Untitled

Resources used:

https://r-spatial.org/r/2018/10/25/ggplot2-sf.html

R and Mapping

Current solutions for creating maps usually involves GIS software, such as ArcGIS, QGIS, eSpatial, etc., which allow to visually prepare a map, in the same approach as one would prepare a poster or a document layout. On the other hand, R, a free and open-source software development environment (IDE) that is used for computing statistical data and graphic in a programmable language, has developed advanced spatial capabilities over the years, and can be used to draw maps programmatically.

R is a powerful and flexible tool. R can be used from calculating data sets to creating graphs and maps with the same data set. R is also free, which makes it easily accessible to anyone. Some other advantages of using R is that it has an interactive language, data structures, graphics availability, a developed community, and the advantage of adding more functionalities through an entire ecosystem of packages. R is a scriptable language that allows the user to write out a code in which it will execute the commands specified.

Using R to create maps brings these benefits to mapping. Elements of a map can be added or removed with ease — R code can be tweaked to make major enhancements with a stroke of a key. It is also easy to reproduce the same maps for different data sets. It is important to be able to script the elements of a map, so that it can be re-used and interpreted by any user. In essence, comparing typical GIS software and R for drawing maps is similar to comparing word processing software (e.g. Microsoft Office or LibreOffice) and a programmatic typesetting system such as LaTeX, in that typical GIS software implement a WYSIWIG approach ("What You See Is What You Get"), while R implements a WYSIWYM approach ("What You See Is What You Mean").

The package `ggplot2` implements the grammar of graphics in R, as a way to create code that make sense to the user: The grammar of graphics is a term used to breaks up graphs into semantic components, such as geometries and layers. Practically speaking, it allows (and

forces!) the user to focus on graph elements at a higher level of abstraction, and how the data must be structured to achieve the expected outcome. While `ggplot2` is becoming the de facto standard for R graphs, it does not handle spatial data specifically. The current state-of-the-art of spatial objects in R relies on `Spatial` classes defined in the package `sp`, but the new package `sf` has recently implemented the "simple feature" standard, and is steadily taking over `sp`. Recently, the package `ggplot2` has allowed the use of simple features from the package `sf` as layers in a graph[1]. The combination of `ggplot2` and `sf` therefore enables to programmatically create maps, using the grammar of graphics, just as informative or visually appealing as traditional GIS software.

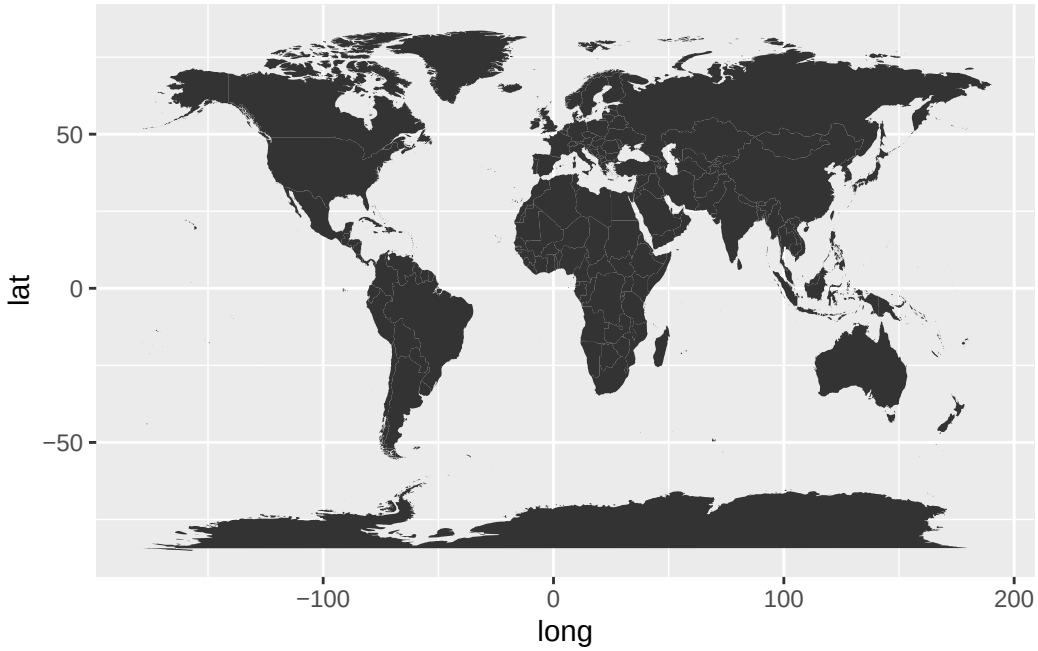
Mapping with ggplot

First, lets make some plots created with our old faithful, ggplot. THe data used for these plots comes with the tidyverse!

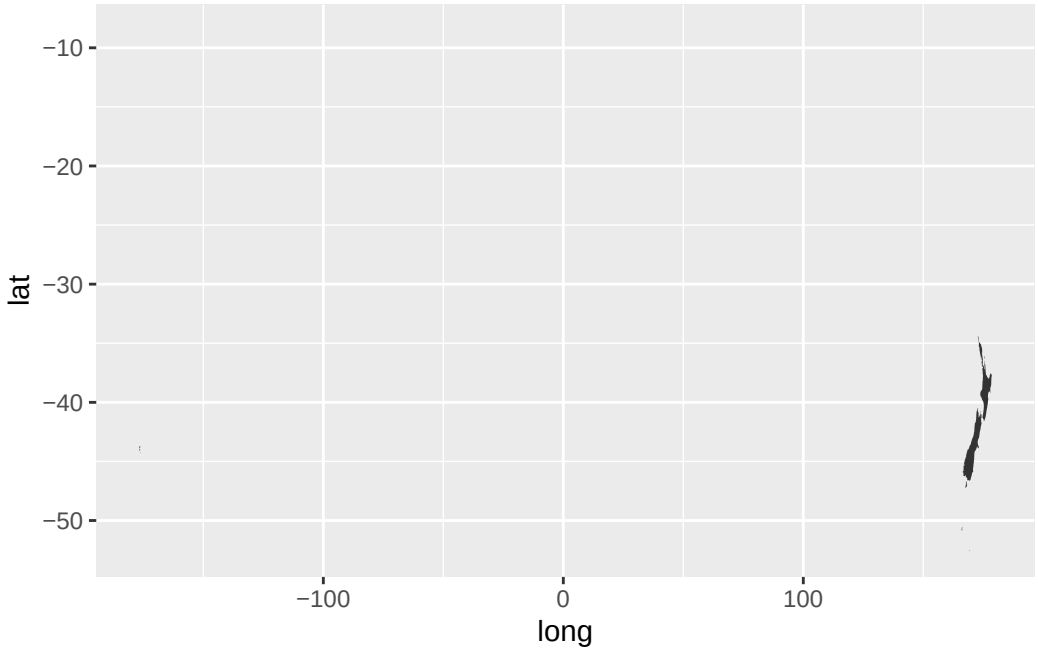
```
#'label: ggplot maps
library(tidyverse)
```

```
-- Attaching core tidyverse packages ------------------------ tidyverse 2.0.0 --
v dplyr     1.1.2     v readr     2.1.4
v forcats   1.0.0     v stringr   1.5.0
v ggplot2   3.4.2     v tibble    3.2.1
v lubridate 1.9.2     v tidyr     1.3.0
v purrr     1.0.1
-- Conflicts ------------------------------------------ tidyverse_conflicts() --
x dplyr::filter() masks stats::filter()
x dplyr::lag()    masks stats::lag()
i Use the conflicted package (<http://conflicted.r-lib.org/>) to force all conflicts to becor
```

```
# ggplot maps are static

# World map

map_data("world") |>
  ggplot(aes(long, lat, group = group)) +
  geom_polygon()
```




```r
# New Zealand map

world_map <- map_data("world", region = "New Zealand")

ggplot(world_map, aes(long, lat, group = group)) +
  geom_polygon()
```

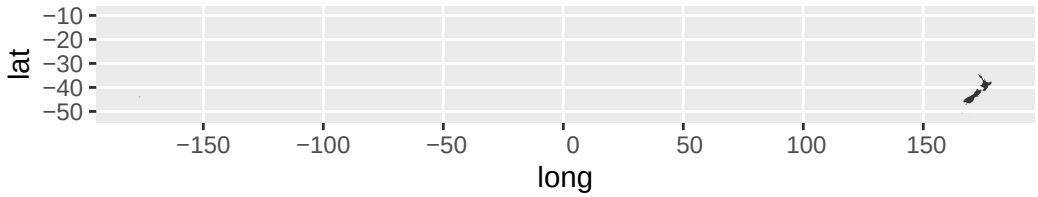


Although, we can make them more 'map-like' really quickly with a function we will look into more shortly.

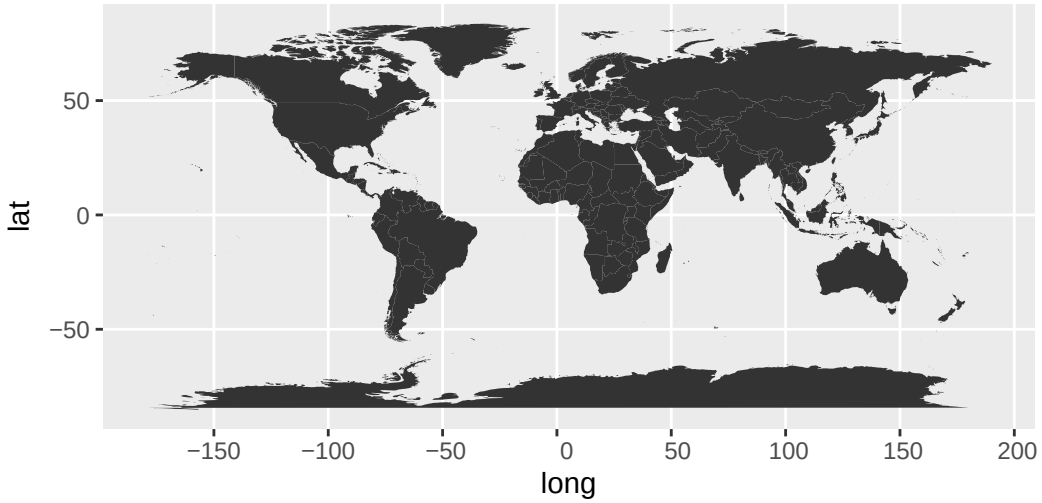
```
#|label: improving ggplot maps

library(sf)
```

```
Linking to GEOS 3.11.2, GDAL 3.6.2, PROJ 9.2.0; sf_use_s2() is TRUE
```

```
# fixing display using coord_sf from the sf package
ggplot(world_map, aes(long, lat, group = group)) +
  geom_polygon() +
  coord_sf()
```




```
map_data("world") |>
  ggplot(aes(long, lat, group = group)) +
  geom_polygon() +
  coord_sf()
```



Getting started

Many R packages are available from CRAN, the Comprehensive R Archive Network, which is the primary repository of R packages. The full list of packages necessary for this series of tutorials can be installed with:

```
install.packages(c("cowplot", "googleway", "ggplot2", "ggrepel",  "ggspatial", "libwgeom",


install.packages("cowplot")
install.packages("googleway")
install.packages("ggrepel")
install.packages("ggspatial")
install.packages("libwgeom")
install.packages("sf")
install.packages("rnaturalearth")
install.packages("rnaturalearthdata")
```

We start by loading the basic packages necessary for all maps, i.e. `ggplot2` and `sf`. We also suggest to use the classic dark-on-light theme for `ggplot2` (`theme_bw`), which is appropriate for maps:

```
#|label: load packages
library(ggplot2)
library(ggthemes)
library(sf)
```

The package `rnaturalearth` provides a map of countries of the entire world. Use `ne_countries` to pull country data and choose the scale (`rnaturalearthhires` is necessary for `scale = "large"`). The function can return `sp` classes (default) or directly `sf` classes, as defined in the argument `returnclass`:

Note that sf is preferred and sp is deprecated.

```
#|label: settomg up earth data

library("rnaturalearth")
```

```
The legacy packages maptools, rgdal, and rgeos, underpinning this package
will retire shortly. Please refer to R-spatial evolution reports on
https://r-spatial.org/r/2023/05/15/evolution4.html for details.
This package is now running under evolution status 0
```

```
Support for Spatial objects (`sp`) will be deprecated in {rnaturalearth} and will be removed
```

```
library("rnaturalearthdata")
```

```
Attaching package: 'rnaturalearthdata'
```

```
The following object is masked from 'package:rnaturalearth':

    countries110
```

```
world <- ne_countries(scale = "medium", returnclass = "sf")
nz <- ne_countries(country = "New Zealand", scale = "medium", returnclass = "sf")

class(world)  ## [1] "sf"   ## [1] "data.frame"
```

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

```
class(nz)
```

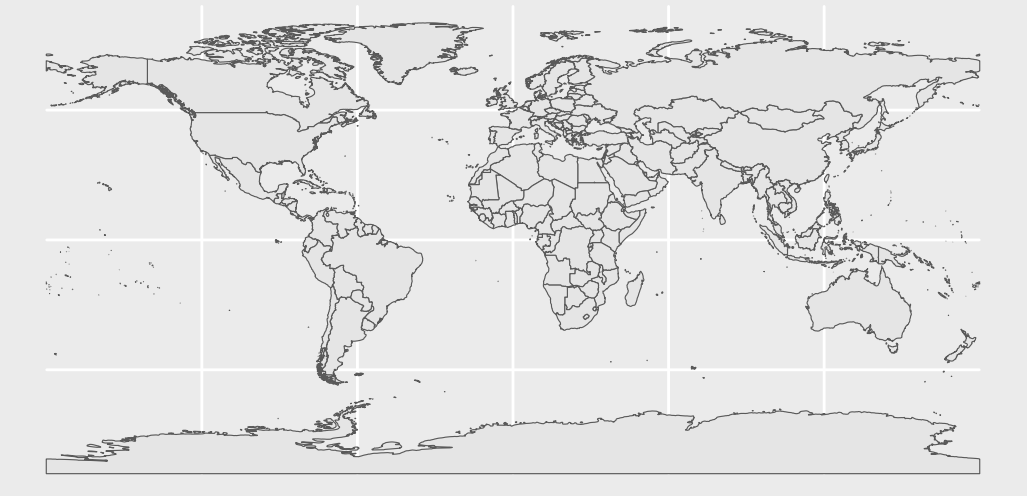
```
[1] "sf"         "data.frame"
```

General concepts illustrated with the world map

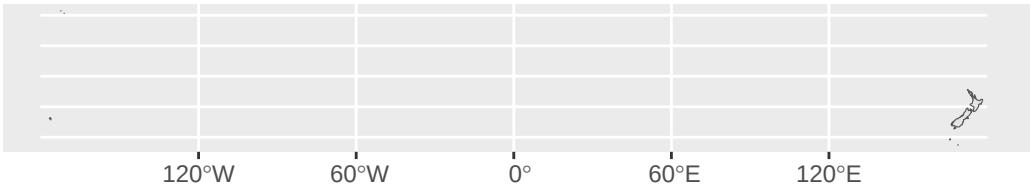
Data and basic plot (`ggplot` and `geom_sf`)

First, let us start with creating a base map of the world using `ggplot2`. This base map will then be extended with different map elements, as well as zoomed in to an area of interest. We can check that the world map was properly retrieved and converted into an `sf` object, and plot it with `ggplot2`:

```
#|label: basic ggplot sf map
ggplot(data = world) +     # this data is coming from the natural earth data
  geom_sf()
```



```
ggplot(data = nz) +     # this data is coming from the natural earth data
  geom_sf()
```



This call nicely introduces the structure of a `ggplot` call: The first part `ggplot(data = world)` initiates the `ggplot` graph, and indicates that the main data is stored in the `world` object. The line ends up with a `+` sign, which indicates that the call is not complete yet, and each subsequent line correspond to another layer or scale. In this case, we use the `geom_sf` function, which simply adds a geometry stored in a `sf` object. By default, all geometry functions use the main data defined in `ggplot()`, but we will see later how to provide additional data.

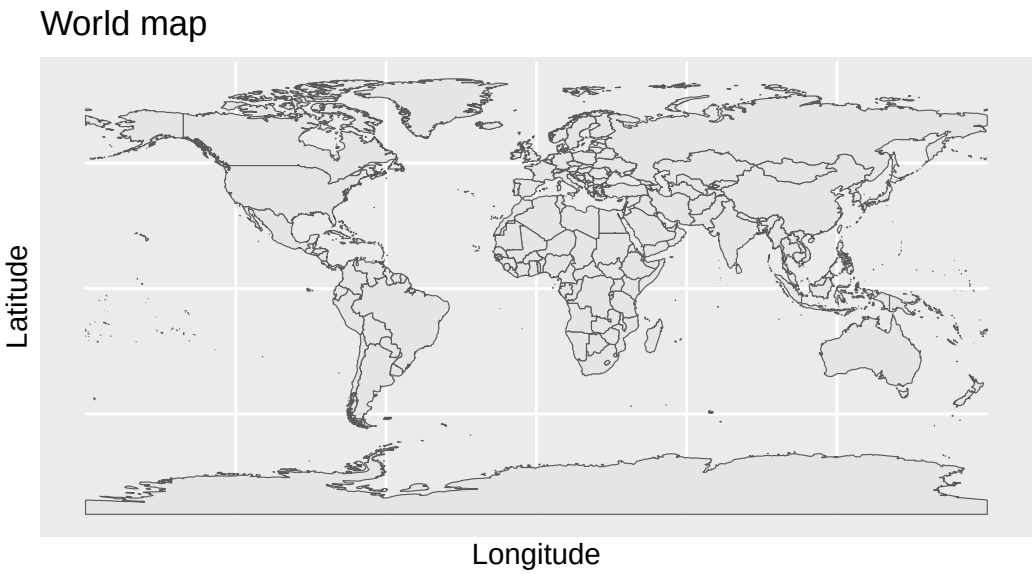
Note that layers are added one at a time in a `ggplot` call, so the order of each layer is very important. All data will have to be in an `sf` format to be used by `ggplot2`; data in other formats (e.g. classes from `sp`) will be manually converted to `sf` classes if necessary.

Title, subtitle, and axis labels (`ggtitle`, `xlab`, `ylab`)

A title and a subtitle can be added to the map using the function `ggtitle`, passing any valid character string (e.g. with quotation marks) as arguments. Axis names are absent by default on a map, but can be changed to something more suitable (e.g. "Longitude" and "Latitude"), depending on the map:

Build on your map as you would any other ggplot visualisation!

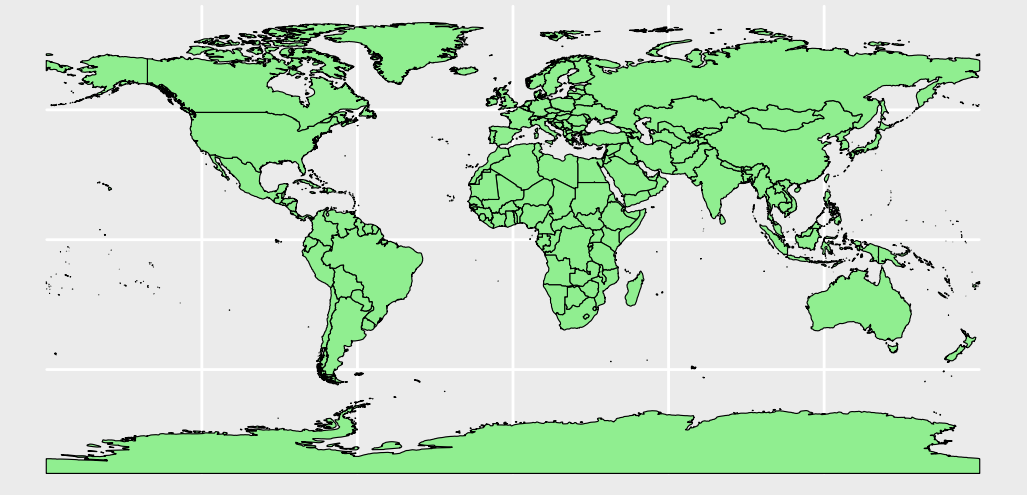
```
#|label: built on ggplot
ggplot(data = world) +
  geom_sf() +
  xlab("Longitude") +
  ylab("Latitude") +
  ggtitle("World map")
```



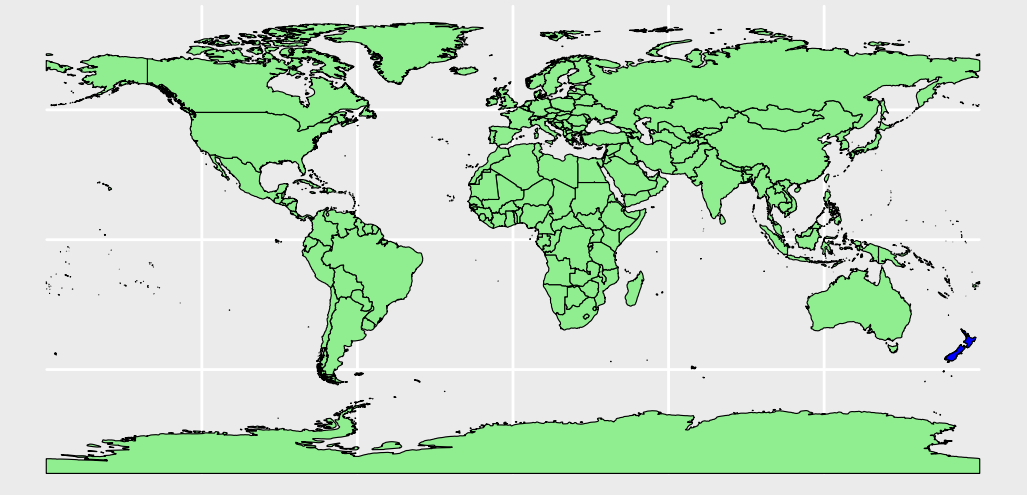
Map color (`geom_sf`)

In many ways, `sf` geometries are no different than regular geometries, and can be displayed with the same level of control on their attributes. Here is an example with the polygons of the countries filled with a green color (argument `fill`), using black for the outline of the countries (argument `color`):

```
#|label: showing colour and fill
ggplot(data = world) +
  geom_sf(color = "black", fill = "lightgreen")
```

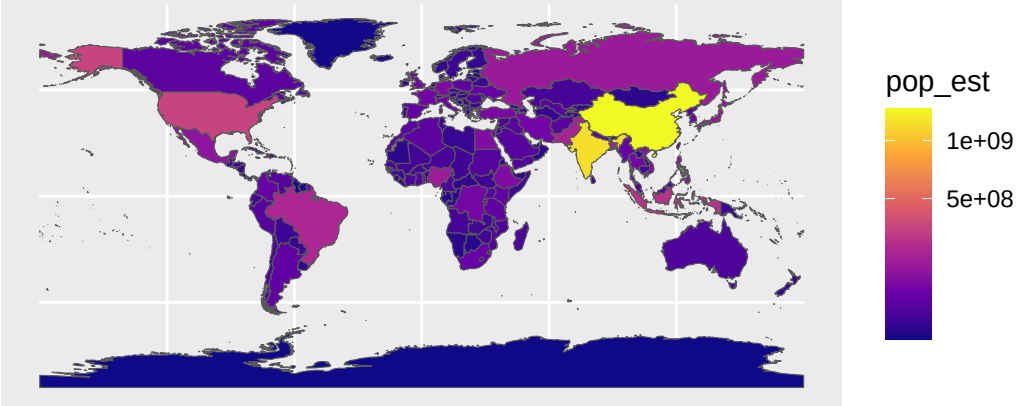


```
# now lets make two layers, one for NZ, that is different coloured.
ggplot() +
  geom_sf(data = world, color = "black", fill = "lightgreen") +
  geom_sf(data = nz, color = "black", fill = "blue")
```



The package `ggplot2` allows the use of more complex color schemes, such as a gradient on one variable of the data. Here is another example that shows the population of each country. In this example, we use the "viridis" colorblind-friendly palette for the color gradient (with `option = "plasma"` for the plasma variant), using the square root of the population (which is stored in the variable `POP_EST` of the `world` object):

```
#|label: other fill alternatives
ggplot(data = world) +
  geom_sf(aes(fill = pop_est)) +
  scale_fill_viridis_c(option = "plasma", trans = "sqrt")
```



Projection and extent (`coord_sf`)

The function `coord_sf` allows to deal with the coordinate system, which includes both projection and extent of the map. By default, the map will use the coordinate system of the first layer that defines one (i.e. scanned in the order provided), or if none, fall back on WGS84 (latitude/longitude, the reference system used in GPS). Using the argument `crs`, it is possible to override this setting, and project on the fly to any projection. This can be achieved using any valid PROJ4 string (here, the European-centric ETRS89 Lambert Azimuthal Equal-Area projection):

Note on Coordinate Reference System (CRS) determines the location that points are placed on a plot

```
#|label:
ggplot(data = world) +
  geom_sf() +
  coord_sf(crs = "+proj=laea +lat_0=52 +lon_0=10 +x_0=4321000 +y_0=3210000 +ellps=GRS80 +u
```

Spatial Reference System Identifier (SRID) or an European Petroleum Survey Group (EPSG) code are available for the projection of interest, they can be used directly instead of the full PROJ4 string. The two following calls are equivalent for the ETRS89 Lambert Azimuthal Equal-Area projection, which is EPSG code 3035:

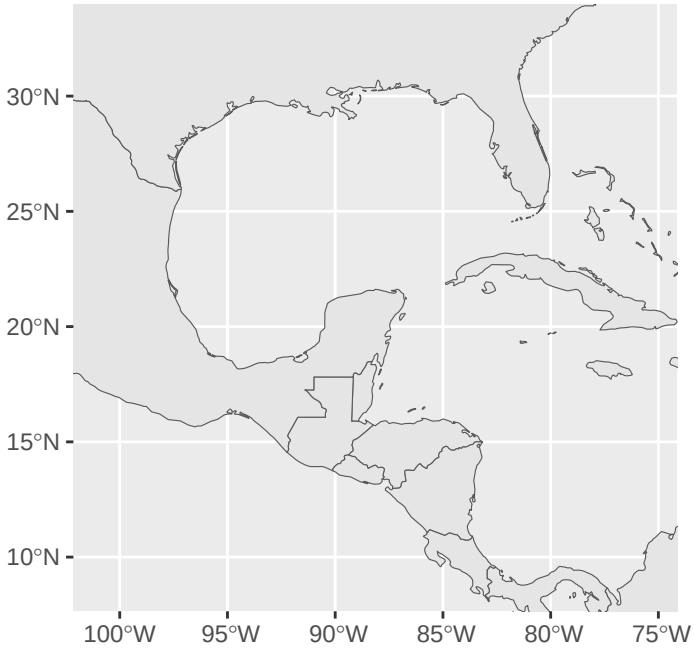
```
#|label: shortened CRS
ggplot(data = world) +
  geom_sf() +
  coord_sf(crs = "+init=epsg:3035")
```

```
Warning in CPL_crs_from_input(x): GDAL Message 1: +init=epsg:XXXX syntax is
deprecated. It might return a CRS with a non-EPSG compliant axis order.
```

```
ggplot(data = world) +
  geom_sf() +
  coord_sf(crs = st_crs(3035))
```

The extent of the map can also be set in `coord_sf`, in practice allowing to "zoom" in the area of interest, provided by limits on the x-axis (`xlim`), and on the y-axis (`ylim`). Note that the limits are automatically expanded by a fraction to ensure that data and axes don't overlap; it can also be turned off to exactly match the limits provided with `expand = FALSE`:

```
#|label: zooming on a map


ggplot(data = world) +
  geom_sf() +
  coord_sf(xlim = c(-102.15, -74.12),
           ylim = c(7.65, 33.97),
           expand = FALSE
           )
```



Scale bar and North arrow (package `ggspatial`)

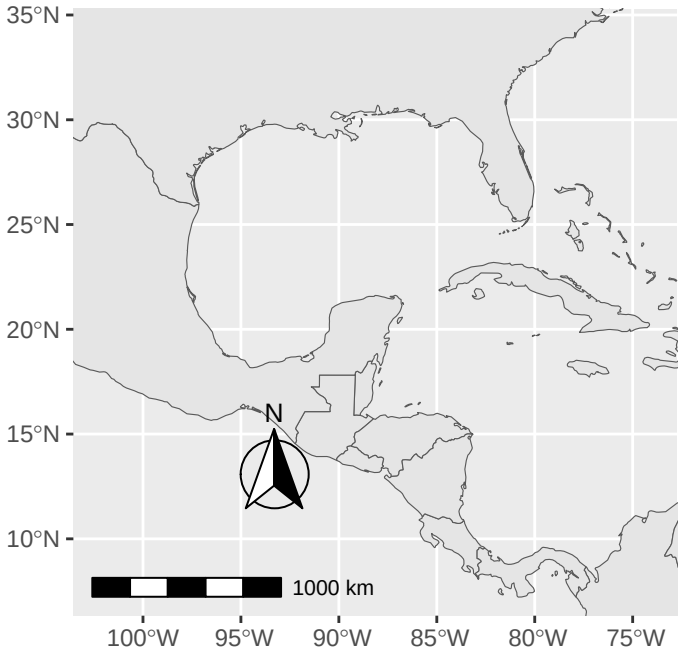
Several packages are available to create a scale bar on a map (e.g. `prettymapr`, `vcd`, `ggsn`, or `legendMap`). We introduce here the package `ggspatial`, which provides easy-to-use functions...

`scale_bar` that allows to add simultaneously the north symbol and a scale bar into the `ggplot` map. Five arguments need to be set manually: `lon`, `lat`, `distance_lon`, `distance_lat`, and `distance_legend`. The location of the scale bar has to be specified in longitude/latitude in the `lon` and `lat` arguments. The shaded distance inside the scale bar is controlled by the `distance_lon` argument. while its width is determined by `distance_lat`. Additionally, it is possible to change the font size for the legend of the scale bar (argument `legend_size`, which defaults to 3). The North arrow behind the "N" north symbol can also be adjusted for its length (`arrow_length`), its distance to the scale (`arrow_distance`), or the size the N north symbol itself (`arrow_north_size`, which defaults to 6). Note that all distances (`distance_lon`, `distance_lat`, `distance_legend`, `arrow_length`, `arrow_distance`) are set to `"km"` by default in `distance_unit`; they can also be set to nautical miles with "nm", or miles with "mi".

```
#|label: adding North arrow and scale bar
library("ggspatial")

ggplot(data = world) +
```

```
    geom_sf() +
    annotation_scale(location = "bl", width_hint = 0.5) +
    annotation_north_arrow(location = "bl",
                           which_north = "true",
                           pad_x = unit(0.75, "in"),
                           pad_y = unit(0.5, "in"),
                           style = north_arrow_fancy_orienteering) +
    coord_sf(xlim = c(-102.15, -74.12), ylim = c(7.65, 33.97))
```

```
Scale on map varies by more than 10%, scale bar may be inaccurate
```




```
## Scale on map varies by more than 10%, scale bar may be inaccurate
```

Note the warning of the inaccurate scale bar: since the map use unprojected data in longitude/latitude (WGS84) on an equidistant cylindrical projection (all meridians being parallel), length in (kilo)meters on the map directly depends mathematically on the degree of latitude. Plots of small regions or projected data will often allow for more accurate scale bars.

Country names and other names (`geom_text` and `annotate`)

The `world` data set already contains country names and the coordinates of the centroid of each country (among more information). We can use this information to plot country names, using `world` as a regular `data.frame` in `ggplot2`. The function `geom_text` can be used to add a layer of text to a map using geographic coordinates. The function requires the data needed to enter the country names, which is the same data as the world map. Again, we have a very flexible control to adjust the text at will on many aspects:

- The size (argument `size`);
- The alignment, which is centered by default on the coordinates provided. The text can be adjusted horizontally or vertically using the arguments `hjust` and `vjust`, which can either be a number between 0 (right/bottom) and 1 (top/left) or a character ("left", "middle", "right", "bottom", "center", "top"). The text can also be offset horizontally or vertically with the argument `nudge_x` and `nudge_y`;
- The font of the text, for instance its color (argument `color`) or the type of font (`fontface`);
- The overlap of labels, using the argument `check_overlap`, which removes overlapping text. Alternatively, when there is a lot of overlapping labels, the package `ggrepel` provides a `geom_text_repel` function that moves label around so that they do not overlap.
- For the text labels, we are defining the centroid of the counties with `st_centroid`, from the package `sf`. Then we combined the coordinates with the centroid, in the `geometry` of the spatial data frame. The package `sf` is necessary for the command `st_centroid`.

Define centroid! The centre of a polygon i.e. a country/shape on a map

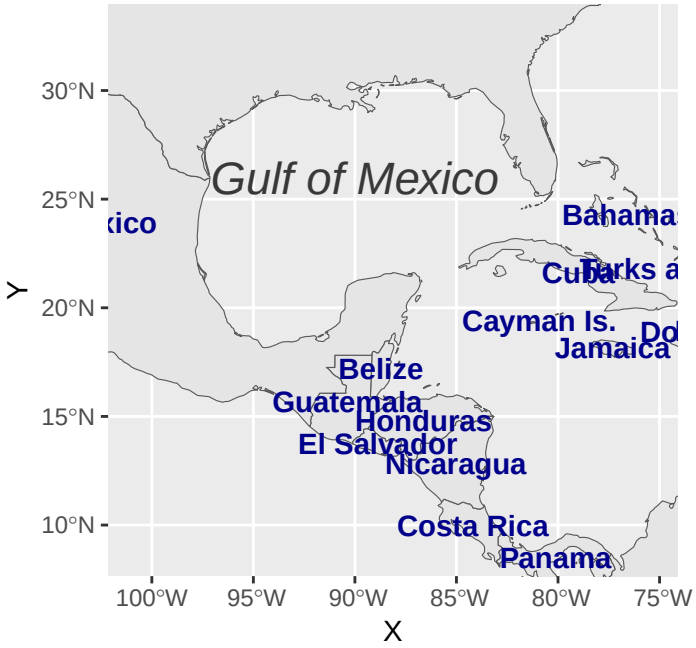
Additionally, the `annotate` function can be used to add a single character string at a specific location, as demonstrated here to add the Gulf of Mexico:

```
#|label: adding centroids

library("sf")

world <- st_make_valid(world) # this is an additional step needed because the centroids co
world_points<- st_centroid(world)
```

```
Warning: st_centroid assumes attributes are constant over geometries
```

```
world_points <- cbind(world, st_coordinates(st_centroid(world$geometry)))

ggplot(data = world) +
```

```
geom_sf() +
geom_text(data= world_points,
          aes(x=X, y=Y, label=name),
          color = "darkblue",
          fontface = "bold",
          check_overlap = FALSE) +
annotate(geom = "text",
         x = -90,
         y = 26,
         label = "Gulf of Mexico",
         fontface = "italic",
         color = "grey22",
         size = 6) +
coord_sf(xlim = c(-102.15, -74.12),
         ylim = c(7.65, 33.97),
         expand = FALSE)
```



Final map

Now to make the final touches, the theme of the map can be edited to make it more appealing. We suggested the use of `theme_bw` for a standard theme, but there are many other themes

that can be selected from (see for instance `?ggtheme` in `ggplot2`, or the package ggthemes which provide several useful themes). Moreover, specific theme elements can be tweaked to get to the final outcome:

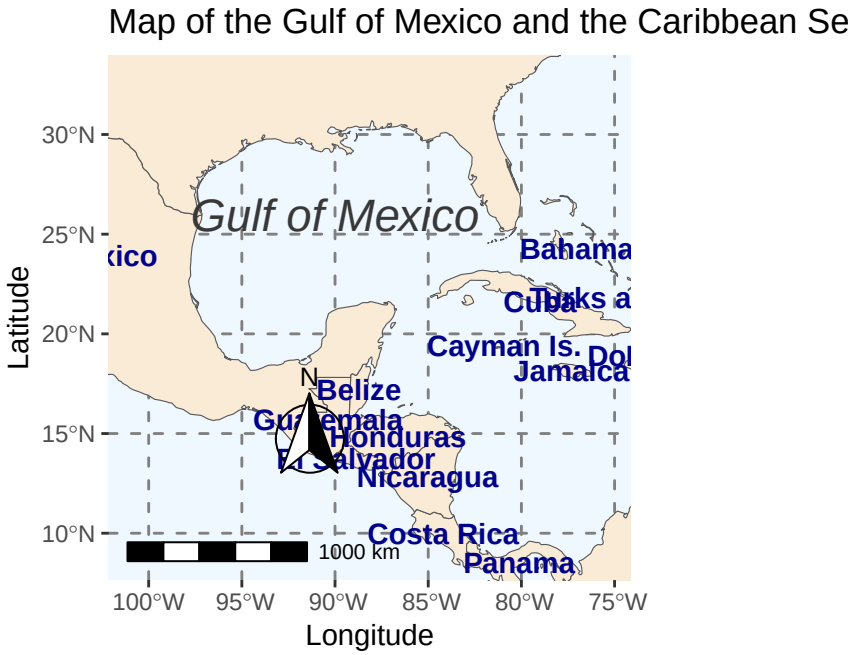
- Position of the legend: Although not used in this example, the argument `legend.position` allows to automatically place the legend at a specific location (e.g. `"topright"`, `"bottomleft"`, etc.);
- Grid lines (graticules) on the map: by using `panel.grid.major` and `panel.grid.minor`, grid lines can be adjusted. Here we set them to a gray color and dashed line type to clearly distinguish them from country borders lines;
- Map background: the argument `panel.background` can be used to color the background, which is the ocean essentially, with a light blue;
- Many more elements of a theme can be adjusted, which would be too long to cover here. We refer the reader to the documentation for the function `theme`.

```
#|label: cool as map

ggplot(data = world) +
  geom_sf(fill= "antiquewhite") +
  geom_text(data= world_points,
            aes(x=X,
                y=Y,
                label=name),
            color = "darkblue",
            fontface = "bold",
            check_overlap = FALSE) +
  annotate(geom = "text",
           x = -90,
           y = 26,
           label = "Gulf of Mexico",
           fontface = "italic",
           color = "grey22",
           size = 6) +
  annotation_scale(location = "bl",
                   width_hint = 0.5) +
  annotation_north_arrow(location = "bl",
                         which_north = "true",
                         pad_x = unit(0.75, "in"),
                         pad_y = unit(0.5, "in"),
                         style = north_arrow_fancy_orienteering) +
  coord_sf(xlim = c(-102.15, -74.12),
           ylim = c(7.65, 33.97),
```

```
          expand = FALSE) +
  xlab("Longitude") +
  ylab("Latitude") +
  ggtitle("Map of the Gulf of Mexico and the Caribbean Sea") +
  theme(panel.grid.major = element_line(color = gray(.5),
                                        linetype = "dashed",
                                        size = 0.5),
        panel.background = element_rect(fill = "aliceblue"))
```

```
Warning: The `size` argument of `element_line()` is deprecated as of ggplot2 3.4.0.
i Please use the `linewidth` argument instead.
```

```
Scale on map varies by more than 10%, scale bar may be inaccurate
```



Saving the map with `ggsave`

The final map now ready, it is very easy to save it using `ggsave`. This function allows a graphic (typically the last plot displayed) to be saved in a variety of formats, including the most common PNG (raster bitmap) and PDF (vector graphics), with control over the size and

resolution of the outcome. For instance here, we save a PDF version of the map, which keeps the best quality, and a PNG version of it for web purposes:

```
#|label: our old friend ggsave
#|eval: false
#|echo: true

# ggsave("map.pdf")
# ggsave("map_web.png",
#        width = 6,
#        height = 6,
#        dpi = "screen")
```