Spatial Data

R for Advanced Stata Users

Luiza Andrade, Rob Marty, Rony Rodriguez-Ramirez, Luis Eduardo San Martin, Leonardo Viotti
DIME |The World Bank

07 December 2021

Table of contents

Setting the stage

Setting the stage

Install new packages

```
install.packages(c("sf",
                   "rworldmap",
                   "ggmap",
                   "wesanderson"),
                 dependencies = TRUE)
```

And load them

```
library(here)
library(tidyverse)
library(sf)
library(rworldmap)
library(ggmap)
library(wesanderson)
```

Setting the stage

Datasets we will use today

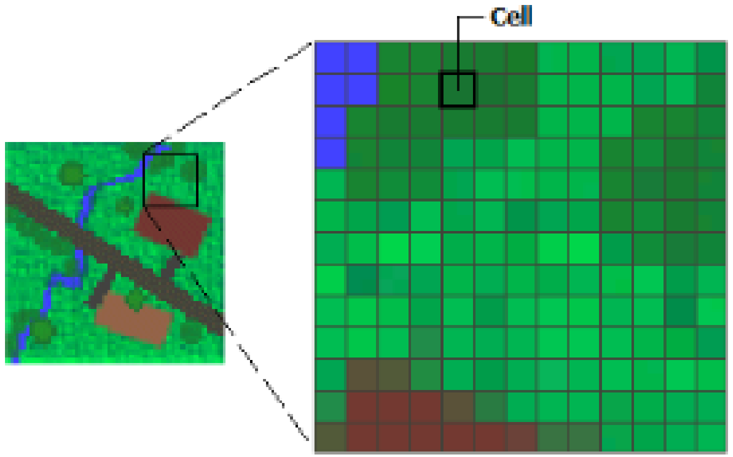
```
# Load data
whr_panel   <- read_rds(here("DataWork",
                             "DataSets",
                             "Final",
                             "whr_panel.RDS"))

wb_projects <- read_csv(here("DataWork",
                             "DataSets",
                             "Final",
                             "wb_projects.csv"))
```

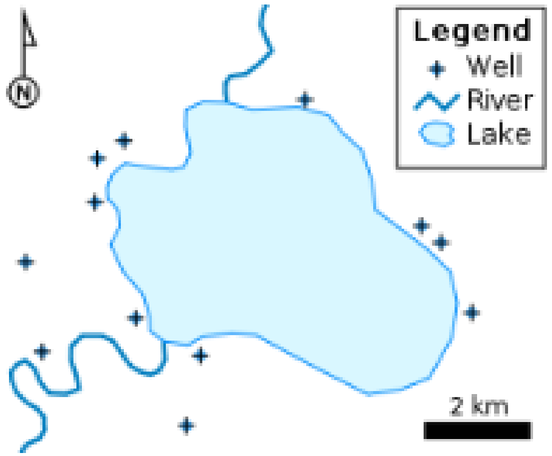
Introduction

Introduction

There are two main types of spatial data: vector and raster data.

- **Raster:** spatially-referenced grids where each cell has one value.
- **Vectors or shapefiles:** spatial-referenced objects consisting of points, lines and polygons. These shapes are attached to a dataframe, where each row corresponds to a different spatial element.





Introduction

- This session could be a whole course on its own, but we only have an hour and half.
- To narrow our subject, we will focus on only one type of spatial data, shapefiles.
- This is the most common type of spatial data that non-GIS experts will encounter in their work.
- We will focus mostly on how to visualize spatial data, although we will also cover some simple geometry operations.
- We will use the `sf` package, which is the tidyverse-compatible package for geospatial data in R.
- If you want to know more about geospatial data in R, we recommend the book https://geocompr.robinlovelace.net/, by Robin Lovelace, Jakub Nowosad, and Jannes Muenchow.

Loading a shapefile with sf

The first thing we will do in this session is to recreate this data set:

```
worldmap <-
  st_read(here("DataWork",
               "DataSets",
               "Final",
               "worldmap.shp"))
```

```
## Reading layer `worldmap' from data source `C:\WBG\Repos\dime-r-training\DataWork\DataSets\Final\worldmap.shp' using d
## Simple feature collection with 244 features and 15 fields
## geometry type:  MULTIPOLYGON
## dimension:      XY
## bbox:           xmin: -180 ymin: -89.9989 xmax: 180 ymax: 83.5996
## geographic CRS: WGS 84
```

```
plot(worldmap)
```

Exploring the data

Creating a polygon shapefile

Loading spatial data

Load a built-in map using the `rworldmap` package

```
worldmap <- getMap(resolution="low")
```

Look at the data structure

```
View(worldmap)
```

This object is a list with three main components:

- Data
- Polygons
- Projection

Spatial data structure: the data

- The data portion of a shapefile is a data frame like any other in R.
- To access it, we need to refer to the data element in our list by typing `objectname@data`.

Exercise ⌨

Explore the dataset in `worldmap` using the functions `head()` and `names()`.

```
names()
```

Spatial data structure: the data

- The data portion of a shapefile is a data frame like any other in R.
- To access it, we need to refer to the data element in our list by typing `objectname@data`.

Exercise ⌨

Explore the dataset in `worldmap` using the functions `head()` and `names()`.

```
names(worldmap@data)
```

```
##  [1] "ScaleRank"    "LabelRank"    "FeatureCla"   "SOVEREIGNT"   "SOV_A3"
##  [6] "ADM0_DIF"     "LEVEL"        "TYPE"         "ADMIN"        "ADM0_A3"
## [11] "GEOU_DIF"     "GEOUNIT"      "GU_A3"        "SU_DIF"       "SUBUNIT"
## [16] "SU_A3"        "NAME"         "ABBREV"       "POSTAL"       "NAME_FORMA"
## [21] "TERR_"        "NAME_SORT"    "MAP_COLOR"    "POP_EST"      "GDP_MD_EST"
## [26] "FIPS_10_"     "ISO_A2"       "ISO_A3"       "ISO_N3"       "ISO3"
## [31] "LON"          "LAT"          "ISO3.1"       "ADMIN.1"      "REGION"
## [36] "continent"    "GEO3major"    "GEO3"         "IMAGE24"      "GLOCAF"
## [41] "Stern"        "SRESmajor"    "SRES"         "GBD"          "AVOIDnumeric"
```

Spatial data structure: the data

```
head(worldmap@data)
```

```
##   ScaleRank LabelRank        FeatureCla     SOVEREIGNT SOV_A3 ADM0_DIF LEVEL
## 1         3         3 Admin-0 countries    Netherlands    NL1        1     2
## 2         1         1 Admin-0 countries    Afghanistan    AFG        0     2
## 3         1         1 Admin-0 countries         Angola    AGO        0     2
## 4         1         1 Admin-0 countries United Kingdom    GB1        1     2
## 5         1         1 Admin-0 countries        Albania    ALB        0     2
## 6         3         3 Admin-0 countries        Finland    FI1        1     2
##                TYPE       ADMIN ADM0_A3 GEOU_DIF     GEOUNIT GU_A3 SU_DIF
## 1           Country       Aruba     ABW        0       Aruba   ABW      0
## 2 Sovereign country Afghanistan     AFG        0 Afghanistan   AFG      0
## 3 Sovereign country      Angola     AGO        0      Angola   AGO      0
## 4        Dependency    Anguilla     AIA        0    Anguilla   AIA      0
## 5 Sovereign country     Albania     ALB        0     Albania   ALB      0
## 6           Country       Aland     ALD        0       Aland   ALD      0
##       SUBUNIT SU_A3        NAME ABBREV POSTAL                  NAME_FORMA
## 1       Aruba   ABW       Aruba  Aruba     AW                        <NA>
## 2 Afghanistan   AFG Afghanistan   Afg.     AF Islamic State of Afghanistan
## 3      Angola   AGO      Angola   Ang.     AO          Republic of Angola
## 4    Anguilla   AIA    Anguilla   Ang.     AI                        <NA>
## 5     Albania   ALB     Albania   Alb.     AL         Republic of Albania
## 6       Aland   ALD       Aland  Aland     AI               Eland Islands
##   TERR_   NAME_SORT MAP_COLOR  POP_EST GDP_MD_EST FIPS_10_ ISO_A2 ISO_A3 ISO_N3
## 1 Neth.       Aruba         9   103065     2258.0     <NA>     AW    ABW    533
## 2  <NA> Afghanistan         7 28400000    22270.0     <NA>     AF    AFG      4
## 3  <NA>      Angola         1 12799293   110300.0     <NA>     AO    AGO     24
## 4  U.K.    Anguilla         3    14436      108.9     <NA>     AI    AIA    660
## 5  <NA>     Albania         6  3639453    21810.0     <NA>     AL    ALB      8
## 6  Fin.       Aland         6    27153         NA     <NA>    -99    ALA    248
```

Spatial data structure: the data

We can treat the data in a geospatial object just like any other data frame

Exercise ⌨

Use the command `select()` from tidyverse's `dplyr` package to keep only the following variables in the `worldmap` data: `ADMIN, REGION, continent, POP_EST, GDP_MD_EST`.

```
worldmap@data <-
  worldmap@data %>%
  select(ADMIN, REGION, continent, POP_EST, GDP_MD_EST)
```

Spatial data structure: the data

We can treat the data in a geospatial object just like any other data frame

Exercise ⌨

Explore the `worldmap` data using `summary()`.

```
summary()
```

Spatial data structure: the data

We can treat the data in a geospatial object just like any other data frame

Exercise ⌨

Explore the `worldmap` data using `summary()`.

```
summary(worldmap@data)
```

```
##              ADMIN                   REGION           continent
##  Afghanistan    :  1   Europe       :65   Africa       : 57
##  Aland          :  1   Africa       :57   Antarctica   :  1
##  Albania        :  1   Asia         :45   Australia    : 26
##  Algeria        :  1   South America:44   Eurasia      :110
##  American Samoa:  1   Australia    :26   North America:  3
##  Andorra        :  1   (Other)      : 4   South America: 44
##  (Other)        :238   NA's         : 3   NA's         :  3
##     POP_EST              GDP_MD_EST
##  Min.   :0.000e+00   Min.   :       0
##  1st Qu.:2.507e+05   1st Qu.:    2329
##  Median :4.489e+06   Median :   20775
##  Mean   :2.793e+07   Mean   :  292888
##  3rd Qu.:1.557e+07   3rd Qu.:  116050
##  Max.   :1.339e+09   Max.   :14260000
##  NA's   :1           NA's   :6
```

Spatial data structure: polygons

```
plot(worldmap)
```

Spatial data structure: projection

```
worldmap@proj4string
```

```
## CRS arguments:
##  +proj=longlat +ellps=WGS84 +datum=WGS84 +no_defs
```

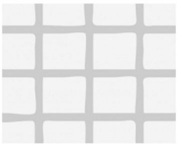
Click here to see why Josh and CJ are confused

Spatial data structure: projection

Coordinate reference systems map pairs of numbers to a location.

- **Geographic Coordinate Systems** live on a sphere; here, the units are in decimal degrees (latitude = angle from equator; longitude = angle from prime meridian)
  - Using the WGS84 coordinate system the World Bank MC building is located at 38.89 degrees latitude and -77.04 degrees longitude.
- **Projected Coordinate Systems** project the earth onto a flat surface (units here are typically in meters from some reference point).
  - Using to the World Mercator projection, the World Bank is located 4680364.64 meters north and -8576320.73 meters east.

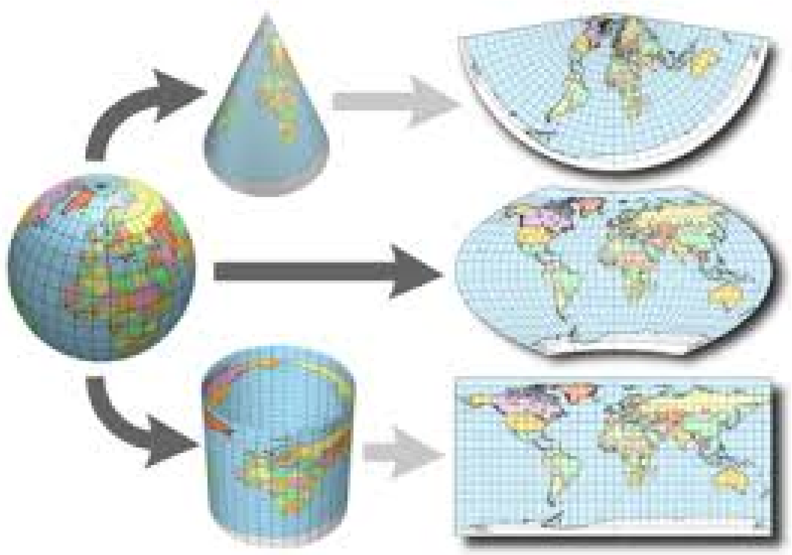
Geographic (3D)



Projected (2D)

Spatial data structure: projection

Projecting the earth onto a flat surface distorts distorts the earth in some way (shape, area, distance or direction).



> Projections are also the main source of error when plotting spatial data: if two spatial objects have different reference systems, plotting them together will result in quite weird maps

Projecting spatial data in sf

Creating an sf object

The `sf` package deals with spatial data in a special way: it allows as to treat it as a regular data frame, while maintaining its spatial component.

st_as_sf(x)

Transforms objects into `sf` objects

- **...:** the object to be transformed

Exercise ⌨

Turn the `worldmap` object into an `sf` object.

```
st_as_sf()
```

Creating an sf object

The `sf` package deals with spatial data in a special way: it allows as to treat it as a regular data frame, while maintaining its spatial component.

st_as_sf(x)

Transforms objects into `sf` objects

- **...:** the object to be transformed

Exercise ⌨

Turn the `worldmap` object into an `sf` object.

```
worldmap <-
  st_as_sf(worldmap)
```

Creating an sf object

```
class(worldmap)
```

```
## [1] "sf"         "data.frame"
```

```
summary(worldmap)
```

```
##             ADMIN                  REGION            continent
##  Afghanistan   :  1   Europe       :65   Africa       : 57
##  Aland         :  1   Africa       :57   Antarctica   :  1
##  Albania       :  1   Asia         :45   Australia    : 26
##  Algeria       :  1   South America:44   Eurasia      :110
##  American Samoa:  1   Australia    :26   North America:  3
##  Andorra       :  1   (Other)      : 4   South America: 44
##  (Other)       :238   NA's         : 3   NA's         :  3
##     POP_EST              GDP_MD_EST                 geometry
##  Min.   :0.000e+00   Min.   :        0   MULTIPOLYGON :244
##  1st Qu.:2.507e+05   1st Qu.:     2329   epsg:NA      :  0
##  Median :4.489e+06   Median :    20775   +proj=long...:  0
##  Mean   :2.793e+07   Mean   :   292888
##  3rd Qu.:1.557e+07   3rd Qu.:   116050
```

Creating an sf object

```
plot(worldmap)
```

Projections in sf

Here are two useful `sf` commands:

st_crs(x)

Displays the current projection of an `sf` object

st_transform(x, crs)

Projects object **x** using projection **crs**

Projections in sf

Exercise ⌨

Create two objects derived from `worldmap`, but with different projections:

- Use the Mollweid projection (`crs` = `"+proj=moll"`) to create `worldmap_moll`
- Use the Mercator projection (`crs` = `"EPSG:3857"`) to create `worldmap_mercator`

```
worldmap_moll <-
worldmap_mercator <-
```

Projections in sf

Exercise ⌨

Create two objects derived from `worldmap`, but with different projections:

- Use the Mollweid projection (`crs` = `"+proj=moll"`) to create `worldmap_moll`
- Use the Mercator projection (`crs` = `"EPSG:3857"`) to create `worldmap_mercator`

```
worldmap_moll <-
  worldmap %>%
  st_transform("+proj=moll")

worldmap_mercator <-
  worldmap %>%
  st_transform("EPSG:3857")
```

Projections in sf

```
worldmap_moll %>%
  select(REGION) %>%
  plot()

worldmap_mercator %>%
  select(REGION) %>%
  filter(REGION != "Antarctica") %>%
  plot()
```

> Why did I use `select` above?

Projections in sf

Projections in sf

Visualizing polygons

Combining non-spatial and spatial data

- To create the `worldmap` shapefile that you have in your final data folder, we combined the data in `whr_panel` and the polygon in `worldmap`. Given what we have seen, this is as simple as joining two data sets

We need to make a few adjustment to the data so the join works:

```
worldmap <-
  worldmap %>%
  mutate(country = as.character(ADMIN),
         country = str_replace_all(country, "United States of America", "United States"),
         country = str_replace_all(country, "Northern Cyprus", "North Cyprus"),
         country = str_replace_all(country, "Hong Kong S.A.R.", "Hong Kong"),
         country = str_replace_all(country, "Republic of Serbia", "Serbia"),
         country = str_replace_all(country, "Somaliland", "Somaliland Region"),
         country = str_replace_all(country, "West Bank", "Palestinian Territories"),
         country = str_replace_all(country, "Democratic Republic of the Congo", "Congo (Kinshasa)"),
         country = str_replace_all(country, "Republic of the Congo", "Congo (Brazzaville)"),
         country = str_replace_all(country, "United Republic of Tanzania", "Tanzania"))

whr_panel <-
  whr_panel %>%
  filter(year == 2015)
```

Then we can join them:

```
worldmap <-
  worldmap %>%
  left_join(whr_panel)
```

Visualizing polygons

- `ggplot` has a special geometry for `sf`: `geom_sf`
- `geom_sf` takes into account the spatial features to maintain proportions

```
ggplot(worldmap) +
  geom_sf()
```

Visualizing polygons

Visualizing polygons

Exercise ⌨

Use the `fill` aesthetics inside `geom_sf` to show the happiness score in the map.

```
ggplot(worldmap) +
  geom_sf()
```

Visualizing polygons

Exercise ⌨

Use the `fill` aesthetics inside `geom_sf` to show the happiness score in the map.

```
ggplot(worldmap) +
  geom_sf(aes(fill = happiness_score))
```

Visualizing polygons

Visualizing polygons

Exercise ⌨

Use the `fill` aesthetics inside `geom_sf` to show the happiness score in the map.

```
ggplot(worldmap %>%
         filter(REGION != "Antarctica")) +
  geom_sf(aes(fill = happiness_score)) +
  labs(fill = "Happiness Score") +
  scale_fill_gradient(low = "blue",
                      high = "yellow") +
  theme_void() +
  theme(legend.position = "top")
```

Visualizing polygons

Visualizing points

Visualizing points

When you have GPS coordinates, using `ggplot` to map them is very easy: use `geom_points` and link `x` to the longitude variable and `y` to the latitude variable.

Exercise ⌨

Create a scatter plot of the projects in the `wb_projects` dataset.

```
ggplot() +
  geom_point(aes(x = ,
                 y = ))
```

Visualizing points

When you have GPS coordinates, using `ggplot` to map them is very easy: use `geom_points` and link `x` to the longitude variable and `y` to the latitude variable.

Exercise ⌨

Create a scatter plot of the projects in the `wb_projects` dataset.

```
ggplot() +
   geom_point(data = wb_projects,
              aes(x = longitude,
                  y = latitude)
```

Visualizing points

Visualizing points

```
ggplot() +
   geom_point(data = wb_projects,
              aes(x=longitude,
                  y=latitude),
              size = .1) + # Smaller dots
  coord_quickmap() + # Correct distortion
  theme_void() # Clean background
```

Visualizing points

Adding a basemap

The package `ggmap` allows us to layers as a basemap. The code is the same as `ggplot`, except here we start the code with `ggmap()` instead of `gplot()`.

Here is how we can retrieve basemaps:

```
# Create an object with Africa only
africa <-
  worldmap %>%
  filter(REGION == "Africa")

# Calculate which part of the world we want images for
# (this is called a bounding box)
africa_box <-
  st_bbox(africa)

# Save the basemap
africa_basemap <-
  get_stamenmap(as.vector(africa_box),
                zoom = 3, # The higher the zoom, the more details you get
                maptype = "watercolor")
```

Adding a basemap

```
ggmap(africa_basemap)
```

Customizing basemaps

You can also use other image sources than Stamen Maps with the `get_map` function:

- Google Maps (`"google"`), OpenStreetMap (`"osm"`), Stamen Maps (`"stamen"`)

Here are a few other map types you can use with `get_stamenmap`:

- `"terrain"`, `"terrain-background"`, `"terrain-labels"`, `"terrain-lines"`, `"toner"`, `"toner-2010"`, `"toner-2011"`, `"toner-background"`, `"toner-hybrid"`, `"toner-labels"`, `"toner-lines"`, `"toner-lite"`, `"watercolor"`)

Finally, you can use the options `color` and `alpha` to change from black and white to color and increase transparency of the basemap.

Adding layers on top of a basemap

```
ggmap(africa_basemap) +
   geom_point(data = wb_projects,
              aes(x=longitude,
                  y=latitude),
              size = .1) +
  theme_void()
```

> Note that with `ggmap` we don't need the option `coord_quickmap`

Adding layers on top of a basemap

Combining our two maps

Now, instead of a basemap, let's layer these points on top of our hapiness score map.

```
ggplot() +
  geom_sf(data = africa,
          aes(fill = happiness_score)) +
  geom_point(data = wb_projects,
             aes(x = longitude,
                 y = latitude),
             size = .1) +
  labs(fill="Happiness\nScore") +
  scale_fill_gradient(low = "blue",
                      high = "yellow") +
  theme_void()
```

Combining our two maps

Why projections matter

Why projections matter

```
# Use a different projection for our Africa map
africa_moll <-
  st_transform(africa,
               "+proj=moll")

# And create the same graph from the last slide
ggplot() +
  geom_sf(data = africa_moll,
          aes(fill = happiness_score)) +
   geom_point(data = wb_projects,
              aes(x=longitude,
                  y=latitude)) +
  labs(fill="Happiness\nScore") +
  scale_fill_gradient(low = "blue",
                      high = "yellow") +
  theme_void()
```

Why projections matter

Transforming GPS data into a shapefile

- As we saw earlier, shapefiles can contain points, polygons or lines.
- So far, we have only use the `wb_projects` coordinates as if they were numbers like any others.
- To be able to change the projection of `wb_projects`, we need to convert it into a spatial object.

st_as_sf(x, coords, crs)

Transforms objects into `sf` objects

- **...**: the object to be transformed
- coords: a vector with the names of the variables in the data that indicate longitude and latitude, in this order
- crs: the coordinate reference system of the points in the data

Transforming GPS data into a shapefile

Exercise ⌨

Turn the `wb_projects` object into an `sf` object.

```
st_as_sf(x,
         coords = c("longitude_variable", "latitude_variable"),
         crs = 4326) # Shortcut to WGS84, the coordinate reference system used by most GPS
```

Transforming GPS data into a shapefile

Exercise ⌨

Turn the `wb_projects` object into an `sf` object.

```
wb_projects <-
  st_as_sf(wb_projects,
        coords = c("longitude", "latitude"),
        crs = 4326)
```

Matching projections

Exercise ⌨

Change the projection of the `wb_projects` object to Mollweid.

> Tip: use the CRS shortcut `"+proj=moll"`

```
wb_projects_moll <-
```

Matching projections

Exercise ⌨

Change the projection of the `wb_projects` object to Mollweid.

> Tip: use the CRS shortcut `"+proj=moll"`

```
wb_projects_moll <-
  st_transform(wb_projects,
               "+proj=moll")
```

Combining plots with the same projection

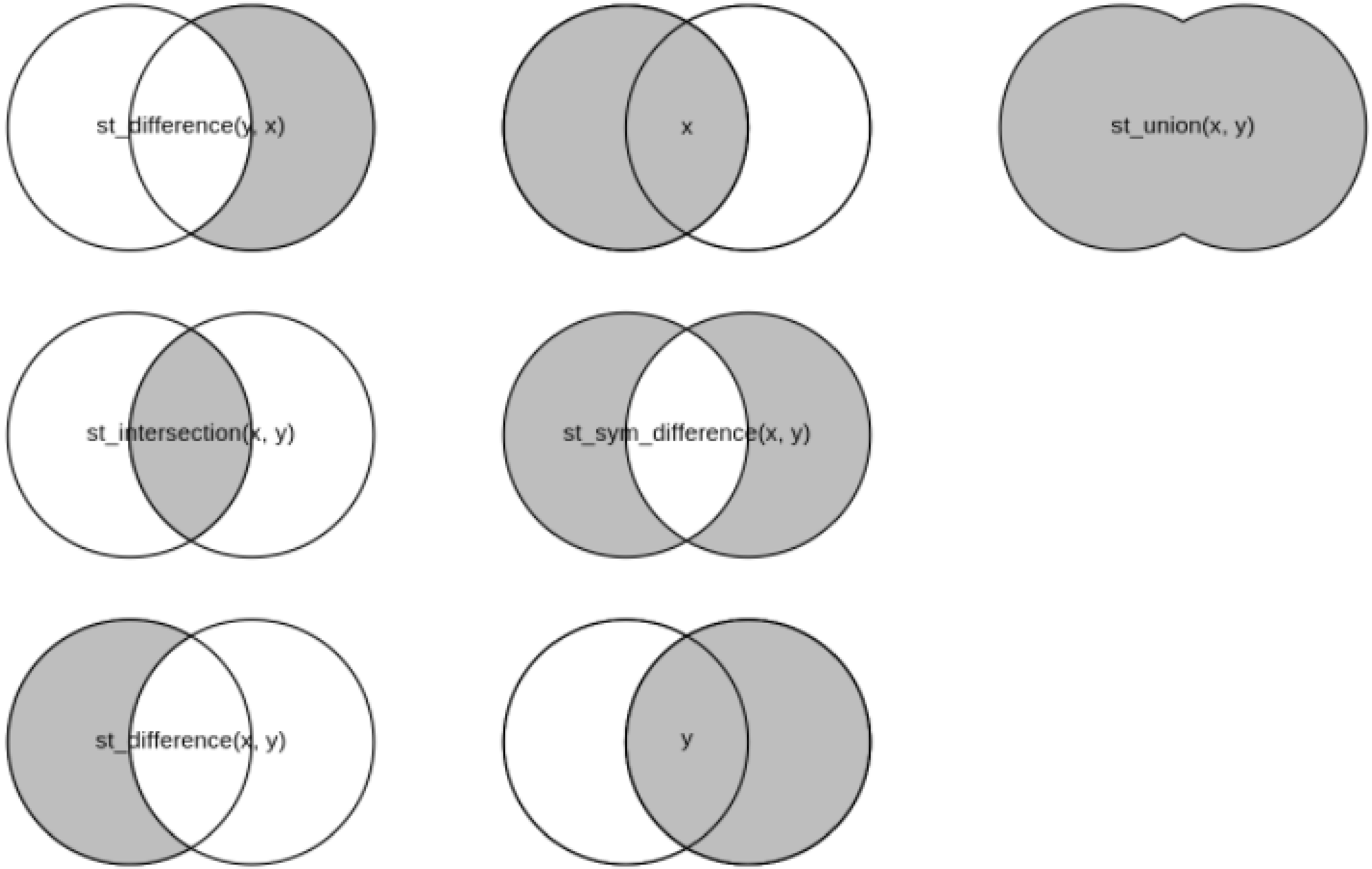
```
ggplot() +
  geom_sf(data = africa_moll,
          aes(fill = happiness_score)) +
  geom_sf(data = wb_projects_moll) +
  labs(fill="Happiness Score and WB Projects") +
  scale_fill_gradient(low = "blue",
                      high = "yellow") +
  theme_void()
```

Combining plots with the same projection

Basic geometry operations

Basic geometry operations

Here are some of the most common shapefile operations and their corresponding `sf` commands:



Final challenge

Exercise ⌨

Create a map of the World Bank projects in Mozambique

Here's some pseudo code:

```
# 1 Create a polygon of Mozambique by subsetting the worldmap sf
# 2 Make sure the Moz polygon and the wb_projects shapefile have the same projection
# 3 Create a shapefile containing only Moz projects using one of the sf functions in the previous image
# 4 Create a map with the resulting data and customize as you like
```

Final challenge

Useful Resources

- Rspatial provides tutorials for many topics in GIS.
- Nick Eubank Tutorials -- another great set of tutorials.
- This provides useful links to a bunch of other resources.
- Visualizing geospatial data
- Geocomputation with R

Thank you!