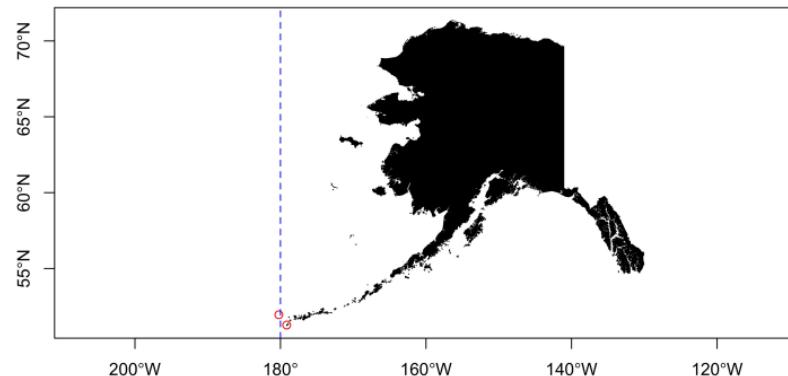


Geospatial stuff is hard

Projections

Dateline

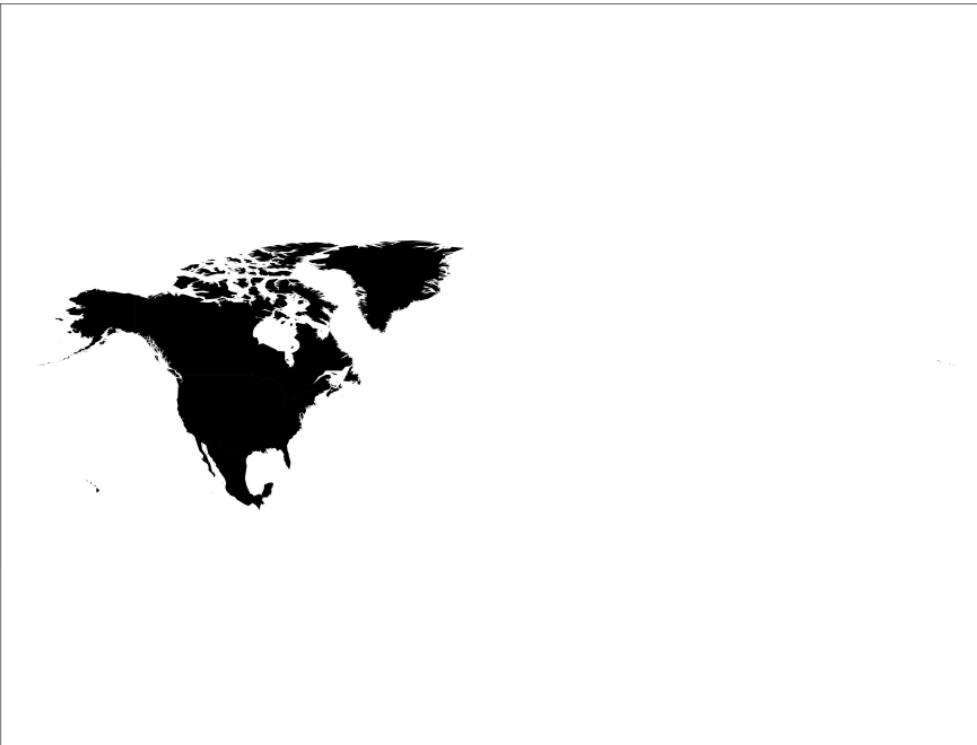
How long is the flight between the Western most and the Eastern most points in the US?



Great circle distance

```
par(mar=c(0,0,0,0))
ak1 = c(179.776, 51.952)
ak2 = c(-179.146, 51.273)
inter = geosphere::gcIntermediate(ak1, ak2, n=50, addStartEnd=TRUE)
plot(st_geometry(world), col="black", ylim=c(-90,90), axes=TRUE)
lines(inter,col='red',lwd=2,lty=3)
```

Plotting is hard



Geospatial Data and R

Packages for geospatial data in R

R has a rich package ecosystem for read/writing, manipulating, and analyzing geospatial data.

Some core packages:

- `sp` - core classes for handling spatial data, additional utility functions - **Deprecated**
- `rgdal` - R interface to `gdal` (Geospatial Data Abstraction Library) for reading and writing spatial data - **Deprecated**
- `rgeos` - R interface to `geos` (Geometry Engine Open Source) library for querying and manipulating spatial data. Reading and writing WKT. - **Deprecated**
- `sf` - Combines the functionality of `sp`, `rgdal`, and `rgeos` into a single package based on tidy simple features.
- `raster` - classes and tools for handling spatial raster data.
- `stars` - Reading, manipulating, writing and plotting spatiotemporal arrays (rasters)

Installing sf

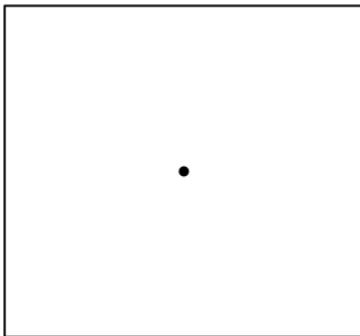
This is the hardest part of using the `sf` package, difficulty comes from its dependence on several external libraries (`geos`, `gdal`, and `proj`).

- Windows - installing from source works when Rtools is installed (system requirements are downloaded from `rwinlib`)
- MacOS - install dependencies via homebrew: `gdal`, `geos`, `proj`, `udunits`.
- Linux - Install development packages for GDAL ($\geq 2.0.0$), GEOS ($\geq 3.3.0$), Proj4 ($\geq 4.8.0$), `udunits2` from your package manager of choice.

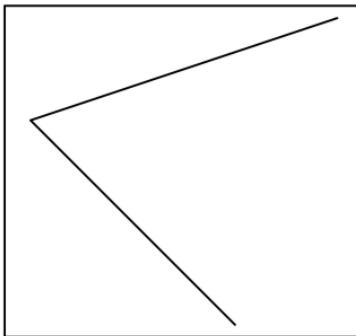
More specific details are included in the repo README on github.

Simple Features

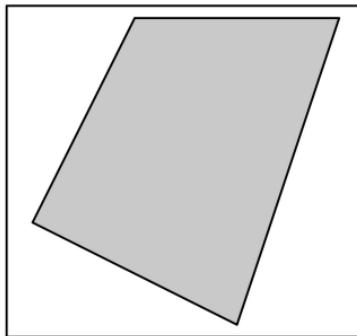
Point



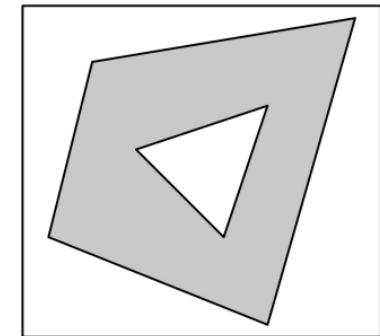
Linestring



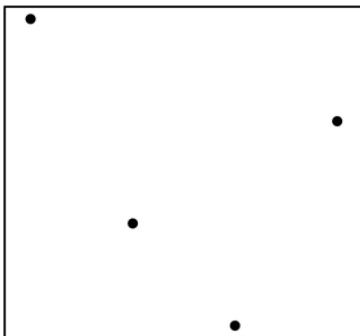
Polygon



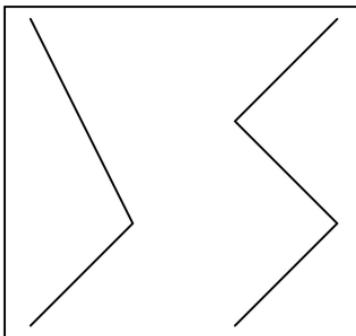
Polygon w/ Hole(s)



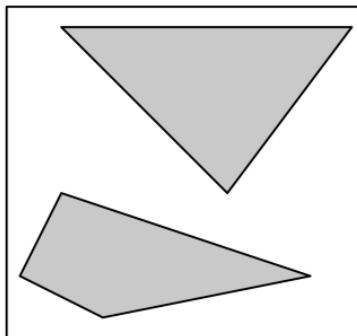
Multipoint



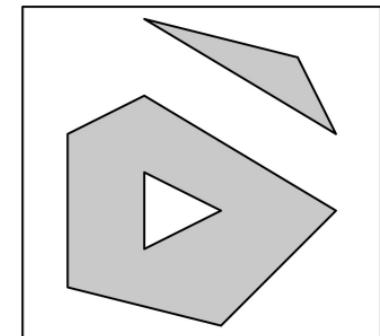
Multilinestring



Multipolygon



Multipolygon w/ Hole(s)



Reading, writing, and converting simple features

- sf
 - st_read / st_write - Shapefile, GeoJSON, KML, ...
 - read_sf / write_sf - Same, supports tibbles ...
 - st_as_sf / st_as_wkt - WKT
 - st_as_sf / st_as_binary - WKB
 - st_as_sf / as(x, "Spatial") - sp

See sf vignette #2 - Reading, Writing and Converting Simple Features.

Shapefiles

```
fs::dir_info("data/gis/nc_counties/") %>% select(path:size)

## # A tibble: 4 × 3
##   path                      type     size
##   <fs::path>                <fct>  <fs::bytes>
## 1 data/gis/nc_counties/dbf file    41K
## 2 data/gis/nc_counties/prj file   165
## 3 data/gis/nc_counties/shp file  1.41M
## 4 data/gis/nc_counties/shx file    900
```

NC Counties

```
(st_read("data/gis/nc_counties/", quiet=FALSE))

## Reading layer `nc_counties' from data source
##   '/Users/rundel/Desktop/Sta523-Fa21/website/static/slides/data/gis/nc_counties' using driver 'ESRI Shapefile'
## Simple feature collection with 100 features and 8 fields
## Geometry type: MULTIPOLYGON
## Dimension:     XY
## Bounding box: xmin: -84.32186 ymin: 33.84175 xmax: -75.46003 ymax: 36.58815
## Geodetic CRS: NAD83

## Simple feature collection with 100 features and 8 fields
## Geometry type: MULTIPOLYGON
## Dimension:     XY
## Bounding box: xmin: -84.32186 ymin: 33.84175 xmax: -75.46003 ymax: 36.58815
## Geodetic CRS: NAD83
## First 10 features:
##          AREA PERIMETER COUNTYP010 STATE          COUNTY  FIPS STATE_FIPS SQUARE_MIL
## 1  0.11175964  1.610396    1994    NC      Ashe County 37009       37  429.350
## 2  0.06159483  1.354829    1996    NC      Alleghany County 37005       37  236.459
## 3  0.14023009  1.769388    1998    NC      Surry County 37171       37  538.863
## 4  0.08912401  1.425249    1999    NC      Gates County 37073       37  342.340
## 5  0.06865730  4.428217    2000    NC      Currituck County 37053       37  263.871
## 6  0.11859434  1.404309    2001    NC      Stokes County 37169       37  455.793
## 7  0.06259671  2.106357    2002    NC      Camden County 37029       37  240.615
```

sf tibbles

```
(nc = read_sf("data/gis/nc_counties/"))
```

```
## Simple feature collection with 100 features and 8 fields
## Geometry type: MULTIPOLYGON
## Dimension: XY
## Bounding box: xmin: -84.32186 ymin: 33.84175 xmax: -75.46003 ymax: 36.58815
## Geodetic CRS: NAD83
## # A tibble: 100 × 9
##       AREA PERIMETER COUNTYP010 STATE COUNTY      FIPS STATE_FIPS SQUARE_MIL
##       <dbl>     <dbl>     <dbl> <chr> <chr>      <chr> <chr>     <dbl>
## 1 0.112      1.61     1994 NC   Ashe County    37009 37      429.
## 2 0.0616     1.35     1996 NC   Alleghany Coun... 37005 37      236.
## 3 0.140      1.77     1998 NC   Surry County   37171 37      539.
## 4 0.0891     1.43     1999 NC   Gates County   37073 37      342.
## 5 0.0687     4.43     2000 NC   Currituck Coun... 37053 37      264.
## 6 0.119      1.40     2001 NC   Stokes County  37169 37      456.
## 7 0.0626     2.11     2002 NC   Camden County  37029 37      241.
## 8 0.115      1.46     2003 NC   Warren County   37185 37      444.
## 9 0.143      2.40     2004 NC   Northampton Co... 37131 37      551.
## 10 0.0925    1.81     2005 NC   Hertford County 37091 37      356.
## # ... with 90 more rows, and 1 more variable: geometry <MULTIPOLYGON [°]>
```

sf classes

```
str(nc, max.level=1)

## sf [100 x 9] (S3: sf/tbl_df/tbl/data.frame)
## - attr(*, "sf_column")= chr "geometry"
## - attr(*, "agr")= Factor w/ 3 levels "constant","aggregate",..: NA NA NA NA NA NA NA NA
##   ..- attr(*, "names")= chr [1:8] "AREA" "PERIMETER" "COUNTYP010" "STATE" ...

class(nc)

## [1] "sf"          "tbl_df"       "tbl"          "data.frame"

class(nc$geometry)

## [1] "sfc_MULTIPOLYGON" "sfc"

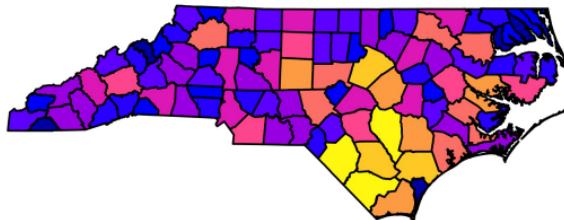
class(nc$geometry[[1]])

## [1] "XY"           "MULTIPOLYGON"  "sfg"
```

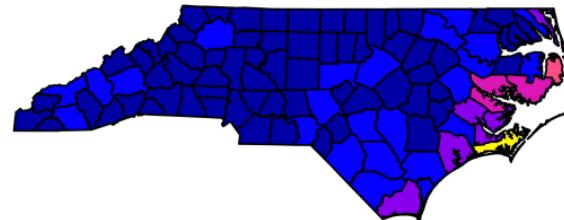
Plotting

```
plot(nc)
```

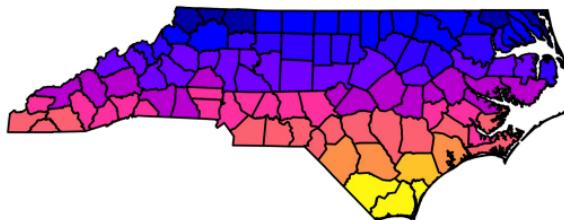
AREA



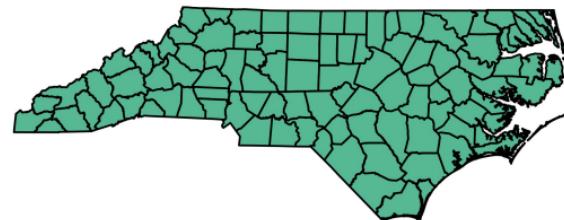
PERIMETER



COUNTYP010



STATE



COUNTY



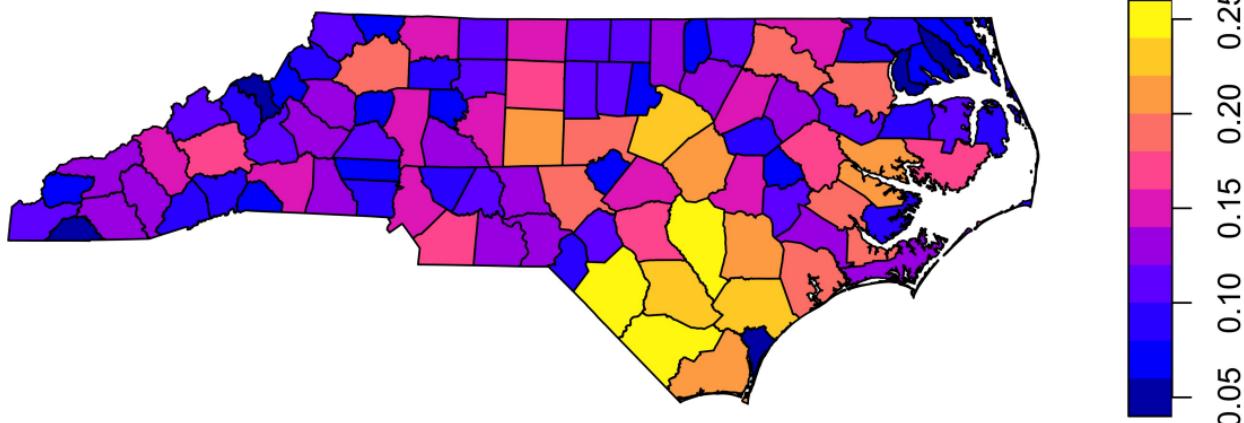
FIPS



More Plotting

```
plot(nc["AREA"])
```

AREA



Graticules

```
par(oma=c(0,2,0,0))
plot(nc["AREA"], graticule=TRUE, axes=TRUE, las=1)
```

Geometries

```
par(oma=c(0,2,0,0))
plot(st_geometry(nc), graticule=TRUE, axes=TRUE, las=1)
```

ggplot2

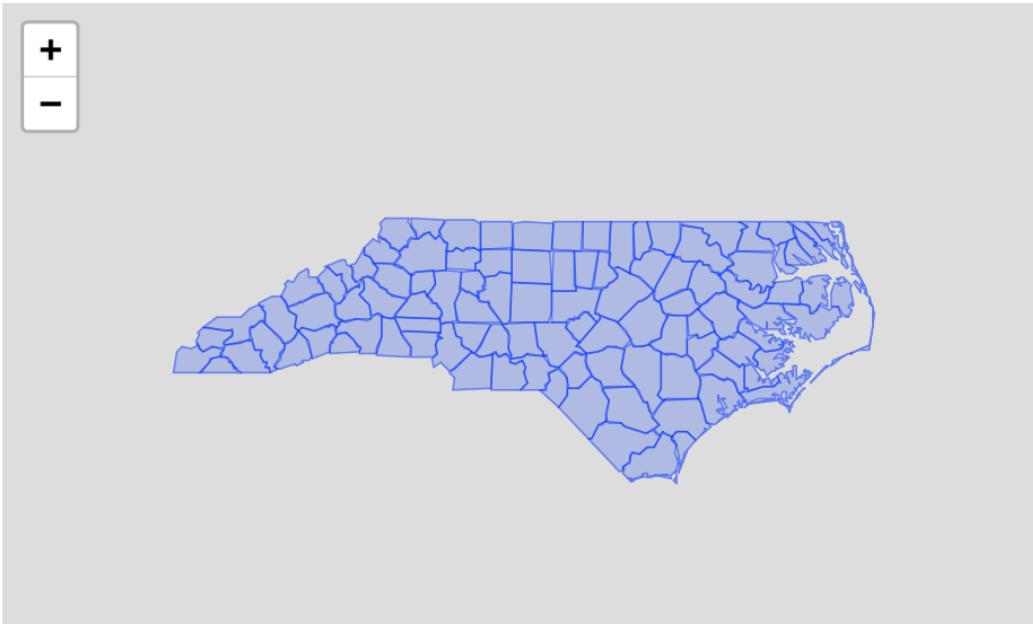
```
ggplot(nc, aes(fill=AREA)) +  
  geom_sf()
```

ggplot2 + palettes

```
ggplot(nc, aes(fill=AREA)) +  
  geom_sf() +  
  scale_fill_viridis_c()
```

leaflet

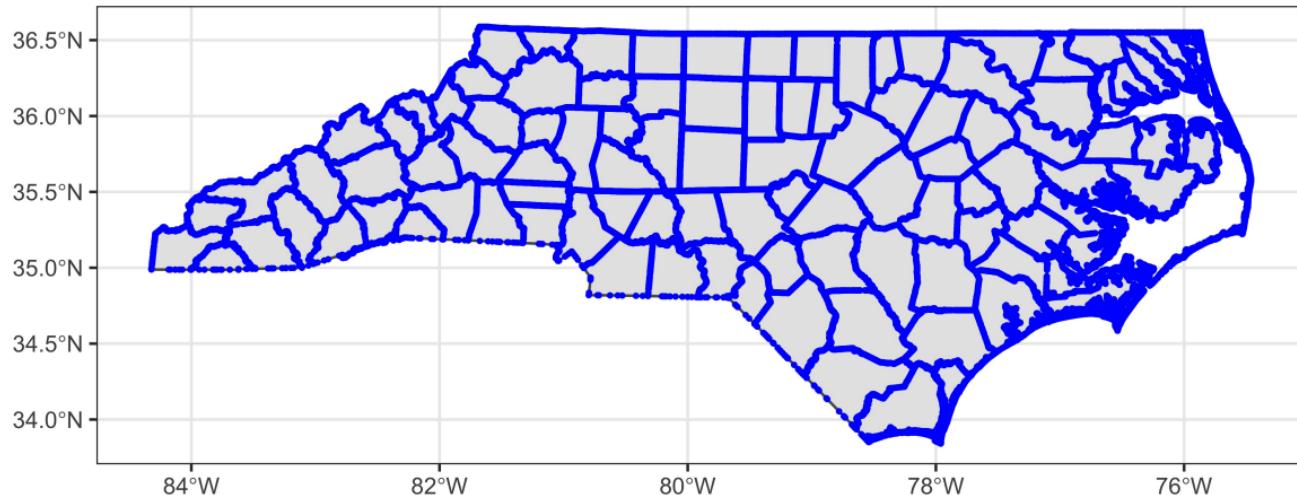
```
st_transform(nc, "+proj=longlat +datum=WGS84") %>%  
  leaflet::leaflet(width = 600, height = 400) %>%  
    leaflet::addPolygons(  
      weight = 1,  
      popup = ~COUNTY,  
      highlightOptions = leaflet::highlightOptions(color = "red", weight = 2, bringToFront = TRUE)  
    )
```



GIS in R

Geometry casting

```
nc_pts = st_cast(nc, "MULTIPOINT")
ggplot() +
  geom_sf(data=nc) +
  geom_sf(data=nc_pts, size=0.5, color="blue")
```



Grouping

```
(nc_state = st_union(nc))

## Geometry set for 1 feature
## Geometry type: MULTIPOLYGON
## Dimension: XY
## Bounding box: xmin: -84.32186 ymin: 33.84175 xmax: -75.46003 ymax: 36.58815
## Geodetic CRS: NAD83

## MULTIPOLYGON (((-75.82791 36.19327, -75.82931 3...
```



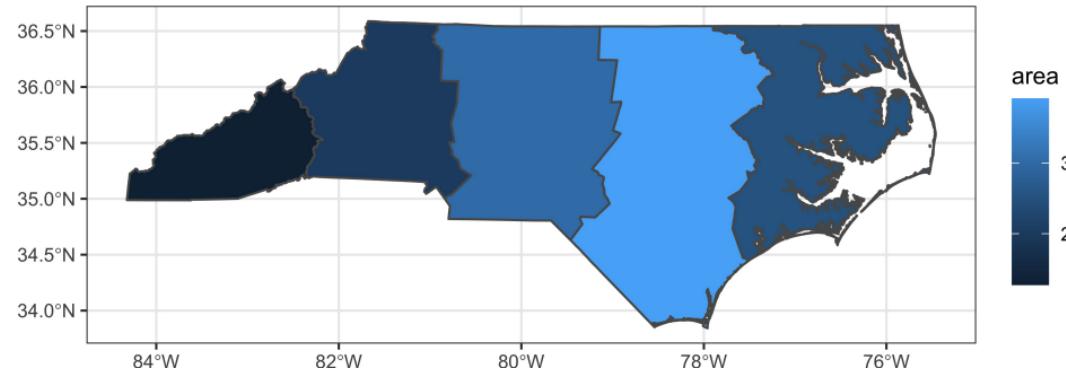
```
ggplot() + geom_sf(data=nc_state)
```

sf & dplyr

```
nc_cut = nc %>%  
  mutate(  
    ctr_x = st_centroid(nc) %>% st_coordinates() %>% .[,1],  
    region = cut(ctr_x, breaks = 5)  
)  
  
## Warning in st_centroid.sf(nc): st_centroid assumes attributes are constant over geometries of x  
  
ggplot(nc_cut) +  
  geom_sf(aes(fill=region)) +  
  guides(fill = "none")
```

sf & dplyr (cont.)

```
nc_cut2 = nc_cut %>%  
  group_by(region) %>%  
  summarize(  
    area = sum(AREA)  
)  
  
ggplot() + geom_sf(data=nc_cut2, aes(fill=area))
```

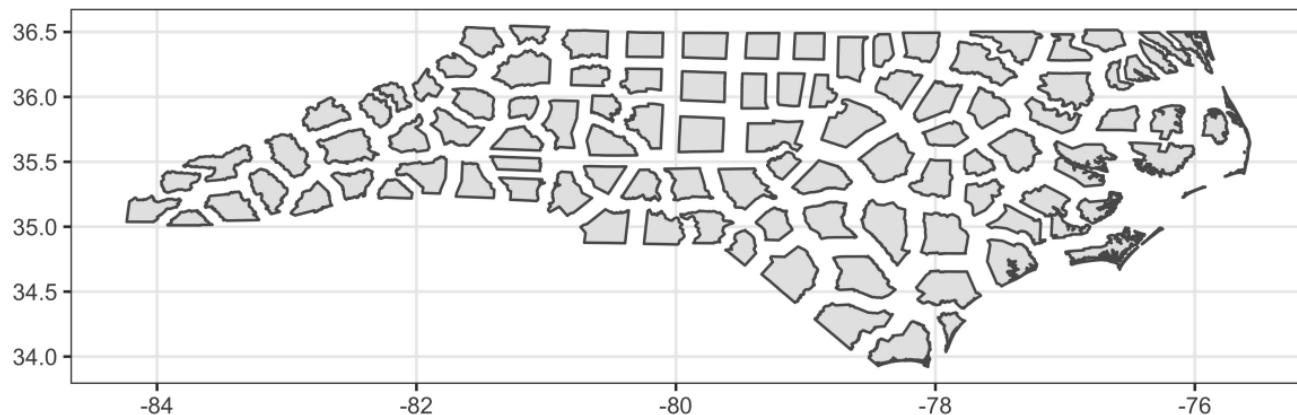


Affine Transformations

```
rotate = function(a) matrix(c(cos(a), sin(a), -sin(a), cos(a)), 2, 2)  
(ggplot() + geom_sf(data=nc_state) * rotate(-pi/4))) +  
(ggplot() + geom_sf(data=nc_state) * rotate(pi/6)))
```

Scaling + Translations

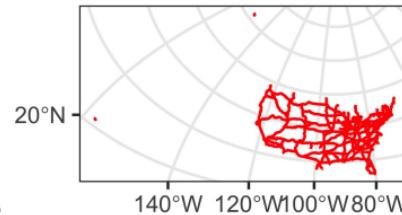
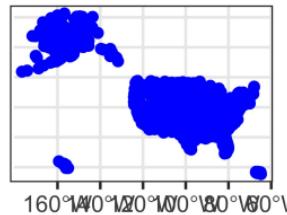
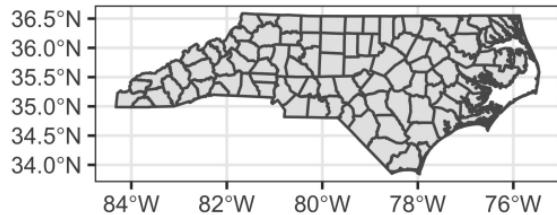
```
ctrd = st_centroid(st_geometry(nc))
nc_scaled = (st_geometry(nc) - ctrd) * 0.66 + ctrd
ggplot() + geom_sf(data=nc_scaled)
```



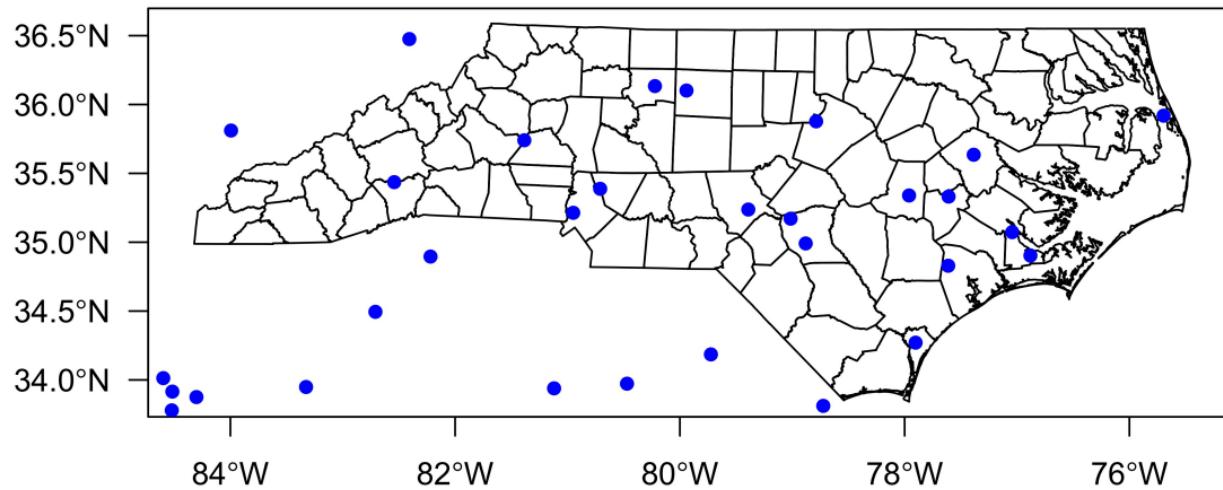
Some other data

```
air = read_sf("data/gis/airports/", quiet=TRUE)
hwy = read_sf("data/gis/us_interstates/", quiet=TRUE)
```

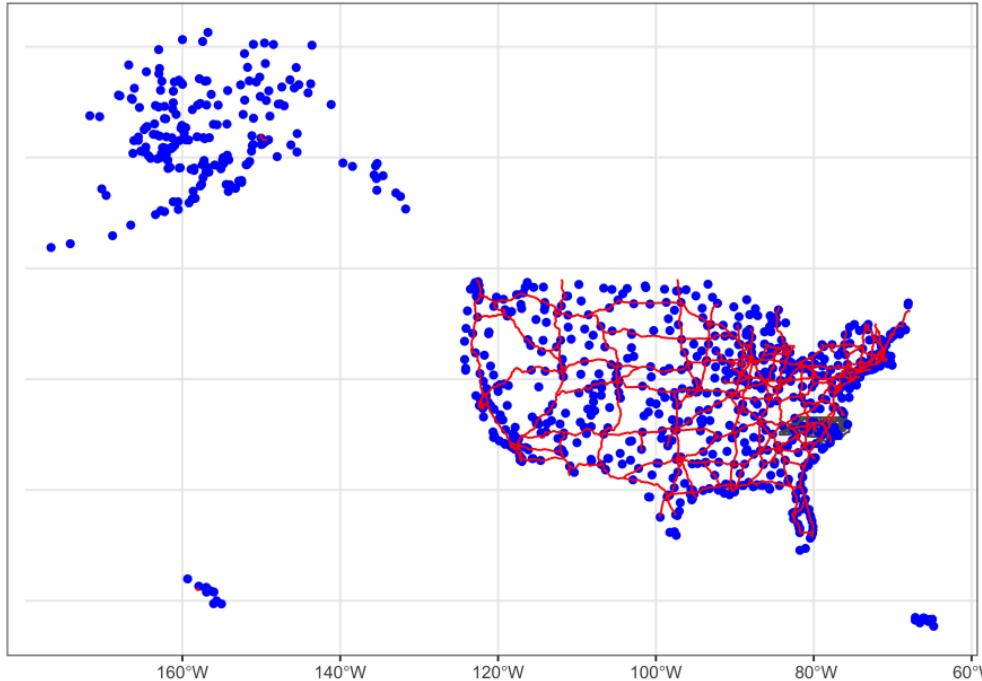
```
(ggplot(nc) + geom_sf() +
(ggplot(air) + geom_sf(color = "blue")) +
(ggplot(hwy) + geom_sf(color = "red"))
```



Overlays?



Overlays? (ggplot)



Projections

```
st_crs(nc)
```

```
## Coordinate Reference System:  
##   User input: NAD83  
##   wkt:  
## GEOGCRS["NAD83",  
##   DATUM["North American Datum 1983",  
##         ELLIPSOID["GRS 1980",6378137,298.257222101,  
##                     LENGTHUNIT["metre",1]],]  
##   PRIMEM["Greenwich",0,  
##           ANGLEUNIT["degree",0.0174532925199433]],  
##   CS[ellipsoidal,2],  
##     AXIS["latitude",north,  
##           ORDER[1],  
##           ANGLEUNIT["degree",0.0174532925199433]],  
##     AXIS["longitude",east,  
##           ORDER[2],  
##           ANGLEUNIT["degree",0.0174532925199433]],  
##   ID["EPSG",4269]]
```

```
st_crs(hwy)
```

```
## Coordinate Reference System:  
##   User input: NAD83 / UTM zone 15N  
##   wkt:  
## PROJCRS["NAD83 / UTM zone 15N",  
##   BASEGEOGCRS["NAD83",  
##     DATUM["North American Datum 1983",  
##             ELLIPSOID["GRS 1980",6378137,298.257222101,  
##                         LENGTHUNIT["metre",1]]],
```

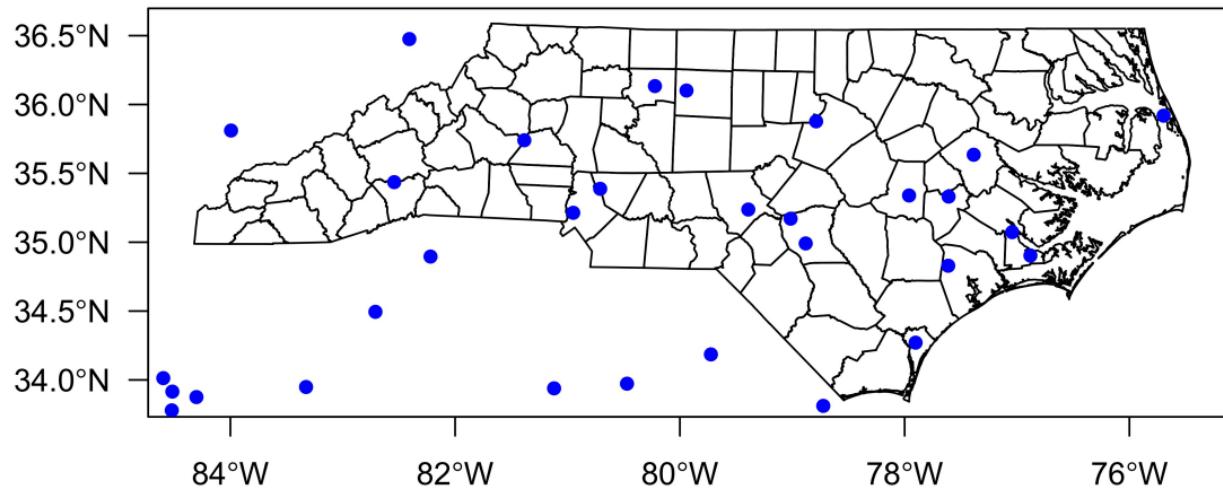
```
st_crs(air)
```

```
## Coordinate Reference System:  
##   User input: NAD83  
##   wkt:  
## GEOGCRS["NAD83",  
##   DATUM["North American Datum 1983",  
##         ELLIPSOID["GRS 1980",6378137,298.257222101,  
##                     LENGTHUNIT["metre",1]],]  
##   PRIMEM["Greenwich",0,  
##           ANGLEUNIT["degree",0.0174532925199433]],  
##   CS[ellipsoidal,2],  
##     AXIS["latitude",north,  
##           ORDER[1],  
##           ANGLEUNIT["degree",0.0174532925199433]],  
##     AXIS["longitude",east,  
##           ORDER[2],  
##           ANGLEUNIT["degree",0.0174532925199433]],  
##   ID["EPSG",4269]]
```

Aside - UTM Zones

Airport Example

NC Airports



Sparse Insections

```
st_intersects(nc[20:30,], air) %>% str()

## # List of 11
## $ : int(0)
## $ : int 268
## $ : int 717
## $ : int(0)
## $ : int(0)
## $ : int(0)
## $ : int(0)
## - attr(*, "predicate")= chr "intersects"
## - attr(*, "region.id")= chr [1:11] "1" "2" "3" "4" ...
## - attr(*, "ncol")= int 940
## - attr(*, "class")= chr [1:2] "sgbp" "list"
```

Dense Injections

```
st_intersects(nc, air, sparse=FALSE) %>% str()  
## #> logi [1:100, 1:940] FALSE FALSE FALSE FALSE FALSE FALSE ...  
  
st_intersects(nc, air, sparse=FALSE) %>% .[20:30, 260:270]  
  
##      [,1]  [,2]  [,3]  [,4]  [,5]  [,6]  [,7]  [,8]  [,9]  [,10]  [,11]  
## [1,] FALSE  
## [2,] FALSE  
## [3,] FALSE  
## [4,] FALSE  
## [5,] FALSE  
## [6,] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE TRUE FALSE FALSE  
## [7,] FALSE  
## [8,] FALSE  
## [9,] FALSE  
## [10,] FALSE  
## [11,] FALSE FALSE
```

Which counties have airports?

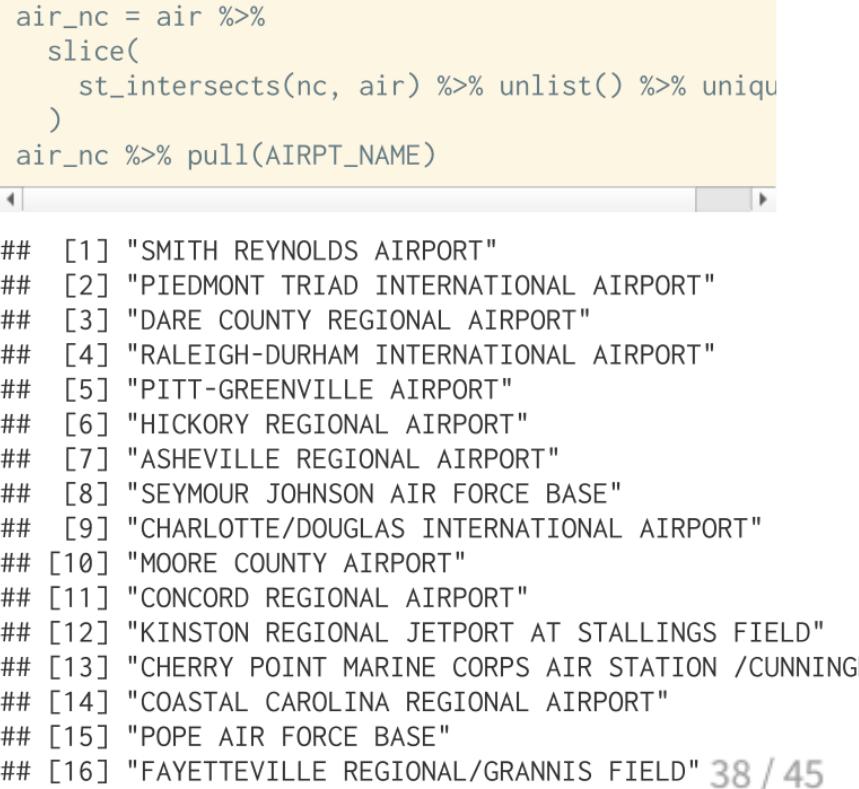
```
nc_air = nc %>%
  mutate(
    n_air = map_int(st_intersects(nc, air), length) %>%
  filter(n_air > 0)

nc_air %>% pull(COUNTY)
```



```
air_nc = air %>%
  slice(
    st_intersects(nc, air) %>% unlist() %>% unique
  )
air_nc %>% pull(AIRPT_NAME)

## [1] "SMITH REYNOLDS AIRPORT"
## [2] "PIEDMONT TRIAD INTERNATIONAL AIRPORT"
## [3] "DARE COUNTY REGIONAL AIRPORT"
## [4] "RALEIGH-DURHAM INTERNATIONAL AIRPORT"
## [5] "PITT-GREENVILLE AIRPORT"
## [6] "HICKORY REGIONAL AIRPORT"
## [7] "ASHEVILLE REGIONAL AIRPORT"
## [8] "SEYMOUR JOHNSON AIR FORCE BASE"
## [9] "CHARLOTTE/DOUGLAS INTERNATIONAL AIRPORT"
## [10] "MOORE COUNTY AIRPORT"
## [11] "CONCORD REGIONAL AIRPORT"
## [12] "KINSTON REGIONAL JETPORT AT STALLINGS FIELD"
## [13] "CHERRY POINT MARINE CORPS AIR STATION / CUNNINGHAM FIELD"
## [14] "COASTAL CAROLINA REGIONAL AIRPORT"
## [15] "POPE AIR FORCE BASE"
## [16] "FAYETTEVILLE REGIONAL/GRANNIS FIELD"
```



Highway Example

Highways

```
ggplot() +  
  geom_sf(data=nc) +  
  geom_sf(data=hwy, col='red')
```

NC Interstate Highways

```
hwy_nc = st_intersection(hwy, nc)

## Warning: attribute variables are assumed to be spatially constant throughout all geometries

ggplot() +
  geom_sf(data=nc) +
  geom_sf(data=hwy_nc, col='red')
```

Counties near the interstate (Projection)

```
nc_utm  = st_transform(nc, "+proj=utm +zone=17 +datum=NAD83 +units=m +no_defs")
hwy_utm = st_transform(hwy, "+proj=utm +zone=17 +datum=NAD83 +units=m +no_defs")
hwy_nc = st_intersection(hwy_utm, nc_utm)

## Warning: attribute variables are assumed to be spatially constant throughout all geometries

ggplot() +
  geom_sf(data=nc_utm) +
  geom_sf(data=hwy_nc, col='red')
```

Counties near the interstate (Buffering)

```
hwy_nc_buffer = hwy_nc %>%
  st_buffer(10000)

ggplot() +
  geom_sf(data=nc_utm) +
  geom_sf(data=hwy_nc, color='red') +
  geom_sf(data=hwy_nc_buffer, fill='red', alpha=0.3)
```

Counties near the interstate (Buffering + Union)

```
hwy_nc_buffer = hwy_nc %>%  
  st_buffer(10000) %>%  
  st_union() %>%  
  st_sf()  
  
ggplot() +  
  geom_sf(data=nc_utm) +  
  geom_sf(data=hwy_nc, color='red') +  
  geom_sf(data=hwy_nc_buffer, fill='red', alpha=0.3)
```

Example

How many counties in North Carolina are within 5, 10, 20, or 50 km of an interstate highway?