S Classes and Methods for Spatial Data: 
the sp Package

Edzer J. Pebesma*   Roger S. Bivand†

Feb 2005

Contents

1 Introduction 2

2 Spatial data classes 2

3 Manipulating spatial objects 3
  3.1 Standard methods ............................... 3
  3.2 Spatial methods ................................. 4

4 Spatial points 4
  4.1 Points without attributes ...................... 4
  4.2 Points with attributes .......................... 7

5 Grids 11
  5.1 Creating grids from topology .................. 11
  5.2 Creating grids from points .................... 13
  5.3 Gridded data with attributes .................. 14
  5.4 Are grids stored as points or as matrix/array? 15
  5.5 Row and column selection of a region .......... 16

6 Lines 17
  6.1 Building line objects from scratch ............ 17
  6.2 Building line objects with attributes .......... 18

7 Polygons 19
  7.1 Building from scratch ........................... 19
  7.2 Polygons with attributes ........................ 20

*Dept of Physical Geography, Faculty of Geosciences, Utrecht University, P.O. Box 80.115, 3508 TC Utrecht, The Netherlands e.pebesma@geog.uu.nl
†Economic Geography Section, Department of Economics, Norwegian School of Economics and Business Administration, Breiviksveien 40, N-5045 Bergen, Norway; Roger.Bivand@nhh.no
1 Introduction

The \texttt{sp} package provides classes and methods for dealing with spatial data in S (R and S-Plus\footnote{Our primary efforts target R; depending on the needs, we will address S-Plus as well}). The spatial data structures implemented include points, lines, polygons and grids; each of them with or without attribute data. We have chosen to use S4 classes and methods style (Chambers, 1998) to allow validation of objects created. Although we mainly aim at using spatial data in the geographical (two-dimensional) domain, the data structures that have a straightforward implementation in higher dimensions (points, grids) do allow this.

The motivation to write this package was born on a pre-conference spatial data workshop during DSC 2003. At that time, the advantage of having multiple R packages for spatial statistics seemed to be hindered by a lack of a uniform interface for handling spatial data. Each package had its own conventions on how spatial data were stored and returned. With this package, and packages supporting the classes provided here, we hope that R will become a more coherent tool for analyzing different types of spatial data.

The package is available, or will be available soon on CRAN. From the package home page, \url{http://r-spatial.sourceforge.net/}, a graph gallery with R code, and the development source tree are available.

This vignette describes the classes, methods and functions provided by \texttt{sp}. Instead of manipulating the class slots (components) directly, we provide methods and functions to create the classes from elementary types such as matrices, data.frames or lists and to convert them back to any of these types. Also, coercion (type casting) from one class to the other is provided, where relevant.

Package \texttt{sp} is loaded by

\begin{verbatim}
> library(sp)
\end{verbatim}

2 Spatial data classes

The spatial data classes implemented are points, grids, lines, rings and polygons. Package \texttt{sp} provides classes for the spatial-only information (the topology), e.g. \texttt{SpatialPoints}, and extensions for the case where we attribute information stored in a \texttt{data.frame} is available for each point, e.g. \texttt{SpatialPointsDataFrame}. The available data classes are:
<table>
<thead>
<tr>
<th>data type</th>
<th>class</th>
<th>attributes?</th>
<th>contains</th>
</tr>
</thead>
<tbody>
<tr>
<td>points</td>
<td>SpatialPoints</td>
<td>No</td>
<td>Spatial*</td>
</tr>
<tr>
<td>points</td>
<td>SpatialPointsDataFrame</td>
<td>Yes</td>
<td>SpatialPoints*</td>
</tr>
<tr>
<td>pixels</td>
<td>SpatialPixels</td>
<td>No</td>
<td>SpatialPoints*</td>
</tr>
<tr>
<td>pixels</td>
<td>SpatialPixelsDataFrame</td>
<td>Yes</td>
<td>SpatialPoints*</td>
</tr>
<tr>
<td>full grid</td>
<td>SpatialGrid</td>
<td>No</td>
<td>SpatialPoints*</td>
</tr>
<tr>
<td>full grid</td>
<td>SpatialGridDataFrame</td>
<td>Yes</td>
<td>SpatialGrid*</td>
</tr>
<tr>
<td>line</td>
<td>SLine</td>
<td>No</td>
<td>Spatial*</td>
</tr>
<tr>
<td>lines</td>
<td>SLines</td>
<td>No</td>
<td>Spatial*, SLine list</td>
</tr>
<tr>
<td>lines</td>
<td>SpatialLines</td>
<td>No</td>
<td>Spatial*, SLines list</td>
</tr>
<tr>
<td>lines</td>
<td>SpatialLinesDataFrame</td>
<td>Yes</td>
<td>SpatialLines*</td>
</tr>
<tr>
<td>rings</td>
<td>Sring</td>
<td>No</td>
<td>SLine*</td>
</tr>
<tr>
<td>rings</td>
<td>Srings</td>
<td>No</td>
<td>Spatial*, Srings list</td>
</tr>
<tr>
<td>rings</td>
<td>SpatialRings</td>
<td>No</td>
<td>Spatial*, Srings list</td>
</tr>
<tr>
<td>rings</td>
<td>SpatialRingsDataFrame</td>
<td>Yes</td>
<td>SpatialRings*</td>
</tr>
</tbody>
</table>

* by direct extension; ** by setIs() relationship;

The class `Spatial` does never hold actual data, it only provides the information common to all derived classes: the spatial coordinates bounding box and information about the coordinate reference system (geographic projection information).

In the following sections we will show how we can create objects of these classes from scratch or from other classes, and which methods and functions are available for them.

## 3 Manipulating spatial objects

Although entries in spatial objects are in principle accessible through their slot name, e.g. `x@coords` contains the coordinates of an object of class or extending `SpatialPoints`, we strongly encourage users to access the data by using functions and methods, in this case `coordinates(x)` to retrieve the coordinates.

### 3.1 Standard methods

Selecting, retrieving or replacing certain attributes in spatial objects with attributes is done using standard methods

- `[ select "rows" (items) and/or columns in the data attribute table; e.g. `meuse[1:2, "zinc"]` returns a `SpatialPointsDataFrame` with the first two points and an attribute table with only variable "zinc".]
- `[[] select a column from the data attribute table]
- `[<- assign or replace values to a column in the data attribute table]
Other methods available are: plot, summary, print, dim and names (operate on the data.frame part), as.data.frame, as.matrix and image (for gridded data), lines (for line data), points (for point data), subset (points and grids) and stack (point and grid data.frames).

3.2 Spatial methods

A number of spatial methods are available for the classes in sp:

- `dimensions(x)` returns number of spatial dimensions
- `y = transform(x, "latlong")` transform from one coordinate reference system (geographic projection) to another (requires package spproj)
- `bbox(x)` returns the coordinate bounding box
- `coordinates(x)` returns a matrix with the spatial coordinates
- `rings(x)` retrieve the spatial rings (polygons) of an object deriving from SpatialRings
- `gridded(x)` tells whether x derives from SpatialPixels
- `spplot(x)` plot attributes, possibly in combination with other types of data (points, lines, grids, polygons), and possibly in as a conditioning plot for multiple attributes
- `overlay(x, y)` combine two spatial layers of different type, e.g. retrieve the polygon or grid values on a set of points, or retrieve the points (or a function of their attributes) within (sets of) polygons.
- `spsample(x)` sampling of spatial points in continuous space within a polygon, a gridded area, or on a spatial line. Subsetting and sample can be used to subsample full spatial entities.

4 Spatial points

4.1 Points without attributes

We can generate a set of 10 points on the unit square \([0,1] \times [0,1]\) by

```r
> xc = round(runif(10), 2)
> yc = round(runif(10), 2)
> xy = cbind(xc, yc)
> xy

   xc  yc
[1,] 0.67 0.30
[2,] 0.96 0.62
```
this 10 × 2 matrix can be converted into a \texttt{SpatialPoints} object by

\begin{verbatim}
> xy.sp = SpatialPoints(xy)
> xy.sp
SpatialPoints:
   xc  yc
[1,] 0.67 0.30
[2,] 0.96 0.62
[3,] 0.92 0.91
[4,] 0.77 0.85
[5,] 0.72 0.46
[6,] 0.74 0.39
[7,] 0.63 0.64
[8,] 0.19 0.72
[9,] 0.70 0.20
[10,] 0.37 0.28
Coordinate Reference System (CRS) arguments: NA
\end{verbatim}

\begin{verbatim}
> plot(xy.sp, pch = 2)
\end{verbatim}

The plot is shown in figure 1.

We can retrieve the coordinates from \texttt{xy.sp} by

\begin{verbatim}
> xy.cc = coordinates(xy.sp)
> class(xy.cc)
[1] "matrix"
> dim(xy.cc)
[1] 10 2
\end{verbatim}

and other methods retrieve the bounding box, the dimensions, select points (not dimensions or columns), coerce to a data.frame, or print a summary:

\begin{verbatim}
> bbox(xy.sp)

   min  max
xc 0.19 0.96
yc 0.20 0.91
\end{verbatim}
Figure 1: plot of `SpatialPoints` object; aspect ratio of x and y axis units is 1
> dimensions(xy.sp)
[1] 2

> xy.sp[1:2]
SpatialPoints:
   xc  yc
[1,] 0.67 0.30
[2,] 0.96 0.62
Coordinate Reference System (CRS) arguments: NA

> xy.df = as.data.frame(xy.sp)
> class(xy.df)
[1] "data.frame"

> dim(xy.df)
[1] 10 2

> summary(xy.sp)
Object of class SpatialPoints
Coordinates:
   min  max
xc 0.19 0.96
yc 0.20 0.91
Is projected: NA
proj4string : [NA]
Number of points: 10

4.2 Points with attributes

One way of creating a SpatialPointsDataFrame object is by building it from a SpatialPoints object and a data.frame containing the attributes:

> df = data.frame(z1 = round(5 + rnorm(10), 2), z2 = 20:29)
> df
   z1 z2
1  3.10 20
2  4.15 21
3  3.68 22
4  4.45 23
5  6.62 24
6  5.57 25
7  3.66 26
8  3.75 27
9  5.19 28
10 5.02 29
> xy.spdf = SpatialPointsDataFrame(xy.sp, df)
> xy.spdf

    coordinates    z1    z2
  1   (0.67, 0.3) 3.10  20
  2   (0.96, 0.62) 4.15  21
  3   (0.92, 0.91) 3.68  22
  4   (0.77, 0.85) 4.45  23
  5   (0.72, 0.46) 6.62  24
  6   (0.74, 0.39) 5.57  25
  7   (0.63, 0.64) 3.66  26
  8   (0.19, 0.72) 3.75  27
  9   (0.7, 0.2)  5.19  28
 10   (0.37, 0.28) 5.02  29

> summary(xy.spdf)

Object of class SpatialPointsDataFrame
Coordinates:
  min   max
xc 0.19 0.96
yc 0.20 0.91
Is projected: NA
proj4string : [NA]
Number of points: 10
Data attributes:
     z1    z2
Min. :3.100 Min. :20.00
1st Qu.:3.697 1st Qu.:22.25
Median :4.300 Median :24.50
Mean :4.519  Mean :24.50
3rd Qu.:5.147 3rd Qu.:26.75
Max. :6.620  Max. :29.00

> dimensions(xy.spdf)

[1] 2

> xy.spdf[1:2, ]

    coordinates    z1    z2
  1   (0.67, 0.3) 3.10  20
  2   (0.96, 0.62) 4.15  21

> xy.spdf[1]

    coordinates    z1
  1   (0.67, 0.3) 3.10
> xy.spdf[1:2, "z2"]

  coordinates z2
1 (0.67, 0.3) 20
2 (0.96, 0.62) 21

> xy.df = as.data.frame(xy.spdf)
> xy.df[1:2, ]

   z1  z2  xc  yc
1  3.10 20 0.67 0.30
2  4.15 21 0.96 0.62

> xy.cc = coordinates(xy.spdf)
> class(xy.cc)
[1] "matrix"

> dim(xy.cc)
[1] 10  2

A note on selection with []: the behaviour is as much as possible copied from that of data.frames, but coordinates are always sticky and allways a SpatialPointsDataFrame is returned; drop=FALSE is not allowed. If coordinates should be dropped, use the as.data.frame method and select the non-coordinate data, or use [[ to select a single attribute column (example below).

SpatialPointsDataFrame objects can be created directly from data.frames by specifying which columns contain the coordinates:

> df1 = data.frame(xy, df)
> coordinates(df1) = c("xc", "yc")
> df1

   coordinates  z1  z2
1 (0.67, 0.3) 3.10 20
2 (0.96, 0.62) 4.15 21
3 (0.92, 0.91) 3.68 22
or

```r
> df2 = data.frame(xy, df)
> coordinates(df2) = ~xc + yc
> df2[1:2, ]
```

```
coordinates z1 z2
1 (0.67, 0.3) 3.10 20
2 (0.96, 0.62) 4.15 21
```

```r
> as.data.frame(df2)[1:2,]
```

```
xc yc z1 z2
1 0.67 0.30 3.10 20
2 0.96 0.62 4.15 21
```

Note that in this form, `coordinates` by setting (specifying) the coordinates promotes its argument, an object of class `data.frame` to an object of class `SpatialPointsDataFrame`. The method `as.data.frame` coerces back to the original `data.frame`. When used on a right-hand side of an equation, `coordinates retrieves` the matrix with coordinates:

```r
> coordinates(df2)[1:2,]
```

```
xc yc
[1,] 0.67 0.30
[2,] 0.96 0.62
```

Elements (columns) in the data.frame part of an object can be manipulated (retrieved, assigned) directly:

```r
> df2["z2"]
```

```
```

```r
> df2["z2"][10] = 20
> df2["z3"] = 1:10
> summary(df2)
```
Object of class SpatialPointsDataFrame
Coordinates:
               min    max
xc 0.19  0.96
yc 0.20  0.91
Is projected: NA
proj4string : [NA]
Number of points: 10
Data attributes:
      z1  z2  z3
Min. :3.10  Min. :20.00 Min. : 1.00
1st Qu.:3.69 1st Qu.:21.25 1st Qu.: 3.25
Median :4.30 Median :23.50 Median : 5.50
Mean  :4.52 Mean  :23.60 Mean  : 5.50
3rd Qu.:5.15 3rd Qu.:25.75 3rd Qu.: 7.75
Max. :6.62 Max. :28.00 Max. :10.00

Plotting attribute data can be done by using either spplot to colour symbols, or bubble which uses symbol size:

> bubble(df2, "z1", key.space = "bottom")
> spplot(df2, "z1", key.space = "bottom")

the resulting plots are shown in figure 2.

5 Grids

Package sp has two classes for grid topology: SpatialPixels and SpatialGrid. The pixels form stores coordinates and is for partial grids, or unordered points; the SpatialGrid form does not store coordinates but holds full grids (i.e., SpatialGridDataFrame holds attribute values for each grid cell). Objects can be coerced from one representation to the other.

5.1 Creating grids from topology

When we know the offset, the cell sizes and the dimensions of a grid, we can specify this by using the function GridTopology:

> gt = GridTopology(cellcentre.offset = c(1, 1, 2), cellsize = c(1, +    1, 1), cells.dim = c(3, 4, 6))
> grd = SpatialGrid(gt)
> summary(grd)

Object of class SpatialGrid
Coordinates:
               min    max
Figure 2: plot of SpatialPointsDataFrame object, using symbol size (bubble, top) or colour (spplot, bottom)
The grid parameters can be retrieved by the function

```r
> gridparameters(grd)
```

<table>
<thead>
<tr>
<th>cellcentre.offset</th>
<th>cellsize</th>
<th>cells.dim</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>6</td>
</tr>
</tbody>
</table>

5.2 Creating grids from points

In the following example a three-dimensional grid is constructed from a set of point coordinates:

```r
> pts = expand.grid(x = 1:3, y = 1:4, z = 2:7)
> grd.pts = SpatialPixels(SpatialPoints(pts))
> summary(grd.pts)
```

Object of class SpatialPixels
Coordinates:

<table>
<thead>
<tr>
<th>min</th>
<th>max</th>
</tr>
</thead>
<tbody>
<tr>
<td>x</td>
<td>1</td>
</tr>
<tr>
<td>y</td>
<td>3</td>
</tr>
<tr>
<td>z</td>
<td>2</td>
</tr>
</tbody>
</table>

Is projected: NA
proj4string : [NA]
Number of points: 72

```r
> grd = as(grd.pts, "SpatialGrid")
> summary(grd)
```

Object of class SpatialGrid
Coordinates:
large coordinates, this value may have to be increased. A warning is issued if full rows and/or columns are missing.

5.3 Gridded data with attributes

Spatial, gridded data are data with coordinates on a regular lattice. To form such a grid we can go from coordinates:

```r
> attr = expand.grid(xc = 1:3, yc = 1:3)
> grd.attr = data.frame(attr, z1 = 1:9, z2 = 9:1)
> coordinates(grd.attr) = ~xc + yc
> gridded(grd.attr)
[1] FALSE

> gridded(grd.attr) = TRUE
> gridded(grd.attr)
[1] TRUE

> summary(grd.attr)

Object of class SpatialPixelsDataFrame
Coordinates:
  min max
xc 1 3
yc 1 3
Is projected: NA
proj4string : [NA]
Number of points: 9
```
Data attributes:

<table>
<thead>
<tr>
<th></th>
<th>z1</th>
<th>z2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min.</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1st Qu.</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Median</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Mean</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>3rd Qu.</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Max.</td>
<td>9</td>
<td>9</td>
</tr>
</tbody>
</table>

5.4 Are grids stored as points or as matrix/array?

The form in which gridded data comes depends on whether the grid was created from a set of points or from a matrix or external grid format (e.g. read through rgdal). Retrieving the form, or conversion to another can be done by as(x, "Class"), or by using the function fullgrid:

> fullgrid(grd)
[1] TRUE

> fullgrid(grd.pts)
[1] FALSE

> fullgrid(grd.attr)
[1] FALSE

> fullgrid(grd.pts) = TRUE
> fullgrid(grd.attr) = TRUE
> fullgrid(grd.pts)
[1] TRUE

> fullgrid(grd.attr)
[1] TRUE

The advantage of having grids in cell form is that when a large part of the grid contains missing values, these cells do not have to be stored; also, no ordering of grid cells is required. For plotting by a grid with levelplot, this form is required and spplot (for grids a front-end to levelplot) will convert...
grids that are not in this form. In contrast, image requires a slightly altered version of the full grid form. A disadvantage of the cell form is that the coordinates for each point have to be stored, which may be prohibitive for large grids. Grids in cell form do have an index to allow for fast transformation to the full grid form.

Besides print, summary, plot, objects of class SpatialGridDataFrame have methods for

- [ select rows (points) or columns (variables)
- [[] retrieve a column from the attribute table (data.frame part)
- [[<- assign or replace a column in the attribute table (data.frame part)
- coordinates retrieve the coordinates of grid cells
- as.matrix retrieve the data as a matrix. The first index (rows) is the x-column, the second index (columns) the y-coordinate. Row index 1 is the smallest x-coordinate; column index 1 is the largest y-coordinate (top-to-bottom).
- as coercion methods for data.frame, SpatialPointsDataFrame
- image plot an image of the grid

Finally, spplot, a front-end to levelplot allows the plotting of a single grid plot or a lattice of grid plots.

5.5 Row and column selection of a region

Rows/columns selection can be done when gridded data is in the full grid form (as SpatialGridDataFrame). In this form also rows and/or columns can be de-selected (in which case a warning is issued):

> fullgrid(grd.attr) = FALSE
> grd.attr[1:5, "z1"]

Object of class SpatialPixelsDataFrame
Object of class SpatialPoints
Grid topology:
    cellcentre.offset cellsize cells.dim
    xc  1  1  3
    yc  2  1  2
SpatialPoints:
    
    xc yc
    [1,] 1 3
    [2,] 2 3
    [3,] 3 3
    [4,] 1 2
6 Lines

6.1 Building line objects from scratch

In many instances, line coordinates will be retrieved from external sources. The following example shows how to build an object of class SpatialLines from scratch. Note that the Slines objects have to be given character ID values, and that these values must be unique for Slines objects combined in a SpatialLines object.

> l1 = cbind(c(1, 2, 3), c(3, 2, 2))
> l1a = cbind(l1[, 1] + 0.05, l1[, 2] + 0.05)
> l2 = cbind(c(1, 2, 3), c(1, 1.5, 1))
> Sl1 = Sline(l1)
> Sl1a = Sline(l1a)
> Sl2 = Sline(l2)
> S1 = Slines(list(Sl1, Sl1a), ID = "a")
> S2 = Slines(list(Sl2), ID = "b")
> S1 = SpatialLines(list(S1, S2))
> summary(S1)

Object of class SpatialLines
Coordinates:
6.2 Building line objects with attributes

The class \texttt{SpatialLinesDataFrame} is designed for holding lines data that have an attribute table (data.frame) attached to it:

```r
> df = data.frame(z = c(1, 2), row.names = getSLSlinesIDSlots(Sl))
> Sldf = SpatialLinesDataFrame(Sl, data = df)
> summary(Sldf)
```

Object of class \texttt{SpatialLinesDataFrame}

Coordinates:

\begin{verbatim}
  min  max
  r1  1 3.05
  r2  1 3.05
Is projected: NA
\end{verbatim}
Not many useful methods for it are available yet. The plot method only plots
the lines, ignoring attribute table values. Suggestions for useful methods are
welcome.

7 Polygons

7.1 Building from scratch

The following example shows how a set of polygons are built from scratch. Note
that Sr4 has the opposite direction (anti-clockwise) as the other three (clock-
wise); it is meant to represent a hole in the Sr3 polygon. The default value for
the hole colour pbg is "transparent", which will not show, but which often does
not matter, because another polygon fills the hole — here it is set to "white".
Note that the Srings objects have to be given character ID values, and that
these values must be unique for Srings objects combined in a SpatialRings
object.

> Sr1 = Sring(cbind(c(2, 4, 4, 1, 2), c(2, 3, 5, 4, 2)))
> Sr2 = Sring(cbind(c(5, 4, 2, 5), c(2, 3, 2, 2)))
> Sr3 = Sring(cbind(c(4, 4, 5, 10, 4), c(5, 3, 2, 5, 5)))
> Sr4 = Sring(cbind(c(5, 6, 6, 5, 5), c(4, 4, 3, 3, 4)), hole = TRUE)
> Srs1 = Srings(list(Sr1), "s1")
> Srs2 = Srings(list(Sr2), "s2")
> Srs3 = Srings(list(Sr3, Sr4), "s3/4")
> SR = SpatialRings(list(Srs1, Srs2, Srs3), 1:3)
> plot.SpatialRings(SR, col = 1:3, pbg = "white")
7.2 Polygons with attributes

Polygons with attributes, objects of class `SpatialRingsDataFrame`, are built from the `SpatialRings` object (topology) and the attributes (data.frame). The `row.names` of the attributes data frame are matched with the ID slots of the `SpatialRings` object, and the rows of the data frame will be re-ordered if necessary.

```r
> attr = data.frame(a = 1:3, b = 3:1, row.names = c("s3/4", "s2", + "s1"))
> SrDf = SpatialRingsDataFrame(SR, attr)
> as(SrDf, "data.frame")

 a b
s1 3 1
s2 2 2
s3/4 1 3

> spplot(SrDf)

Loading required package: grid
or, as another way to create the `SpatialRingsDataFrame` object:

> SrDf = attr
> rings(SrDf) = SR

8 Interfaces to GIS and external formats

8.1 Reading grids through rgdal
8.2 Reading ESRI shapefiles
points, lines, polygons?
8.3 Reading ArcGIS coverages

References