Spatstat Quick Reference guide

February 22, 2020

`spatstat-package` *The Spatstat Package*

Description

This is a summary of the features of **spatstat**, a package in R for the statistical analysis of spatial point patterns.

Details

spatstat is a package for the statistical analysis of spatial data. Its main focus is the analysis of spatial patterns of points in two-dimensional space. The points may carry auxiliary data ('marks'), and the spatial region in which the points were recorded may have arbitrary shape.

The package is designed to support a complete statistical analysis of spatial data. It supports

- creation, manipulation and plotting of point patterns;
- exploratory data analysis;
- spatial random sampling;
- simulation of point process models;
- parametric model-fitting;
- non-parametric smoothing and regression;
- formal inference (hypothesis tests, confidence intervals);
- model diagnostics.

Apart from two-dimensional point patterns and point processes, **spatstat** also supports point patterns in three dimensions, point patterns in multidimensional space-time, point patterns on a linear network, patterns of line segments in two dimensions, and spatial tessellations and random sets in two dimensions.

The package can fit several types of point process models to a point pattern dataset:

- Poisson point process models (by Berman-Turner approximate maximum likelihood or by spatial logistic regression)
- Gibbs/Markov point process models (by Baddeley-Turner approximate maximum pseudolikelihood, Coeurjolly-Rubak logistic likelihood, or Huang-Ogata approximate maximum likelihood)

- Cox/cluster point process models (by Waagepetersen's two-step fitting procedure and minimum contrast, composite likelihood, or Palm likelihood)
- determinantal point process models (by Waagepetersen's two-step fitting procedure and minimum contrast, composite likelihood, or Palm likelihood)

The models may include spatial trend, dependence on covariates, and complicated interpoint interactions. Models are specified by a `formula` in the R language, and are fitted using a function analogous to `lm` and `glm`. Fitted models can be printed, plotted, predicted, simulated and so on.

Getting Started

For a quick introduction to **spatstat**, read the package vignette *Getting started with spatstat* installed with **spatstat**. To read that document, you can either

- visit `https://cran.r-project.org/package=spatstat` and click on `Getting Started with Spatstat`
- start R, type `library(spatstat)` and `vignette('getstart')`
- start R, type `help.start()` to open the help browser, and navigate to `Packages` > `spatstat` > `Vignettes`.

Once you have installed **spatstat**, start R and type `library(spatstat)`. Then type `beginner` for a beginner's introduction, or `demo(spatstat)` for a demonstration of the package's capabilities.

For a complete course on **spatstat**, and on statistical analysis of spatial point patterns, read the book by Baddeley, Rubak and Turner (2015). Other recommended books on spatial point process methods are Diggle (2014), Gelfand et al (2010) and Illian et al (2008).

The **spatstat** package includes over 50 datasets, which can be useful when learning the package. Type `demo(data)` to see plots of all datasets available in the package. Type `vignette('datasets')` for detailed background information on these datasets, and plots of each dataset.

For information on converting your data into **spatstat** format, read Chapter 3 of Baddeley, Rubak and Turner (2015). This chapter is available free online, as one of the sample chapters at the book companion website, `https://spatstat.github.io/book`.

For information about handling data in **shapefiles**, see Chapter 3, or the Vignette *Handling shapefiles in the spatstat package*, installed with **spatstat**, accessible as `vignette('shapefiles')`.

Updates

New versions of **spatstat** are released every 8 weeks. Users are advised to update their installation of **spatstat** regularly.

Type `latest.news` to read the news documentation about changes to the current installed version of **spatstat**.

See the Vignette *Summary of recent updates*, installed with **spatstat**, which describes the main changes to **spatstat** since the book (Baddeley, Rubak and Turner, 2015) was published. It is accessible as `vignette('updates')`.

Type `news(package="spatstat")` to read news documentation about all previous versions of the package.

FUNCTIONS AND DATASETS

Following is a summary of the main functions and datasets in the **spatstat** package. Alternatively an alphabetical list of all functions and datasets is available by typing `library(help=spatstat)`.

For further information on any of these, type `help(name)` or `?name` where `name` is the name of the function or dataset.

CONTENTS:

I. CREATING AND MANIPULATING DATA

Types of spatial data:

The main types of spatial data supported by **spatstat** are:

`ppp`	point pattern
`owin`	window (spatial region)
`im`	pixel image
`psp`	line segment pattern
`tess`	tessellation
`pp3`	three-dimensional point pattern
`ppx`	point pattern in any number of dimensions
`lpp`	point pattern on a linear network

To create a point pattern:

`ppp`	create a point pattern from (x, y) and window information `ppp(x, y, xlim, ylim)` for rectangular window `ppp(x, y, poly)` for polygonal window `ppp(x, y, mask)` for binary image window
`as.ppp`	convert other types of data to a ppp object
`clickppp`	interactively add points to a plot
`marks<-`, `%mark%`	attach/reassign marks to a point pattern

To simulate a random point pattern:

`runifpoint`	generate n independent uniform random points
`rpoint`	generate n independent random points
`rmpoint`	generate n independent multitype random points
`rpoispp`	simulate the (in)homogeneous Poisson point process
`rmpoispp`	simulate the (in)homogeneous multitype Poisson point process
`runifdisc`	generate n independent uniform random points in disc
`rstrat`	stratified random sample of points
`rsyst`	systematic random sample of points
`rjitter`	apply random displacements to points in a pattern
`rMaternI`	simulate the Matérn Model I inhibition process
`rMaternII`	simulate the Matérn Model II inhibition process
`rSSI`	simulate Simple Sequential Inhibition process

rStrauss	simulate Strauss process (perfect simulation)
rHardcore	simulate Hard Core process (perfect simulation)
rStraussHard	simulate Strauss-hard core process (perfect simulation)
rDiggleGratton	simulate Diggle-Gratton process (perfect simulation)
rDGS	simulate Diggle-Gates-Stibbard process (perfect simulation)
rPenttinen	simulate Penttinen process (perfect simulation)
rNeymanScott	simulate a general Neyman-Scott process
rPoissonCluster	simulate a general Poisson cluster process
rMatClust	simulate the Matérn Cluster process
rThomas	simulate the Thomas process
rGaussPoisson	simulate the Gauss-Poisson cluster process
rCauchy	simulate Neyman-Scott Cauchy cluster process
rVarGamma	simulate Neyman-Scott Variance Gamma cluster process
rthin	random thinning
rcell	simulate the Baddeley-Silverman cell process
rmh	simulate Gibbs point process using Metropolis-Hastings
simulate.ppm	simulate Gibbs point process using Metropolis-Hastings
runifpointOnLines	generate n random points along specified line segments
rpoisppOnLines	generate Poisson random points along specified line segments

To randomly change an existing point pattern:

rshift	random shifting of points
rjitter	apply random displacements to points in a pattern
rthin	random thinning
rlabel	random (re)labelling of a multitype point pattern
quadratresample	block resampling

Standard point pattern datasets:

Datasets in **spatstat** are lazy-loaded, so you can simply type the name of the dataset to use it; there is no need to type `data(amacrine)` etc.

Type `demo(data)` to see a display of all the datasets installed with the package.

Type `vignette('datasets')` for a document giving an overview of all datasets, including background information, and plots.

amacrine	Austin Hughes' rabbit amacrine cells
anemones	Upton-Fingleton sea anemones data
ants	Harkness-Isham ant nests data
bdspots	Breakdown spots in microelectrodes
bei	Tropical rainforest trees
betacells	Waessle et al. cat retinal ganglia data
bramblecanes	Bramble Canes data
bronzefilter	Bronze Filter Section data
cells	Crick-Ripley biological cells data
chicago	Chicago crimes
chorley	Chorley-Ribble cancer data
clmfires	Castilla-La Mancha forest fires
copper	Berman-Huntington copper deposits data
dendrite	Dendritic spines
demohyper	Synthetic point patterns
demopat	Synthetic point pattern

finpines	Finnish Pines data
flu	Influenza virus proteins
gordon	People in Gordon Square, London
gorillas	Gorilla nest sites
hamster	Aherne's hamster tumour data
humberside	North Humberside childhood leukaemia data
hyytiala	Mixed forest in Hyytiälä, Finland
japanesepines	Japanese Pines data
lansing	Lansing Woods data
longleaf	Longleaf Pines data
mucosa	Cells in gastric mucosa
murchison	Murchison gold deposits
nbfires	New Brunswick fires data
nztrees	Mark-Esler-Ripley trees data
osteo	Osteocyte lacunae (3D, replicated)
paracou	Kimboto trees in Paracou, French Guiana
ponderosa	Getis-Franklin ponderosa pine trees data
pyramidal	Pyramidal neurons from 31 brains
redwood	Strauss-Ripley redwood saplings data
redwoodfull	Strauss redwood saplings data (full set)
residualspaper	Data from Baddeley et al (2005)
shapley	Galaxies in an astronomical survey
simdat	Simulated point pattern (inhomogeneous, with interaction)
spiders	Spider webs on mortar lines of brick wall
sporophores	Mycorrhizal fungi around a tree
spruces	Spruce trees in Saxonia
swedishpines	Strand-Ripley Swedish pines data
urkiola	Urkiola Woods data
waka	Trees in Waka national park
waterstriders	Insects on water surface

To manipulate a point pattern:

plot.ppp	plot a point pattern (e.g. `plot(X)`)
iplot	plot a point pattern interactively
edit.ppp	interactive text editor
[.ppp	extract or replace a subset of a point pattern `pp[subset]` or `pp[subwindow]`
subset.ppp	extract subset of point pattern satisfying a condition
superimpose	combine several point patterns
by.ppp	apply a function to sub-patterns of a point pattern
cut.ppp	classify the points in a point pattern
split.ppp	divide pattern into sub-patterns
unmark	remove marks
npoints	count the number of points
coords	extract coordinates, change coordinates
marks	extract marks, change marks or attach marks
rotate	rotate pattern
shift	translate pattern
flipxy	swap x and y coordinates
reflect	reflect in the origin
periodify	make several translated copies
affine	apply affine transformation

`scalardilate`	apply scalar dilation
`density.ppp`	kernel estimation of point pattern intensity
`Smooth.ppp`	kernel smoothing of marks of point pattern
`nnmark`	mark value of nearest data point
`sharpen.ppp`	data sharpening
`identify.ppp`	interactively identify points
`unique.ppp`	remove duplicate points
`duplicated.ppp`	determine which points are duplicates
`uniquemap.ppp`	map duplicated points to unique points
`connected.ppp`	find clumps of points
`dirichlet`	compute Dirichlet-Voronoi tessellation
`delaunay`	compute Delaunay triangulation
`delaunayDistance`	graph distance in Delaunay triangulation
`convexhull`	compute convex hull
`discretise`	discretise coordinates
`pixellate.ppp`	approximate point pattern by pixel image
`as.im.ppp`	approximate point pattern by pixel image

See `spatstat.options` to control plotting behaviour.

To create a window:

An object of class `"owin"` describes a spatial region (a window of observation).

`owin`	Create a window object `owin(xlim, ylim)` for rectangular window `owin(poly)` for polygonal window `owin(mask)` for binary image window
`Window`	Extract window of another object
`Frame`	Extract the containing rectangle ('frame') of another object
`as.owin`	Convert other data to a window object
`square`	make a square window
`disc`	make a circular window
`ellipse`	make an elliptical window
`ripras`	Ripley-Rasson estimator of window, given only the points
`convexhull`	compute convex hull of something
`letterR`	polygonal window in the shape of the R logo
`clickpoly`	interactively draw a polygonal window
`clickbox`	interactively draw a rectangle

To manipulate a window:

`plot.owin`	plot a window. `plot(W)`
`boundingbox`	Find a tight bounding box for the window
`erosion`	erode window by a distance r
`dilation`	dilate window by a distance r
`closing`	close window by a distance r
`opening`	open window by a distance r
`border`	difference between window and its erosion/dilation
`complement.owin`	invert (swap inside and outside)
`simplify.owin`	approximate a window by a simple polygon
`rotate`	rotate window

flipxy	swap x and y coordinates
shift	translate window
periodify	make several translated copies
affine	apply affine transformation
as.data.frame.owin	convert window to data frame

Digital approximations:

as.mask	Make a discrete pixel approximation of a given window
as.im.owin	convert window to pixel image
pixellate.owin	convert window to pixel image
commonGrid	find common pixel grid for windows
nearest.raster.point	map continuous coordinates to raster locations
raster.x	raster x coordinates
raster.y	raster y coordinates
raster.xy	raster x and y coordinates
as.polygonal	convert pixel mask to polygonal window

See spatstat.options to control the approximation

Geometrical computations with windows:

edges	extract boundary edges
intersect.owin	intersection of two windows
union.owin	union of two windows
setminus.owin	set subtraction of two windows
inside.owin	determine whether a point is inside a window
area.owin	compute area
perimeter	compute perimeter length
diameter.owin	compute diameter
incircle	find largest circle inside a window
inradius	radius of incircle
connected.owin	find connected components of window
eroded.areas	compute areas of eroded windows
dilated.areas	compute areas of dilated windows
bdist.points	compute distances from data points to window boundary
bdist.pixels	compute distances from all pixels to window boundary
bdist.tiles	boundary distance for each tile in tessellation
distmap.owin	distance transform image
distfun.owin	distance transform
centroid.owin	compute centroid (centre of mass) of window
is.subset.owin	determine whether one window contains another
is.convex	determine whether a window is convex
convexhull	compute convex hull
triangulate.owin	decompose into triangles
as.mask	pixel approximation of window
as.polygonal	polygonal approximation of window
is.rectangle	test whether window is a rectangle
is.polygonal	test whether window is polygonal
is.mask	test whether window is a mask
setcov	spatial covariance function of window
pixelcentres	extract centres of pixels in mask
clickdist	measure distance between two points clicked by user

Pixel images: An object of class "im" represents a pixel image. Such objects are returned by some of the functions in **spatstat** including Kmeasure, setcov and density.ppp.

im	create a pixel image
as.im	convert other data to a pixel image
pixellate	convert other data to a pixel image
as.matrix.im	convert pixel image to matrix
as.data.frame.im	convert pixel image to data frame
as.function.im	convert pixel image to function
plot.im	plot a pixel image on screen as a digital image
contour.im	draw contours of a pixel image
persp.im	draw perspective plot of a pixel image
rgbim	create colour-valued pixel image
hsvim	create colour-valued pixel image
[.im	extract a subset of a pixel image
[<-.im	replace a subset of a pixel image
rotate.im	rotate pixel image
shift.im	apply vector shift to pixel image
affine.im	apply affine transformation to image
X	print very basic information about image X
summary(X)	summary of image X
hist.im	histogram of image
mean.im	mean pixel value of image
integral.im	integral of pixel values
quantile.im	quantiles of image
cut.im	convert numeric image to factor image
is.im	test whether an object is a pixel image
interp.im	interpolate a pixel image
blur	apply Gaussian blur to image
Smooth.im	apply Gaussian blur to image
connected.im	find connected components
compatible.im	test whether two images have compatible dimensions
harmonise.im	make images compatible
commonGrid	find a common pixel grid for images
eval.im	evaluate any expression involving images
im.apply	evaluate a function of several images
scaletointerval	rescale pixel values
zapsmall.im	set very small pixel values to zero
levelset	level set of an image
solutionset	region where an expression is true
imcov	spatial covariance function of image
convolve.im	spatial convolution of images
transect.im	line transect of image
pixelcentres	extract centres of pixels
transmat	convert matrix of pixel values to a different indexing convention
rnoise	random pixel noise

Line segment patterns

An object of class "psp" represents a pattern of straight line segments.

psp	create a line segment pattern

as.psp	convert other data into a line segment pattern
edges	extract edges of a window
is.psp	determine whether a dataset has class "psp"
plot.psp	plot a line segment pattern
print.psp	print basic information
summary.psp	print summary information
[.psp	extract a subset of a line segment pattern
subset.psp	extract subset of line segment pattern
as.data.frame.psp	convert line segment pattern to data frame
marks.psp	extract marks of line segments
marks<-.psp	assign new marks to line segments
unmark.psp	delete marks from line segments
midpoints.psp	compute the midpoints of line segments
endpoints.psp	extract the endpoints of line segments
lengths.psp	compute the lengths of line segments
angles.psp	compute the orientation angles of line segments
superimpose	combine several line segment patterns
flipxy	swap x and y coordinates
rotate.psp	rotate a line segment pattern
shift.psp	shift a line segment pattern
periodify	make several shifted copies
affine.psp	apply an affine transformation
pixellate.psp	approximate line segment pattern by pixel image
as.mask.psp	approximate line segment pattern by binary mask
distmap.psp	compute the distance map of a line segment pattern
distfun.psp	compute the distance map of a line segment pattern
density.psp	kernel smoothing of line segments
selfcrossing.psp	find crossing points between line segments
selfcut.psp	cut segments where they cross
crossing.psp	find crossing points between two line segment patterns
extrapolate.psp	extrapolate line segments to infinite lines
nncross	find distance to nearest line segment from a given point
nearestsegment	find line segment closest to a given point
project2segment	find location along a line segment closest to a given point
pointsOnLines	generate points evenly spaced along line segment
rpoisline	generate a realisation of the Poisson line process inside a window
rlinegrid	generate a random array of parallel lines through a window

Tessellations

An object of class "tess" represents a tessellation.

tess	create a tessellation
quadrats	create a tessellation of rectangles
hextess	create a tessellation of hexagons
polartess	tessellation using polar coordinates
quantess	quantile tessellation
venn.tess	Venn diagram tessellation
dirichlet	compute Dirichlet-Voronoi tessellation of points
delaunay	compute Delaunay triangulation of points
as.tess	convert other data to a tessellation
plot.tess	plot a tessellation
tiles	extract all the tiles of a tessellation

[.tess	extract some tiles of a tessellation
[<-.tess	change some tiles of a tessellation
intersect.tess	intersect two tessellations or restrict a tessellation to a window
chop.tess	subdivide a tessellation by a line
rpoislinetess	generate tessellation using Poisson line process
tile.areas	area of each tile in tessellation
bdist.tiles	boundary distance for each tile in tessellation
connected.tess	find connected components of tiles
shift.tess	shift a tessellation
rotate.tess	rotate a tessellation
reflect.tess	reflect about the origin
flipxy.tess	reflect about the diagonal
affine.tess	apply affine transformation

Three-dimensional point patterns

An object of class "pp3" represents a three-dimensional point pattern in a rectangular box. The box is represented by an object of class "box3".

pp3	create a 3-D point pattern
plot.pp3	plot a 3-D point pattern
coords	extract coordinates
as.hyperframe	extract coordinates
subset.pp3	extract subset of 3-D point pattern
unitname.pp3	name of unit of length
npoints	count the number of points
runifpoint3	generate uniform random points in 3-D
rpoispp3	generate Poisson random points in 3-D
envelope.pp3	generate simulation envelopes for 3-D pattern
box3	create a 3-D rectangular box
as.box3	convert data to 3-D rectangular box
unitname.box3	name of unit of length
diameter.box3	diameter of box
volume.box3	volume of box
shortside.box3	shortest side of box
eroded.volumes	volumes of erosions of box

Multi-dimensional space-time point patterns

An object of class "ppx" represents a point pattern in multi-dimensional space and/or time.

ppx	create a multidimensional space-time point pattern
coords	extract coordinates
as.hyperframe	extract coordinates
subset.ppx	extract subset
unitname.ppx	name of unit of length
npoints	count the number of points
runifpointx	generate uniform random points
rpoisppx	generate Poisson random points
boxx	define multidimensional box
diameter.boxx	diameter of box
volume.boxx	volume of box

shortside.boxx	shortest side of box
eroded.volumes.boxx	volumes of erosions of box

Point patterns on a linear network

An object of class "linnet" represents a linear network (for example, a road network).

linnet	create a linear network
clickjoin	interactively join vertices in network
iplot.linnet	interactively plot network
simplenet	simple example of network
lineardisc	disc in a linear network
delaunayNetwork	network of Delaunay triangulation
dirichletNetwork	network of Dirichlet edges
methods.linnet	methods for linnet objects
vertices.linnet	nodes of network
pixellate.linnet	approximate by pixel image

An object of class "lpp" represents a point pattern on a linear network (for example, road accidents on a road network).

lpp	create a point pattern on a linear network
methods.lpp	methods for lpp objects
subset.lpp	method for subset
rpoislpp	simulate Poisson points on linear network
runiflpp	simulate random points on a linear network
chicago	Chicago crime data
dendrite	Dendritic spines data
spiders	Spider webs on mortar lines of brick wall

Hyperframes

A hyperframe is like a data frame, except that the entries may be objects of any kind.

hyperframe	create a hyperframe
as.hyperframe	convert data to hyperframe
plot.hyperframe	plot hyperframe
with.hyperframe	evaluate expression using each row of hyperframe
cbind.hyperframe	combine hyperframes by columns
rbind.hyperframe	combine hyperframes by rows
as.data.frame.hyperframe	convert hyperframe to data frame
subset.hyperframe	method for subset
head.hyperframe	first few rows of hyperframe
tail.hyperframe	last few rows of hyperframe

Layered objects

A layered object represents data that should be plotted in successive layers, for example, a background and a foreground.

layered	create layered object
plot.layered	plot layered object
[.layered	extract subset of layered object

Colour maps

A colour map is a mechanism for associating colours with data. It can be regarded as a function, mapping data to colours. Using a colourmap object in a plot command ensures that the mapping from numbers to colours is the same in different plots.

colourmap	create a colour map
plot.colourmap	plot the colour map only
tweak.colourmap	alter individual colour values
interp.colourmap	make a smooth transition between colours
beachcolourmap	one special colour map

II. EXPLORATORY DATA ANALYSIS

Inspection of data:

summary(X)	print useful summary of point pattern X
X	print basic description of point pattern X
any(duplicated(X))	check for duplicated points in pattern X
istat(X)	Interactive exploratory analysis
View(X)	spreadsheet-style viewer

Classical exploratory tools:

clarkevans	Clark and Evans aggregation index
fryplot	Fry plot
miplot	Morisita Index plot

Smoothing:

density.ppp	kernel smoothed density/intensity
relrisk	kernel estimate of relative risk
Smooth.ppp	spatial interpolation of marks
bw.diggle	cross-validated bandwidth selection for density.ppp
bw.ppl	likelihood cross-validated bandwidth selection for density.ppp
bw.CvL	Cronie-Van Lieshout bandwidth selection for density estimation
bw.scott	Scott's rule of thumb for density estimation
bw.abram	Abramson's rule for adaptive bandwidths
bw.relrisk	cross-validated bandwidth selection for relrisk
bw.smoothppp	cross-validated bandwidth selection for Smooth.ppp
bw.frac	bandwidth selection using window geometry
bw.stoyan	Stoyan's rule of thumb for bandwidth for pcf

Modern exploratory tools:

clusterset	Allard-Fraley feature detection
nnclean	Byers-Raftery feature detection
sharpen.ppp	Choi-Hall data sharpening
rhohat	Kernel estimate of covariate effect
rho2hat	Kernel estimate of effect of two covariates
spatialcdf	Spatial cumulative distribution function
roc	Receiver operating characteristic curve

Summary statistics for a point pattern: Type `demo(sumfun)` for a demonstration of many of the summary statistics.

`intensity`	Mean intensity
`quadratcount`	Quadrat counts
`intensity.quadratcount`	Mean intensity in quadrats
`Fest`	empty space function F
`Gest`	nearest neighbour distribution function G
`Jest`	J-function $J = (1 - G)/(1 - F)$
`Kest`	Ripley's K-function
`Lest`	Besag L-function
`Tstat`	Third order T-function
`allstats`	all four functions F, G, J, K
`pcf`	pair correlation function
`Kinhom`	K for inhomogeneous point patterns
`Linhom`	L for inhomogeneous point patterns
`pcfinhom`	pair correlation for inhomogeneous patterns
`Finhom`	F for inhomogeneous point patterns
`Ginhom`	G for inhomogeneous point patterns
`Jinhom`	J for inhomogeneous point patterns
`localL`	Getis-Franklin neighbourhood density function
`localK`	neighbourhood K-function
`localpcf`	local pair correlation function
`localKinhom`	local K for inhomogeneous point patterns
`localLinhom`	local L for inhomogeneous point patterns
`localpcfinhom`	local pair correlation for inhomogeneous patterns
`Ksector`	Directional K-function
`Kscaled`	locally scaled K-function
`Kest.fft`	fast K-function using FFT for large datasets
`Kmeasure`	reduced second moment measure
`envelope`	simulation envelopes for a summary function
`varblock`	variances and confidence intervals
	for a summary function
`lohboot`	bootstrap for a summary function

Related facilities:

`plot.fv`	plot a summary function
`eval.fv`	evaluate any expression involving summary functions
`harmonise.fv`	make functions compatible
`eval.fasp`	evaluate any expression involving an array of functions
`with.fv`	evaluate an expression for a summary function
`Smooth.fv`	apply smoothing to a summary function
`deriv.fv`	calculate derivative of a summary function
`pool.fv`	pool several estimates of a summary function
`nndist`	nearest neighbour distances
`nnwhich`	find nearest neighbours
`pairdist`	distances between all pairs of points
`crossdist`	distances between points in two patterns
`nncross`	nearest neighbours between two point patterns
`exactdt`	distance from any location to nearest data point
`distmap`	distance map image
`distfun`	distance map function

nnmap	nearest point image
nnfun	nearest point function
density.ppp	kernel smoothed density
Smooth.ppp	spatial interpolation of marks
relrisk	kernel estimate of relative risk
sharpen.ppp	data sharpening
rknn	theoretical distribution of nearest neighbour distance

Summary statistics for a multitype point pattern: A multitype point pattern is represented by an object X of class "ppp" such that marks(X) is a factor.

relrisk	kernel estimation of relative risk
scan.test	spatial scan test of elevated risk
Gcross,Gdot,Gmulti	multitype nearest neighbour distributions $G_{ij}, G_{i\bullet}$
Kcross,Kdot, Kmulti	multitype K-functions $K_{ij}, K_{i\bullet}$
Lcross,Ldot	multitype L-functions $L_{ij}, L_{i\bullet}$
Jcross,Jdot,Jmulti	multitype J-functions $J_{ij}, J_{i\bullet}$
pcfcross	multitype pair correlation function g_{ij}
pcfdot	multitype pair correlation function $g_{i\bullet}$
pcfmulti	general pair correlation function
markconnect	marked connection function p_{ij}
alltypes	estimates of the above for all i, j pairs
Iest	multitype I-function
Kcross.inhom,Kdot.inhom	inhomogeneous counterparts of Kcross, Kdot
Lcross.inhom,Ldot.inhom	inhomogeneous counterparts of Lcross, Ldot
pcfcross.inhom,pcfdot.inhom	inhomogeneous counterparts of pcfcross, pcfdot
localKcross,localKdot	local counterparts of Kcross, Kdot
localLcross,localLdot	local counterparts of Lcross, Ldot
localKcross.inhom,localLcross.inhom	local counterparts of Kcross.inhom, Lcross.inhom

Summary statistics for a marked point pattern: A marked point pattern is represented by an object X of class "ppp" with a component X$marks. The entries in the vector X$marks may be numeric, complex, string or any other atomic type. For numeric marks, there are the following functions:

markmean	smoothed local average of marks
markvar	smoothed local variance of marks
markcorr	mark correlation function
markcrosscorr	mark cross-correlation function
markvario	mark variogram
markmarkscatter	mark-mark scatterplot
Kmark	mark-weighted K function
Emark	mark independence diagnostic $E(r)$
Vmark	mark independence diagnostic $V(r)$
nnmean	nearest neighbour mean index
nnvario	nearest neighbour mark variance index

For marks of any type, there are the following:

Gmulti	multitype nearest neighbour distribution
Kmulti	multitype K-function
Jmulti	multitype J-function

Alternatively use cut.ppp to convert a marked point pattern to a multitype point pattern.

Programming tools:

applynbd	apply function to every neighbourhood in a point pattern
markstat	apply function to the marks of neighbours in a point pattern
marktable	tabulate the marks of neighbours in a point pattern
pppdist	find the optimal match between two point patterns

Summary statistics for a point pattern on a linear network:

These are for point patterns on a linear network (class lpp). For unmarked patterns:

linearK	K function on linear network
linearKinhom	inhomogeneous K function on linear network
linearpcf	pair correlation function on linear network
linearpcfinhom	inhomogeneous pair correlation on linear network

For multitype patterns:

linearKcross	K function between two types of points
linearKdot	K function from one type to any type
linearKcross.inhom	Inhomogeneous version of linearKcross
linearKdot.inhom	Inhomogeneous version of linearKdot
linearmarkconnect	Mark connection function on linear network
linearmarkequal	Mark equality function on linear network
linearpcfcross	Pair correlation between two types of points
linearpcfdot	Pair correlation from one type to any type
linearpcfcross.inhom	Inhomogeneous version of linearpcfcross
linearpcfdot.inhom	Inhomogeneous version of linearpcfdot

Related facilities:

pairdist.lpp	distances between pairs
crossdist.lpp	distances between pairs
nndist.lpp	nearest neighbour distances
nncross.lpp	nearest neighbour distances
nnwhich.lpp	find nearest neighbours
nnfun.lpp	find nearest data point
density.lpp	kernel smoothing estimator of intensity
distfun.lpp	distance transform
envelope.lpp	simulation envelopes
rpoislpp	simulate Poisson points on linear network
runiflpp	simulate random points on a linear network

It is also possible to fit point process models to lpp objects. See Section IV.

Summary statistics for a three-dimensional point pattern:

These are for 3-dimensional point pattern objects (class pp3).

F3est	empty space function F
G3est	nearest neighbour function G
K3est	K-function
pcf3est	pair correlation function

Related facilities:

`envelope.pp3`	simulation envelopes
`pairdist.pp3`	distances between all pairs of points
`crossdist.pp3`	distances between points in two patterns
`nndist.pp3`	nearest neighbour distances
`nnwhich.pp3`	find nearest neighbours
`nncross.pp3`	find nearest neighbours in another pattern

Computations for multi-dimensional point pattern:

These are for multi-dimensional space-time point pattern objects (class `ppx`).

`pairdist.ppx`	distances between all pairs of points
`crossdist.ppx`	distances between points in two patterns
`nndist.ppx`	nearest neighbour distances
`nnwhich.ppx`	find nearest neighbours

Summary statistics for random sets:

These work for point patterns (class `ppp`), line segment patterns (class `psp`) or windows (class `owin`).

`Hest`	spherical contact distribution H
`Gfox`	Foxall G-function
`Jfox`	Foxall J-function

III. MODEL FITTING (COX AND CLUSTER MODELS)

Cluster process models (with homogeneous or inhomogeneous intensity) and Cox processes can be fitted by the function `kppm`. Its result is an object of class `"kppm"`. The fitted model can be printed, plotted, predicted, simulated and updated.

`kppm`	Fit model
`plot.kppm`	Plot the fitted model
`summary.kppm`	Summarise the fitted model
`fitted.kppm`	Compute fitted intensity
`predict.kppm`	Compute fitted intensity
`update.kppm`	Update the model
`improve.kppm`	Refine the estimate of trend
`simulate.kppm`	Generate simulated realisations
`vcov.kppm`	Variance-covariance matrix of coefficients
`coef.kppm`	Extract trend coefficients
`formula.kppm`	Extract trend formula
`parameters`	Extract all model parameters
`clusterfield`	Compute offspring density
`clusterradius`	Radius of support of offspring density
`Kmodel.kppm`	K function of fitted model
`pcfmodel.kppm`	Pair correlation of fitted model

For model selection, you can also use the generic functions `step`, `drop1` and `AIC` on fitted point process models. For variable selection, see `sdr`.

The theoretical models can also be simulated, for any choice of parameter values, using `rThomas`, `rMatClust`, `rCauchy`, `rVarGamma`, and `rLGCP`.

Lower-level fitting functions include:

lgcp.estK	fit a log-Gaussian Cox process model
lgcp.estpcf	fit a log-Gaussian Cox process model
thomas.estK	fit the Thomas process model
thomas.estpcf	fit the Thomas process model
matclust.estK	fit the Matérn Cluster process model
matclust.estpcf	fit the Matérn Cluster process model
cauchy.estK	fit a Neyman-Scott Cauchy cluster process
cauchy.estpcf	fit a Neyman-Scott Cauchy cluster process
vargamma.estK	fit a Neyman-Scott Variance Gamma process
vargamma.estpcf	fit a Neyman-Scott Variance Gamma process
mincontrast	low-level algorithm for fitting models by the method of minimum contrast

IV. MODEL FITTING (POISSON AND GIBBS MODELS)

Types of models

Poisson point processes are the simplest models for point patterns. A Poisson model assumes that the points are stochastically independent. It may allow the points to have a non-uniform spatial density. The special case of a Poisson process with a uniform spatial density is often called Complete Spatial Randomness.

Poisson point processes are included in the more general class of Gibbs point process models. In a Gibbs model, there is *interaction* or dependence between points. Many different types of interaction can be specified.

For a detailed explanation of how to fit Poisson or Gibbs point process models to point pattern data using **spatstat**, see Baddeley and Turner (2005b) or Baddeley (2008).

To fit a Poisson or Gibbs point process model:

Model fitting in **spatstat** is performed mainly by the function `ppm`. Its result is an object of class `"ppm"`.

Here are some examples, where `X` is a point pattern (class `"ppp"`):

command	*model*
`ppm(X)`	Complete Spatial Randomness
`ppm(X ~ 1)`	Complete Spatial Randomness
`ppm(X ~ x)`	Poisson process with intensity loglinear in x coordinate
`ppm(X ~ 1, Strauss(0.1))`	Stationary Strauss process
`ppm(X ~ x, Strauss(0.1))`	Strauss process with conditional intensity loglinear in x

It is also possible to fit models that depend on other covariates.

Manipulating the fitted model:

plot.ppm	Plot the fitted model
predict.ppm	Compute the spatial trend and conditional intensity of the fitted point process model
coef.ppm	Extract the fitted model coefficients
parameters	Extract all model parameters
formula.ppm	Extract the trend formula

`intensity.ppm`	Compute fitted intensity
`Kmodel.ppm`	K function of fitted model
`pcfmodel.ppm`	pair correlation of fitted model
`fitted.ppm`	Compute fitted conditional intensity at quadrature points
`residuals.ppm`	Compute point process residuals at quadrature points
`update.ppm`	Update the fit
`vcov.ppm`	Variance-covariance matrix of estimates
`rmh.ppm`	Simulate from fitted model
`simulate.ppm`	Simulate from fitted model
`print.ppm`	Print basic information about a fitted model
`summary.ppm`	Summarise a fitted model
`effectfun`	Compute the fitted effect of one covariate
`logLik.ppm`	log-likelihood or log-pseudolikelihood
`anova.ppm`	Analysis of deviance
`model.frame.ppm`	Extract data frame used to fit model
`model.images`	Extract spatial data used to fit model
`model.depends`	Identify variables in the model
`as.interact`	Interpoint interaction component of model
`fitin`	Extract fitted interpoint interaction
`is.hybrid`	Determine whether the model is a hybrid
`valid.ppm`	Check the model is a valid point process
`project.ppm`	Ensure the model is a valid point process

For model selection, you can also use the generic functions `step`, `drop1` and `AIC` on fitted point process models. For variable selection, see `sdr`.

See `spatstat.options` to control plotting of fitted model.

To specify a point process model:

The first order "trend" of the model is determined by an R language formula. The formula specifies the form of the *logarithm* of the trend.

`X ~ 1`	No trend (stationary)
`X ~ x`	Loglinear trend $\lambda(x, y) = \exp(\alpha + \beta x)$
	where x, y are Cartesian coordinates
`X ~ polynom(x,y,3)`	Log-cubic polynomial trend
`X ~ harmonic(x,y,2)`	Log-harmonic polynomial trend
`X ~ Z`	Loglinear function of covariate `Z`
	$\lambda(x, y) = \exp(\alpha + \beta Z(x, y))$

The higher order ("interaction") components are described by an object of class `"interact"`. Such objects are created by:

`Poisson()`	the Poisson point process
`AreaInter()`	Area-interaction process
`BadGey()`	multiscale Geyer process
`Concom()`	connected component interaction
`DiggleGratton()`	Diggle-Gratton potential
`DiggleGatesStibbard()`	Diggle-Gates-Stibbard potential
`Fiksel()`	Fiksel pairwise interaction process
`Geyer()`	Geyer's saturation process
`Hardcore()`	Hard core process
`HierHard()`	Hierarchical multiype hard core process

`HierStrauss()`	Hierarchical multiype Strauss process
`HierStraussHard()`	Hierarchical multiype Strauss-hard core process
`Hybrid()`	Hybrid of several interactions
`LennardJones()`	Lennard-Jones potential
`MultiHard()`	multitype hard core process
`MultiStrauss()`	multitype Strauss process
`MultiStraussHard()`	multitype Strauss/hard core process
`OrdThresh()`	Ord process, threshold potential
`Ord()`	Ord model, user-supplied potential
`PairPiece()`	pairwise interaction, piecewise constant
`Pairwise()`	pairwise interaction, user-supplied potential
`Penttinen()`	Penttinen pairwise interaction
`SatPiece()`	Saturated pair model, piecewise constant potential
`Saturated()`	Saturated pair model, user-supplied potential
`Softcore()`	pairwise interaction, soft core potential
`Strauss()`	Strauss process
`StraussHard()`	Strauss/hard core point process
`Triplets()`	Geyer triplets process

Note that it is also possible to combine several such interactions using `Hybrid`.

Finer control over model fitting:

A quadrature scheme is represented by an object of class `"quad"`. To create a quadrature scheme, typically use `quadscheme`.

`quadscheme`	default quadrature scheme
	using rectangular cells or Dirichlet cells
`pixelquad`	quadrature scheme based on image pixels
`quad`	create an object of class `"quad"`

To inspect a quadrature scheme:

`plot(Q)`	plot quadrature scheme `Q`
`print(Q)`	print basic information about quadrature scheme `Q`
`summary(Q)`	summary of quadrature scheme `Q`

A quadrature scheme consists of data points, dummy points, and weights. To generate dummy points:

`default.dummy`	default pattern of dummy points
`gridcentres`	dummy points in a rectangular grid
`rstrat`	stratified random dummy pattern
`spokes`	radial pattern of dummy points
`corners`	dummy points at corners of the window

To compute weights:

`gridweights`	quadrature weights by the grid-counting rule
`dirichletWeights`	quadrature weights are Dirichlet tile areas

Simulation and goodness-of-fit for fitted models:

`rmh.ppm`	simulate realisations of a fitted model
`simulate.ppm`	simulate realisations of a fitted model
`envelope`	compute simulation envelopes for a fitted model

Point process models on a linear network:

An object of class `"lpp"` represents a pattern of points on a linear network. Point process models can also be fitted to these objects. Currently only Poisson models can be fitted.

`lppm`	point process model on linear network
`anova.lppm`	analysis of deviance for point process model on linear network
`envelope.lppm`	simulation envelopes for point process model on linear network
`fitted.lppm`	fitted intensity values
`predict.lppm`	model prediction on linear network
`linim`	pixel image on linear network
`plot.linim`	plot a pixel image on linear network
`eval.linim`	evaluate expression involving images
`linfun`	function defined on linear network
`methods.linfun`	conversion facilities

V. MODEL FITTING (DETERMINANTAL POINT PROCESS MODELS)

Code for fitting *determinantal point process models* has recently been added to **spatstat**.

For information, see the help file for `dppm`.

VI. MODEL FITTING (SPATIAL LOGISTIC REGRESSION)

Logistic regression

Pixel-based spatial logistic regression is an alternative technique for analysing spatial point patterns that is widely used in Geographical Information Systems. It is approximately equivalent to fitting a Poisson point process model.

In pixel-based logistic regression, the spatial domain is divided into small pixels, the presence or absence of a data point in each pixel is recorded, and logistic regression is used to model the presence/absence indicators as a function of any covariates.

Facilities for performing spatial logistic regression are provided in **spatstat** for comparison purposes.

Fitting a spatial logistic regression

Spatial logistic regression is performed by the function `slrm`. Its result is an object of class `"slrm"`. There are many methods for this class, including methods for `print`, `fitted`, `predict`, `simulate`, `anova`, `coef`, `logLik`, `terms`, `update`, `formula` and `vcov`.

For example, if `X` is a point pattern (class `"ppp"`):

command	*model*
`slrm(X ~ 1)`	Complete Spatial Randomness
`slrm(X ~ x)`	Poisson process with intensity loglinear in x coordinate
`slrm(X ~ Z)`	Poisson process with intensity loglinear in covariate `Z`

Manipulating a fitted spatial logistic regression

anova.slrm	Analysis of deviance
coef.slrm	Extract fitted coefficients
vcov.slrm	Variance-covariance matrix of fitted coefficients
fitted.slrm	Compute fitted probabilities or intensity
logLik.slrm	Evaluate loglikelihood of fitted model
plot.slrm	Plot fitted probabilities or intensity
predict.slrm	Compute predicted probabilities or intensity with new data
simulate.slrm	Simulate model

There are many other undocumented methods for this class, including methods for `print`, `update`, `formula` and `terms`. Stepwise model selection is possible using `step` or `stepAIC`. For variable selection, see `sdr`.

VII. SIMULATION

There are many ways to generate a random point pattern, line segment pattern, pixel image or tessellation in **spatstat**.

Random point patterns:

runifpoint	generate n independent uniform random points
rpoint	generate n independent random points
rmpoint	generate n independent multitype random points
rpoispp	simulate the (in)homogeneous Poisson point process
rmpoispp	simulate the (in)homogeneous multitype Poisson point process
runifdisc	generate n independent uniform random points in disc
rstrat	stratified random sample of points
rsyst	systematic random sample (grid) of points
rMaternI	simulate the Matérn Model I inhibition process
rMaternII	simulate the Matérn Model II inhibition process
rSSI	simulate Simple Sequential Inhibition process
rHardcore	simulate hard core process (perfect simulation)
rStrauss	simulate Strauss process (perfect simulation)
rStraussHard	simulate Strauss-hard core process (perfect simulation)
rDiggleGratton	simulate Diggle-Gratton process (perfect simulation)
rDGS	simulate Diggle-Gates-Stibbard process (perfect simulation)
rPenttinen	simulate Penttinen process (perfect simulation)
rNeymanScott	simulate a general Neyman-Scott process
rMatClust	simulate the Matérn Cluster process
rThomas	simulate the Thomas process
rLGCP	simulate the log-Gaussian Cox process
rGaussPoisson	simulate the Gauss-Poisson cluster process
rCauchy	simulate Neyman-Scott process with Cauchy clusters
rVarGamma	simulate Neyman-Scott process with Variance Gamma clusters
rcell	simulate the Baddeley-Silverman cell process
runifpointOnLines	generate n random points along specified line segments
rpoisppOnLines	generate Poisson random points along specified line segments

Resampling a point pattern:

quadratresample	block resampling

rjitter	apply random displacements to points in a pattern
rshift	random shifting of (subsets of) points
rthin	random thinning

See also varblock for estimating the variance of a summary statistic by block resampling, and lohboot for another bootstrap technique.

Fitted point process models:

If you have fitted a point process model to a point pattern dataset, the fitted model can be simulated.

Cluster process models are fitted by the function kppm yielding an object of class "kppm". To generate one or more simulated realisations of this fitted model, use simulate.kppm.

Gibbs point process models are fitted by the function ppm yielding an object of class "ppm". To generate a simulated realisation of this fitted model, use rmh. To generate one or more simulated realisations of the fitted model, use simulate.ppm.

Other random patterns:

rlinegrid	generate a random array of parallel lines through a window
rpoisline	simulate the Poisson line process within a window
rpoislinetess	generate random tessellation using Poisson line process
rMosaicSet	generate random set by selecting some tiles of a tessellation
rMosaicField	generate random pixel image by assigning random values in each tile of a tessellation

Simulation-based inference

envelope	critical envelope for Monte Carlo test of goodness-of-fit
bits.envelope	critical envelope for balanced two-stage Monte Carlo test
qqplot.ppm	diagnostic plot for interpoint interaction
scan.test	spatial scan statistic/test
studpermu.test	studentised permutation test
segregation.test	test of segregation of types

VIII. TESTS AND DIAGNOSTICS

Hypothesis tests:

quadrat.test	χ^2 goodness-of-fit test on quadrat counts
clarkevans.test	Clark and Evans test
cdf.test	Spatial distribution goodness-of-fit test
berman.test	Berman's goodness-of-fit tests
envelope	critical envelope for Monte Carlo test of goodness-of-fit
scan.test	spatial scan statistic/test
dclf.test	Diggle-Cressie-Loosmore-Ford test
mad.test	Mean Absolute Deviation test
anova.ppm	Analysis of Deviance for point process models

More recently-developed tests:

dg.test	Dao-Genton test
bits.test	Balanced independent two-stage test
dclf.progress	Progress plot for DCLF test
mad.progress	Progress plot for MAD test

Sensitivity diagnostics:

Classical measures of model sensitivity such as leverage and influence have been adapted to point process models.

`leverage.ppm`	Leverage for point process model
`influence.ppm`	Influence for point process model
`dfbetas.ppm`	Parameter influence
`dffit.ppm`	Effect change diagnostic

Diagnostics for covariate effect:

Classical diagnostics for covariate effects have been adapted to point process models.

`parres`	Partial residual plot
`addvar`	Added variable plot
`rhohat`	Kernel estimate of covariate effect
`rho2hat`	Kernel estimate of covariate effect (bivariate)

Residual diagnostics:

Residuals for a fitted point process model, and diagnostic plots based on the residuals, were introduced in Baddeley et al (2005) and Baddeley, Rubak and Møller (2011).

Type `demo(diagnose)` for a demonstration of the diagnostics features.

`diagnose.ppm`	diagnostic plots for spatial trend
`qqplot.ppm`	diagnostic Q-Q plot for interpoint interaction
`residualspaper`	examples from Baddeley et al (2005)
`Kcom`	model compensator of K function
`Gcom`	model compensator of G function
`Kres`	score residual of K function
`Gres`	score residual of G function
`psst`	pseudoscore residual of summary function
`psstA`	pseudoscore residual of empty space function
`psstG`	pseudoscore residual of G function
`compareFit`	compare compensators of several fitted models

Resampling and randomisation procedures

You can build your own tests based on randomisation and resampling using the following capabilities:

`quadratresample`	block resampling
`rjitter`	apply random displacements to points in a pattern
`rshift`	random shifting of (subsets of) points
`rthin`	random thinning

IX. DOCUMENTATION

The online manual entries are quite detailed and should be consulted first for information about a particular function.

The book Baddeley, Rubak and Turner (2015) is a complete course on analysing spatial point patterns, with full details about **spatstat**.

Older material (which is now out-of-date but is freely available) includes Baddeley and Turner (2005a), a brief overview of the package in its early development; Baddeley and Turner (2005b), a more detailed explanation of how to fit point process models to data; and Baddeley (2010), a complete set of notes from a 2-day workshop on the use of **spatstat**.

Type `citation("spatstat")` to get a list of these references.

Licence

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