geoplot: cartography in gretl

Allin Cottrell and Jack Lucchetti

April 14, 2021

This document describes the `geoplot` addon package for gretl, which is new in version 2020c. We have found it preferable, for reason of efficiency, to implement its core mapping functionality via built-in functions, coded in C. For basic usage, therefore, it's not necessary to load the package explicitly via "`include geoplot.gfn`", as one would usually expect for an addon.

Section 1 below covers some preliminaries which we hope will help the reader understand the basics of cartography via gretl. Section 2 describes the basic workflow for producing a map image. Section 3 then provides a simple worked example and section 4 addresses a potential stumbling block. Section 5 goes over in detail the options to the core `geoplot` function; section 6 tells you what's available via gretl's graphical interface; section 7 explains some "expert" refinements; and section 8 gives our current thinking on possible future directions for maps in gretl. Three appendices cover some technical points that may be of interest to expert users.

1 Preliminaries

Given gretl's user base and vocation, we assume that people will be primarily interested in "thematic" maps, in which geographical areas get different colors according to some variable of interest (for example regions of a country are colored according to their unemployment rates). Fancier maps are out of scope for the present. From here on we'll simply refer to maps of this sort as "maps" and the geographical entities they contain (which may be countries, states, counties, länder or whatever) as "regions". Plotting a map typically involves drawing a number of polygons, filled with appropriate colors, to some device (the screen, or a file).

The essential ingredients for doing this are

1. A geometrical description of the regions.
2. The data for coloring the polygons.
3. Appropriate software for producing the map.

1.1 The geometry

Let's say we have n regions, indexed by i. Region i is represented geometrically as a collection of k_i polygons (think islands in an archipelago), indexed by j. Each polygon is defined by $h_{i,j}$ coordinates. Typically, each coordinate vector has two elements, latitude and longitude.

The information on each region has two components:

Metadata At minimum this should include the region's identifier(s), as strings and/or numerical codes. Other information, such as land area, may also be included. You can think of this as a dataset with n observations and several variables, possibly string-valued.

Polygons A representation of the region's shape on the map, in the form of one or more polygons, each taking the form of an array of X–Y pairs, typically latitude and longitude. You can think of this as an array of arrays of 2-column matrices: the outer array is of size n; inner array i contains k_i matrices, each with two columns.

Several file formats can be used for storing the geometry information.[1] Gretl supports what are probably the two most common formats:

- GeoJSON files: plain JSON files with a pre-specified internal structure, regulated by RFC 7946. Basically, an array of regions (or "features") with each element containing the metadata and the polygons, under the `properties` and `geometry` keys, respectively. This is our preferred format.
- ESRI shapefiles: more of a "legacy" format, but still very common in the wild. These maps come as collections of several files, usually zipped together. The essential components are an xBase file, with `dbf` extension, holding the metadata; the shapefile proper with extension `shp`, holding the polygons; and an index file with extension `shx`, used to speed up operations when reading the data.

1.2 The payload data

By "payload" we mean the data used for coloring the regions. We assume that the payload is available as a gretl series. This typically means that the user has a data file (in native `gdt` format or some other format gretl can read) in which each line represents a region, as illustrated in Table 1. Note in particular the "id" column. We assume that the map metadata contain sufficient information to establish a correspondence with the dataset containing the payload: either a numerical code or a suitable string-valued variable. One thing one quickly learns in exploring a variety of `geojson` and `shp` files is that there's no telling how the regions will be ordered; one *cannot* assume that they occur in what one might think of as "standard" order (e.g. alphabetical order for US states).

id	State	Pop2019	Pop2010
1	Alabama	4903185	4779736
2	Alaska	731545	710231
101	American Samoa	55641	55519
3	Arizona	6278717	6392017
4	Arkansas	3017825	2915918
5	California	39512223	37254523
6	Colorado	5758736	5029196
7	Connecticut	3565287	3574097
	⋮		

Table 1: Typical format for a payload dataset

1.3 The software backend

In principle one could represent maps using any one of the many plotting libraries around, but gretl uses gnuplot, which we already use for all other kinds of plot. Some insight into the gnuplot commands we use can be gained from Appendix Appendix A.

Given the geometry data and the payload, writing a gnuplot script for producing the map is straightforward. And in most cases gnuplot can produce a plot in short order. You might have to wait a little if there are many regions, of complex shapes, represented in high precision in the source map file.

2 The workflow

Typical workflow for producing a thematic map in gretl is likely to be as follows.

[1] The site `https://ec.europa.eu/eurostat/web/gisco/geodata/reference-data/administrative-units-statistical-units/nuts` offers a nice collection for European NUTS regions (NUTS = Nomenclature of Territorial Units for Statistics).

1. You `open` the map-datafile as a gretl dataset; this reads in the metadata so gretl's `$nobs` will be equal to the number of regions, n.
2. You add the payload data, via the `append` or `join` commands or in some other way.
3. You decide on some details of your map (appearance, format, etc.), with sensible defaults being available.
4. Finally, you create the map.

Point 1 is handled by using the existing `open` command on the map-datafile. The filename extensions recognized for this purpose are `json` or `geojson` for GeoJSON files, `dbf` or `shp` for ESRI shapefiles.[2] Point 2 is also handled by existing gretl commands.

As for points 3 and 4, these are handled by the new (built-in) `geoplot` function, which has the following signature.

```
function void geoplot(const string mapfile,
                      const series payload[null],
                      const bundle options[null])
```

Here `mapfile` is the (required) name of the file containing the polygons, `payload` is the (optional) series with which to colorize the polygons, and `options` is an (optional) bundle to contain one or more elements governing the appearance or destination of the plot.

- If the `geoplot` call follows on the opening of a map metadata file in the same session, you can give the accessor `$mapfile` in place of an actual filename for the `mapfile` argument, since gretl already knows what file we're talking about.
- If the `payload` argument is given as `null` or omitted then the map is drawn "as is", without any colorization. This can be useful if you just want to see what the polygons look like.
- If the `options` bundle is omitted all options are set to their default values—which means, in short, that you see the map on screen but nothing is saved. For full details on the available options see section 5.

3 An example

For this example we'll produce a map showing GDP per capita of the six founder countries of the EU, using three files: script `founders.inp`, data file `founders.csv` and map `founders.geojson`. In this case the required files are small enough to be readily inspected by hand. The content of `founders.csv`, which holds what will be the payload, is shown in Listing 1.

```
Name,code,pop,area,gdp
Belgium,BE,11365834,30528,534230
France,FR,67024633,632833,2833687
Germany,DE,82437641,357386,3874437
Italy,IT,61219113,301338,2147744
Luxembourg,LU,589370,2586.4,65683
Netherlands,NL,17220721,41543,880716
```

Listing 1: Content of `founders.csv`

The JSON file is too big to show here in full but small enough to examine in any text editor.[3] Listing 2 contains a representative excerpt. Note that while Belgium is a single polygon France is an array of polygons ("`MultiPolygon`"), because of Corsica.

[2] In principle we could read the polygons at this point and store them in RAM, but for now we don't. We just read in the metadata, but store the path to the associated geometry file internally.

[3] Even Microsoft's `Notepad`!

```
{"type": "FeatureCollection", "features": [
 {"geometry": {"type": "Polygon", "coordinates": [[[40.40360,
     30.79039], [40.59686, 30.49366], [40.65087, 30.29746], ... ]]},
   "type": "Feature", "properties": {"CNTR_NAME": "Belgique",
     "ISO3_CODE": "BEL", "CNTR_ID": "BE", "NAME_ENGL": "Belgium",
     "FID": "BE"}, "id": "BE"},
 {"geometry": {"type": "MultiPolygon", "coordinates": [[[[40.18497,
     29.45664], [40.23634, 29.39875], [40.57754, 29.35021], ...],
     [[[42.66689, 20.70300], [42.57348, 20.41660], ...]]},
   "type": "Feature", "properties": {"CNTR_NAME": "France",
     "ISO3_CODE": "FRA", "CNTR_ID": "FR", "NAME_ENGL": "France",
     "FID": "FR"}, "id": "FR"},
  ...
```

Listing 2: Excerpt of `founders.geojson`

```
open founders.geojson --frompkg=geoplot

join founders.csv gdp pop --ikey=FID --okey=code
series gdppc = 1000*gdp/pop

opts = defbundle("plotfile", "GDPpc.plt", "inlined", 1)
geoplot($mapfile, gdppc, opts)
```

Listing 3: Content of `founders.inp`

The `founders.inp` script is shown in Listing 3, and what we get after opening the `geojson` file in gretl is in Listing 4.

```
     CNTR_NAME    ISO3_CODE      CNTR_ID    NAME_ENGL          FID

1     Belgique          BEL           BE      Belgium           BE
2       France          FRA           FR       France           FR
3  Deutschland          DEU           DE      Germany           DE
4       Italia          ITA           IT        Italy           IT
5    Luxemburg          LUX           LU   Luxembourg           LU
6    Nederland          NLD           NL  Netherlands           NL
```

Listing 4: The "founders" metadata

Next, we perform the `join` with `FID` (from the JSON file) as the inner key and `code` (from the CSV file) as the outer key. Finally, we call the `geoplot` function to create an on-screen map. We specify the `mapfile` to use and the `payload` to colorize. Via the `options` argument we add a couple of points: the gnuplot input file should be saved under the name `GDPpc.plt`, and the geometry data should be "inlined" in this file, making it self-contained.

Running the script will produce a gnuplot file resembling the following:

```
set term wxt persist

unset key
set cbrange [33.3288:117.018]
set xrange [31.7826:51.4213]
set yrange [14.7701:36.0553]
```

```
$MapData << EOD
40.4036 30.79039 47.00315
40.59686 30.49366 47.00315

[...]

38.92268 31.40258 51.142806
38.59809 31.50169 51.142806
38.59737 31.60855 51.142806

EOD
plot for [i=0:*] $MapData index i with filledcurves fc palette, \
  $MapData using 1:2 with lines lc "white" lw 1
```

and feeding the above into gnuplot yields the map shown in Figure 1.

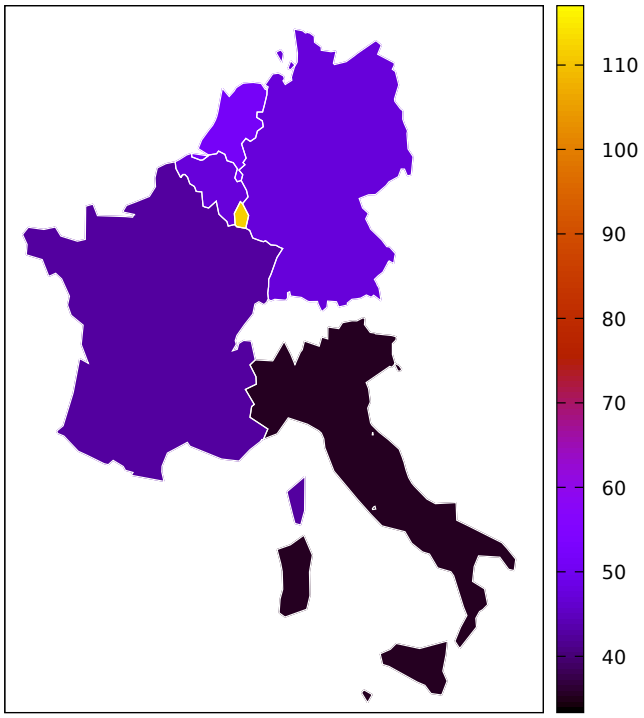


Figure 1: Output of script `founders.inp` (default gnuplot palette)

4 Alignment problems

In order to produce a correct map it is essential that everything be aligned properly: the map metadata, the payload series, and the geometries of the regions. "Region i" must have the same referent in all three contexts.

If the source map (GeoJSON or shapefile) is not broken we can assume that the original metadata and the geometries are indeed aligned correctly. But problems may arise (a) in aligning the payload and (b) if one wishes to exclude some regions from the map. We discuss these issues in turn.

4.1 Aligning the payload

In the somewhat unlikely case that the payload you wish to plot is already included in the map metadata, no problem. But when the map data and the payload come from different sources it may be tricky to get

them aligned properly. This problem is not specific to the mapping apparatus—it's a more general issue concerning the matching of data from different sources, addressed at length in the chapter titled "Joining data sources" in the the *Gretl User's Guide*—but it may be helpful to offer a few comments here.

As mentioned above, the relevant tools provided by gretl are `append` and `join`. A simple `append` will work only if the regions appear in the same order in the map and payload datasets. This is fairly easily checked if the number of regions is small and each dataset contains readily comparable identifiers. Otherwise—if the orders clearly differ or it's hard to tell—it will be necessary to use `join`.

Look back at Listing 3. In that case the map and payload datasets contained the same set of two-letter identifiers for the countries—albeit under different names, `FID` and `code`—so `join` using the `--ikey` and `--okey` options worked fine. In a different case, however, the respective identifiers may not match up. For example, region names might be in English in one dataset and in, say, Italian in the other. Then you'll have to exercise your intelligence, but one idea is to create an intermediate "Rosetta stone" file, maybe as CSV, giving the mapping between the two identifiers, as in:

```
# rosetta.csv
ID_en,ID_it
Apulia,Puglia
Sardinia,Sardegna
...
```

Then you can use `join` on the Rosetta file to add to the map dataset the required identifier that's initially lacking.

4.2 Sub-sampling

In some cases one may wish to leave out certain outlying regions. For example, it's quite common to produce thematic maps of the USA that omit Hawaii, and perhaps Alaska. In principle leaving out regions threatens to break the required alignment of payload and geometry, but this is handled: if you sub-sample the map dataset using the `smpl` command, `geoplot` automatically drops the associated polygons from the plot.

This is illustrated in Listing 5. Figure 2 shows the results with and without exclusion of Alaska and Hawaii.[4]

A related case is where the payload value is missing (`NA`) for one or more regions. Here you have a choice. By default, regions whose payload is `NA` are shown in outline, not colored, but either of two alternatives can be selected by passing a string under the key `missvals` in the options bundle: if the value is `"skip"` the affected regions are omitted; if it's `"fill"` they are colored gray. (The value `"outline"` may be given, confirming the default.)

5 Options for the `geoplot` function

We first present all the currently supported options in alphabetical order. Below the listing we give some further explanation of the usage of `plotfile`, `show` and `inlined`.

`border`: boolean, show a rectangular border around the map. Default: true. (FIXME maybe reverse the default?)

`height`: scalar, giving the height of the plot in pixels. Default: 600. Even if the desired output is a vector graphic (PDF or EPS) rather than a bitmap (see `plotfile` below), setting this value relative to the default can be used to adjust the size of the plot. For example `height = 400` will give a PDF graphic that's two-thirds of the default size.

`inlined`: boolean, to have the polygon data written directly into the gnuplot file. Default: false, the data are read from a separate file.

[4] Given the role of this example we don't bother adding a real payload, but just simulate data using the `normal` function.

```
open us-states.geojson --quiet --frompkg=geoplot
x = normal() # fake up some data!
opts = defbundle("plotfile", "us0.plt", "palette", "blues")

# show the entire USA
opts.title = "USA (complete)"
geoplot($mapfile, x, opts)

# skip Alaska and Hawaii
smpl postal != "AK" && postal != "HI" --restrict
opts.title = "USA (mainland)"
opts.plotfile = "us1.plt"
geoplot($mapfile, x, opts)
```

Listing 5: US maps, complete vs contiguous states

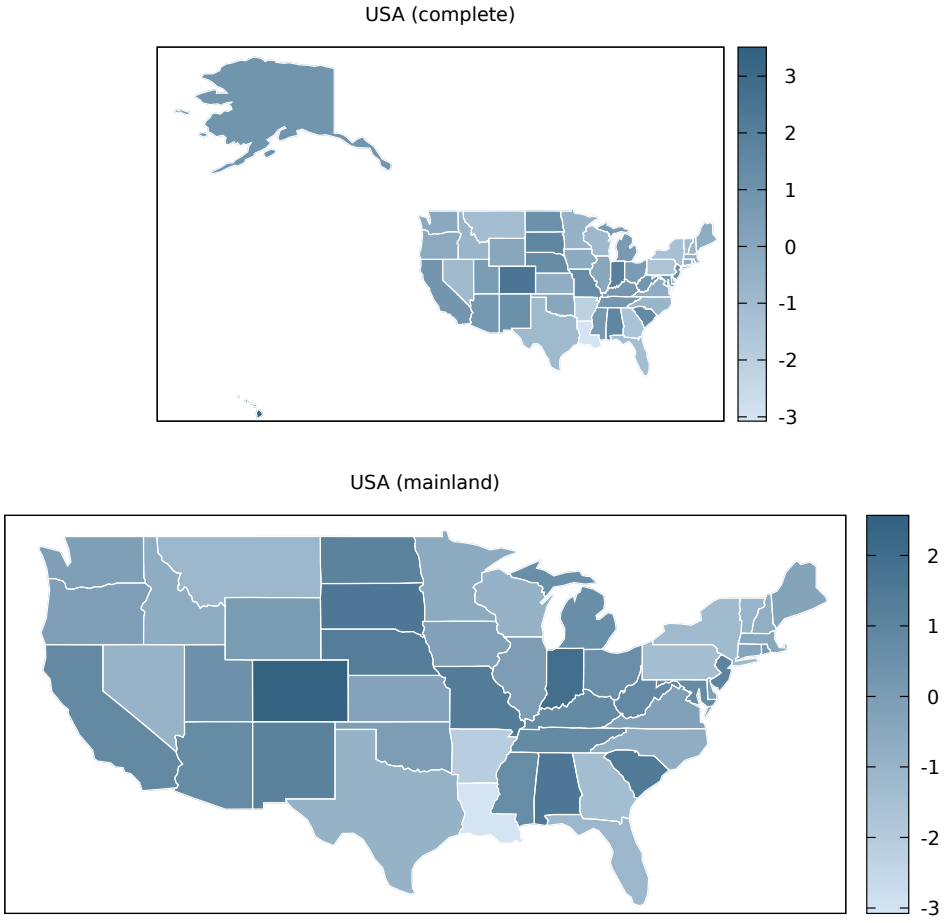


Figure 2: Output of Listing 5

`linecolor`: string, naming the color in which to draw the borders of the regions. By default this is white if a payload is plotted, black if only outlines are shown.

`linewidth`: scalar, giving the width of the lines representing the borders of the regions. Setting this to 0 suppresses those lines (unless no payload is supplied). Default: 1.0.

`literal`: string containing `gnuplot` commands, for insertion before the actual `plot` command.

`logscale`: boolean, use log scale for the payload. Default: false.

`missvals`: string, see section 4.2.

`plotfile`: filename, allowing the user to direct output, either to a specified `gnuplot` command file or to a graphic file. If a command file is wanted the extension should be `plt`. If a graphic file is wanted you should give one of the following extensions: `png`, `pdf`, `eps`, `emf` or `svg`. If `plotfile` is given, but not as a full path, the file is written to the user's working directory.

`projection`: string, see Appendix B.

`palette`: string, giving either a `gnuplot set palette` command or a predefined option, of which there are currently three: `blues`, `oranges` and `green-to-red`. For example, the syntax

```
options.palette = "set palette defined (0 '#D4E4F2', 1 'steelblue')"
```

will give you a pleasing blue gradient—which also happens to be what you get by giving

```
options.palette = "blues"
```

If no such string is given you get the default built-in `gnuplot` palette.

`show`: boolean, should the plot should be shown on-screen right away? Default: true. (Otherwise a file of some sort is written but not displayed—see `plotfile` above.)

`tics`: boolean, for turning on the printing of X (longitude) and Y (latitude) tics. Default: tics are suppressed, unless `geoplot` is invoked without any payload.

`title`: string specifying a title for the plot. Default: no title.

It may be helpful to run through various `geoplot` scenarios with an eye to usage of the options.

1. You just want to see the map on-screen. Then don't give `plotfile` (or set it to `null`) and accept the default of `show` = 1.
2. You want to see the map on-screen but also save the plot command file that generated it (maybe you want to edit the commands or pass them to `gnuplot` independently of gretl). Then specify `plotfile` with a `plt` extension.
3. As in case 2 but you don't care to see the map on-screen: add `show` = 0.
4. You want to generate a graphic file (maybe for inclusion in a document or web page). Then give `plotfile` with one of the recognized graphic format extensions. In this case `show` is automatically turned off.

Note that if you set `show` to 0 and do *not* specify `plotfile` that is tantamount to saying "Don't do anything!", which is regarded as an error.

5.1 Inlined data or not?

As mentioned above, `geoplot` can pass the map coordinates to gnuplot either by writing them directly into the plot command file (`inlined` = 1), or by writing them to a separate data file whose name is recorded in the command file (`inlined` = 0).

From the user's point of view, this distinction makes a difference only if you're saving the plot command file (as in scenario 1 or 2 above). In that context, the advantage of having the data inlined is that, being all in one file, the information required to generate a map cannot easily become "unstuck". The disadvantage is that the command file may be very large, and perhaps not so easy to edit; besides the actual gnuplot commands it may contain many thousands of lines of coordinates data (which in general *should not be touched*, on pain of breaking the map). At present we have `inlined` set to 0 by default but that may change; we recommend making an explicit choice via the `options` bundle.

Note that if you specify `plotfile` as a gnuplot command file, but not `inlined`, you'll get two output files: the specified `plt` file plus a data file named by adding the extension `dat`. For example you might get `mygeo.plt` and `mygeo.plt.dat`, while with `inlined` = 1 you'd just get a big `mygeo.plt`.

6 Maps via the GUI

To this point we have referred exclusively to executing commands and calling functions. You can, of course, execute commands and call functions in the GUI program via script or via the gretl console, but what about point-and-click? Well, there is a certain amount you can do in that way.

First, you can open a shapefile or GeoJSON file using the menu item /File/Open data/User file. In the bottom right-hand corner of the "open file" dialog, use the pull-down list to select "Shapefiles" or "GeoJSON files". You can also drag-and-drop such files onto the main gretl window to the same effect.

Once map metadata are loaded in this way, the option Display map becomes available via the context ("right-click") menu in the main window, and also under /View/Graph specified vars. If the current dataset contains one or more series that seem to gretl to be plausible "payload" variables,[5] invoking Display map will produce a dialog box that allows you to select one, in which case you'll get a choice of color palette to represent it. Otherwise you just get to view the map outlines.

Further, the window shown by Display map offers a right-click menu that allows saving the map (as PDF, EPS, PNG or EMF), copying it to the clipboard, or saving it "as an icon".

So far, that's it. We may at some point expand the Display map dialog to offer more of the choices available via the `options` argument to the `geoplot` function. (**TODO**: even if we don't load up this dialog with lots of options we should at least add a Help button which gives a brief account of how to exploit more options via scripting.)

7 "Expert" refinements

To recap, we have explained how map metadata can be brought in via the `open` command (or via the GUI); how to add "payload" data; and how to generate a map using the `geoplot` function. So far so good, but that leaves open some questions that might occur to ambitious users. Can I open a map file, add a payload series, and save a modified version of the map file including the payload? And in relation to a map of the USA (for example), is there a way to include Alaska and Hawaii, but "tuck them underneath" the continental US, like I see in some graphics on the web?

Short answer: Yes. You can import a GeoJSON file (or shapefile) as a gretl "bundle", using the `bread` function; make changes to the bundle, then save it as GeoJSON using `bwrite`.

To get control over this it's necessary to understand the structure of the bundle that `bread` produces when given map input. This mimics the structure of a GeoJSON file (even if the input comes from a shapefile), as shown in Listing 6; the labeling of elements is as in GeoJSON, with gretl types in parentheses.

[5] Admittedly, the heuristic employed for this purpose is not terribly clever.

```
FeatureCollection (bundle)
  features (array of n bundles)
    features[i] (bundle)
      features[i].properties (bundle)
      features[i].geometry   (bundle)
        features[i].geometry.type (string)
        features[i].geometry.coordinates (array)
```

Listing 6: Structure of map data, gretl types in parentheses

7.1 Injecting payload data

With this in mind, let's look at the relatively simple case of injecting a payload series into a map file. Listing 7 revisits the EU founders map discussed in section 3. As before, we start by opening the metadata and "joining" the GDP per capita data. But now we open the GeoJSON as a bundle, and for each `feature` (country) we augment its `properties` bundle with the corresponding value of the `gdppc` series (under the key "`gdppc`"). Finally, we write the modified data to file.

7.2 Rearranging regions

We now consider the case of rearranging regions of a given country (or more generally, `features` within a given `FeatureCollection`). Here we use the function `geoplot_translate_feature`, which requires inclusion of `geoplot.gfn` since it's not built in. Its signature is

```
void geoplot_translate_feature(bundle *b, int f,
                               matrix shift,
                               matrix center[null],
                               matrix scale[null])
```

You pass in a map bundle obtained via `bread` (in pointer form), the sequential index of the feature to translate, and a 2-vector `shift` giving displacement in the X and Y directions. If in addition you want to rescale the feature you pass two more 2-vectors: `center` holds the coordinates of the feature's centroid and `scale` the scale factors to apply in the two directions.

An example script is shown in Listing 8 and the result of plotting the modifed GeoJSON file in Figure 3. We obtain the second argument to pass to the translator by inspection of the map dataset: Alaska is feature 48 and Hawaii feature 5. In this case we decide to move Alaska 34° East and 35° South and shrink it substantially. Getting the effect one wants is likely to take some trial and error, but two geoplot features can be helpful.

First, if you plot just the map outlines (no payload) then you should see the X and Y values on the axes, giving you at least a rough idea of the shifts you might want. Second, geoplot contains the function `geoplot_describe_json` which gives you a good deal of relevant information. The signature of this function is

```
bundle geoplot_describe_json (const bundle jb, int verbose[1])
```

You pass a map bundle and a verbosity level, as in

```
include geoplot.gfn
bundle us = bread("us-states.geojson")
geoplot_describe_json(us, 3)
```

On searching the `verbose` = 3 output for Alaska one finds (here's a small snippet):

```
  48: geometry type = MultiPolygon, no id
      ...
```

```
open founders.geojson --quiet --frompkg=geoplot
join founders.csv gdp pop --ikey=FID --okey=code
series gdppc = 1000*gdp/pop

# open full GeoJSON as bundle
bundle b = bread($mapfile)

# add GDP per capita to properties
loop i=1..nelem(b.features)
   b.features[i].properties.gdppc = gdppc[i]
endloop

# save modified geojson file
bwrite(b, "founders_mod.json")
```

Listing 7: Adding payload data to a map file: `founders_mod.inp`

```
include geoplot.gfn

open us-states.geojson --quiet --frompkg=geoplot
bundle b = bread($mapfile)

# Shrink Alaska and place underneath the "lower 48"
matrix shift = {34, -35}
matrix center = {-150.885, 62.5503}
matrix scale = {0.3, 0.35}
geoplot_translate_feature(&b, 48, shift, center, scale)

# Shift Hawaii alongside Alaska
shift = {51, 5}
geoplot_translate_feature(&b, 5, shift)

# save modified geojson file
bwrite(b, "us_modified.json")
```

Listing 8: Moving Alaska and Hawaii

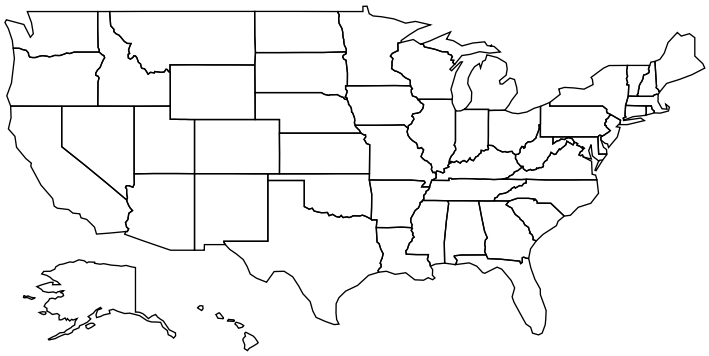


Figure 3: Alaska and Hawaii moved

```
name: Alaska
...
Extents: X = {-171.791,-129.98}; Y = {54.4042,70.6964}
```

The `Extents` data enable you to figure out plausible values for the `center` of a feature.

8 Future directions?

We've alluded above to possible extensions of geoplot. Here we collect various ideas.

- The `geoplot` function could be complemented with a "command block" variant, on the pattern of the existing gretl `plot` block. Some users might find this sort of interface more comprehensible and convenient.
- We could provide a more fully featured graphical interface for selection of options that inflect the appearance of maps.
- Besides just colorizing map polygons, we might add support for showing geographical features such cities, roads or rivers. Labeling of regions might also be nice to have.
- An ambitious project for the longer term could be adding support for TopoJSON, an extension of GeoJSON that encodes topology. See `https://github.com/topojson/topojson`.

Coda

In the foregoing we have mostly kept things simple with toy examples. In concluding, we'll show off with a "real" example: Figure 4 shows the distribution of COVID cases across Italian provinces as of 2020-05-15. The appearance of this plot was tuned using the following option settings:

```
string cmds = sprintf("set colorbox user origin 0.9,0.45 size 0.03,0.4\n")
cmds ~= sprintf("set xrange [6.4:20.5]")
bundle opts = defbundle("plotfile", "covid.pdf")
opts.logscale = 1
opts.border = 0
opts.linewidth = 0.4
opts.palette = "green-to-red"
opts.literal = cmds
opts.height = 900
```

As you'll have seen in the previous figures, the default gnuplot "colorbox" is quite large, occupying the full height of the plot. This doesn't look so great for a tall, skinny country like Italy, so we used the `literal` option to pass in commands to make the colorbox smaller and reposition it; to prevent it from going off the right edge of the plot we also made the `xrange` a little wider than the default. We were able to determine what the revised `xrange` should look like by examining a plot with no payload, showing the values on the axes.

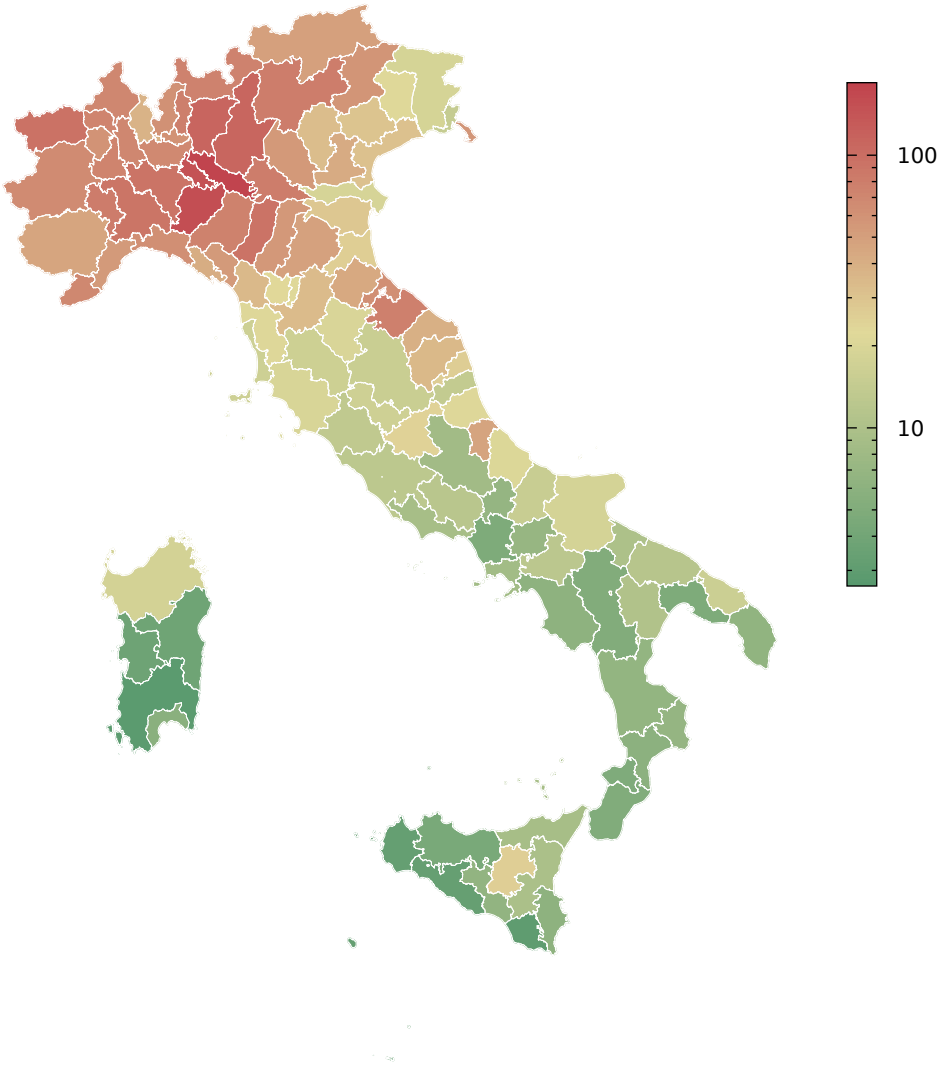
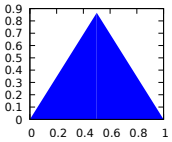


Figure 4: COVID-19 cases per 10 000 by province as of 2020-05-15, log scale

Appendix A Representation of polygons in gnuplot

The following gnuplot code

```
unset key
plot '-' using 1:2:3 with filledcurves fillcolor "blue"
0 0 0
0.5 0 0.866
1 0 0
e
```

produces an equilateral triangle: 

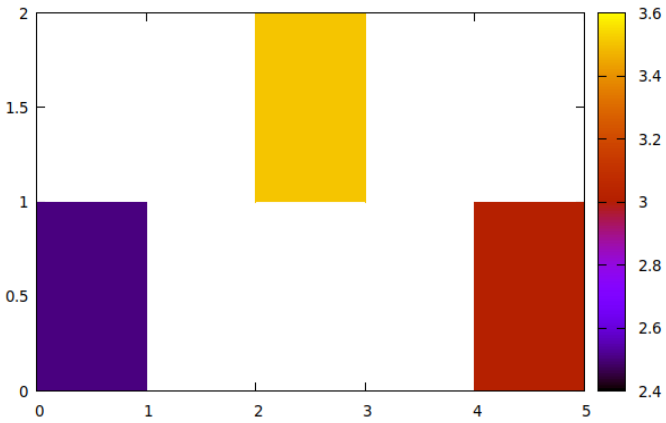
The internal coloring of polygons can be set using "`fillcolor palette`". For example,

```
unset key
$coords << EOD
0 0 2.5
0 1 2.5
1 1 2.5
1 0 2.5

2 1 3.5
2 2 3.5
3 2 3.5
3 1 3.5

4 0 3
4 1 3
5 1 3
5 0 3
EOD
plot for [i=0:*] $coords index i with filledcurves fillcolor palette
```

(where the third column of the data indexes into the palette) produces



A nice way to customize the palette is via "`set palette defined`" (see the gnuplot manual; also see section 5 above).

Appendix B Projections

Geoplot assumes (mostly, but see below) that incoming map coordinates are given as degrees of latitude (Y) and longtitude (X). This is mandated by RFC 7946, which has governed GeoJSON since 2016; it also appears to be the most common case for ESRI shapefiles.

Everyone knows that the Earth is not actually a sphere, but let's assume it is for simplicity. Then a degree of latitude is always the same length on the ground: 1/360 of the planet's circumference. But the length of a degree of longitude varies, from 1/360 of Earth's circumference at the equator to zero at the poles. So imagine that we pass the X–Y pairs to our plotting engine on the assumption that "a degree" is always the same size: the result will be more or less OK close to the equator but at higher or lower latitudes features will be seriously stretched horizontally (or squashed vertically) relative to what we're used to seeing. To avoid this effect some sort of projection is required.

By default geoplot uses what we might call a "quasi-Mercator" projection. In most cases this should produce maps that look quite acceptable and it has the advantage of simplicity. All we do is take the height of the plot as specified by the user (or a default of 600 pixels) and figure out what the width should be to make a degree of longitude the same size as a degree of latitude at the mid-point latitude. However, we offer four alternatives, as follows:

EPSG id	description	option string
3857	standard Mercator	`"Mercator"`
4326	"null" projection	`"EPSG4326"`
2163	U.S. National Atlas Equal Area	`"EPSG2163"`
3035	Europe Equal Area	`"EPSG3035"`

Figure 5 compares the available projections for the contiguous United States. In this case the default geoplot projection and standard Mercator are practically indistinguishable. EPSG:4326, which treats degrees as everywhere the same size, exhibits the horizontal stretching mentioned above. EPSG:2163 gives the impression of looking at the USA on a section of the globe.

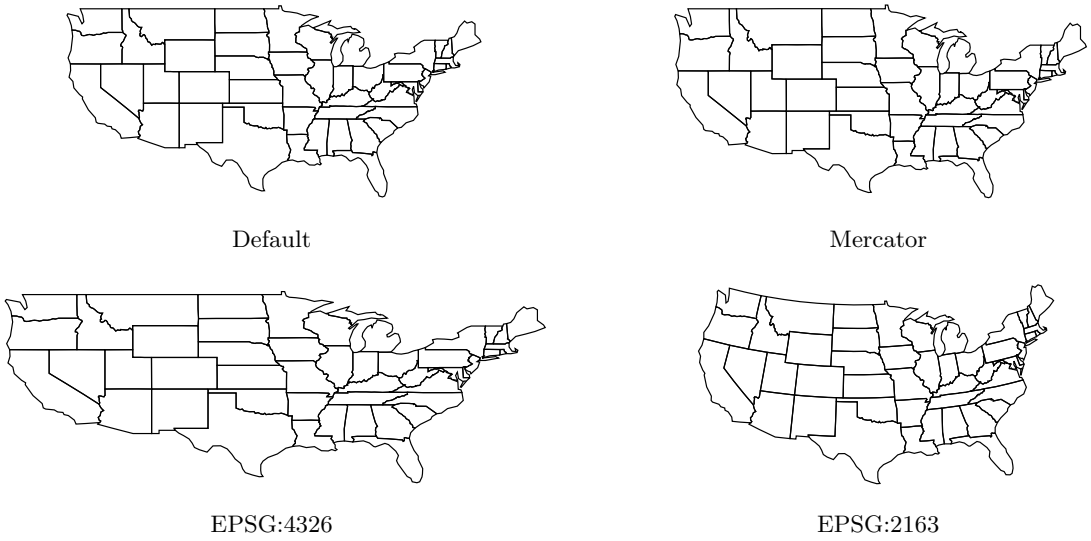


Figure 5: Comparison of projections

To select one of the alternatives, you add the appropriate string to the `options` bundle passed to the `geoplot` function under the key `projection`. Please note that EPSG:2163 is specially tuned for the USA, and will produce weird-looking or non-existent results for other parts of the world. EPSG:3035 is similarly tuned for Europe. They are both so-called Lambert Azimuthal Equal Area projections.

Non-standard coordinates

In certain map files—maybe GeoJSON predating RFC 7946, and perhaps some shapefiles—the X–Y coordinates are not in the expected form of degrees of latitude and longitude. In that case they probably already encode some sort of projection, and so should not be "re-projected". For GeoJSON files, geoplot makes an attempt to determine whether a non-standard coordinate system is used, as was allowed under the obsolete GeoJSON 2008 specification. In that case we automatically cancel projection; we also do this if the X or Y values are out of bounds for representing degrees (that is, $|X| > 360$ or $|Y| > 180$).

Failing such automatic detection, one can try specifying EPSG:4326 to get the X and Y units to be treated as equal in size, in effect cancelling projection, as in

```
bundle options
options.projection = "EPSG4326"
```

Limiting the area shown

Section 4.2 explains how to exclude certain features from a map using the `smpl` command. In some cases, however, one may wish to limit what is shown in a different way, by specifying ranges for latitude and longitude. This can be done by supplying 2-vectors in the `geoplot` options bundle under the keys `xrange` (longitude) and `yrange` (latitude). For example, to plot just the area from 40° to 60° North and 10° to 30° East you can do

```
options.yrange = {40,60}
options.xrange = {10,30}
```

Specifying such ranges in degrees works fine if you are using the default `geoplot` projection, Mercator or EPSG:4326. But it doesn't work for azimuthal projections, where neither meridians nor parallels are straight lines. Rather, you should first plot the entire map using the projection you want, with axis tics turned on to show the linearized coordinates. Then specify the ranges in terms of these values. For example, here's how one might restrict a US map to the contiguous states via ranges:

```
open us-states.geojson --frompkg=geoplot
bundle opts
opts.projection = "EPSG2163" # azimuthal
opts.tics = 1
# take a look-see
geoplot($mapfile, null, opts)
# suitable ranges, by inspection
opts.xrange = {-330,410}
opts.yrange = {-350,130}
geoplot($mapfile, null, opts)
```

Further reading

For anyone wishing to follow up on this sort of thing, there are many websites presenting information on coordinate systems and projections. Two of the most useful ones, in our experience, are:

Reference materials: `https://spatialreference.org/`

Explanation: `https://source.opennews.org/articles/choosing-right-map-projection/`

Appendix C Specialized functions

The functions shown below are implemented in hansl and included in the geoplot addon; to use them you must first do

```
include geoplot.gfn
```

```
bundle geoplot_describe_json (const bundle jb, int verbose[1])
```

Provides a systematic description of the GeoJSON bundle `jb`, the amount of detail depending on the `verbose` setting, which has a maximum of 3. By assigning the return value one can obtain a bundle containing the information but for some purposes the printed output may suffice. See section 7.2.

```
void geoplot_set_properties (bundle *b, list L)
```

Rewrites the `properties` within the bundle representation of a map, `b`, to include all and only the series referenced in the list `L`. Provides a means of adding "payload" data (see section 1.2) and also pruning unwanted metadata. In the example below, `us-states.geojson` originally contains 40 items of metadata per state, most of them unlikely to be of interest.

```
# example
open us-states.geojson --quiet --frompkg=geoplot
join statepop.gdt population --ikey=postal --okey=Code

# select only the properties we actually want
list L = name postal population
bundle b = bread($mapfile)
geoplot_set_properties(&b, L)
bwrite(b, "us_pruned.json")
```

```
function void geoplot_translate_feature (bundle *b, int f,
                                         matrix shift,
                                         matrix center[null],
                                         matrix scale[null])
```

Shifts the feature with sequential index `f`, optionally rescaling it. See section 7.2 for an example and explanation.

```
function matrix geoplot_seek_feature(const bundle b,
                                     string name,
                                     bool do_plot[1])
```

Searches the map bundle `b` for features matching `name` (on a case-insensitive basis). If one or more matches are found their 1-based indices are returned in a row vector. If a single match is found metadata for the feature are printed and if `do_plot` is not set to zero a plot of the feature is shown.

```
include geoplot.gfn
open us-states.geojson --frompkg=geoplot --quiet
```

```
map = bread($mapfile)
# no matches
geoplot_seek_feature(map, "nowhere")
# two matches
geoplot_seek_feature(map, "CAROLINA")
# one match, plot shown
geoplot_seek_feature(map, "Florida")
```

```
function void geoplot_simplify(bundle *b,
                               scalar preserve[0.1:1:0.75])
```

Simplifies the polygons in the map bundle `b` using Visvalingam's algorithm. This may be useful if for a certain geography of interest the only map file readily available is at a higher resolution than you need. Smaller values of the `preserve` parameter preserve less detail or in other words simplify the map more radically; the default value of 0.75 may be considered conservative if you start with a very detailed map.

```
include geoplot.gfn
open highres.geojson --quiet
bundle map = bread($mapfile)
geoplot_simplify(&map, 0.5)
bwrite(map, "simplified.geojson")
open simplified.geojson --quiet
# see if the level of detail is OK
geoplot($mapfile)
```