Map overlay and spatial aggregation in sp

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1 Introduction

According to the free e-book by Davidson (2008),

> An overlay is a clear sheet of plastic or semi-transparent paper. It is used to display supplemental map and tactical information related to military operations. It is often used as a supplement to orders given in the field. Information is plotted on the overlay at the same scale as on the map, aerial photograph, or other graphic being used. When the overlay is placed over the graphic, the details plotted on the overlay are shown in their true position.

This suggests that *map overlay* is concerned with combining two, or possibly more, map layers by putting them on top of each other. This kind of overlay can be obtained in R e.g. by plotting one map layer, and plotting a second map layer on top of it. If the second one contains polygons, transparent colours can be used to avoid hiding of the first layer. When using the `spplot` command, the `sp.layout` argument can be used to combine multiple layers.

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O'Sullivan and Unwin (2003) argue in chapter 10 (Putting maps together: map overlay) that map overlay has to do with the combination of two (or more) maps. They mainly focus on the combination of the selection criteria stemming from several map layers, e.g. finding the deciduous forest area that is less than 5 km from the nearest road. They call this *boolean overlays*.

One could look at this problem as a polygon-polygon overlay, where we are looking for the intersection of the polygons with the deciduous forest with the polygons delineating the area less than 5 km from a road. Other possibilities are to represent one or both coverages as grid maps, and find the grid cells for which both criteria are valid (grid-grid overlay). A third possibility would be that one of the criteria is represented by a polygon, and the other by a grid (polygon-grid overlay, or grid-polygon overlay). In the end, as O'Sullivan and Unwin argue, we can overlay any spatial type (points, lines, polygons, pixels/grids) with any other. In addition, we can address spatial attributes (as the case of grid data), or only the geometry (as in the case of the polygon-polygon intersection).

This vignette will explain how the `over` method in package `sp` can be used to compute map overlays, meaning that instead of overlaying maps visually, the digital information that comes from combining two digital map layers is retrieved. From there, methods to *aggregate* (compute summary statistics; Heuvelink and Pebesma, 1999) over a spatial domain will be developed and demonstrated.

2 Geometry overlays

We will use the word *geometry* to denote the purely spatial characteristics, meaning that attributes (qualities, properties of something at a particular location) are ignored. With *location* we denote a point, line, polygon or grid cell. Section 3 will discuss how to retrieve and possibly aggregate or summarize attributes found there.

Given two geometries, `A` and `B`, the following equivalent commands

```
> A %over% B
> over(A, B)
```

retrieve the geometry (location) indices of `B` at the locations of `A`. More in particular, an integer vector of length `length(A)` is returned, with `NA` values for locations in `A` not matching with locations in `B` (e.g. those points outside a set of polygons).

Selecting points of `A` *inside* or *on* some geometry `B` (e.g. a set of polygons) `B` is done by

```
> A[B, ]
```

which is short for

```
> A[!is.na(over(A, B)), ]
```

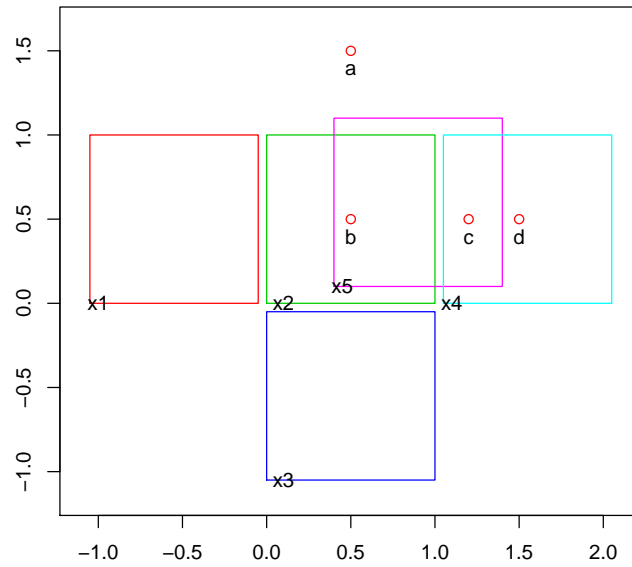We will now illustrate this with toy data created by

Figure 1: Toy data: points (a-d), and (overlapping) polygons (x1-x5)

```
> library(sp)
> x = c(0.5, 0.5, 1.2, 1.5)
> y = c(1.5, 0.5, 0.5, 0.5)
> xy = cbind(x,y)
> dimnames(xy)[[1]] = c("a", "b", "c", "d")
> pts = SpatialPoints(xy)
> xpol = c(0,1,1,0,0)
> ypol = c(0,0,1,1,0)
> pol = SpatialPolygons(list(
+        Polygons(list(Polygon(cbind(xpol-1.05,ypol))), ID="x1"),
+        Polygons(list(Polygon(cbind(xpol,ypol))), ID="x2"),
+        Polygons(list(Polygon(cbind(xpol,ypol-1.05))), ID="x3"),
+        Polygons(list(Polygon(cbind(xpol+1.05,ypol))), ID="x4"),
+        Polygons(list(Polygon(cbind(xpol+.4, ypol+.1))), ID="x5")
+        ))
```

and shown in figure 1.

Now, the polygons `pol` in which points `pts` lie are

```
> over(pts, pol)
```

3

```
[1] NA  5  5  4
```

As points **b** and **c** fall in two overlapping polygons, we can retrieve the complete information as a list:

```
> over(pts, pol, returnList = TRUE)

[[1]]
integer(0)

[[2]]
[1] 2 5

[[3]]
[1] 4 5

[[4]]
[1] 4
```

and the appropriate points falling in any of the polygons are selected by

```
> pts[pol]

SpatialPoints:
    x   y
b 0.5 0.5
c 1.2 0.5
d 1.5 0.5
Coordinate Reference System (CRS) arguments: NA
```

The reverse, identical sequence of commands for selecting polygons **pol** that have (one or more) points of **pts** in them is done by

```
> over(pol, pts)

[1] NA  2 NA  3  2

> over(pol, pts, returnList = TRUE)

[[1]]
integer(0)

[[2]]
[1] 2

[[3]]
integer(0)

[[4]]
```

```
[1] 3 4

[[5]]
[1] 2 3

> row.names(pol[pts])

[1] "x2" "x4" "x5"
```

3   Using over to extract attributes

This section shows how over(x,y) is used to extract attribute values of argument y at locations of x. The return value is either an (aggregated) data frame, or a list.

We now create an example SpatialPointsDataFrame and a SpatialPolygonsDataFrame using the toy data created earlier:

```
> zdf = data.frame(z1 = 1:4, z2 = 4:1, f = c("a", "a", "b", "b"),
+     row.names = c("a", "b", "c", "d"))
> zdf

  z1 z2 f
a  1  4 a
b  2  3 a
c  3  2 b
d  4  1 b

> ptsdf = SpatialPointsDataFrame(pts, zdf)
> zpl = data.frame(z = c(10, 15, 25, 3, 0), zz = 1:5, f = c("z",
+     "q", "r", "z", "q"), row.names = c("x1", "x2", "x3", "x4",
+     "x5"))
> zpl

    z zz f
x1 10  1 z
x2 15  2 q
x3 25  3 r
x4  3  4 z
x5  0  5 q

> poldf = SpatialPolygonsDataFrame(pol, zpl)
```

In the simplest example

```
> over(pts, poldf)
```

```
    z zz    f
a NA NA <NA>
b 15  2    q
c  3  4    z
d  3  4    z
```

a `data.frame` is created with each row corresponding to the first element of the `poldf` attributes at locations in `pts`.

As an alternative, we can pass a user-defined function to process the table (selecting those columns to which the function makes sense):

```
> over(pts, poldf[1:2], fn = mean)

    z  zz
a  NA  NA
b 7.5 3.5
c 1.5 4.5
d 3.0 4.0
```

To obtain the complete list of table entries at each point of `pts`, we use the `returnList` argument:

```
> over(pts, poldf, returnList = TRUE)

[[1]]
[1] z  zz f
<0 rows> (or 0-length row.names)

[[2]]
    z zz f
x2 15  2 q
x5  0  5 q

[[3]]
   z zz f
x4 3  4 z
x5 0  5 q

[[4]]
   z zz f
x4 3  4 z
```

The same actions can be done when the arguments are reversed:

```
> over(pol, ptsdf)

   z1 z2    f
x1 NA NA <NA>
```

	y: points	y: lines	y: polygons	y: pixels/grids
x: points	s	r	s	s
x: lines	r	r	r	r
x: polygons	s	r	r	s
x: pixels/grids	s	r	s	s

Table 1: `over` methods implemented for different `x` and `y` arguments (x: sp; r: rgeos).

```
x2  2  3     a
x3 NA NA <NA>
x4  3  2     b
x5  2  3     a

> over(pol, ptsdf[1:2], fn = mean)

    z1   z2
x1  NA   NA
x2 2.0  3.0
x3  NA   NA
x4 3.5  1.5
x5 2.5  2.5
```

4   Lines, and Polygon-Polygon overlays with `rgeos`

Package `sp` provides many of the `over` methods, but not all. Package `rgeos` provides functions to compute geometry intersections, i.e. for any set of (points, lines, polygons) to determine whether they have one ore more points in common. The `over` methods not provided by package `sp` can thus be completed; it involves *any* `over` methods where a `SpatialLines` object is involved (either as `x` or `y`), and the method where `x` and `y` are both of class `SpatialPolygons` (table 1). For this purpose, objects of class `SpatialPixels` or `SpatialGrid` are converted to `SpatialPolygons`. For the toy example extended with lines, see figure 2.

The set of `over` operations on the polygons, lines and points is shown below (note that lists and vectors are named in this case):

```
> library(rgeos)
> over(pol, pol)

x1 x2 x3 x4 x5
 1  2  3  4  2

> over(pol, pol, returnList = TRUE)

$x1
x1
```
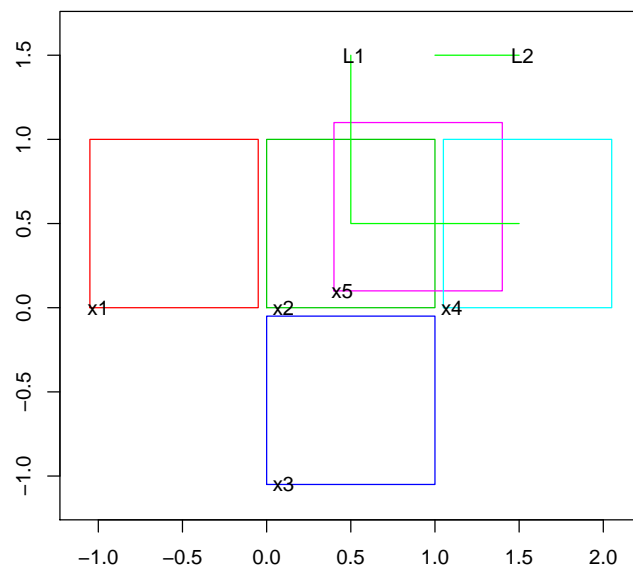
Figure 2: Toy data: two lines and (overlapping) polygons (x1-x5)

```
 1

$x2
x2 x5
 2  5

$x3
x3
 3

$x4
x4 x5
 4  5

$x5
x2 x4 x5
 2  4  5
```
```
> over(pol, L)
```
```
x1 x2 x3 x4 x5
NA  1 NA  1  1
```
```
> over(L, pol)
```
```
L1 L2
 2 NA
```
```
> over(L, pol, returnList = TRUE)
```
```
$L1
x2 x4 x5
 2  4  5

$L2
named integer(0)
```
```
> over(L, L)
```
```
L1 L2
 1  2
```
```
> over(pts, L)
```
```
a b c d
1 1 1 1
```
```
> over(L, pts)
```
```
L1 L2
 1 NA
```

Another example overlays a line with a grid, shown in figure 3.

```
> data(meuse.grid)
> gridded(meuse.grid) = ~x + y
> Pt = list(x = c(178274.9, 181639.6), y = c(329760.4, 333343.7))
> sl = SpatialLines(list(Lines(Line(cbind(Pt$x, Pt$y)), "L1")))
> image(meuse.grid)
> xo = over(sl, geometry(meuse.grid), returnList = TRUE)
> image(meuse.grid[xo[[1]], ], col = grey(0.5), add = T)
> lines(sl)
```
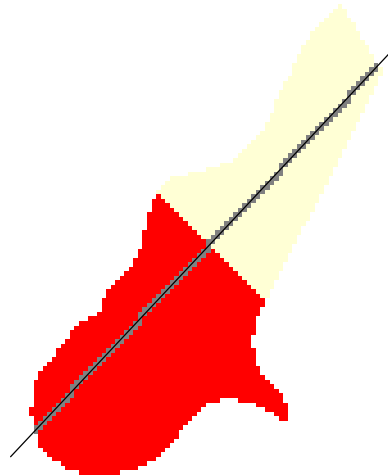

Figure 3: Overlay of line with grid, identifying cells crossed (or touched) by the line

5 Aggregation

In the following example, the values of a fine grid with 40 m x 40 m cells are aggregated to a course grid with 400 m x 400 m cells.

```
> data(meuse.grid)
> gridded(meuse.grid) = ~x + y
> off = gridparameters(meuse.grid)$cellcentre.offset + 20
> gt = GridTopology(off, c(400, 400), c(8, 11))
> SG = SpatialGrid(gt)
> agg = aggregate(meuse.grid[3], SG)
```

Figure 4 shows the result of this aggregation (agg, in colors) and the points (+) of the original grid (meuse.grid). Function aggregate aggregates its first argument over the geometries of the second argument, and returns a geometry with attributes. The default aggregation function (mean) can be overridden.
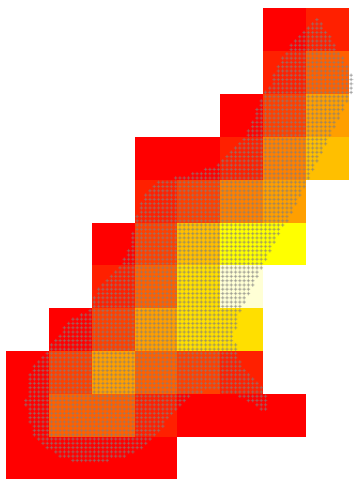

Figure 4: aggregation over meuse.grid distance values to a 400 m x 400 m grid

An example of the aggregated values of meuse.grid along (or under) the line shown in Figure **??** are

```
> sl.agg = aggregate(meuse.grid, sl)
> class(sl.agg)
```

```
[1] "SpatialLinesDataFrame"
attr(,"package")
[1] "sp"

> as.data.frame(sl.agg)

      part.a    part.b      dist     soil ffreq
L1 0.4904459 0.5095541 0.3100566 1.770701    NA
```

Function `aggregate` returns a spatial object of the same class of `sl` (`SpatialLines`), and `as.data.frame` shows the attribute table as a `data.frame`.

References

- O'Sullivan, D., Unwin, D. (2003) Geographical Information Analysis. Wiley, NJ.

- Davidson, R., 2008. Reading topographic maps. Free e-book from: http://www.map-reading.com/

- Heuvelink, G.B.M., and E.J. Pebesma, 1999. Spatial aggregation and soil process modelling Geoderma 89, 1-2, 47-65. http://dx.doi.org/10.1016/S0016-7061(98)00077-9