

Package ‘stelfi’

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Description Fit Hawkes and log-Gaussian Cox process models with extensions. Introduced in Hawkes (1971) <[doi:10.2307/2334319](https://doi.org/10.2307/2334319)> a Hawkes process is a self-exciting temporal point process where the occurrence of an event immediately increases the chance of another. We extend this to consider self-inhibiting process and a non-homogeneous background rate. A log-Gaussian Cox process is a Poisson point process where the log-intensity is given by a Gaussian random field. We extend this to a joint likelihood formulation fitting a marked log-Gaussian Cox model. In addition, the package offers functionality to fit self-exciting spatiotemporal point processes. Models are fitted via maximum likelihood using 'TMB' (Template Model Builder). Where included 1) random fields are assumed to be Gaussian and are integrated over using the Laplace approximation and 2) a stochastic partial differential equation model, introduced by Lindgren, Rue, and Lindström. (2011) <[doi:10.1111/j.1467-9868.2011.00777.x](https://doi.org/10.1111/j.1467-9868.2011.00777.x)>, is defined for the field(s).

License GPL (>= 3)

URL <https://github.com/cmjt/stelfi/>

BugReports <https://github.com/cmjt/stelfi/issues>

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fit_hawkes	<i>Self-exciting Hawkes process(es)</i>
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Description

Fit a Hawkes process using Template Model Builder (TMB). The function `fit_hawkes()` fits a self-exciting Hawkes process with a constant background rate. Whereas, `fit_hawkes_cbf()` fits a Hawkes processes with a user defined custom background function (non-homogeneous background rate). The function `fit_mhawkes()` fits a multivariate Hawkes process that allows for between- and within-stream self-excitement.

Usage

```
fit_hawkes(  
  times,  
  parameters = list(),  
  model = 1,  
  marks = c(rep(1, length(times))),  
  tmb_silent = TRUE,  
  optim_silent = TRUE,  
  ...  
)
```

```
fit_hawkes_cbf(  
  times,  
  parameters = list(),  
  model = 1,  
  marks = c(rep(1, length(times))),  
  background,  
  background_integral,  
  background_parameters,  
  background_min,  
  tmb_silent = TRUE,  
  optim_silent = TRUE  
)
```

```
fit_mhawkes(  
  times,  
  stream,  
  parameters = list(),  
  tmb_silent = TRUE,  
  optim_silent = TRUE,  
  ...  
)
```

Arguments

`times` A vector of numeric observed time points.

parameters	A named list of parameter starting values: <ul style="list-style-type: none"> • mu, a vector of base rates for each stream of the multivariate Hawkes process, • alpha, a matrix of the between- and within-stream self-excitement: the diagonal elements represent the within-stream excitement and the off-diagonals the excitement between streams, • beta, a vector of the exponential intensity decay for each stream of the multivariate Hawkes process,
model	A numeric indicator specifying which model to fit: <ul style="list-style-type: none"> • model = 1, fits a Hawkes process with exponential decay (default); • model = 2, fits a Hawkes process with an alpha that can be negative.
marks	Optional, a vector of numeric marks, defaults to 1 (i.e., no marks).
tmb_silent	Logical, if TRUE (default) then TMB inner optimisation tracing information will be printed.
optim_silent	Logical, if TRUE (default) then for each iteration <code>optim()</code> output will be printed.
...	Additional arguments to pass to <code>optim()</code>
background	A function taking one parameter and an independent variable, returning a scalar.
background_integral	The integral of background.
background_parameters	The parameter(s) for the background function background. This could be a list of multiple values.
background_min	A function taking one parameter and two points, returns min of background between those points.
stream	A character vector specifying the stream ID of each observation in times

Details

A univariate Hawkes (Hawkes, AG. 1971) process is a self-exciting temporal point process with conditional intensity function $\lambda(t) = \mu + \alpha \sum_{i: \tau_i < t} e^{(-\beta*(t-\tau_i))}$. Here μ is the constant baseline rate, α is the instantaneous increase in intensity after an event, and β is the exponential decay in intensity. The term $\sum_{i: \tau_i < t} \dots$ describes the historic dependence and the clustering density of the temporal point process, where the τ_i are the events in time occurring prior to time t . From this we can derive the following quantities 1) $\frac{\alpha}{\beta}$ is the branching ratio, it gives the average number of events triggered by an event, and 2) $\frac{1}{\beta}$ gives the rate of decay of the self-excitement. Including mark information results in the conditional intensity $\lambda(t; m(t)) = \mu + \alpha \sum_{i: \tau_i < t} m(\tau_i) e^{(-\beta*(t-\tau_i))}$, where $m(t)$ is the temporal mark. This model can be fitted with `fit_hawkes()`.

An in-homogenous marked Hawkes process has conditional intensity function $\lambda(t) = \mu(t) + \alpha \sum_{i: \tau_i < t} e^{(-\beta*(t-\tau_i))}$. Here, the background rate, $\mu(t)$, varies in time. Such a model can be fitted using `fit_hawkes_cbf()` where the parameters of the custom background function are estimated before being passed to TMB.

A multivariate Hawkes process that allows for between- and within-stream self-excitement. The conditional intensity for the j^{th} ($j = 1, \dots, N$) stream is given by $\lambda(t)^{j*} = \mu_j + \sum_{k=1}^N \sum_{i: \tau_i < t} \alpha_{jk} e^{(-\beta_j*(t-\tau_i))}$, where $j, k \in (1, \dots, N)$. Here, α_{jk} is the excitement caused by the k^{th} stream on the j^{th} . Therefore, α is an $N \times N$ matrix where the diagonals represent the within-stream excitement and the off-diagonals represent the excitement between streams.

Value

A list containing components of the fitted model, see `TMB::MakeADFun`. Includes

- `par`, a numeric vector of estimated parameter values;
- `objective`, the objective function;
- `gr`, the TMB calculated gradient function; and
- `simulate`, (where available) a simulation function.

References

Hawkes, AG. (1971) Spectra of some self-exciting and mutually exciting point processes. *Biometrika*, **58**: 83–90.

See Also

[show_hawkes](#)

Examples

```
### ***** ###
## A Hawkes model
### ***** ###
data(retweets_niwa, package = "stelfi")
times <- unique(sort(as.numeric(difftime(retweets_niwa, min(retweets_niwa), units = "mins"))))
params <- c(mu = 0.05, alpha = 0.05, beta = 0.1)
fit <- fit_hawkes(times = times, parameters = params)
get_coefs(fit)
### ***** ###
## A Hawkes model with marks (ETAS-type)
### ***** ###
data("nz_earthquakes", package = "stelfi")
earthquakes <- nz_earthquakes[order(nz_earthquakes$origintime),]
earthquakes <- earthquakes[!duplicated(earthquakes$origintime), ]
times <- earthquakes$origintime
times <- as.numeric(difftime(times, min(times), units = "hours"))
marks <- earthquakes$magnitude
params <- c(mu = 0.05, alpha = 0.05, beta = 1)
fit <- fit_hawkes(times = times, parameters = params, marks = marks)
get_coefs(fit)

### ***** ###
## A Hawkes process with a custom background function
### ***** ###
if(require("hawkesbow")) {
times <- hawkesbow::hawkes(1000, fun = function(y) {1 + 0.5*sin(y)},
M = 1.5, repr = 0.5, family = "exp", rate = 2)$p
## The background function must take a single parameter and
## the time(s) at which it is evaluated
background <- function(params,times) {
```

```

A = exp(params[[1]])
B = stats::plogis(params[[2]]) * A
return(A + B *sin(times))
}
## The background_integral function must take a
## single parameter and the time at which it is evaluated
background_integral <- function(params,x) {
  A = exp(params[[1]])
  B = stats::plogis(params[[2]]) * A
  return((A*x)-B*cos(x))
}
param = list(alpha = 0.5, beta = 1.5)
background_param = list(1,1)
fit <- fit_hawkes_cbf(times = times, parameters = param,
background = background,
background_integral = background_integral,
background_parameters = background_param)
get_coefs(fit)
}

### ***** ###
## A multivariate Hawkes model
### ***** ###
data(multi_hawkes, package = "stelfi")
fit <- fit_mhawkes(times = multi_hawkes$times, stream = multi_hawkes$stream,
parameters = list(mu = c(0.2,0.2),
alpha = matrix(c(0.5,0.1,0.1,0.5),byrow = TRUE,nrow = 2),
beta = c(0.7,0.7)))
get_coefs(fit)

```

fit_lgcp

Spatial or spatiotemporal log-Gaussian Cox process (LGCP)

Description

Fit a log-Gaussian Cox process (LGCP) using Template Model Builder (TMB) and the `R_inla` namespace for the SPDE-based construction of the latent field.

Usage

```

fit_lgcp(
  locs,
  sf,
  smesh,
  tmesh,
  parameters,
  covariates,

```

```

    tmb_silent = TRUE,
    nlminb_silent = TRUE,
    ...
)

```

Arguments

locs	A data.frame of x and y locations, $2 \times n$. If a spatiotemporal model is to be fitted then there should be the third column (t) of the occurrence times.
sf	An sf of type POLYGON specifying the spatial region of the domain.
smesh	A Delaunay triangulation of the spatial domain returned by <code>fmesher::fm_mesh_2d()</code> .
tmesh	Optional, a temporal mesh returned by <code>fmesher::fm_mesh_1d()</code> .
parameters	A named list of parameter starting values: <ul style="list-style-type: none"> • beta, a vector of fixed effects coefficients to be estimated, β (same length as <code>ncol(covariates) + 1</code>); • log_tau, the $\log(\tau)$ parameter for the GMRF; • log_kappa, $\log(\kappa)$ parameter for the GMRF; • atanh_rho, optional, $\arctan(\rho)$ AR1 temporal parameter. Default values are used if none are provided. NOTE: these may not always be appropriate.
covariates	Optional, a matrix of covariates at each smesh and tmesh node combination.
tmb_silent	Logical, if TRUE (default) then TMB inner optimisation tracing information will be printed.
nlminb_silent	Logical, if TRUE (default) then for each iteration <code>nlminb()</code> output will be printed.
...	optional extra arguments to pass into <code>stats::nlminb()</code> .

Details

A log-Gaussian Cox process (LGCP) where the Gaussian random field, $Z(\mathbf{x})$, has zero mean, variance-covariance matrix \mathbf{Q}^{-1} , and covariance function C_Z . The random intensity surface is $\Lambda(\mathbf{x}) = \exp(\mathbf{X}\beta + G(\mathbf{x}) + \epsilon)$, for design matrix \mathbf{X} , coefficients β , and random error ϵ .

Shown in Lindgren et. al., (2011) the stationary solution to the SPDE (stochastic partial differential equation) $(\kappa^2 - \Delta)^{\frac{\nu + \frac{d}{2}}{2}} G(s) = W(s)$ is a random field with a Matérn covariance function, $C_Z \propto \kappa \|x - y\|^\nu K_{\nu, \kappa} \|x - y\|$. Here ν controls the smoothness of the field and κ controls the range.

A Markovian random field is obtained when $\alpha = \nu + \frac{d}{2}$ is an integer. Following Lindgren et. al., (2011) we set $\alpha = 2$ in 2D and therefore fix $\nu = 1$. Under these conditions the solution to the SPDE is a Gaussian Markov Random Field (GMRF). This is the approximation we use.

The (approximate) spatial range = $\frac{\sqrt{8\nu}}{\kappa} = \frac{\sqrt{8}}{\kappa}$ and the standard deviation of the model, $\sigma = \frac{1}{\sqrt{4\pi\kappa^2\tau^2}}$. Under INLA (Lindgren and Rue, 2015) methodology the practical range is defined as the distance such that the correlation is ~ 0.139 .

Value

A list containing components of the fitted model, see `TMB::MakeADFun`. Includes

- `par`, a numeric vector of estimated parameter values;
- `objective`, the objective function;
- `gr`, the TMB calculated gradient function; and
- `simulate`, a simulation function.

References

Lindgren, F., Rue, H., and Lindström, J. (2011) An explicit link between Gaussian fields and Gaussian Markov random fields: the stochastic partial differential equation approach. *Journal of the Royal Statistical Society: Series B (Statistical Methodology)*, **73**: 423–498.

Lindgren, F. and Rue, H. (2015) Bayesian spatial modelling with R-INLA. *Journal of Statistical Software*, **63**: 1–25.

See Also

[fit_mlgcp](#) and [sim_lgcp](#)

Examples

```
### ***** ###
## A spatial only LGCP
### ***** ###
if(requireNamespace("fmesher")) {
  data(xyt, package = "stelfi")
  domain <- sf::st_as_sf(xyt$window)
  locs <- data.frame(x = xyt$x, y = xyt$y)
  bnd <- fmesher::fm_as_segm(as.matrix(sf::st_coordinates(domain)[, 1:2]))
  smesh <- fmesher::fm_mesh_2d(boundary = bnd,
    max.edge = 0.75, cutoff = 0.3)
  fit <- fit_lgcp(locs = locs, sf = domain, smesh = smesh,
    parameters = c(beta = 0, log_tau = log(1), log_kappa = log(1)))
### ***** ###
## A spatiotemporal LGCP, AR(1)
### ***** ###
ndays <- 2
locs <- data.frame(x = xyt$x, y = xyt$y, t = xyt$t)
w0 <- 2
tmesh <- fmesher::fm_mesh_1d(seq(0, ndays, by = w0))
fit <- fit_lgcp(locs = locs, sf = domain, smesh = smesh, tmesh = tmesh,
  parameters = c(beta = 0, log_tau = log(1), log_kappa = log(1), atanh_rho = 0.2))
}
```


fit_mlgcp

*Marked spatial log-Gaussian Cox process (mLGCP)***Description**

Fit a marked LGCP using Template Model Builder (TMB) and the `R_inla` namespace for the SPDE-based construction of the latent field.

Usage

```
fit_mlgcp(
  locs,
  sf,
  marks,
  smesh,
  parameters = list(),
  methods,
  strfixed = matrix(1, nrow = nrow(locs), ncol = ncol(marks)),
  fields = rep(1, ncol(marks)),
  covariates,
  pp_covariates,
  marks_covariates,
  tmb_silent = TRUE,
  nlminb_silent = TRUE,
  ...
)
```

Arguments

<code>locs</code>	A data.frame of x and y locations, 2xn.
<code>sf</code>	An sf of type POLYGON specifying the spatial region of the domain.
<code>marks</code>	A matrix of marks for each observation of the point pattern.
<code>smesh</code>	A Delaunay triangulation of the spatial domain returned by <code>fmesher::fm_mesh_2d()</code> .
<code>parameters</code>	a list of named parameters: <code>log_tau</code> , <code>log_kappa</code> , <code>betamarks</code> , <code>betapp</code> , <code>marks_coefs_pp</code> .
<code>methods</code>	An integer value: <ul style="list-style-type: none"> • 0 (default), Gaussian distribution, parameter estimated is mean; • 1, Poisson distribution, parameter estimated is intensity; • 2, binomial distribution, parameter estimated is logit/probability; • 3, gamma distribution, the implementation in TMB is shape-scale.
<code>strfixed</code>	A matrix of fixed structural parameters, defined for each event and mark. Defaults to 1. If mark distribution <ul style="list-style-type: none"> • Normal, then this is the log of standard deviation; • Poisson, then not used; • Binomial, then this is the number of trials;

	<ul style="list-style-type: none"> • Gamma, then this is the log of the scale.
fields	A binary vector indicating whether there is a new random field for each mark. By default, each mark has its own random field.
covariates	Covariate(s) corresponding to each area in the spatial mesh
pp_covariates	Which columns of the covariates apply to the point process
marks_covariates	Which columns of the covariates apply to the marks. By default, all covariates apply to the marks only.
tmb_silent	Logical, if TRUE (default) then TMB inner optimisation tracing information will be printed.
nlmnb_silent	Logical, if TRUE (default) then for each iteration nlmnb() output will be printed.
...	optional extra arguments to pass into stats::nlminb().

Details

The random intensity surface of the point process is (as [fit_lgcp](#)) $\Lambda(\mathbf{x}) = \exp(\mathbf{X}\beta + G(\mathbf{x}) + \epsilon)$, for design matrix \mathbf{X} , coefficients β , and random error ϵ .

Each mark, m_j , is jointly modelled and has their own random field $M_j(s) = f^{-1}((\mathbf{X}\beta)_{m_j} + G_{m_j}(\mathbf{x}) + \alpha_{m_j} G(\mathbf{x}) + \epsilon_{m_j})$ where α . are coefficient(s) linking the point process and the mark(s).

$M_j(s)$ depends on the distribution of the marks. If the marks are from a Poisson distribution, it is the intensity (as with the point process). If the marks are from a Binomial distribution, it is the success probability, and the user must supply the number of trials for each event (via `strfixed`). If the marks are normally distributed then this models the mean, and the user must supply the standard deviation (via `strfixed`). The user can choose for the point processes and the marks to share a common GMRF, i.e. $G_m(s) = G_{pp}(s)$; this is controlled via the argument `fields`.

Value

A list containing components of the fitted model, see `TMB::MakeADFun`. Includes

- `par`, a numeric vector of estimated parameter values;
- `objective`, the objective function; and
- `gr`, the TMB calculated gradient function.

References

Lindgren, F., Rue, H., and Lindström, J. (2011) An explicit link between Gaussian fields and Gaussian Markov random fields: the stochastic partial differential equation approach. *Journal of the Royal Statistical Society: Series B (Statistical Methodology)*, **73**: 423–498.

See Also

[fit_lgcp](#)

Examples

```
### ***** ###
## A joint likelihood marked LGCP model
### ***** ###
if(requireNamespace("fmesher")){
  data(marked, package = "stelfi")
  loc.d <- 3 * cbind(c(0, 1, 1, 0, 0), c(0, 0, 1, 1, 0))
  domain <- sf::st_sf(geometry = sf::st_sfc(sf::st_polygon(list(loc.d))))
  smesh <- fmesher::fm_mesh_2d(loc.domain = loc.d, offset = c(0.3, 1),
  max.edge = c(0.3, 0.7), cutoff = 0.05)
  locs <- cbind(x = marked$x, y = marked$y)
  marks <- cbind(m1 = marked$m1) ## Gaussian mark
  parameters <- list(betamarks = matrix(0, nrow = 1, ncol = ncol(marks)),
  log_tau = rep(log(1), 2), log_kappa = rep(log(1), 2),
  marks_coefs_pp = rep(0, ncol(marks)), betapp = 0)
  fit <- fit_mlgcp(locs = locs, marks = marks,
  sf = domain, smesh = smesh,
  parameters = parameters, methods = 0, fields = 1)
}
```

fit_stelfi

Modelling spatiotemporal self-excitement

Description

Fits spatiotemporal Hawkes models. The self-excitement is Gaussian in space and exponentially decaying in time.

Usage

```
fit_stelfi(
  times,
  locs,
  sf,
  smesh,
  parameters,
  covariates,
  GMRF = FALSE,
  time_independent = TRUE,
  tmb_silent = TRUE,
  nlminb_silent = TRUE,
  ...
)
```

Arguments

times	A vector of numeric observed time points.
locs	A data.frame of x and y locations, 2xn.
sf	An sf of type POLYGON specifying the spatial region of the domain.
smesh	A Delaunay triangulation of the spatial domain returned by <code>fmesher::fm_mesh_2d()</code> .
parameters	A list of named parameters: <ul style="list-style-type: none"> • <code>coefs</code>, logged base rate of the Hawkes process and coefficients of covariates • <code>alpha</code>, intensity jump after an event occurrence • <code>beta</code>, rate of exponential decay of intensity after event occurrence • <code>tau</code>, τ parameter for the GMRF (supplied only if <code>GMRF = TRUE</code>) • <code>kappa</code>, κ parameter for the GMRF (supplied only if <code>GMRF = TRUE</code>) • <code>xsigma</code>, standard deviation on x-axis of self-exciting kernel (if <code>time_independent = FALSE</code>, it is the s.d. after 1 time unit) • <code>ysigma</code>, standard deviation on y-axis of self-exciting kernel (if <code>time_independent = FALSE</code>, it is the s.d. after 1 time unit) • <code>rho</code>, correlation between x and y for the self-exciting kernel (the off-diagonal elements in the kernel's covariate matrix are <code>xsigma * ysigma * rho</code>)
covariates	Optional, a matrix of covariates at each smesh node.
GMRF	Logical, default FALSE. If TRUE, a Gaussian Markov Random Field is included as a latent spatial effect.
time_independent	Logical, default TRUE. If FALSE, Gaussian kernels have a covariate matrix that is proportional to time since the event. Warning, this is very memory intensive.
tmb_silent	Logical, if TRUE (default) then TMB inner optimisation tracing information will be printed.
nlmnb_silent	Logical, if TRUE (default) then for each iteration <code>nlminb()</code> output will be printed.
...	Additional arguments to pass to <code>optim()</code>

Details

Temporal self-excitement follows an exponential decay function. The self-excitement over space follows a Gaussian distribution centered at the triggering event. There are two formulations of this model. The default is that the Gaussian function has a fixed spatial covariance matrix, independent of time. Alternatively, covariance can be directly proportional to time, meaning that the self-excitement radiates out from the center over time. This can be appropriate when the mechanism causing self-excitement travels at a finite speed, but is very memory-intensive. The spatiotemporal intensity function used by `stelfi` is $\lambda(s, t) = \mu + \alpha \sum_{i: \tau_i < t} (\exp(-\beta * (t - \tau_i)) G_i(s - x_i, t - \tau_i))$ where

- μ is the background rate,
- β is the rate of temporal decay,
- α is the increase in intensity after an event,

- τ_i are the event times,
- x_i are the event locations (in 2D Euclidean space), and
- $G_i(s - x_i, t - \tau_i)$ is the spatial self-excitement kernel.

$G_i(\cdot, \cdot)$ can take two forms:

- For time-independent spatial excitement (`time_independent = TRUE`), $G_i(s - x_i, t - \tau_i) = f(s - x_i)$ where f is the density function of $N(0, \Sigma)$.
- For time-dependent spatial excitement (`time_independent = FALSE`), $G_i(s - x_i, t - \tau_i) = f(s - x_i)$ where f is the density function of $N(0, (t - \tau_i)\Sigma)$.

Value

A list containing components of the fitted model, see `TMB::MakeADFun`. Includes

- `par`, a numeric vector of estimated parameter values;
- `objective`, the objective function; and
- `gr`, the TMB calculated gradient function.

See Also

[fit_hawkes](#) and [fit_lgcp](#)

Examples

```
## No GMRF
if(requireNamespace("fmesher")){
  data(xyt, package = "stelfi")
  N <- 50
  locs <- data.frame(x = xyt$x[1:N], y = xyt$y[1:N])
  times <- xyt$t[1:N]
  domain <- sf::st_as_sf(xyt>window)
  bnd <- fmesher::fm_as_segm(as.matrix(sf::st_coordinates(domain)[, 1:2]))
  smesh <- fmesher::fm_mesh_2d(boundary = bnd, max.edge = 0.75, cutoff = 0.3)
  param <- list(mu = 3, alpha = 1, beta = 3, xsigma = 0.2, ysigma = 0.2, rho = 0.8)
  fit <- fit_stelfi(times = times, locs = locs, sf = domain, smesh = smesh, parameters = param)
  get_coefs(fit)
}
## GMRF
param <- list(mu = 5, alpha = 1, beta = 3, kappa = 0.9, tau = 1, xsigma = 0.2,
  ysigma = 0.2, rho = 0.8)
fit <- fit_stelfi(times = times, locs = locs, sf = domain, smesh = smesh,
  parameters = param, GMRF = TRUE)
get_coefs(fit)
}
```

 get_coefs

Extract reported parameter estimates

Description

Return parameter estimates from a fitted model.

Usage

```
get_coefs(obj)
```

Arguments

obj A fitted model as returned by one of [fit_hawkes](#), [fit_hawkes_cbf](#), [fit_lgcp](#), [fit_mlgcp](#), or [fit_stelfi](#).

Value

A matrix of estimated parameters and standard errors returned by `TMB::sdreport("report")`.

See Also

[fit_hawkes](#), [fit_hawkes_cbf](#), [fit_lgcp](#), [fit_mlgcp](#), and [fit_stelfi](#)

Examples

```
## Hawkes
data(retweets_niwa, package = "stelfi")
times <- unique(sort(as.numeric(difftime(retweets_niwa, min(retweets_niwa), units = "mins"))))
params <- c(mu = 9, alpha = 3, beta = 10)
fit <- fit_hawkes(times = times, parameters = params)
get_coefs(fit)
## LGCP
if(requireNamespace("fmesher")) {
  data(xyt, package = "stelfi")
  domain <- sf::st_as_sf(xyt$window)
  locs <- data.frame(x = xyt$x, y = xyt$y)
  bnd <- fmesher::fm_as_segm(as.matrix(sf::st_coordinates(domain)[, 1:2]))
  smesh <- fmesher::fm_mesh_2d(boundary = bnd, max.edge = 0.75, cutoff = 0.3)
  fit <- fit_lgcp(locs = locs, sf = domain, smesh = smesh,
  parameters = c(beta = 0, log_tau = log(1), log_kappa = log(1)))
  get_coefs(fit)
}
```

get_fields	<i>Estimated random field(s)</i>
------------	----------------------------------

Description

Extract the estimated mean, or standard deviation, of the values of the Gaussian Markov random field for a fitted log-Gaussian Cox process model at each node of smesh.

Usage

```
get_fields(obj, smesh, tmesh, plot = FALSE, sd = FALSE)
```

Arguments

obj	A fitted model object returned by fit_lgcp .
smesh	A Delaunay triangulation of the spatial domain returned by <code>fmesher::fm_mesh_2d()</code> .
tmesh	Optional, a temporal mesh returned by <code>fmesher::fm_mesh_1d()</code> .
plot	Logical, if TRUE then the returned values are plotted. Default FALSE.
sd	Logical, if TRUE then standard errors returned. Default FALSE.

Value

A numeric vector or a list of returned values at each smesh node.

See Also

[fit_lgcp](#) and [fit_mlgcp](#)

Examples

```
if(requireNamespace("fmesher")) {
  data(xyt, package = "stelfi")
  domain <- sf::st_as_sf(xyt$window)
  locs <- data.frame(x = xyt$x, y = xyt$y)
  bnd <- fmesher::fm_as_segm(as.matrix(sf::st_coordinates(domain)[, 1:2]))
  smesh <- fmesher::fm_mesh_2d(boundary = bnd, max.edge = 0.75, cutoff = 0.3)
  fit <- fit_lgcp(locs = locs, sf = domain, smesh = smesh,
  parameters = c(beta = 0, log_tau = log(1), log_kappa = log(1)))
  get_fields(fit, smesh, plot = TRUE)
}
```

get_weights	<i>Mesh weights</i>
-------------	---------------------

Description

Calculate the areas (weights) around the mesh nodes that are within the specified spatial polygon sf of the domain.

Usage

```
get_weights(mesh, sf, plot = FALSE)
```

Arguments

mesh	A spatial mesh of class <code>fmesher::fm_mesh_2d()</code>
sf	An sf of type POLYGON specifying the region of the domain.
plot	Logical, whether to plot the calculated mesh weights. Default, FALSE.

Value

Either a simple features, sf, object or values returned by `geom_sf`.

See Also

<https://becarioprecario.bitbucket.io/spde-gitbook/>.

Examples

```
data(horse_mesh, package = "stelfi")
data(horse_sf, package = "stelfi")
get_weights(horse_mesh, horse_sf, plot = TRUE)
```

horse_mesh	<i>Example Delaunay triangulation</i>
------------	---------------------------------------

Description

Example Delaunay triangulation

Format

A `fmesher::fm_mesh_2d()` based on the outline of a horse

horse_sf	<i>Example sf POLYGON</i>
----------	---------------------------

Description

Example sf POLYGON

Format

A sf POLYGON of a horse outline

iraq_terrorism	<i>Terrorism in Iraq, 2013 - 2017</i>
----------------	---------------------------------------

Description

A dataset containing information of terrorism activity carried out by the Islamic State of Iraq and the Levant (ISIL) in Iraq, 2013 - 2017.

Format

A simple features dataframe, of type POINT, with 4208 observations and 16 fields:

iyear numeric year 2013–2017
imonth numeric month index 1–12
iday numeric day 1–31 (zeros are a non-entry)
country country (IRAQ)
latitude latitude location
longitude longitude location
utm_x x-coord location UTM
utm_y y-coord location UTM
success logical, was fatal? TRUE = fatal
nkill number of fatalities per attack
specificity spatial accuracy of event: 1 = most accurate, 5 = worst
gname character name of attack perpetrators (ISIL)
x_coord x coordinate from location projected onto a sphere
y_coord y coordinate from location projected onto a sphere
z_coord z coordinate from location projected onto a sphere
popdensity scaled: number of people per kilometer squared
luminosity scaled: luminosity
tt scaled: time to nearest city in minutes

Source

<https://www.start.umd.edu/gtd/>

marked

Example marked point pattern data set

Description

Example marked point pattern data set

Format

A data frame with 159 rows and 5 variables:

x x coordinate

y y coordinate

m1 mark, Gaussian distributed

m2 mark, Bernoulli distributed

m3 mark, Gamma distributed

meshmetrics

Calculate a number of different geometric attributes of a Delaunay triangulation

Description

Calculates a number of geometric attributes for a given Delaunay triangulation based on the circumscribed and inscribed circle of each triangle.

Usage

```
meshmetrics(mesh)
```

Arguments

mesh A `fmesher::fm_mesh_2d` object.

Details

A triangle's circumcircle (circumscribed circle) is the unique circle that passes through each of its three vertices. A triangle's incircle (inscribed circle) is the largest circle that can be contained within it (i.e., touches its three edges).

Value

An object of class `sf` with the following data for each triangle in the triangulation

- V1, V2, and V3 corresponding vertices of mesh matches `mesh$graph$tv`;
- ID, numeric triangle id;
- `angleA`, `angleB`, and `angleC`, the interior angles;
- circumcircle radius, `circumradius`, `circumcircle_R` (R);
- incircle radius `incircle_r` (r);
- centroid locations of the circumcircle, `circumcenter`, (`c_0x`, `c_0y`);
- centroid locations of the incircle, `incenter`, (`i_0x`, `i_0y`);
- the radius-edge ratio `radius_edge` $\frac{R}{l_{min}}$, where l_{min} is the minimum edge length;
- the radius ratio `radius_ratio` $\frac{r}{R}$;
- `area`, `area` (A);
- `quality` a measure of "quality" defined as $\frac{4\sqrt{3}|A|}{\sum_{i=1}^3 L_i^2}$, where L_i is the length of edge i .

Examples

```
data(horse_mesh, package = "stelfi")
metrics <- meshmetrics(horse_mesh)
if(require("ggplot2")) {
  ggplot(metrics) + geom_sf(aes(fill = radius_ratio))
}
```

mesh_2_sf

Transform a `fmesher::fm_mesh_2d` into a `sf` object

Description

Transform a `fmesher::fm_mesh_2d` into a `sf` object

Usage

```
mesh_2_sf(mesh)
```

Arguments

`mesh` A `fmesher::fm_mesh_2d` object.

Value

A simple features, `sf`, object.

Source

Modified from `sp` based function suggested by Finn in the R-inla discussion Google Group <https://groups.google.com/g/r-inla-discussion-group/c/z1n1ex1ZrKM>.

See Also[meshmetrics](#)**Examples**

```
data(horse_mesh, package = "stelfi")
sf <- mesh_2_sf(horse_mesh)
if(require("ggplot2")) {
  ggplot(sf) + geom_sf()
}
```

multi_hawkes*Example multivariate Hawkes dataset*

Description

Two-stream multivariate Hawkes data with $\mu_1 = \mu_2 = 0.2$, $\beta_1 = \beta_2 = 0.7$, and $\alpha = \text{matrix}(c(0.5, 0.1, 0.1, 0.5), \text{byrow} = \text{TRUE}, \text{nrow} = 2)$.

Format

A data frame with 213 observations and 2 variables:

times ordered time stamp of observation

stream character giving stream ID (i.e., Stream 1 or Stream 2) of observation

nz_earthquakes*Earthquakes in Canterbury, NZ, 2010 - 2014*

Description

Earthquake data from Canterbury, New Zealand 16-Jan-2010–24-Dec-2014.

Format

A simple features dataframe, of type POINT, with 3824 observations and 3 fields:

origintime The UTC time of the event's occurrence

magnitude The magnitude of the earthquake

depth The focal depth of the event (km)

Source

<https://quakesearch.geonet.org.nz/>

nz_murders	<i>Murders of NZ, 2004 - 2019</i>
------------	-----------------------------------

Description

A dataset of recorded murder cases in New Zealand 2004 - 2019.

Format

A simple features dataframe, of type POINT, with 967 observations and 11 fields:

sex Biological sex of victim
age Age of victim (years)
date Month and day of murder
year Year
cause Cause of death
killer Killer
name Name of victim
full_date Date object of observation on single days
month Month name of observation
cause_cat Cause of death as category
region NZ region

Source

Data scraped and cleaned by Charlie Timmings, honours student at the University of Auckland from the website <https://interactives.stuff.co.nz/2019/the-homicide-report/>

retweets_niwa	<i>Retweets of NIWA's viral leopard seal Tweet</i>
---------------	--

Description

A dataset of retweet times of NIWA's viral leopard seal tweet on the 5th Feb 2019 (https://twitter.com/niwa_nz/status/1092610541401587712).

Format

A vector of length 4890 specifying the date and time of retweet (UTC)

Source

https://twitter.com/niwa_nz/status/1092610541401587712

sasquatch

Sasquatch (bigfoot) sightings in the USA, 2000 - 2005

Description

Subset of data sourced from the Bigfoot Field Researchers Organization (BFRO) (<https://data.world/timothyrenner/bfro-sightings-data>).

Format

A simple features dataframe, of type POINT, with 972 observations and 27 fields:

observed Text observation summary
location_details Text location summary
county County
state State
season Season
title Report title
date Date
number Report number
classification Report classification
geohash Geohash code
temperature_high Reported weather measure
temperature_mid Reported weather measure
temperature_low Reported weather measure
dew_point Reported weather measure
humidity Reported weather measure
cloud_cover Reported weather measure
moon_phase Reported measure
precip_intensity Reported weather measure
precip_probability Reported weather measure
precip_type Reported weather measure
pressure Reported weather measure
summary Text weather summary
uv_index Reported weather measure
visibility Reported weather measure
wind_bearing Reported weather measure
wind_speed Reported weather measure
year Year

Source

<https://data.world/timothyrenner/bfro-sightings-data>

show_field

Plot the estimated random field(s) of a fitted LGCP

Description

Plots the values of x at each node of smesh, with optional control over resolutions using dims.

Usage

```
show_field(x, smesh, sf, dims = c(500, 500), clip = FALSE)
```

Arguments

<code>x</code>	A vector of values, one value per each smesh node.
<code>smesh</code>	A Delaunay triangulation of the spatial domain returned by <code>fmesher::fm_mesh_2d()</code> .
<code>sf</code>	Optional, sf of type POLYGON specifying the region of the domain.
<code>dims</code>	A numeric vector of length 2 specifying the spatial pixel resolution. Default <code>c(500, 500)</code> .
<code>clip</code>	Logical, if TRUE then plotted values are ‘clipped’ to the domain supplied as sf.

Value

A gg class object, values returned by `geom_tile` and `geom_sf`.

See Also

[show_lambda](#) and [get_fields](#)

Examples

```
if(requireNamespace("fmesher")){
  if(require("sf")){
    data(xyt, package = "stelfi")
    domain <- sf::st_as_sf(xyt$window)
    bnd <- fmesher::fm_as_segm(as.matrix(sf::st_coordinates(domain)[, 1:2]))
    smesh <- fmesher::fm_mesh_2d(boundary = bnd, max.edge = 0.75, cutoff = 0.3)
    parameters <- c(beta = 1, log_tau = log(1), log_kappa = log(1))
    simdata <- sim_lgcp(parameters = parameters, sf = domain, smesh = smesh)
    show_field(c(simdata$x), smesh = smesh, sf = domain)
    show_field(c(simdata$x), smesh = smesh, sf = domain, clip = TRUE)
  }
}
```

 show_hawkes

Plot Hawkes intensity

Description

Plots a Hawkes intensity function, options to extend to non-homogeneous background intensity.

Plots a number of goodness-of-fit plots for a fitted Hawkes process. Includes 1) a comparison of the compensator and observed events, 2) a histogram of transformed interarrival times, 3) a Q-Q plot of transformed interarrival times, and 4) the CDF of consecutive interarrival times. In addition, results of a Kolmogorov-Smirnov and Ljung-Box hypothesis test for the interarrival times are printed.

Usage

```
show_hawkes(obj)

show_hawkes_GOF(
  obj,
  background_integral = NULL,
  plot = TRUE,
  return_values = FALSE
)
```

Arguments

obj	Either object returned by fit_hawkes/fit_hawkes_cbf or a named list with elements times and params. If the latter, then times should be a numeric vector of observed time points, and params must contain, alpha (intensity jump after an event occurrence) and beta (exponential intensity decay). In addition, should contain either mu (base rate of the Hawkes process) or background_parameters (parameter(s) for the assumed non-homogeneous background function; could be a list of multiple values). May also contain marks (a vector of numerical marks).
background_integral	Function, as defined in fit_hawkes_cbf .
plot	Logical, whether to plot goodness-of-fit plots. Default TRUE.
return_values	Logical, whether to return GOF values. Default FALSE.

Value

[show_hawkes](#) returns a gtable object with geom_line and geom_histogram values.

[show_hawkes_GOF](#) returns no value unless return_values = TRUE, in this case a list of interarrival times is returned.

Examples

```

data(retweets_niwa, package = "stelfi")
times <- unique(sort(as.numeric(difftime(retweets_niwa, min(retweets_niwa), units = "mins"))))
params <- c(mu = 9, alpha = 3, beta = 10)
show_hawkes(list(times = times, params = params))
fit <- fit_hawkes(times = times, parameters = params)
show_hawkes(fit)
data(retweets_niwa, package = "stelfi")
times <- unique(sort(as.numeric(difftime(retweets_niwa, min(retweets_niwa), units = "mins"))))
params <- c(mu = 9, alpha = 3, beta = 10)
show_hawkes_GOF(list(times = times, params = params))
fit <- fit_hawkes(times = times, parameters = params)
show_hawkes_GOF(fit)

```

show_lambda

*Plot the estimated intensity from a fitted LGCP model***Description**

Plots the estimated spatial intensity from a fitted log-Gaussian Cox process model. If `obj` is a spatiotemporal model then `timestamp` provides control over which temporal index to plot the estimated spatial intensity.

Usage

```

show_lambda(
  obj,
  smesh,
  sf,
  tmesh,
  covariates,
  clip = FALSE,
  dims = c(500, 500),
  timestamp = 1
)

```

Arguments

<code>obj</code>	A fitted LGCP model object for, for example, <code>fit_lgcp()</code> .
<code>smesh</code>	A Delaunay triangulation of the spatial domain returned by <code>fmesher::fm_mesh_2d()</code> .
<code>sf</code>	An <code>sf</code> of type POLYGON specifying the spatial region of the domain.
<code>tmesh</code>	Optional, a temporal mesh returned by <code>fmesher::fm_mesh_1d()</code> .
<code>covariates</code>	Optional, a matrix of covariates at each <code>smesh</code> and <code>tmesh</code> node combination.
<code>clip</code>	Logical, if TRUE then plotted values are ‘clipped’ to the domain supplied as <code>sf</code> .
<code>dims</code>	A numeric vector of length 2 specifying the spatial pixel resolution. Default <code>c(500, 500)</code> .
<code>timestamp</code>	The index of time stamp to plot. Default 1.

Value

A gg class object, values returned by `geom_tile` and `geom_sf`.

See Also

[fit_lgcp](#), [show_field](#), and [get_fields](#)

Examples

```
if(requireNamespace("fmesher")) {
  data(xyt, package = "stelfi")
  domain <- sf::st_as_sf(xyt$window)
  locs <- data.frame(x = xyt$x, y = xyt$y)
  bnd <- fmesher::fm_as_segm(as.matrix(sf::st_coordinates(domain)[, 1:2]))
  smesh <- fmesher::fm_mesh_2d(boundary = bnd, max.edge = 0.75, cutoff = 0.3)
  fit <- fit_lgcp(locs = locs, sf = domain, smesh = smesh,
  parameters = c(beta = 0, log_tau = log(1), log_kappa = log(1)))
  show_lambda(fit, smesh = smesh, sf = domain)
}
```

 sim_hawkes

Simulate a self-exciting Hawkes process

Description

Simulates a self-exciting Hawkes process.

Usage

```
sim_hawkes(mu, alpha, beta, n = 100, plot = FALSE, seed = 123, method = "1")
```

Arguments

<code>mu</code>	A numeric specifying base rate of the Hawkes process.
<code>alpha</code>	A numeric specifying intensity jump after an event occurrence.
<code>beta</code>	A numeric specifying exponential intensity decay
<code>n</code>	A numeric depending on method: if <code>method = "1"</code> specifies end of the time line within which to simulate the process, if <code>method = "2"</code> specifies the number of observations to simulate. Default, 100.
<code>plot</code>	Logical, if TRUE data plotted along with the intensity. Default, FALSE.
<code>seed</code>	The seed. Default, 123
<code>method</code>	A character "1" or "2" specifying the method (see details) to simulate Hawkes process. Default, "1".

Details

Option of two methods to simulate a Hawkes process: if `method = "1"` then a univariate Hawkes process as `hawkes::simulateHawkes()` is simulated, if `method = "2"` then an accept/reject framework is used.

Value

A numeric vector of simulated event times.

See Also

[fit_hawkes](#)

Examples

```
sim_hawkes(10.2, 3.1, 8.9)
sim_hawkes(10.2, 3.1, 8.9, method = "2")
```

 sim_lgcp

Simulate a log-Gaussian Cox process (LGCP)

Description

Simulate a realisation of a log-Gaussian Cox process (LGCP) using the TMB C++ template. If `rho` is supplied in parameters as well as `tmesh` then spatiotemporal (AR(1)) data will be simulated.

Usage

```
sim_lgcp(parameters, sf, smesh, tmesh, covariates, all = FALSE)
```

Arguments

<code>parameters</code>	<p>A named list of parameter starting values:</p> <ul style="list-style-type: none"> • <code>beta</code>, a vector of fixed effects coefficients to be estimated, β (same length as <code>ncol(covariates) + 1</code>); • <code>log_tau</code>, the $\log(\tau)$ parameter for the GMRF; • <code>log_kappa</code>, $\log(\kappa)$ parameter for the GMRF; • <code>atanh_rho</code>, optional, $\arctan(\rho)$ AR1 temporal parameter. <p>Default values are used if none are provided. NOTE: these may not always be appropriate.</p>
<code>sf</code>	An <code>sf</code> of type POLYGON specifying the spatial region of the domain.
<code>smesh</code>	A Delaunay triangulation of the spatial domain returned by <code>fmesher::fm_mesh_2d()</code> .
<code>tmesh</code>	Optional, a temporal mesh returned by <code>fmesher::fm_mesh_1d()</code> .
<code>covariates</code>	Optional, a matrix of covariates at each <code>smesh</code> and <code>tmesh</code> node combination.
<code>all</code>	Logical, if TRUE then all model components are returned.

Value

A named list. If `all = FALSE` then only the simulated values of the GMRF at each mesh node are returned, `x`, alongside the number of events, `y`, simulated at each node.

See Also

[fit_lgcp](#)

Examples

```
if(requireNamespace("fmesher")){
  if(require("sf")) {
    data(xyt, package = "stelfi")
    domain <- sf::st_as_sf(xyt$window)
    bnd <- fmesher::fm_as_segm(as.matrix(sf::st_coordinates(domain)[, 1:2]))
    smesh <- fmesher::fm_mesh_2d(boundary = bnd,
      max.edge = 0.75, cutoff = 0.3)
    parameters <- c(beta = 1, log_tau = log(1), log_kappa = log(1))
    sim <- sim_lgcp(parameters = parameters, sf = domain, smesh = smesh)
    ## spatiotemporal
    ndays <- 2
    w0 <- 2
    tmesh <- fmesher::fm_mesh_1d(seq(0, ndays, by = w0))
    parameters <- c(beta = 1, log_tau = log(1), log_kappa = log(1), atanh_rho = 0.2)
    sim <- sim_lgcp(parameters = parameters, sf = domain, smesh = smesh, tmesh = tmesh)
  }
}
```

stelfi

A package to fit Hawkes and Log-Gaussian Cox Point Process models using Template Model Builder

Description

Fit Hawkes and log-Gaussian Cox process models with extensions. Introduced in Hawkes (1971) a Hawkes process is a self-exciting temporal point process where the occurrence of an event immediately increases the chance of another. We extend this to consider self-inhibiting process and a non-homogeneous background rate. A log-Gaussian Cox process is a Poisson point process where the log-intensity is given by a Gaussian random field. We extend this to a joint likelihood formulation fitting a marked log-Gaussian Cox model. In addition, the package offers functionality to fit self-exciting spatiotemporal point processes. Models are fitted via maximum likelihood using 'TMB' (Template Model Builder) (Kristensen, Nielsen, Berg, Skaug, and Bell, 2016). Where included 1) random fields are assumed to be Gaussian and are integrated over using the Laplace approximation and 2) a stochastic partial differential equation model, introduced by Lindgren, Rue, and Lindström. (2011), is defined for the field(s).

Model fitting

- The functions `fit_hawkes` and `fit_hawkes_cbf` fit self-exciting Hawkes (Hawkes AG., 1971) processes to temporal point pattern data.
- The function `fit_lgcp` fit a log-Gaussian Cox process to either spatial or spatiotemporal point pattern data. If a spatiotemporal model is fitted a AR1 process is assumed for the temporal progression.
- The function `fit_mlgcp` fits a joint likelihood model between the point locations and the mark(s).
- The function `fit_stelfi` fits self-exciting spatiotemporal Hawkes models to point pattern data. The self-excitement is Gaussian in space and exponentially decaying over time. In addition, a GMRF can be included to account for latent spatial dependency.

References

- Hawkes, AG. (1971) Spectra of some self-exciting and mutually exciting point processes. *Biometrika*, **58**: 83–90.
- Lindgren, F., Rue, H., and Lindström, J. (2011) An explicit link between Gaussian fields and Gaussian Markov random fields: the stochastic partial differential equation approach. *Journal of the Royal Statistical Society: Series B (Statistical Methodology)*, **73**: 423–498.
- Kristensen, K., Nielsen, A., Berg, C. W., Skaug, H., and Bell B. M. (2016). TMB: Automatic Differentiation and Laplace Approximation. *Journal of Statistical Software*, **70**: 1–21.

 uk_serial

Serial killers of the UK, 1828 - 2015

Description

A dataset containing the names and number of recorded murders committed by some of the infamous UK serial killers from 1828 to 2015.

Format

A dataframe with 62 rows and 8 variables:

number_of_kills approx number of murders committed

years The years of operation

name Name of convicted serial killer

aka Some serial killers were given nicknames

year_start Year the murders began

year_end Year the murders ended

date_of_first_kill Date, if known, first murder was committed

population_million Est popn in millions at time of first murder

Source

<https://www.murderuk.com/>

See Also

<https://www.significancemagazine.com/culture/577-a-time-to-kill-great-british-serial-killers>

xyt

Self-exciting point pattern

Description

Simulated self-exciting spatiotemporal point pattern of class stppp

Format

A stppp object with 653 observations

window Domain of the point pattern of class owin

n Number of observations, 653

x x coordinate

y y coordinate

markformat none

t Timestamp of points

tlim Time frame 0 2

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