Package 'ETAS'

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Type Package

Title Modeling Earthquake Data Using ETAS Model

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Description Fits the space-time Epidemic Type Aftershock Sequence (ETAS) model to earthquake catalogs using a stochastic declustering approach. The ETAS model is a spatio-temporal marked point process model and a special case of the Hawkes process. The package is based on a Fortran program by Jiancang Zhuang (available at <http://bemlar.ism.ac.jp/zhuang/software.html>), which is modified and translated into C++ and C such that it can be called from R.

Depends R (>= 3.1.0), maps

Imports spatstat, Rcpp, fields

LinkingTo Rcpp

License GPL (>= 2)

LazyData true

LazyLoad true

NeedsCompilation yes

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R topics documented:

`catalog` *Create an Earthquake Catalog*

Description

Creates an object of class "catalog" representing an earthquake catalog dataset. An earthquake catalog is a chronologically ordered list of time, epicenter and magnitude of all recorded earthquakes in geographical region during a specific time period.

Usage

```
catalog(data, time.begin=NULL, study.start=NULL,
        study.end=NULL, study.length=NULL,
        lat.range=NULL, long.range=NULL,
        region.poly=NULL, mag.threshold=NULL,
        flatmap=TRUE, dist.unit = "degree", tz="GMT")
```

Arguments

`data`	A `data.frame` containing date, time, latitude, longitude and magnitude of earthquakes.
`time.begin`	The beginning of time span of the catalog. A character string or an object that can be converted to date-time (calendar dates plus time to the nearest second) by `as.POSIXlt`. The default `NULL` sets it to the date-time of the first event.
`study.start`	The start of the study period. A character string or an object that can be converted to date-time by `as.POSIXlt`. If not specified (`NULL`), then `time.begin` is used.
`study.end`	The end of the study period. A character string or an object that can be converted to date-time by `as.POSIXlt`. The default `NULL` sets it to the date-time of the last event.
`study.length`	A single numeric value specifying the length of the study period in decimal days. Incompatible with `study.end`: either `study.end` or `study.length` can be specified, but not both.
`lat.range`	The latitude range of a rectangular study region. A numeric vector of size 2 giving (latmin, latmax). By default (`NULL`) the range of the latitudes of events is used.
`long.range`	The longitude range of a rectangular study region. A numeric vector of size 2 giving (longmin, longmax). By default (`NULL`) the range of the longitudes of events is used.

region.poly	Polygonal boundary of a non-rectangular study region. A list with components **lat** and **long** of equal length specifying the coordinates of the vertices of a polygonal study region. The vertices must be listed in **anticlockwise** order.
mag.threshold	The magnitude threshold of the catalog. A positive numeric value. The default (NULL) sets it to the minimum magnitude of all events.
flatmap	Logical flag indicating whether to transform the spherical coordinates $(long, lat)$ on the earth surface to flat map (planar) coordinates (x, y) in order to approximate the great-circle distance on the sphere by the corresponding Euclidean distance on the flat map.
dist.unit	A character string specifying the unit of geographical coordinates and spatial distances between events. Options are "degree" (the default case) and "km".
tz	A character string specifying the time zone to be used for the date-time conversion in as.POSIXlt. The default "GMT" is the UTC (Universal Time, Coordinated).

Details

The data is required to have at least 5 columns with names date, time, lat, long and mag containing, respectively, the date, time, latitude, longitude and magnitude of each event in the catalog.

The geographical study region can be rectangular or polygonal:

- **rectangular study region** can be specified by lat.range and long.range which must be numeric vectors of length 2.
- **polygonal study region** can be specified by region.poly which contains coordinates of the vertices of the polygon. It must be either a list with components **lat** and **long** of equal length or a data.frame with columns **lat** and **long**. The vertices must be listed in *anticlockwise* order and no vertex should be repeated (i.e. do not repeat the first vertex).

The function inside.owin in the spatstat is used to indicate whether events lie inside the study region. Only events inside the study region and the study period (study.start, study.end) are considered as *target* events. Other events are assumed to be *complementary* events.

If the events in data are not chronologically sorted, then a warning will be produced and the events will be sorted in ascending order with respect to time of occurrence.

If flatmap=TRUE, longitude-latitude coordinates convert to flat map coordinates:

- if dist.unit="degree", then the Equirectangular projection

  $$x = \cos(cnt.lat/180\pi)(long - cnt.long)$$

  and $y = lat - cnt.lat$ is used to obtain the flat map coordinates (x, y) in degrees, where $cnt.lat$ and $cnt.long$ are, respectively, the latitude and longitude of the centroid of the geographical region.
- if dist.unit="km", then the projection

  $$x = 111.32\cos(lat/180\pi)long$$

  and $y = 110.547lat$ is used where x and y are in (approximate) kilometers.

Value

An object of class "catalog" containing an earthquake catalog dataset.

Author(s)

Abdollah Jalilian <jalilian@razi.ac.ir>

References

Zhuang J (2012). Long-term Earthquake Forecasts Based on the Epidemic-type Aftershock Sequence (ETAS) Model for Short-term Clustering. *Research in Geophysics*, **2**(1), 52–57. doi:10.4081/rg.2012.e8.

See Also

etas.

Examples

```
  summary(iran.quakes)

  # creating a catalog with rectangular study region
  iran.cat <- catalog(iran.quakes, time.begin="1973/01/01",
     study.start="1985/01/01", study.end="2016/01/01",
     lat.range=c(25, 42), long.range=c(42, 63),
     mag.threshold=4.5)

  print(iran.cat)
  ## Not run:
  plot(iran.cat)

## End(Not run)

  # equivalently, specifying the length of the study period
  iran.cat2 <- catalog(iran.quakes, time.begin="1973/01/01",
     study.start="1985/01/01", study.length=11322,
     lat.range=c(25, 42), long.range=c(42, 63),
     mag.threshold=4.5)

  print(iran.cat2)


  # specifying a polygonal geographical region
  jpoly <- list(long=c(134.0, 137.9, 143.1, 144.9, 147.8,
      137.8, 137.4, 135.1, 130.6), lat=c(31.9, 33.0, 33.2,
      35.2, 41.3, 44.2, 40.2, 38.0, 35.4))
  # creating a catalog with polygonal study region
  japan.cat <- catalog(japan.quakes, time.begin="1966-01-01",
      study.start="1970-01-01", study.end="2010-01-01",
      region.poly=jpoly, mag.threshold=4.5)

  print(japan.cat)
  ## Not run:
```

```
  plot(japan.cat)

## End(Not run)
```

---

date2day *Convert date-time data to numeric data in decimal days*

Description

A function to convert date-time data to decimal days with respect to a date-time origin.

Usage

```
date2day(dates, start=NULL, tz="", ...)
```

Arguments

dates	A date-time or date object. Typically, it is a character vector containing date-time information.
start	A date-time or date object. Determines the origin of the conversion.
tz	Optional. Timezone specification to be used for the conversion.
...	Arguments to be passed to as.POSIXlt.

Details

The arguments dates and start must be of appropriate format to be passed to as.POSIXlt function.

Value

A numeric vector of the same length as dates.

Author(s)

Abdollah Jalilian <jalilian@razi.ac.ir>

See Also

as.POSIXlt and difftime for appropriate format of the data to be converted.

Examples

```
# date-time data of Iran's earthquakes between 1973/01/01 and 2016/01/01
dt <- paste(iran.quakes$date, iran.quakes$time)
# origin of the conversion
start <- "1973/01/01 00:00:00"
# time in days since 1973-01-01 (UTC)
date2day(dt, start, tz="GMT")
```

etas *Fit the space-time ETAS model to data*

Description

A function to fit the space-time version of the Epidemic Type Aftershock Sequence (ETAS) model to a catalog of earthquakes (a spatio-temporal point pattern) and perform a stochastic declustering method.

Usage

```
etas(object, param0 = NULL, bwd = NULL, nnp = 5, bwm = 0.05,
     verbose = TRUE, plot.it = FALSE, ndiv = 1000, no.itr = 11,
     rel.tol=1e-03, eps = 1e-06, cxxcode = TRUE, nthreads = 1)
```

Arguments

`object`	An object of class `"catalog"` containing an earthquake catalog dataset.
`param0`	Initial guess for model parameters. A numeric vector of appropriate length (currently 8). See details.
`bwd`	Optional. Bandwidths for smoothness and integration on the geographical region `win`. A numeric vector which has the length of the number of events. If not supplied, the following arguments `nnp` and `bwm` determine bandwidths.
`nnp`	Number of nearest neighbors for bandwidth calculations. An integer.
`bwm`	Minimum bandwidth. A positive numeric value.
`verbose`	Logical flag indicating whether to print progress reports.
`plot.it`	Logical flag indicating whether plot probabilities of each event being a background event on a map.
`ndiv`	An integer indicating the number of knots on each side of the geographical region for integral approximation.
`no.itr`	An integer indicating the number of iterations for convergence of the iterative approach of simultaneous estimation and declustering algorithm. See details.
`rel.tol`	Relative iteration convergence tolerance of the iterative estimation approach.
`eps`	Optimization convergence tolerance in the Davidon-Fletch-Powell algorithm
`cxxcode`	Logical flag indicating whether to use the C++ code. The C++ code is slightly faster and allows parallel computing.
`nthreads`	An integer indicating number of threads in the parallel region of the C++ code

Details

Ogata (1988) introduced the epidemic type aftershock sequence (ETAS) model based on Gutenberg-Richter law and modified Omori law. In its space-time representation (Ogata, 1998), the ETAS model is a temporal marked point process model, and a special case of marked Hawkes process, with conditional intensity function

$$\lambda(t, x, y|H_t) = \mu(x, y) + \sum_{t_i<t} k(m_i)g(t - t_i)f(x - x_i, y - y_i|m_i)$$

where

H_t: is the observational history up to time t, but not including t; that is

$$H_t = \{(t_i, x_i, y_i, m_i) : t_i < t\}$$

$\mu(x, y)$: is the background intensity. Currently it is assumed to take the semi-parametric form

$$\mu(x, y) = \mu u(x, y)$$

where μ is an unknown constant and $u(x, y)$ is an unknown function.

$k(m)$: is the expected number of events triggered from an event of magnitude m given by

$$k(m) = A \exp(\alpha(m - m_0))$$

$g(t)$: is the p.d.f of the occurrence times of the triggered events, taking the form

$$g(t) = \frac{p - 1}{c}(1 + \frac{t}{c})^{-p}$$

$f(x, y|m)$: is the p.d.f of the locations of the triggered events, considered to be either the long tail inverse power density

$$f(x, y|m) = \frac{q - 1}{\pi\sigma(m))}(1 + \frac{x^2 + y^2}{\sigma(m)})^{-q}$$

or the light tail Gaussian density (currently not implemented)

$$f(x, y|m) = \frac{1}{2\pi\sigma(m)} \exp(-\frac{x^2 + y^2}{2\sigma(m)})$$

with

$$\sigma(m) = D \exp(\gamma(m - m_0))$$

The ETAS models classify seismicity into two components, background seismicity $\mu(x, y)$ and clustering seismicity $\lambda(t, x, y|H_t) - \mu(x, y)$, where each earthquake event, whether it is a background event or generated by another event, produces its own offspring according to the branching rules controlled by $k(m)$, $g(m)$ and $f(x, y|m)$.

Background seismicity rate $u(x, y)$ and the model parameters

$$\theta = (\mu, A, c, \alpha, p, D, q, \gamma)$$

are estimated simultaneously using an iterative approach proposed in Zhuang et al. (2002). First, for an initial $u_0(x, y)$, the parameter vector θ is estimated by maximizing the log-likelihood function

$$l(\theta) = \sum_i \lambda(t_i, x_i, y_i | H_{t_i}) - \int \lambda(t, x, y | H_t) dx dy dt.$$

Then the procedure calculates the probability of being a background event for each event in the catalog by

$$\phi_i = \frac{\mu(x_i, y_i)}{\lambda(t_i, x_i, y_i | H_{t_i})}.$$

Using these probabilities and kernel smoothing method with Gaussian kernel and appropriate choice of bandwidth (determined by `bwd` or `nnp` and `bwm` arguments), the background rate $u_0(x, y)$ is updated. These steps are repeated until the estimates converge (stabilize).

The `no.itr` argument specifies the maximum number of iterations in the iterative simultaneous estimation and declustering algorithm. The estimates often converge in less than ten iterations. The relative iteration convergence tolerance and the optimization convergence tolerance are, respectively, determined by `rel.tol` and `eps` arguments. The progress of the computations can be traced by setting the `verbose` and `plot.it` arguments to be `TRUE`.

If `cxxcode = TRUE`, then the internal function `etasfit` uses the C++ code implemented using the **Rcpp** package, which allows multi-thread parallel computing on multi-core processors with OpenMP. The argument `nthreads` in this case determines the number of threads in the parallel region of the code. If `nthreads = 1` (the default case), then a serial version of the C++ code carries out the computations.

This version of the ETAS model assumes that the earthquake catalog is complete and the data are stationary in time. If the catalog is incomplete or there is non-stationarity (e.g. increasing or cyclic trend) in the time of events, then the results of this function are not reliable.

Value

A list with components

param: The ML estimates of model parameters.

bk: An estimate of the $u(x, y)$.

pb: The probabilities of being background event.

opt: The results of optimization: the value of the log-likelihood function at the optimum point, its gradient at the optimum point and AIC of the model.

rates: Pixel images of the estimated total intensity, background intensity, clustering intensity and conditional intensity.

Note

This function is based on a `C` port of the original `Fortran` code by Jiancang Zhuang, Yosihiko Ogata and their colleagues. The `etas` function is intended to be used for small and medium-size earthquake catalogs. For large earthquake catalogs, due to time-consuming computations, it is highly recommended to use the parallel `Fortran` code on a server machine. The `Fortran` code (implemented for parallel/non-parallel computing) can be obtained from http://bemlar.ism.ac.jp/zhuang/software.html.

Author(s)

Abdollah Jalilian <jalilian@razi.ac.ir>

References

Ogata Y (1988). Statistical Models for Earthquake Occurrences and Residual Analysis for Point Processes. *Journal of the American Statistical Association*, **83**(401), 9–27. doi:10.2307/2288914.

Ogata Y (1998). Space-time Point-process Models for Earthquake Occurrences. *Annals of the Institute of Statistical Mathematics*, **50**(2), 379–402. doi:10.1023/a:1003403601725.

Zhuang J, Ogata Y, Vere-Jones D (2002). Stochastic Declustering of Space-Time Earthquake Occurrences. *Journal of the American Statistical Association*, **97**(458), 369–380. doi:10.1198/016214502760046925.

Zhuang J, Ogata Y, Vere-Jones D (2006). Diagnostic Analysis of Space-Time Branching Processes for Earthquakes. In *Case Studies in Spatial Point Process Modeling*, pp. 275–292. Springer Nature. doi:10.1007/0-387-31144-0_15.

Zhuang J (2011). Next-day Earthquake Forecasts for the Japan Region Generated by the ETAS Model. *Earth, Planets and Space*, **63**(3), 207–216. doi:10.5047/eps.2010.12.010.

See Also

`catalog` for constructing data. `probs` for estimated declustering probabilities. `resid.etas` for diagnostic plots.

Examples

```
  # fitting the ETAS model to an Iranian catalog
  # preparing the catalog
  iran.cat <- catalog(iran.quakes, time.begin="1973/01/01",
     study.start="1986/01/01", study.end="2016/01/01",
     lat.range=c(26, 40), long.range=c(44, 63), mag.threshold=5)
  print(iran.cat)
  ## Not run:
  plot(iran.cat)
## End(Not run)

  # setting initial parameter values
  param0 <- c(0.46, 0.23, 0.022, 2.8, 1.12, 0.012, 2.4, 0.35)

  # fitting the model
  ## Not run:
  iran.fit <- etas(iran.cat, param0=param0)
## End(Not run)


  # fitting the ETAS model to an Italian catalog
  # preparing the catalog
  italy.cat <- catalog(italy.quakes, dist.unit="km")
  ## Not run:
  plot(italy.cat)
## End(Not run)
```

```
  # setting initial parameter values
  mu <- 1
  k0 <- 0.005
  c <- 0.005
  alpha <- 1.05
  p <- 1.01
  D <- 1.1
  q <- 1.52
  gamma <- 0.6
  # reparametrization: transform k0 to A
  A <- pi * k0 / ((p - 1) * c^(p - 1) * (q - 1) * D^(q - 1))
  param0 <- c(mu, A, c, alpha, p, D, q, gamma)

  # fitting the model
  ## Not run:
  nthreads <- parallel::detectCores()
  italy.fit <- etas(italy.cat, param0, nthreads=nthreads)
## End(Not run)


  # fitting the ETAS model to a Japanese catalog
  # setting the target polygonal study region
  jpoly <- list(long=c(134.0, 137.9, 143.1, 144.9, 147.8,
      137.8, 137.4, 135.1, 130.6), lat=c(31.9, 33.0, 33.2,
      35.2, 41.3, 44.2, 40.2, 38.0, 35.4))
  # preparing the catalog
  japan.cat <- catalog(japan.quakes, study.start="1953-05-26",
      study.end="1990-01-08", region.poly=jpoly, mag.threshold=4.5)
  ## Not run:
  plot(japan.cat)
## End(Not run)

  # setting initial parameter values
  param0 <- c(0.592844590, 0.204288231, 0.022692883, 1.495169224,
  1.109752319, 0.001175925, 1.860044210, 1.041549634)

  # fitting the model
  ## Not run:
  nthreads <- parallel::detectCores()
  japan.fit <- etas(japan.cat, param0, nthreads=nthreads)
## End(Not run)
```

`etas.object` *Class of Fitted ETAS Models*

Description

A class `etas` to represent a fitted ETAS model. The output of `etas`.

Details

An object of class `etas` represents an ETAS model that has been fitted to a spatio-temporal point pattern (catalog) of earthquakes. It is the output of the model fitter, `etas`.

The class `etas` has methods for the following standard generic functions:

generic	method	description
`print`	`print.etas`	print details

Author(s)

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See Also

`etas`,

Examples

```
# fitting the ETAS model to an Iranian catalog

data(iran.quakes)
summary(iran.quakes)

  # fitting the ETAS model to an Iranian catalog
# preparing the catalog
iran.cat <- catalog(iran.quakes, time.begin="1973/01/01",
   study.start="1986/01/01", study.end="2016/01/01",
   lat.range=c(26, 40), long.range=c(44, 63), mag.threshold=5)
print(iran.cat)
## Not run:
plot(iran.cat)
## End(Not run)

# setting initial parameter values
param0 <- c(0.46, 0.23, 0.022, 2.8, 1.12, 0.012, 2.4, 0.35)

# fitting the model
## Not run:
iran.fit <- etas(iran.cat, param0=param0)
## End(Not run)
```

`iran.quakes` *An Iranian Earthquake Catalog*

Description

A data frame with 5970 rows and 5 columns giving occurrence date, time, longitude, latitude and magnitude of shallow earthquakes (depth < 100 km) occurred since 1973-01-01 till 2016-01-01 in Iran and its vicinity (40-65E and 22-42N). Only earthquakes with magnitude greater than or equal to 4.5 are included.

Usage

```
data(iran.quakes)
```

Format

An object of class "data.frame" containing the following columns:

- date Occurrence date in the format "yyyy-mm-dd"
- time Occurrence time (UTC) in the format "hh:mm:ss"
- long Latitude of epicenter in decimal degrees
- lat Latitude of epicenter in decimal degrees
- mag Magnitude in body-wave magnitude scale (mb)

Source

The ANSS Comprehensive Catalog (ComCat): http://earthquake.usgs.gov/earthquakes/search/

Examples

```
  summary(iran.quakes)

  gregion <- list(lat = c(26, 25, 29, 38, 35), long = c(52, 59, 58, 45, 43))
  # creat an earthquake catalog
  iran.cat <- catalog(iran.quakes, study.start = "1991/01/01",
     study.end = "2011/01/01", region.poly = gregion, mag.threshold = 4.5)


  ## Not run:
  plot(iran.cat)
  iran.fit <- etas(iran.cat)
## End(Not run)

  zagros <- list(lat = c(27, 26, 29, 29, 35, 33),
     long = c(52, 58, 58, 54, 48, 46))
  iran.cat <- catalog(iran.quakes, study.start = "1991/01/01",
     study.end = "2011/01/01", region.poly = zagros, mag.threshold = 4)
```

italy.quakes *An Italian Earthquake Catalog*

Description

A data frame with 2158 rows and 6 columns giving occurrence date, time, longitude, latitude, magnitude and depth of earthquakes occurred since 2005-04-16 till 2013-11-01 in Italy and its vicinity (6.15-19E and 35-48N) with magnitude greater than or equal to 3.

Usage

```
data(italy.quakes)
```

Format

An object of class "data.frame" containing the following columns:

- `date` Occurrence date in the format "yyyy/mm/dd"
- `time` Occurrence time in decimal days after the first earthquake
- `long` Latitude of epicenter in decimal degrees
- `lat` Latitude of epicenter in decimal degrees
- `mag` Magnitude of each earthquake by JMA (Japan Meteorological Agency)
- `depth` Depth of each earthquake

Source

Data are retrieved from the Italian Seismological Instrumental and Parametric Data Base (ISIDE) available at http://iside.rm.ingv.it by Marcello Chiodi and Giada Adelfio in the **etasFLP** package.

References

Marcello Chiodi and Giada Adelfio (2015). etasFLP: Mixed FLP and ML Estimation of ETAS Space-Time Point Processes. R package version 1.3.0. https://CRAN.R-project.org/package=etasFLP.

Examples

```
  # creat an earthquake catalog
  italy.cat <- catalog(italy.quakes, dist.unit="km")

  ## Not run:
  plot(italy.cat)
## End(Not run)

  # set initial parameter values
  mu <- 1
```

```
  k0 <- 0.005
  c <- 0.005
  alpha <- 1.05
  p <- 1.01
  D <- 1.1
  q <- 1.52
  gamma <- 0.6
  # reparametrization: transform k0 to A
  A <- pi * k0 / ((p - 1) * c^(p - 1) * (q - 1) * D^(q - 1))
  param0 <- c(mu, A, c, alpha, p, D, q, gamma)

  ## Not run:
  italy.fit <- etas(italy.cat, param0)
## End(Not run)
```

`japan.quakes` *A Japanese Earthquake Catalog*

Description

A data frame with 13724 rows and 6 columns giving occurrence date, time, longitude, latitude, magnitude and depth of shallow earthquakes (depth < 100 km) occurred since 1926-01-08 till 2007-12-29 in Japan and its vicinity (128-145E and 27-45N). Only earthquakes with magnitude greater than or equal to 4.5 are included.

Usage

```
data(japan.quakes)
```

Format

An object of class "`data.frame`" containing the following columns:

- `date` Occurrence date in the format "yyyy/mm/dd"
- `time` Occurrence time in the format "hh:mm:ss.ss"
- `long` Latitude of epicenter in decimal degrees
- `lat` Latitude of epicenter in decimal degrees
- `mag` Magnitude of each earthquake by JMA (Japan Meteorological Agency)
- `depth` Depth of each earthquake

Source

Data are retrieved from the Japan Meteorological Agency (JMA) by Jiancang Zhuang and acoppany the **Fortran** code at `http://bemlar.ism.ac.jp/zhuang/software.html`.

References

Zhuang J, Ogata Y, Vere-Jones D (2002). Stochastic Declustering of Space-Time Earthquake Occurrences. *Journal of the American Statistical Association*, **97**(458), 369–380. doi:10.1198/016214502760046925.

Zhuang J, Ogata Y, Vere-Jones D (2006). Diagnostic Analysis of Space-Time Branching Processes for Earthquakes. In *Case Studies in Spatial Point Process Modeling*, pp. 275–292. Springer Nature. doi:10.1007/0-387-31144-0_15.

Examples

```
  # set the target polygonal study region
  jpoly <- list(long=c(134.0, 137.9, 143.1, 144.9, 147.8,
      137.8, 137.4, 135.1, 130.6), lat=c(31.9, 33.0, 33.2,
      35.2, 41.3, 44.2, 40.2, 38.0, 35.4))

  # creat an earthquake catalog
  japan.cat <- catalog(japan.quakes, study.start="1953-05-26",
      study.end="1990-01-08", region.poly=jpoly, mag.threshold=4.5)

  ## Not run:
  plot(japan.cat)
## End(Not run)

  param0 <- c(0.592844590, 0.204288231, 0.022692883, 1.495169224,
  1.109752319, 0.001175925, 1.860044210, 1.041549634)

  ## Not run:
  nthreads <- parallel::detectCores()
  japan.fit <- etas(japan.cat, param0, nthreads=nthreads)
## End(Not run)
```

`lambda` *Clustering Part of Conditional Intensity Function of the ETAS Model*

Description

A function to compute the clustering part of the conditional intensity function of the ETAS model at specified time and location.

Usage

```
lambda(t, x, y, param, object)
```

Arguments

t	A numeric value. The time that the conditional intensity is to be computed at.
x	A numeric value. The x-coordinate of the location that the conditional intensity is to be computed at.

`y`	A numeric value. The y-coordinate of the location that the conditional intensity is to be computed at.
`param`	Vector of model parameters.
`object`	An object of class `"catalog"` containing an earthquake catalog dataset.

Details

For a given t, x and y, this function computes

$$\sum_{t_i<t} k(m_i)g(t-t_i)f(x-x_i, y-y_i|m_i).$$

Value

A numeric value.

Author(s)

Abdollah Jalilian <`jalilian@razi.ac.ir`>

References

Zhuang J, Ogata Y, Vere-Jones D (2002). Stochastic Declustering of Space-Time Earthquake Occurrences. *Journal of the American Statistical Association*, **97**(458), 369–380. doi:10.1198/016214502760046925.

Zhuang J, Ogata Y, Vere-Jones D (2006). Diagnostic Analysis of Space-Time Branching Processes for Earthquakes. In *Case Studies in Spatial Point Process Modeling*, pp. 275–292. Springer Nature. doi:10.1007/0-387-31144-0_15.

See Also

`etas` `catalog`

Examples

```
  iran.cat <- catalog(iran.quakes, time.begin="1973/01/01",
     study.start="1996/01/01", study.end="2016/01/01",
     lat.range=c(25, 42), long.range=c(42, 63), mag.threshold=4.5)

  param <- c(0.46, 0.23, 0.022, 2.8, 1.12, 0.012, 2.4, 0.35)

  ## Not run:
  lambda(15706, 40.12, 34.5, param, iran.cat)
## End(Not run)
```

`rates` *Declustering Probabilities, Background Seismicity Rate and Clustering Coefficient*

Description

Functions to estimate the declustering probabilities, background seismicity rate and clustering (triggering) coefficient for a fitted ETAS model.

Usage

```
probs(fit)
rates(fit, lat.range = NULL, long.range = NULL,
      dimyx=NULL, plot.it=TRUE)
```

Arguments

`fit`	A fitted ETAS model. An object of class `"etas"`.
`lat.range`	Latitude range of the rectangular grid. A numeric vector of length 2.
`long.range`	Longitude range of the rectangular grid. A numeric vector of length 2.
`dimyx`	Dimensions of the rectangular discretization grid for the geographical study region. A numeric vector of length 2.
`plot.it`	Logical flag indicating whether to plot the rates or return them as pixel images.

Details

The function `probs` returns estimates of the declustering probabilities

$$p_j = 1 - \frac{\mu(x_j, y_j)}{lambda(t_j, x_j, y_j | H_{t_j})}$$

where $1 - p_j$ is the probability that event j is a background event.

The function `rates` returns kernel estimate of the background seismicity rate $\mu(x, y)$ and the clustering (triggering) coefficient

$$\omega(x, y) = 1 - \frac{\mu(x, y)}{\Lambda(x, y)}$$

where $\Lambda(x, y)$ is the total spatial intensity function.

The argument `dimyx` determines the rectangular discretization grid dimensions. If it is given, then it must be a numeric vector of length 2 where the first component `dimyx[1]` is the number of subdivisions in the y-direction (latitude) and the second component `dimyx[2]` is the number of subdivisions in the x-direction (longitude).

Value

If `plot.it=TRUE`, the function produces plots of the background seismicity and total spatial rate, clustering coefficient and conditional intensity function at the end of study period.

If `plot.it=FALSE`, it returns a list with components

- **bkgd** the estimated background siesmicity rate
- **total** the estimated total spatial rate
- **clust** the estimated clustering coefficient
- **lamb** the estimated conditional intensity function at time $t = t_{\rm start}$

Author(s)

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References

Zhuang J, Ogata Y, Vere-Jones D (2002). Stochastic Declustering of Space-Time Earthquake Occurrences. *Journal of the American Statistical Association*, **97**(458), 369–380. doi:10.1198/016214502760046925.

Zhuang J, Ogata Y, Vere-Jones D (2006). Diagnostic Analysis of Space-Time Branching Processes for Earthquakes. In *Case Studies in Spatial Point Process Modeling*, pp. 275–292. Springer Nature. doi:10.1007/0-387-31144-0_15.

Zhuang J (2011). Next-day Earthquake Forecasts for the Japan Region Generated by the ETAS Model. *Earth, Planets and Space*, **63**(3), 207–216. doi:10.5047/eps.2010.12.010.

See Also

`etas`

Examples

```
  # preparing the catalog
  iran.cat <- catalog(iran.quakes, time.begin="1973/01/01",
     study.start="1996/01/01", study.end="2016/01/01",
     lat.range=c(25, 42), long.range=c(42, 63), mag.threshold=4.5)

  print(iran.cat)
  ## Not run:
  plot(iran.cat)
## End(Not run)

  # initial parameters values
  param01 <- c(0.46, 0.23, 0.022, 2.8, 1.12, 0.012, 2.4, 0.35)

  # fitting the model and
  ## Not run:
  iran.fit <- etas(iran.cat, param0=param01)
## End(Not run)
```

```
  # estimating the declustering probabilities
  ## Not run:
  pr <- probs(iran.fit)
  plot(iran.cat$longlat.coord[,1:2], cex=2 * (1 - pr$prob))
## End(Not run)

  # estimating the  background seismicity rate and clustering coefficient
  ## Not run:
  rates(iran.fit, dimyx=c(100, 125))
  iran.rates <- rates(iran.fit, dimyx=c(200, 250), plot.it=FALSE)
  summary(iran.rates$background)
## End(Not run)
```

`resid.etas` *Residuals Analysis and Diagnostics Plots*

Description

A function to compute and plot spatial and temporal residuals as well as transformed times for a fitted ETAS model.

Usage

```
resid.etas(fit, type="raw", n.temp=1000, dimyx=NULL)
```

Arguments

`fit`	A fitted ETAS model. An object of class `"etas"`.
`type`	A character string specifying the type residuals to be computed. Options are `"raw"` (the default case), `"reciprocal"` and `"pearson"`.
`n.temp`	An integer specifying the number of partition points for temporal residuals.
`dimyx`	Dimensions of the discretization for the smoothed spatial residuals. A numeric vector of length 2.

Details

The function computes the temporal residuals

$$R^{temp}(I_j, h) = \sum_{i=1}^{N} \delta_i 1[t_i \in I_j] h(t_i) \lambda^{temp}(t_i | H_{t_i}) - \int_{I_j} h(t) \lambda^{temp}(t | H_t) dt$$

for $I_j = ((j-1)T/n.temp, jT/n.temp]$, $j = 1, ..., n.temp$, and the (smoothed version of) spatial residuals

$$R^{spat}(B_j, h) = h(\tilde{x}_i, \tilde{y}_i) \lambda^{spat}(\tilde{x}_i, \tilde{y}_i)(\tilde{\delta}_i - \tilde{w}_i)$$

for a Berman-Turner quadrature scheme with quadrature points $(\tilde{x}_i, \tilde{y}_i)$ and quadrature weights $\tilde{w}_i$, $i = 1, ..., n.spat$. Raw, reciprocal and Pearson residuals obtain with $h = 1$, $h = 1/\lambda$ and $h = 1/\sqrt{\lambda}$, respectively.

In addition, the function computes transformed times

$$\tau_j = \int_0^{t_j} \lambda^{temp}(t|H_t)dt$$

and

$$U_j = 1 - \exp(-(t_j - t_{j-1}))$$

Value

The function produces plots of temporal and smoothed spatial residuals, transformed times τ_j against j and Q-Q plot of U_j.

It also returns a list with components

- **tau** the transformed times
- **U** related quantities with the transformed times
- **tres** the temporal residuals
- **sres** the smoothed spatial residuals

Author(s)

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References

Baddeley A, Rubak E, Turner R (2015). *Spatial Point Patterns: Methodology and Applications with R*. Chapman and Hall/CRC Press, London. http://www.crcpress.com/Spatial-Point-Patterns-Methodology-and-Applications-with-R/Baddeley-Rubak-Turner/9781482210200/.

Baddeley A, Turner R (2000). Practical Maximum Pseudolikelihood for Spatial Point Patterns. *Australian & New Zealand Journal of Statistics*, **42**(3), 283–322. doi:10.1111/1467-842X.00128.

Baddeley A, Turner R, Moller J, Hazelton M (2005). Residual Analysis for Spatial Point Processes. *Journal of the Royal Statistical Society: Series B (Statistical Methodology)*, **67**(5), 617–666. doi:10.1111/j.1467-9868.2005.00519.x.

Ogata Y (1988). Statistical Models for Earthquake Occurrences and Residual Analysis for Point Processes. *Journal of the American Statistical Association*, **83**(401), 9–27. doi:10.2307/2288914.

Zhuang J (2006). Second-order Residual Analysis of Spatiotemporal Point Processes and Applications in Model Evaluation *Journal of the Royal Statistical Society: Series B (Statistical Methodology)*, **68**(4), 635–653. doi:10.1111/j.1467-9868.2006.00559.x.

See Also

etas

Examples

```
  iran.cat <- catalog(iran.quakes, time.begin="1973/01/01",
     study.start="1986/01/01", study.end="2016/01/01",
     lat.range=c(26, 40), long.range=c(44, 63), mag.threshold=5)
  print(iran.cat)
  ## Not run:
  plot(iran.cat)
## End(Not run)

  # setting initial parameter values
  param0 <- c(0.46, 0.23, 0.022, 2.8, 1.12, 0.012, 2.4, 0.35)

  # fitting the model
  ## Not run:
  iran.fit <- etas(iran.cat, param0=param0)

  # diagnostic plots
  resid.etas(iran.fit)
## End(Not run)
```

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