7

GEOSPATIAL

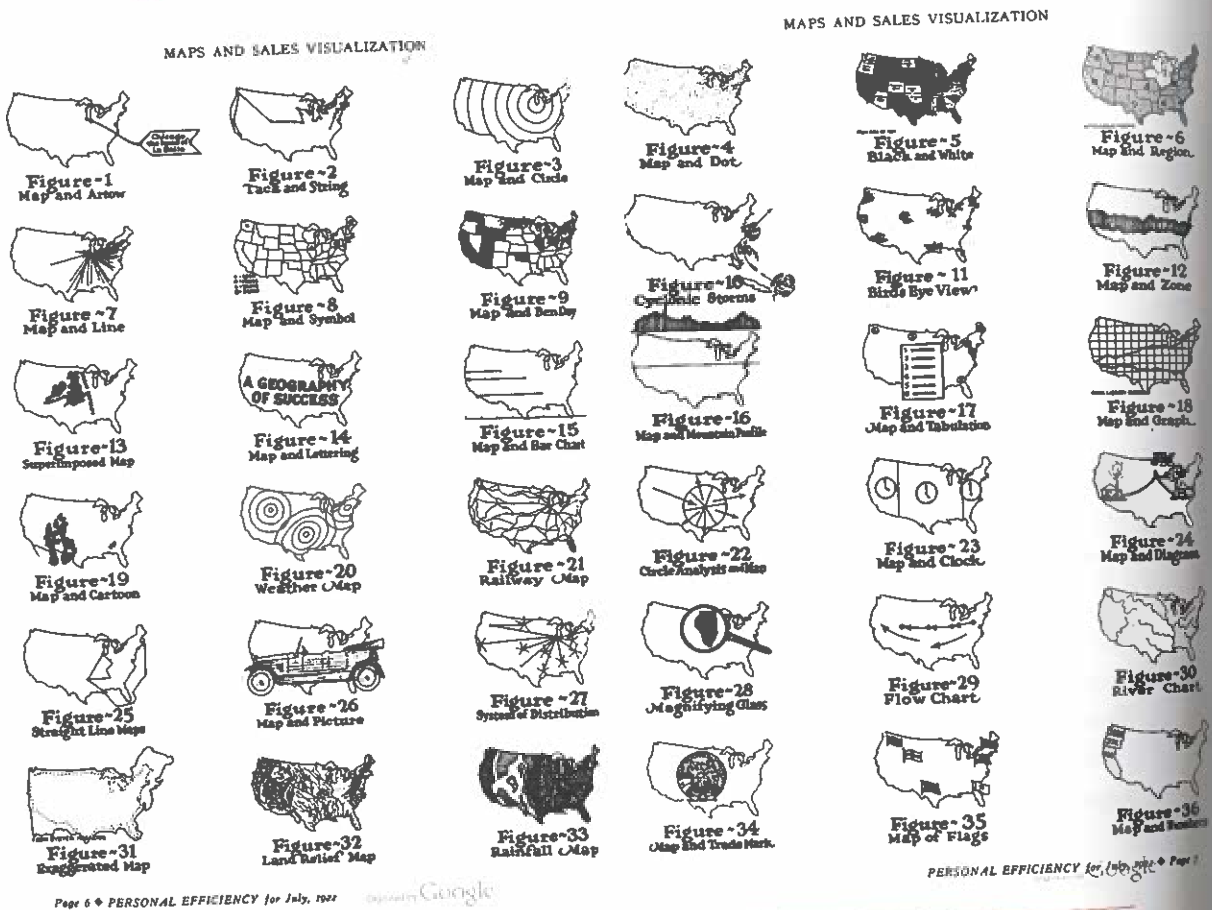
There is an obvious advantage to plotting geographic data on a map—people can find themselves in the data. They can literally *see* themselves in the data, a connection with the subject matter that other visualizations cannot muster. Plotting geographic data may mean adding color to geographic areas likes states or countries, or adding circles, squares, lines, or other shapes on top of a geographic map.

Data-driven maps are not new. In 1922, the "Maps and Sales Visualization" on the next page shows the reader thirty-six different ways to place data on a map. The author writes:

> The use of maps has to do with the visual representation of space. Therefore, in all map work we start with an outline . . . The fact that the Earth is a globe makes visualization of maps a difficult process; arbitrary methods have to be used to get the surface of the ball represented in a flat picture.

This chapter begins with some of the basic challenges of visualizing geographic data and then presents some alternatives to the basic map, the modern version of this 1922 visualization.

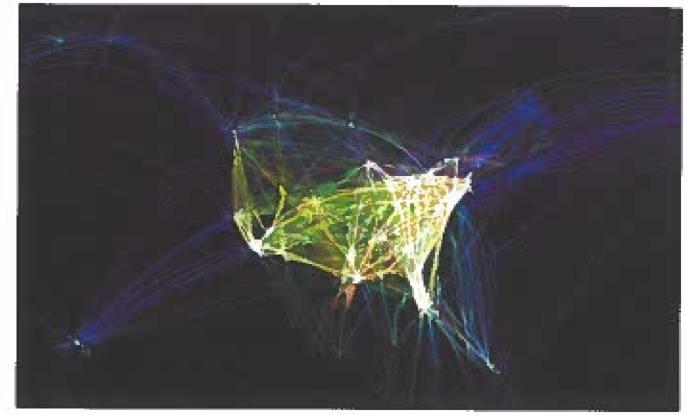
The maps in this chapter use a color palette often used by the *Washington Post*. Maps of the U.S. political system in this chapter use the basic red-blue color palette used by many newsrooms.



E.P. Hermann's (1922) "Maps and Sales Visualization" shows an early example of the multitude of ways to place data on a map.

THE CHALLENGES OF MAPS

Aaron Koblin's *Flight Patterns* is one of those maps that can entrance the reader. Koblin plots all flight paths in the skies above the United States in twenty-four hours. The static version of the map (there is an interactive version in which you can zoom into any area of the country) shows the entire country, major airports, and the activity of the skies above. It's not a visualization that ranks the biggest airports or tells you how to avoid delays, but it quickly shows the traffic patterns in American skies.



Aaron Koblin's *Flight Patterns* project, which consists of static and interactive maps, shows all flight paths in the skies above the United States over twenty-four hours.

There are some distinct challenges when creating maps. The biggest is that the size of a geographic area may not correspond to the importance of the data value. Russia is more than 6.6 million square miles, almost twice the size of Canada, and so it takes up a lot of space on a map. At 270,000 square miles, Texas is roughly the size of California and Colorado put together, but it's actually less than half the size of Alaska (665,000 square miles), which you might not know because most maps of the United States tend to distort it and arbitrarily position it out to sea, south of California. The point is that the data values for Russia, Texas, and Alaska may not correspond to their importance in the data, and the map can distort our perception of the important values being visualized.

I find that many people should approach their desire to create a map with more skepticism and critical thought. Is a map truly the best way to present geographic data? Or are you just showing where people live? Does it show the relationships we want to explore or are we simply relying on the fact that we have geographic identifiers? This chapter will explore the perceptual issues of maps and why they are not always the best medium through which to demonstrate our points. This isn't to say we should *never* make a map—in many cases we need to make a map to better understand our data—but, especially with maps, we should always take a step back and consider whether it is the right visualization choice.

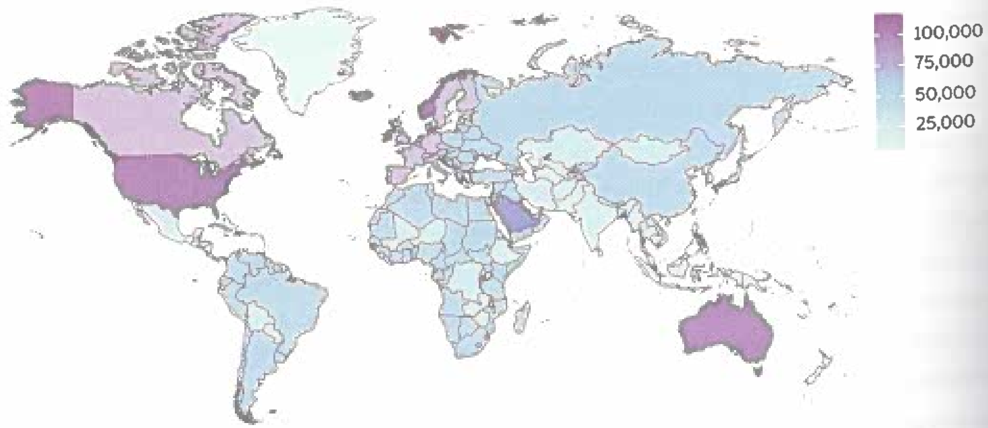
The message is simple: there are many ways to present geographic data, and there are lots of objects, shapes, and colors you can add to maps. Which kind of map you use to visualize your data will depend on two questions: How important are the geographic patterns? And how important is it for your reader to see a familiar map?

CHOROPLETH MAP

Perhaps the most familiar data map has perhaps the most unfamiliar name: a choropleth map. Choropleth maps use colors, shades, or patterns on geographic units to show proportionate quantities and magnitudes. You likely already know how to read this choropleth map of per capita GDP around the world—it's a simple and recognizable shape that lets you quickly and easily find countries (and, by extension, yourself) in the visualization.

This color palette is also easy to understand—smaller numbers correspond to lighter colors and larger numbers to darker colors (and what is sometimes called a "color ramp"). More often than I care to count, map creators will use an incorrect color palette. For example, for this map, someone might use a diverging color palette in which colors progress outward from a central midpoint. Unless we are comparing per capita GDP above and below some midpoint number, such as the average GDP, the diverging color palette is a bad choice. Instead, we should follow what has become a simple standard of lighter colors to darker colors. We discuss color palettes in more detail in Chapter 12.

PER CAPITA GDP AROUND THE WORLD IN 2017



Source: The World Bank

The choropleth map is perhaps the most familiar data map. Colors correspond to data values and are assigned to the different geographic areas on the map.

It may be bit difficult to find smaller countries or countries that you don't already know, but the overall shape is familiar, well-known, and easy to understand. Did you know Luxembourg had the highest per capita GDP in 2017 at more than $104,000 per person (for reference, per capita GDP in the United States was $59,500)? It's a country of only one thousand square miles (for reference, France is almost 250,000 square miles) and difficult to find on this map, but it has the highest per capita income.

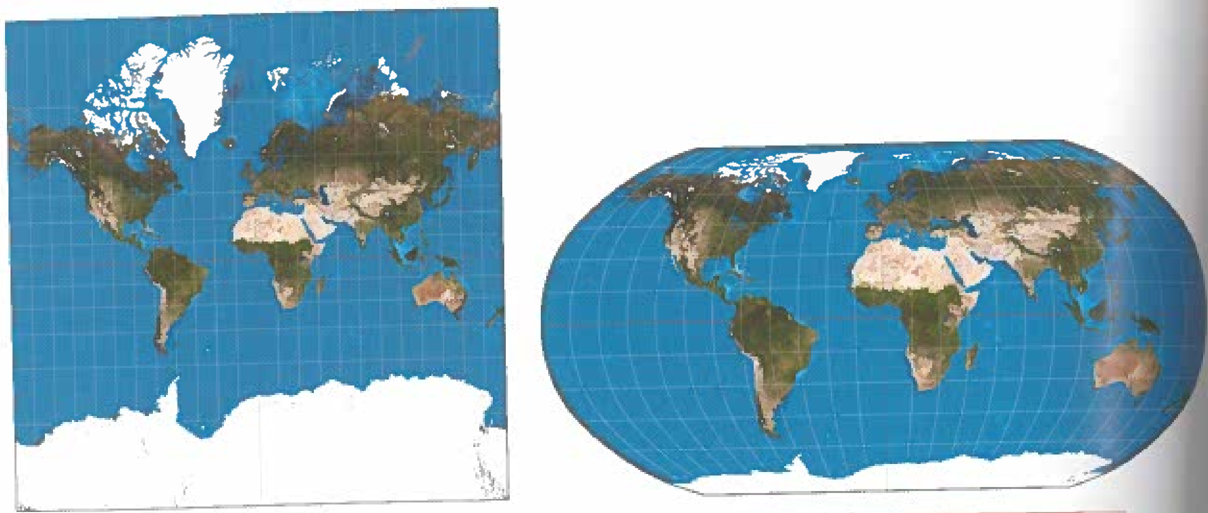
Maps like these introduce a geographic distortion—the size of the geographic area may not correspond to the importance of the data value. Even with this distortion, however, maps are an easy and familiar way to present geographic data to our readers.

There are a variety of alternative map types that correct this geographic distortion. Cartograms, for example, resize the geographic units according to their data values (see page 233) and a tile grid map uses a series of equal-sized squares (see page 238), not to mention the other chart types we can use to plot geographic data, such as a heat map (see page 112). The tradeoff with any of these alternative approaches is that the map is no longer as familiar to the reader as the standard map. But, as Kenneth Field, author of the data visualization and cartography book *Cartography*, once noted, "None of these maps are right and none of these maps are wrong. They are all just a different representation of the truth."

CHOOSING THE PROJECTION

One challenge with mapping data is the map *projection* the creator chooses. The world is a globe, but maps are flat. A mapmaker must choose a map projection to transform the world's sphere into a two-dimensional plane. All maps distort the surface of the planet to some degree and there is considerable debate about which projection does the best job depicting the earth in two dimensions.

The one you are likely most familiar with is the Mercator projection. This is the map used in early versions of Google Maps and is the default in many data visualization tools like Tableau and PowerBI. Developed in 1569 by Flemish geographer and cartographer Gerardus Mercator, it became the standard map projection for nautical purposes. A sailor could draw a straight line between two points and measure the angle between that line (called a *rhumb line*) and the meridian (the vertical line that runs between the north and south poles) to find their bearing. While it may be useful for sailing the seas, the Mercator projection distorts the size of objects as the latitude increases from the equator to the north and south poles. Thus, countries closer to the poles—like Greenland and Antarctica—appear much larger than they actually are. In the Mercator map shown on the next page (on the left), Greenland looks to



Map projections can influence our perception of the map. The Mercator projection on the left, for example, looks considerably different than the Robinson projection on the right. Source: Wikimedia user Strebe.

be about the same size as South America, when it is in fact about one-eighth the actual size. In the Robinson projection on the right, country areas are closer to their true sizes.

There are three major categories of map projections:

CONIC

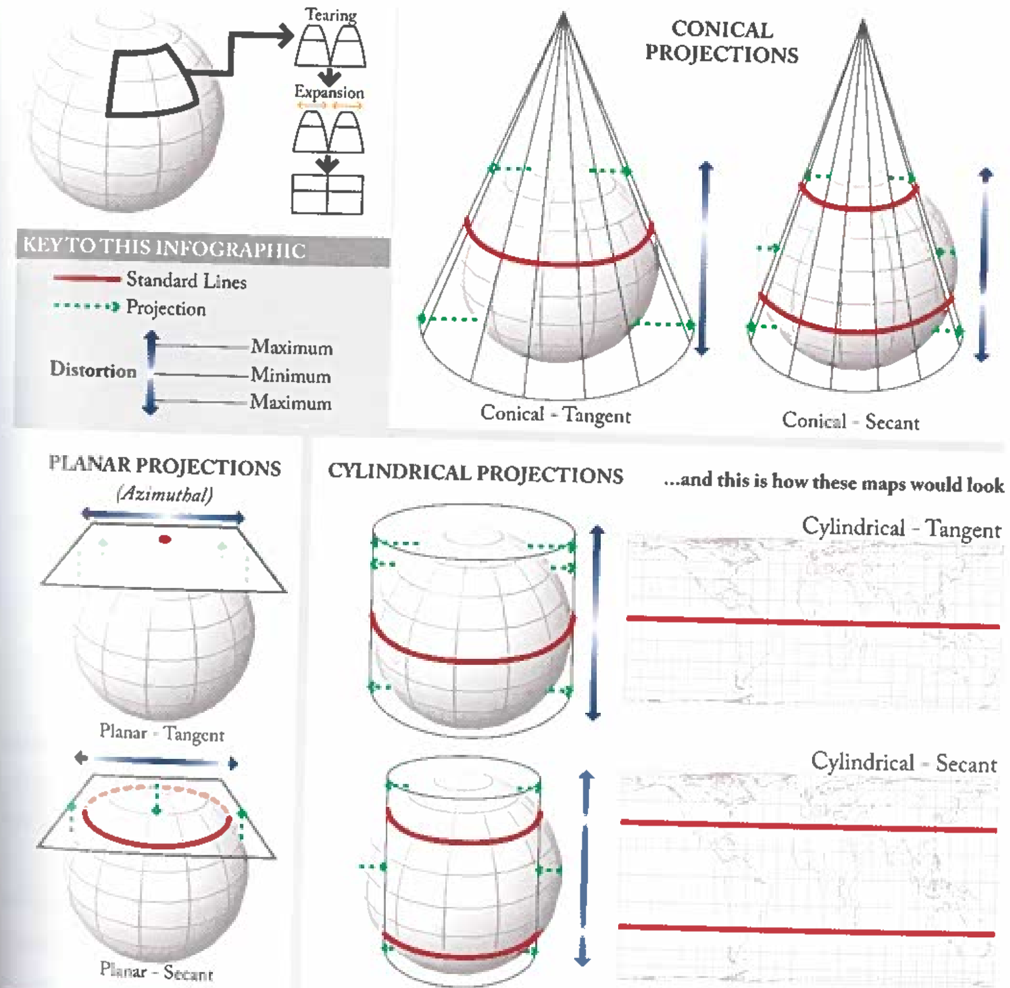
- Conic maps are as though a cone was placed over the Earth and unwrapped. Conic projections are best suited for mapping long east-west geographies, such as the United States and Russia, because the distortion is constant along common parallels. The Albers Equal Area Conic and the Lambert Conformal Conic are two of the more well-known projections.

CYLINDRICAL

- Cylindrical maps work like conic maps but use cylinders instead of cones. Like the Mercator projection, cylindrical maps inflate geographic areas farther from the center.

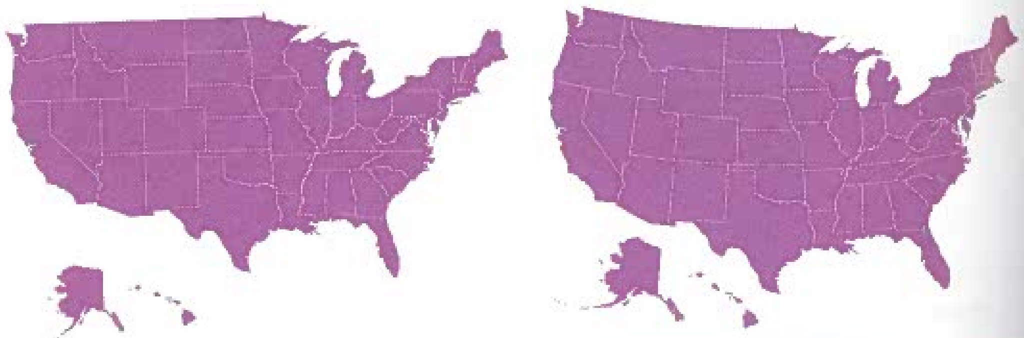
PLANAR (AZIMUTHAL)

- With this approach, the planet is projected on a flat surface. All points are at the same proportional distance from the center point, such as the north pole, but the distortion gets larger as you move further from that center point.



To some degree, all maps distort the surface of the planet. Alberto Cairo's diagram from *The Truthful Art* shows a selection of different types of map projections.

There isn't necessarily a right or wrong map projection, though I'm sure some cartographers would disagree! But each has tradeoffs, and serious mapmakers dig deep into the different properties of these projections and weigh the different options. Many people in the data visualization field shy away from the Mercator projection because of its obvious drawbacks, though it can work well for small areas. For the United States, you can tell a map is using the Mercator projection because the top left border of the country is a straight line. The Albers projection, by comparison, preserves the east-west perspective, which you can see by the slight curvature in the northern border.



Notice how the northern border of the United States looks straight in the Mercator map on the left but is more curved in the Albers projection on the right.

CHOOSING THE BINS

As we start to add data to a choropleth map, our first consideration is the choice of intervals (or "bins") that will shade the geographic units. Placing data into discrete categories is, at its core, an aggregation problem. By combining several states or countries into a single bin, we don't know how different those units are from one another.

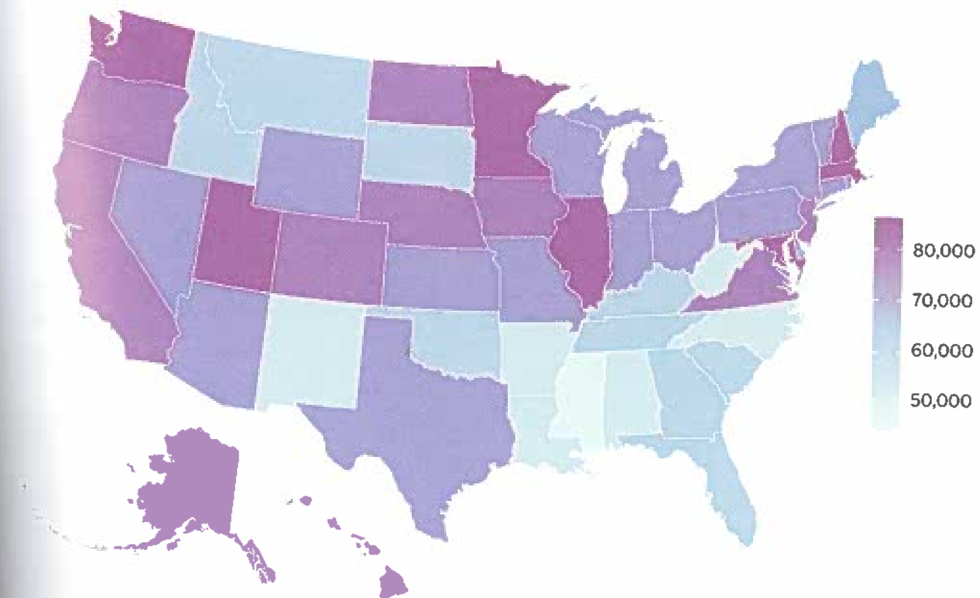
The map of the United States on the facing page, for example, shows median household income in 2018 in each state. How the states are placed into groups (the "bins"), the map shading, and ultimately our reader's perception of the data depends on our choices. Massachusetts ($86,345) and Maryland ($86,223) had the highest median household incomes in 2018 and fall into the highest bin with the darkest color; New Mexico ($48,283) and Mississippi ($42,781) are at the other end of the distribution and are shown with the lightest shades.

There are four primary binning methods for creating maps.

NO BINS

This is essentially a continuous color palette (or "ramp") in which each data value receives its own unique color tone. On the one hand, this is easy because we don't need to think too much when we create the map—the colors ramp up from the lightest color for the lowest value to the darkest color for the highest value. On the other hand, the resulting color gradient may generate spatial patterns masked by subtle changes in color. In this example, it's hard to distinguish the differences between Iowa ($68,718), Nebraska ($67,515), and Wyoming ($62,539).

MEDIAN HOUSEHOLD INCOME IN THE UNITED STATES IN 2018



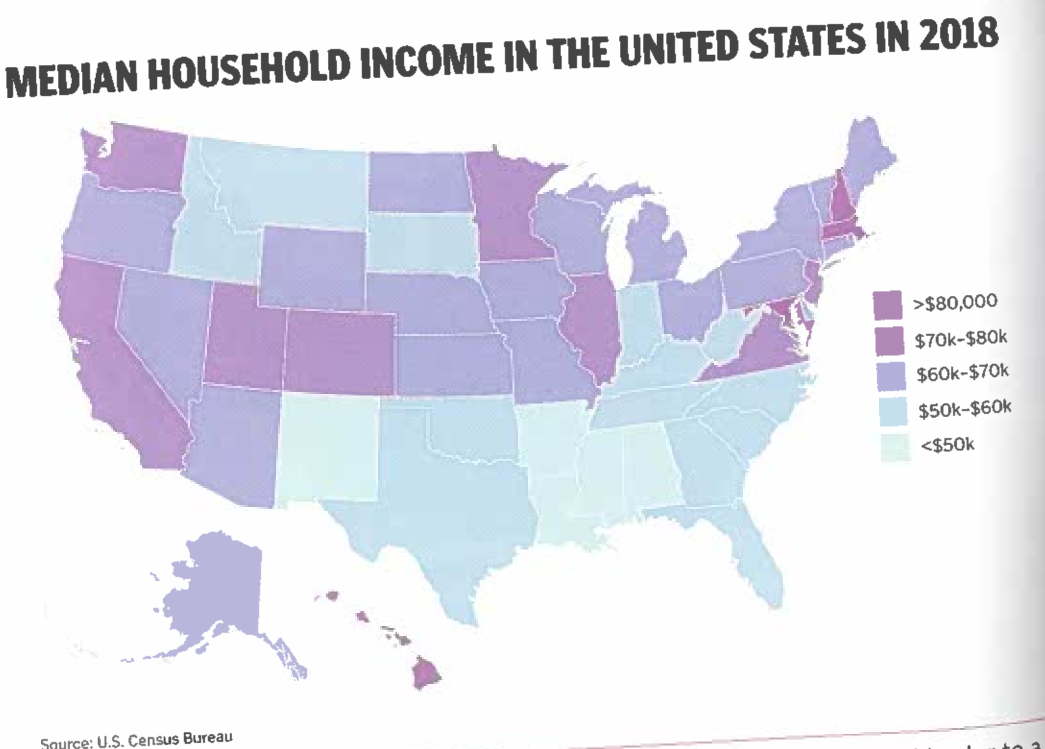
Source: U.S. Census Bureau

The continuous color palette (or "ramp") seamlessly goes from lighter colors (smaller values) to darker colors (larger values).

EQUAL INTERVAL BINS

In maps with a discrete number of bins, the default approach is to typically divide the data range into an equal number of groups. For example, in a map with four bins and a data range from 1 to 100, we end up with four equal groups (1–25, 26–50, 51–75, and 76–100).

This approach more clearly distinguishes geographic units (such as states) than the continuous (no bins) option, but it can mask the magnitudes of those changes by putting states in the same or different bins. In cases where the distributions are highly skewed, this approach may unevenly distribute the geographic units across the bins. In this map, the bins are split into equal units of $10,000, which results in five states in the bottom category, ten in the next, seventeen in the middle, fourteen in the next, and five in the top category.

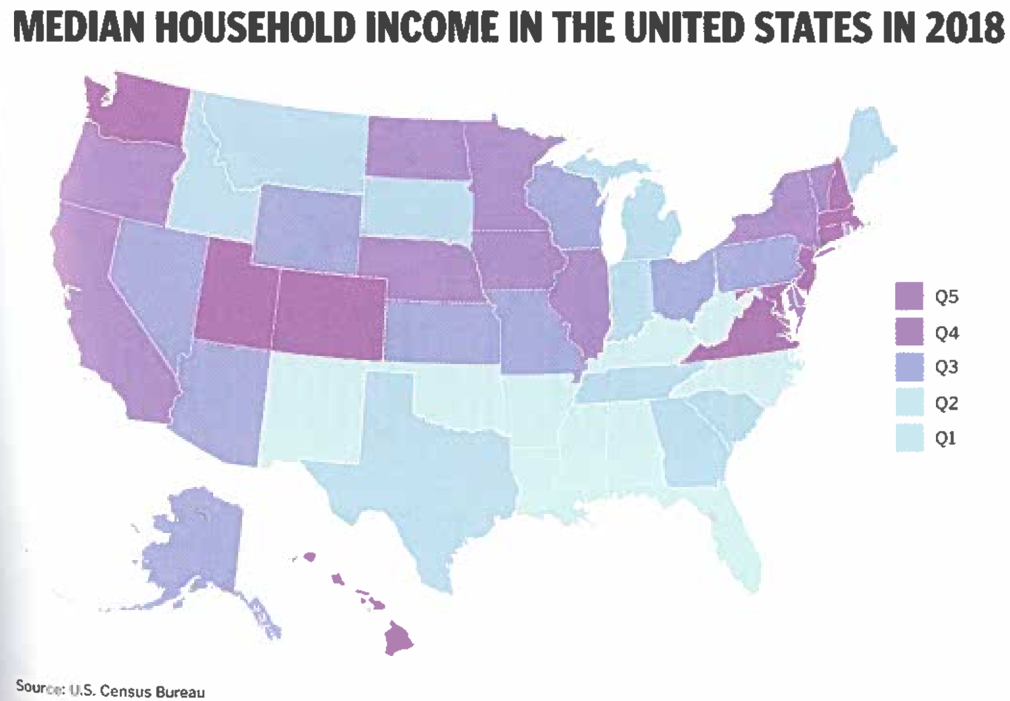


Dividing the data into equal intervals—such as $10,000 gaps—is one way to add color to a data map.

DATA DISTRIBUTION BINS

We could also cut the data into different bins. For example, instead of having a bin at equal intervals, we could arrange the bins to hold the same *number of observations*, such as quartiles (four groups), quintiles (five groups), or deciles (ten groups). Or we could use other measures to collapse the data into groups, such as the variance or standard deviation.

The data distribution approach clearly shows differences between the geographic units, but the created cutoffs may not be numerically meaningful. In this map that divides the country into five equal groups (quintiles), Connecticut is just barely in the top group with a median household income of $72,812, while Minnesota is placed in the next lower bin, even though it has a very close income estimate of $71,817.

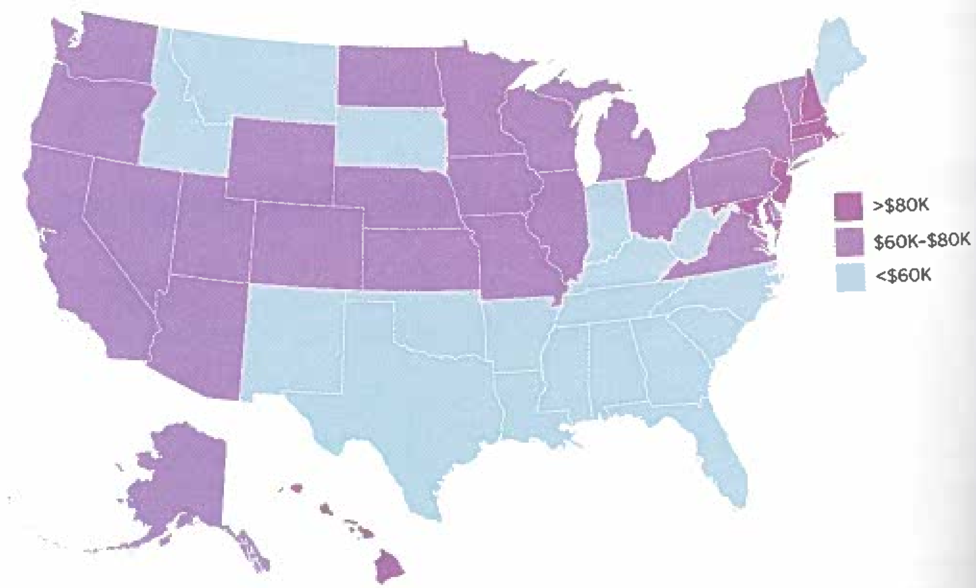


Another way to divide the geographic units is to divide the data into an equal number of observations, such as quartiles (four groups) or quintiles (five groups).

ARBITRARY BINS

In this approach, the map creator chooses the bin cutoffs based on round numbers, natural breaks, or some other arbitrary criterion. This method lets us avoid some of the odd breaks that might occur, such as the Connecticut-Minnesota example above, but it can also be misleading. A method in which the selected bins are based on larger groups or round numbers—even without looking at the data—might look like this:

MEDIAN HOUSEHOLD INCOME IN THE UNITED STATES IN 2018



Source: U.S. Census Bureau

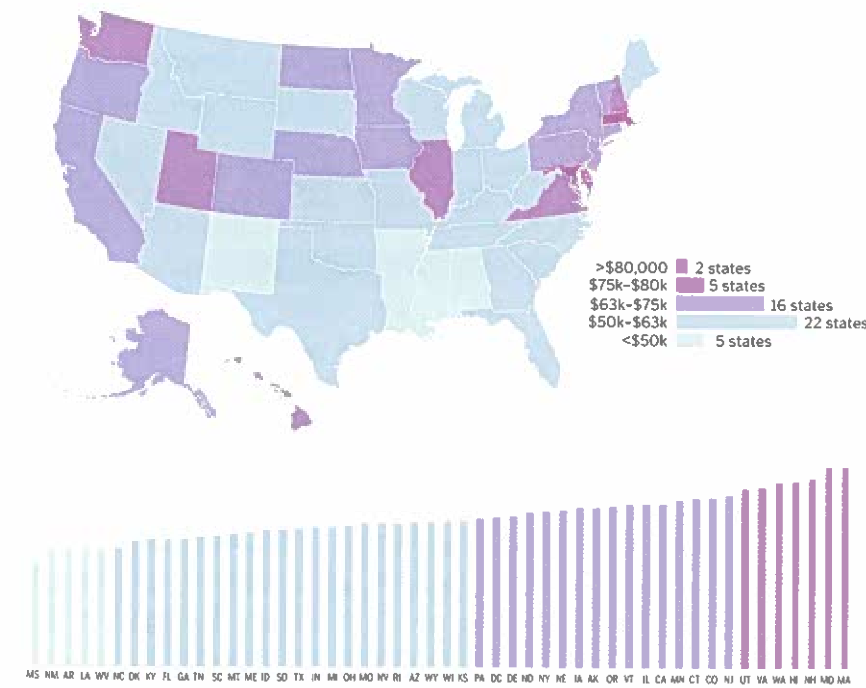
Depending on the goals of your data map, you can also divide the data into an arbitrary number of bins.

ALTERNATIVE OPTIONS

This isn't to say any of these maps are right or wrong, but they highlight the importance of binning decisions in choropleth maps. To make the best binning decision, we can draw on Mark Monmonier's 2018 book, *How to Lie with Maps*. Instead of using equally sized bins arbitrarily or letting the software tool decide which breaks to use, try considering—and showing—the actual distribution. If I add a column chart to the arbitrary bin method map, the bin breaks and the distinct differences between the values is apparent. Adding another graph takes up more space, but it gives readers a clear picture of the data.

Including the number of observations in each bin somewhere in the visualization can also reveal the distribution to your reader. In this version, the legend is converted to a small bar chart to show the number of observations in each bin.

MEDIAN HOUSEHOLD INCOME IN THE UNITED STATES IN 2018



Source: U.S. Census Bureau

One way to help readers better understand the data in a map is to pair it with another visualization type, like a bar chart. This visualization has a small bar chart embedded within the legend to make clear how many states are in each group. This is not a necessary component, but one that can help the reader understand the distribution of the data on the map.

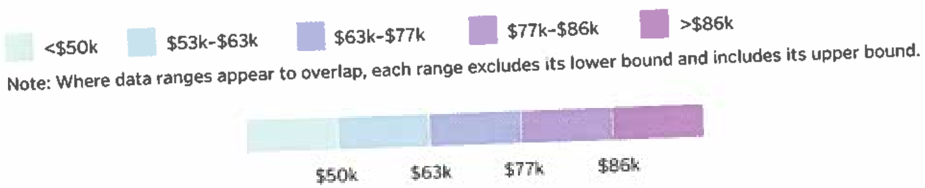
LABELING THE BINS

Another consideration when we create a map is how we *label* the bins. Let's use the visualization we just created of the map and bar chart of median household income.

In that map, the definition of the bins is arbitrary. The top bin is defined as ">$86,000" but because the maximum value in the next category $81,346 (New Hampshire), the top bin label could just as easily be ">$85,000," ">$82,000," or even ">$81,346."

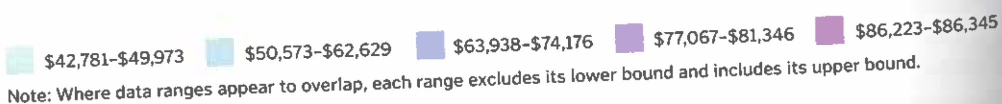
The legend for this map can be defined several ways.

1. Instead of round numbers, we could use the actual income amounts, which still leaves us with arbitrary bins. In this case, it isn't clear whether $86,000 is in the fourth or fifth group. There are a few ways to do this, for instance with separate boxes or a single image with labels just below. (One possible solution is to explicitly note which bins are inclusive or exclusive of the upper and lower bounds.)

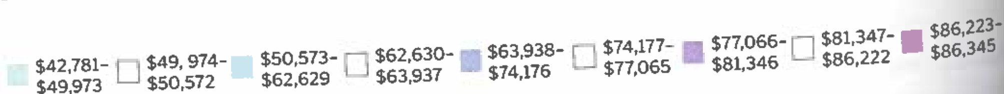


2. Another alternative is to define the bins on the actual data values.

This has the advantage of clearly showing the data values—for example, we can see the gap between $49,973 and $50,573 in the first two bins. The disadvantage is that the legend is overly detailed and complex. As the reader, you might wonder why all this precision is necessary and, depending on the content, you might wonder what's going on in the gap between the maximum of one bin and the minimum of the next.



3. Alternatively, we could create a legend that includes these "gap" bins:



Although accurate and comprehensive, this legend feels busy and obscures the five original bins by adding four non-data bins that connect them.

There is no one-size-fits-all solution to this challenge, but here we have laid out the issues and tradeoffs of creating and labeling bins. Always consider the necessary level of precision (i.e., the number of decimal places), the overall number of bins, and the smoothness of the data (that is, if the data show no visible jumps, round-numbered bins may be fine).

SHOULD IT BE A MAP?

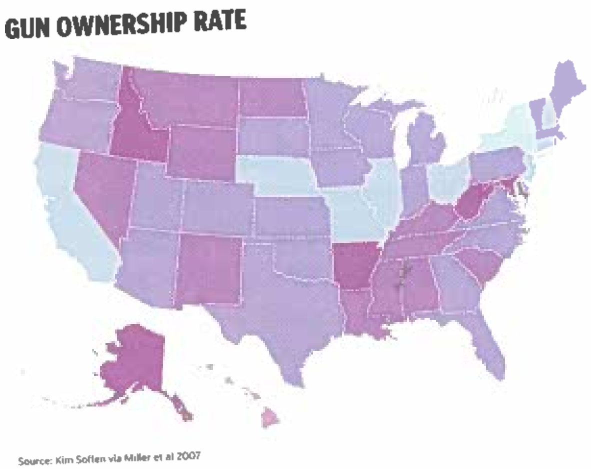
Before we start exploring other types of maps, let's first ask ourselves whether a map accomplishes our goals and best communicates our argument. Many maps are made simply because the creator has geographic data, not because the map is the best medium for that content.

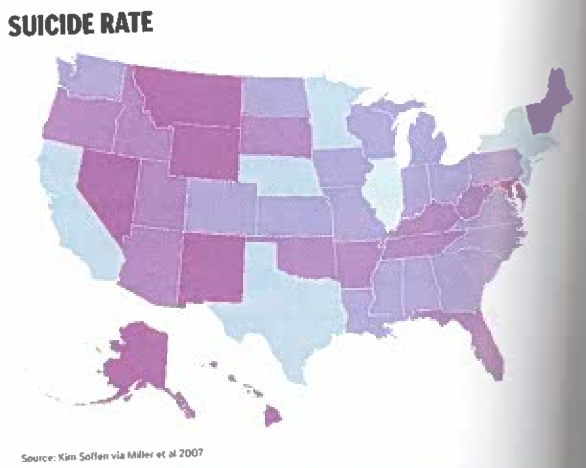
Take this simple example. A 2016 *Washington Post* story examined the relationship between rates of suicide and gun ownership in the United States. The story explains:

> One 2006 study found that from the 1980s to the 2000s, every 10 percent decline in gun ownership in a census region accompanied a 2.5 percent drop in suicide rates. There are numerous other studies that show similar results.
>
> This pattern becomes clear when looking state by state. The states that have higher rates of gun ownership, where people have more access to guns, also have higher rates of suicide. Suicides are twice as common in states with high gun ownership than those with low gun ownership, even after controlling for rates of mental illness and other factors, according to a 2007 study.

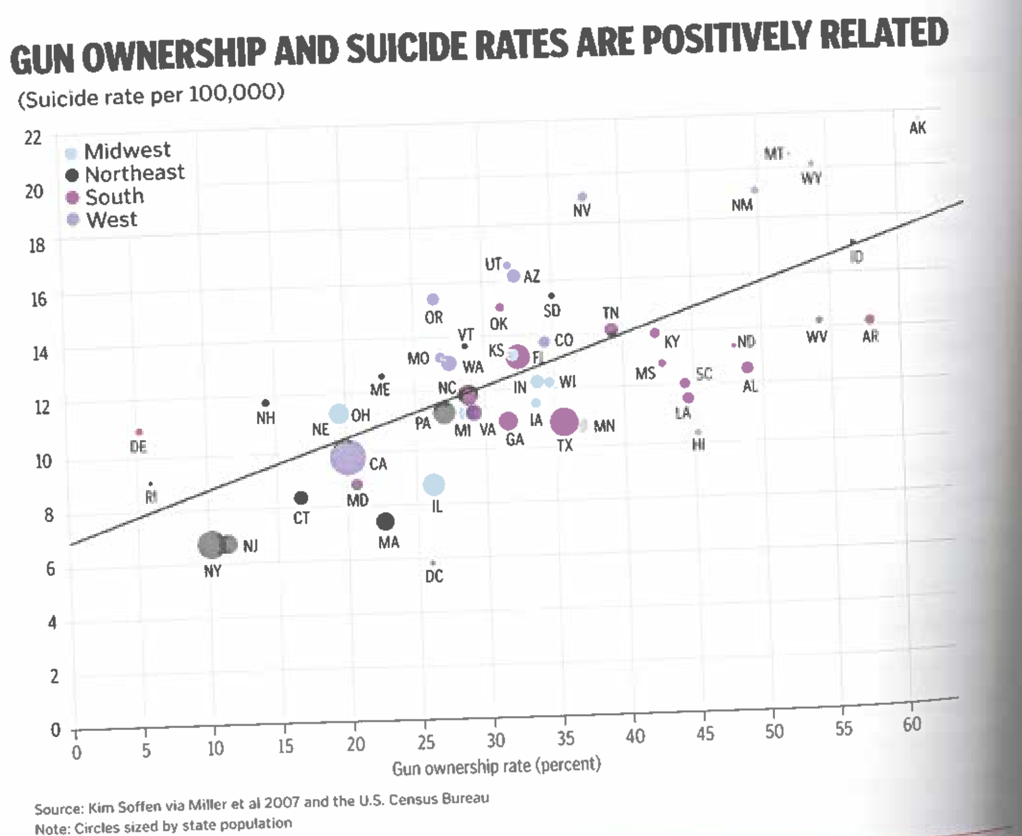
Below these two paragraphs were two maps, which I have recreated on the next page as choropleth maps. Do these maps help you see the positive relationship between the gun ownership rate and the suicide rate? Can you pick out states that have the highest suicide rates and the highest gun ownership rates? I can't. Instead, I found myself jumping back and forth between the two maps trying to identify individual states and regions.

Instead, what if we placed the same data in a bubble plot? We could put the suicide rate on the vertical axis and the gun ownership rate on the horizontal axis, and scale the size of the circles by population. Adding color to differentiate between areas of the country makes it clearer that states in the upper-right area of the graph tend to be western and southern states, where gun ownership is higher and, it turns out, gun-control laws are weaker.





Note: The original maps in the *Washington Post* story were actually tile grid maps—see page 238. Data were extracted from the *Washington Post* story and Miller et al. If you or someone you care for is in distress, suicide prevention and crisis resources are available at the National Suicide Prevention Lifeline in the United States at 1-800-273-8255. Many other countries have similar hotlines.



A scatterplot can be an alternative to a pair of maps.

Bubble plots may be less familiar to readers than simple choropleth maps, but with a clear title and a little annotation, this chart can better demonstrate the relationship between gun ownership and suicide. As you prepare to create your next map, ask yourself, "Is a map the best visualization to communicate my argument?"

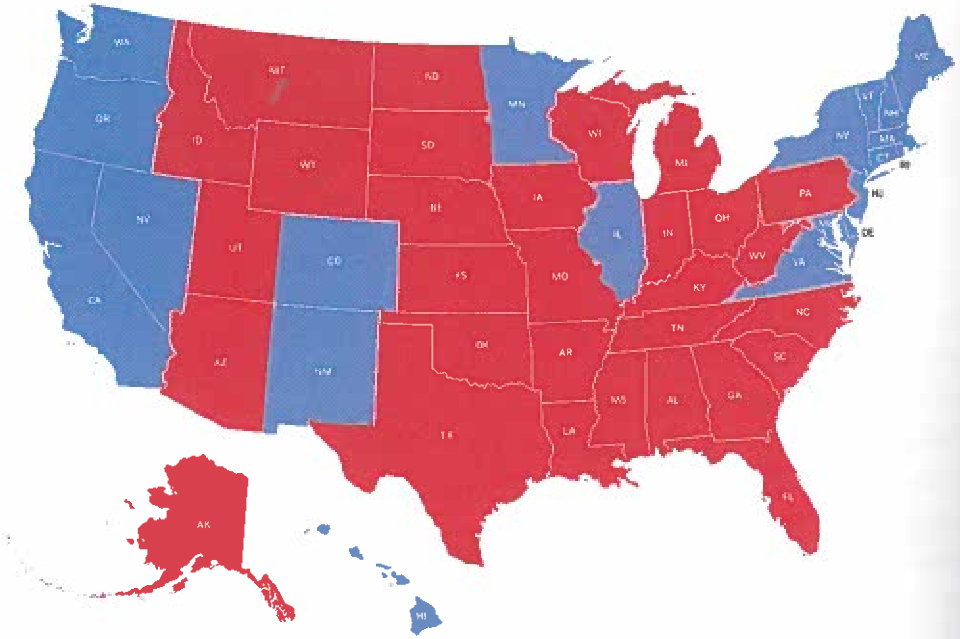
CARTOGRAM

One way to adjust for the geographic distortion of a typical choropleth map is with a *cartogram*, which reshapes geographic areas based on their values. There is an obvious tradeoff here: On one hand, these adjustments more accurately visualize the data because cartograms correlate the data and the geographic size. On the other hand, these graphs are not like the standard maps that we know and recognize. They are therefore not as intuitive for your reader. Your decision about whether to use a standard map or a cartogram will, as always, depend on your goals and your audience.

In his book *Cartography*, Kenneth Field summarizes the purpose of cartograms:

> The intent of most thematic maps is to provide the reader with a map from which comparisons can be made, and so geography is almost always inappropriate. This fact alone creates problems for perception and cognition. Accounting for these problems might be addressed in many ways such as manipulating the data itself. Alternatively, instead of changing the data and maintaining the geography, you can retain the data values but modify the geography to create a cartogram.

There are four primary types of cartograms: *contiguous*, *noncontiguous*, *graphical*, and *gridded*. One of the best ways to demonstrate the value of a cartogram is to examine the U.S. electoral college. In the U.S. election system, each state is assigned a number of electoral votes corresponding to its population, not its geographic size. Thus, states like Idaho, Montana, and Wyoming, which are very large in terms of square miles (325,412 square miles in total) but home to relatively few people, only have ten electoral votes between them. Massachusetts, by contrast, has eleven electoral votes and is 7,838 squares miles, less than 2.5 percent of the size of those three states. In this choropleth map of the 2016 presidential election, Idaho, Montana, and Wyoming take up a disproportionate share of space on the map relative to their electoral votes.

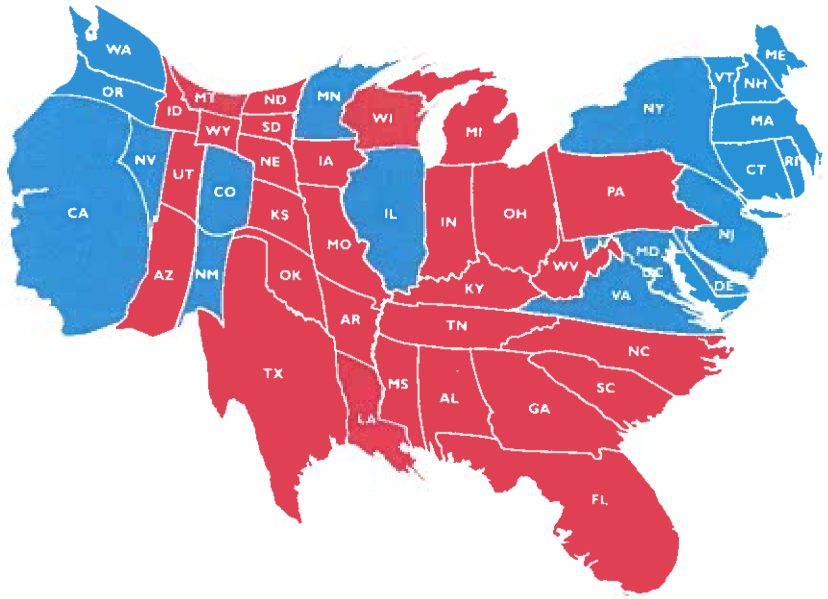


Source: Courtesy Kenneth Field, Esri Inc.

A standard choropleth map, this one shows the results of the 2016 U.S. Presidential election. Notice how much space large, but less populous states, like Idaho (ID), Montana (MT), and Wyoming (WY) in the northwest are compared with smaller but more populous states, like Massachusetts (MA) and Rhode Island (RI) in the northeast.

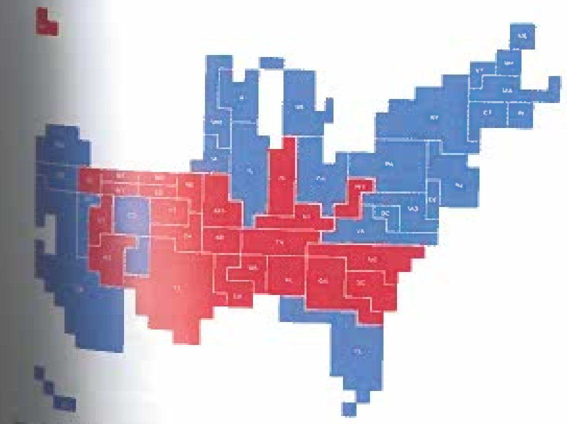
CONTIGUOUS CARTOGRAM

The contiguous cartogram adjusts the size of each geographic unit according to the data. In the map at the top of the next page, for example, each state is sized to its number of electoral votes (or population, if you'd rather think of it that way). The version on the bottom-left of the next page uses squares to scale each state while retaining the original approximate geographic location and borders. The third map scales the counties in each state according to the vote share, which generates a more purple shade to the country, reflecting the split between the two political parties. Each of these approaches distorts the overall shape of the country as the data warps the geography, so they will look somewhat foreign to readers. The tradeoff becomes clear here—we can more accurately scale the states according to their data values, but the geography no longer looks as familiar.

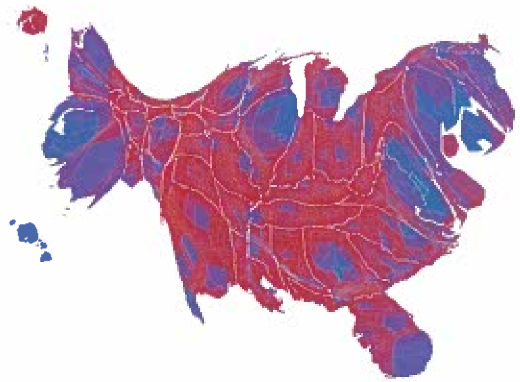


Source: Courtesy Kenneth Field, Esri Inc.

To address the fact that large but less populous states take up a disproportionate amount of space on the map, a cartogram scales the size of geographic units according to another data value. This map scales the states to their number of electoral votes.



Source: Courtesy Kenneth Field, Esri Inc.



Source: Courtesy Kenneth Field, Esri Inc.

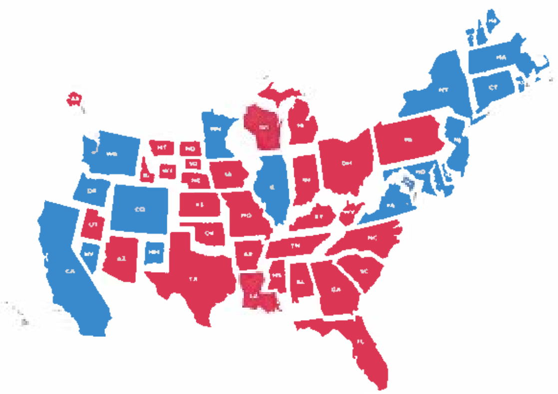
Other contiguous cartograms (using squares on the left or scaling counties on the right) are alternative ways to try to overcome the geographic distortions that occur in the standard choropleth map. But these maps are almost surely to be less familiar to readers than the standard map.

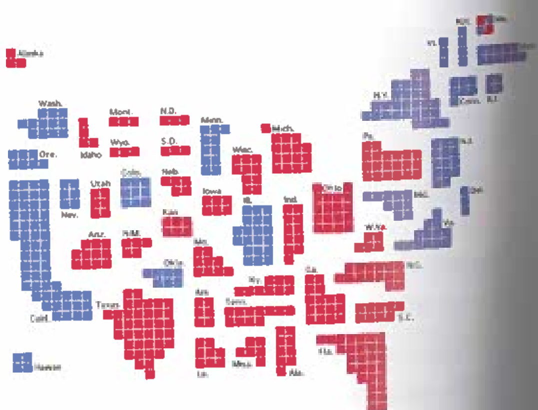
NONCONTIGUOUS CARTOGRAM

Now that you've seen a contiguous cartogram, you can probably guess what a noncontiguous cartogram looks like. In this approach, the size of the geographic units are based on the data value, such as population, but the units are broken apart and not kept adjacent to one another. In this way, we maintain the shape of the individual units but distort the overall view. One advantage of the noncontiguous cartogram is that we can build in more space for labels and annotation.

The map on the left scales each U.S. state according to its number of electoral votes and includes color to denote which candidate won those votes. The exact shape of each geographic unit also isn't necessary—the map on the right uses collections of squares for each state, here scaled to the number of electoral votes. In this version, we can again see how Idaho, Montana, and Wyoming look a lot smaller, while New York becomes much larger.

The noncontiguous cartogram was invented in the mid-1970s by Judy Olson, a geographer then at Boston University. "Probably one of the most interesting aspects of the noncontiguous cartogram," she wrote in her 1976 paper, "is that the empty area between units is meaningful. If the highest-density unit is used as the anchor [in other words, if the most dense geographic unit is used to scale all the other units], then the empty areas reflect the degree of discrepancy between the density in the most-crowded unit and the density in other units. The effect can be quite dramatic."





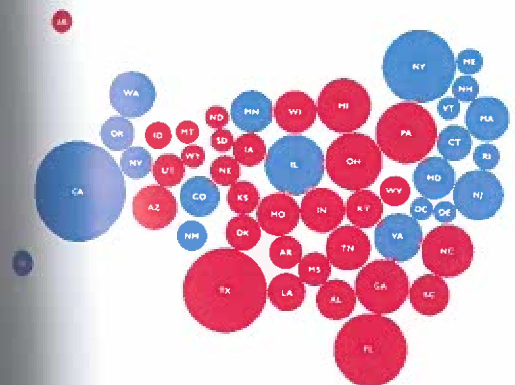
Source: Courtesy Kenneth Field, Esri Inc.

Noncontiguous cartograms like these break up the geographic areas. This helps for adding labels and annotation, but is a more unfamiliar chart type.

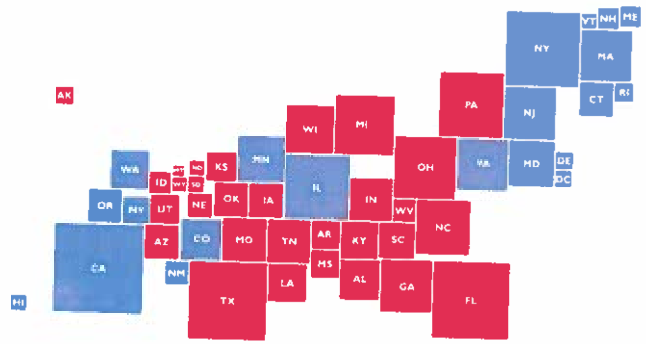
GRAPHICAL CARTOGRAM

Graphical cartograms do not maintain the original shape of the geographic units and instead use other shapes sized to the data values. Perhaps the most well-known graphical cartogram is the Dorling map—named for geographer Danny Dorling at the University of Leeds—which uses circles sized by area to the data.

A variant on the Dorling map is the DeMers Cartogram (or tilegram), which uses squares instead of circles. One advantage with the DeMers approach is that it minimizes the space between the geographic units. A disadvantage is that the entire geography becomes less recognizable. These two graphical cartograms again show the number of electoral votes in each state, and the colors again show which candidate won the state's electoral votes.



Source: Courtesy Kenneth Field, Esri Inc.



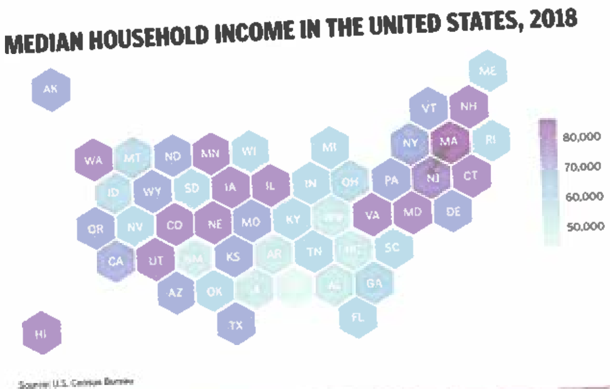
Source: Courtesy Kenneth Field, Esri Inc.

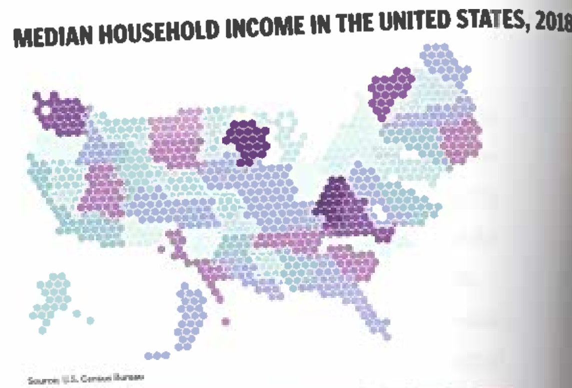
The Dorling (left) and Demers (right) cartograms move further away from the standard geographic maps and use shapes instead.

GRIDDED CARTOGRAMS

The fourth and final cartogram is the gridded cartogram, in which different shapes are scaled to the data and arranged so they maintain the general shape of the major geography. People most often use squares or hexagons to create these kinds of maps.

Take these hexagon grid maps, for example. The advantage of the hexagon over other shapes is that it offers us more flexibility to arrange the tiles closer to the true geography of the country. The map on the left shows one hexagon per state, shaded to encode median

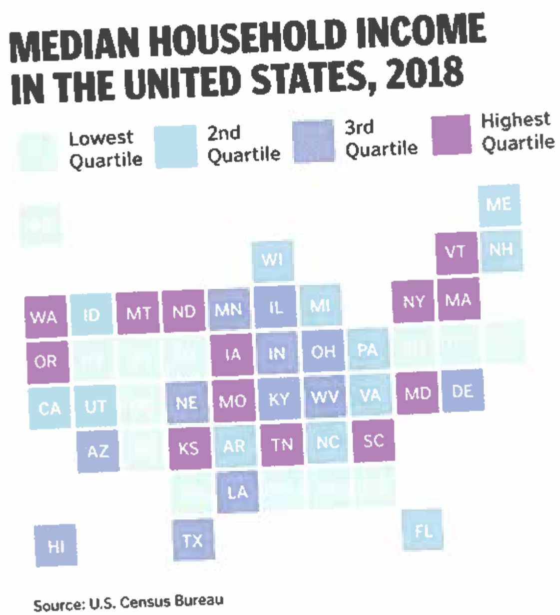




The hexagon grid map is named exactly for what it is: A gridded set of hexagons—either one for each geographic unit or scaled to its data value.

household income. The version on the right uses multiple hexagons per state with the color and number of hexagons corresponding to the data value.

Another popular gridded cartogram uses a single square for each geographic unit. This is often called a *tile grid map*. Here, median household income is divided into four groups (or quartiles).

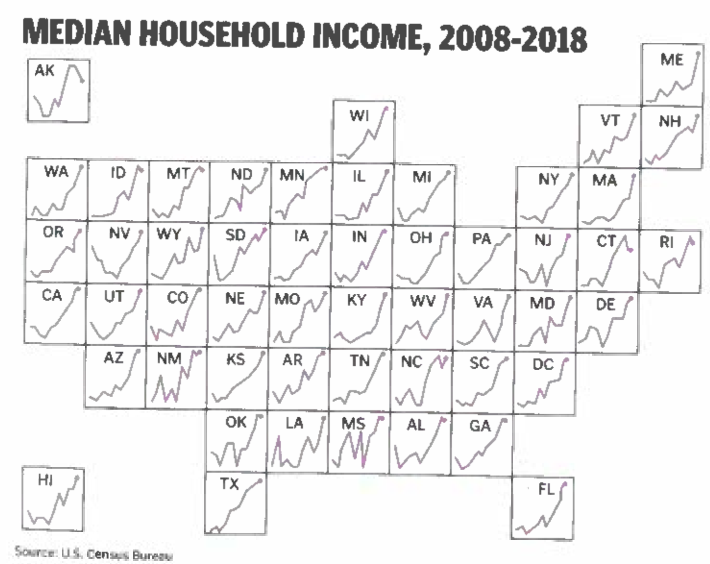


The tile grid map uses a single square for each geographic unit.

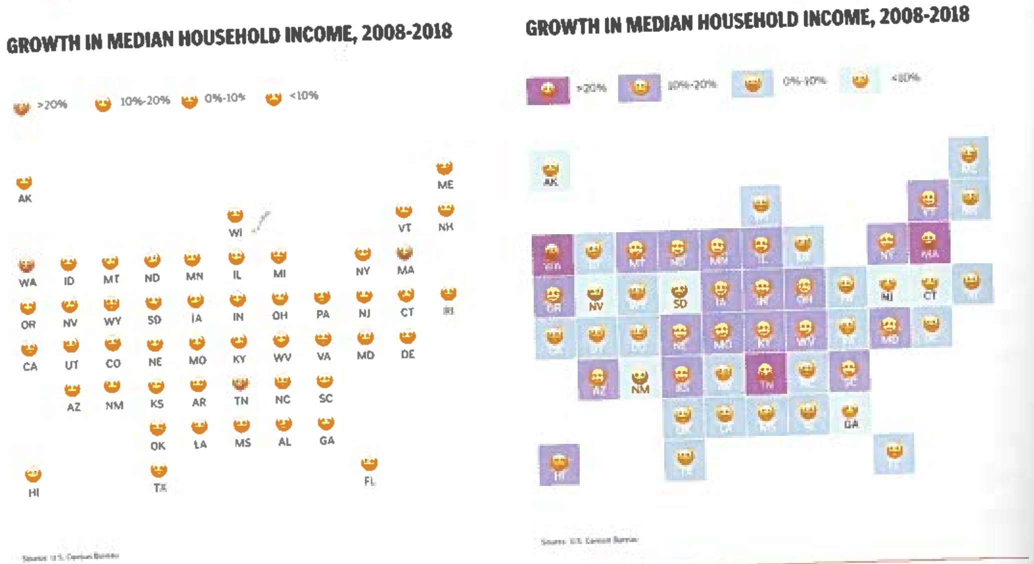
As with all visualizations, there are tradeoffs. The advantage of the tile grid map is that each state is the same size, which abstracts from the geographic distortion. The disadvantage is that the geographic units are now not necessarily in the right place. In the tile grid map on the previous page, South Carolina is located east of North Carolina, California doesn't touch Arizona, and Wisconsin is north of Minnesota, all of which are not their real geographic relative locations. The arrangement of the tiles can be changed of course, but any decision is going to be arbitrary because we have moved away from true geography. But this map can also be easier to construct (it can be made in Excel with resized spreadsheet cells) than choropleths or cartograms.

Another advantage of the tile grid map is that it enables you to add more data in a consistent shape. In this tile grid map of the United States, small lines (or sparklines) are included in the square of each state showing the change in median household income between 2008 and 2018.

Another advantage of tile grid maps (and graphical cartograms, for that matter) is that we can add other shapes to the different geographic areas. Both of the tile grid maps on the next page use emojis to categorize the same household income estimates shown so far. Again, there's a clear tradeoff here: the emojis are a little more fun and a little more visual, but it has



One advantage of the tile grid map is because each state is the same size, we can add small lines, bars, or other graph types to each square.



Another advantage of tile grid maps is that we can use other shapes, such as emojis.

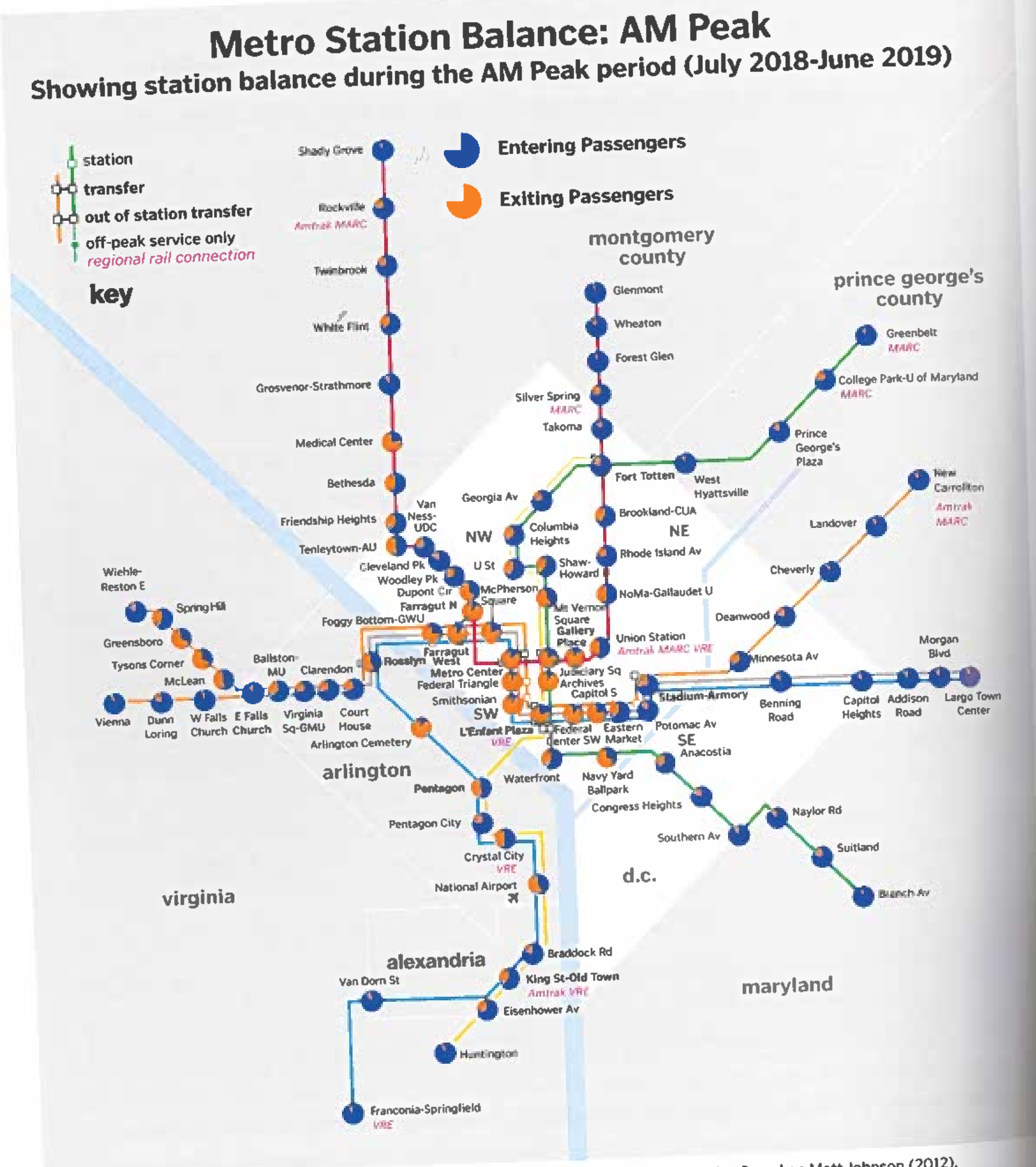
a very different tone and makes it visually more difficult to immediately pick out values for groups of states or larger geographic patterns as in the original map. Adding some boundaries or shading (as in version on the right) merges the two approaches.

NON-AREA-BASED CARTOGRAM

There is one other class of cartograms worth mentioning. Maps do not always have to encode data, and they don't necessarily need to encode them accurately. A non-area based cartogram (or distance cartogram) distorts the physical geography by displaying relative time and distance. This version of the Washington, DC metro (subway) map, for example, shows relatively constant distances between stops, when in fact the distances vary considerably. Check out the western part of the Orange line that runs concurrently with the Silver line. The distance between my metro stop at East Falls Church and Ballston-MU, and between the Ballston-MU and Virginia Square-GMU stops are the same on the map, but the first trip is 2.7 miles long and the second trip is only half a mile long. Stretching the stops out to their actual distances is unnecessary here because the purpose of the map is to provide a compact view of the subway lines so riders can quickly and efficiently plan their trip.

This version of the Washington, DC, metro map from designer Jacob Berman shows relatively constant distances between stops, even though that's not geographically the case.

A familiar map like this also gives us the opportunity to add data. As an example, the next map shows the number of passengers entering and exiting each station in the morning rush hour. Each station is turned into a pie chart in which the blue segment represents the share of people entering each station and the orange represents the share of people exiting. Even if



Source: Map from Jacob Berman; data from the Washington Metropolitan Area Transit Authority. Based on Matt Johnson (2012).

We can add other graphs to maps—pie charts here represent the share of people entering and exiting each metro stop in the morning. Even if you're not familiar with the DC metro, you can see how people tend to commute from the outer parts of the area (more blue areas in the pie charts) to downtown (more orange areas in the pie charts).

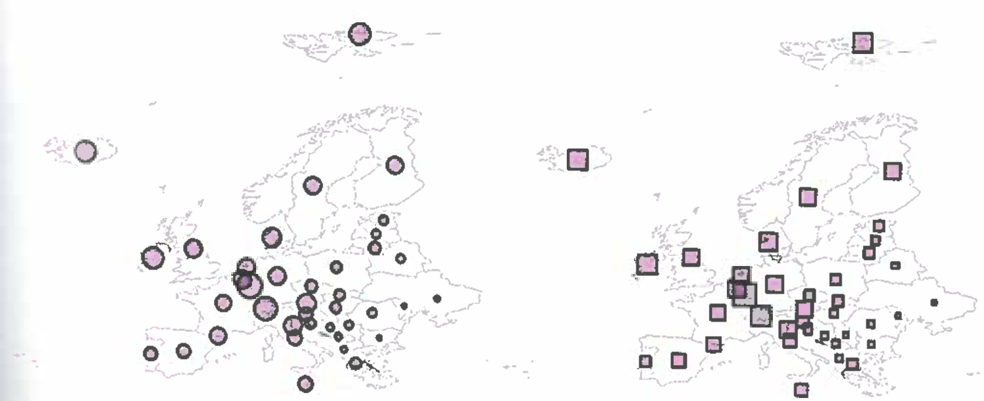
you're not familiar with this subway system, you can see the movement from the outer areas to the center city in the morning.

But let's make sure we remember our audience. These maps would be of interest to people who regularly use the DC metro system, but they would not be as valuable if I was an urban planner making an argument in Atlanta or Dallas or Berlin, because those audiences might not be familiar with the shape and arrangement. As always, we must consider the needs, expertise, and expectations of our audience.

PROPORTIONAL SYMBOL AND DOT DENSITY MAPS

Color and size are not the only encoding techniques we can use to visualize data on a map. Different shapes and objects—lines, arrows, points, circles, icons, even small compact bar graphs and pie charts—can all be placed on a map. These are known as *proportional symbol maps*, because the symbols are sized proportionate to the data. Be careful not to clutter the map or the reader will have difficulty identifying the most important information.

PER CAPITA GDP IN EUROPE, 2017



Source: The World Bank

Different shapes and objects—lines, arrows, points, circles, and more—can all be placed on a map, sized according to the data value.

The two maps on the previous page show per capita GDP for European countries encoded with circles and squares, rather than using color to shade countries. Notice the importance of using a transparent color to make overlapping shapes visible, a technique we've seen in previous visualizations. Where there are dense clusters of areas, such as around Belgium and Netherlands, it can be difficult to find the shapes for individual countries. Aside from our inherent difficulty of discerning exact quantities from shapes like circles, the dense clusters can be a barrier to seeing specific geographic units.

A *dot density map* or *dot distribution map* takes the proportional symbol map in a slightly different direction by using dots or other symbols to show the presence of a data value. Symbols can either represent a single data value (*one-to-one*) or a many values (*one-to-many*). These kinds of maps can be data intensive, but they can also illuminate spatial patterns and clusters that would otherwise be difficult to visualize in a choropleth map or cartogram.

Dot density maps are valuable because they quickly and easily show geographic densities through the clustering of the symbols. The primary challenge, however, is that because these

Dot density maps include a dot or other symbol for a single (or many) data values. The "similarity" Gestalt principle helps us see the clusters of people around the country.

Source: Image Copyright, 2013, Weldon Cooper Center for Public Service, Rector and Visitors of the University of Virginia (Dustin A. Cable, creator).

maps require exact geographic locations like addresses or longitude-latitude pairs, which are not usually available (or publishable), the symbols must be placed in a random or arbitrary position within a specific geographic area.

Consider the dot density map of the United States on the previous page. It uses data from the 2010 U.S. decennial census and places a dot for each of the country's 308 million residents in their Census blocks. Colors denote different racial and ethnic groups: blue for White people; green for Black people; red for Asian people; orange for Hispanic or Latino people; and brown for Native American people and people of multiple or other races. As with the map shown in Chapter 2, there is nothing in this map *except for the data*—no state borders, city markers, or other labels. We can still recognize it as the shape of the United States because people cluster in cities, and on borders and coasts.

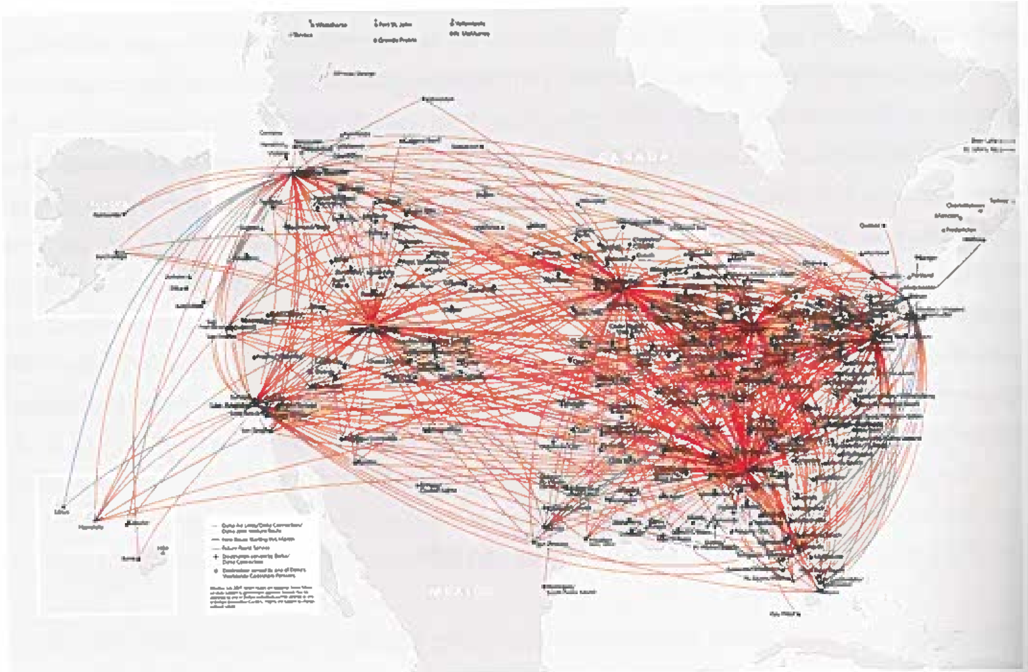
FLOW MAP

Flow maps show movement between places. Arrows and lines denote the direction of the flow, and the width of the line can correspond to the data value. Flow maps can also encode qualitative data, but in those cases the width of the directional symbols may not be scaled to a data value. We saw one such example of a flow map on page 128 to show import and export trade flows between the United States and other areas of the world.

There are different types of flow maps. *Radial flow maps* (also called *origin-destination maps*), show flows from a single source to many destinations. A *distributive flow map* is similar, except that the flow from the single source can fork into many different lines. I like to think of these maps as the ones in the back pages of the airplane magazine, like this one in the back of the Delta Airlines magazine (see next page). This is a distributive flow map because it shows all of the various connections.

As a slight aside here, you might take a look at this map and think, "Wow, that's cluttered! How am I supposed to track my flight here?" But that's not the purpose of the map—instead, the intention of the map (or at least how I infer it) is to demonstrate Delta's domestic "unrivaled coverage"—all the many flights Delta offers around the United States. Showing the tangled web of *all* the flights communicates that point.

Perhaps the most famous flow map (at least in the data visualization field) is Charles-Joseph Minard's 1869 map of Napoleon's Russian Campaign of 1812 to 1813 and the connected, but lesser-known map of Hannibal's 218 BC march through the Alps to Rome. Minard was a French civil engineer who conducted in-depth studies over many decades to



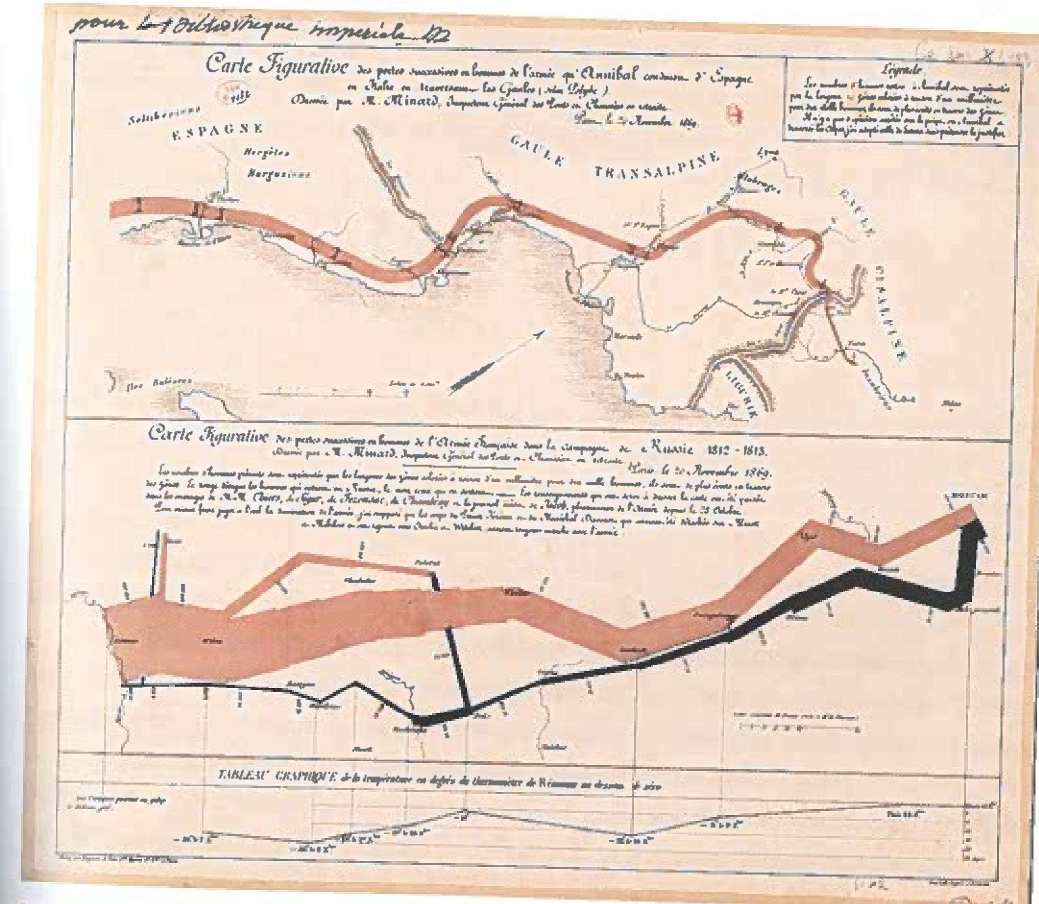
Flow maps show movement between places. Even though this flow map from Delta Airlines looks cluttered, it meets the airline's goal: demonstrating "unrivaled coverage."

create compelling visualizations in support of his research. Minard's Napoleon map—the bottom panel of the image on the next page—shows the "progressive losses in men" that Napoleon's army suffered as it marched into Russia and back.

Starting from the left, 420,000 men invaded Russia in June 1812. By the time the army reached Moscow four months later, only 100,000 troops were still alive. When Napoleon ordered a retreat in the fall, the army was forced to fight through blistering cold (dropping to a low of −30 degrees Celsius), and was ultimately reduced to 10,000 soldiers when it exited Russia in late 1813.

Minard's map integrates six different data values into a single view:

1. The number of troops (thickness of the lines);
2. The distance traveled (scale in the lower-right);
3. The temperature (line graph at the bottom);
4. The time (also included in the line graph at bottom);



Charles Joseph Minard's Hannibal and Napoleon maps show the march of two different armies. Photo courtesy of Ecole nationale des ponts et chaussées.

5. The direction of travel (denoted by color—brown going eastward and black in retreat); and
6. Geography (cities, rivers, and battles—some but not all are included).

In her book on Minard's graphs, *The Minard System*, author Sandra Rendgen writes the following:

> Minard created his visualization more than fifty years after the [Napoleon] campaign. It is a brilliant conceptual transfer: in applying the flow method to a military campaign, Minard shifts

his entire focus to a single variable: the number of people in the flow. This variable sees only one type of variation—*a sharp and steady decline*. It seems to have been this potent and poignant message that made these two maps (and particularly the Napoleon one) so successful in telling a story about the cataclysm of war.

CONCLUSION

In this chapter we surveyed the promises and perils of visualizing geographic data. Sometimes the varying sizes of geographic units may distort the data. Other times sizing the geography to the data may make a familiar geography look foreign.

When working with geographic data, your instinct may be to create a map. But take a moment to consider: Is a map the best way to present your data? Does your reader need to see the exact differences between data values? If so, the aggregation problem inherent in many maps may make that difficult. Are there clear geographic patterns to be seen in the data? If not, then the map may not actually help the reader see your point.

If a data map *is* the right approach, carefully consider the map projection you use and whether the standard choropleth map is the best choice. Maybe some kind of cartogram—even with all its flaws—would be a better fit for your context and reader.

You may also determine that the best approach is to *combine* visualization types. Depending on your final publication type, you might use multiple visualizations, say, a map with a bar chart or table. This approach can help give your readers a familiar visualization type in which they can identify themselves and their location, but also help them gain a better, more detailed view of the actual data.

8

RELATIONSHIP

The charts in this chapter show relationships and correlations between two or more variables. Perhaps the most familiar chart type in this class is the scatterplot, a chart in which the data are encoded to a single horizontal and vertical axis. Other shapes and objects can also be used to visualize the relationship between two or more variables—a parallel coordinates plot uses lines, while a chord diagram uses arcs within a circle. These charts can show the reader correlations and even causal relationships.

For this chapter, I use the color palette and font from a famous bubble chart created by the Swedish academic Hans Rosling and his colleagues at Gapminder, a foundation dedicated to visualizing statistics. Rosling's Gapminder project didn't lay out a specific data visualization style guide, but the visualizations in this chapter use the basic colors and font (Bariol), with additional styles based on other visualizations from the Gapminder website.

SCATTERPLOT

The scatterplot is perhaps the most common visualization to illustrate correlations (or lack thereof) between two variables—one variable is plotted along a horizontal axis, and the other along a vertical axis. The specific observations are plotted in the created space. Unlike a bar chart, the scatterplot axes do not necessarily need to start at zero, especially if zero is not a possible value for the data series.