Geospatial Analysis with sf

Data Science for Public Policy

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Motivation

- Many data are inherently spatial. We need tools to manipulate, explore, communicate, and model spatial data.
- Point-and-click tools suffer many of the drawbacks outlined in earlier note sets.
- Proprietary geospatial tools are prohibitively expensive.
- Everyone loves maps.

`library(sf)` and geospatial data

Geospatial data are multidimensional. The outline of a simple rectangular state like Kansas may have a few vertices and a complex state like West Virginia may have many more vertices. Furthermore, geospatial data have auxiliary information about bounding boxes and projections. Fortunately, `library(sf)` can store all of this information in a rectangular tibble that works well with `library(dplyr)` and `library(ggplot2)`.

`library(sf)` stores geospatial data, which are **points**, **lines**, or **polygons** in a `geometry` column. Consider this example:

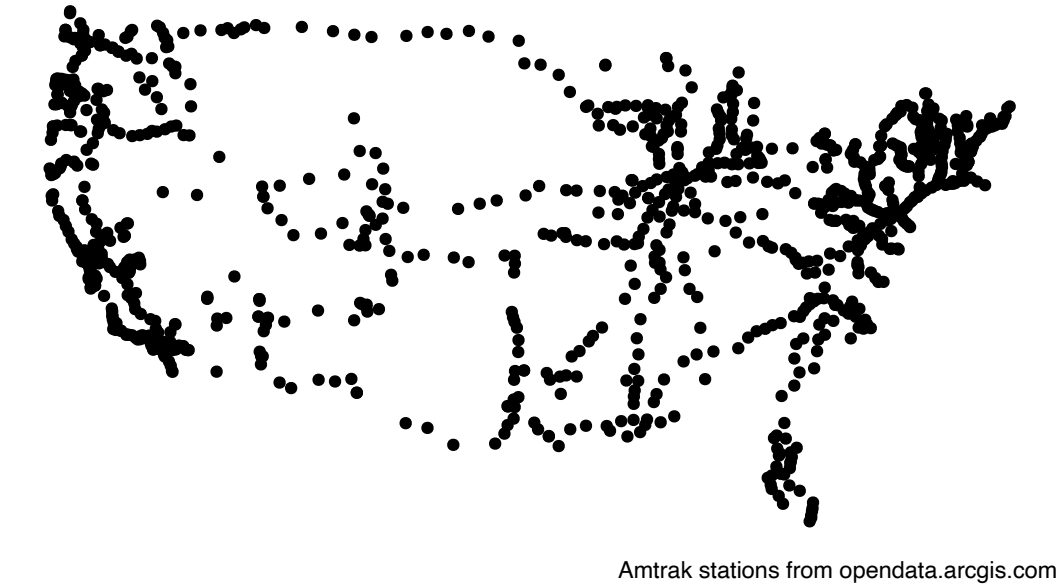
```r
library(sf)

amtrak_stations_file <-
  here("tutorials", "08_sf-geospatial/", "data", "amtrak_stations.geojson")

# download Amtrak data
if(!file.exists(amtrak_stations_file)) {

  download.file(
    url = "https://opendata.arcgis.com/datasets/628537f4cf774cde8aa9721212226390_0.geojson",
    destfile = amtrak_stations_file
  )

}

# read sf data
amtrak_stations <- st_read(amtrak_stations_file, quiet = TRUE)

# print the geometry column
# NOTE: geometry columns are "sticky" -- geometry is returned even though it
# isn't include in select()
amtrak_stations %>%
  select(stationnam)
```

```
Simple feature collection with 1096 features and 1 field
Geometry type: POINT
Dimension:     XY
Bounding box:  xmin: -124.2883 ymin: 25.84956 xmax: -68.67001 ymax: 49.27376
Geodetic CRS:  WGS 84
First 10 features:
              stationnam                   geometry
1              Alma, MI POINT (-84.64484 43.39173)
2             Albany, NY  POINT (-73.80919 42.7445)
3   Abbotsford-Colby, WI POINT (-90.31467 44.92856)
4           Aberdeen, MD POINT (-76.16326 39.50845)
5            Absecon, NJ POINT (-74.50148 39.42405)
6        Albuquerque, NM  POINT (-106.648 35.08207)
7  Antioch-Pittsburg, CA  POINT (-121.816 38.01771)
8            Arcadia, MO POINT (-90.62441 37.59217)
9      Atlantic City, NJ   POINT (-74.4399 39.3627)
10           Ardmore, OK POINT (-97.12552 34.17247)
```

Points

Points are zero-dimensional geospatial objects. Points are often a single longitude and latitude. Let's map the Amtrak stations from the above example:

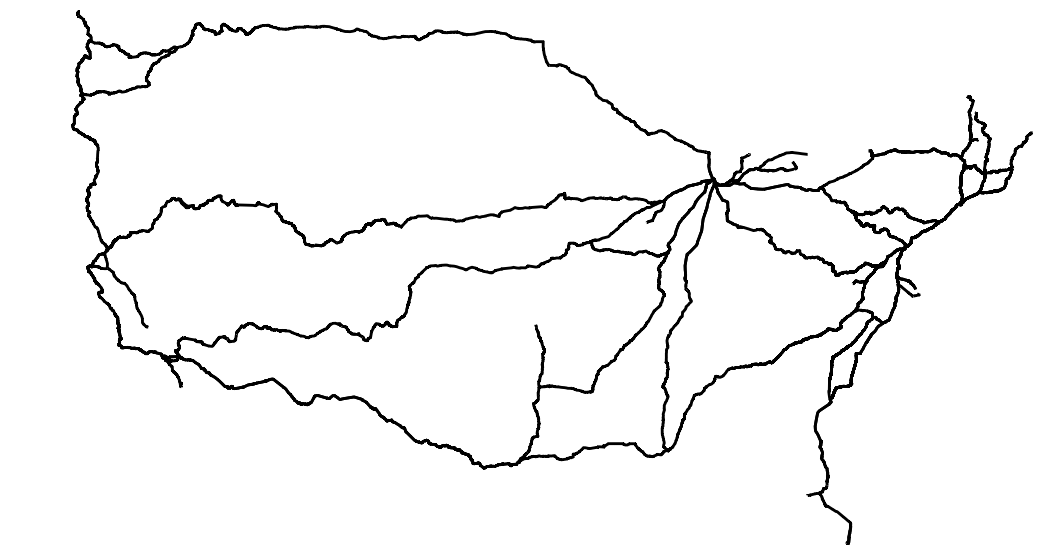
```
# create a map
amtrak_stations %>%
  ggplot() +
  geom_sf() +
  labs(
    title = "Example of point data",
    caption = "Amtrak stations from opendata.arcgis.com") +
  theme_void()
```



Lines

Lines are one-dimensional geospatial objects. Lines are often a sequence of longitudes and latitudes. Here is an example of Amtrak train routes from the Bureau of Transportation Statistics:

```r
amtrak_routes_file <- here("tutorials", "08_sf-geospatial/", "data", "Amtrak_Routes.geojson")

# load sf data
amtrak_routes <- st_read(amtrak_routes_file, quiet = TRUE)

# create map with lines data
amtrak_routes %>%
  ggplot() +
  geom_sf() +
  labs(
    title = "Example of line data",
    caption = "Amtrak routes from Bureau of Transportation Statistics"
  ) +
  theme_void()
```



Polygons

Polygons are two-dimensional geospatial objects. Polygons are often a sequence of longitudes and latitudes outlining a shape. Here is a simple example with of the Continental United States:

```r
# load and subset states data
states <- tigris::states(cb = TRUE, progress_bar = FALSE) %>%
  filter(!STATEFP %in% c("78", "69", "66", "60", "72", "02", "15"))

states %>%
  ggplot() +
  geom_sf() +
  labs(title = "Example of polygon data") +
  theme_void()
```

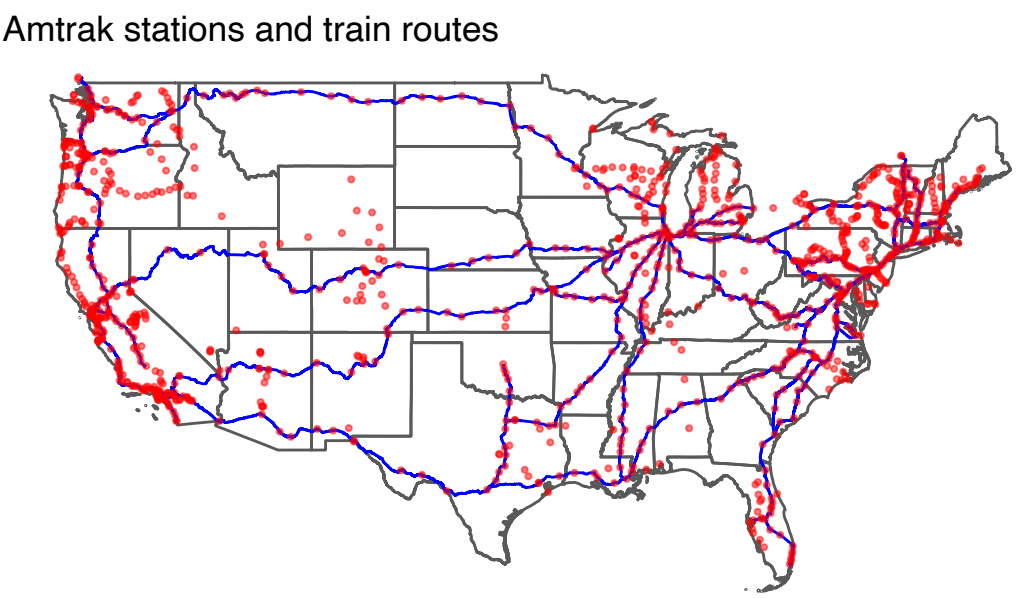
`geom_sf()`

`geom_sf()` plots `sf` data. The function automatically references the `geometry` column and does not require any aesthetic mappings. `geom_sf()` works well with layers and it is simple to combine point, line, and polygon data.

`geom_sf()` works like `geom_point()` for point data, `geom_line()` for line data, and `geom_area()` for polygon data (e.g. fill controls the color of shapes and color controls the border colors of shapes for polygons).

```r
amtrak_map <- ggplot() +
  geom_sf(
    data = states,
```

```
    fill = NA
  ) +
  geom_sf(
    data = amtrak_routes,
    color = "blue"
  ) +
  geom_sf(
    data = amtrak_stations,
    color = "red",
    size = 0.75,
    alpha = 0.5
  ) +
  labs(title = "Amtrak stations and train routes") +
  theme_void()

amtrak_map
```



Getting and loading spatial data

Shapefiles

Shapefiles are a proprietary file format created by ESRI, the company that creates ArcGIS. Shapefiles are popular because ESRI dominated the GIS space for a long time. A shapefile is actually usually three or more binary files.

`st_read()` reads shapefiles into R in the `sf` format. Simply point the function to the file ending in `.shp`. Note that the other binary files associated with the shapefile must also be located in the same directory as the `.shp` file.

GeoJSON

.geojson is an open source file type for storing geospatial data. It is plain text, which means it plays well with version control.

`st_read()` also reads GeoJSON data. Point the function at a file ending in .geojson to read the data.

.csv files

Lots of geographic information is stored in .csv files–especially for point data where it is sensible to have a longitude and latitude columns. Loading point data from .csv files requires two steps. First, read the file with `read_csv()`. Second, use `st_as_sf()` to convert the tibble into an sf object and specify the columns with longitude and latitude with the `coords` argument:

```
st_as_sf(data, coords = c("lon", "lat"))
```

Note: It is trickier (but far less common) to load line, polygon, and multipolygon data from .csvs.

`library(tigris)`

`library(tigris)` is an exceptional package that downloads and provides TIGER/Line shapefiles from the US Census Bureau. TIGER stands for Topologically Integrated Geographic Encoding and Referencing.

The package provides lots of data with simple functions (full list here) like `counties()` to access counties, `tracts()` to access census tracts, and `roads()` to access roads. The `state` and `county` arguments accept names and FIPS codes.

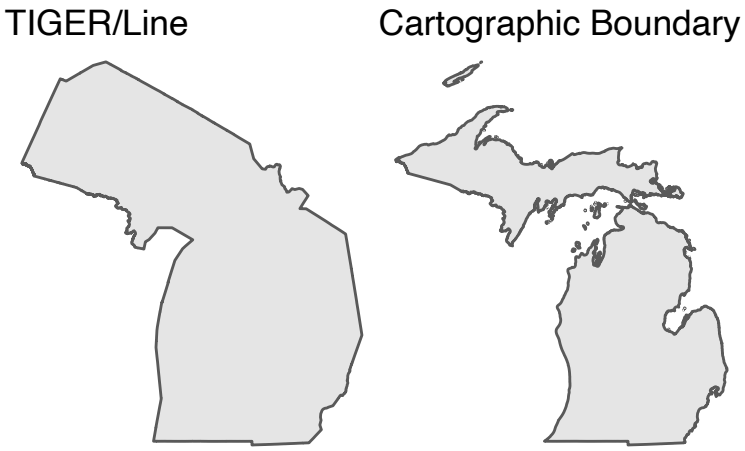
`library(tigris)` has a new `shift` option that elides Alaska and Hawaii next to the Continental United States.

Exercise 1

1. Using `library(tigris)`, pull roads data for DC with `state = "DC"` and `county = "District of Columbia"`.
2. Create a map with `geom_sf()` and `theme_void()`.

TIGER line files are high-resolution and follow legal boundaries. Sometimes the maps are counterintuitive. For example, the outline of Michigan will include the Great Lakes, which is uncommon. Cartographic boundary files are quicker to download and are clipped to the coastline, which better aligns with expectations.

```
library(tigris)

mi <- states(progress_bar = FALSE) %>%
  filter(STUSPS == "MI") %>%
  ggplot() +
  geom_sf() +
  labs(title = "TIGER/Line") +
  theme_void()

mi_cb <- states(cb = TRUE, progress_bar = FALSE) %>%
  filter(STUSPS == "MI") %>%
  ggplot() +
  geom_sf() +
  labs(title = "Cartographic Boundary") +
  theme_void()

mi + mi_cb
```



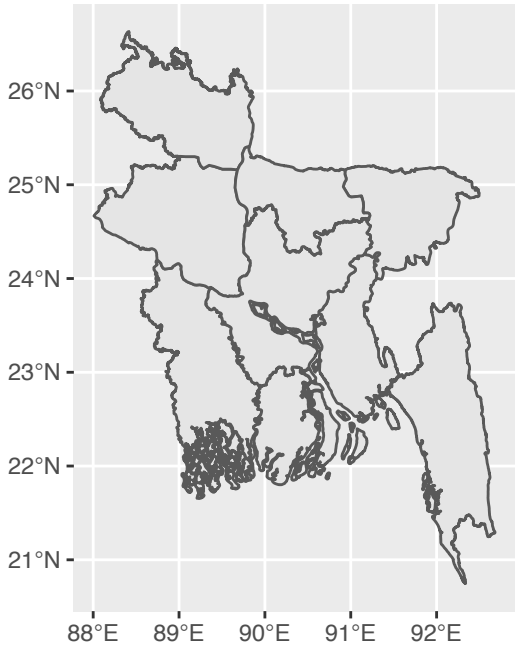
`library(rgeoboundaries)`

The `rgeoboundaries` package is a client for the geoBoundaries API, providing country political administrative boundaries for countries around the world. This package can be installed from GitHub using the `remotes` package as follows

```
library(remotes)
remotes::install_github("wmgeolab/rgeoboundaries")
```

The `rgeoboundaries` package can provide boundaries for countries at different administrative division levels. For example, here we obtain the adm1 boundaries (the first subnational level) for Bangladesh. The `type` argument of the `geoboundaries()` function can be set to obtain a simplified version of the boundaries.

```
library(rgeoboundaries)

bangladesh <- geoboundaries(
  country = "Bangladesh",
  adm_lvl = "adm1",
  type = "SSCGS" # Simplified Single Country Globally Standardized
)

ggplot(data = bangladesh) +
  geom_sf()
```



Exercise 2

We want to read in and map the locations of World Bank development projects in Bangladesh downloaded from AidData, which includes geographic and other information about development projects.

1. Copy the below code into your script to read in `aiddata_bangladesh.csv` with read_csv().

```
aiddata <- read_csv(
  paste0(
    "https://raw.githubusercontent.com/awunderground/awunderground-data/",
    "main/aiddata/aiddata_bangladesh.csv"
    )
  )
```

2. Use `st_as_sf()` to convert the .csv to `sf`.
3. Use `st_set_crs(value = 4326)` to set the CRS (we will discuss below).
4. Add a basemap of adm1 boundaries for Bangladesh using the `bangladesh` object created above.
5. Map the Bangladesh development project data with `color = status`.

`library(tidycensus)`

`library(tidycensus)`, which was created by the creator of `library(tigris)`, is also a valuable source of geographic data. Simply include `geometry = TRUE` in functions like `get_acs()` to pull the shapes data as `sf`. The `state` and `county` arguments accept names and FIPS codes.

`library(tidycensus)` sometimes requires the same Census API Key we used in the API tutorial (sign up here). You should be able to install your API key into your version of R with `census_api_key("your-key-string", install = TRUE)`. To obtain your keystring, you can use `library(dotenv)` and `Sys.getenv(<key name in .env file>)`.

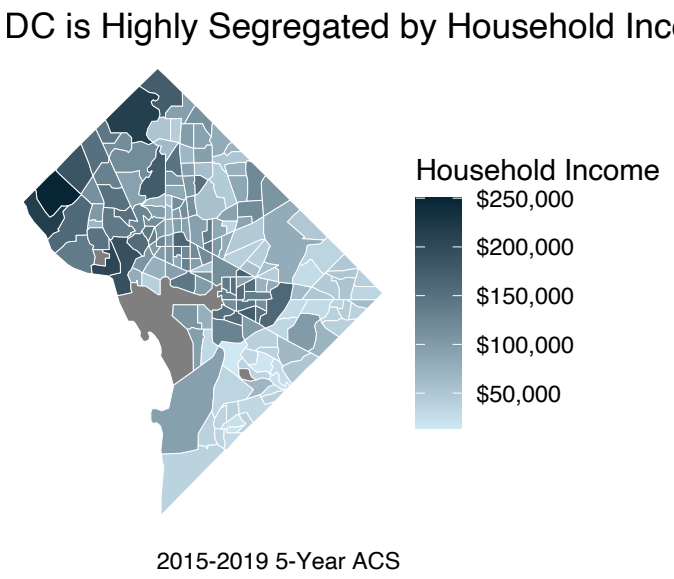
`library(tidycensus)` has two big differences from `library(tigris)`: 1. it can pull Census data with the geographic data, and 2. it only provides cartographic boundary files that are smaller and quicker to load and more familiar than TIGER/Line shapefiles by default.

```r
library(tidycensus)

dc_income <- get_acs(
  geography = "tract",
  variables = "B19013_001",
  state = "DC",
  county = "District of Columbia",
  geometry = TRUE,
  year = 2019,
  progress = FALSE
)
```

Both `library(tigris)` and `library(tidycensus)` have a `year` parameter that determines the year of the data obtained in functions like `tidycensus::get_acs()` or `tigris::states()`. This parameter currently defaults to 2020 for `get_acs()` and `tigris` functions. `tidycensus::get_acs()` also notably defaults to pulling 5-year ACS data. We recommend reading the documentation for these functions to understand the parameter options and their default values.

Choropleths

Choropleths are maps that use fill to display the variation in a variable across geographies.



Exercise 3

1. Copy the code that pulls income in DC by census tract under `library(tidycensus)`.
2. Try to recreate the above choropleth using `fill`.
3. **Hint:** Use `scale_fill_gradient()` with `low = "#cfe8f3"` and `high = "#062635"`.

Spatial concepts

Geospatial work requires making an assumption about the shape of the Earth and a decision about how to project three-dimensions on to a two-dimensional surface. **Note:** the Earth is an ellipsoid where the diameter from pole-to-pole is smaller than from equator to equator. In other words, it is swollen at the equator.

Geographic coordinate reference systems: data with a three-dimensional representation of the Earth. (i.e. The data have not been projected from what we think of as a globe to what we think of as a map). Data are typically stored as longitude and latitude.

Projected coordinate reference system: data with a two-dimensional representation of the Earth. A projected CRS is the combination of a geographic CRS and a projection. Data are typically stored in feet or meters, which is useful for distance-based spatial operations like calculating distances and creating buffers.

Projection: A mathematical transformation that converts three-dimensional coordinates for a spheroid/ellipsoid into a two-dimensions.

Popular projections

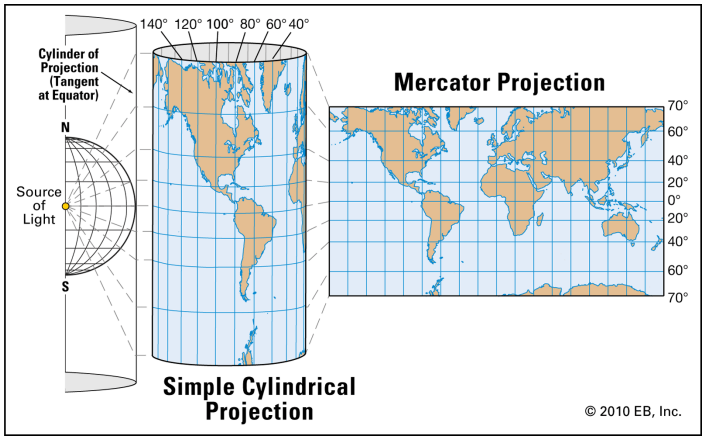
All projections are wrong, but all projections are wrong in different ways with different uses.

Cylindrical projections maintain lines of longitude and latitude but distort areas and distances. Conic projections distort longitudes and latitudes but maintain areas. Azimuthal projections maintain distances but struggle to project large areas.

Mercator projection

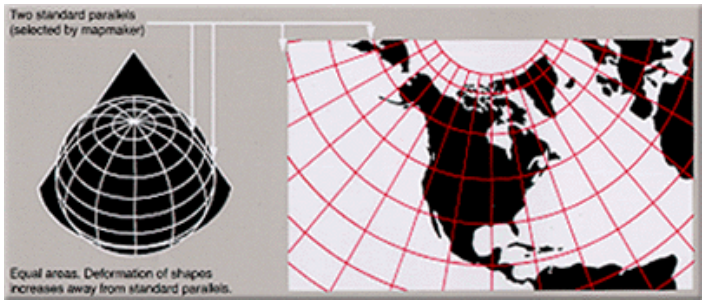
The Mercator projection is widespread because it maintains straight lines for longitude and latitude. This was useful for navigators on the open sea hundreds of years ago. This is less useful in the 21st century. The Mercator projection is conformal, so while it maintains angles, it seriously distorts area. To see this, play the Mercator Puzzle.

Source: Encyclopædia Britannica



Albers Equal Area Projection

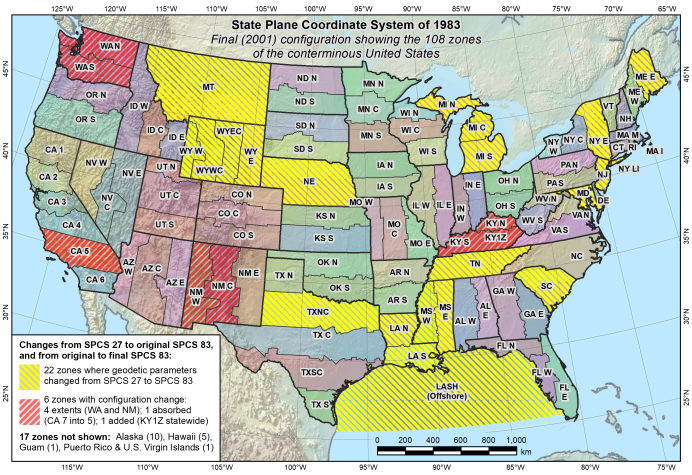
The Albers Equal Area projection, which is a conic projection, doesn't maintain angles, but it is an equal area projection. It is the default projection of the Urban Institute.



State Plane Coordinate Systems (SPCS)

The State Plane Coordinate System is a collection of 124 coordinate systems for specific areas of the United States. States with east-west directions, like Tennessee use the Lambert conformal conic projection. North-south states like Illinois use the transverse Mercator projection. SPCS is not a projection, but the coordinate systems are projected. This site has a thorough introduction.

Source: NOAA



EPSG Codes

A CRS can be uniquely identified by EPSG codes and proj4 strings. EPSG comes from the European Petrol Survey Group, which no longer exists. EPSG codes are 4-6 numbers. Always check to see if a CRS is specified after loading spatial data. Here are some defaults:

- The EPSG code will always be 4326 for GeoJSONs.
- .csv files with longitude and latitude will typically be 4326.
- R should read the CRS from `.prj` file when reading shapefiles. If it fails, open the `.prj` file and use this tool to identify the EPSG code.

Use `st_crs()` to see the CRS. Use `st_set_crs()` to set the CRS. Use `st_transform()` to transform the CRS. Note that `st_set_crs()` simply adds or updates CRS information - it does not transform the data. When using multiple different geospatial datasets for mapping (e.g. layering points and polygons), they should have the same CRS prior to mapping.

epsg.io and spatialreference.org are useful for finding and learning more about EPSG codes.

Datum

Datum: a reference point for measuring locations on the surface of the Earth. The datum defines an anchor point for coordinate systems and thus allows a unique set of longitudes and latitudes to fully define the surface of the Earth.

The invention of GPS has standardized datums. Geodetic datums like the North American Datum of 1983 (**NAD83**) and the World Geodetic System of 1984

(**WGS84**) now dominate. In fact, all GPS measurements are based on WGS84. This blog describes the importance of datums.

library(crsuggest)

library(crsuggest) can simplify the process of picking a CRS.

```
library(crsuggest)

suggest_crs(amtrak_stations)
```

```
# A tibble: 10 x 6
   crs_code crs_name                          crs_type  crs_gcs crs_un~1 crs_p~2
   <chr>    <chr>                             <chr>       <dbl> <chr>    <chr>
 1 6350     NAD83(2011) / Conus Albers        projected    6318 m        +proj=~
 2 5072     NAD83(NSRS2007) / Conus Albers    projected    4759 m        +proj=~
 3 5071     NAD83(HARN) / Conus Albers        projected    4152 m        +proj=~
 4 5070     NAD83 / Conus Albers              projected    4269 m        +proj=~
 5 5069     NAD27 / Conus Albers              projected    4267 m        +proj=~
 6 6925     NAD83(2011) / Kansas LCC (ftUS)   projected    6318 us-ft    +proj=~
 7 6924     NAD83(2011) / Kansas LCC          projected    6318 m        +proj=~
 8 6923     NAD83 / Kansas LCC (ftUS)         projected    4269 us-ft    +proj=~
 9 6922     NAD83 / Kansas LCC                projected    4269 m        +proj=~
10 6467     NAD83(2011) / Kansas North (ftUS) projected    6318 us-ft    +proj=~
# ... with abbreviated variable names 1: crs_units, 2: crs_proj4
```

```
virginia_stations <- amtrak_stations %>%
  filter(state == "VA")

suggest_crs(virginia_stations)
```

```
# A tibble: 10 x 6
   crs_code crs_name                              crs_t~1 crs_gcs crs_u~2 crs_p~3
   <chr>    <chr>                                 <chr>     <dbl> <chr>   <chr>
 1 6593     NAD83(2011) / Virginia North (ftUS)   projec~    6318 us-ft   +proj=~
 2 6592     NAD83(2011) / Virginia North          projec~    6318 m       +proj=~
 3 3686     NAD83(NSRS2007) / Virginia North (f~  projec~    4759 us-ft   +proj=~
 4 3685     NAD83(NSRS2007) / Virginia North      projec~    4759 m       +proj=~
 5 32146    NAD83 / Virginia North                projec~    4269 m       +proj=~
 6 32046    NAD27 / Virginia North                projec~    4267 us-ft   +proj=~
 7 2924     NAD83(HARN) / Virginia North (ftUS)   projec~    4152 us-ft   +proj=~
 8 2853     NAD83(HARN) / Virginia North          projec~    4152 m       +proj=~
```

```
 9 2283     NAD83 / Virginia North (ftUS)        projec~    4269 us-ft   +proj=~
10 6488     NAD83(2011) / Maryland (ftUS)        projec~    6318 us-ft   +proj=~
# ... with abbreviated variable names 1: crs_type, 2: crs_units, 3: crs_proj4
```

The top suggestion for `virginia_stations` is `CRS == 6593`. If we look up this CRS we see it has geodetic datum NAD83 and is based on the Lambert Conformal Conic projection used for SPCS. If we look up the best SPCS for Northern Virginia, we get `CRS == 3686`, which is the third recommendation.

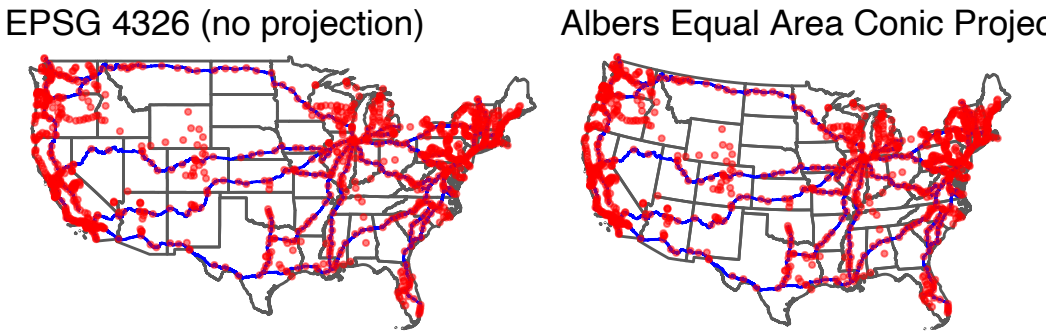
The differences between these two recommendations are not significant.

Bottom line

That's a lot of technical information. When mapping in the US

1. Use `CRS = 4326` when you load the data to understand the locations you are mapping. *This is not a projection* but plotting the data acts like a projection.
2. Use `CRS = 5070` if you are mapping the entire Continental US. Other useful EPSG codes are available here.
3. Use the recommended state plane coordinate system for state and local maps.

Here's the map from earlier with EPSG 4326 on the left and EPSG 5070 (Alber's Equal Area Conic Projection) on the right:



Exercise 4

1. Copy-and-paste the AidData exercise from exercise 2.
2. Repeat the mapping with a EPSG code that makes sense for Bangladesh using `st_transform()` (**Hint:** you can identify the EPSG code using `suggest_crs(aiddata)`).

3. Copy-and-paste the AidData exercise from exercise 2 again.
4. Repeat the mapping with a EPSG code that makes sense for Bangladesh using `coord_sf(crs = ####)` where `####` is the EPSG code from step 2 (**Hint:** `coord_sf()` can be added to your mapping code following a +). This skips the need for `st_transform()` when making maps.

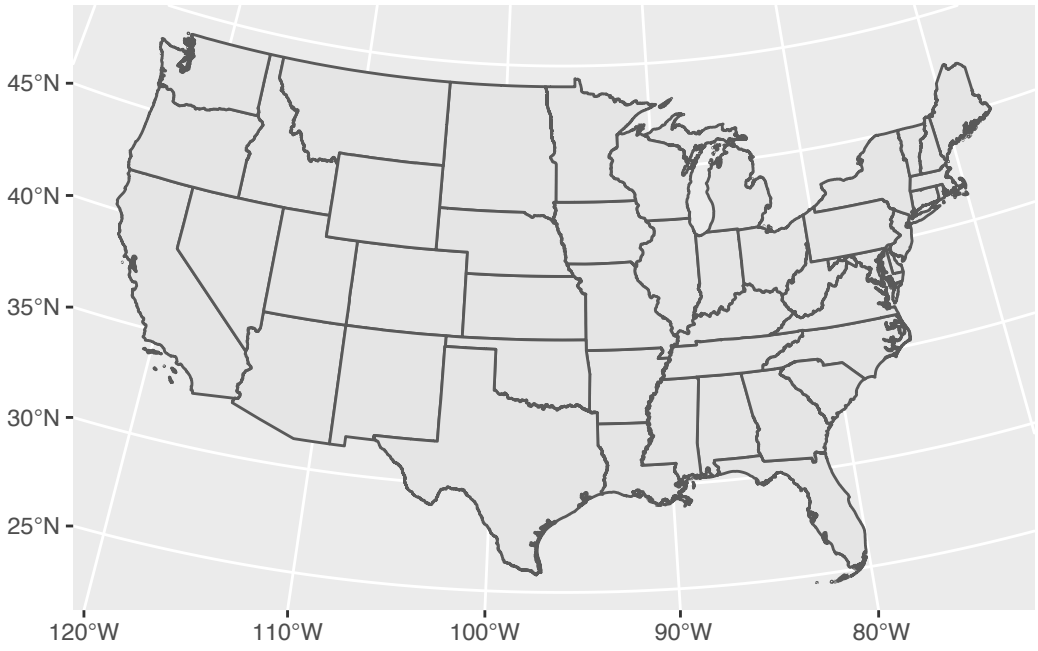
Spatial operations

We often want to manipulate spatial data or use spatial data for calculations. This section covers a few common operations.

Aggregation

Sometimes we want to aggregate smaller geographies into larger geographies. This is simple with a `group_by()` and `summarize()` workflow. Suppose we want to combine North Dakota and South Dakota into Dakota.

```
# states to combine
dmv_names <- c("South Dakota", "North Dakota")

# add a projection
states <- states %>%
  st_transform(crs = 5070)

# aggregate states and make a map
states %>%
  mutate(new_NAME = if_else(NAME %in% dmv_names, "Dakota", NAME)) %>%
  group_by(new_NAME) %>%
  summarize() %>%
  ggplot() +
  geom_sf()
```



Spatial Joins

Spatial joins are joins like `left_join()` but the join is based on geography instead of "by" variables. **Note:** both geographies must have the same CRS. Like with any join, it is important to track the number of rows before and after joins and to note that joins may be one-to-one, one-to-many.

`st_join()` performs a left spatial join in R. `st_intersects` means observations will join if the geographies in `x` touch the geographies in `y`. The `sf` package offers a number of different geometric confirmations that can be used for spatial joins, such as `st_covered_by` (identifies if `x` is copletely within `y`), `st_within` (identifies if `x` is within a specified distance of `y`) and many more. The sf cheat sheet provides a good outline of the different options.

Suppose we want to count the number of Amtrak stations in each state.

```
# set states CRS to 4326 to match the Amtrak data
amtrak_stations <- st_transform(amtrak_stations, crs = 5070)

# dimension before join
dim(amtrak_stations)
```

```
[1] 1096   12
```

```
# spatial join using intersection
amtrak <- st_join(states, amtrak_stations, join = st_intersects)

# dimension after join -- lose international stations
dim(amtrak)
```

```
[1] 1080   21
```

```
# count the number of stations per state
amtrak %>%
  as_tibble() %>% # converting from sf to tibble speeds calculations
  group_by(NAME) %>%
  summarize(number_of_stations = n()) %>%
  arrange(desc(number_of_stations))
```

```
# A tibble: 49 x 2
   NAME         number_of_stations
   <chr>                     <int>
 1 California                  184
 2 Oregon                       87
 3 New York                     80
 4 Pennsylvania                 63
 5 Michigan                     54
 6 Washington                   50
 7 Illinois                     41
 8 Wisconsin                    37
 9 Florida                      31
10 Texas                        31
# ... with 39 more rows
```

Buffers

Adding buffers to points, lines, and polygons is useful for counting shapes near other shapes. For instance, we may want to count the number of housing units within 500 meters of a metro station or the number of schools more than 5 miles from a fire station.

Suppose we want to count the number of Amtrak stations within 5 kilometers of each Amtrak station. We can buffer the Amtrak station points, join the unbuffered data to the buffered data, and then count.

```r
# add a buffer of 5 kilometers to each station
# the units package is useful for setting buffers with different units
amtrak_stations_buffered <- st_buffer(
  amtrak_stations,
  dist = units::set_units(5, "km")
)

# spatial join the unbuffered shapes to the buffer shapes
amtrak_stations_joined <- st_join(
  amtrak_stations_buffered,
  amtrak_stations,
  join = st_intersects
)

# count the station names
amtrak_stations_joined %>%
  as_tibble() %>%
  count(stationnam.x, sort = TRUE)
```

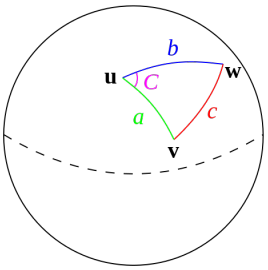
```
# A tibble: 1,007 x 2
   stationnam.x                  n
   <chr>                     <int>
 1 Monterey, CA                 27
 2 Yosemite National Park, CA   17
 3 Boston, MA                    9
 4 Salem, OR                     9
 5 Seaside, OR                   8
 6 Manchester Center, VT         6
 7 Eugene, OR                    5
 8 Las Vegas, NV                 5
 9 Oakland, CA                   5
10 Palm Springs, CA              5
# ... with 997 more rows
```

Distances

Euclidean distance is common for calculating straight line distances but does not make sense for calculating distances on the surface of an ellipsoid like Earth.

$$d(\vec{p}, \vec{q}) = \sqrt{\sum_{i=1}^{n} (q_i - p_i)^2}$$

Instead, it is common to use Haversine distance which accounts for the curvature in the globe.



Suppose we want to find the closest and furthest Amtrak stations from Washington DC's Union Station.

```
# create a data frame with just Union Station
union_station <- amtrak_stations %>%
  filter(state == "DC")

no_union_station <- amtrak_stations %>%
  filter(state != "DC")

# calculate the distance from Union Station to all other stations
amtrak_distances <- st_distance(union_station, no_union_station)

# find the closest station
amtrak_stations %>%
  slice(which.min(amtrak_distances)) %>%
  select(stationnam, city)
```

```
Simple feature collection with 1 feature and 2 fields
Geometry type: POINT
Dimension:     XY
Bounding box:  xmin: 1618448 ymin: 1915016 xmax: 1618448 ymax: 1915016
Projected CRS: NAD83 / Conus Albers
      stationnam       city                geometry
1 Alexandria, VA Alexandria POINT (1618448 1915016)
```

```
# find the further station
amtrak_stations %>%
  slice(which.max(amtrak_distances)) %>%
  select(stationnam, city)
```

```
Simple feature collection with 1 feature and 2 fields
Geometry type: POINT
```

```
Dimension:     XY
Bounding box:  xmin: -2328052 ymin: 2299661 xmax: -2328052 ymax: 2299661
Projected CRS: NAD83 / Conus Albers
   stationnam    city                  geometry
1 Fortuna, CA Fortuna POINT (-2328052 2299661)
```

Geospatial modeling

Cross-sectional regression models assume that the error term is independently and identically distributed, which in turn means the dependent variable is independently and identically distributed. This is often a reasonable assumption.

The assumption of independence often falls apart with spatial data. If number of coal power plants in a state is an independent variable and atmospheric carbon dioxide in a state is the dependent variable, then it doesn't make much sense to assume that North Carolina and South Carolina are independent. If South Carolina has many coal burning power plants, then the emissions could affect atmospheric carbon dioxide in North Carolina.

Spatial regression methods attempt to account for this dependence between observations.

Spatial autocorrelation: Correlation between observations that are geographically close.

Process:

1. Estimate a non-spatial regression model.
2. Use tests of spatial autocorrelation like Moran's I, Geary's c, or Getis and Ord's G-statistic on the residuals to test for spatial autocorrelation.
3. If spatial autocorrelation exists, the use a spatial error model or a spatial lag model.

Parting Thoughts

This note set works entirely with vector spatial data. Vector data consists of vertices turned into points, lines, and polygons.

Some spatial data are raster data, which are stored as pixels or grid cells. For example, a raster data set may have an even one square mile grid over the entire United States with data about the amount of soy crops within each pixel. It is common for satellite data to be converted to rasters. This website contains good example of raster data.

More Resources

- Drawing Beautiful Maps with sf - part 1
- Drawing Beautiful Maps with sf - part 2
- R Spatial Workshop Notes
- Analyzing US Census Data by Kyle Walker – Chapter 6
- sf Cheat Sheet