh, field = field, ...)` is a shortcut to `fm_evaluate(fm_evaluator(mesh, ...), field = field)`.
- `fm_evaluator()`: Returns an `fm_evaluator` list object with evaluation information. The `proj` element is a `fm_basis` object, containing (at least) a mapping matrix `A` and a logical vector `ok`, that indicates which locations were mappable to the input mesh. For `fm_mesh_2d` and `inla.mesh` input, `proj` also contains a matrix `bary` and vector `t`, with the barycentric coordinates within the triangle each input location falls in.
- `fm_evaluator(default)`: The default method calls `fm_basis` and creates a basic `fm_evaluator` object
- `fm_evaluator(fm_mesh_2d)`: The `...` arguments are passed on to `fm_evaluator_lattice()` if no `loc` or `lattice` is provided.
- `fm_evaluator_lattice()`: Creates an `fm_lattice_2d()` object, by default covering the input mesh.
- `fm_evaluator(inla.mesh)`: Converts legacy `inla.mesh` to `fm_mesh_2d` and calls the `fm_evaluator` method again.
- `fm_evaluator(inla.mesh.1d)`: Converts legacy `inla.mesh` to `fm_mesh_1d` and calls the `fm_evaluator` method again.

Author(s)

Finn Lindgren <finn.lindgren@gmail.com>

See Also

[fm_mesh_2d\(\)](#), [fm_mesh_1d\(\)](#), [fm_lattice_2d\(\)](#)

Examples

```
if (TRUE) {
  n <- 20
  loc <- matrix(runif(n * 2), n, 2)
  mesh <- fm_rcdt_2d_inla(loc, refine = list(max.edge = 0.05))
  proj <- fm_evaluator(mesh)
  field <- cos(mesh$loc[, 1] * 2 * pi * 3) * sin(mesh$loc[, 2] * 2 * pi * 7)
  image(proj$x, proj$y, fm_evaluate(proj, field))
}

# if (require("ggplot2") &&
#   require("ggpolypath")) {
#   ggplot() +
#     gg(data = fm_as_sfc(mesh), col = field)
# }
```

 fm_fem

Compute finite element matrices

Description

(...)

Usage

```
fm_fem(mesh, order = 2, ...)
```

S3 method for class 'fm_mesh_1d'

```
fm_fem(mesh, order = 2, ...)
```

S3 method for class 'fm_mesh_2d'

```
fm_fem(mesh, order = 2, aniso = NULL, ...)
```

S3 method for class 'inla.mesh.1d'

```
fm_fem(mesh, order = 2, ...)
```

S3 method for class 'inla.mesh'

```
fm_fem(mesh, order = 2, ...)
```

S3 method for class 'fm_tensor'

```
fm_fem(mesh, order = 2, ...)
```

Arguments

mesh	fm_mesh_1d or other supported mesh class object
order	integer
...	Currently unused
aniso	If non-NULL, a list(gamma, v). Calculates anisotropic structure matrices (in addition to the regular) for γ and v for an anisotropic operator $\nabla \cdot H \nabla$, where $H = \gamma I + vv^T$. Currently (2023-08-05) the fields need to be given per vertex.

Value

fm_fem.fm_mesh_1d: A list with elements c0, c1, g1, g2. When mesh\$degree == 2, also g01, g02, and g12.

fm_fem.fm_mesh_2d: A list with elements c0, c1, g1, va, ta, and more if order > 1. When aniso is non-NULL, also g1aniso matrices, etc.

fm_fem.fm_tensor: A list with elements cc, g1, g2.

Examples

```
str(fm_fem(fmexample$mesh))
```

 fm_gmrf

 SPDE, GMRF, and Matérn process methods

Description

[Experimental] Methods for SPDEs and GMRFs.

Usage

```
fm_matern_precision(x, alpha, rho, sigma)
```

```
fm_matern_sample(x, alpha = 2, rho, sigma, n = 1, loc = NULL)
```

```
fm_covariance(Q, A1 = NULL, A2 = NULL, partial = FALSE)
```

```
fm_sample(n, Q, mu = 0, constr = NULL)
```

Arguments

x	A mesh object, e.g. from fm_mesh_1d() or fm_mesh_2d().
alpha	The SPDE operator order. The resulting smoothness index is $\nu = \alpha - \dim / 2$.
rho	The Matérn range parameter (scale parameter $\kappa = \sqrt{8 * \nu} / \rho$)
sigma	The nominal Matérn std.dev. parameter

n	The number of samples to generate
loc	locations to evaluate the random field, compatible with <code>fm_evaluate(x, loc = loc, field = ...)</code>
Q	A precision matrix
A1, A2	Matrices, typically obtained from <code>fm_basis()</code> and/or <code>fm_block()</code> .
partial	[Experimental] If TRUE, compute the partial inverse of Q, i.e. the elements of the inverse corresponding to the non-zero pattern of Q. (Note: This can be done efficiently with the Takahashi recursion method, but to avoid an RcppEigen dependency this is currently disabled, and a slower method is used until the efficient method is reimplemented.)
mu	Optional mean vector
constr	Optional list of constraint information, with elements A and e. Should only be used for a small number of exact constraints.

Value

`fm_matern_sample()` returns a matrix, where each column is a sampled field. If `loc` is NULL, the `fm_dof(mesh)` basis weights are given. Otherwise, the evaluated field at the `nrow(loc)` locations `loc` are given (from version 0.1.4.9001)

Functions

- `fm_matern_precision()`: Construct the (sparse) precision matrix for the basis weights for Whittle-Matérn SPDE models. The boundary behaviour is determined by the provided mesh function space.
- `fm_matern_sample()`: Simulate a Matérn field given a mesh and covariance function parameters, and optionally evaluate at given locations.
- `fm_covariance()`: Compute the covariance between "A1 x" and "A2 x", when x is a basis vector with precision matrix Q.
- `fm_sample()`: Generate n samples based on a sparse precision matrix Q

Examples

```
library(Matrix)
mesh <- fm_mesh_1d(-20:120, degree = 2)
Q <- fm_matern_precision(mesh, alpha = 2, rho = 15, sigma = 1)
x <- seq(0, 100, length.out = 601)
A <- fm_basis(mesh, x)
plot(x,
     as.vector(Matrix::diag(fm_covariance(Q, A))),
     type = "l",
     ylab = "marginal variances"
)

plot(x,
     fm_evaluate(mesh, loc = x, field = fm_sample(1, Q)[, 1]),
     type = "l",
     ylab = "process sample"
```


)

fm_int *Multi-domain integration*

Description

Construct integration points on tensor product spaces

Usage

```
fm_int(domain, samplers = NULL, ...)

## S3 method for class 'list'
fm_int(domain, samplers = NULL, ...)

## S3 method for class 'numeric'
fm_int(domain, samplers = NULL, name = "x", ...)

## S3 method for class 'character'
fm_int(domain, samplers = NULL, name = "x", ...)

## S3 method for class 'factor'
fm_int(domain, samplers = NULL, name = "x", ...)

## S3 method for class 'SpatRaster'
fm_int(domain, samplers = NULL, name = "x", ...)

## S3 method for class 'fm_lattice_2d'
fm_int(domain, samplers = NULL, name = "x", ...)

## S3 method for class 'fm_mesh_1d'
fm_int(domain, samplers = NULL, name = "x", int.args = NULL, ...)

## S3 method for class 'fm_mesh_2d'
fm_int(
  domain,
  samplers = NULL,
  name = NULL,
  int.args = NULL,
  format = NULL,
  ...
)

## S3 method for class 'inla.mesh.lattice'
fm_int(domain, samplers = NULL, name = "x", ...)
```

```
## S3 method for class 'inla.mesh.1d'
fm_int(domain, samplers = NULL, name = "x", int.args = NULL, ...)

## S3 method for class 'inla.mesh'
fm_int(
  domain,
  samplers = NULL,
  name = NULL,
  int.args = NULL,
  format = NULL,
  ...
)
```

Arguments

domain	Functional space specification; single domain or a named list of domains
samplers	For single domain fm_int methods, an object specifying one or more subsets of the domain, and optional weighting in a weight variable. For fm_int.list, a list of sampling definitions, where data frame elements may contain information for multiple domains, in which case each row represent a separate tensor product integration subspace.
...	Additional arguments passed on to other methods
name	For single-domain methods, the variable name to use for the integration points. Default 'x'
int.args	List of arguments passed to line and integration methods. <ul style="list-style-type: none"> • method: "stable" (to aggregate integration weights onto mesh nodes) or "direct" (to construct a within triangle/segment integration scheme without aggregating onto mesh nodes) • nsub1, nsub2: integers controlling the number of internal integration points before aggregation. Points per triangle: (nsub2+1)^2. Points per knot segment: nsub1
format	character; determines the output format, as either "sf" (default when the sampler is NULL) or "sp". When NULL, determined by the sampler type.

Value

A data.frame, tibble, sf, or SpatialPointsDataFrame of 1D and 2D integration points, including a weight column and .block column.

Methods (by class)

- fm_int(list): Multi-domain integration
- fm_int(numeric): Discrete double or integer space integration
- fm_int(character): Discrete character space integration
- fm_int(factor): Discrete factor space integration

- `fm_int(SpatRaster)`: `SpatRaster` integration. Not yet implemented.
- `fm_int(fm_lattice_2d)`: `fm_lattice_2d` integration. Not yet implemented.
- `fm_int(fm_mesh_1d)`: `fm_mesh_1d` integration. Supported samplers:
 - NULL for integration over the entire domain;
 - A length 2 vector defining an interval;
 - A 2-column matrix with a single interval in each row;
 - A tibble with a named column containing a matrix, and optionally a weight column.
- `fm_int(fm_mesh_2d)`: `fm_mesh_2d` integration. Any sampler class with an associated `fm_int_mesh_2d()` method is supported.

Examples

```
# Integration on the interval (2, 3.5) with Simpson's rule
ips <- fm_int(fm_mesh_1d(0:4), samplers = cbind(2, 3.5))
plot(ips$x, ips$weight)

# Create integration points for the two intervals [0,3] and [5,10]

ips <- fm_int(
  fm_mesh_1d(0:10),
  matrix(c(0, 3, 5, 10), nrow = 2, byrow = TRUE)
)
plot(ips$x, ips$weight)

# Convert a 1D mesh into integration points
mesh <- fm_mesh_1d(seq(0, 10, by = 1))
ips <- fm_int(mesh, name = "time")
plot(ips$time, ips$weight)

if (require("ggplot2", quietly = TRUE)) {
  #' Integrate on a 2D mesh with polygon boundary subset
  ips <- fm_int(fmexample$mesh, fmexample$boundary_sf[[1]])
  ggplot() +
    geom_sf(data = fm_as_sfc(fmexample$mesh, multi = TRUE), alpha = 0.5) +
    geom_sf(data = fmexample$boundary_sf[[1]], fill = "red", alpha = 0.5) +
    geom_sf(data = ips, aes(size = weight)) +
    scale_size_area()
}

ips <- fm_int(
  fm_mesh_1d(0:10, boundary = "cyclic"),
  rbind(c(0, 3), c(5, 10))
)
plot(ips$x, ips$weight)
```

fm_is_within	<i>Query if points are inside a mesh</i>
--------------	--

Description

Queries whether each input point is within a mesh or not.

Usage

```
fm_is_within(x, y, ...)
```

```
## Default S3 method:
fm_is_within(x, y, ...)
```

Arguments

x	A set of points of a class supported by fm_evaluator(y, loc = x)
y	An inla.mesh
...	Currently unused

Value

A logical vector

Examples

```
all(fm_is_within(fmexample$loc, fmexample$mesh))
```

fm_lattice_2d	<i>Make a lattice object</i>
---------------	------------------------------

Description

Construct a lattice grid for [fm_mesh_2d\(\)](#)

Usage

```
fm_lattice_2d(...)
```

```
## Default S3 method:
fm_lattice_2d(
  x = seq(0, 1, length.out = 2),
  y = seq(0, 1, length.out = 2),
  z = NULL,
  dims = if (is.matrix(x)) {
```

```

        dim(x)
    } else {
        c(length(x), length(y))
    },
    units = NULL,
    crs = NULL,
    ...
)

```

Arguments

...	Passed on to submethods
x	vector or grid matrix of x-values. Vector values are sorted before use. Matrix input is assumed to be a grid of x-values with the same ordering convention of <code>as.vector(x)</code> as <code>rep(x, times = dims[2])</code> for vector input.
y	vector or grid matrix of y-values. Vector values are sorted before use. Matrix input is assumed to be a grid of y-values with the same ordering convention of <code>as.vector(y)</code> as <code>rep(y, each = dims[1])</code> for vector input.
z	if x is a matrix, a grid matrix of z-values, with the same ordering as x and y. If x is a vector, z is ignored.
dims	the size of the grid, length 2 vector
units	One of <code>c("default", "longlat", "longsinlat", "mollweide")</code> or NULL (equivalent to "default").
crs	An optional <code>fm_crs</code> , <code>sf::st_crs</code> , or <code>sp::CRS</code> object

Value

An `fm_lattice_2d` object with elements

dims integer vector

x x-values for original vector input

y y-values for original vector input

loc matrix of (x, y) values or (x, y, z) values. May be altered by [fm_transform\(\)](#)

segm `fm_segm` object

crs `fm_crs` object or NULL

Author(s)

Finn Lindgren <finn.lindgren@gmail.com>

See Also

[fm_mesh_2d\(\)](#)

Other object creation and conversion: [fm_as_fm\(\)](#), [fm_as_lattice_2d\(\)](#), [fm_as_mesh_1d\(\)](#), [fm_as_mesh_2d\(\)](#), [fm_as_segm\(\)](#), [fm_as_sfc\(\)](#), [fm_as_tensor\(\)](#), [fm_mesh_1d\(\)](#), [fm_mesh_2d\(\)](#), [fm_segm\(\)](#), [fm_simplify\(\)](#), [fm_tensor\(\)](#)

Examples

```

lattice <- fm_lattice_2d(
  seq(0, 1, length.out = 17),
  seq(0, 1, length.out = 10)
)

## Use the lattice "as-is", without refinement:
mesh <- fm_rcdt_2d_inla(lattice = lattice, boundary = lattice$segm)
mesh <- fm_rcdt_2d_inla(lattice = lattice, extend = FALSE)

## Refine the triangulation, with limits on triangle angles and edges:
mesh <- fm_rcdt_2d(
  lattice = lattice,
  refine = list(max.edge = 0.08),
  extend = FALSE
)

## Add an extension around the lattice, but maintain the lattice edges:
mesh <- fm_rcdt_2d(
  lattice = lattice,
  refine = list(max.edge = 0.08),
  interior = lattice$segm
)

## Only add extension:
mesh <- fm_rcdt_2d(lattice = lattice, refine = list(max.edge = 0.08))

```

fm_list

Handle lists of fmesher objects

Description

Methods for constructing and manipulating fm_list objects.

Usage

```

fm_list(x, ..., .class_stub = NULL)

fm_as_list(x, ..., .class_stub = NULL)

## S3 method for class 'fm_list'
c(...)

## S3 method for class 'fm_list'
x[i]

```

Arguments

x	fm_list object from which to extract element(s)
...	Arguments passed to each individual conversion call.
.class_stub	character; class stub name of class to convert each list element to. If NULL, uses fm_as_fm and auto-detects if the resulting list has consistent class, and then adds that to the class list. If non-null, uses paste0("fm_as_", .class_stub) for conversion, and verifies that the resulting list has elements consistent with that class.
i	indices specifying elements to extract

Value

An fm_list object, potentially with fm_{class_stub}_list added.

Methods (by generic)

- c(fm_list): The ... arguments should be coercible to fm_list objects.
- [: Extract sub-list

Functions

- fm_list(): Convert each element of a list, or convert a single non-list object and return in a list
- fm_as_list(): Convert each element of a list, or convert a single non-list object and return in a list

Examples

```
fm_as_list(list(fmexample$mesh, fm_segm_join(fmexample$boundary_fm)))
```

fm_manifold

Query the mesh manifold type

Description

Extract a manifold definition string, or a logical for matching manifold type

Usage

```
fm_manifold(x, type = NULL)
```

```
fm_manifold_get(x)
```

```
## Default S3 method:
```

```
fm_manifold_get(x)
```

```
## S3 method for class 'character'
fm_manifold_get(x)

fm_manifold_type(x)

fm_manifold_dim(x)
```

Arguments

x	An object with manifold information, or a character string
type	character; if NULL (the default), returns the manifold definition string by calling <code>fm_manifold_get(x)</code> . If character, returns TRUE if the manifold type of x matches at least one of the character vector elements.

Value

`fm_manifold()`: Either logical (matching manifold type yes/no), or character (the stored manifold, when `is.null(type)` is TRUE)

`fm_manifold_get()`: character or NULL

`fm_manifold_type()`: character or NULL; "M" (curved manifold), "R" (flat space), "S" (generalised spherical space), "T" (general tensor product space), or "G" (metric graph)

`fm_manifold_dim()`: integer or NULL

Functions

- `fm_manifold_get()`: Method for obtaining a text representation of the manifold characteristics, e.g. "R1", "R2", "M2", or "T3". The default method assumes that the manifold is stored as a character string in a "manifold" element of the object, so it can be extracted with `x[["manifold"]]`. Object classes that do not store the information in this way need to implement their own method.

Examples

```
fm_manifold_get(fmexample$mesh)
fm_manifold(fmexample$mesh)
fm_manifold(fmexample$mesh, "R2")
fm_manifold_type(fmexample$mesh)
fm_manifold_dim(fmexample$mesh)
```

fm_mesh_1d

Make a 1D mesh object

Description

Create a `fm_mesh_1d` object.

Usage

```
fm_mesh_1d(
  loc,
  interval = range(loc),
  boundary = NULL,
  degree = 1,
  free.clamped = FALSE,
  ...
)
```

Arguments

loc	B-spline knot locations.
interval	Interval domain endpoints.
boundary	Boundary condition specification. Valid conditions are c('neumann', 'dirichlet', 'free', 'cyclic'). Two separate values can be specified, one applied to each endpoint.
degree	The B-spline basis degree. Supported values are 0, 1, and 2.
free.clamped	If TRUE, for 'free' boundaries, clamp the basis functions to the interval endpoints.
...	Additional options, currently unused.

Value

An fm_mesh_1d object

Author(s)

Finn Lindgren <finn.lindgren@gmail.com>

See Also

Other object creation and conversion: [fm_as_fm\(\)](#), [fm_as_lattice_2d\(\)](#), [fm_as_mesh_1d\(\)](#), [fm_as_mesh_2d\(\)](#), [fm_as_segm\(\)](#), [fm_as_sfc\(\)](#), [fm_as_tensor\(\)](#), [fm_lattice_2d\(\)](#), [fm_mesh_2d\(\)](#), [fm_segm\(\)](#), [fm_simplify\(\)](#), [fm_tensor\(\)](#)

Examples

```
if (require("ggplot2")) {
  m <- fm_mesh_1d(c(1, 2, 3, 5, 8, 10),
    boundary = c("neumann", "free"),
    degree = 2
  )
  ggplot() +
    geom_fm(data = m, xlim = c(0.5, 10.5))
}
```

fm_mesh_2d

*Make a 2D mesh object***Description**

Make a 2D mesh object

Usage

```
fm_mesh_2d(...)

fm_mesh_2d_inla(
  loc = NULL,
  loc.domain = NULL,
  offset = NULL,
  n = NULL,
  boundary = NULL,
  interior = NULL,
  max.edge = NULL,
  min.angle = NULL,
  cutoff = 1e-12,
  max.n.strict = NULL,
  max.n = NULL,
  plot.delay = NULL,
  crs = NULL,
  ...
)
```

Arguments

...	Currently passed on to <code>fm_mesh_2d_inla</code>
loc	Matrix of point locations to be used as initial triangulation nodes. Can alternatively be a <code>sf</code> , <code>sfc</code> , <code>SpatialPoints</code> or <code>SpatialPointsDataFrame</code> object.
loc.domain	Matrix of point locations used to determine the domain extent. Can alternatively be a <code>SpatialPoints</code> or <code>SpatialPointsDataFrame</code> object.
offset	The automatic extension distance. One or two values, for an inner and an optional outer extension. If negative, interpreted as a factor relative to the approximate data diameter (default=-0.10???)
n	The number of initial nodes in the automatic extensions (default=16)
boundary	one or more (as list) of <code>fm_segm()</code> objects, or objects supported by <code>fm_as_segm()</code>
interior	one object supported by <code>fm_as_segm()</code>
max.edge	The largest allowed triangle edge length. One or two values.
min.angle	The smallest allowed triangle angle. One or two values. (Default=21)
cutoff	The minimum allowed distance between points. Point at most as far apart as this are replaced by a single vertex prior to the mesh refinement step.

max.n.strict	The maximum number of vertices allowed, overriding min.angle and max.edge (default=-1, meaning no limit). One or two values, where the second value gives the number of additional vertices allowed for the extension.
max.n	The maximum number of vertices allowed, overriding max.edge only (default=-1, meaning no limit). One or two values, where the second value gives the number of additional vertices allowed for the extension.
plot.delay	If logical TRUE or a negative numeric value, activates displaying the result after each step of the multi-step domain extension algorithm.
crs	An optional <code>fm_crs()</code> , <code>sf::crs</code> or <code>sp::CRS</code> object

Value

An `inla.mesh` object.

Functions

- `fm_mesh_2d_inla()`: Legacy method for `INLA::inla.mesh.2d()` Create a triangle mesh based on initial point locations, specified or automatic boundaries, and mesh quality parameters.

INLA compatibility

For mesh and curve creation, the `fm_rcdt_2d_inla()`, `fm_mesh_2d_inla()`, and `fm_nonconvex_hull_inla()` methods will keep the interface syntax used by `INLA::inla.mesh.create()`, `INLA::inla.mesh.2d()`, and `INLA::inla.nonconvex.hull()` functions, respectively, whereas the `fm_rcdt_2d()`, `fm_mesh_2d()`, and `fm_nonconvex_hull()` interfaces may be different, and potentially change in the future.

Author(s)

Finn Lindgren <finn.lindgren@gmail.com>

See Also

`fm_rcdt_2d()`, `fm_mesh_2d()`, `fm_delaunay_2d()`, `fm_nonconvex_hull()`, `fm_extensions()`, `fm_refine()`

Other object creation and conversion: `fm_as_fm()`, `fm_as_lattice_2d()`, `fm_as_mesh_1d()`, `fm_as_mesh_2d()`, `fm_as_seg()`, `fm_as_sfc()`, `fm_as_tensor()`, `fm_lattice_2d()`, `fm_mesh_1d()`, `fm_seg()`, `fm_simplify()`, `fm_tensor()`

Examples

```
fm_mesh_2d_inla(boundary = fm_extensions(cbind(2, 1), convex = 1, 2))
```

fm_nonconvex_hull *Compute an extension of a spatial object*

Description

Constructs a potentially nonconvex extension of a spatial object by performing dilation by convex + concave followed by erosion by concave. This is equivalent to dilation by convex followed by closing (dilation + erosion) by concave.

Usage

```
fm_nonconvex_hull(x, ...)
```

```
## S3 method for class 'sfc'
fm_nonconvex_hull(
  x,
  convex = -0.15,
  concave = convex,
  preserveTopology = TRUE,
  dTolerance = NULL,
  crs = fm_crs(x),
  ...
)
```

```
fm_extensions(x, convex = -0.15, concave = convex, dTolerance = NULL, ...)
```

```
## S3 method for class 'matrix'
fm_nonconvex_hull(x, ...)
```

```
## S3 method for class 'sf'
fm_nonconvex_hull(x, ...)
```

```
## S3 method for class 'Spatial'
fm_nonconvex_hull(x, ...)
```

```
## S3 method for class 'sfg'
fm_nonconvex_hull(x, ...)
```

Arguments

x	A spatial object
...	Arguments passed on to the <code>fm_nonconvex_hull()</code> sub-methods
convex	numeric vector; How much to extend
concave	numeric vector; The minimum allowed reentrant curvature. Default equal to convex

preserveTopology	logical; argument to <code>sf::st_simplify()</code>
dTolerance	If not zero, controls the <code>dTolerance</code> argument to <code>sf::st_simplify()</code> . The default is $\text{pmin}(\text{convex}, \text{concave}) / 40$, chosen to give approximately 4 or more subsegments per circular quadrant.
crs	Options crs object for the resulting polygon

Details

Morphological dilation by convex, followed by closing by concave, with minimum concave curvature radius concave. If the dilated set has no gaps of width between

$$2\text{convex}(\sqrt{1 + 2\text{concave}/\text{convex}} - 1)$$

and 2concave , then the minimum convex curvature radius is convex.

The implementation is based on the identity

$$\text{dilation}(a)\&\text{closing}(b) = \text{dilation}(a + b)\&\text{erosion}(b)$$

where all operations are with respect to disks with the specified radii.

When convex, concave, or dTolerance are negative, `fm_diameter * abs(...)` is used instead.

Differs from `sf::st_buffer(x, convex)` followed by `sf::st_concave_hull()` (available from GEOS 3.11) in how the amount of allowed concavity is controlled.

Value

`fm_nonconvex_hull()` returns an extended object as an sfc polygon object (regardless of the class).

`fm_extensions()` returns a list of sfc objects.

Functions

- `fm_nonconvex_hull()`: Basic nonconvex hull method.
- `fm_extensions()`: Constructs a potentially nonconvex extension of a spatial object by performing dilation by convex + concave followed by erosion by concave. This is equivalent to dilation by convex followed by closing (dilation + erosion) by concave.

INLA compatibility

For mesh and curve creation, the `fm_rcdt_2d_inla()`, `fm_mesh_2d_inla()`, and `fm_nonconvex_hull_inla()` methods will keep the interface syntax used by `INLA::inla.mesh.create()`, `INLA::inla.mesh.2d()`, and `INLA::inla.nonconvex.hull()` functions, respectively, whereas the `fm_rcdt_2d()`, `fm_mesh_2d()`, and `fm_nonconvex_hull()` interfaces may be different, and potentially change in the future.

References

Gonzalez and Woods (1992), Digital Image Processing

See Also

[fm_nonconvex_hull_inla\(\)](#)

Examples

```
inp <- matrix(rnorm(20), 10, 2)
out <- fm_nonconvex_hull(inp, convex = 1)
plot(out)
points(inp, pch = 20)
if (TRUE) {
  inp <- sf::st_as_sf(as.data.frame(matrix(1:6, 3, 2)), coords = 1:2)
  bnd <- fm_extensions(inp, convex = c(0.75, 2))
  plot(fm_mesh_2d(boundary = bnd, max.edge = c(0.25, 1)), asp = 1)
}
```

fm_nonconvex_hull_inla

Non-convex hull computation

Description

Legacy method for `INLA::inla.nonconvex.hull()`

Usage

```
fm_nonconvex_hull_inla(
  x,
  convex = -0.15,
  concave = convex,
  resolution = 40,
  eps = NULL,
  eps_rel = NULL,
  crs = NULL,
  ...
)

fm_nonconvex_hull_inla_basic(
  x,
  convex = -0.15,
  resolution = 40,
  eps = NULL,
  crs = NULL
)
```

Arguments

x	A spatial object
convex	numeric vector; How much to extend
concave	numeric vector; The minimum allowed reentrant curvature. Default equal to convex
resolution	The internal computation resolution. A warning will be issued when this needs to be increased for higher accuracy, with the required resolution stated.
eps, eps_rel	The polygonal curve simplification tolerances used for simplifying the resulting boundary curve. See fm_simplify_helper() for details.
crs	Options crs object for the resulting polygon
...	Unused.

Details

Requires `splancs::nndistF()`

Value

`fm_nonconvex_hull_inla()` returns an `fm_segm/inla.mesh.segment` object, for compatibility with `inla.nonconvex.hull()`.

Functions

- `fm_nonconvex_hull_inla_basic()`: Special method for `convex = 0`.

INLA compatibility

For mesh and curve creation, the [fm_rcdt_2d_inla\(\)](#), [fm_mesh_2d_inla\(\)](#), and [fm_nonconvex_hull_inla\(\)](#) methods will keep the interface syntax used by `INLA::inla.mesh.create()`, `INLA::inla.mesh.2d()`, and `INLA::inla.nonconvex.hull()` functions, respectively, whereas the [fm_rcdt_2d\(\)](#), [fm_mesh_2d\(\)](#), and [fm_nonconvex_hull\(\)](#) interfaces may be different, and potentially change in the future.

See Also

[fm_nonconvex_hull\(\)](#)

Other nonconvex inla legacy support: [fm_segm_contour_helper\(\)](#), [fm_simplify_helper\(\)](#)

Examples

```
fm_nonconvex_hull_inla(cbind(0, 0), convex = 1)
```

fm_pixels

*Generate lattice points covering a mesh***Description**

Generate terra, sf, or sp lattice locations

Usage

```
fm_pixels(
  mesh,
  dims = c(150, 150),
  xlim = NULL,
  ylim = NULL,
  mask = TRUE,
  format = "sf",
  minimal = TRUE,
  nx = deprecated(),
  ny = deprecated()
)
```

Arguments

mesh	An fm_mesh_2d object
dims	A length 2 integer vector giving the dimensions of the target lattice.
xlim, ylim	Length 2 numeric vectors of x- and y- axis limits. Defaults taken from the range of the mesh or mask; see minimal.
mask	If logical and TRUE, remove pixels that are outside the mesh. If mask is an sf or Spatial object, only return pixels covered by this object.
format	character; "sf", "terra" or "sp"
minimal	logical; if TRUE (default), the default range is determined by the minimum of the ranges of the mesh and mask, otherwise only the mesh.
nx	[Deprecated] Number of pixels in x direction, or a numeric vector of x-values
ny	[Deprecated] Number of pixels in y direction, or a numeric vector of y-values

Value

sf, SpatRaster, or SpatialPixelsDataFrame covering the mesh or mask.

Author(s)

Finn Lindgren <finn.lindgren@gmail.com>

Examples

```

if (require("ggplot2", quietly = TRUE)) {
  dims <- c(50, 50)
  pxl <- fm_pixels(
    fmexample$mesh,
    dims = dims,
    mask = fmexample$boundary_sf[[1]],
    minimal = TRUE
  )
  pxl$val <- rnorm(NROW(pxl)) +
    fm_evaluate(fmexample$mesh, pxl, field = 2 * fmexample$mesh$loc[, 1])
  ggplot() +
    geom_tile(
      data = pxl,
      aes(geometry = geometry, fill = val),
      stat = "sf_coordinates"
    ) +
    geom_sf(data = fm_as_sfc(fmexample$mesh), alpha = 0.2)
}

if (require("ggplot2", quietly = TRUE) &&
    require("terra", quietly = TRUE) &&
    require("tidyterra", quietly = TRUE)) {
  pxl <- fm_pixels(fmexample$mesh,
    dims = c(50, 50), mask = fmexample$boundary_sf[[1]],
    format = "terra"
  )
  pxl$val <- rnorm(NROW(pxl) * NCOL(pxl))
  pxl <-
    terra::mask(
      pxl,
      mask = pxl$.mask,
      maskvalues = c(FALSE, NA),
      updatevalue = NA
    )
  ggplot() +
    geom_spatraster(data = pxl, aes(fill = val)) +
    geom_sf(data = fm_as_sfc(fmexample$mesh), alpha = 0.2)
}

```

Description

Calculate basis functions on [fm_mesh_1d\(\)](#) or [fm_mesh_2d\(\)](#), without necessarily matching the default function space of the given mesh object.

Usage

```

fm_raw_basis(
  mesh,
  type = "b.spline",
  n = 3,
  degree = 2,
  knot.placement = "uniform.area",
  rot.inv = TRUE,
  boundary = "free",
  free.clamped = TRUE,
  ...
)

```

Arguments

mesh	An fm_mesh_1d() or fm_mesh_2d() object.
type	b.spline (default) for B-spline basis functions, sph.harm for spherical harmonics (available only for meshes on the sphere)
n	For B-splines, the number of basis functions in each direction (for 1d meshes n must be a scalar, and for planar 2d meshes a 2-vector). For spherical harmonics, n is the maximal harmonic order.
degree	Degree of B-spline polynomials. See fm_mesh_1d() .
knot.placement	For B-splines on the sphere, controls the latitudinal placements of knots. "uniform.area" (default) gives uniform spacing in $\sin(\text{latitude})$, "uniform.latitude" gives uniform spacing in latitudes.
rot.inv	For spherical harmonics on a sphere, rot.inv=TRUE gives the rotationally invariant subset of basis functions.
boundary	Boundary specification, default is free boundaries. See fm_mesh_1d() for more information.
free.clamped	If TRUE and boundary is "free", the boundary basis functions are clamped to 0/1 at the interval boundary by repeating the boundary knots. See fm_mesh_1d() for more information.
...	Unused

Value

A matrix with evaluated basis function

Author(s)

Finn Lindgren <finn.lindgren@gmail.com>

See Also

[fm_mesh_1d\(\)](#), [fm_mesh_2d\(\)](#), [fm_basis\(\)](#)

Examples

```

loc <- rbind(c(0, 0), c(1, 0), c(1, 1), c(0, 1))
mesh <- fm_mesh_2d(loc, max.edge = 0.15)
basis <- fm_raw_basis(mesh, n = c(4, 5))

proj <- fm_evaluator(mesh, dims = c(10, 10))
image(proj$x, proj$y, fm_evaluate(proj, basis[, 7]), asp = 1)

if (interactive() && require("rgl")) {
  plot_rgl(mesh, col = basis[, 7], draw.edges = FALSE, draw.vertices = FALSE)
}

```

fm_rcdt_2d

*Refined Constrained Delaunay Triangulation***Description**

Computes a refined constrained Delaunay triangulation on R2 or S2.

Usage

```

fm_rcdt_2d(...)

fm_rcdt_2d_inla(
  loc = NULL,
  tv = NULL,
  boundary = NULL,
  interior = NULL,
  extend = (missing(tv) || is.null(tv)),
  refine = FALSE,
  lattice = NULL,
  globe = NULL,
  cutoff = 1e-12,
  quality.spec = NULL,
  crs = NULL,
  ...
)

fm_delaunay_2d(loc, crs = NULL, ...)

```

Arguments

...	Currently passed on to <code>fm_mesh_2d_inla</code> or converted to <code>fmesh_rcdt()</code> options.
loc	Input coordinates that should be part of the mesh. Can be a matrix, <code>sf</code> , <code>sfc</code> , <code>SpatialPoints</code> , or other object supported by <code>fm_unify_coords()</code> .

tv	Initial triangulation, as a N-by-3 index vector into loc boundary, interior
	Objects supported by <code>fm_as_segm()</code> . If boundary is numeric, <code>fm_nonconvex_hull(loc, convex = boundary)</code> is used.
extend	logical or list specifying whether to extend the data region, with parameters list("n") the number of edges in the extended boundary (default=16) list("offset") the extension distance. If negative, interpreted as a factor relative to the approximate data diameter (default=-0.10) Setting to FALSE is only useful in combination lattice or boundary.
refine	logical or list specifying whether to refine the triangulation, with parameters list("min.angle") the minimum allowed interior angle in any triangle. The algorithm is guaranteed to converge for min.angle at most 21 (default=21) list("max.edge") the maximum allowed edge length in any triangle. If negative, interpreted as a relative factor in an ad hoc formula depending on the data density (default=Inf) list("max.n.strict") the maximum number of vertices allowed, overriding min.angle and max.edge (default=-1, meaning no limit) list("max.n") the maximum number of vertices allowed, overriding max.edge only (default=-1, meaning no limit)
lattice	An <code>fm_lattice_2d</code> object, generated by <code>fm_lattice_2d()</code> , specifying points on a regular lattice.
globe	If non-NULL, an integer specifying the level of subdivision for global mesh points, used with <code>fmesh_globe_points()</code>
cutoff	The minimum allowed distance between points. Point at most as far apart as this are replaced by a single vertex prior to the mesh refinement step.
quality.spec	List of vectors of per vertex max.edge target specification for each location in loc, boundary/interior (segm), and lattice. Only used if refining the mesh.
crs	Optional crs object

Value

An `fm_mesh_2d` object

Functions

- `fm_rcdt_2d_inla()`: Legacy method for the `INLA::inla.mesh.create()` interface
- `fm_delaunay_2d()`: Construct a plain Delaunay triangulation.

INLA compatibility

For mesh and curve creation, the `fm_rcdt_2d_inla()`, `fm_mesh_2d_inla()`, and `fm_nonconvex_hull_inla()` methods will keep the interface syntax used by `INLA::inla.mesh.create()`, `INLA::inla.mesh.2d()`, and `INLA::inla.nonconvex.hull()` functions, respectively, whereas the `fm_rcdt_2d()`, `fm_mesh_2d()`, and `fm_nonconvex_hull()` interfaces may be different, and potentially change in the future.

Examples

```
(m <- fm_rcdt_2d_inla(
  boundary = fm_nonconvex_hull(cbind(0, 0), convex = 5)
))

fm_delaunay_2d(matrix(rnorm(30), 15, 2))
```

fm_row_kron	<i>Row-wise Kronecker products</i>
-------------	------------------------------------

Description

Takes two Matrices and computes the row-wise Kronecker product. Optionally applies row-wise weights and/or applies an additional 0/1 row-wise Kronecker matrix product.

Usage

```
fm_row_kron(M1, M2, repl = NULL, n.repl = NULL, weights = NULL)
```

Arguments

M1	A matrix that can be transformed into a sparse Matrix.
M2	A matrix that can be transformed into a sparse Matrix.
repl	An optional index vector. For each entry, specifies which replicate the row belongs to, in the sense used in <code>INLA::inla.spde.make.A</code>
n.repl	The maximum replicate index, in the sense used in <code>INLA::inla.spde.make.A()</code> .
weights	Optional scaling weights to be applied row-wise to the resulting matrix.

Value

A `Matrix::sparseMatrix` object.

Author(s)

Finn Lindgren <finn.lindgren@gmail.com>

Examples

```
fm_row_kron(rbind(c(1, 1, 0), c(0, 1, 1)), rbind(c(1, 2), c(3, 4)))
```

fm_segm	<i>Make a spatial segment object</i>
---------	--------------------------------------

Description

Make a spatial segment object

Usage

```
fm_segm(...)

## Default S3 method:
fm_segm(loc = NULL, idx = NULL, grp = NULL, is.bnd = TRUE, crs = NULL, ...)

## S3 method for class 'fm_segm'
fm_segm(..., grp = NULL, grp.default = 0L, is.bnd = NULL)

## S3 method for class 'fm_segm_list'
fm_segm(x, grp = NULL, grp.default = 0L, ...)

fm_segm_join(x, grp = NULL, grp.default = 0L, is.bnd = NULL)

fm_segm_split(x, grp = NULL, grp.default = 0L)

## S3 method for class 'inla.mesh.segment'
fm_segm(..., grp.default = 0)

## S3 method for class 'inla.mesh'
fm_segm(x, ...)

## S3 method for class 'fm_mesh_2d'
fm_segm(x, boundary = TRUE, grp = NULL, ...)

fm_is_bnd(x)

fm_is_bnd(x) <- value
```

Arguments

<code>...</code>	Passed on to submethods
<code>loc</code>	Matrix of point locations, or <code>SpatialPoints</code> , or <code>sf/sfc</code> point object.
<code>idx</code>	Segment index sequence vector or index pair matrix. The indices refer to the rows of <code>loc</code> . If <code>loc==NULL</code> , the indices will be interpreted as indices into the point specification supplied to <code>fm_rcdt_2d()</code> . If <code>is.bnd==TRUE</code> , defaults to linking all the points in <code>loc</code> , as <code>c(1:nrow(loc), 1L)</code> , otherwise <code>1:nrow(loc)</code> .

grp	When joining segments, use these group labels for segments instead of the original group labels.
is.bnd	TRUE if the segments are boundary segments, otherwise FALSE.
crs	An optional <code>fm_crs()</code> , <code>sf::st_crs()</code> or <code>sp::CRS()</code> object
grp.default	If <code>grp.default</code> is NULL, use these group labels for segments with NULL group.
x	Mesh to extract segments from
boundary	logical; if TRUE, extract the boundary segments, otherwise interior constrain segments.
value	logical

Value

An `fm_seg` or `fm_seg_list` object

Methods (by class)

- `fm_seg(fm_seg)`: Join multiple `fm_seg` objects into a single `fm_seg` object. If `is.bnd` is non-NULL, it overrides the input segment information. Otherwise, it checks if the inputs are consistent.
- `fm_seg(fm_seg_list)`: Join `fm_seg` objects from a `fm_seg_list` into a single `fm_seg` object. Equivalent to `fm_seg_join(x)`
- `fm_seg(fm_mesh_2d)`: Extract the boundary or interior segments of a 2d mesh. If `grp` is non-NULL, extracts only segments matching the matching the set of groups given by `grp`.

Functions

- `fm_seg()`: Create a new `fm_seg` object.
- `fm_seg_join()`: Join multiple `fm_seg` objects into a single `fm_seg` object. If `is.bnd` is non-NULL, it overrides the segment information. Otherwise it checks for consistency.
- `fm_seg_split()`: Split an `fm_seg` object by `grp` into an `fm_seg_list` object, optionally keeping only some groups.

See Also

Other object creation and conversion: `fm_as_fm()`, `fm_as_lattice_2d()`, `fm_as_mesh_1d()`, `fm_as_mesh_2d()`, `fm_as_seg()`, `fm_as_sfc()`, `fm_as_tensor()`, `fm_lattice_2d()`, `fm_mesh_1d()`, `fm_mesh_2d()`, `fm_simplify()`, `fm_tensor()`

Examples

```
fm_seg(rbind(c(0, 0), c(1, 0), c(1, 1), c(0, 1)), is.bnd = FALSE)
fm_seg(rbind(c(0, 0), c(1, 0), c(1, 1), c(0, 1)), is.bnd = TRUE)
```

```
fm_seg_join(fmexample$boundary_fm)
```

```
fm_seg(fmexample$mesh, boundary = TRUE)
fm_seg(fmexample$mesh, boundary = FALSE)
```

`fm_segmlist`*Methods for fm_segmlist*

Description

fm_segmlist lists can be combined into fm_segmlist list objects.

Usage

```
## S3 method for class 'fm_segmlist'
c(...)

## S3 method for class 'fm_segmlist'
c(...)

## S3 method for class 'fm_segmlist'
x[i]
```

Arguments

<code>...</code>	Objects to be combined.
<code>x</code>	fm_segmlist object from which to extract element(s)
<code>i</code>	indices specifying elements to extract

Value

A fm_segmlist object

Methods (by generic)

- `c(fm_segmlist)`: The `...` arguments should be coercible to fm_segmlist objects.
- `[:`: Extract sub-list

Functions

- `c(fm_segmlist)`: The `...` arguments should be fm_segmlist objects, or coercible with `fm_as_segmlist(list(...))`.

See Also

[fm_as_segmlist\(\)](#)

Examples

```
m <- c(A = fm_segmlist(1:2), B = fm_segmlist(3:4))
str(m)
str(m[2])
```

fm_simplify	<i>Recursive curve simplification.</i>
-------------	--

Description

[Experimental] Simplifies polygonal curve segments by joining nearly co-linear segments. Uses a variation of the binary splitting Ramer-Douglas-Peucker algorithm, with an ellipse of half-width eps ellipse instead of a rectangle, motivated by prediction ellipse for Brownian bridge.

Usage

```
fm_simplify(x, eps = NULL, eps_rel = NULL, ...)
```

Arguments

x	An <code>fm_segm()</code> object.
eps	Absolute straightness tolerance. Default NULL, no constraint.
eps_rel	Relative straightness tolerance. Default NULL, no constraint.
...	Currently unused.

Details

Variation of Ramer-Douglas-Peucker. Uses width epsilon ellipse instead of rectangle, motivated by prediction ellipse for Brownian bridge.

Value

The simplified `fm_segm()` object.

Author(s)

Finn Lindgren <finn.lindgren@gmail.com>

References

Ramer, Urs (1972). "An iterative procedure for the polygonal approximation of plane curves". *Computer Graphics and Image Processing*. **1** (3): 244–256. doi:10.1016/S0146664X(72)800170

Douglas, David; Peucker, Thomas (1973). "Algorithms for the reduction of the number of points required to represent a digitized line or its caricature". *The Canadian Cartographer*. **10** (2): 112–122. doi:10.3138/FM576770U75U7727

See Also

Other object creation and conversion: `fm_as_fm()`, `fm_as_lattice_2d()`, `fm_as_mesh_1d()`, `fm_as_mesh_2d()`, `fm_as_segm()`, `fm_as_sfc()`, `fm_as_tensor()`, `fm_lattice_2d()`, `fm_mesh_1d()`, `fm_mesh_2d()`, `fm_segm()`, `fm_tensor()`

Examples

```

theta <- seq(0, 2 * pi, length.out = 1000)
(seg1 <- fm_seg1(cbind(cos(theta), sin(theta)),
  idx = seq_along(theta)
))
(seg1 <- fm_simplify(seg1, eps_rel = 0.1))
(seg2 <- fm_simplify(seg1, eps_rel = 0.2))
plot(seg1)
lines(seg1, col = 2)
lines(seg2, col = 3)

(seg1 <- fm_seg1(cbind(theta, sin(theta * 4)),
  idx = seq_along(theta)
))
(seg1 <- fm_simplify(seg1, eps_rel = 0.1))
(seg2 <- fm_simplify(seg1, eps_rel = 0.2))
plot(seg1)
lines(seg1, col = 2)
lines(seg2, col = 3)

```

fm_split_lines

Split lines at triangle edges

Description

Compute intersections between line segments and triangle edges, and filter out segment of length zero.

Usage

```

fm_split_lines(mesh, ...)

## S3 method for class 'fm_mesh_2d'
fm_split_lines(mesh, segm, ...)

## S3 method for class 'inla.mesh'
fm_split_lines(mesh, ...)

```

Arguments

mesh	An fm_mesh_2d or inla.mesh object
...	Unused.
segm	An fm_seg1() object with segments to be split

Value

An fm_seg1() object with the same crs as the mesh, with an added field origin, that for each new segment gives the originator index into to original segm object for each new line segment.

Author(s)

Finn Lindgren <finn.lindgren@gmail.com>

Examples

```
mesh <- fm_mesh_2d(  
  boundary = fm_segm(  
    rbind(c(0, 0), c(1, 0), c(1, 1), c(0, 1)),  
    is.bnd = TRUE  
  )  
)  
splitter <- fm_segm(rbind(c(0.8, 0.2), c(0.2, 0.8)))  
segm_split <- fm_split_lines(mesh, splitter)  
  
plot(mesh)  
lines(splitter)  
points(segm_split$loc)
```

fm_subdivide

Split triangles of a mesh into subtriangles

Description

[Experimental] Splits each mesh triangle into $(n + 1)^2$ subtriangles. The current version drops any edge constraint information from the mesh.

Usage

```
fm_subdivide(mesh, n = 1)
```

Arguments

mesh an [fm_mesh_2d](#) object
n number of added points along each edge. Default is 1.

Value

A refined [fm_mesh_2d](#) object

Author(s)

Finn Lindgren <finn.lindgren@gmail.com>

Examples

```

mesh <- fm_rcdt_2d_inla(
  loc = rbind(c(0, 0), c(1, 0), c(0, 1)),
  tv = rbind(c(1, 2, 3))
)
mesh_sub <- fm_subdivide(mesh, 3)
mesh
mesh_sub

plot(mesh_sub, edge.color = 2)

plot(fm_subdivide(fmexample$mesh, 3), edge.color = 2)
plot(fmexample$mesh, add = TRUE, edge.color = 1)

```

fm_tensor

Make a tensor product function space

Description

[Experimental] Tensor product function spaces. The interface and object storage model is experimental and may change.

Usage

```
fm_tensor(x, ...)
```

Arguments

x list of function space objects, such as [fm_mesh_2d\(\)](#).
... Currently unused

Value

A fm_tensor or fm_tensor_list object. Elements of fm_tensor:

fun_spaces fm_list of function space objects

manifold character; manifold type summary. Regular subset of Rd "Rd", if all function spaces have type "R", torus connected "Td" if all function spaces have type "S", and otherwise "Md" In all cases, d is the sum of the manifold dimensions of the function spaces.

See Also

Other object creation and conversion: [fm_as_fm\(\)](#), [fm_as_lattice_2d\(\)](#), [fm_as_mesh_1d\(\)](#), [fm_as_mesh_2d\(\)](#), [fm_as_segm\(\)](#), [fm_as_sfc\(\)](#), [fm_as_tensor\(\)](#), [fm_lattice_2d\(\)](#), [fm_mesh_1d\(\)](#), [fm_mesh_2d\(\)](#), [fm_segm\(\)](#), [fm_simplify\(\)](#)

Examples

```

m <- fm_tensor(list(
  space = fmexample$mesh,
  time = fm_mesh_1d(1:5)
))
m2 <- fm_as_tensor(m)
m3 <- fm_as_tensor_list(list(m, m))
c(fm_dof(m$fun_spaces$space) * fm_dof(m$fun_spaces$time), fm_dof(m))
str(fm_evaluator(m, loc = list(space = cbind(0, 0), time = 2.5)))
str(fm_basis(m, loc = list(space = cbind(0, 0), time = 2.5)))
str(fm_fem(m))

```

fm_transform

*Object coordinate transformation***Description**

Handle transformation of various inla objects according to coordinate reference systems of crs (from sf::st_crs()), fm_crs, sp::CRS, fm_CRS, or INLA::inla.CRS class.

Usage

```

fm_transform(x, crs, ...)

## Default S3 method:
fm_transform(x, crs, ..., crs0 = NULL)

## S3 method for class 'NULL'
fm_transform(x, crs, ...)

## S3 method for class 'matrix'
fm_transform(x, crs, ..., passthrough = FALSE, crs0 = NULL)

## S3 method for class 'sf'
fm_transform(x, crs, ..., passthrough = FALSE)

## S3 method for class 'sfc'
fm_transform(x, crs, ..., passthrough = FALSE)

## S3 method for class 'sfg'
fm_transform(x, crs, ..., passthrough = FALSE)

## S3 method for class 'Spatial'
fm_transform(x, crs, ..., passthrough = FALSE)

## S3 method for class 'fm_mesh_2d'
fm_transform(x, crs = fm_crs(x), ..., passthrough = FALSE, crs0 = fm_crs(x))

```

```

## S3 method for class 'fm_lattice_2d'
fm_transform(x, crs = fm_crs(x), ..., passthrough = FALSE, crs0 = fm_crs(x))

## S3 method for class 'fm_segm'
fm_transform(x, crs = fm_crs(x), ..., passthrough = FALSE, crs0 = fm_crs(x))

## S3 method for class 'fm_list'
fm_transform(x, crs, ...)

## S3 method for class 'inla.mesh'
fm_transform(x, crs = fm_crs(x), ...)

## S3 method for class 'inla.mesh.lattice'
fm_transform(x, crs, ...)

## S3 method for class 'inla.mesh.segment'
fm_transform(x, crs, ...)

```

Arguments

x	The object that should be transformed from it's current CRS to a new CRS
crs	The target crs object
...	Potential additional arguments
crs0	The source crs object for spatial classes without crs information
passthrough	Default is FALSE. Setting to TRUE allows objects with no CRS information to be passed through without transformation. Use with care!

Value

A transformed object, normally of the same class as the input object.

See Also

[fm_CRS\(\)](#)

Examples

```

fm_transform(
  rbind(c(0, 0), c(0, 90), c(0, 91)),
  crs = fm_crs("sphere"),
  crs0 = fm_crs("longlat_norm")
)

```

fm_vertices	<i>Extract vertex locations from an fm_mesh_2d</i>
-------------	--

Description

Extracts the vertices of an `fm_mesh_2d` object.

Usage

```
fm_vertices(x, format = NULL)
```

Arguments

x	An <code>fm_mesh_2d</code> object.
format	character; "sf", "df", "sp"

Value

An `sf`, `data.frame`, or `SpatialPointsDataFrame` object, with the vertex coordinates, and a `.vertex` column with the vertex indices.

Author(s)

Finn Lindgren <finn.lindgren@gmail.com>

See Also

[fm_centroids\(\)](#)

Examples

```
if (require("ggplot2", quietly = TRUE)) {  
  vrt <- fm_vertices(fmexample$mesh, format = "sf")  
  ggplot() +  
    geom_sf(data = fm_as_sfc(fmexample$mesh)) +  
    geom_sf(data = vrt, color = "red")  
}
```

`geom_fm`*ggplot2 geomes for fmesher related objects*

Description

[Experimental]

`geom_fm` is a generic function for generating geomes from various kinds of fmesher objects, e.g. `fm_seg` and `fm_mesh_2d`. The function invokes particular methods which depend on the `class` of the data argument. Requires the `ggplot2` package.

Note: `geom_fm` is not yet a "proper" `ggplot2` geom method; the interface may therefore change in the future.

Usage

```
geom_fm(mapping = NULL, data = NULL, ...)

## S3 method for class 'fm_mesh_2d'
geom_fm(
  mapping = NULL,
  data = NULL,
  ...,
  mappings = NULL,
  defs = NULL,
  crs = NULL,
  mapping_int = deprecated(),
  mapping_bnd = deprecated(),
  defs_int = deprecated(),
  defs_bnd = deprecated()
)

## S3 method for class 'fm_seg'
geom_fm(mapping = NULL, data = NULL, ..., crs = NULL)

## S3 method for class 'fm_mesh_1d'
geom_fm(
  mapping = NULL,
  data = NULL,
  ...,
  xlim = NULL,
  basis = TRUE,
  knots = TRUE,
  derivatives = FALSE,
  weights = NULL
)
```


Arguments

mapping	an object for which to generate a geom.
data	an object for which to generate a geom.
...	Arguments passed on to the geom method.
mappings	optional list of aes mappings for the non-triangle parts of the mesh, named "int" for interior constraint edges, "bnd" for boundary edges, and "loc" for the vertices.
defs	optional list of non-aes settings for the non-triangle parts of the mesh, named "int" for interior constraint edges, "bnd" for boundary edges, and "loc" for the vertices.
crs	Optional crs to transform the object to before plotting.
mapping_int, mapping_bnd, defs_int, defs_bnd	[Deprecated] arguments; see mappings and defs.
xlim	numeric 2-vector; specifies the interval for which to compute functions. Default is data\$interval
basis	logical; if TRUE (default), show the spline basis functions
knots	logical; if TRUE (default), show the spline knot locations
derivatives	logical; if TRUE (not default), draw first order derivatives instead of function values
weights	numeric vector; if provided, draw weighted basis functions and the resulting weighted sum.

Value

A combination of ggplot2 geoms.

Methods (by class)

- `geom_fm(fm_mesh_2d)`: Converts an `fm_mesh_2d()` object to `sf` with `fm_as_sf()` and uses `geom_sf` to visualize the triangles and edges.
The mesh vertices are only plotted if `mappings$loc` or `defs$loc` is non-NULL, e.g. `defs = list(loc = list())`. Default argument settings:

```
... = linewidth = 0.25, color = "grey" # default for triangle mapping
defs = list(
  int = list(linewidth = 0.5, color = "blue"),
  bnd = list(linewidth = 1, color = "black"),
  loc = list(size = 1, color = "red")
)
```
- `geom_fm(fm_seg)`: Converts an `fm_seg()` object to `sf` with `fm_as_sf()` and uses `geom_sf` to visualize it.
- `geom_fm(fm_mesh_1d)`: Evaluates and plots the basis functions defined by an `fm_mesh_1d()` object.

Examples

```

ggplot() +
  geom_fm(data = fmexample$mesh)

m <- fm_mesh_2d(
  cbind(10, 20),
  boundary = fm_extensions(cbind(10, 20), c(25, 65)),
  max.edge = c(4, 10),
  crs = fm_crs("+proj=longlat")
)
ggplot() +
  geom_fm(data = m)
ggplot() +
  geom_fm(data = m, defs = list(loc = list()))
ggplot() +
  geom_fm(data = m, crs = fm_crs("epsg:27700"))

# Compute a mesh vertex based function on a different grid
px <- fm_pixels(fm_transform(m, fm_crs("mollweide_globe")))
px$fun <- fm_evaluate(m,
  loc = px,
  field = sin(m$loc[, 1] / 5) * sin(m$loc[, 2] / 5)
)
ggplot() +
  geom_tile(aes(geometry = geometry, fill = fun),
    data = px,
    stat = "sf_coordinates"
  ) +
  geom_fm(
    data = m, alpha = 0.2, linewidth = 0.05,
    crs = fm_crs("mollweide_globe")
  )

m <- fm_mesh_1d(c(1, 2, 4, 6, 10), boundary = c("n", "d"), degree = 2)
ggplot() +
  geom_fm(data = m, weights = c(4, 2, 4, -1))

m <- fm_mesh_1d(
  c(1, 2, 3, 5, 7),
  boundary = c("dirichlet", "neumann"),
  degree = 2
)
ggplot() +
  geom_fm(data = m)

```

plot.fm_mesh_2d *Draw a triangulation mesh object*

Description

Plots an `fm_mesh_2d()` object using standard graphics.

Usage

```
## S3 method for class 'fm_mesh_2d'
lines(x, ..., add = TRUE)

## S3 method for class 'fm_mesh_2d'
plot(
  x,
  col = "white",
  t.sub = seq_len(nrow(x$graph$tv)),
  add = FALSE,
  lwd = 1,
  xlim = range(x$loc[, 1]),
  ylim = range(x$loc[, 2]),
  main = NULL,
  size = 1,
  draw.vertices = FALSE,
  vertex.color = "black",
  draw.edges = TRUE,
  edge.color = rgb(0.3, 0.3, 0.3),
  draw.segments = draw.edges,
  rgl = deprecated(),
  visibility = "front",
  asp = 1,
  axes = FALSE,
  xlab = "",
  ylab = "",
  ...
)
```

Arguments

<code>x</code>	An <code>fm_mesh_2d()</code> object.
<code>...</code>	Further graphics parameters, interpreted by the respective plotting systems.
<code>add</code>	If TRUE, adds to the current plot instead of starting a new one.
<code>col</code>	Color specification. A single named color, a vector of scalar values, or a matrix of RGB values. Requires <code>rgl=TRUE</code> .
<code>t.sub</code>	Optional triangle index subset to be drawn.

<code>lwd</code>	Line width for triangle edges.
<code>xlim</code>	X-axis limits.
<code>ylim</code>	Y-axis limits.
<code>main</code>	Deprecated.
<code>size</code>	argument <code>cex</code> for vertex points.
<code>draw.vertices</code>	If TRUE, draw triangle vertices.
<code>vertex.color</code>	Color specification for all vertices.
<code>draw.edges</code>	If TRUE, draw triangle edges.
<code>edge.color</code>	Color specification for all edges.
<code>draw.segments</code>	If TRUE, draw boundary and interior constraint edges more prominently.
<code>rgl</code>	Deprecated
<code>visibility</code>	If "front" only display mesh faces with normal pointing towards the camera.
<code>asp</code>	Aspect ratio for new plots. Default 1.
<code>axes</code>	logical; whether axes should be drawn on the plot. Default FALSE.
<code>xlab, ylab</code>	character; labels for the axes.

Value

None

Author(s)

Finn Lindgren <finn.lindgren@gmail.com>

See Also

[plot.fm_segm\(\)](#), [plot_rgl.fm_mesh_2d\(\)](#)

Examples

```
mesh <- fm_rcdt_2d(globe = 10)
plot(mesh)

mesh <- fm_mesh_2d(cbind(0, 1), offset = c(1, 1.5), max.edge = 0.5)
plot(mesh)
```

plot.fm_seg	<i>Draw fm_seg objects.</i>
-------------	-----------------------------

Description

Draws a `fm_seg()` object with generic or `rgl` graphics.

Usage

```
## S3 method for class 'fm_seg'
plot(x, ..., add = FALSE)

## S3 method for class 'fm_seg'
lines(
  x,
  loc = NULL,
  col = NULL,
  colors = c("black", "blue", "red", "green"),
  add = TRUE,
  xlim = NULL,
  ylim = NULL,
  rgl = FALSE,
  asp = 1,
  axes = FALSE,
  xlab = "",
  ylab = "",
  visibility = "front",
  ...
)

## S3 method for class 'fm_seg_list'
plot(x, ...)

## S3 method for class 'fm_seg_list'
lines(x, ...)
```

Arguments

<code>x</code>	An <code>fm_seg()</code> object.
<code>...</code>	Additional parameters, passed on to graphics methods.
<code>add</code>	If TRUE, add to the current plot, otherwise start a new plot.
<code>loc</code>	Point locations to be used if <code>x\$loc</code> is NULL.
<code>col</code>	Segment color specification.
<code>colors</code>	Colors to cycle through if <code>col</code> is NULL.
<code>xlim, ylim</code>	X and Y axis limits for a new plot.

rgl	If TRUE, use rgl for plotting.
asp	Aspect ratio for new plots. Default 1.
axes	logical; whether axes should be drawn on the plot. Default FALSE.
xlab, ylab	character; labels for the axes.
visibility	If "front" only display mesh faces with normal pointing towards the camera.

Value

None

Author(s)

Finn Lindgren <finn.lindgren@gmail.com>

See Also

[fm_segm\(\)](#), [plot.fm_mesh_2d](#)

Examples

```
plot(fm_segm(fmexample$mesh, boundary = TRUE))
lines(fm_segm(fmexample$mesh, boundary = FALSE), col = 2)
```

plot_rgl

Low level triangulation mesh plotting

Description

Plots a triangulation mesh using rgl.

Usage

```
plot_rgl(x, ...)

lines_rgl(x, ..., add = TRUE)

## S3 method for class 'fm_segm'
lines_rgl(
  x,
  loc = NULL,
  col = NULL,
  colors = c("black", "blue", "red", "green"),
  ...,
  add = TRUE
)
```

```

## S3 method for class 'fm_mesh_2d'
plot_rgl(
  x,
  col = "white",
  color.axis = NULL,
  color.n = 512,
  color.palette = cm.colors,
  color.truncate = FALSE,
  alpha = NULL,
  lwd = 1,
  specular = "black",
  draw.vertices = TRUE,
  draw.edges = TRUE,
  draw.faces = TRUE,
  draw.segments = draw.edges,
  size = 2,
  edge.color = rgb(0.3, 0.3, 0.3),
  t.sub = seq_len(nrow(x$graph$tv)),
  visibility = "",
  S = deprecated(),
  add = FALSE,
  ...
)

## S3 method for class 'fm_segm'
plot_rgl(x, ..., add = FALSE)

## S3 method for class 'fm_segm_list'
plot_rgl(x, ...)

## S3 method for class 'fm_segm_list'
lines_rgl(x, ...)

```

Arguments

<code>x</code>	A <code>fm_mesh_2d()</code> object
<code>...</code>	Additional parameters passed to and from other methods.
<code>add</code>	If TRUE, adds to the current plot instead of starting a new one.
<code>loc</code>	Point locations to be used if <code>x\$loc</code> is NULL.
<code>col</code>	Segment color specification.
<code>colors</code>	Colors to cycle through if <code>col</code> is NULL.
<code>color.axis</code>	The min/max limit values for the color mapping.
<code>color.n</code>	The number of colors to use in the color palette.
<code>color.palette</code>	A color palette function.
<code>color.truncate</code>	If TRUE, truncate the colors at the color axis limits.
<code>alpha</code>	Transparency/opaqueness values. See <code>rgl.material</code> .

lwd	Line width for edges. See <code>rgl.material</code> .
specular	Specular color. See <code>rgl.material</code> .
draw.vertices	If TRUE, draw triangle vertices.
draw.edges	If TRUE, draw triangle edges.
draw.faces	If TRUE, draw triangles.
draw.segments	If TRUE, draw boundary and interior constraint edges more prominently.
size	Size for vertex points.
edge.color	Edge color specification.
t.sub	Optional triangle index subset to be drawn.
visibility	If "front" only display mesh faces with normal pointing towards the camera.
S	Deprecated.

Value

An rgl device identifier, invisibly.

Author(s)

Finn Lindgren <finn.lindgren@gmail.com>

See Also

[plot.fm_mesh_2d\(\)](#)

Examples

```
if (interactive() && require("rgl")) {
  mesh <- fm_rcdt_2d(globe = 10)
  plot_rgl(mesh, col = mesh$loc[, 1])
}
```

print.fm_basis *Print method for fm_basis*

Description

Prints information for an [fm_basis](#) object.

Usage

```
## S3 method for class 'fm_basis'
print(x, ..., prefix = "")
```


Arguments

x	fm_basis() object
...	Unused
prefix	a prefix to be used for each line. Default is an empty string.

Value

invisible(x)

See Also

[fm_basis\(\)](#)

Examples

```
print(fm_basis(fmexample$mesh, fmexample$loc, full = TRUE))
```

print.fm_evaluator *Print method for fm_evaluator()*

Description

Prints information for an [fm_evaluator](#) object.

Usage

```
## S3 method for class 'fm_evaluator'  
print(x, ...)
```

Arguments

x	fm_evaluator() object
...	Unused

Value

invisible(x)

See Also

[fm_evaluator\(\)](#)

Examples

```
print(fm_evaluator(fmexample$mesh, fmexample$loc))
```

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