Types of Spatial Data

Bayesian modelling for spatial and spatio-temporal data

MSc in Epidemiology

Week 6

Terminology

- The data are seen as being a realization of a stochastic process, that is, of a set of random numbers each of which is associated with a spatial location.
- A spatial process in d dimensions is denoted as:

$$\{Z(\boldsymbol{s}) : \boldsymbol{s} \in \mathcal{D} \subset \mathbb{R}^d\}$$

where

- Z is the attribute we observe (e.g. temperature, number of sudden infant deaths etc.)
- $\boldsymbol{s}$ is the location where Z is observed (e.g. coordinates such as latitude and longitude)
- $\mathcal{D}$ is the domain, and it is called the *index set* = possible locations

Symbols are as follows: $\{\}$ a set (a collection of elements); $\in$ element of or belongs to; $\subset$ subset of; $\mathbb{R}$ real numbers set

Type of spatial data

Cressie (1993) distinguishes three types of spatial data, based on the nature of the spatial domain $\mathcal{D}$:

- Areal data (also known as lattice data): $\mathcal{D}$ is fixed (of regular or irregular shape) and partitioned into a finite number of areal units (e.g. census tract, pixels) with well-defined boundaries.
- Geostatistical (or point-referenced) data: $\mathcal{D}$ is a continuous fixed set. By continuous we mean that $Z(\boldsymbol{s})$ can be observed everywhere within $\mathcal{D}$. By fixed we mean that the points in $\mathcal{D}$ are non-stochastic.
- Point pattern data: $\mathcal{D}$ is itself random. Its index set gives the locations of random *events* that are the spatial point pattern.

Example of areal data [1]

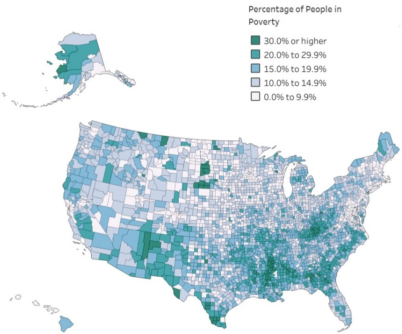


Figure: Percentage of people in poverty by County: 2015-2019. Source: American Community Survey 2015-2019 5-Year Data Release.

- This figure is an example of a ***choropleth map***, which uses shades of color (or grey scale) to classify the values of the variable that we are mapping into classes.
- The "sites" $\boldsymbol{s} \in \mathcal{D}$ in this case are actually the polygons themselves.

Example of areal data [2]

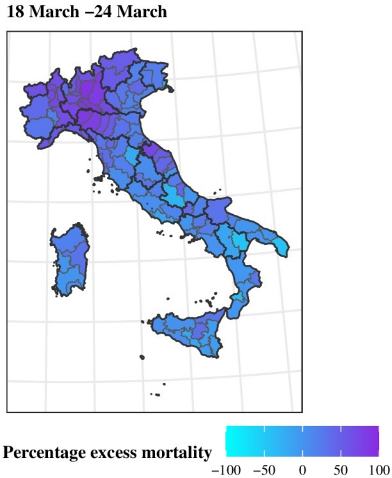


Figure: Map of the percent excess mortality for the 107 Italian provinces during the first wave of Covid-19 pandemic. Epidemiological week 18-24 March, 2020; males.

Example of regular lattice data [3]

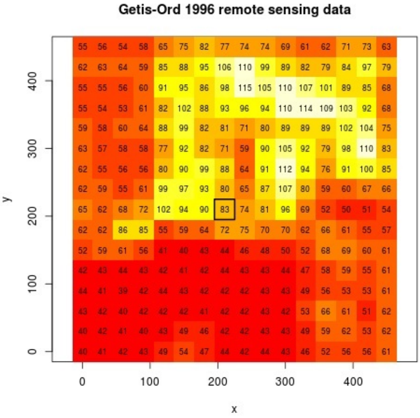


Figure: Regular lattice: Getis-Ord remote sensing example data (from package `spdep`).

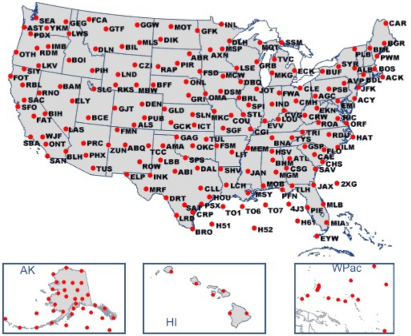


Figure: Map of wind and temperature stations in US (2019).

The data are gathered at a discrete set of points in an region of interest ($\mathcal{D}$), with the aim of understanding the behaviour of an unobserved, spatially continuous phenomenon that exists throughout that region and could, in principle, be observed at any point in $\mathcal{D}$.

Example of geostatistical data [2]

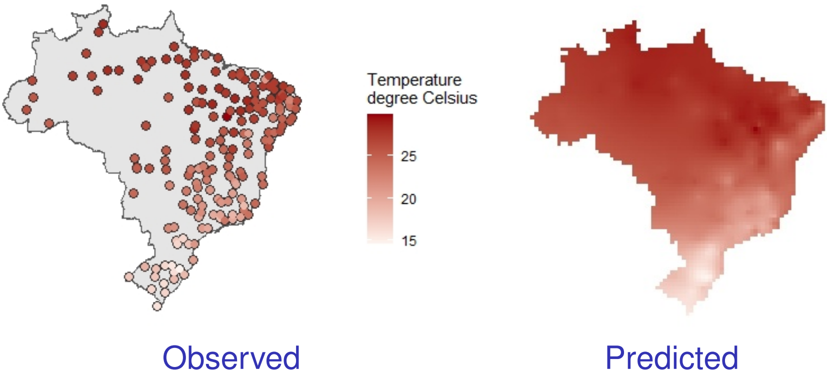


Figure: Average air temperature in degree Celsius (March-November 2018)

We can reconstruct a surface from the finite set of observations taken at a finite number of spatial locations.

Examples of point pattern data [1]

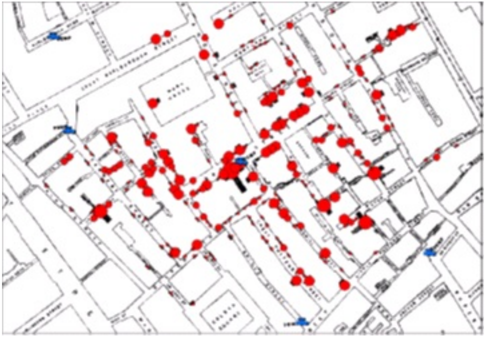


Figure: John Snow's map of the 1854 London cholera outbreak

In 1854, cholera hit the city of London. No one knew where the disease started. So, British physician John Snow started mapping the outbreak. The question of primary interest is whether, and if so where and when, statistically unusual local concentrations of cases occur.

Examples of point pattern data [2]

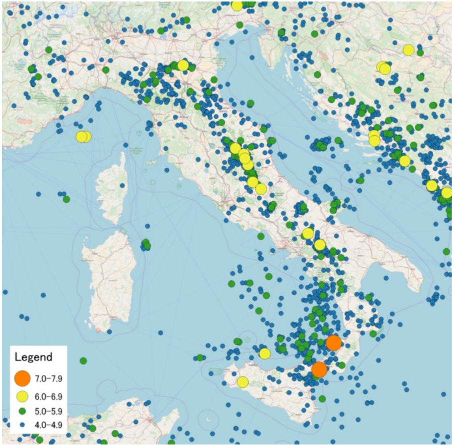


Figure: Location of earthquakes in Italy 1900-2017 (moment magnitude scale). Source: Wikipedia.

Data we will work with

In this module, we will work with:

- Areal or lattice data
- Geostatistical or spatial-referenced data

The are two fundamental distinctions: spatial vector data and raster.

- Vector represents the world using points, lines and polygons or combinations of those, where:
  - *Point*, is a single point location, such as a geocoded address or a temperature sensor or the location of a bus stop;
  - *Line*, is a set of ordered points, connected by straight line segments such as route travel or connections between locations;
  - *Polygon*, is an area, marked by one or more enclosing lines such as local authority districts or census tracts.

Simple features, `sf` package (Pebesma 2018) support 17 geometry types. Of these, 7 are used in the vast majority of geographic research:

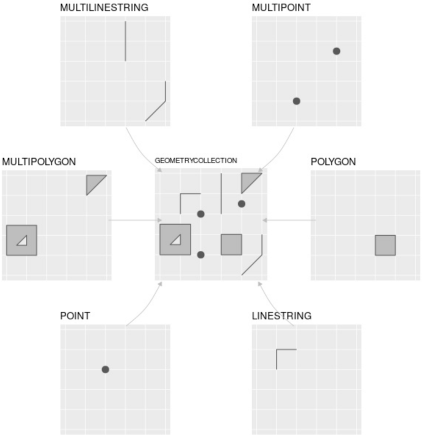
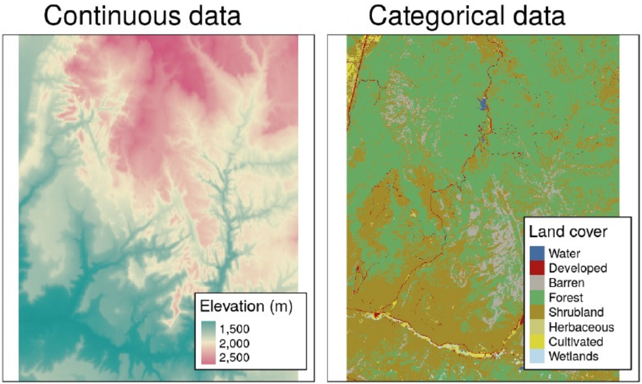


Figure: Core geometry types supported by the R package sf. Source: Lovelace et al. (2019); Section 2.2.

Spatial data in R: Rasters

- Raster: divides the surface into cells (also called pixels) of constant size. Each cell has a value associated with it, which might be numeric or categorical.
    - Raster maps usually represent continuous phenomena such as elevation, temperature, population density.
    - Raster data are the basis of images used in web-mapping and have been a source of data since the origins of aerial photography and satellite-based remote sensing devices.

Examples of continuous and categorical raster data.



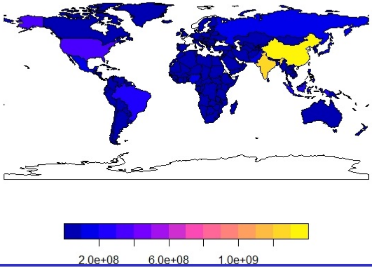
Source: Lovelace et al. (2019); Section 2.3

Some R packages we will start to work with in week 6

- `sf`, which is a recently developed package for spatial vector data (points, lines, polygons etc.) and combines the functionality of three previous packages `sp`, `rgeos` and `rgdal`. It refers to a formal standard that describes how objects in the real world can be represented in computers, with emphasis on the spatial geometry of these objects
- `sp`, which precedes `sf`, and with the `rgdal` and `rgeos` package, it creates a powerful tool to works with spatial data. Many R packages still depends on the `sp` package
- `spdep`, which includes functions and tests for evaluating spatial patterns and autocorrelation
- `tidyverse`, which is a coherent system of packages for data manipulation, exploration and visualization
- `ggplot2`, `tmap` and `mapview` for visualization and maps
- `SpatialEpi`, which provides methods for spatial epidemiology

Many spatial R packages still depends on the `sp`, thus it is important to know how to convert `sp` to and from `sf` objects

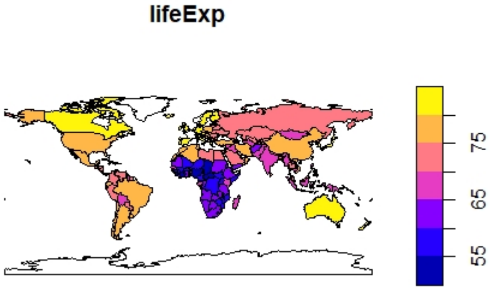
```
library(spData); library(sf); library(tidyverse)

# world is a sf object containing a world map data
# from Natural Earth with a few variables from World Bank
world <- st_read(system.file("shapes/world.gpkg", package="spData"))
plot(world["pop"])                  # plot world population

world_sp <- as(world, "Spatial")   # from sf to sp object
class(world_sp)                     # "SpatialPolygonsDataFrame"

world_sf <- st_as_sf(world_sp)     # from sp to sf object
class(world_sf)                     # "sf"  "data.frame"
```



`sf` works well with the `tidyverse` collection of R packages.

For example, functions can be combined using the pipe operator $\% > \%$ (given that both packages are loaded)

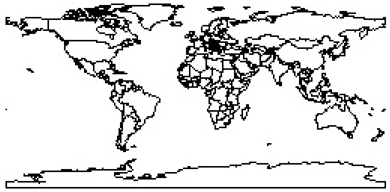
```
# Select and plot information for a single attribute
world %>% select(lifeExp) %>% plot()
```



`sf` object includes spatial metadata like the coordinate reference system (CRS), which are stored in a list column.

We can extract and plot only the geometry with the function *st_geometry*()

```
# Extract geometry
worlg_geo <- st_geometry(world)

# Extract and plot out only the geometries
world %>% st_geometry() %>% plot()
```



Articles and books cited in this lecture

Cressie, N. (1993), *Statistics for Spatial Data*, John Wiley & Sons, Inc.

Lovelace, R., Nowosad, J., and Muenchow, J. (2019), *Geocomputation with R*, CRC Press, the online version of the book is at http://geocompr.robinlovelace.net/.

Pebesma, E. (2018), "Simple Features for R: Standardized Support for Spatial Vector Data," *The R Journal*, 10, 2073–4859, https://journal.r-project.org/archive/2018/RJ-2018-009/RJ-2018-009.pdf.