

Geographic visualization and analysis in R with tigris

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Abstract The TIGER/Line shapefiles from the United States Census Bureau are commonly used for the mapping and analysis of US demographic trends. The *tigris* package provides a uniform interface for R users to download and work with these shapefiles. Functions in *tigris* allow R users to request Census geographic datasets using familiar geographic identifiers and return those datasets as Spatial DataFrames. Once downloaded, *tigris* helps R users flexibly combine geographic datasets and join them to tabular data. In turn, *tigris* helps facilitate both the visualization of and analysis spatial data in R. This article provides an overview of such geospatial workflows in R, and illustrates how the *tigris* package can assist with such workflows by providing programmatic access to spatial data.

Introduction

Analysis and visualization of geographic data are often core components of the analytical workflow for researchers and data scientists; as such, access to open and reliable geographic datasets are of paramount importance. The United States Census Bureau provides access to such data in the form of its TIGER/Line shapefile products. The files are extracts from the Census Bureau's Master Address File/Topologically Integrated Geographic Encoding and Referencing (TIGER) database, which in turn are released to the public as shapefiles, a common format for encoding geographic data as vectors (e.g. points, lines, and polygons). Available TIGER/Line shapefiles include all of the Census Bureau's areal enumeration units, such as states, counties, Census tracts, and Census blocks; transportation data such as roads and railways; and both linear and areal hydrography. The TIGER/Line files are updated annually, and include columns that allow them to be joined with other tabular data, including demographic data products released by the Census Bureau (?).

The *tigris* package aims to simplify the process of working with these datasets for R users. With functions in *tigris*, R users can specify the data type and geography for which they would like to obtain geographic data, and return the corresponding TIGER/Line data as an R object of class `Spatial*DataFrame` as read in by the *rgdal* package. This article provides an overview of the *tigris* package, and gives examples that show how it can contribute to common geographic visualization and spatial analysis workflows in R. The first section explains the core functionality of the package; the second section discusses how R users can create both static and interactive visualizations with data from the package, leveraging functionality in R packages like *ggplot2*, *rgeos*, and *leaflet*; and the final section shows how *tigris* can integrate with spatial statistics packages like *GWModel* to facilitate geospatial analyses.

Geographic data and Census visualization in R

To cover:

- Overview of the TIGER/Line shapefiles
- Objects of class `Spatial` in R and the *rgdal* package
- Other packages, including:
 - *USCensus2010*
 - *acs*
 - *choroplethr*
- Space *tigris* occupies - uniform interface for downloading and delimiting all TIGER/Line and cartographic boundary shapefiles

Core functionality

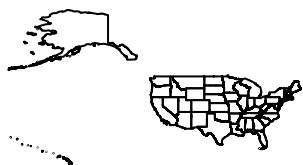
The core functionality in *tigris* involves the usage of a series of functions, each corresponding to a single Census Bureau geography of interest, to access geographic data from the US Census Bureau. *tigris* grants access to both the core TIGER/Line shapefiles as well as the Census Bureau's Cartographic Boundary Files. Cartographic Boundary Files, following the Census Bureau (2015), "are simplified representations of selected geographic areas from the Census Bureau's MAF/TIGER geographic database" (?). However, these files are also clipped to the shoreline of the United States, which can introduce additional detail for coastal features.

To download geographic data using *tigris*, the R user calls the function corresponding to the desired geography. For example, to obtain a *SpatialPolygonsDataFrame* of US states from the TIGER/Line dataset, the user calls the *states* function in *tigris*, which can then be plotted with the *plot* function from the *sp* package:

```
library(tigris)
library(sp)

us_states <- states()

plot(us_states)
```



The *states* function call instructs *tigris* to fetch a TIGER/Line shapefile from the US Census Bureau that represents the boundaries of the 50 US states, the District of Columbia, and US territories. *tigris* then uses the *rgdal* package to load the data into the user's R session as an object of class *SpatialDataFrame*. Many functions in *tigris* have a parameter, *cb*, that if set to *TRUE* will direct *tigris* to load a cartographic boundary file instead. Cartographic boundary files default to a simplified resolution of 1:500,000; in some cases, as with *states*, resolutions of 1:5 million and 1:20 million are example. For example, an R user could specify the following modifications to the *states* function, and retrieve a simplified dataset.

```
us_states_20m <- states(cb = TRUE, resolution = '20m')

#> Warning in readOGR(dsn = cache_dir, layer = shape, encoding = "UTF-8",
#> verbose = FALSE, : Z-dimension discarded

ri <- us_states[us_states$NAME == 'Rhode Island', ]
ri_20m <- us_states_20m[us_states_20m$NAME == 'Rhode Island', ]

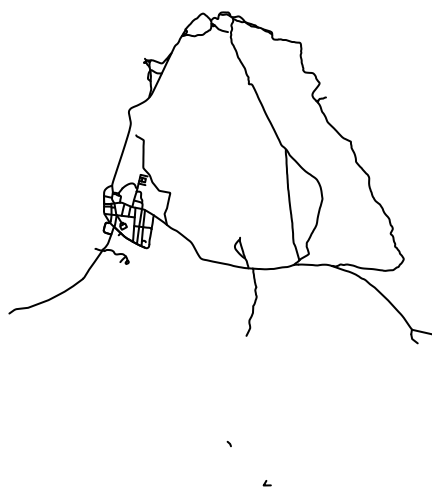
plot(ri)
plot(ri_20m, border = 'red', add = TRUE)
```



The plot illustrates some of the differences between the TIGER/Line shapefiles and the cartographic boundary files, in this instance for the state of Rhode Island. TIGER/Line files include water area, whereas the cartographic boundary files do not; however, in interior areas, they are not nearly as detailed.

In many instances, Census geographic data are only available at sub-national levels, or the R user might want to specify how to subset the data geographically *a priori* by state and optionally county. Census geographic data are referenced, however, by their Federal Information Processing Standard (FIPS) codes, which are codes that uniquely identify geographic entities in the Census database. When applicable, *tigris* uses smart state and county lookup to simplify this process for R users, allowing users to subset data based on the name or postal code of the desired state, or name of the county, rather than their FIPS codes.

```
kw_roads <- roads('HI', 'Kalawao')  
  
#> Using FIPS code '15' for state 'HI'  
#> Using FIPS code '005' for 'Kalawao County'  
  
plot(kw_roads)
```



When *tigris* downloads Census shapefiles to the R user's computer, it uses the *rappdirs* package to cache the downloads for future access. In turn, once the R user has downloaded the Census geographic data, *tigris* will know where to look for it and will not need to re-download.

Some Census shapefiles, like roads, are only available by county; however, an R user may want a roads dataset that represents multiple counties. *tigris* has built-in functionality to handle these circumstances. Data loaded into R by *tigris* have a special attribute, *tigris_type*, that identifies the type of geographic data represented by the object. In turn, objects of the same *tigris_type* can be combined using the function *rbind_tigris*, which takes multiple *tigris* objects (or optionally a list) and combines them into a single object.

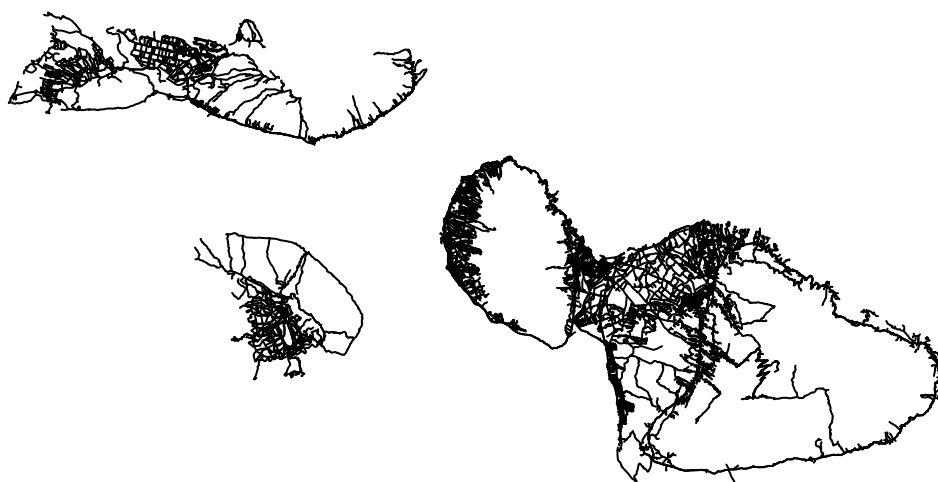
```
tigris_type(kw_roads)
#> [1] "road"

maui_roads <- roads('HI', 'Maui')

#> Using FIPS code '15' for state 'HI'
#> Using FIPS code '009' for 'Maui County'

maui_kw_roads <- rbind_tigris(kw_roads, maui_roads)

plot(maui_kw_roads)
```



The Census Bureau releases updated TIGER/Line shapefiles every year, and these yearly updates are available to *tigris* users. *tigris* defaults to the 2014 shapefiles, which at the time of this writing is the most recent year available for the cartographic boundary files. However, *tigris* users can supply a different year to a *tigris* function as a named argument to obtain data for a different year; for example, `year = 2015` in the function call will fetch the most recent TIGER/Line shapefiles from 2015. Additionally, R users can set this as a global option in their R session by entering the command `options(tigris_year = 2015)`.

Visualization with *tigris*

A core component of geospatial analysis in R is mapping and visualization, and *tigris* assists with this by providing programmatic access to quality US Census geographic datasets for R users. On a basic level, R users can quickly visualize *tigris* datasets with the `plot` function available in *sp*, as evidenced in the examples above. *tigris* objects also work well with the popular *ggplot2* package for visualization in R. The example below uses *ggplot2* to visualize state legislative districts in Vermont from *tigris*:

```
library(tigris)
library(ggplot2)
library(ggthemes)

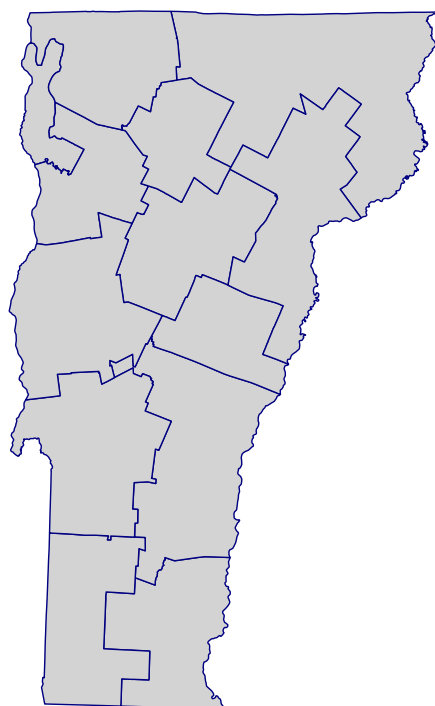
vt <- state_legislative_districts('Vermont', house = 'upper', cb = TRUE)

#> Using FIPS code '50' for state 'Vermont'

vt_map <- fortify(vt)

#> Regions defined for each Polygons

ggplot() +
  geom_map(data = vt_map, map = vt_map,
    aes(x = long, y = lat, map_id = id),
    color = "navy", fill = "lightgrey",
    size = 0.25) +
  coord_map() +
  theme_map()
```



Commonly, geographic visualization will involve more than just plotting the outlines of the data, however. Instead, practitioners will want to use mapping to show the geographic distribution of some attribute of interest, which may be derived from some analysis in an R data frame. To facilitate this process, *tigris* includes a function, `geo_join`, to ease the sometimes-messy process of merging tabular data to spatial data frames. Such joined data can then be used for statistical mapping, such as with a choropleth map that shows variation in an attribute by the shading of polygons.

In turn, data functions in *tigris* along with `geo_join` can be used in visualization workflows alongside spatial data management and mapping packages in R. The following example uses `geo_join` to merge spatial data from *tigris* to demographic data from the *acs* package, and then creates a static map from the data with the *tmap* package for thematic mapping.

The R user first loads the three main libraries, in addition to *stringr* and *rgdal* for data processing. The user specifies the names of counties for which to fetch Census tract spatial data, and passes this to the `tracts` function to create an object of class `SpatialPolygonsDataFrame` representing Census tracts in the Dallas-Fort Worth, Texas metropolitan area.

```
library(tigris)
library(acs)
library(stringr)
library(tmap)
library(rgdal)

dfw_counties <- c('Dallas', 'Tarrant', 'Denton', 'Rockwall', 'Collin ',
                  'Wise', 'Parker', 'Ellis', 'Kaufman', 'Hunt', 'Delta', 'Johnson')

dfw_tracts <- tracts('Texas', county = dfw_counties, cb = TRUE)
```

The next step involves fetching data from the US Census Bureau's data API using the *acs* package. However, counties in the *acs* package are not referenced by name, but rather by numeric FIPS codes. When loaded, *tigris* also loads a data frame named `fips_codes` that provides a reference between the names of states and counties, and their corresponding FIPS codes; this information in turn can be leveraged in a function to convert the vector of county names to a vector of numeric FIPS codes, and used to get demographic data, in this instance on median household income, from the Census Bureau. The R user then merges the demographic data to the shape data using *tigris*'s `geo_join` function.

```

to_fips <- function(state, county_name) {
  with_county <- paste(county_name, 'County')
  sub1 <- fips_codes[fips_codes$county == with_county & fips_codes$state == state, ]
  return(as.numeric(sub1$county_code))
}

dfw_fips <- sapply(dfw_counties, function(x) to_fips('TX', x))

income_data <- acs.fetch(endyear = 2012,
                        geography = geo.make(state = "TX",
                                             county = dfw_fips,
                                             tract = "*"),
                        variable = "B19013_001")

income_df <- data.frame(paste0(as.character(income_data@geography$state),
                              str_pad(as.character(income_data@geography$county), 3, 'left', '0')),
                      str_pad(as.character(income_data@geography$tract), 5, 'left', '0')),
                      income_data@estimate)

colnames(income_df) <- c("GEOID", "hhincome")

dfw_merged <- geo_join(dfw_tracts, income_df, "GEOID", "GEOID")

```

The data are now ready for visualization. To provide spatial reference to the Census tracts on the map, major roads can be obtained with the `primary_roads` function in `tigris`, and added to the map as well. The R user then projects the spatial data to an appropriate projected coordinate system - in this case Universal Transverse Mercator Zone 14N - and maps the data with functions in the `tmap` package.

```

rds <- primary_roads()

to_utm14n <- function(x) {
  return(spTransform(x, CRS('+init=epsg:26914'))))
}

tm_shape(to_utm14n(dfw_merged)) +
  tm_fill('hhincome', style = 'quantile', n = 7, palette = 'Greens', title = '') +
tm_shape(rds) +
  tm_lines(col = 'darkgrey') +
tm_layout(bg.color = 'ivory', title = 'Median household income by Census tract, Dallas-Fort Worth',
          legend.position = c('right', 'bottom'), title.bg.color = 'ivory', legend.text.size = 1,
          legend.width = 0.2, legend.frame = TRUE) +
tm_credits('Data source: 2008-2012 American Community Survey',
          position = c('left', 'bottom'))

```

The resultant map is comparable to cartographic output from a desktop geographic information system, and can be produced entirely within R without having to seek out and download data externally.

Spatial analysis with `tigris`

In addition to visualization, `tigris` works well within common spatial analysis workflows in R. Geospatial analyses in R span a wide variety of packages, but are arguably associated most commonly with the `rgeos` package, which is an R interface to the C Geometry Engine - Open Source. The `rgeos` package includes functions that in many cases mirror the analytical capabilities of geographic information systems software.

Data from `tigris` alongside analytic functions from `rgeos` equips R users to quickly answer a host of common geographic questions using Census data. The previous example showed how to visualize a quantitative attribute from the American Community Survey using geographic data from `tigris`, and added a second `tigris` layer, primary roads, to provide reference. Spatial analysis functions from `rgeos` can explicitly consider how different `tigris` layers relate to one another spatially, which in turn can contribute to broader spatial analysis workflows.

Consider the following hypothetical example: an analyst wishes to identify the Census block groups within 500 meters of the Red River in Fargo, North Dakota. Functions in `tigris` combined with

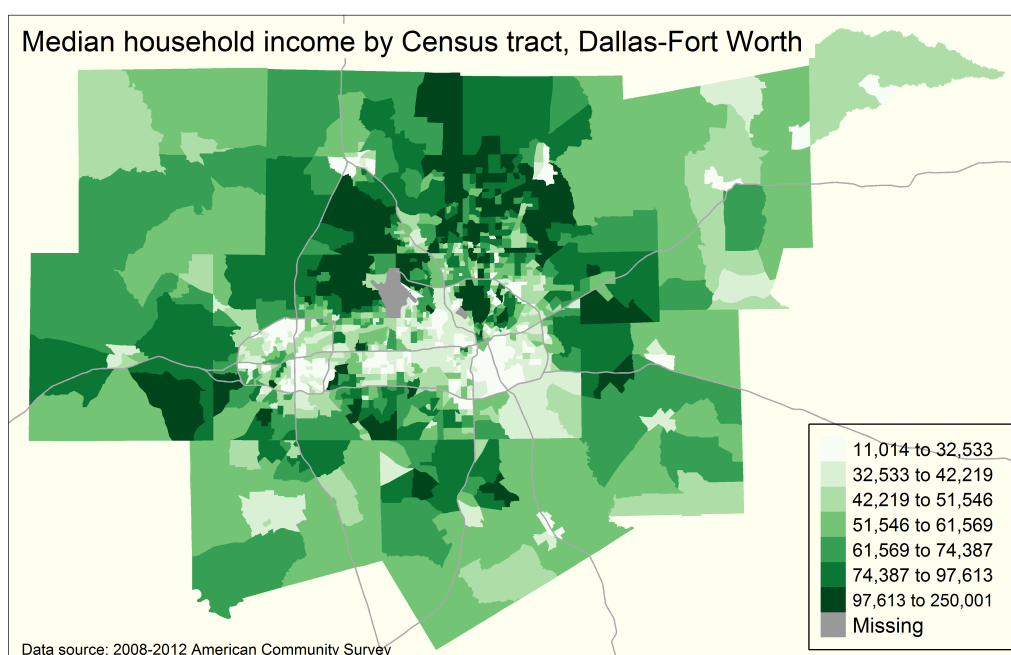


Figure 1: Map of median household income by Census tract in the Dallas-Fort Worth, Texas metropolitan area.

`rgdal` and `rgeos` make this process straightforward. To begin, the analyst identifies which datasets are needed to answer this question. Block groups are available by state and optionally by county, and water features are available by county within states; the `block_groups` and `linear_water` functions can be called to fetch the requisite data for Cass County, ND. Beyond this, the analyst will need to call the `places` function to get outlines of Census-designated places, which includes city boundaries; the outline of Fargo can be extracted from here. Each function is wrapped in the `to_utm14n` function used earlier to transform the data for North Dakota into an appropriate projected coordinate system. The analyst then subsets the data to retrieve a `SpatialLinesDataFrame` that represents the Red River from the original water dataset, and a `SpatialPolygonsDataFrame` with one polygon representing the shape of Fargo.

```
library(tigris)
library(rgeos)
library(rgdal)

to_utm14n <- function(x) {
  return(spTransform(x, CRS('+init=epsg:26914'))))
}

water <- to_utm14n(linear_water('ND', 'Cass'))

bgs <- to_utm14n(block_groups('ND', 'Cass'))

pl <- to_utm14n(places('ND'))

red_river <- gLineMerge(water[grep('Red Riv', water$FULLNAME), ])

fargo <- pl[pl$NAME == 'Fargo', ]
```

From here, the analyst can use spatial analysis functions available within `rgeos` to retrieve the desired block groups. First, the analyst calls `gWithin` to find the block groups that are located within the city of Fargo, returning a new `SpatialPolygonsDataFrame` named `fargo_bgs`. Next, the `gDistance` function is used to generate a new column in `fargo_bgs` that represents the distance from each block

group to the Red River in meters, which is the unit of measurement of the dataset's projected coordinate system. Finally, the analyst can subset `fargo_bgs` to identify those block groups with a distance value less than 500 meters.

```
fargo_bgs <- bgs[as.vector(gWithin(bgs, fargo, byid = TRUE)), ]

fargo_bgs$distance <- as.vector(gDistance(fargo_bgs, red_river, byid = TRUE))

within_500m <- fargo_bgs[fargo_bgs$distance < 500, ]
```

These results can then be visualized using the `ggmap` package:

```
library(ggmap)

fargo_xy <- spTransform(within_500m, CRS("+proj=longlat +datum=WGS84"))

data <- fortify(fargo_xy)

ggmap(get_map(location = 'Fargo', zoom = 12, source = 'stamen', maptype = 'toner-lite')) +
  geom_polygon(data = data, aes(x = long, y = lat, group = group),
    alpha = 0.5, fill = 'blue', color = 'black')
```

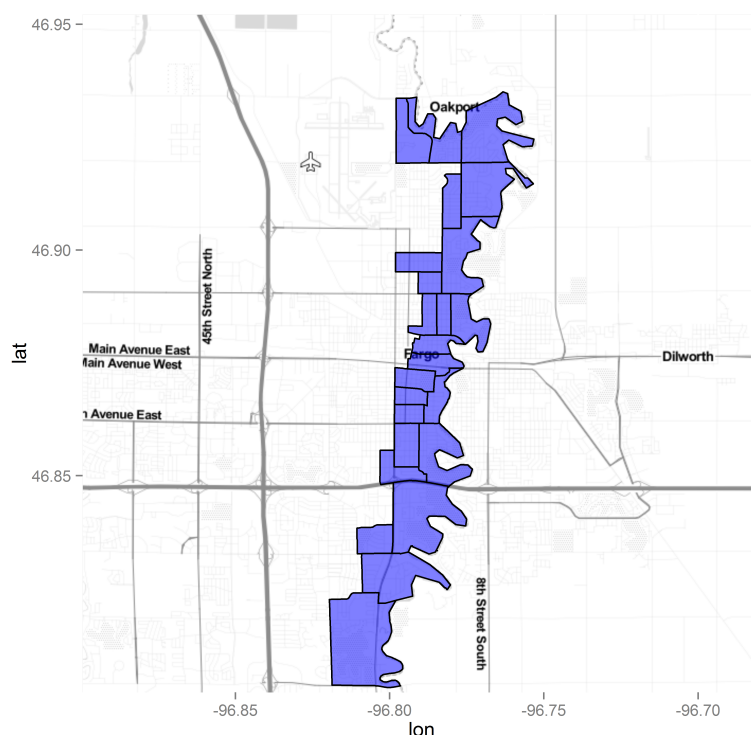


Figure 2: Block groups in Fargo, North Dakota within 500m of the Red River.

In this example, the entire process of data retrieval and subsetting through spatial analysis, which commonly requires multiple steps in a traditional GIS environment, is reduced to a few lines of R code.

Putting it all together: mapping data from the US Internal Revenue Service

To this point, this paper has employed simplified examples to demonstrate the functionality of `tigris`; the following scenario combines these examples into an applied analytic and visualization workflow. This example presumes that an R user would like to produce a series of interactive maps for major US metropolitan areas using aggregated taxation data from the United States Internal Revenue Service (IRS), which are made available at the zip code level. Zip codes, however, are not physical areas but rather designations given by the United States Postal Service (USPS) to guide mail routes. The US Census Bureau provides approximations of zip code geography, called Zip Code Tabulation Areas

(ZCTAs). ZCTAs are geographies built from Census blocks that comprise those blocks in which a plurality (check this) of street addresses have a given zip code. ZCTAs are available in *tigris* from the *zctas* function.

Additionally, ZCTAs do not have a clear correspondence between their boundaries and those of other Census units; in turn, ZCTA boundaries will commonly cross those of metropolitan areas, which are county-based. However, *tigris* provides programmatic access to metropolitan area boundaries as well, which in turn can be used to identify intersecting ZCTAs through spatial overlay with the *rgeos* package. The resultant spatial data can then be merged to data from the IRS and visualized.

Such a workflow could resemble the following. An analyst reads in raw data from the IRS website as an R data frame, and uses the *dplyr* package to subset the data frame and identify the average total income reported to the IRS by zip code, assigning it to the variable *df*.

```
library(dplyr)
library(stringr)
library(readr)

# Read in the IRS data
zip_data <- 'https://www.irs.gov/pub/irs-soi/13zpallnoagi.csv'

df <- read_csv(zip_data) %>%
  mutate(zip_str = str_pad(as.character(ZIPCODE), width = 5, side = 'left', pad = '0'),
         incpr = A02650 / N02650) %>%
  select(zip_str, incpr)
```

The analyst then defines a function that will leverage *tigris* to read in Census ZCTA and metropolitan area datasets as objects of class *SpatialPolygonsDataFrame*, and return the ZCTAs that intersect a given metropolitan area as defined by the analyst.

```
library(tigris)
library(rgeos)

# Write function to get ZCTAs for a given metro
get_zips <- function(metro_name) {

  zips <- zctas(cb = TRUE)

  metros <- core_based_statistical_areas(cb = TRUE)

  # Subset for specific metro area (be careful with duplicate cities like "Washington")
  my_metro <- metros[grepl(sprintf("^%s", metro_name), metros$NAME, ignore.case = TRUE), ]

  # Find all ZCTAs that intersect the metro boundary
  my_zips <- zips[as.vector(gIntersects(zips, my_metro, byid = TRUE)), ]

  # Return those ZCTAs
  return(my_zips)

}
```

Next, the analyst writes a second function to create an interactive map of the ZCTAs with the *leaflet* package, which converts objects of class *Spatial*DataFrame* to interactive, web-based maps using the *htmlwidgets* package.

```
library(leaflet)

# Function to map the IRS data
map_zips <- function(data, palette = "PuRd") {

  data_merged <- geo_join(data, df, "ZCTA5CE10", "zip_str")

  pal <- colorQuantile(palette, NULL, n = 7, na.color = '#DBDBDB')

  label <- paste0("Zip Code ", data_merged$ZCTA5CE10, ": $",
                 as.character(round(1000 * data_merged$incpr, 2)))
```

```

leaflet() %>%
  addProviderTiles("CartoDB.DarkMatter") %>%
  addPolygons(data = data_merged,
    fillColor = ~pal(data_merged$incpr),
    fillOpacity = 0.7,
    weight = 0.2,
    smoothFactor = 0.2,
    label = label) %>%
  addLegend(pal = pal,
    values = round(1000 * data_merged$incpr, 2),
    position = "bottomright",
    title = "Average reported income to IRS")
}

```

The analyst can then call the functions to create custom IRS taxation maps by metro area as desired. For example:

```
get_zips('Nashville') %>% map_zips()
```

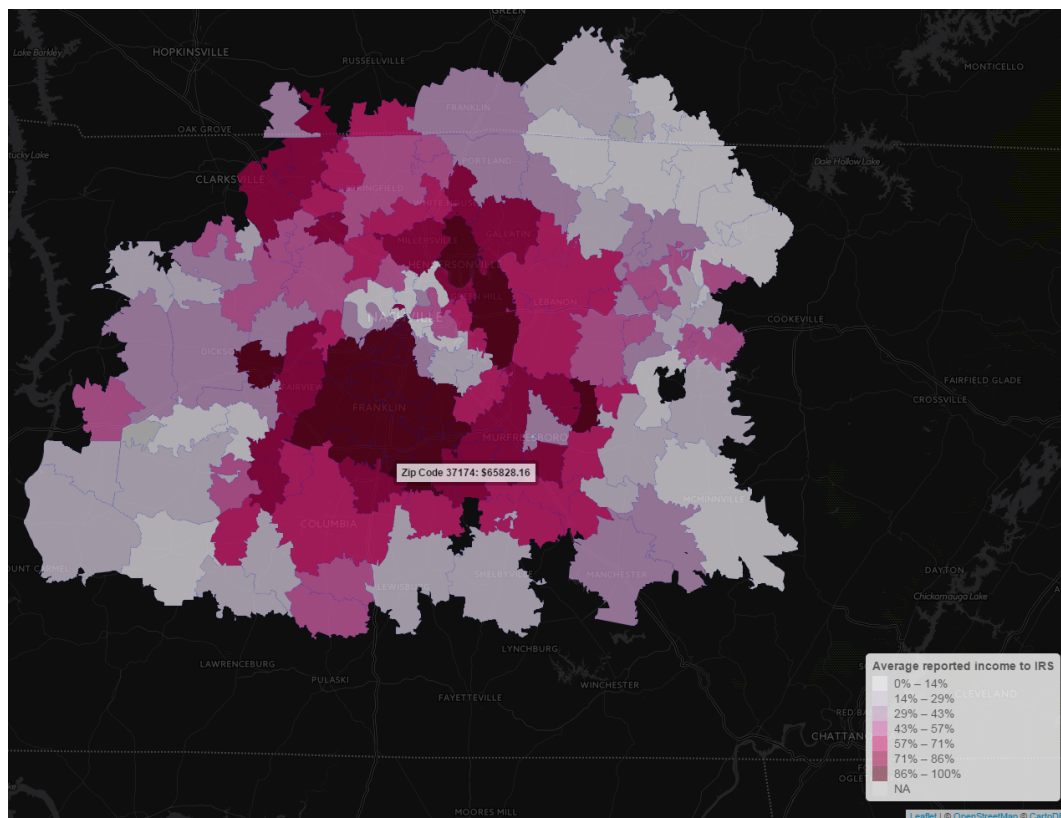


Figure 3: Interactive Leaflet map of average reported IRS income by zip code, Nashville, Tennessee area.

```
get_zips('Sacramento') %>% map_zips(palette = 'YlGnBu')
```

Conclusion

Some comments here about how tigris fits in with other geospatial analysis and visualization packages; how the R ecosystem rivals traditional desktop GIS in its functionality and in many ways is more flexible.

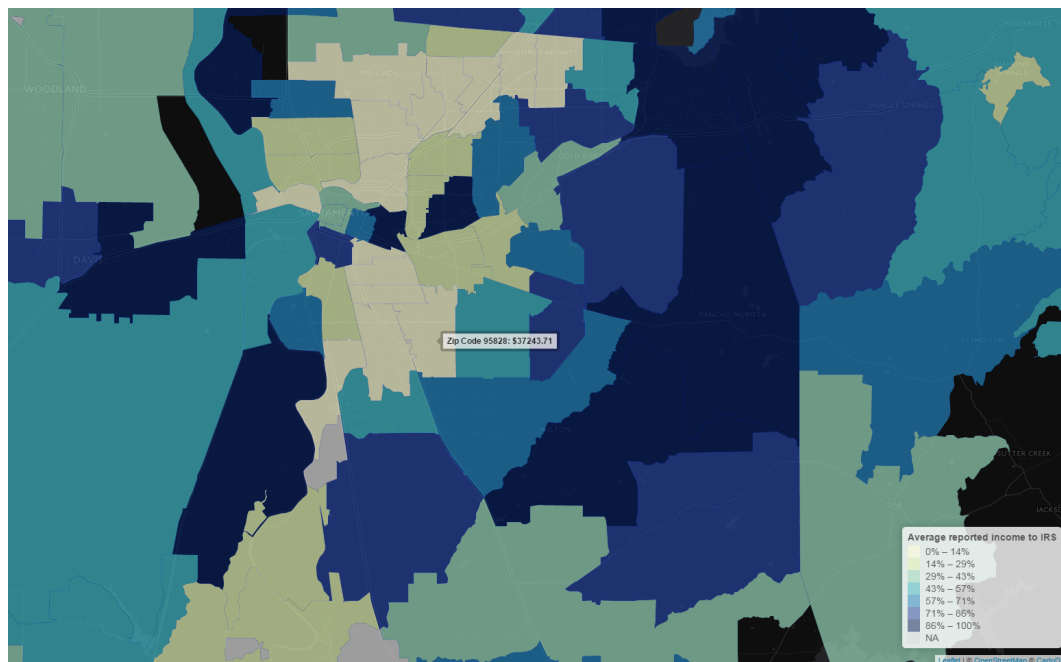


Figure 4: Interactive Leaflet map of average reported IRS income by zip code, Sacramento, California area.

Bibliography

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