

Package: adlaplaceFem (via r-universe)

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Title Finite Element Approximations for Adlaplace

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Description Finite-element approximations for hierarchical models with the adlaplace Laplace approximation framework. Provides tensor-product B-spline FEM ingredients for Matern Gaussian random fields (mass, stiffness, and higher-order Grams), including hierarchical locally refined B-spline bases, design and Gram matrix construction on regular grids, optional terra SpatRaster / SpatVector input, and AD tape builders for random_fem_ssq_* / random_fem_det_*.

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Contents

fem_bspline	2
fem_bspline_ld	3
fem_chol_pattern	4
fem_logdet_debug	5
fem_precision	5
fem_precision_payload	6
fem_Q_structure	6
hb_basis	7
hb_knots	7
hinv_trace_index-methods	8
matern-class	9
matern_est	10
matern_fem_covariance	11
replace_vars-methods	12
rsmatern-class	12

Index	15
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fem_bspline	<i>Tensor-product B-spline FEM ingredients for a 2D Matern GRF</i>
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Description

Builds the design matrix of tensor-product B-splines at evaluation coordinates together with sparse mass, stiffness, and higher-order Gram matrices used in the SPDE FEM precision for operator orders $\alpha = 2$ and 3 .

Usage

```
fem_bspline(coords, knots, degree = 2L, ...)  
  
## S4 method for signature 'list'  
fem_bspline(coords, knots, degree = 2L, ...)
```

```
## S4 method for signature 'data.frame'
fem_bspline(coords, knots, degree = 2L, ...)
```

Arguments

<code>coords</code>	Evaluation locations. For a <code>data.frame</code> (e.g. <code>sites_eval</code> from <code>expand.grid</code>), rows are point coordinates with columns <code>x</code> and <code>y</code> . For a plain <code>list(x, y)</code> of axis sequences, the full tensor grid is formed with <code>expand.grid</code> . With terra , <code>SpatRaster</code> / <code>SpatVector</code> are also accepted.
<code>knots</code>	Knot-line positions on each axis: <code>list(x = seq(...), y = seq(...))</code> of unique increasing breakpoints (domain endpoints included). These are expanded to open B-spline knot vectors. With terra , a <code>SpatRaster</code> whose grid defines knot lines, or an "hb_knots" object from <code>hb_knots()</code> , is also accepted.
<code>degree</code>	B-spline degree; must be ≥ 2 . Default 2 ($\alpha = 2$). Use <code>degree = 3</code> when assembling G3 for $\alpha = 3$.
<code>...</code>	Passed to methods (unused for <code>list</code> / <code>data.frame</code>).

Details

Coefficient ordering is column-major (`vec`) over the n_x by n_y array of tensor basis indices: basis (i, j) maps to column $i + (j - 1) * n_x$.

Value

A list with:

- A** `dgCMatrix` design, n by $n_x * n_y$
- C, G, G2** sparse Grams
- G3** sparse Gram or `NULL` if `degree < 3`
- degree, knots, n_basis** metadata (`n_basis = c(n_x, n_y)`)

Examples

```
sites_list <- list(x = seq(0, 1, by = 0.25), y = seq(0, 1, by = 0.25))
sites_eval <- do.call(expand.grid, sites_list)
fem <- fem_bspline(sites_eval, sites_list, degree = 2L)
```

fem_bspline_1d

One-dimensional linear B-spline FEM (mass and stiffness)

Description

One-dimensional linear B-spline FEM (mass and stiffness)

Usage

```
fem_bspline_1d(knots, degree = 1L)
```

Arguments

knots Strictly increasing knot positions, including the domain ends.

degree B-spline degree. The Matérn-1/2 term uses degree 1.

Value

List with open knots, degree, sparse Grams C and G, and n basis functions.

fem_chol_pattern	<i>Symbolic LDL pattern for a sparse FEM precision structure</i>
------------------	--

Description

Builds the permutation and unit-lower pattern required by `adlaplace`'s `chol_update` for a precision with the same sparsity as `Q_structure` (typically the union of FEM Gram patterns).

Usage

```
fem_chol_pattern(Q_structure)
```

Arguments

Q_structure Symmetric sparse matrix with the structural nonzeros of `Q(theta)` (numeric values only need to make the matrix positive definite for symbolic analysis; diagonals are inflated if needed).

Value

A list with `perm` (0-based), `L1` (`dtCMatrix` / unit lower), and `perm_inv` (0-based), suitable for the `chol` slot of a `random_fem_*` precision payload.

fem_logdet_debug	<i>Sparse LDL log-determinant of a FEM precision at given (range, sd)</i>
------------------	---

Description

Exercises the same chol_update_csc path used by random_fem_det_*. Useful for diagnosing non-finite joint densities.

Usage

```
fem_logdet_debug(precision, range, sd, log_scale = NULL)
```

Arguments

precision	List from fem_precision_payload .
range, sd	Practical range and field SD (natural or log scale).
log_scale	Logical length-1 or length-2: whether range/sd are already on the log scale. Default FALSE (NULL).

Value

List with logdet, coef, D, first_bad, n_bad, n, alpha.

fem_precision	<i>Assemble FEM Matern precision Q2 or Q3 from Grams</i>
---------------	--

Description

Assemble FEM Matern precision Q2 or Q3 from Grams

Usage

```
fem_precision(kappa, tau, C, G, G2 = NULL, G3 = NULL, alpha = 2L)
```

Arguments

kappa, tau	Positive SPDE parameters.
C, G, G2, G3	Sparse Grams from fem_bspline() .
alpha	1 (1D Matern nu = 1/2: $\tau^2 (\kappa^2 C + G)$), 2, or 3.

Value

Sparse dgCMatrix precision.

fem_precision_payload	<i>Build random_fem_ssq_* / random_fem_det_* precision payload for adlaplace</i>
-----------------------	--

Description

Build random_fem_ssq_* / random_fem_det_* precision payload for adlaplace

Usage

```
fem_precision_payload(fem, alpha = 2L)
```

Arguments

fem	Result of <code>fem_bspline()</code> (or list with C, G, G2, optional G3).
alpha	1, 2, or 3. Alpha 1 uses C and G only and stores a zero G2 so the payload layout stays the same.

Value

List for density_data@precision: Grams, chol pattern, and Q CSC coefficients aligned for on-tape assembly.

fem_Q_structure	<i>Structural nonzero pattern for Q2 or Q3 from Grams</i>
-----------------	---

Description

Structural nonzero pattern for Q2 or Q3 from Grams

Usage

```
fem_Q_structure(C, G, G2, G3 = NULL)
```

Arguments

C, G, G2, G3	Sparse Grams from <code>fem_bspline()</code> ; G3 may be NULL for alpha = 2.
--------------	--

Value

Symmetric sparse matrix with the union of Gram nonzero patterns.

hb_basis	<i>Truncated hierarchical B-spline space</i>
----------	--

Description

Expands `hb_knots()` breakpoint lines to open knot vectors and builds the THB embedding (active sets and sparse map S) for a B-spline degree.

Usage

```
hb_basis(knots, degree = 2L)
```

```
hb_summary(hb)
```

Arguments

knots	An "hb_knots" object from <code>hb_knots()</code> .
degree	B-spline degree (must be ≥ 2).
hb	An "hb_basis" object from <code>hb_basis()</code> .

Value

An "hb_basis" object used by `fem_bspline()` and `matern()`.

Functions

- `hb_summary()`: Per-level active basis counts and total hierarchical dof.

hb_knots	<i>Hierarchical tensor-product B-spline knot specifications</i>
----------	---

Description

Builds nested knot-line locations from a coarse raster box and optional inner refinement extents. Knot **lines** do not depend on B-spline degree; pass the result to `hb_basis()` or `matern()` to form the THB space.

Usage

```
hb_knots(outer, inner = NULL, fact = 2L)
```

Arguments

outer	Level-0 box: <code>list(xmin, xmax, ymin, ymax, resolution)</code> , or a terra <code>SpatRaster</code> (converted to that list). resolution is dx or c(dx, dy).
inner	NULL (outer only), one extent, or a list of levels. An extent is <code>c(xmin, xmax, ymin, ymax)</code> , a terra <code>SpatExtent</code> , or <code>list(xmin, xmax, ymin, ymax)</code> .
fact	Integer ≥ 2 , recycled to <code>length(inner)</code> . <code>fact[i]</code> is the cell-size ratio from the previous level, so level-i resolution is <code>outer\$resolution / prod(fact[1:i])</code> .

Details

Each element of `inner` is one refinement level: a single extent, or a list of extents for sibling boxes at that level. `list(ext)` and `list(list(ext))` are the same one-level, one-box specification. `list(ext1, ext2)` is two levels; siblings are `list(list(ext1, ext2))`. Extents are snapped to the nested cell grid at that level (spacing `outer$resolution / prod(fact[1:i])`) and clipped to the parent level.

Value

An "hb_knots" list, one element per level, each with knots and rasters (`xmin, xmax, ymin, ymax, resolution`).

`hinv_trace_index-methods`

Slots of a FEM quadratic form inside the joint inverse Hessian

Description

`density_data` method for [hinv_trace_index](#). One 0-based index into `H_inv@x` per stored upper-triangle entry of `Q`, in that CSC order. `-1L` marks a pair the symbolic inverse does not store. Returns NULL when `shard` is not a `random_fem_ssqr` density.

Usage

```
## S4 method for signature 'density_data'
hinv_trace_index(shard, H_inv)
```

Arguments

shard	A <code>density_data</code> shard.
H_inv	Symbolic upper triangle of the joint inverse Hessian.

Value

An integer vector, or NULL when `shard` is not a `random_fem_ssqr` density.

See Also

[hinv_trace_index](#)

matern-class

Matern FEM spatial random field term

Description

Formula term for a 2D Matern GRF via tensor-product B-spline FEM, wired to `adlaplaceFem` kernels `random_fem_ssqr_2 / random_fem_det_2` (shape `nu = 1`) or `random_fem_ssqr_3 / random_fem_det_3` (`nu = 2`). The quadratic form is a random shard; the log-determinant is a parameters companion via `adlaplace::extra_density()`. The first argument is a **column name** in data (like `adlaplace::iid()`): that column holds observation locations as a 2-column matrix, WKT text, or HEX WKB points. Knot lines are supplied at construction; the observation design matrix is built later in `design()` from data.

Usage

```
matern(
  x,
  knots,
  shape = 1L,
  init = c(1, 1),
  lower = c(1e-09, 1e-09),
  upper = c(Inf, Inf),
  parscale = c(1, 1),
  log = TRUE
)

## S4 method for signature 'matern'
extra_density(term)

## S4 method for signature 'matern'
design(term, data)

## S4 method for signature 'matern'
precision(term, data)

## S4 method for signature 'matern'
random_info(term, data)

## S4 method for signature 'matern'
theta_info(term)

## S4 method for signature 'matern'
beta_info(term, data)
```

Arguments

`x` Name of the geometry / coordinate column in data.

knots	Knot lines as <code>list(x = ..., y = ...)</code> , a terra <code>SpatRaster</code> (extent endpoints plus interior cell centers), or an "hb_knots" object from <code>hb_knots()</code> .
shape	Matern smoothness <code>nu</code> (1 or 2). Default 1L (SPDE $\alpha = 2$, quadratic B-splines). Use 2 for $\nu = 2$ / cubic B-splines.
init	Initial values for <code>(range, sd)</code> on the natural scale, where $\text{range} = \sqrt{8 \cdot \nu} / \kappa$ is the practical range (same units as coordinates; matches <code>geostatsp/INLA</code>) and <code>sd</code> is the marginal SD of the Matern field. Internally converted to SPDE (κ , τ).
lower, upper	Bounds for <code>(range, sd)</code> .
parscale	Optimization scales for <code>(range, sd)</code> .
log	Whether each theta is optimized on the log scale (recycled to <code>(range, sd)</code>).
term	A <code>matern</code> term.
data	Model data frame (passed by <code>adlaplace</code> generics).

Details

In 2D, B-spline degree and SPDE order α equal `shape + 1`.

Value

A `matern` term object.

Functions

- `extra_density(matern)`: Companion parameters density for the FEM log-determinant shard.
- `design(matern)`: Design matrix of B-spline basis evaluations at coordinates in `data[[term@name]]`.
- `precision(matern)`: FEM precision payload for `random_fem_*`.
- `random_info(matern)`: Random-effect metadata (one row per basis weight).
- `theta_info(matern)`: Theta info for practical range $= \sqrt{8 \cdot \nu} / \kappa$ and field `sd` (log scale when `term@log` is `TRUE`).
- `beta_info(matern)`: Beta info (none).

matern_est

Posterior mean, SD, and simulations of a matern field on a raster

Description

Evaluates the fitted Matern GRF on `eval_grid` under the Laplace approximation for the random effects (outer parameters fixed at the MLE). Returns a `SpatRaster` with layers `mean`, `sd`, and optionally `sim1 ... simn`.

Usage

```
matern_est(fit, eval_grid, n = 0L, cores = 1L)
```

Arguments

fit	An "adlaplace_fit" from <code>adlaplace::adlaplace()</code> that includes exactly one <code>matern()</code> term.
eval_grid	A terra SpatRaster whose cell centers are evaluation sites.
n	Number of posterior simulations of the field. Default 0 (mean and sd only).
cores	Number of PSOCK workers used to build the design matrix. Each worker evaluates a contiguous block of cells, including <code>A_fine %*% S</code> for a hierarchical basis. Default 1 (no cluster). The posterior mean, SD, and simulations are formed on the calling process after the blocks are row-bound.

Value

A SpatRaster with $n + 2$ layers: mean, sd, and `sim1...simn` when $n > 0$.

`matern_fem_covariance` *Covariance of a FEM Matérn field at data locations*

Description

Evaluates the B-spline design A at the geometry column in `data` and returns $A Q^{-1} A'$. Q is the SPDE precision at the practical range $\sqrt{8 * \text{nu}} / \text{kappa}$ and marginal SD `sd`, with $\text{nu} = \text{shape}$.

Usage

```
matern_fem_covariance(term, data, range, sd)
```

Arguments

term	A <code>matern</code> term with cached FEM Grams.
data	Data frame containing the geometry column named in <code>term</code> .
range	Practical Matérn range, in the same units as the coordinates.
sd	Marginal standard deviation of the Matérn field.

Value

A dense n by n covariance matrix, with $n = \text{nrow}(\text{data})$.

replace_vars-methods	<i>Replace data-column names in an rsmatern term</i>
----------------------	--

Description

Method for `adlplace::replace_vars()`. Rewrites the time column, the exposure column (`mult`), and the grouping variable (`by`).

Usage

```
## S4 method for signature 'rsmatern'
replace_vars(x, map)
```

Arguments

<code>x</code>	An <code>rsmatern</code> term.
<code>map</code>	Named character vector: names are current column names, values are replacement column names. Names absent from <code>map</code> are left unchanged.

Value

The term with column references and the label updated.

See Also

`adlplace::replace_vars()`

rsmatern-class	<i>Random-slope Matérn-1/2 (Ornstein-Uhlenbeck) FEM term</i>
----------------	--

Description

Stationary one-dimensional Matérn field with smoothness $1/2$, the continuous analogue of AR(1), multiplied by $(\text{mult} - \text{ref_mult})$. Groups in `by` share one $(\text{range}, \text{sd})$ and have independent fields. The precision is the linear B-spline FEM $Q = \tau^2 (\kappa^2 C + G)$ with practical range $\rho = 2/\kappa$ and $\tau = 1 / (\text{sd} * \sqrt{2 * \kappa})$.

Usage

```
rsmatern(
  x,
  mult,
  by,
  knots,
  ref_mult = 0,
```

```

    levels = NULL,
    init = c(1, 0.05),
    lower = NULL,
    upper = NULL,
    log = TRUE,
    parscale = NULL
)

## S4 method for signature 'rsmatern'
design(term, data)

## S4 method for signature 'rsmatern'
precision(term, data)

## S4 method for signature 'rsmatern'
random_info(term, data)

## S4 method for signature 'rsmatern'
theta_info(term)

## S4 method for signature 'rsmatern'
beta_info(term, data)

## S4 method for signature 'rsmatern'
extra_density(term)

```

Arguments

x	Time column.
mult	Exposure column. The basis row is multiplied by <code>data[[mult]] - ref_mult</code> .
by	Grouping column. Levels share (range, sd).
knots	Increasing knot positions on the time axis. Linear B-splines.
ref_mult	Reference exposure (default 0).
levels	Optional group levels, in the order used for the blocks.
init	Length-2 starting values (range, sd).
lower, upper	Length-2 bounds. The default lower range is the knot spacing.
log	Log-transform the two hyperparameters (default TRUE).
parscale	Optional length-2 step scale.
term	An rsmatern term.
data	Model data frame (passed by <code>adlaplace</code> generics).

Value

An `rsmatern` term.

Functions

- `design(rsmatern)`: Design: basis at x , times $(\text{mult} - \text{ref_mult})$, written into the block for `by`.
- `precision(rsmatern)`: Block-diagonal FEM precision, one block per group.
- `random_info(rsmatern)`: One metadata row per basis weight and group.
- `theta_info(rsmatern)`: Hyperparameters (`range`, `sd`).
- `beta_info(rsmatern)`: No fixed effects.
- `extra_density(rsmatern)`: Log-determinant density `random_fem_det_1`.

Slots

`mult` Exposure column multiplied into the basis.

`ref_mult` Reference subtracted from `mult`.

`by` Grouping variable; one independent field per level.

`fem` Cached 1D Grams from `fem_bspline_1d()`.

Index

adlaplace::adlaplace(), [11](#)
adlaplace::extra_density(), [9](#)
adlaplace::iid(), [9](#)
adlaplace::replace_vars(), [12](#)

beta_info, matern-method (matern-class), [9](#)
beta_info, rsmatern-method (rsmatern-class), [12](#)

design(), [9](#)
design, matern-method (matern-class), [9](#)
design, rsmatern-method (rsmatern-class), [12](#)

extra_density, matern-method (matern-class), [9](#)
extra_density, rsmatern-method (rsmatern-class), [12](#)

fem_bspline, [2](#)
fem_bspline(), [5–7](#)
fem_bspline, data.frame-method (fem_bspline), [2](#)
fem_bspline, list-method (fem_bspline), [2](#)
fem_bspline_1d, [3](#)
fem_bspline_1d(), [14](#)
fem_chol_pattern, [4](#)
fem_logdet_debug, [5](#)
fem_precision, [5](#)
fem_precision_payload, [5, 6](#)
fem_Q_structure, [6](#)

hb_basis, [7](#)
hb_basis(), [7](#)
hb_knots, [7](#)
hb_knots(), [3, 7, 10](#)
hb_summary (hb_basis), [7](#)
hinv_trace_index, [8](#)
hinv_trace_index, density_data-method (hinv_trace_index-methods), [8](#)

hinv_trace_index-methods, [8](#)

matern, [10, 11](#)
matern (matern-class), [9](#)
matern(), [7, 11](#)
matern-class, [9](#)
matern_est, [10](#)
matern_fem_covariance, [11](#)

precision, matern-method (matern-class), [9](#)
precision, rsmatern-method (rsmatern-class), [12](#)

random_info, matern-method (matern-class), [9](#)
random_info, rsmatern-method (rsmatern-class), [12](#)
replace_vars, rsmatern-method (replace_vars-methods), [12](#)
replace_vars-methods, [12](#)
rsmatern, [13](#)
rsmatern (rsmatern-class), [12](#)
rsmatern-class, [12](#)

theta_info, matern-method (matern-class), [9](#)
theta_info, rsmatern-method (rsmatern-class), [12](#)