Creating Cartograms for Research within the Social Sciences

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Abstract

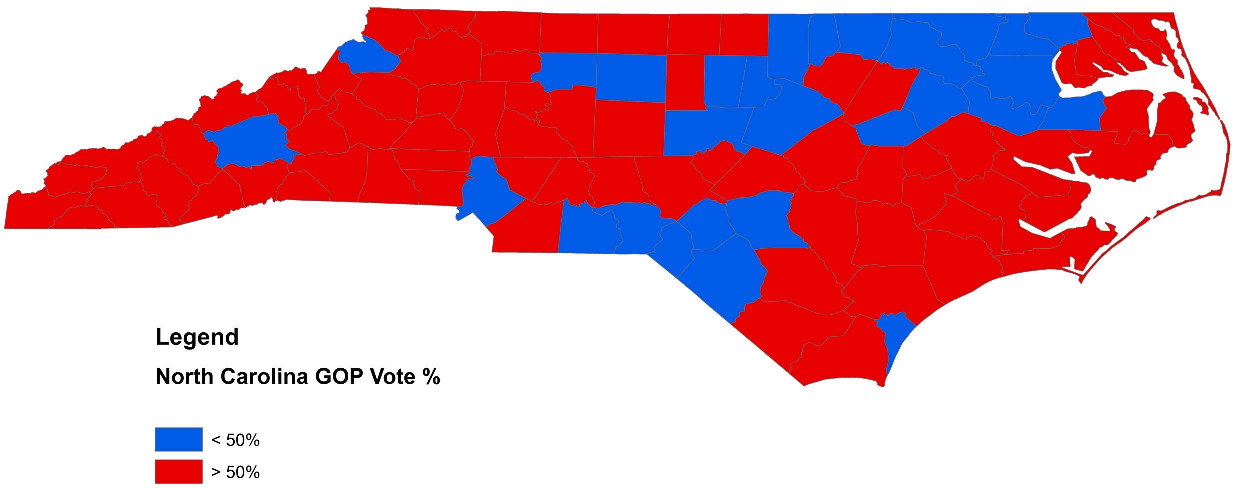
Research involving even a modicum of geographic variance offers the opportunity for scholars to turn opaque tables into appealing maps. However, the standard political boundary map is plagued with rural bias, where sparsely populated areas receive a disproportionate amount of attention. Therefore, this paper presents how one can go about creating maps that correct for the rural bias via cartograms, maps where polygonal units are weighted by their populations in order to correct for distortions. Additionally, the decision tree and technical requirements table is presented so as to aid readers in deciding which corrections that they would like to make in order to keep results aesthetically appealing and comprehensible.

Maps, much like theoretical and statistical models, are abstractions of the world. All are wrong, though some less wrong than others and useful to boot. Despite the common misconception, many unnoticed subjective decisions are made when creating maps, such as how well they should reflect the shape of countries, land area, focus on improving the accuracy of a certain region, among others. Within the context of the social sciences, the goal of maps is to expand the Lasswell (1950) definition of power from "who gets what, when and how" to "who gets what, when, *where*, and how" (Smith, 1974). When incorporating the information related to *where*, the goal is not to provide a perfect representation of physical geography for circumstances like sailing, but rather to demonstrate loci of power. The conundrum that faces social scientists is that unlike the natural sciences where topological features, water sheds, and weather patterns are of primary interest, the social sciences rely upon sociological and political phenomenon that arise from the unique and often stochastic behaviors of humans (Gotway-Crawford and Young, 2004). Given the natural clustering that occurs with individuals into cities and urban-rural divide (Rodden, 2019; Bishop, 2008), mapping purely political boundaries can often lead to distortions as to population trends and hide some of the key elements of interest in studying political science.

For example, consider the United States and elections. Localities in the form of counties run and report elections, with counties designed to administer land (Stephan, 1971). The result is that great population disparities arise, with some counties numbering in the low hundreds of people, and other counties the millions. Although the severity varies by state, North Carolina exemplifies some of the issues. North Carolina has about a 50-50 split between Republicans and Democrats, yet mapping the state by county often results in the state appearing overwhelming Republican. Figure 1 presents the Congressional election results from 2018, the best year for Democratic candidates within the state in over a decade. However, mapping by county still brings about the appearance that the state is primarily Republican.

As Rodden (2019) finds, one can near perfectly predict support for right wing parties

Figure 1: North Carolina Congressional Vote Share by County, 2018



Data provided from the MIT Elections Data and Science Lab, North Carolina 2018 precinct returns data set.

based upon population concentration and distance from urban centers. Therefore, not only do maps add noise to the data, but additionally create consistent political bias.

To correct for the rural bias therefore requires one modify the boundary units the comprise a map. Physical political boundaries should contribute to the design of a map, but not dictate, as is true of the standard geographic map. There are two means to correct for the rural bias, depending on how much weight one wants to give to population to overcome the rural bias. The first is to create polygon standardized maps. The second is to create population weighted cartograms.

The standardized polygon route should be taken when one seeks to reduce the rural bias of maps, but seeks to maintain the relative position of states via a clean and visually appealing map. Under such a map, all jurisdictions are treated the same by appearing the same size and shape. The primary way to do this would be via a hexagonal map, where jurisdictions, such as states or counties, are overlaid onto a hexagonal grid.

Figure 2 presents an example hexagram choropleth map of the United States. All states are standardized to the same hexagonal size, and a choropleth[1] laid on top, where orange/red states are those with greater rates of provisional ballot use. Note that although rural bias is still present in the map, states such as Massachusetts, Rhode Island, Connecticut, etc., are no longer hidden. These smaller geographic states are now no smaller or larger than rural states such as Wyoming and Montana. Further, the general shape of the united states is preserved, and the placement of states somewhat accurate. However, the drawback is that such a map makes regional patterns, if any, harder to detect due to the somewhat changed placement of states. Additionally, rural bias is still technically present. However, the map is an improvement insofar as one wants to present jurisdictions without severe rural bias.

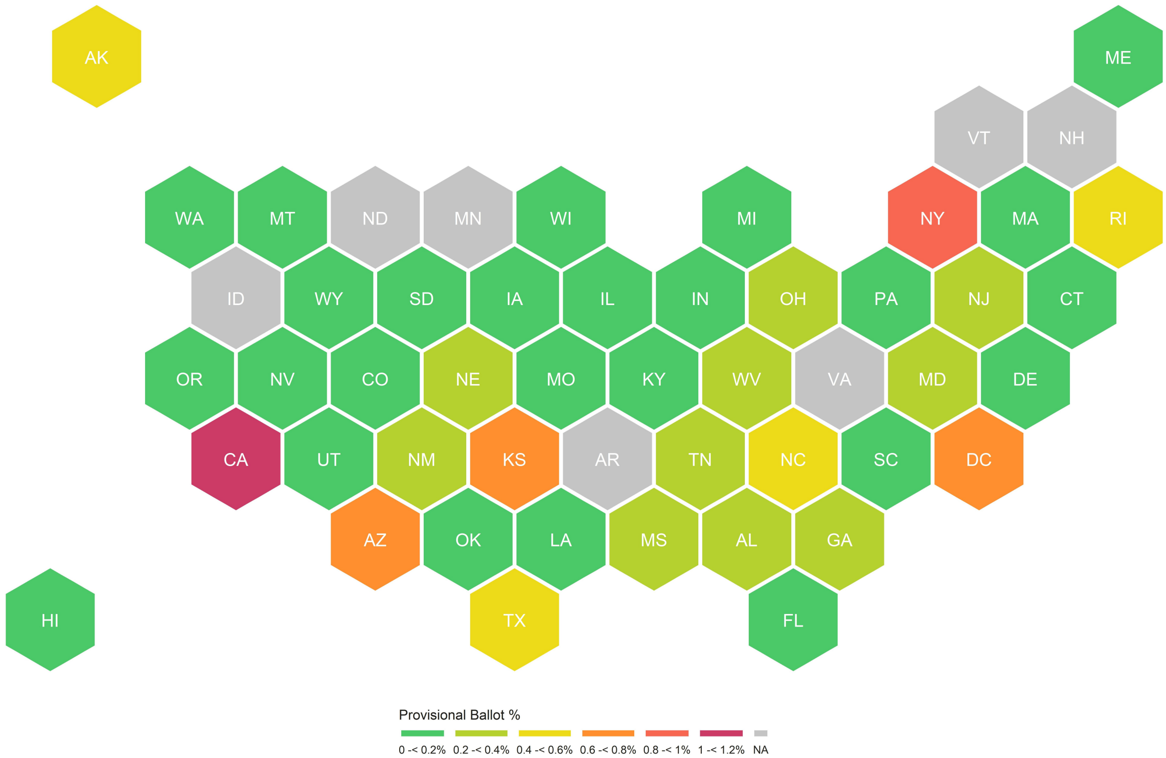
Another way to correct for the rural bias in maps is to make use of cartograms. Cartograms transform maps by weighting the polygonal units by population, such that larger populations lead to larger polygons and shrink the size of polygons with smaller populations. Although seemingly intuitive, there are several problems in developing cartograms. The first is the algorithm employed to specify the transformation. There are several that the user might employ in order to correctly weight and preserve shape and place of the polygons. As Gastner and Newman (2004) specify, the oddities in population density distribution and levels of concavity of the shapes can be sufficient to lead to prohibitively long computational times, especially in the presence of a large set of polygons.[2]

More importantly for the end user are map aesthetics. If the goal is to present information in a more accurate and nuanced manner, then any benefit is lost if the user cannot

[1]Sometime incorrectly called heatmaps.

[2]For example, within the U.S. a cartogram of county maps for all 3,200+ counties is about as large a dataset that can be worked with in most mapping programs. Attempts to plot sub-county, such as at the census block group level would be too computationally expensive and likely fail to converge, among other problems.

Figure 2: Example Hexagram Map: Provisional Ballot Rejections within the U.S.



interpret or recognize the map. Consider for example Figure 3 as presented within research by Curiel, Sanders and Slade (2019). The map presents a choropleth cartogram of United States counties by level of fluoridation. Although the map brings greater attention to high population areas, it also greatly distorts the nation's physical geography to beyond recognition.[3] Anyone from outside the U.S. would likely have no idea what they were looking at, and even Americans likely would not be able to find their state. While the cartogram is not technically wrong, it does not add much to understanding the spatial component of public health matters given that one cannot relate the cartogram back to real physical geography.

Therefore, those interested in maps correcting for need to consider the following steps as displayed in Figure 4.

[3]One conference attendee at the International Association of Dental Research (2019) commented that they thought the map to be an impressionistic drawing of the state of Florida.

Figure 3: United States Cartogram by County of Water Fluoridation

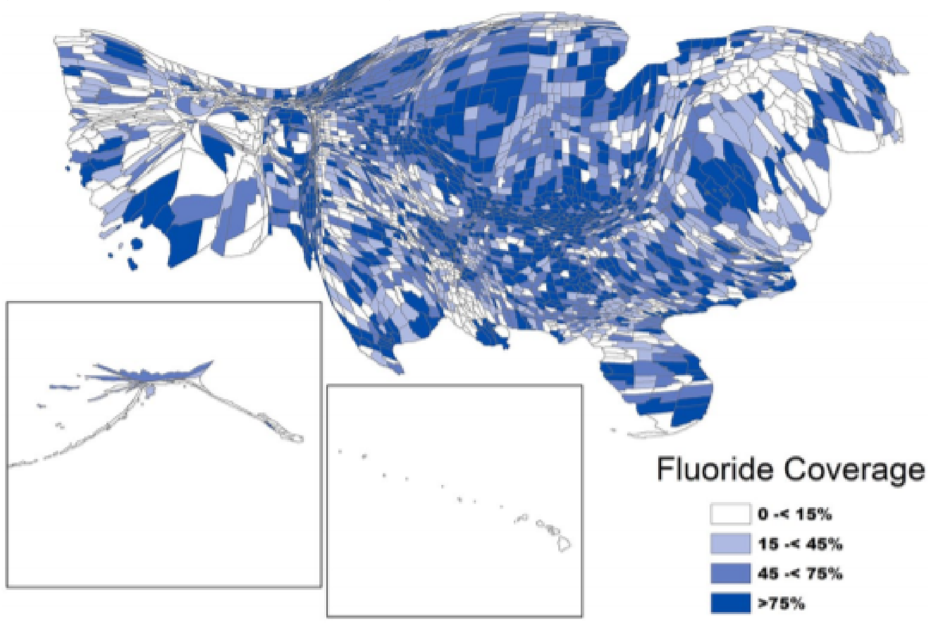
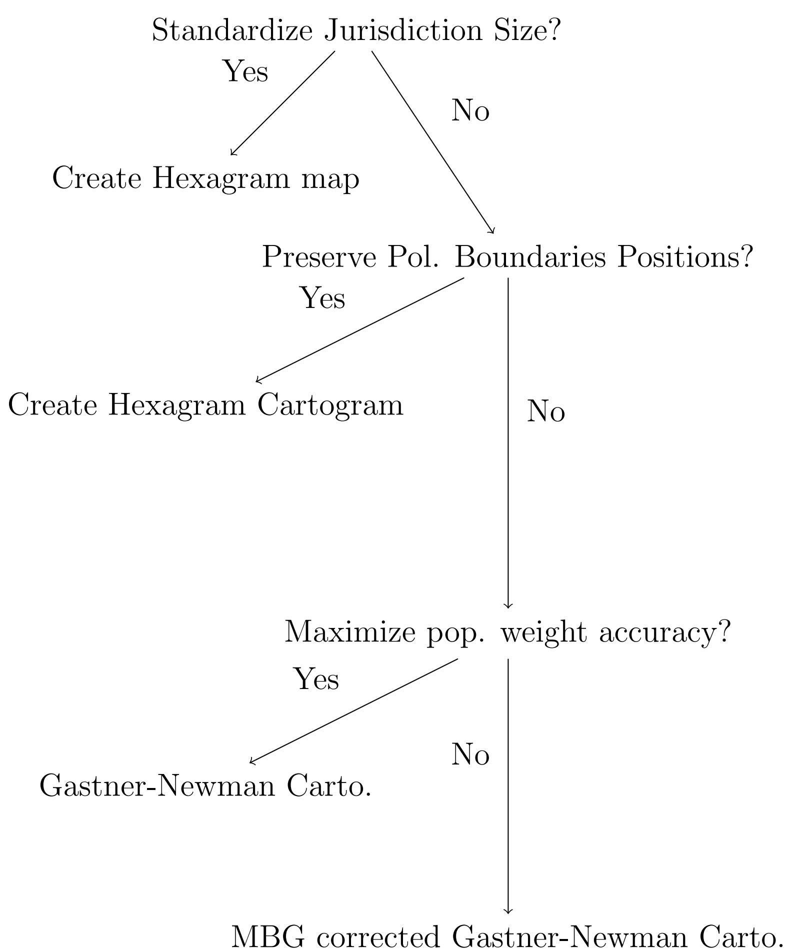


Figure taken from Curiel, Sanders and Slade (2019) with author permission.

Figure 4: Decision Tree for Mapping Rural Bias Reduction



1. Standardize jurisdiction size: The first step of the decision tree is to consider the importance of jurisdictions. If the goal is to unmask jurisdictions hidden because of their small geographic size, but treat jurisdictions as more important than population, then a simple hexagram will do. Such would be the case with presenting results by state within the United States. Presenting partisanship of U.S. senators by state would be an appropriate use; each state gets the same number of senators, so treating them equally in size would be a wise presentation strategy. If not, and more serious population corrections are necessary, then some type of cartogram will be necessary. Hexagrams are best created in R, making use of the hexocart package.

2. Preservation of political boundary positions: The next steps are those of aesthetics, the most important being how strongly the final product should resemble the overall shape of the real geographic map. If the goal is to correct for some of the rural bias while maintaining ease in which a reader can locate a certain area, then an equal interval population spacing weighted hexagram would be the proper method. With such a map, the jurisdictions are first transformed into hexagrams, then weighted by population. Therefore, shape and position are standardized, while population varies. Such a map can be created in R with the hexcarto package. Either normalized population might be employed to better represent high population areas, or equal interval if the goal is to preserve shape and position. However, if preserving position of jurisdictions are not a concern, then more radical mapping techniques can be taken via a Gastner Newman cartogram.

3. Maximize population weight accuracy: If the goal is to prioritize population over physical geography, then the non-modified Gastner-Newman method is appropriate. Under such a map, areas with low populations will barely be visible, and areas with higher populations visualized. Such a map can be better produced in the event of non-extreme population disparities and a medium or lower number of jurisdictions. The

non-modified Gastner-Newman cartogram can be created in ArcGIS. If there is a desire to make some low population areas visible, then the next best method is to add a minimum bounding geography correction, using preferably the convex-hull correction. The modified Gastner-Newman cartogram can be created in ArcGIS.

Upon deciding the best option for your map, the following will discuss how to create the relevant map style of interest. Before proceeding, consider Table 1 and the general technical requirements necessary to create the variety of maps. Note that these are guidelines, and exceptions can be found. However, for the most part these should allow the user when combined with the decision tree to choose the best map for the research design in question. Deviations from these guidelines will result in odd maps that can often defeat the purpose of deviating from a standard physical geographic map in the first place. These shall be discussed in the following sections.

Table 1: General Technical Requirements for Cartogram Creation

Map Type	Polygon #	Population Dist.	Concavity	Rural correction
Hexagram	Medium to high	NA	NA	Low
Hexagram Cart.	Medium to high	Varies	NA	Varies
Normal	Medium to high	Normal*	NA	Greatest
Equal interval quantile	Medium to high	Normal*	NA	Medium
Gastner-Newman	Low to medium	Anything†	Anything	Great
Convex-Hull	Medium	Anything†	Low to medium	High
Envelope	Medium	Anything†	Low	High

* Non-normal populations can be accounted for and presented, though the choice must be made as to whether to hide rural areas (normalized population weights) or overvisualize rural areas (equal interval quantile weights).

† Non-normal populations and extreme values can lead to longer computation times, and in the event of a large number of polygons, a failure to converge.

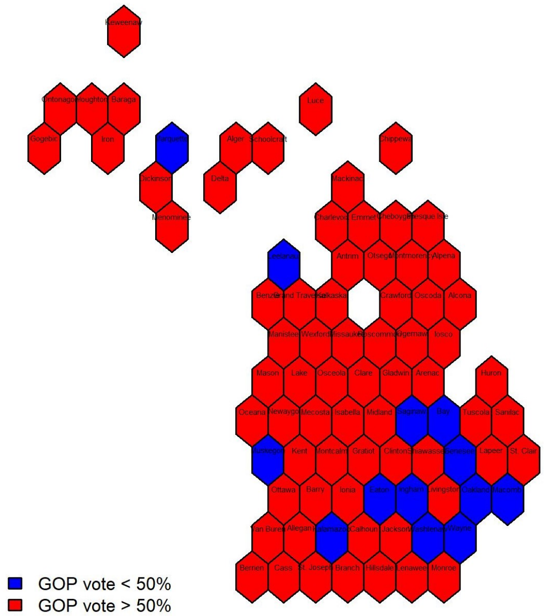
I Hexagrams

The benefit of hexagrams is the forcing of jurisdiction equivalence. Every polygon becomes the same size, and each polygonal unit attaches together due to the nature of hexagons. The hexagram method works best when enough units exist so as to approximate the shape of the highest unit of aggregation, i.e. a nation or state.

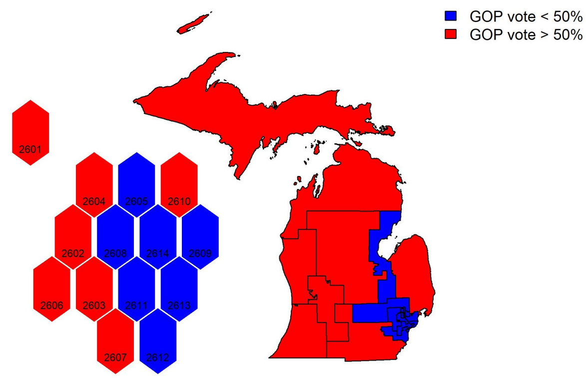
The Hexagram method is best accomplished in R, which automates the process via the makeTilegram2 function within the hexocart package. The makeTilegram2 command takes as an argument only the relevant shapefile and associated spatial information (i.e. dbf, .shx, .prj, etc.). Upon reading in the information, the coordinates for the polygonal units are overlaid on top of a hexagonal grid. From there, the hexagonal grids are arranged such that each chosen hexagon minimizes the distance between the units, the data frame merged onto the new spatial information, and empty hexagons excluded. The following code block exemplifies the code necessary to create a hexagram of Michigan.

```
###packages
library("devtools")
library("roxygen2")
library(rgeos)
library(rgdal)
library(sp)
library(BAMMtools)
###Install the hexocart package
install_github("jcuriel-unc/hexcarto")
library(hexocart)
####
wd = "C:/Users/map_info"
setwd(wd)
## reading in Michigan Shpfile
mi_shp <- readOGR(wd, "mi_county_shpfile") # the folder location for the spatial
#info, followed by the name of the spatial files.
###Running the Hexagram code
mi_hex_county <- makeTilegram2(mi_shp)
plot(mi_hex_county)
```

Figure 5: Michigan Hexagrid Transformation Comparison



(a) Transformation of Michigan Counties



(b) Transformation of Congressional Districts

Figure 5 presents two different transformations of the state of Michigan, one suited to hexagram transformation, and the other not so much. The left panel, Figure 5a, presents county level Congressional election results from 2018 by county, which are then transformed. Michigan contains a total of 83 counties, not all of which are contiguous on a hexagonal grid. Overall, the transformation adheres to the general shape of Michigan, and each county standardized to the same size. Overall, insofar as one needs some type of analysis where all of the county sizes are equalized and state shape adhered to, Figure 5a works.

Figure 5b presents a transformation that does not work. We see the actual Congressional districts presented on the right side, and the hexagrid transformation on the left. The hexagrid makes clear that the Congressional delegation is evenly split, not all Republican, although the resulting map looks nothing like Michigan. There are too few districts for the hexagram to mimic the state's shape. A simplified pie chart or similar figure would better present the divided nature of the Congressional delegation.

It is also possible to in turn weight the hexagram by population. This can be done with the hexocart package via the hexcarto function.[4] The function takes several arguments, depending on the user preferences, besides the shapefile.

1. population field - the name of the population field within the dataframe, inside quotation marks

2. choropleth field - name of the optional field with the values that will later go onto provide the values for the choropleth map

3. color value - The name of the optional field that if true, will provide colors by polygon for the map. Note that if this field and the choro/jenks fields are empty, then the map will be made blue. The colval field should take the form of a value that can be recognized as as color (i.e. blue). Can also be manipulated before hand by the user so that it reflects some non-jenks categorization of values.

4. Jenks - True or False, and if true, then a gray scale coloring scheme based upon the natural breaks of the choropleth field will be added to the map.

5. The name of the field with polygon labels, which if filled, will overlay the polygons with names.

6. Quantile cartogram breaks - A true/false field that allows the user to specify how the user wants to weight the population. The default is true, where the population values are broken by equal interval quantile, and if false, then normalized population without equal interval corrections.

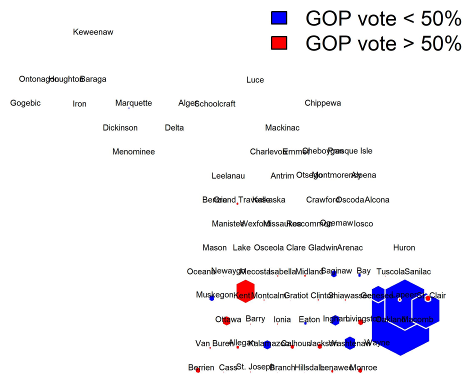
Note that the data and user preferences will greatly impact the options the user will want to pursue. We will take as a given that there are a sufficient number of polygons to justify a hexagram. If so, then the level population normality will strongly influence the best path.

[4]Currently on version 2b.

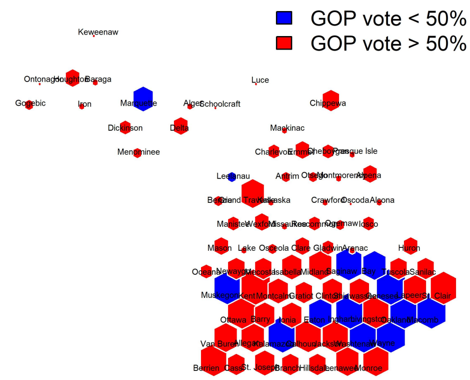
The hexcarto command reports the kurtosis and skewness of the population field, which is then normalized on a zero to one scale in order to grow the hexagons according to their population. The following code presents how to make the hexagram cartograms.

```
###packages
library(hexocart)
library(rgeos)
library(rgdal)
library(sp)
####
wd = "C:/Users/map_info"
setwd(wd)
## reading in Michigan Shpfile
mi_shp <- readOGR(wd, "mi_county_shpfile") # the folder location for the spatial
## Assigning colors
mi_shp$color <- "blue"
mi_shp$color[mi_shp$gop_vote_s>50] <- "red" # the field gop_vote_s refers to GOP
#vote share of the 2 party vote, on a 0 -- 100 scale.
###figure with color, equal intervals by quantile
jpeg("mi_counties_equalint.jpg", res=600, height = 5, width = 5, units = "in")
hexcarto2b(mi_shp, pop_field = "VAP2010", choro_field = "gop_vote_s", colval = "color",
quant_carto_breaks = TRUE, label_field = "NAME" )
legend("topright", fill=c("blue","red"), legend = c("GOP vote < 50%", "GOP vote > 50%"),
dev.off()
### cartogram with the normalized population
jpeg("mi_counties_normal.jpg", res=600, height = 5, width = 5, units = "in")
hexcarto2b(mi_shp, pop_field = "VAP2010", choro_field = "gop_vote_s", colval = "color",
quant_carto_breaks = FALSE, label_field = "NAME" )
```

Figure 6: Correcting for Population via the Hexagram Cartogram Comparison



(a) Normalized Weights



(b) Equal Interval Weights

```
legend("topright", fill=c("blue","red"), legend = c("GOP vote < 50%", "GOP vote > 50%"),
dev.off()
```

Figure 6 presents Michigan Congressional election results by county for 2018, with two different weighting schemes. The first, Figure 6a, weights the hexagons by a county's ranking on a 0–1 normalized scale of population. The skewness and kurtosis for Michigan's population, however, are 4.6 and 26.5 respectively. Therefore, only the southeast corner of the state sees any hexagons of substantive size, with only one Republican majority area somewhat visible. If one plots the text of county names at the county centroid, however, the shape of the state is still apparent, though all rural areas effectively completely discounted.

Figure 6b provides an equal interval weighting scheme, such that the cell size of the least populated areas are weighted at 0.05, and starting at the 20^{th} percentile, every decile increase leads to a 0.05 unit increase in cell width, with a max of 0.5 for the 90^{th} percentile and above. Following the equal interval scheme, the least populace counties are effectively discounted, and the southern portion of the state is fully colored. The map makes clear that most of the population lives within the bottom half of the state, though without the Detroit area completely subsuming everything else.

Therefore, a choice needs to be made by the user as to which map to use based upon project goals: if the population is skewed and not-normal, then a strong population weighting scheme will lead to only metro areas appearing visible. Making non-metro areas more visible is possible, though at the cost of diluting the reader from recognizing where most of the population truly lives. Both maps, however, correct for the status quo rural bias in the standard map.

II Gastner-Newman Cartograms

The hexagram approach ultimately exists to preserve some semblance of shape, though might not work given the priority to prioritize population amidst a low to medium number of polygons. Shape would be a secondary or tertiary concern in such a scenario. Therefore, one would want to make use of the Gastner-Newman cartogram, which equalizes the population density across contiguous areas and minimizes the velocity of change (Gastner and Newman, 2004). The formula can be complex, given that spatial adjacency must be taken into account, though the key point to keep in mind is that the population is prioritized heavily over shape preservation.

An initial obstacle that users will face when creating a Gastner-Newman cartogram is that no official standard version exists for ready use. The R package, "cartogram," runs into numerous errors upon install and has outdated code that often requires the deletion of other packages in order for progress to be made.[5]

That leaves ArcGIS, though the install process is not intuitive. The first step is to download the "cartogram" package and save it to one's preferred location.[6] Upon choosing the folder to save the package into, copy and paste the following into a text file titled

[5] If the reader exists in a world where this has been solved, then by all means make use of the new R cartogram package. For the purpose of this potentially dated manual, Gastner-Newman cartograms will be skipped over.

[6] The site to download the package can be found here: `https://www.arcgis.com/home/item.html?id=d348614c97264ae19b0311019a5f2276`

"register_arcgis.bat." Save into the chosen directory.

```
@echo Registering files...
@for %%f in (*.dll) do start /wait regsvr32 /s "%%f"
@for %%f in (*.olb) do start /wait regsvr32 /s "%%f"
@for %%f in (*.ocx) do start /wait regsvr32 /s "%%f"
@echo Registering Help files...
cd ..\help
@for %%f in (*.olb) do start /wait regsvr32 /s "%%f"
```

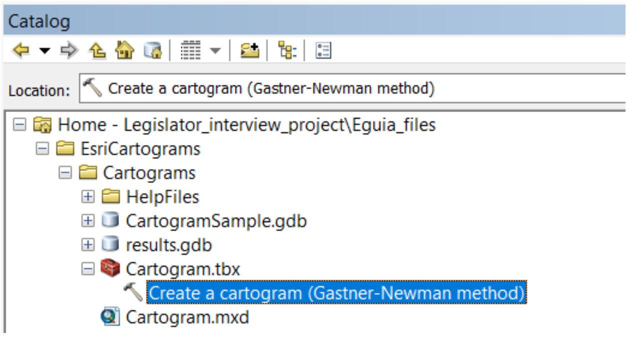
Double click the .bat file, and it will register all .dll files, allowing one to use the toolbox.

The user can find the toolbox in the folder where it was saved from the catalog side bar, as displayed in Figure 7a. From there, the user will be able to double click on the toolbox and receive a graphic user interface for the cartogram tool. Note that in order to use the tool at all, it will be necessary to create a geodatabase in order to save the output. Once the user ensures that a geodatabase is present, the tool can be opened. From there, the user should pay attention to four fields of interest within the graphic user interface: (1) original polygon features, (2) value field of the original features, (3) output cartogram features, and (4) copy original polygon features table. All of these can be seen in Figure 7b.

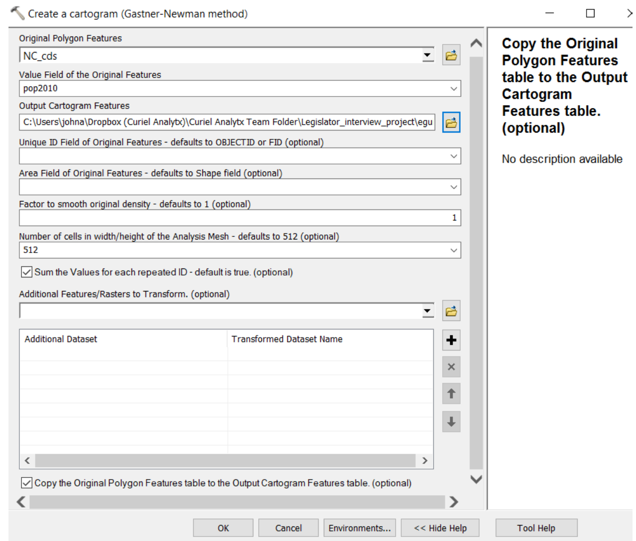
The original polygon features will be the shapefile, the basemap to be transformed. The value field in turn will be the population field to weight the cartogram. As Gastner and Newman (2004) note, it is still possible that extreme values can lead to longer computation times or even failure to converge issues, so the population field might still be transformed/normalized. The output cartogram features in turn will be the name of the feature class saved to a geodatabase. Finally, the copy original polygon features must be selected if the user wants the dbf/table information from the basemap transferred to the cartogram output, which will almost always be the case.

Upon running the script, the user will have a feature class that can be modified and presented as with any map in ArcGIS. Figure 8 presents two Gastner cartogram transfor-

Figure 7: ArcMap Cartogram Interface



(a) Cartogram location

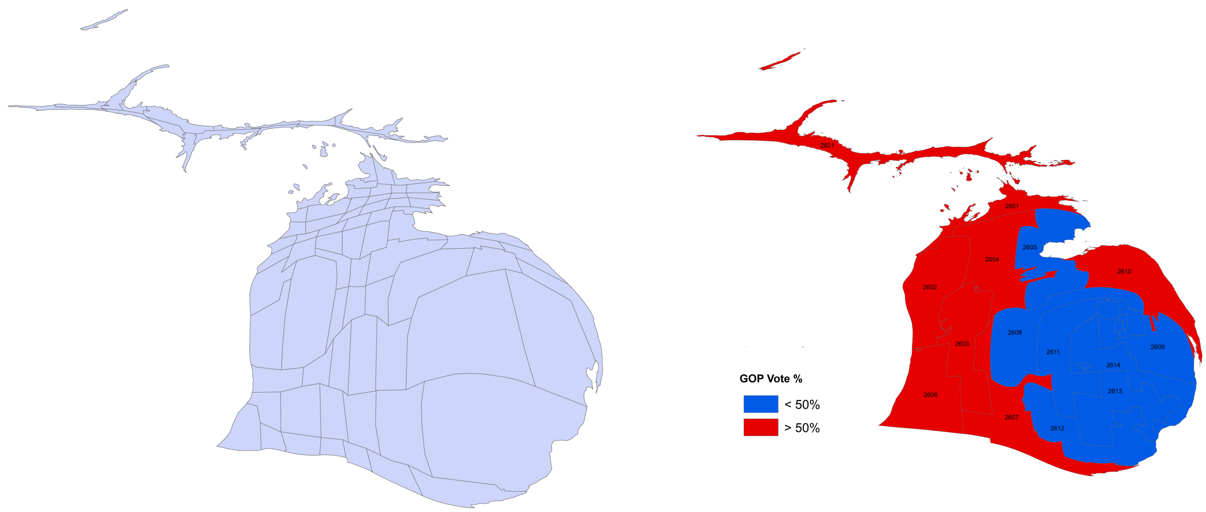


(b) Cartogram GUI

mations of Michigan. Figure 8a presents the transformation by counties, and Figure 8b by Congressional district. Despite the fewer number of Congressional districts, both figures present the same general shape, which is not true of the hexagram transformation. In this regard, Figure 8 displays how Gastner-Newman cartograms are not atomic unit dependent. Also note that while the state is distorted, it is recognizable in a manner that is not true of states in Figure 3. Therefore, both maps work to correct for the rural bias within the state while allowing for ease of reference to the state's physical geography. Figure 8b also makes evident that it is then possible to apply standard choropleth changes to the cartogram layer within ArcMaps.

However, it might be the case that the user seeks to correct for some of the odd geographies that might arise from a Gastner-Newman cartogram. Whether one can will largely depend on the number of polygons and concavity of the map. As the number of polygons increases, the more likely that one can add a correction without heavily distorting the cartogram. If the cartogram as derived from the basemap is able to avoid any concave coastlines or similar features, the less likely that a map will end up as heavily distorted with applied corrections.

Figure 8: Gastner-Newman Cartogram of Michigan



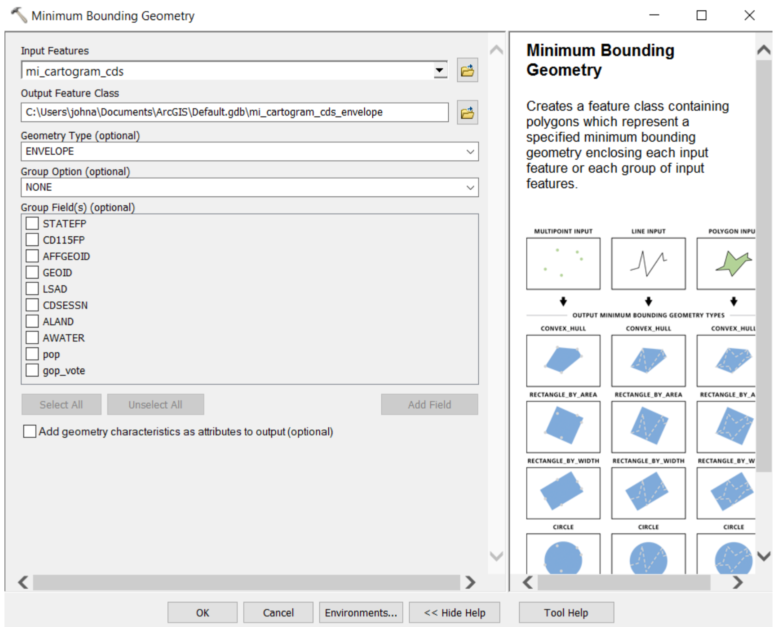
(a) Michigan counties

(b) Michigan congressional districts

Corrections themselves present potential biases, with the two potential avenues comprising the envelope or convex-hull corrections. The envelope correction will transform the atomic polygons into the smallest fitting rectangular polygon as determined by the most convex points. Convex-hull will correct for polygon shapes such that the most convex points of each polygon shall be used to construct the smallest fitting polygon over what is present, which ends almost always in non-rectangular shapes. Of the two, the envelope correction can often be the more visually appealing. However, it is also the case that the envelope correction can lead to polygons that overlay on top of each other, which can hide important features. The convex-hull in turn will lead to some irregular shapes, though offer an improvement over the base Gastner-Newman cartogram without the issue of overlaying polygons.

Figure 9 presents the graphic user interface for the minimum bounding geography tool within ArcMaps, the path being Data Management Tools > Features > minimum bounding geography. The tool accepts three simple arguments from the dropdown fields: the input shapefile, the name of the output shapefile, and finally the geometry type for the correction. The potential geometry types are rectangle by area, rectangle by width, convex-hull, circle,

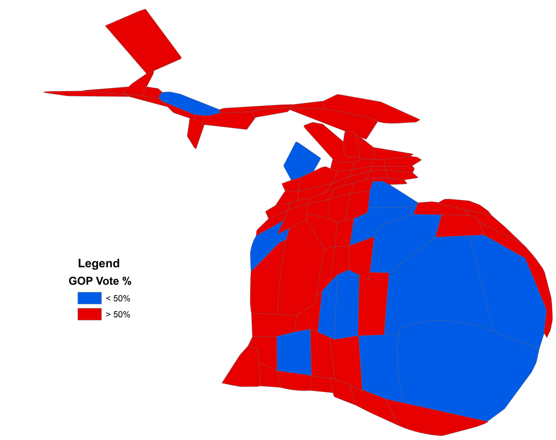
Figure 9: Minimum Bounding Geography Tool



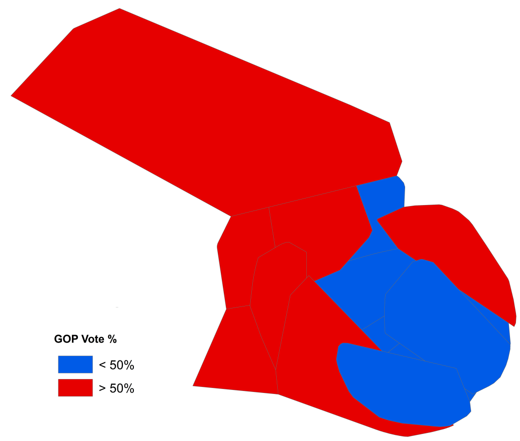
and envelope. The user will want to stick with envelope and convex-hull for the purpose of cartogram smoothing.

Figure 10 presents four maps of Michigan, by county versus Congressional district and convex-hull versus envelope. Figure 10a and 10c display that either the convex-hull or envelope correction work well for Michigan counties. Although there are perhaps some minor overlay issues, the contrast of blue on red is clear, and the upper peninsula is given extra width as compared to the base Gastner-Newman cartogram, but not so much that it is overly large. The corrections preserve the general shape of the state while correcting for the rural bias. The district transformations with only 14 atomic polygons do not end well. Neither transformation has a sufficient number of polygons to cope with the concavity of the upper peninsula. In both convex-hull and envelope corrections, the upper peninsula is a bloc, with the envelope method the worse of the two. The envelope method additionally hides a Democratic district due to drawing order. Therefore, the entire purpose of a cartogram is lost with the minimum bounding geographic corrections to the district maps: the impact of population is lost, and the state no longer resembles the physical geography at all.

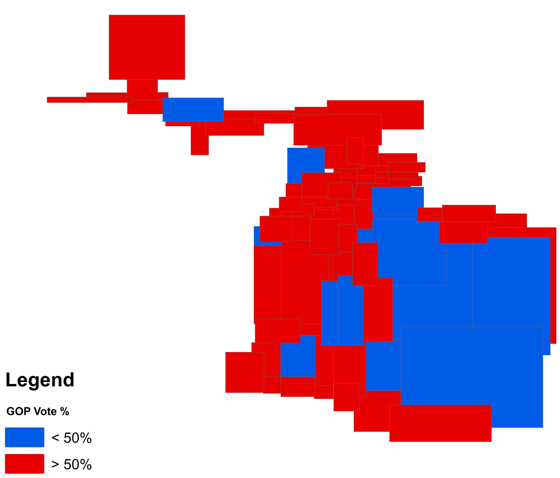
Figure 10: Gastner-Newman Cartogram Correction Examples



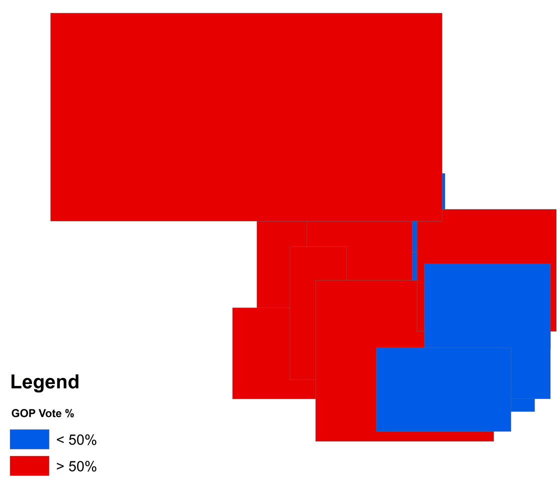
(a) Counties convex-hull correction



(b) Congressional districts convex-hull correction



(c) Counties envelope correction



(d) Congressional districts envelope correction

III Discussion and Conclusion

The most important lesson to keep in mind in the cartogram creation process is that there is no one right answer. The map transformation to employ entirely depends on the research question and goal of the map. What's possible with a map in turn depends on the population distribution, number of polygons, and concavity of the polygons.

Also keep in mind that while hexagrams and the various cartograms can meaningfully correct for rural bias, one should not simply throw a cartogram transformation and see what sticks. Although the map creation process will often involve fine tuning, a great deal of time shall be lost if one puts no forethought into the goal and purpose of a map. As mentioned earlier, all maps are wrong, though some less wrong than others and useful to boot. Therefore, use what works, discard what does not, and keep an open mind.

References

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