Analysing spatio-temporal data with R

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DEVELOPMENT · CENTER

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What are spatio-temporal data?

```
> head(cars)

  speed dist
1     4    2
2     4   10
3     7    4
4     7   22
5     8   16
6     9   10

> summary(cars)

     speed           dist
 Min.   : 4.0   Min.   :  2.00
 1st Qu.:12.0   1st Qu.: 26.00
 Median :15.0   Median : 36.00
 Mean   :15.4   Mean   : 42.98
 3rd Qu.:19.0   3rd Qu.: 56.00
 Max.   :25.0   Max.   :120.00
```

`?cars` reveals these data were recorded in the 1920s. The metric units (mph, ft) suggest: UK or US.

Are these data spatio-temporal?

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6     9   10

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 Mean   :15.4   Mean   : 42.98
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 Max.   :25.0   Max.   :120.00
```

`?cars` reveals these data were recorded in the 1920s. The metric units (mph, ft) suggest: UK or US.

Are these data spatio-temporal?

No – we (geographers, geoinformaticians, geo-whatevers)

- insist on *known* coordinates x, y, t
- prefer known reference systems – but don't insist?

Are these spatio-temporal data?

```
> data(Produc, package="plm")
> head(Produc)

    state year     pcap     hwy   water    util       pc   gsp     emp unemp
1 ALABAMA 1970 15032.67 7325.80 1655.68 6051.20 35793.80 28418 1010.5   4.7
2 ALABAMA 1971 15501.94 7525.94 1721.02 6254.98 37299.91 29375 1021.9   5.2
3 ALABAMA 1972 15972.41 7765.42 1764.75 6442.23 38670.30 31303 1072.3   4.7
4 ALABAMA 1973 16406.26 7907.66 1742.41 6756.19 40084.01 33430 1135.5   3.9
5 ALABAMA 1974 16762.67 8025.52 1734.85 7002.29 42057.31 33749 1169.8   5.5
6 ALABAMA 1975 17316.26 8158.23 1752.27 7405.76 43971.71 33604 1155.4   7.7
```

Answer:

Are these spatio-temporal data?

```
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3 ALABAMA 1972 15972.41 7765.42 1764.75 6442.23 38670.30 31303 1072.3   4.7
4 ALABAMA 1973 16406.26 7907.66 1742.41 6756.19 40084.01 33430 1135.5   3.9
5 ALABAMA 1974 16762.67 8025.52 1734.85 7002.29 42057.31 33749 1169.8   5.5
6 ALABAMA 1975 17316.26 8158.23 1752.27 7405.76 43971.71 33604 1155.4   7.7
```

Answer:

- Yes, if you're willing to do a lot of understanding,
- No, if you don't know where ALABAMA is, or from which country it is a state, or if you don't know what the *year* 1970 refers to.
- state and year do refer, but in a soft (unstandardized) way.

Organisation

9:00–10:30 R, spatial data in R

11:00-12:30 time, time series data in R

14:00-15:30 spatio-temporal data types, operations, statistics

16:00-17:00 ... ctd., flexible, exercises, interaction.

R

- what is R?
- what is an R package? what is a vignette?
- what is CRAN?
- where is the spatial task view? spatio-temporal task view?
- how do I find in package *x* how to do task *y*?
- how do I find out how to do ... with R?

R

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```
> library(fortunes)
> fortune("only how")

Evelyn Hall: I would like to know how (if) I can extract some
of the information from the summary of my nlme.

Simon Blomberg: This is R. There is no if. Only how.
   -- Evelyn Hall and Simon 'Yoda' Blomberg
      R-help (April 2005)
```

I will assume you understand this:

```
> a = data.frame(varA = c(1,1.5,2),
+  varB = c("a", "a", "b"))
> a[1,]

  varA varB
1    1    a

> a[,1]

[1] 1.0 1.5 2.0

> a[[1]]

[1] 1.0 1.5 2.0

> a[1]

  varA
1  1.0
2  1.5
3  2.0

> a[, 1, drop=FALSE]

  varA
1  1.0
2  1.5
3  2.0
```

```
> a["varA"]

  varA
1  1.0
2  1.5
3  2.0

> a[c("varA", "varB")]

  varA varB
1  1.0    a
2  1.5    a
3  2.0    b

> a$varA

[1] 1.0 1.5 2.0

> a$varA <- 3:1
> a

  varA varB
1    3    a
2    2    a
3    1    b
```

Spatial data

Spatial data refresher:

- points, lines, polygons, grids
- storage: shapefiles, grid files, in- or out-of-memory
- data bases (e.g. PostGIS): geometry + attributes
- topology representation of polygons
- spatial indexes
- projected data, or long/lat?

What makes a GIS a GIS?

What makes a GIS a GIS?

- store, retrieve spatial data
- visualize spatial data
- manipulate spatial data
- analyze, model spatial data
  - analyze attributes, as in a data base
  - analyze geometries, or attributes depending on geometry

"A geographic information system is a system designed to capture, store, manipulate, analyze, manage, and present all types of geographical data" (wikipedia, from esri.com)
"In the simplest terms, GIS is the merging of cartography, statistical analysis, and database technology." (wikipedia)

How to get spatial data into R?

Simple answer: using `rgdal` (`readGDAL` or `readOGR`).

How to get spatial data into R?

Simple answer: using `rgdal` (`readGDAL` or `readOGR`). More complete:

- `readGDAL` or `readOGR` read the whole data set from disk into R, that is, into the computers main or working memory ("RAM").
- for grids, there are low-level routines: `GDAL.open` opens a file, and `getRasterData` (or `getRasterTable`) to read *portions* of data; but also (little known!):

```
> library(rgdal)
> x = GDAL.open("NDV_19980401_Gambia__the_Extract.tif")
> object.size(x[])
```

```
207248 bytes
```

```
> object.size(x[1:100, 1:100])
```

```
44296 bytes
```

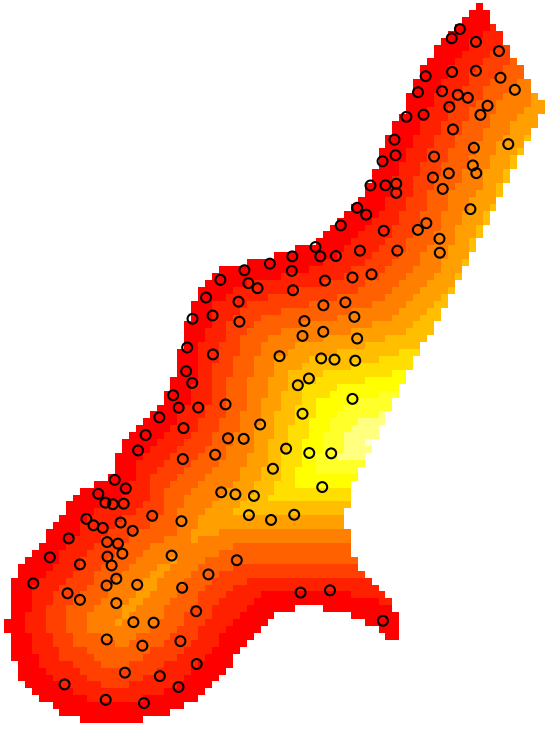
  reads only the portion requested into memory
- Today, people use `raster` when disk caching is needed

overlay: visual

base plot: plotting sequentially, e.g.
lattice (spplot):
note: transparency is a colour attribute

Overlay: visual - 1. by incrementally plotting

```
> library(sp)
> data(meuse.grid)
> coordinates(meuse.grid) = ~x+y
> gridded(meuse.grid) = TRUE
> image(meuse.grid["dist"])
> data(meuse)
> coordinates(meuse) = ~x+y
> points(meuse)
> # add lines, legend, text, ...
```

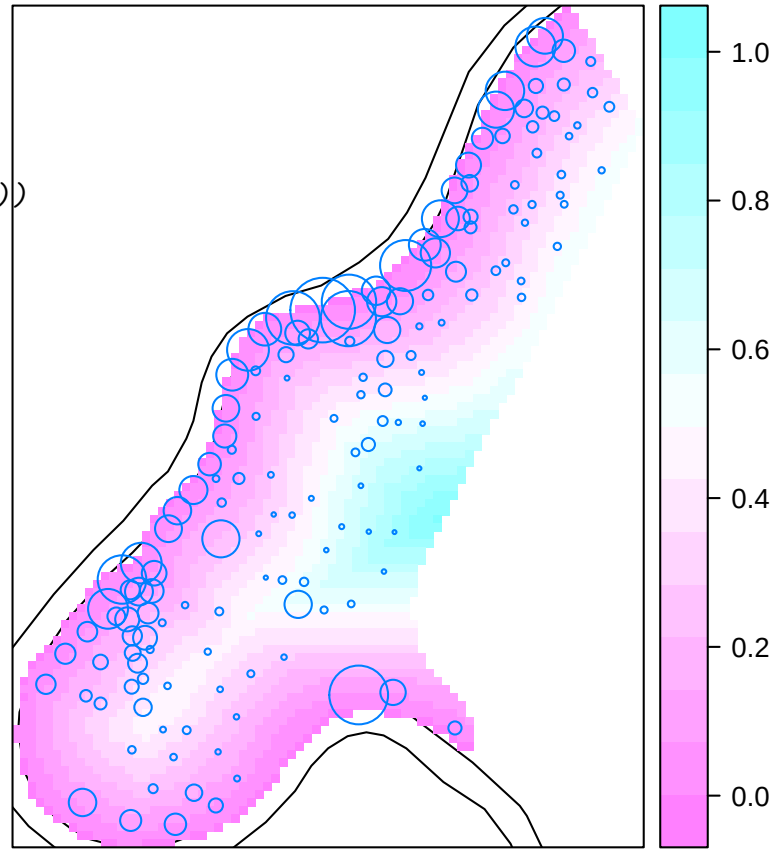


Overlay: visual - 2. using compound plot functions

```
> size = meuse$zinc / mean(meuse$zinc)
> pts = list("sp.points", meuse, pch = 1, cex = size)
> demo(meuse, echo=FALSE, ask=FALSE)
> riv = list("sp.polygons", meuse.riv)
> plt = spplot(meuse.grid["dist"], sp.layout = list(pts, riv))
> class(plt)

[1] "trellis"

> print(plt)
```



- a plot object is created, which contains everything
- this object can be manipulated, but the most used option is to print (i.e., show) it.

Cartography?

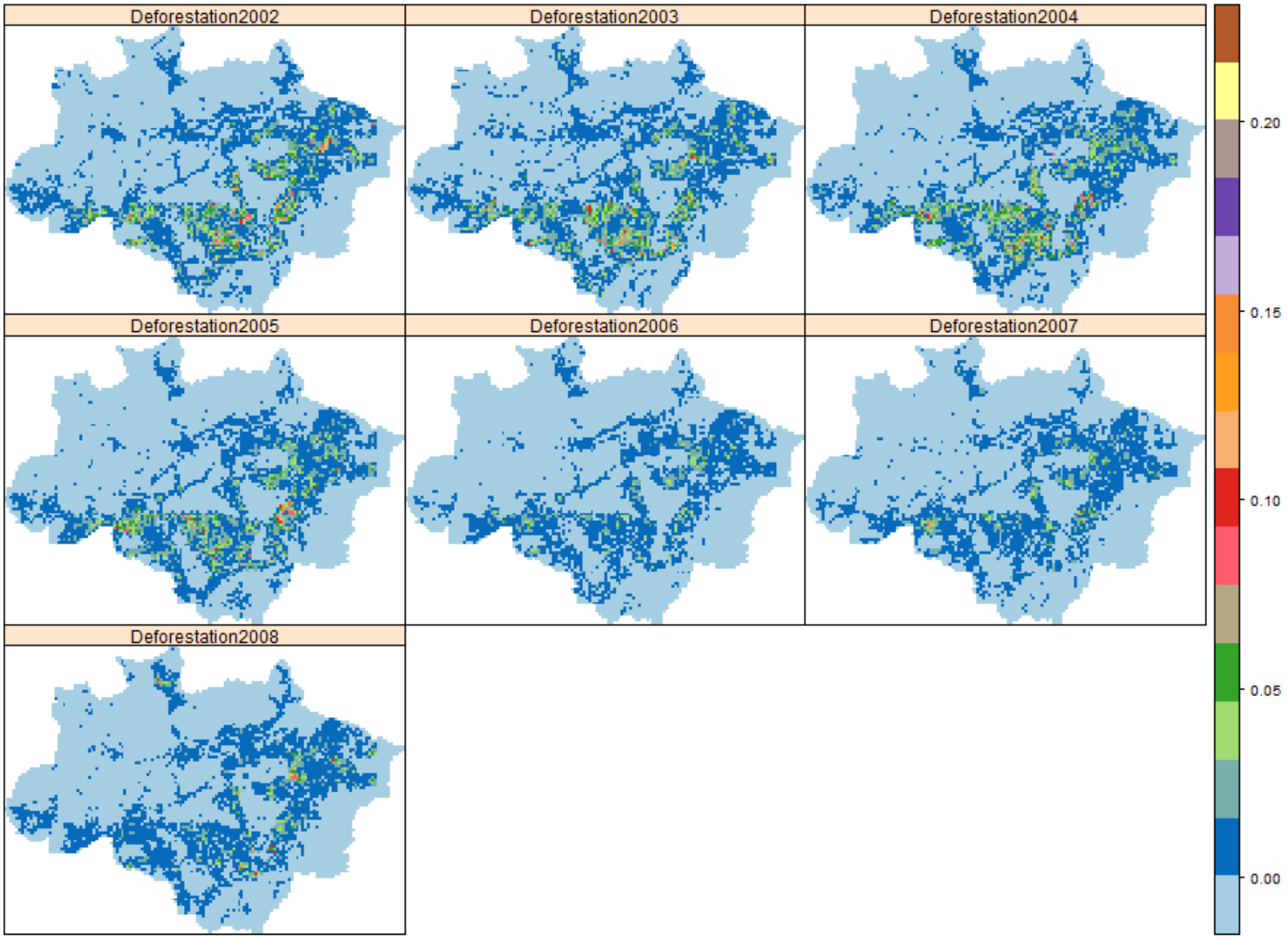
- A map is a plot with longitude and latitude, and a controlled aspect ratio; any plotting software can "do" maps, however
- reference comes from coast lines, rivers, lakes, topography, political boundaries, cities, land use etc.
- reference grid lines (parallels, meridians) may be required, and be non-straigh
- axes tics usually show little, but some information
- custom elements are often present (arrow, scale bar, multi-type legend)
- label placement is challenging (but see: rgeos::polyLabel)

What is R good at?

- simple, repetitive graphs:
  - many, similar graphs, over different pages
  - many graphs combined in a lattice (grid: lattice, ggplot)
- non-interactive, reproducible use
- control of all details
- richness of graphics devices,
- portability, cross-platform, options for deployment

What is R bad at?

- interactive use: zoom, pan, edit graph element etc.
- control is not trivial
- (?) incompatible plotting systems: base, lattice, ggplot, ...



G. Espindola, 2012: Spatiotemporal trends of land use change in the Brazilian Amazon; INPE

Two work horses: rgdal, rgeos

```
> library(rgdal)
Geospatial Data Abstraction Library extensions to R successfully loaded
Loaded GDAL runtime: GDAL 1.9.1, released 2012/05/15
Path to GDAL shared files: /usr/share/gdal/1.9
Loaded PROJ.4 runtime: Rel. 4.7.1, 23 September 2009, [PJ_VERSION: 470]
Path to PROJ.4 shared files: (autodetected)
>
> library(rgeos)
Loading required package: stringr
Loading required package: plyr
rgeos: (SVN revision (unknown))
GEOS runtime version: 3.3.3-CAPI-1.7.4
Polygon checking: TRUE
```

- `rgdal` links to the GDAL (raster) and OGR (vector) data I/O library, as well as `PROJ.4` for CRS (coordinate reference systems) (re)projections
- `rgeos` links to the GEOS (Geometry Open Source) library, which powers PostGIS: does the "usual" geometry operations for features

What is numerical overlay?

Method `over(x,y)` provides: consistent spatial overlay for points, grids, lines and polygons: at the spatial locations of object x retrieve the indexes or attributes from spatial object y and `NA` in case of no match (index `vector` if y has only geometry, attribute `data.frame` if it has attributes too).

```
> over(meuse, geometry(meuse.grid))[1:10]

 [1]   9  24  28  41  93 128  75  71
 [9] 138 161

> over(meuse, meuse.grid)[1:3,]

  part.a part.b       dist soil
1      1      0 0.00135803    1
2      1      0 0.01222430    1
3      1      0 0.10302900    1
  ffreq
1     1
2     1
3     1
```

In SQL, this resembles a left outer join of two tables

What if there are no, or multiple matches?

No match:

```
> m2 = meuse[-1,] # remove first record
> over(meuse, geometry(m2))[1:5]

[1] NA  1  2  3  4

> over(meuse, m2)[1:3, 1:4]

  cadmium copper lead zinc
1      NA     NA   NA   NA
2     8.6     81  277 1141
3     6.5     68  199  640
```

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> over(meuse, geometry(m2))[1:5]

[1] NA  1  2  3  4

> over(meuse, m2)[1:3, 1:4]

  cadmium copper lead zinc
1      NA     NA   NA   NA
2     8.6     81  277 1141
3     6.5     68  199  640
```

Multiple matches:

```
> m2 = meuse[c(1,1:155),] # duplicate first record
> over(meuse, geometry(m2))[1:5]

[1] 2 3 4 5 6

> over(meuse, m2)[1:3, 1:4]

  cadmium copper lead zinc
1    11.7     85  299 1022
2     8.6     81  277 1141
3     6.5     68  199  640
```

So, by default, all multiple maches are ignored.

What if we want multiple matches?

Multiple indices:

```
> m2 = meuse[c(1,1:155),] # duplicate first record
> over(meuse, geometry(m2), returnList = TRUE)[1:3]

[[1]]
[1] 1 2

[[2]]
[1] 3

[[3]]
[1] 4
```

Multiple tables:

```
> over(meuse, m2[1:4], returnList = TRUE)[1:2]

[[1]]
    cadmium copper lead zinc
1      11.7     85  299 1022
1.1    11.7     85  299 1022

[[2]]
  cadmium copper lead zinc
2     8.6     81  277 1141
```

What if we want to compute over multiple matches?

```
> m2 = meuse[c(1,1:155),] # duplicate first record
> over(meuse, m2[1:4], returnList = FALSE, fn = max)[1:2,1:4]

  cadmium copper lead zinc
1    11.7     85  299 1022
2     8.6     81  277 1141
```

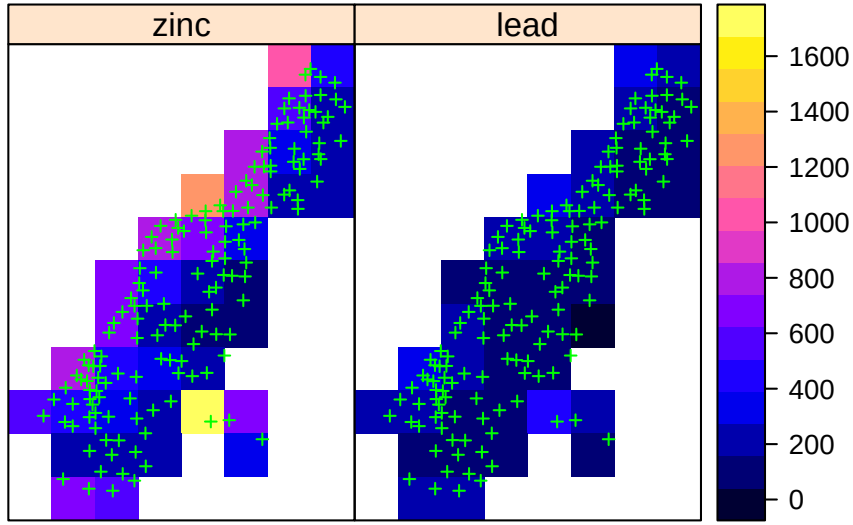
Although this is the same as

```
> over(meuse, meuse)[1:2,1:4]

  cadmium copper lead zinc
1    11.7     85  299 1022
2     8.6     81  277 1141
```

in the first case, actually the maximum is computed (`fn = max`) over the multiple matched records, and returned, as record values. In fact, this process is called *aggregation*.

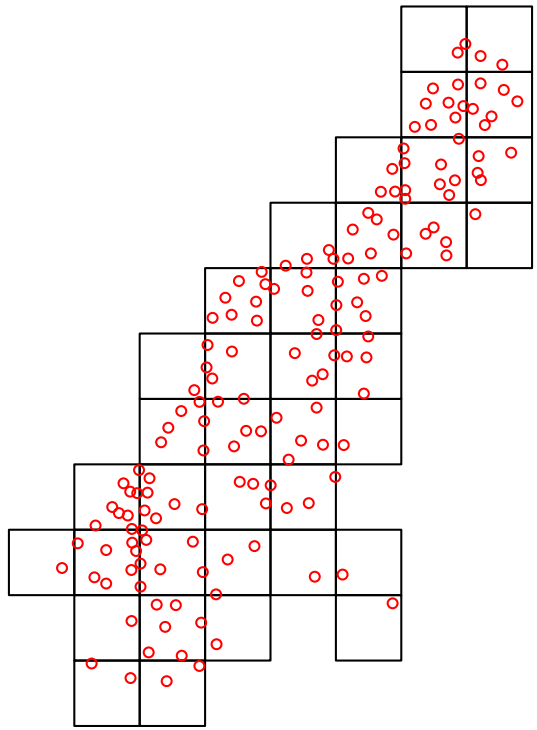
Aggregation, the R way

```
> # for a data.frame, based on a table column:
> m = as(meuse, "data.frame")[c("zinc", "lead")]
> aggregate(m, by = list(ffreq = meuse$ffreq), mean)

  ffreq     zinc     lead
1     1 625.7500 197.9762
2     2 273.2083  99.3750
3     3 309.9565 103.0870

> # create a coarse grid:
> off = gridparameters(meuse.grid)$cellcentre.offset + 20
> gt = GridTopology(off, c(400,400), c(8,11))
> SG = SpatialGrid(gt)
> proj4string(SG) = proj4string(meuse.grid)
> # for a Spatial object, based on another Spatial object:
> agg = aggregate(meuse[c("zinc","lead")], SG, FUN = mean)
> spplot(agg, sp.layout = pts)
```



Which pixels are covered by points? Selection with `over`

```
> SP = as(SG, "SpatialPolygons")
> over(SP, geometry(meuse))

 [1]  NA  NA  NA  NA  NA  NA   1   3
 [9]  NA  NA  NA  NA  NA  NA   8   5
[17]  NA  NA  NA  NA  NA  19  12  24
[25]  NA  NA  NA  NA  52  37  32  31
[33]  NA  NA  NA  55  58  42  NA  NA
[41]  NA  NA  64  62  49 106  NA  NA
[49]  NA  NA  65  86 104 107  NA  NA
[57]  NA  72  70  68 103  NA  NA  NA
[65]  92  77  76  94  82 118  NA  NA
[73]  NA 150  95 143  NA 155  NA  NA
[81]  NA 147 144  NA  NA  NA  NA  NA

> length(SP[!is.na(over(SP, geometry(meuse)))])

[1] 38

> length(SP[meuse]) # equivalent!

[1] 38

> plot(as(SP[meuse], "SpatialPolygons"))
> points(meuse, col = 'red')
```



Possible over methods

Spatial data (see `overlay and aggregation` vignette in sp):

	y: points	y: lines	y: polygons	y: pixels/grids
x: points	sp	rgeos	sp	sp
x: lines	rgeos	rgeos	rgeos	rgeos
x: polygons	sp	rgeos	rgeos	sp
x: pixels/grids	sp	rgeos	sp	sp

Table: `over` methods implemented for different `x` and `y` arguments.

Spatio-temporal data: see `spacetime` vignette

Nine-intersection model

The nine-intersection model is a comprehensive model, from which most relations (touches, overlaps, intersects) can be derived – see http://en.wikipedia.org/wiki/DE-9IM

```
> library(rgeos)
> gRelate(meuse.riv, meuse.riv)

[1] "2FFF1FFF2"

> gRelate(meuse.riv, SP)

[1] "212101212"

> gRelate(meuse.riv, SP, byid = TRUE)[1:5]

[1] "FF2FF1212" "FF2FF1212"
[3] "FF2FF1212" "FF2FF1212"
[5] "FF2FF1212"
```

Exercises: spatial

- run the examples of vignette `intro_sp` in package `sp`
- run the examples of vignette `gstat` in package `gstat`

Representing time series data in R

`zoo`:

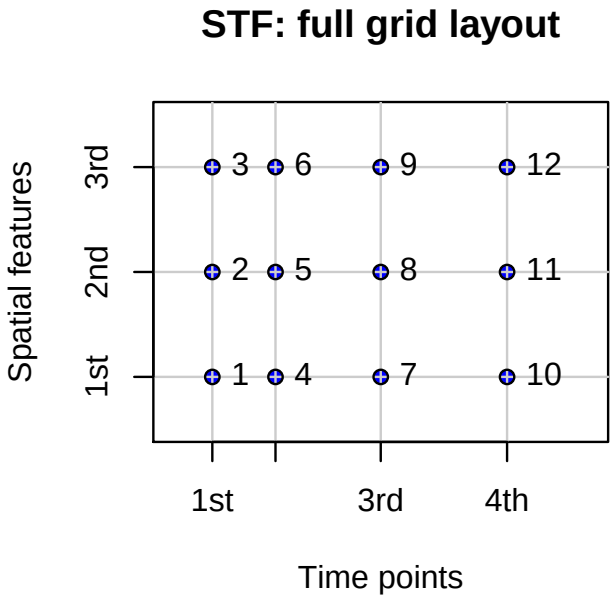
- `zoo`: (S3) classes for ordered observations, including time series
- powerful temporal aggregation, using `as.yearmon`, `as.yearqtr` etc, and user-supplied grouping functions
- `na.fill`, `na.approx`, `na.spline`

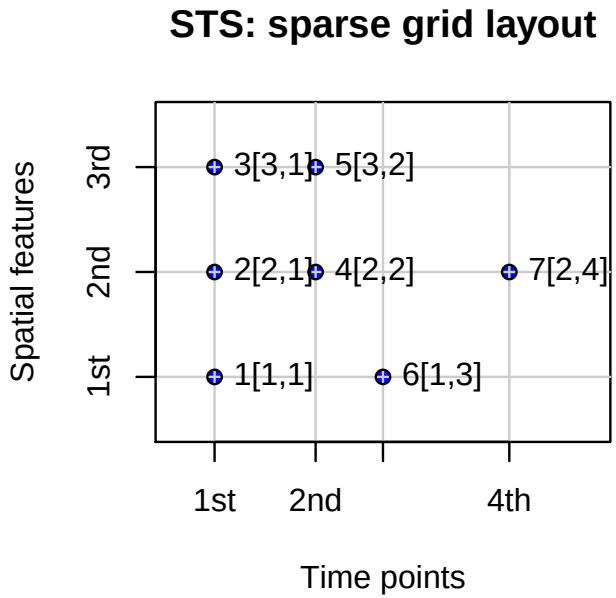
`xts`:

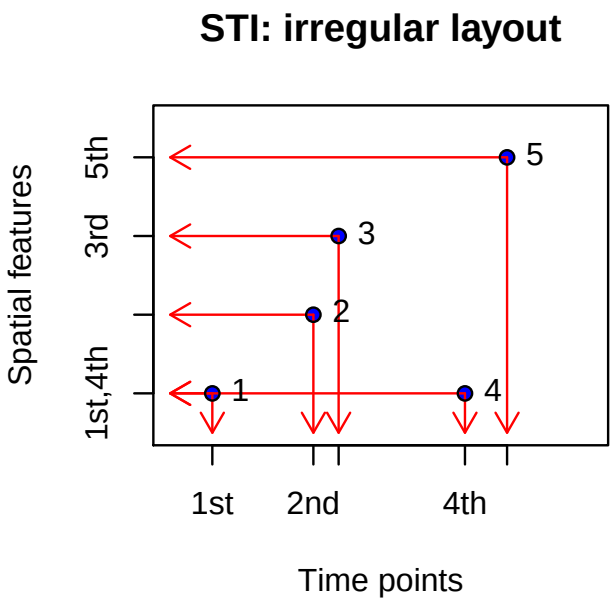
- builds on top of `zoo`
- (S3) explicit time reference required
- "supports" several time based systems: "Date", "POSIXt", "chron", "dates", "times", "timeDate", "yearmon", "yearqtr", "xtime"
- ... but stores time as POSIXct, remembers original class.
- ISO 8601 time (interval) selection
- partly written in C, increasing performance; high-speed trading

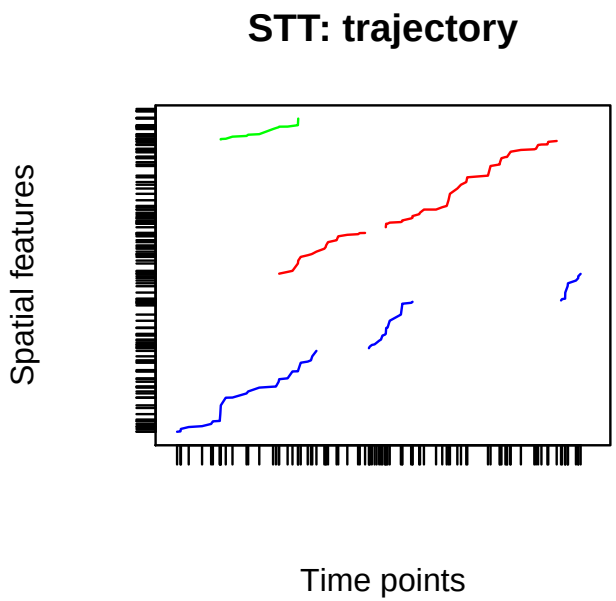
Interestingly, both have no notion of time *intervals*!

Space-time layouts

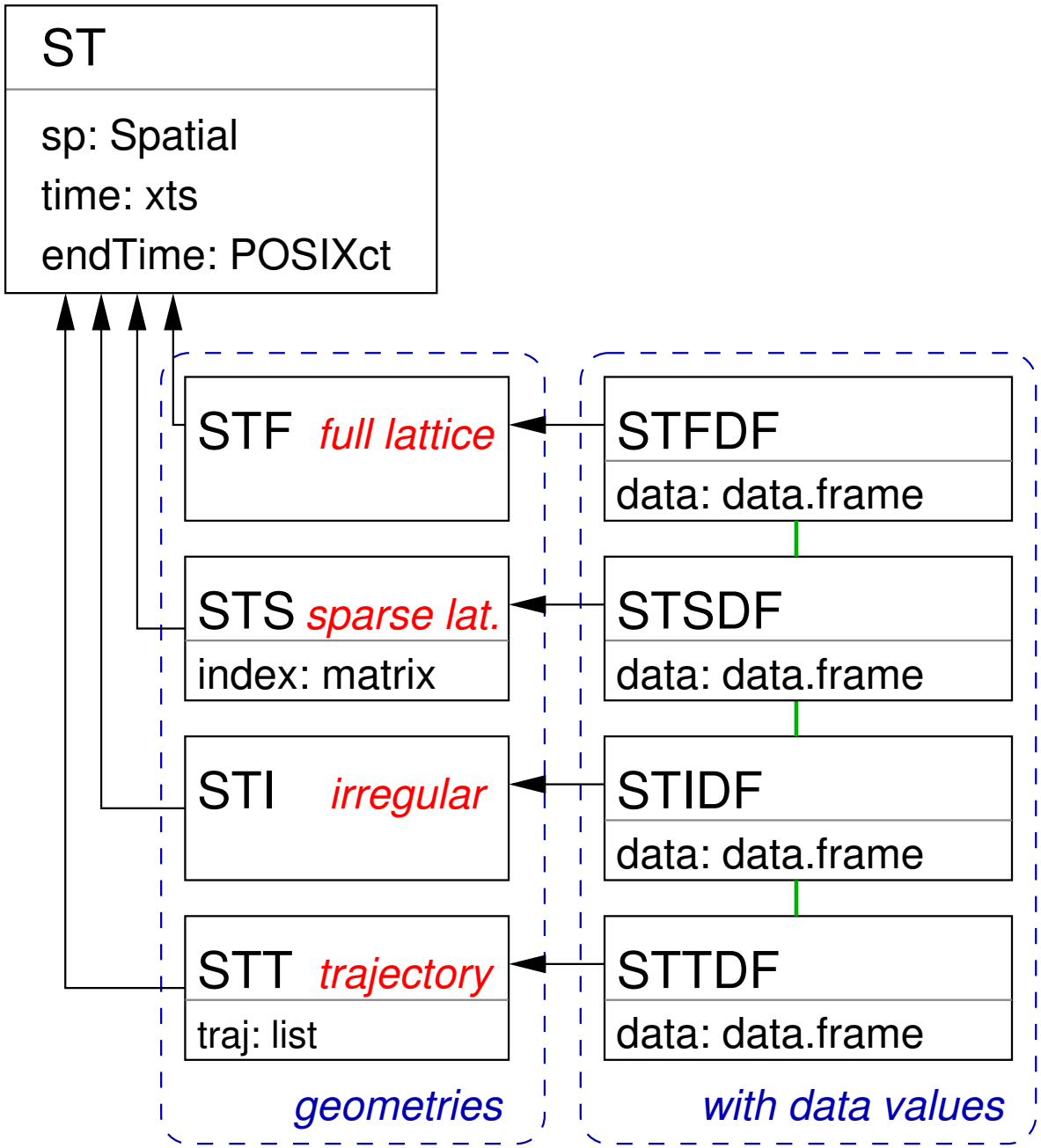




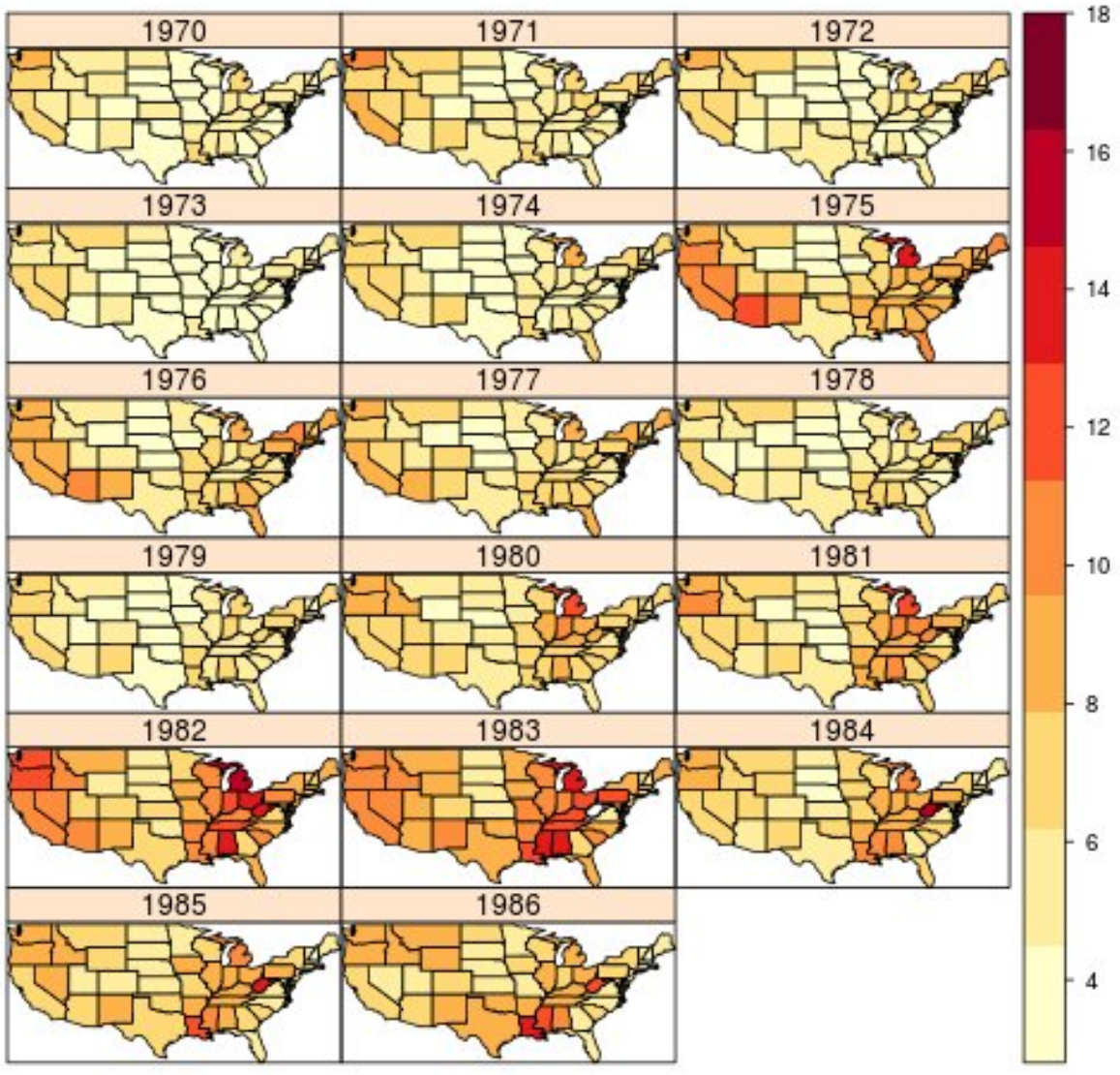




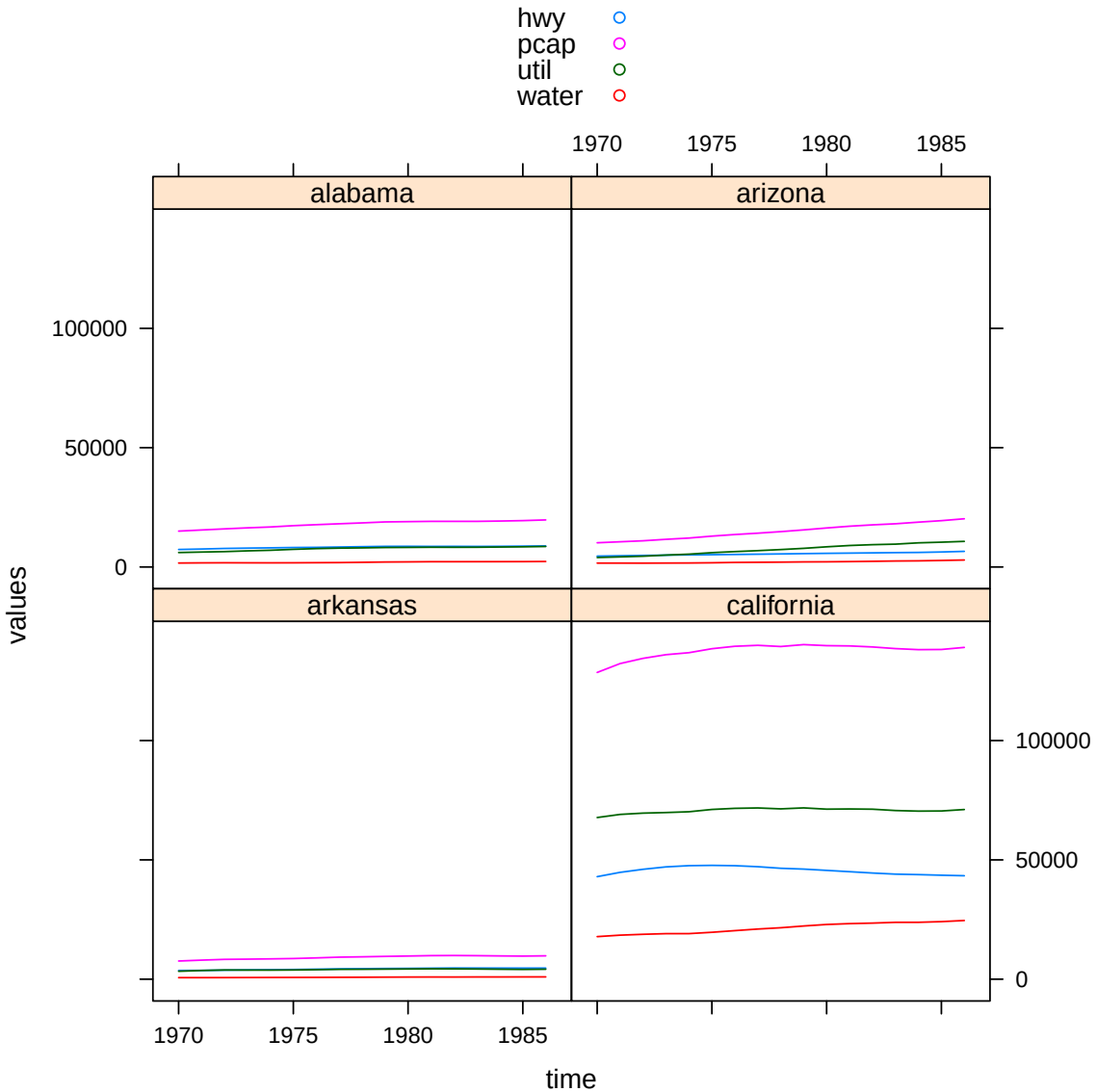
Class layout in `spacetime`



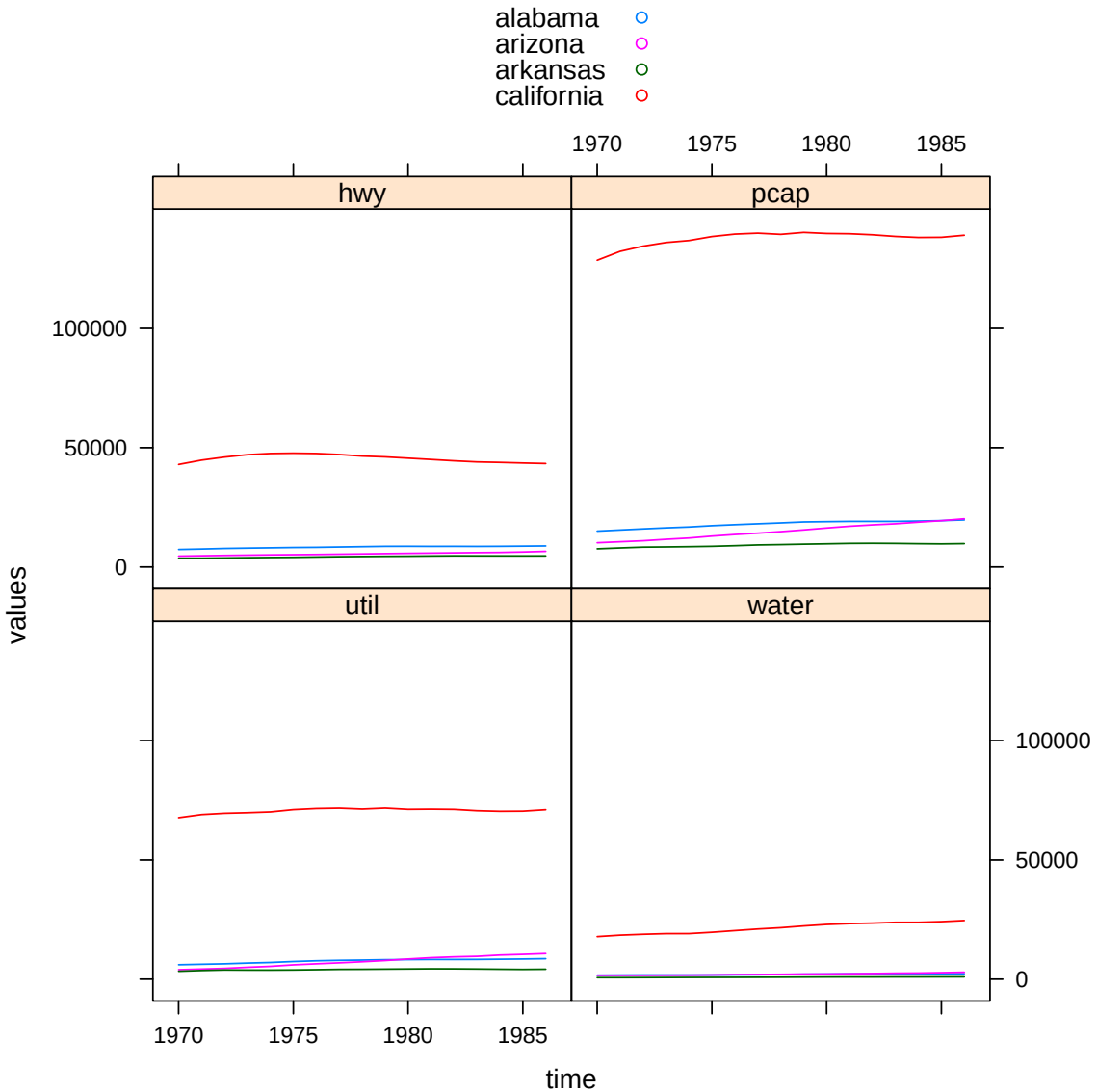
STFDF example: `data(Produc)`



STFDF example: `data(Produc)`



STFDF example: `data(Produc)`

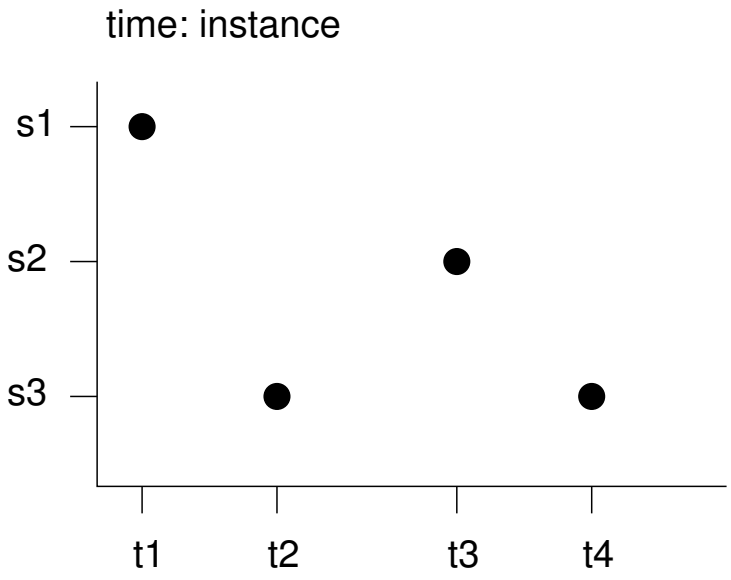


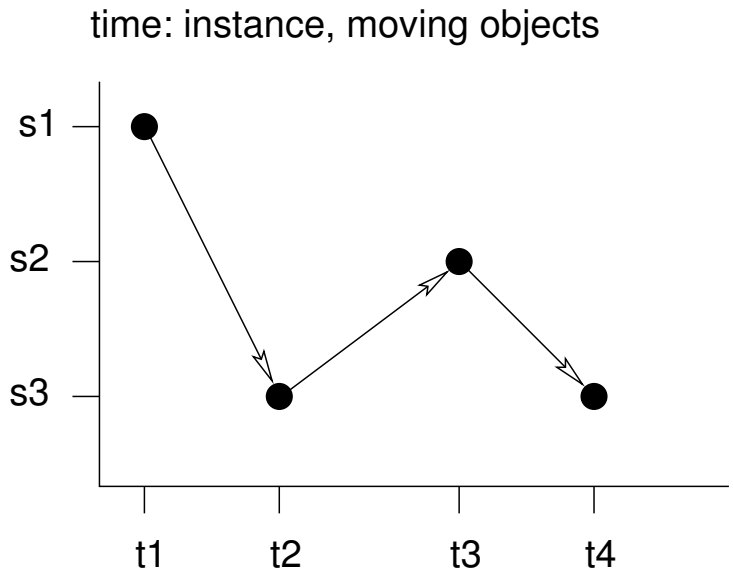
Goals of `spacetime`

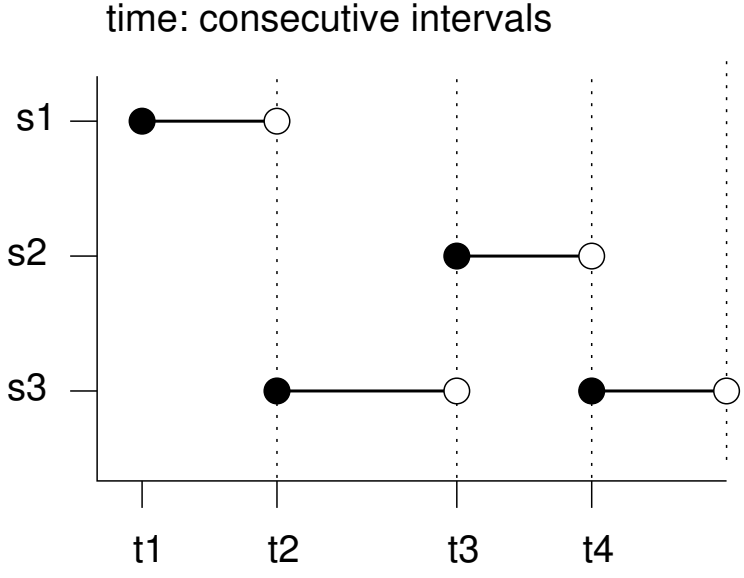
Provide classes and methods for a wide range of spatio-temporal data.
Methods include

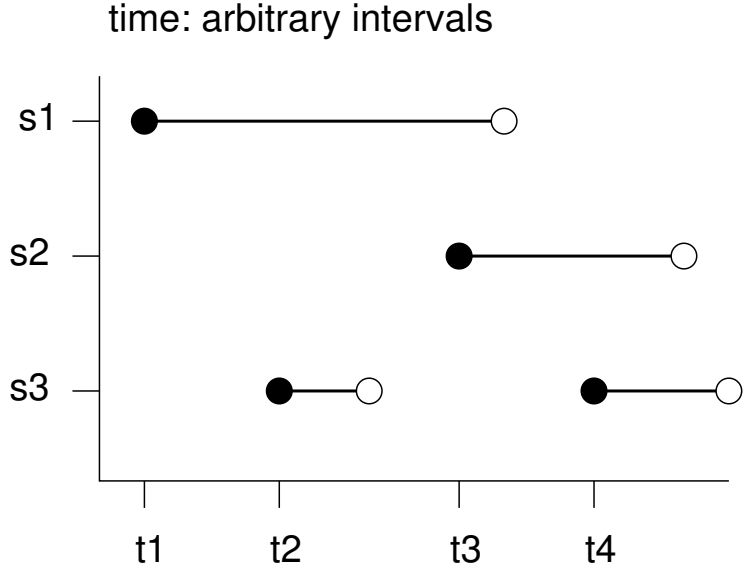
- `stConstruct`, construction from long, space-wide, or time-wide tables, and from `xts` or `Spatial*` objects
- selection using `[`, potentially resulting in `xts` or `Spatial*` objects
- coercion to/from `Spatial*`, `xts`, `zoo`, `stpp`, `RasterStack`, ...
- "pass on" `na.omit`, `na.interp`, `aggregate` etc.
- spatio-temporal `over` and `aggregate`
- plotting
- interface with `raster`, `grass`, `sos4R`, ...

time instance, intervals, movement

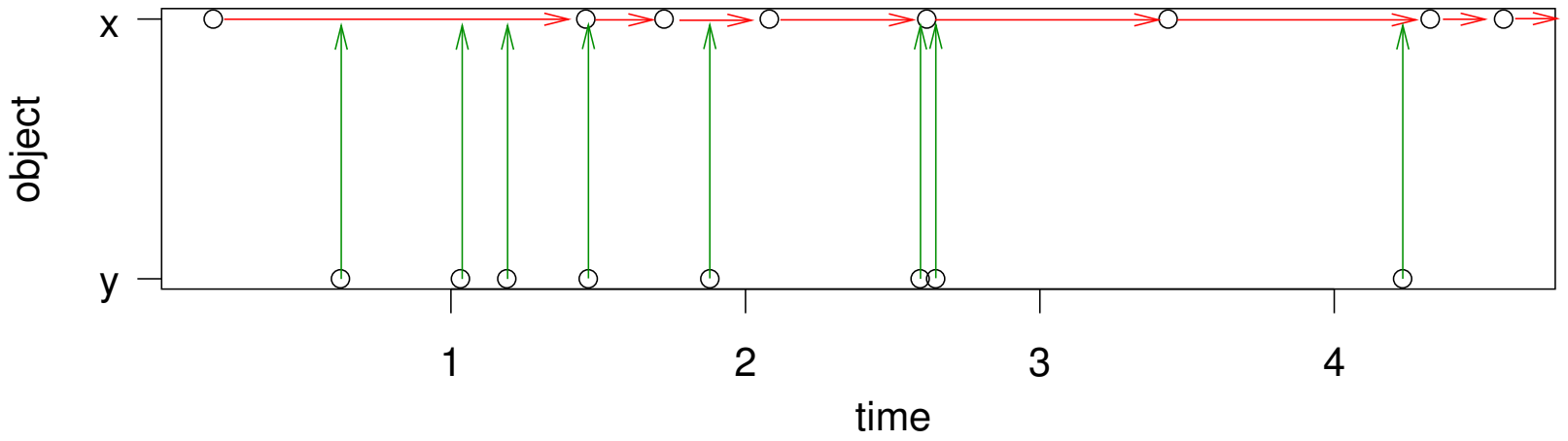








matching time & time intervals



Spatio-temporal statistics

- See task view on CRAN for overview of packages
- Spatio-temporal geostatistics:
  - how dense is our data in {space, time}?
  - st covariance models: anisotropy, seperable, metric, product-sum, sum-metric; st asymmetry;
  - explicit formulation of dynamics through (S)PDE's – often use Kalman filtering, MCMC, or INLA
- Spatio-temporal point patterns:
  - separability vs ST interactions,
  - first- (density) and second-order (K-function) separability, stationarity or inhomogeneity.
- Spatio-temporal lattice data: e.g. spatial panel models (econometrics), disease clusters, epidemiology (`surveillance`)
- Trajectory analysis: visual analytics, clustering (knowledge discovery), classifying activities, home range estimation, time geography and alibi problems.

Exercise:

1. run the commands in vignette `jss816` in package `spacetime`
2. run the commands in vignette `st` in package `gstat`
3. run the commands in the vignette `stpp` in package `stpp` (this is harder; hint: look up the JSTATSOFT paper)