Chapter 2
Designing health maps

Objectives

- Learn the importance of map design.
- Determine how to use color.
- Learn the principles of graphic elements.
- Explore numeric scales.

Introduction

Geographic information systems involve both art and science in map creations and spatial analysis. The art requires understanding **graphic design** principles so that your maps are professional, effective, and trustworthy. These principles have a wide application in many areas besides GIS, including web design and desktop publications.

Map design has changed over time, especially in the field of health. Historic health maps, such as John Snow's 1864 map of cholera deaths or even earlier maps showing New York City's spread of the cholera outbreak in the summer of 1832, were hand drawn using pen and ink.[1] Computerization offered new techniques that enabled not only the application of graphic design principles to maps, but also data-driven **cartography** supported by spatial processing and analytics.[2] Historically, cartographers designed maps for the representation of geographically defined areas, and health scientists used statistical tools to investigate data derived experimentally. Today these fields are merging, and the techniques related to the art of mapmaking and the science of data analytics are joining efforts to share critical health information.

There are two major audiences for maps related to health and medicine: analysts and the general public. Others, such as health-care decision-makers, fall in between. Analysts, such as an epidemiologist searching for spatial patterns of a disease or pandemic, need maps with a lot of details and layers so they can discover and analyze patterns that reveal particular aspects of the disease or pandemic. The general public is just the opposite: it needs to get a message clearly and without working to obtain it. The divergent needs of these two audiences may suggest that mapmakers should determine their audience before designing maps.

Several types of maps are used in a GIS and are typically classified as either reference or thematic. Examples of **reference maps**, which focus on locations of natural or human-made features, are topographic maps, cadastral (legal) plans, atlases, and navigational charts. This book primarily focuses on **thematic maps** related to health data, which are generated for analysis and problem solving. Reference maps have published standards for symbolization, simplifying their design. Thematic maps, however, generally do not have standards because their content varies more than reference maps. Instead, there are principles and guidelines for symbolizing features found in thematic maps. Although map standards vary, application domains such as health, planning, and transportation have specialized symbols available for use in thematic maps.

When you design a map, you have several **graphic elements** at your disposal. These include the shapes and sizes of point markers; colors, styles, and widths of lines; and fill patterns and colors of areas. How you display each of these elements, and in some cases, their accompanying data, will influence viewers to see important aspects of map composition and lead to conclusions about the meaning of the data.

Graphic hierarchy, an essential design principle, dictates that the most important aspects of map composition (or any graphic arrangement) should be readily discernable. Color also plays a central role in graphic hierarchy as well as in other aspects of graphic design, so you will learn guidelines for using color later in this chapter.

Anyone can use a GIS program and easily choose colors and elements for maps. Some smart mapping applications take much of the guesswork out of choosing what colors and styles to use when making a map. Although this may allow you to make useful, informative maps quickly, you must still understand how to apply the optimum symbolization in a map to present data so as to maximize its impact on the viewer.

The graphic design principles that you will learn in this chapter will set you apart from the crowd and enable you to create professional-quality maps that can impart important health issues to map users.

Map design

Cartography, as defined in *Merriam-Webster's Unabridged Dictionary*, is "the science or art of making maps" and is one of the oldest forms of graphic design. Graphic design here means the choice of symbols, colors, text, patterns, and arrangements of graphic elements in visual displays whose primary function is to convey information. Beauty is an important but secondary consideration in this context.

Classically, mapmakers represented a great quantity of data on relatively small, single sheets of paper, as seen in an 1891 Washington, DC, health department map (figure 2-1) showing locations of physicians and druggists serving the poor compared with total deaths.[3]

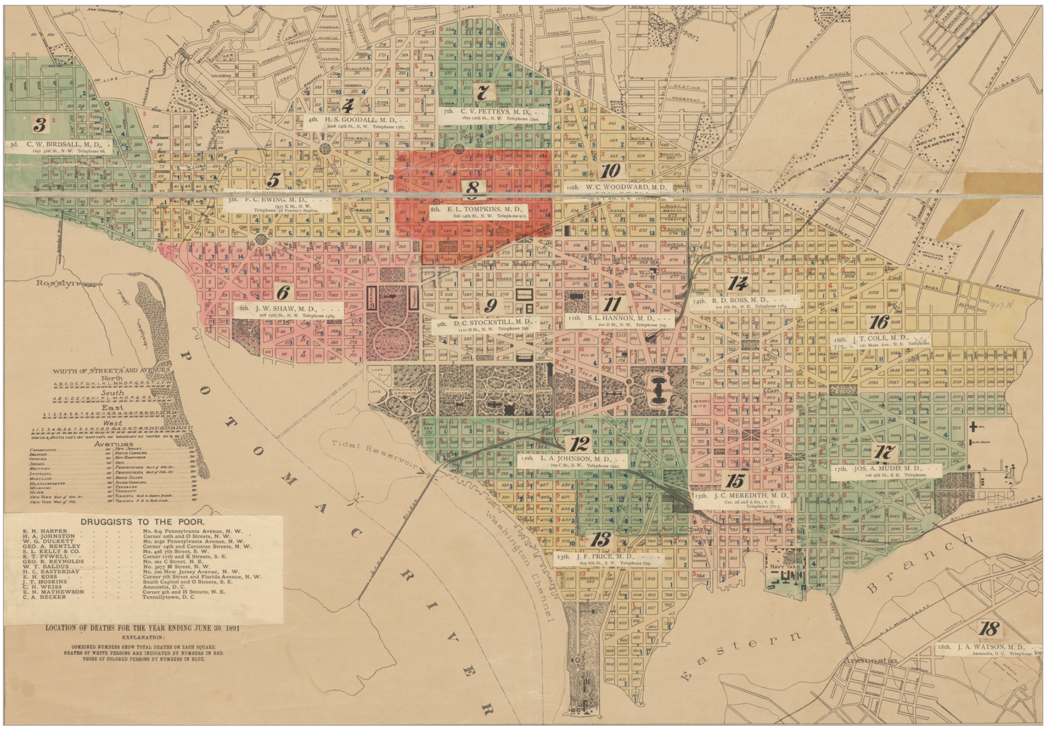

Figure 2-1. Health districts, names, and addresses of "physicians and druggists to the poor" in an 1891 map of Washington, DC.

Today, the availability of digital applications has increased the potential data that can be included on maps and tools for sharing maps and related stories. Over time, this need to clearly represent data has led to the establishment of many map design principles, concepts, standards, and skills. Even if you do not consider yourself an artistic person, the knowledge that you will gain in this chapter will make you a successful map designer. Before applying designs to map elements, you will learn about core graphic design principles.

Graphic hierarchy

As stated in the introduction to this chapter, one of the most useful graphic design principles is graphic hierarchy, the use of color and edge effects to draw attention to parts of a graphic display.[4] For example, in the first panel of figure 2-2, it is not clear what you should study—the lines, squares, or circles. But in the second panel, there is no doubt—the red circles almost jump off the page, while all else fades to context and background. The right panel uses good graphic hierarchy.

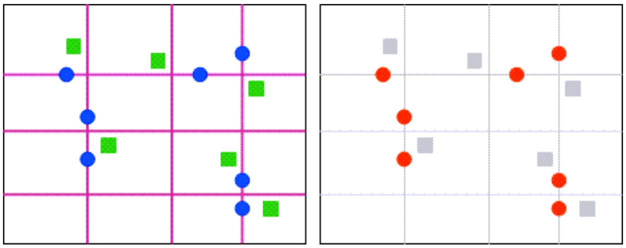

Figure 2-2. Graphic hierarchy is not clear in the first panel, but it is demonstrated in the second panel.

Here are guidelines for using graphical hierarchy on a light background:

- Put graphic elements that should get the most attention in bright colors such as red, orange, yellow, green, or blue. Such graphic elements are called **figure**. These are the red circles in the second panel of figure 2-2, which could mark the locations of some sort of health incident, such as an accident.
- Put graphic elements that orient you or provide a context for interpretation in less saturated colors, especially shades of gray. The less important a feature, the lighter the shade of gray you should use. Such graphic elements are called **ground**. These are the gray elements in the second panel of figure 2-2, and they might represent streets and houses near the accident.
- Place a strong boundary, such as a black line, around polygons that are important to increase figure.
- Use a coarse, heavy crosshatch or pattern (figure 2-3) to make polygons important, placing them in figure. In contrast, a dashed line moves line features more into the background as compared with solid lines.

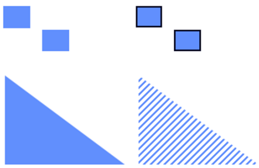

Figure 2-3. Features on the right have increased figure compared with the features on the left.

The main idea for thematic map design is to put the subject in figure and spatial context into ground. If this is not done properly, the focus of the map is lost on the reader. Figure 2-4 includes two maps in which the subject is childhood obesity patients compared with access to green space. The first map is an example of a poor map design where all features are in figure. A better version of the same features and data, the second map shows obesity cases (red circles) in figure and all other context in ground. The poorly designed map uses similar, bright colors for all features. As a result, the locations for the obesity cases are barely visible. In the better version, streets and buildings are the furthest in ground. A light-gray value is used for both and the dark outline for buildings is removed. The polygons that represent parks have a color of a natural feature, green. Making changes to the ground features allows the focus of the map, childhood obesity cases, to be clearly seen.

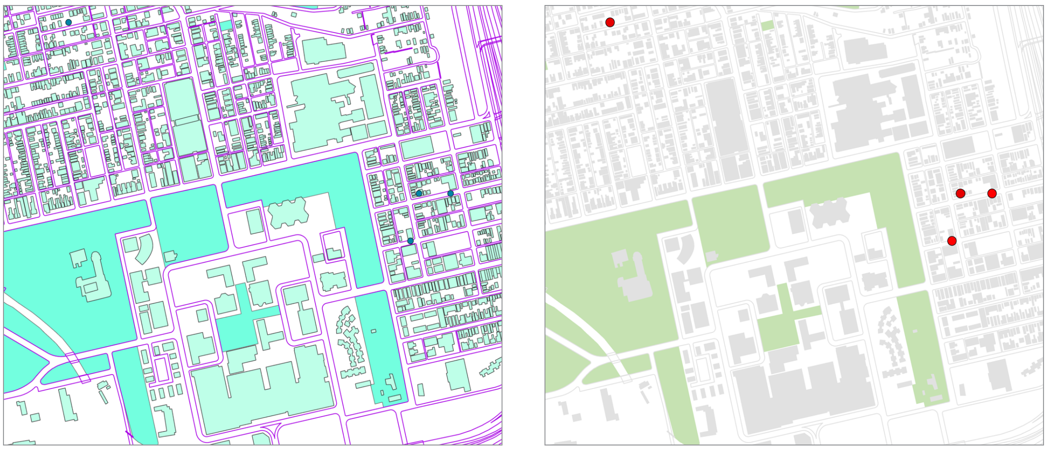

Figure 2-4. Map examples of poor graphic hierarchy (*first panel*) and good graphic hierarchy (*second panel*).

Minimizing ink

A second important graphic design principle credited to Edward Tufte is simply this: minimize ink! Make every pixel of a graphic design have a purpose.[5] For example, as a guideline for a well-known area, such as a map of the world, you probably do not need to include a north arrow. Everyone already knows that the top of a world map points north, so why waste ink? A north arrow on a map where it is not needed is what Tufte calls **chart junk**, graphics with no information payoff that clutter a design. Of course, if the top of your map is not north, you will need a north arrow on your map.

Suppose you have a world map whose focus is to show countries with high infant mortality rates as a figure in a written report. If that's the case, a north arrow and a scale bar where distance is not relative to the map's purpose are not needed and can be dropped. Because it is a figure for a report, text indicating the data source and title can also be removed from the map and placed elsewhere. Too many colors are distracting and can also be removed.

The first map in figure 2.5 has distracting chart junk, while the second map (a version of the same map) removes this and has minimized ink. These changes allow map users to focus on mortality rates and not on map surrounds, such as a north arrow, scale, color fill, and text.

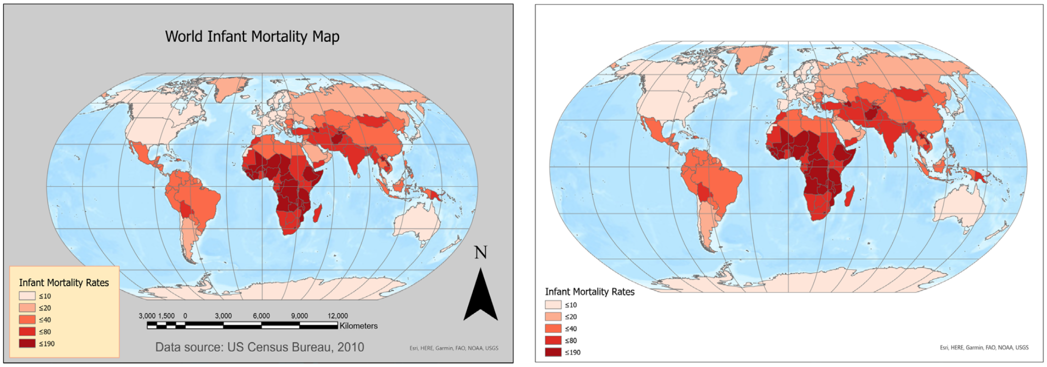

Figure 2-5. The first map contains chart junk and too many colors, whereas the second map eliminates the chart junk for an improved experience.

Part of the minimize-ink principle is to minimize the use of color in general. Use color only for truly important elements, as suggested by the graphic hierarchy principle. Genuinely effective designs, whether they are printed maps, online web maps, figures in a report, or presentation slides, need a lot of white area (such as the background in figure 2-5) and ground materials, and just a few valuable graphics and text in figure.

For example, do not use color for areas such as states, counties, or postal codes unless you need color coding to represent a variable, such as a health condition or population. Otherwise, leave such areas transparent with no color fill. In figure 2-6 the maps display food locations as points and neighborhood boundaries as polygons. The first map has an unnecessary color fill for neighborhoods and makes the food sources difficult to see.

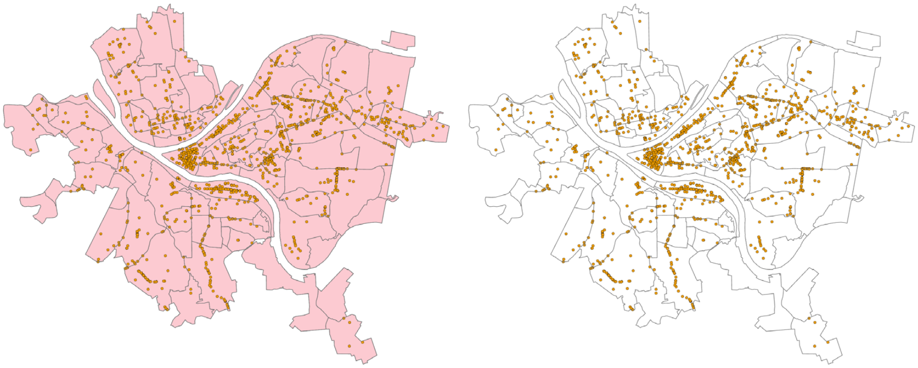

Figure 2-6. Neighborhood boundaries with color fill (*first map*) and no color fill (*second map*).

Basemaps

While a white map background is commonly used for a figure in a report, many GIS applications, especially when accessed through the cloud, often use a **basemap**, which is a starting canvas to which other map features are added. Basemaps can be reference maps on their own. For example, topographic maps represent essential geology and physical features of the earth's surface and influence other map features. Depending on your map's purpose, the basemap can have a significant impact on its appearance and consequently on the viewer's understanding of the map.

Figure 2-7 shows two different basemaps with the same graphic elements, homeless shelters and political boundaries near Los Angeles, California. The first map uses a dark-gray canvas, and the second map uses a lighter terrain as a basemap. In this example the better choice is the second map because it shows better map **contrast**.

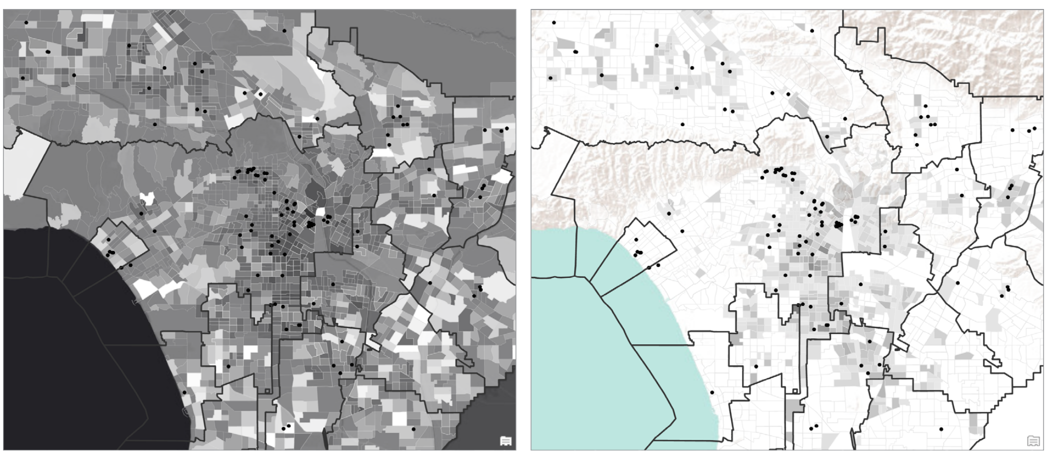

Figure 2-7. The first basemap uses a dark-gray canvas, whereas the second basemap uses a light terrain.

Contrast

Contrast is important because it distinguishes features from the map's background but also from one another. Maps that use good contrast and distinguishable values are often easier to read. **Value** is the amount of black in a color; it is used for controlling visual contrast. For grayscale, value ranges from 0 percent (white) to 100 percent (black) with in-between values of shades of gray. In reference to white sheets of paper and white background for thematic maps, the higher the color value, the more important the feature.

In figure 2-8, the features on the left are all visually important, the ones in the middle on top are more important than those below, and the opposite is true for those on the right.

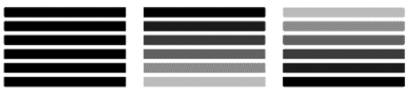

Figure 2-8. Examples of contrast using value.

The mechanism at work is your perception of contrast between features within the vicinity of one another, with opposites having the most contrast. White as background signifies nothing, grays recede into the background, and the black mark signifies something of importance.

The maps in figure 2-9 show the percent of households below the poverty line by US Census tract (American Community Survey 2011–2016) in Los Angeles, California, compared with homeless shelters (black points). The first map has poor color contrast, especially the poverty values. The gray values are too similar and it's not clear whether homeless shelters are in areas of higher poverty. The values on the second map have better contrast, allowing viewers to more easily recognize the areas in poverty compared with shelters.

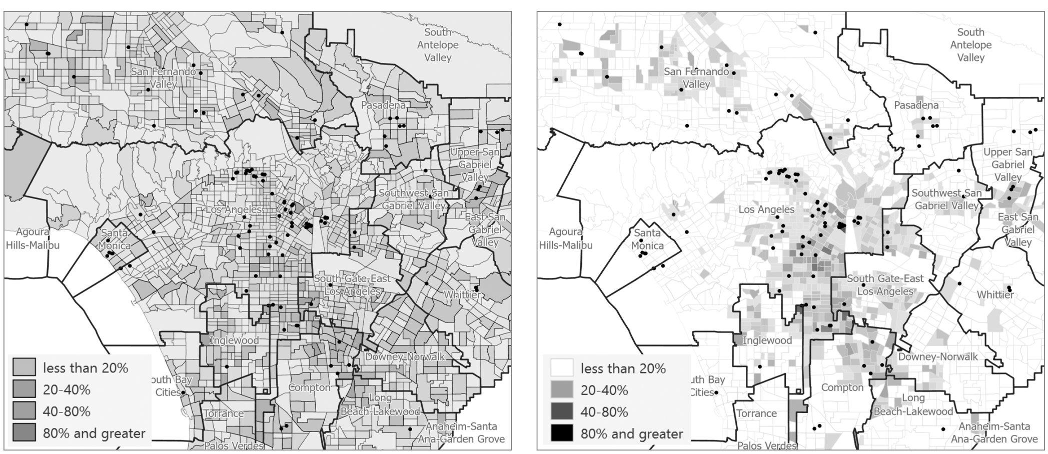

Figure 2-9. Bad (*left*) and good (*right*) map contrast.

Color

Color is one of the most effective graphic elements for communicating spatial information, but it is easy to overuse. There is quite a bit to learn about color as it is applied to map features. First, you should learn these terms from the Graphics Communication Program, 2005:[6]

Hue is the basic color. For example, green is the hue in both light green and dark green.

Color value is the amount of black in a color. In relation to white paper or a white computer screen, white has low value and black has high value.

Monochromatic color scale is a series of colors of the same hue with color value from low to high; for example, the value ranges from white to black on a gray monochromatic scale, from light to dark green in a green monochromatic scale, and so on.

Saturation refers to a color scale that ranges from a pure hue to gray or black. The closer to gray, the more saturated the color.

Figure 2-10 illustrates monochromatic and saturated color scales. In this case, the saturated scale is the more dramatic of the two because the color that is farthest to the right has the highest value, black.

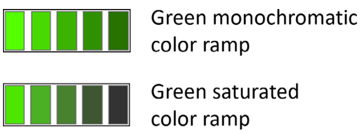

Figure 2-10. Examples of monochromatic and saturated color scales.

Choropleth maps and color ramps

Map designers use monochromatic or saturated colors to represent the magnitude of numeric attributes, such as the number of seasonal flu cases, population, or other numeric values, in color-coded polygon layers known as **choropleth maps**. Color value represents order in categories, ranging from low to high, and a key in a legend interprets the colors and magnitude ranges of ordered categories. A **color ramp** is a particular arrangement of colors for a purpose.

You must read the map's key in the legend to see what range of values each color chip of a scheme represents. For example, in the map in figure 2-11, increasing value in the gray scale corresponds to increasing magnitudes for the number of female breast cancer cases for all races in the lower 48 US states between 2012 and 2016.

The numeric scales for both attributes in figure 2-11 are quantiles, meaning that each interval has the same number of states (10 out of 50, 20 percent in this case—not displayed are Alaska and Hawaii). Quantiles are informative for the analyst who is willing to work at studying a map. You will learn about other numeric scales later in this chapter.

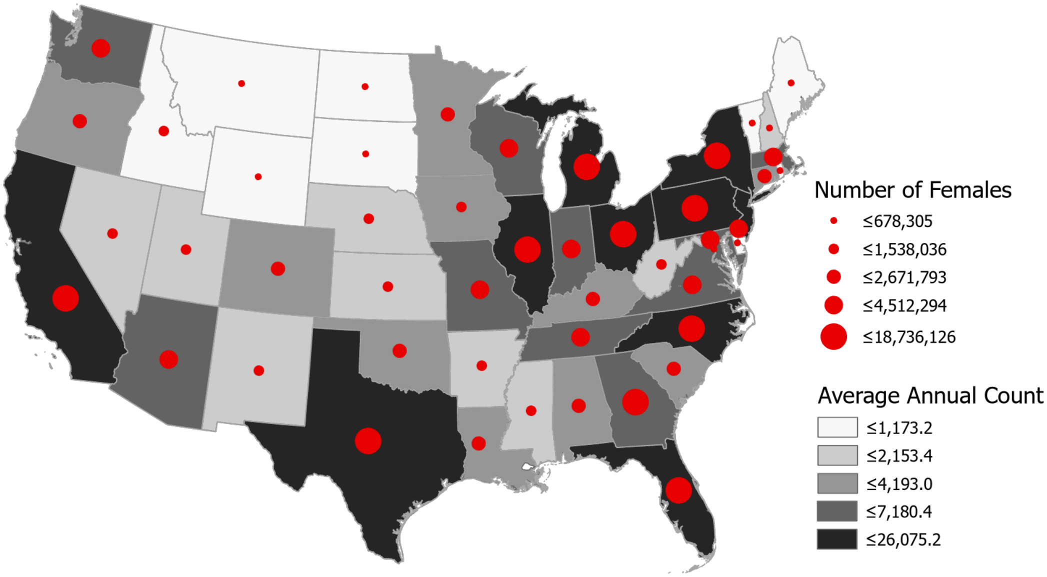

Figure 2-11. Choropleth map showing a count of breast cancer cases compared with total female population.

For choropleth maps, two characteristics vary, specifically color and size of the polygons. The color ramp is intended to carry the information of the attribute, but the viewer may also be influenced by the size of polygons, perceiving more importance for larger polygons than smaller when all polygons should be considered the same. Nevertheless, choropleth maps remain popular and the informed viewer can sort out the correct meaning of such maps.

Figure 2-11 also uses size-graduated point markers—an addition or alternative to choropleth maps—to display a second attribute, the number of females for each state. The larger the circles, the higher the number of females. Each point is a centroid of a state. If you have two attributes per polygon to display on a map, the approach in figure 2-11 works well. Centroids have an advantage in that only one characteristic varies to convey numerical order, the size of the point markers. Polygon centroids can be confusing, leading you to think that you are viewing point feature data when it is area data, but in this case it is obvious that the points are state data.

Additional color guidelines

Some guidelines for using color scale on maps are as follows:

- Monochromatic and saturated color scales: Use either option to color-code most choropleth maps. Increasing color value and saturation in these scales convey order of intervals. Do not use random colors.
- **Dichromatic color scale**: An exception to the first guideline is when there is a natural middle point of a scale, such as a national rate for a disease. In such cases, use a dichromatic color scale—two monochromatic scales joined together with a low color value in the center, with color value increasing toward both ends. Figure 2-12 is an example of using a dichromatic scale to show high and low values for lung cancer rates by US states (not including Alaska and Hawaii) for all ages and all races between 2012 and 2016.

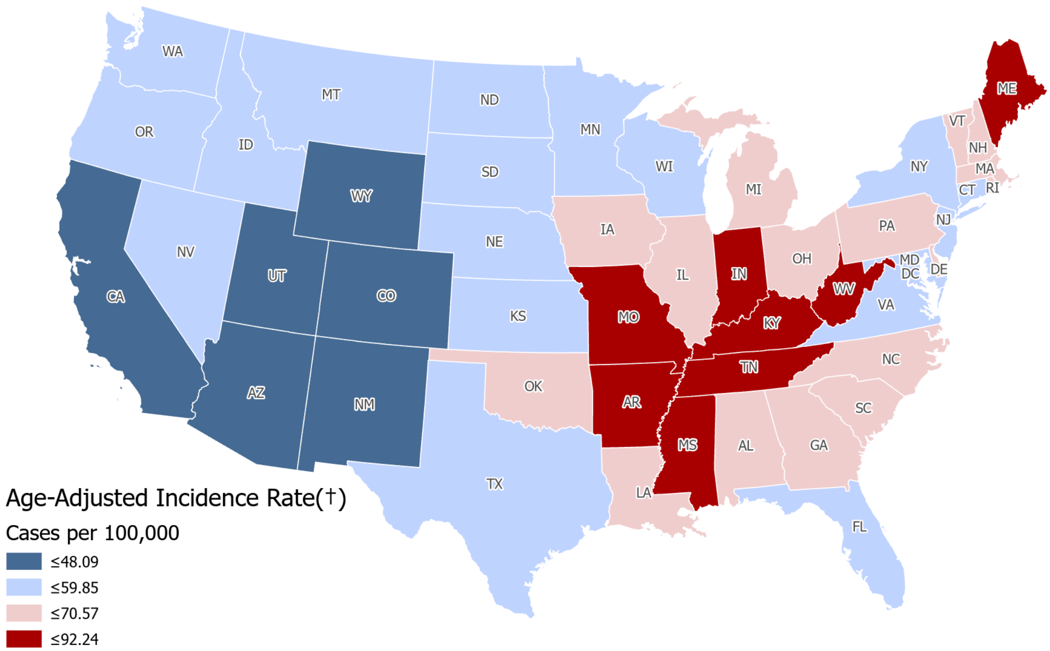

Figure 2-12. Example of a dichromatic color scheme of lung cancer rates for all races, ages, and sexes. Source: National Cancer Institute.

- Unclassed colors: A typical choropleth or dichromatic map uses colors and break points to represent data in discrete polygons. An alternative is an unclassified choropleth map with no clear break points in the data. Such maps show the distribution between a minimum and maximum value. Unclassified color maps support visualizing higher and lower values and remove the problem of determining sometimes imperfect and misleading classifications, but such maps make it difficult to determine values from features on the map. Deciding whether to use a classified or unclassified map comes down to the purpose of the map and its audience and to the extent to which you need to edit the classes of the data (see figure 2-13).

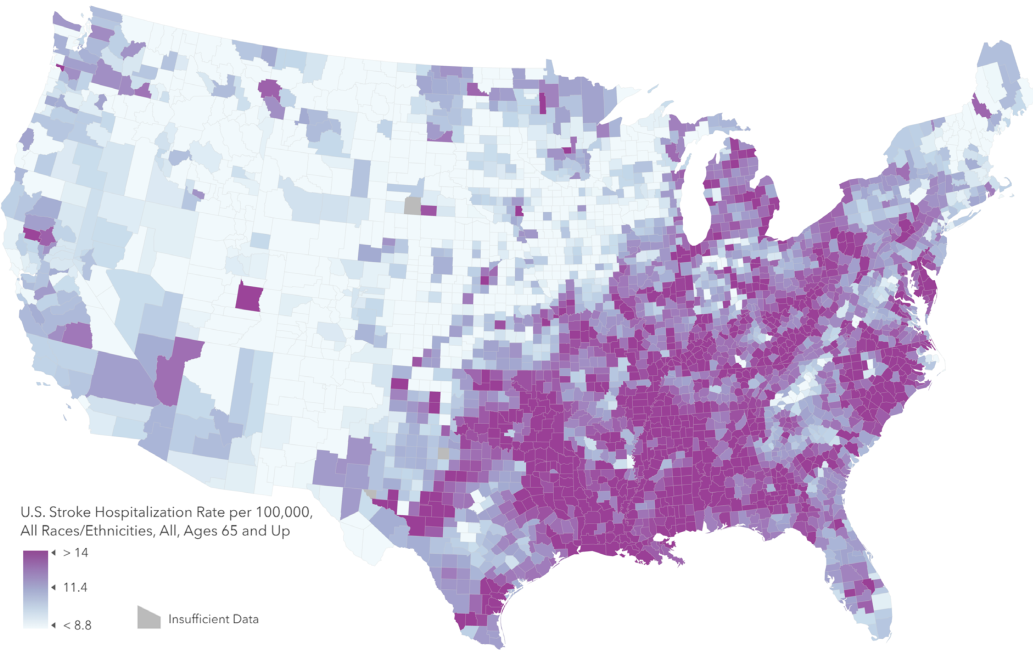

Figure 2-13. Unclassified map showing stroke hospitalization rates for US counties, 2015–2017. Courtesy of Centers for Disease Control and Prevention.

- Importance of high color value: The darker the color in a monochromatic scale, the more important the graphic feature.
- Differentiation of low color value: Use more light shades of a hue than dark shades in monochromatic scales. The human eye can better differentiate among light shades than dark shades.
- Color spectrum: Do not use all the colors of the **color spectrum** (see figure 2-14), as seen in a prism or a rainbow, for color coding. Yellow, in the center of the scale, has the lowest color value, which is confusing because color value starts at a high value for red, decreases in moving to the right until attaining a minimum value for yellow, and then increases further to the right for violet. Thus, the sequence of colors and color values in the spectrum cannot signify steadily increasing or decreasing quantities. Instead of the entire color spectrum, use either half of the spectrum, the hot-color (red) or cool-color (blue) side, with yellow being on an end. Whenever you use a multicolored color ramp for a numeric variable, imagine what it would look like in a black-and-white photocopy. If the result would appear to be a gray monochromatic scale, then color value correctly conveys order in magnitude.

Figure 2-14. Color scheme based on the color spectrum.

With the exception of choropleth maps, maps use color mostly to distinguish different kinds of graphic features from one another and to build graphic hierarchy. You already know to use bright colors for figure and dull, drab colors for ground. The **color wheel** is a device that provides further guidance in choosing colors, especially for differentiating features. It arranges colors in their order along the electromagnetic spectrum but joins the two extremes, red and violet, in a circle (figure 2-15). Brewer (2015) is an excellent book on choosing colors for maps.[7]

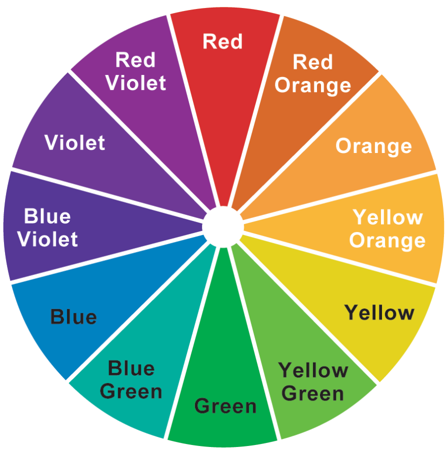

Figure 2-15. Color wheel.

Guidelines for using the color wheel include the following:

- **Complementary colors**: Use opposite colors on the color wheel—those directly across from one another—to differentiate graphic features. Opposites, such as yellow and violet or red and green, are known as complementary colors. When placed next to each other, complementary colors make each other look brighter and produce a dramatic contrast.
- Differentiation: To differentiate graphic features, use three or four colors equally spaced around the wheel, such as red, blue, and yellow or red, blue violet, green, and yellow orange. Use such choices for vector-based features (points, lines, and polygons) that have unique code values for classification and display. Figure 2-16 uses complementary colors to differentiate food sources in a zoomed view of New York City.

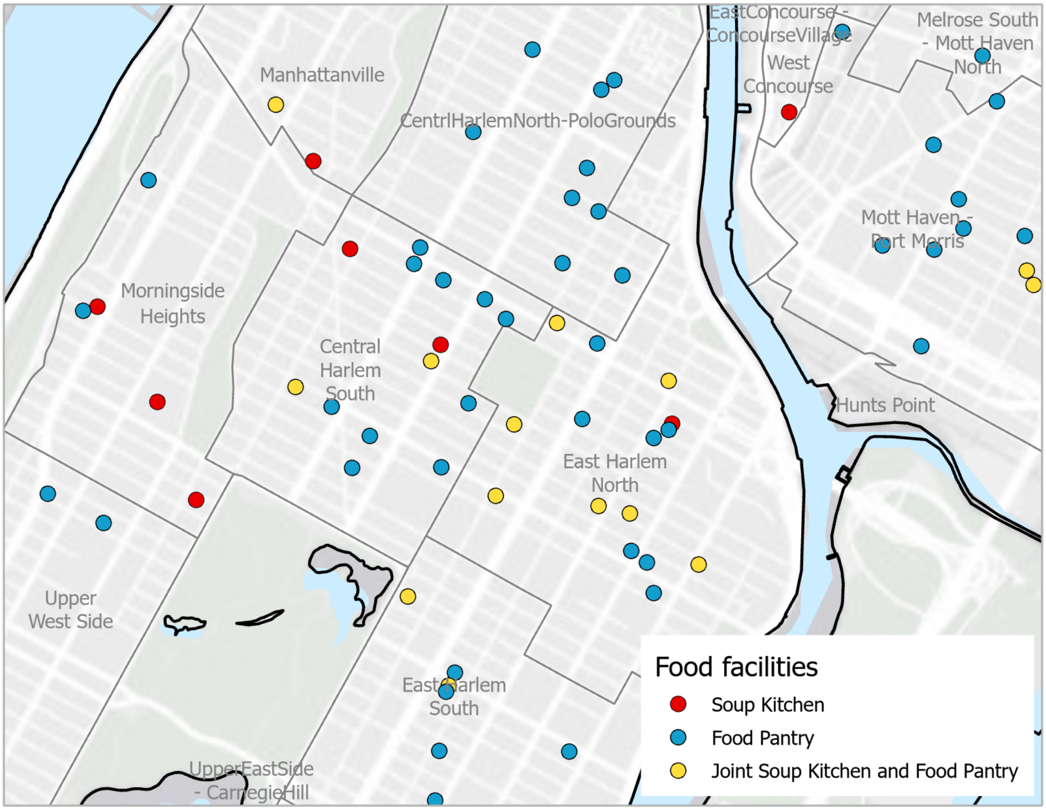

Figure 2-16. In this map of New York City food facilities, complementary colors in the color wheel help emphasize differentiation.

- Analogous colors: Use adjacent colors for harmony, such as blue, blue green, and green or red, red orange, and orange. These are known as **analogous colors**. They are less important in analytical mapping than complementary colors because you usually need to strongly differentiate features. Figure 2-17 uses analogous colors of the color wheel to differentiate zoning boundaries for healthy food stores in New York City.

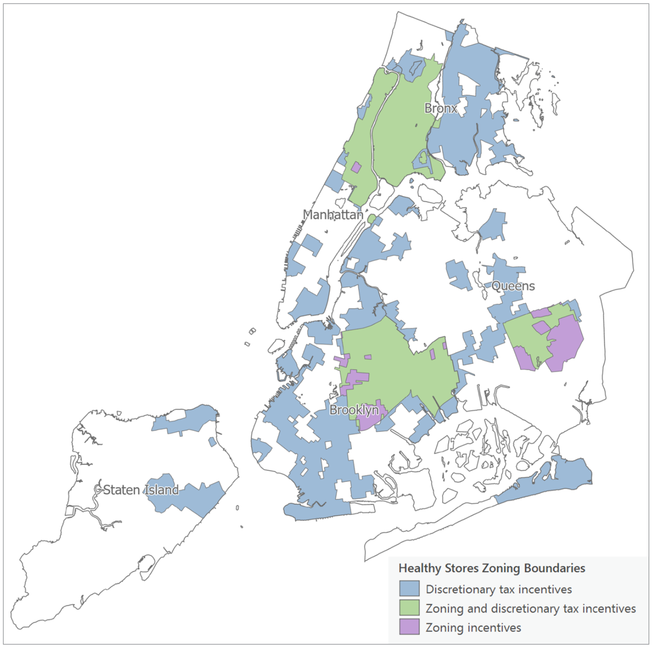

Figure 2-17. In this map of New York City, analogous colors in the color wheel provide visual harmony.

- Color-impaired viewers: Consider colors for those who are color-blind. About 4 percent of the population (8 percent of men and less than 1 percent of women) have some form of color vision impairment. Red-green combinations are the most common impairment, but other hue combinations are also a problem. Color-blind people can see differences in lightness, which is another reason to modify color values and saturation. Good color combinations to help those with color issues are as follows: red–blue or red–purple, orange–blue or orange–purple, brown–blue or brown–purple, yellow–blue or yellow–purple, and yellow–gray or blue–gray.

Keep in mind that colors can have meaning through common experience, conventions, or political and cultural uses. Sometimes, you can put such knowledge to work on a map, tying colors to well-known meanings. For example, the color red often signals danger. In the US, traffic signals use red to stop traffic or pedestrians crossing a street. Green indicates that it is safe to go. Yellow means use caution when proceeding.

If applicable, consider an organization's branding colors. If there is a branding guide for colors, consider using it. You can typically find the exact RGB or CMYK values and color recommendations online. Using a consistent color palette helps build awareness and recognition for an organization.[8]

There is at least one universally accepted rule for using color on maps, and that is to make map features as they are seen in nature—for example, use blue for water bodies and use green for parks.

Graphic elements

Graphic elements in a GIS include vector features as points, lines, and polygons. They vary for map design and include 1) shapes, sizes, outlines, and colors of point symbols; 2) styles, widths, and colors of lines; and 3) color fills, fill patterns, and outlines of polygons (see figure 2-18).

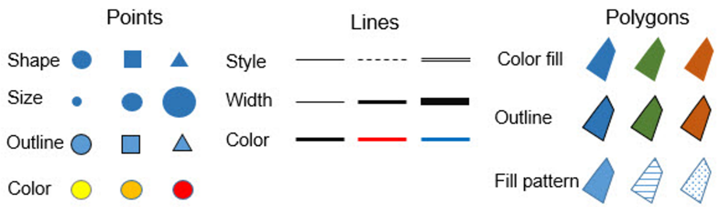

Figure 2-18. Graphic elements for vector features as points, lines, and polygons.

If you were using a graphic design drawing package to make a map, you would have to create a symbol for a feature (for example, a point shape) and copy and paste it to every location with the feature. A GIS has an advantage over graphic design software because geographic coordinates of features, such as points, place the point symbols at all locations for you. Then you choose and configure the symbol from a collection of templates. Furthermore, if there are segments of the features that need to be distinguished using different symbols, each feature will have (or will need) a code attribute so that each feature's type is identified. Once you decide what codes you want to map, you can select a symbol for each code value and the GIS will correctly place the symbols based on their location and code values.

For example, suppose you are working on a map study that identifies outpatient resources, and you obtain a GIS layer that includes more than 20,000 facilities and want to show only a subset of these. Such a table with so many records will probably have codes that identify the type of facility. A code is a nominal class attribute with a finite number of mutually exclusive and exhaustive values. Each feature has one and only one of the available code values, and there should be no variations in spellings (for example, misspellings or abbreviations). In figure 2-19, codes are used to display outpatient locations in New York City for three different facility types: chemical, mental health, and developmental disability services. This map uses three different symbols (circles, squares, and triangles) based on codes to better differentiate each type of facility by neighborhood.

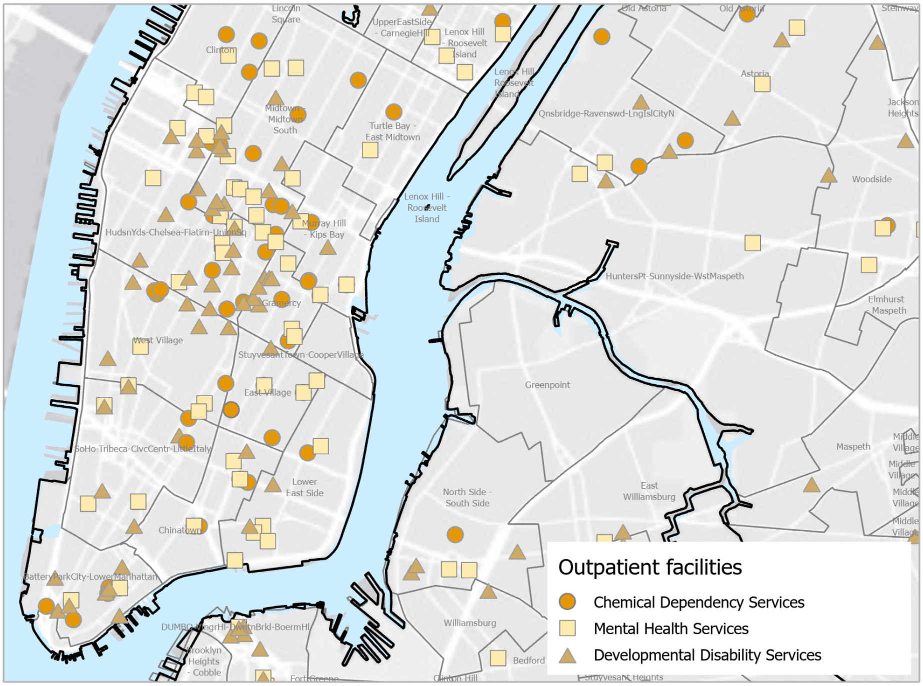

Figure 2-19. Symbolization of outpatient facilities in New York City.

Additional examples might include food inspection violation types or medical diagnosis codes. Other industries use codes such as residential, commercial, industrial, and institutional for land use, or burglary, larceny, auto theft, and larceny for serious property crime types.

Symbolizing points and lines

Points and lines are mathematical objects with no area or width. However, on a map or a graph, we use point markers with area and lines with width to make graphic elements visible. Here are some guidelines for varying the graphic elements for point markers:

- Simple shapes: Use simple shapes. The simpler the shape, the easier it is to see spatial patterns. The order of preference is circles, squares, triangles, stars, and then other solid shapes.
- Point markers with boundaries: Use point markers that have boundary lines and solid-color fill for important points. A boundary makes point markers more prominent (figure) and allows use of some color fills that otherwise do not display well as solid point markers.

Figure 2-20 compares the same map focusing on three types of health services for children by school district in the Bronx borough of New York City with both complex and simple, solid point markers to illustrate this point. The second map, which uses only solid points, is more effective because both color and shape vary to convey the meaning of each point.

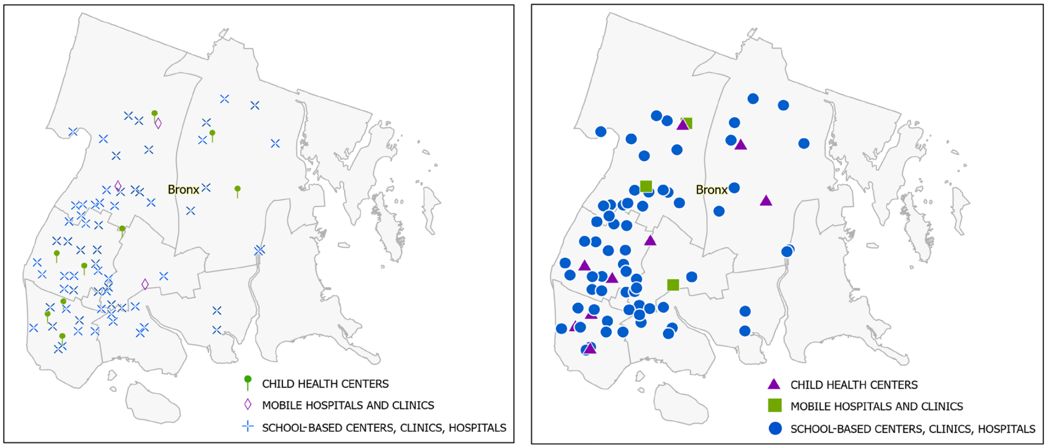

Figure 2-20. Complex (*first map*) versus simple (*second map*) point schemes. The simple point scheme is clearer and easier to read than the complex scheme.

- Size difference exaggeration: If you are using the size of point markers to symbolize a quantity, you have to exaggerate the differences in values. The human eye does not distinguish proportional changes in areas very well, so make the differences in sizes as large as possible (but not so large that you cannot see features behind the points). Figure 2-21 uses this principle to show the number of outpatient facilities by neighborhood in New York City.

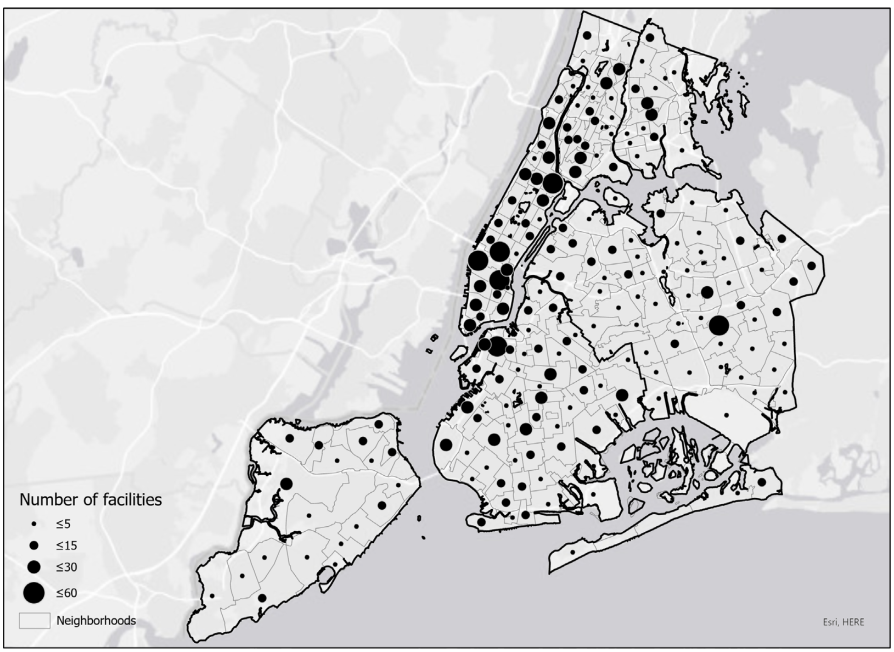

Figure 2-21. Outpatient facilities by neighborhood in New York City.

There are almost always exceptions to rules and guidelines. For example, if you have a compelling reason to use complex point markers instead of simple ones, do so. As a case in point, use well-designed point features for locations that are normally viewed zoomed in to small areas so that the markers are relatively large and users can see the details. Many markers in ArcGIS software are mimetic—they look like what they represent (for example, a hospital)—and are effective if there are only a few features. Figure 2-22 shows hospitals at a large scale (zoomed in). The map also uses a dark-gray basemap as contrast to the white background of the symbol.

Figure 2-22. New York City 2011 health-care facilities labeled by type.

Do not overuse **mimetic symbols** that could easily clutter a map. While it might be tempting to use the hospital symbol to show the locations of veterans health-care facilities across the US, such a map would have more than 1,000 symbols, which is too cluttered and hard to read. The outline of northeastern states in figure 2-23 cannot be seen because of the shape and size of the symbols.

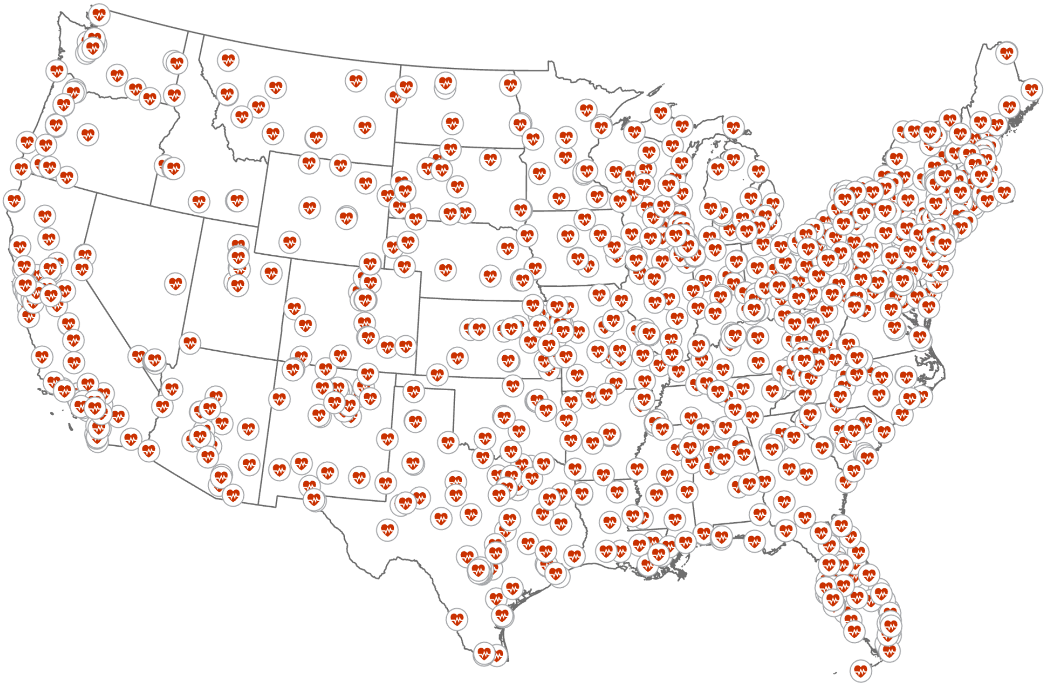

Figure 2-23. Overuse of a mimetic symbol.

Lines are easier to symbolize than points. They are often used in maps to display natural features such as rivers, topography, or humanmade features such as roads. Here are a few guidelines:

- Lines in ground: For analytical maps, most line features are ground and should be black or shades of gray. Exceptions might be transportation studies needing to depict features of a street network such as emergency routes, highway type, or traffic volume. Line width, type, and color apply to distinguish line features.
- Dashed and semitransparent lines: Consider using dashed lines or lines with transparency to signify less-important line features and solid lines for the important ones.
- Polygon boundary lines: Consider using gray instead of black for boundaries of most polygons. Dark gray for boundaries makes the polygons prominent enough but not so prominent that boundaries compete for attention with more-important graphic elements in figure (see figure 2-24).

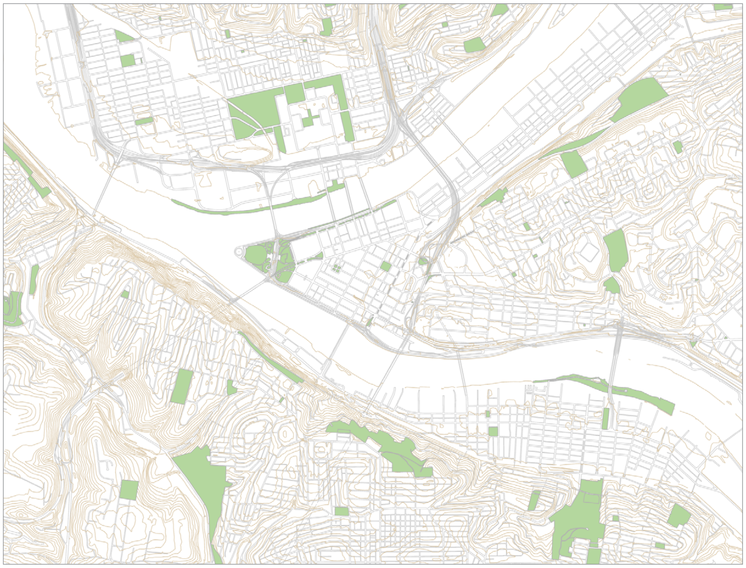

Figure 2-24. Good use of line symbols.

Lines are also used to show linear phenomena such as flows or networks. The map in figure 2-25 uses lines to show color-coded routes that patients in a health plan take to access services for four provider types. (The complete ArcGIS StoryMaps story related to network optimization used in this figure can be viewed at https://arcg.is/0XnTG4.)

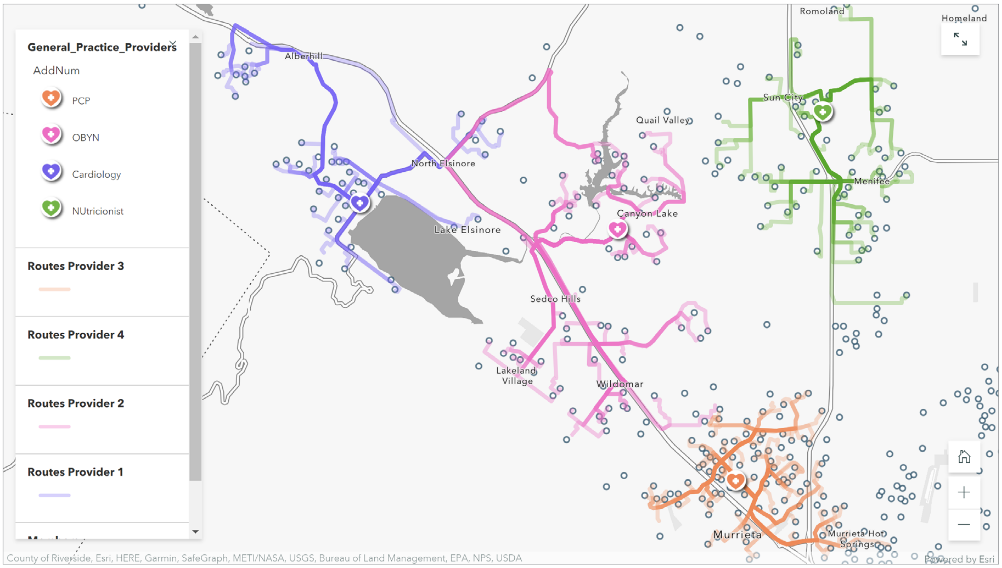

Figure 2-25. In this map, lines are used to show routes.

In figure 2-26, lines are used in a **spider diagram** to connect central points, such as the centroid of census tracts, to related points, such as vaccine distribution facilities. Such a map represents relationships between different kinds of entities. (The complete ArcGIS StoryMaps story related to COVID-19 vaccine distribution used in this figure can be viewed at https://arcg.is/0Sb8f9.)

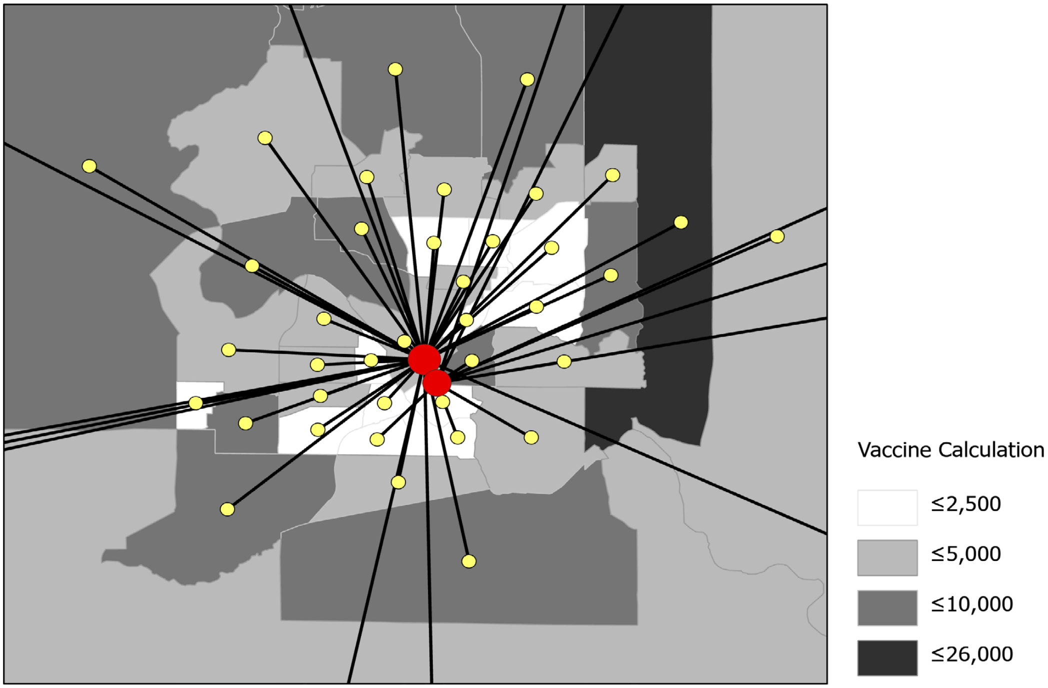

Figure 2-26. COVID-19 vaccine distribution sites and vaccine needs connected by lines. Courtesy of Epistemix.

Symbolizing polygons

When using color fill (or no color and an outline) for polygon features such as parks, buildings, or other boundaries, symbolization is somewhat easy. Deciding on colors, fill, and outlines is all that is needed. Polygons showing numeric data, as seen in choropleth maps, are more complicated.

As mentioned earlier, the size and shape of polygons in choropleth maps can influence map readers. GIS tools can create distorted or equal-area **cartograms** that remove the actual geography of polygons, thus removing the bias of larger areas. Equal-size cartograms are typically squares or hexagons and are often referred to as fishnet or tessellation maps. Figure 2-27 is an example of a fishnet map where squares are used to represent areas of increases or decreases of flu cases. It is also an example of a dichromatic color scale, with blues on one end, reds on the other end, and white in the center.

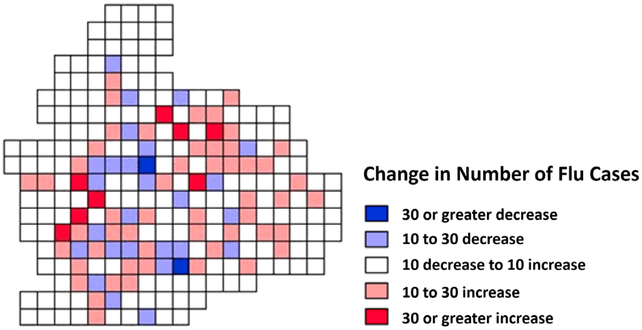

Figure 2-27. Fishnet map example.

Figure 2-28 is a tessellation map of COVID-19 incident rates and number of cases (labeled with each state). As opposed to using the actual shapes of the US states, hexagons are used to show the rates and cases.

Figure 2-28. COVID-19 incident rates and confirmed cases by state at one point in time.

Cartograms also distort polygon features by scaling them, so their size is proportional to the value of a variable in each polygon. While not commonly used in health care, distorted cartograms are becoming more widely accepted. Figure 2-29 is an example of a cartogram created from a choropleth map studying geographic access of adults with severe respiratory failure to treatment centers.[9]

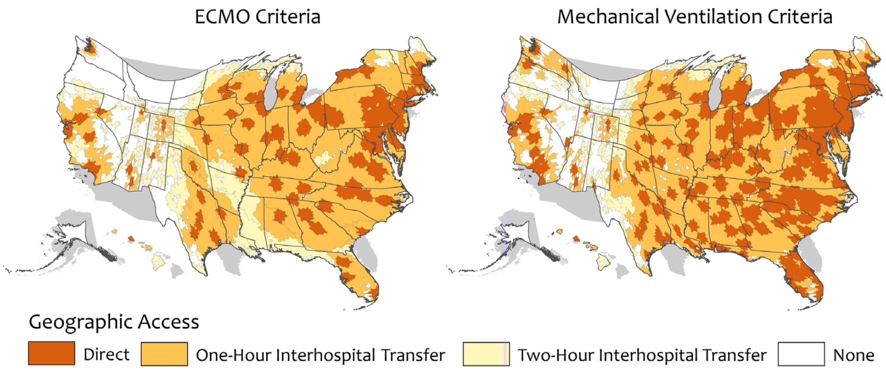

Figure 2-29. Cartogram showing geographic access to high-capability severe acute respiratory failure centers in the US.

To learn how to make your own cartogram, see "How to Build a Cartogram in Microsoft Office and ArcGIS Online" by Helen Thompson at ArcGIS Blog: **https://links.esri.com/BuildCartogram**.

Another alternative to a choropleth map is a **dot density map**, which varies the number of dots in areas in proportion to data values (for example, one dot represents 100 flu cases, number of persons, and so on). Dots are randomly scattered in polygon areas and are well suited to discrete phenomena (see figure 2-30).

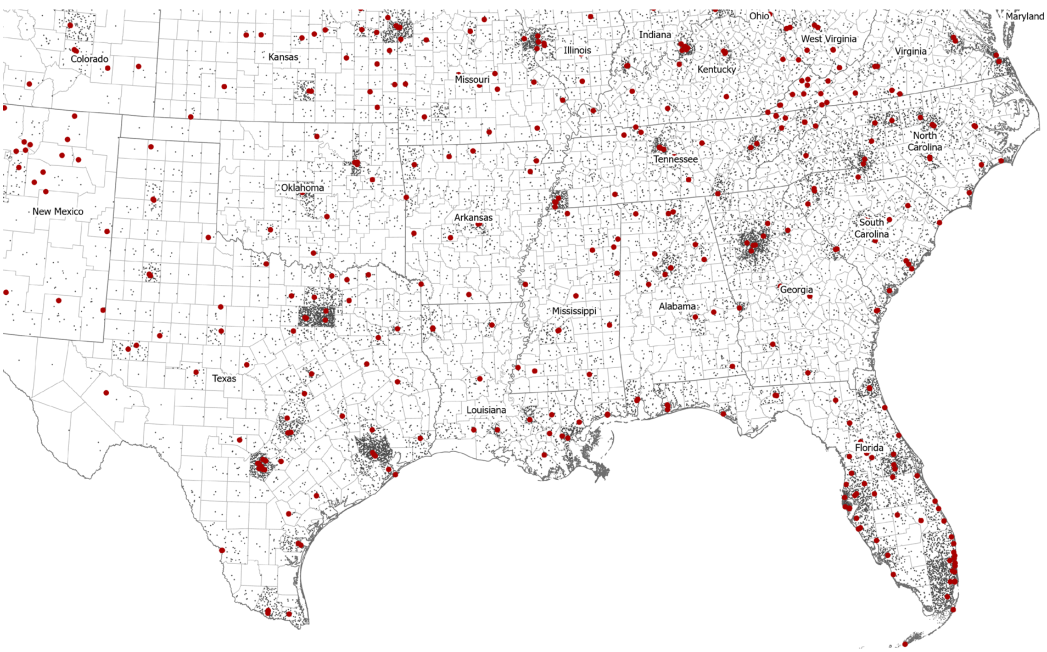

Figure 2-30. Dot density map showing US counties and veteran population (one black dot equals 5,000 veterans) compared with Veterans Affairs (VA) hospital locations (red points).

Numeric intervals

Now that you understand map design, colors, and graphic features, you will learn about displaying quantitative data for maps. Be forewarned that the choice and design of maps using numeric data takes practice with trial and error. It is a skill to be acquired.

You often need to show variation in a numeric attribute, such as population or a disease incident rate, when designing an analytical map. To do so, you must break the numeric scale into **numeric intervals**, which are nonoverlapping and exhaustive intervals covering the range of values for each attribute. Maps have many details, so keep the number of intervals as small as possible to help simplify the reader's ability to absorb information.

Research has shown that most people can hold seven items (plus or minus two) simultaneously in short-term memory. With maps, we reduce that a bit, to five sets of intervals (plus or minus two). There are exceptions to this rule. Dichromatic maps can have more intervals, 10 (plus or minus four). Raster map layers (such as those covered in chapter 1) can easily have 15 or so, because raster layers vary continuously rather than being a collection of discrete features to interpret. If your data is qualitative with just a few attribute values (for example, low, medium, high), your map would have just three intervals.

Break values are the higher values of intervals that break the total attribute range (for example, 100 in the interval 80 to 100). The last break value can always be the maximum data value for the attribute in your data, or it can be any very large number. It is up to you to make sure they are right for your map analysis.

Classification methods

There are many classification methods for choosing break values in a GIS, and you should study your data and the purpose of your map before choosing your classification method and numeric breaks. Consider your audience (general public or scientist) and what they need to know about your data. Does your data have outliers? Is the purpose of the map to show absolute values, such as population, or normalized values, such as percentages, rates, or ratios? Are you showing rates that are above or below a national average? How many features are in your map? For example, a classification method for population by US counties (which number more than 3,000) would differ from pedestrian accidents in city neighborhoods, where there may be fewer than 100 accidents.

A good understanding of statistics is helpful, but there are standard rules that anyone can apply when choosing classes and break points. Always use a mathematical progression or formula instead of picking arbitrary break values. You are less likely to be accused of manipulating a map to influence a viewer's interpretation if break values have a logical progression. Some options are as follows:

- Equal intervals
- Quantiles
- Natural breaks
- Standard deviations
- Increasing interval widths
- Exponential scale

Equal intervals have constant widths, for example, 0–100, 100–200, 200–300, and 300 and greater. Equal interval classes are best for familiar data ranges such as percentages or temperature. Equal intervals are the easiest to interpret, but if the data is skewed, the map may end up with very few features in one or more classes. Figure 2-31 shows heart disease hospitalizations using an equal interval scale. Because this data is skewed, the number of counties varies per bin (or class). In the lowest bin (less than 20.98), there are 105 counties; the next two bins have the highest number of counties (1,430 and 1,541, respectively); the next bin has 143 counties; and the last bin has the lowest number of counties, only 7.

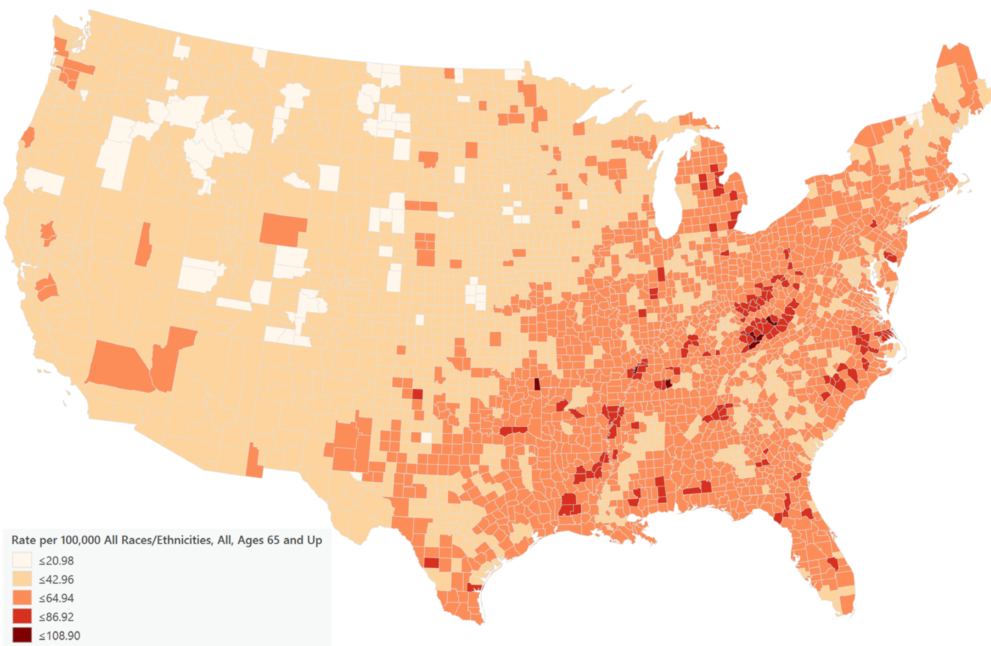

Figure 2-31. Equal interval classification.

Quantile refers to separating a distribution into equal sizes of attribute record per interval. For example, **quartiles**—a special case of the more general quantile with four categories—use break values that identify the lowest 25 percent of values, the next 25 percent of values up to the **median** or middle point, the next 25 percent up from the median, and the top 25 percent. If there are five intervals, each has 20 percent of the distribution, and so forth, with other numbers of break values. Analysts often use quantiles because they provide information about the shape of the distribution. For example, if the top quartile has a relatively long interval width, it is a **long-tailed distribution**, meaning that the data distributions deviate from a bell-shaped curve and most often are skewed to the right, with the right tail elongated. If the interval widths are all about the same size, the distribution is fairly uniform.

Figure 2-32 is a map of heart disease hospitalizations (2015–2017) using a quantile classification method. Twenty percent of the counties (645) are in the lowest bin, 20 percent in the next bin, and so on.

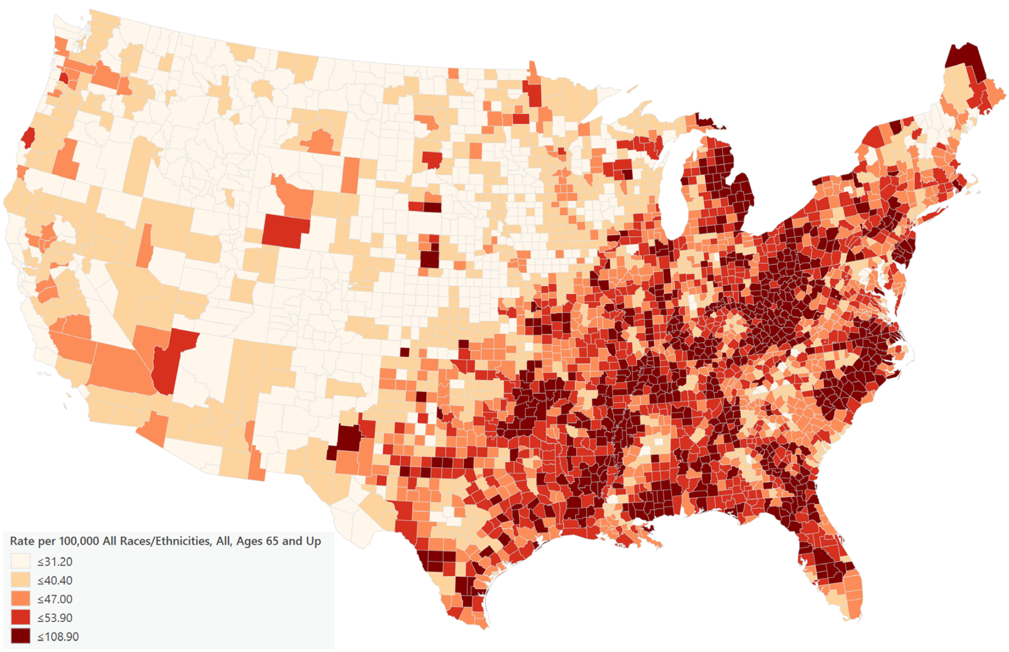

Figure 2-32. Quantile classification example.

The natural breaks method calculates break points by picking the class breaks that best group similar values and maximize the differences between classes. Generally, there are relatively large jumps in value between classes created with this method, which you might apply to selected natural or other phenomena, where it is important to distinguish clusters or groups by attribute value.

Natural breaks are data specific and are not useful when comparing multiple maps. Unlike epidemiologists, who typically start with a quantile classification, cartographers often start with this approach and use a histogram or other graph of the data to determine break value alterations. A modification to the natural breaks method might be to put outliers (or perhaps many zeros) in their own class. To prepare a map for the public, you might consider adjusting the classes to include the national rate and then round data values in the other classes. Figure 2-33 is a modified classification whose break includes the national rate (43.8) with values above and below this.

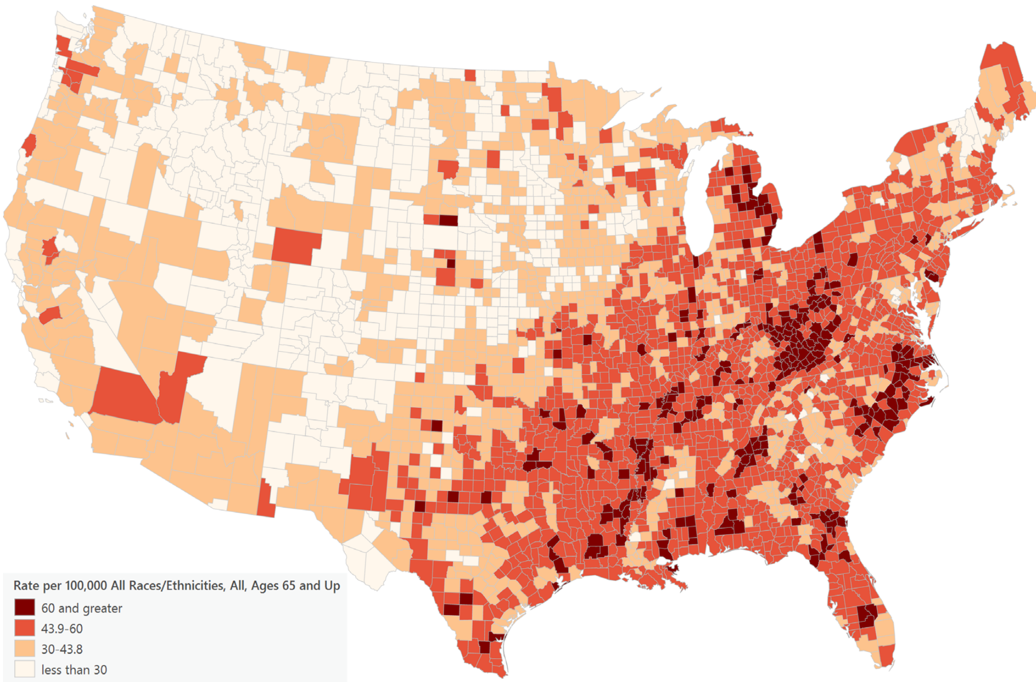

Figure 2-33. Modified natural breaks and legend to include the national median rate of 43.8.

The standard deviations method uses an analyst's knowledge of the normal distribution. If the distribution of an attribute is bell shaped, consider using standard deviations about the mean for break points.

Many populations in nature have skewed or long-tailed distributions. The **increasing interval widths** method is used to accommodate the elongated range of data. For example, many gymnasts have low-level skills, but few have truly incredible skills. In such cases, it is necessary to stretch the intervals for high numbers (the many low-skilled gymnasts). One approach is to keep doubling the interval for each category; for example, intervals 0–5, 5–15, 15–35, and 35–75 have interval widths of 5, 10, 20, and 40. Such edits to break values are done with a manual option of classification methods in a GIS.

The **exponential scale** method is popular for handling long-tailed distributions and is also done manually. Use break values that are powers, such as $2n$ or $3n$, but generally you should start with zero as an additional class if that value is in your data. For example, $2n$ for n=0, 1, 2, 3, 4, . . . yields the sequence 1, 2, 4, 8, 16, . . . , to which it is often relevant to add a separate class for 0. Hence, corresponding classes or intervals are 0, 1–2, 3–4, 5–8, 9–16, and so forth for integer-value quantities. Corresponding break values are 0, 2, 4, 8, and 16.

Additional suggestions for designing numeric scales

For analysts or yourself, start with quantiles. Quantiles never fail to produce a useful scale, but the map user must understand how to interpret order statistics. If you are preparing a map for the general public, try to use equal-width intervals even if they are not the best representation of the shape of the attribute's distribution, because they are easy to interpret. If this method does not work, explore a classification method using a mathematical progression. Decide which method you think is best in terms of the number classes and frequency in each. If none is acceptable, use a more sophisticated design and explain how to interpret the results.

Summary

Graphic design is an art, but it is informed by principles, concepts, and knowledge—thus everyone is capable of good graphic design, not just the artistically inclined.

Graphic hierarchy is a principle that dictates the use of figure and ground to direct the viewer's attention to important parts of a map, chart, or other graphic design. Many of the graphic features on a map provide context or reference material. Such features should be put into ground using dull colors (mostly grays), weak or no boundaries, and thin or dashed lines. The subject of the map—the features that have important patterns—should be put into figure by the use of bright colors, relatively wide black edges, and other distinctive graphic elements.

As a graphic designer, be a minimalist: make every pixel add meaning, or leave pixels white. Leave out chart junk, such as north arrows, when possible. Leave extra map layers out. Use color sparingly and for figure.

Hue, *value*, and *saturation* are terms associated with color. Blue is the hue in light blue and dark blue. Value signifies the amount of ink per square inch on an area, with a lot of white being the lowest value, and black the highest. Saturation refers to a sequence of colors of the same hue that runs from the pure hue to gray or black.

Mapmakers often use monochromatic scales to represent increasing magnitudes on choropleth maps, running from low to high color value, or low to high saturation. Avoid using multiple hues for the same choropleth map. An exception is a dichromatic scale that combines two monochromatic scales; for example, blue for negative quantities and red for positive quantities to represent numeric attributes that have a natural center magnitude such as 0. Another exception is to use either half of the color spectrum (cool colors or hot colors), with yellow at one end, representing low value.

The color wheel is a device for picking effective color combinations. Best for analytical maps are colors that provide the most differentiation—complementary colors (those that are opposite from each other or at equal intervals around the color wheel). **Analogous colors** are adjacent to each other on the color wheel and are used to show association (as opposed to differentiation).

Many map attributes have numeric scales, such as population counts, capacities of facilities, or disease rates. To represent such attributes on a map, the mapmaker must classify these variables into intervals by choosing break values along their range. Each interval is assigned a color from a monochromatic scale that portrays order through color value. A key in the map legend must provide each interval's end values and identify its color for interpretation. Suitable scales for general audiences are equal intervals in multiples of 2, 5, or 10, or exponential scales for long-tailed distributions such as powers of 2 or 3. Quantile scales are best for analysts so they can see the shape of distributions—for example, if those distributions are long-tailed, bell-shaped, or uniform.

Points and lines are mathematical objects with no area or width; nevertheless, mapmakers must show points with shape and area, and lines with width. It is best to use simple point marker shapes, such as circles and squares, because it is difficult to differentiate complex shapes and discover patterns among them. In analytical maps, most line features are ground and thus should have relatively narrow widths and gray color.

The type of map determines a lot about symbolization. There are several map types; the health topics covered in this book primarily use thematic maps, which are effective for analysis and problem solving. Thematic maps generally do not have standards because of their variable content. A thematic map consists of a subject (or subjects) placed in geospatial context, generally for the purpose of solving or investigating a problem, such as how to analyze a disease outbreak in a city or how to assess a network of health-care facilities in a region.

Spatial context for health maps is provided by map layers that identify locations, such as streets, physical features, neighborhood boundaries, or other boundaries. The major design principle for thematic maps is to make the subject prominent while providing the spatial context in the background.

Analytical maps have two major audiences: the analysts who study maps and the public, which needs to get the message of a map. Analysts require maps with many layers and details. Use relatively few intervals (up to seven) for choropleth maps, many kinds of point markers that have simple symbols, and so forth. Maps for analysts may be used only on a computer screen in a GIS package. Once analysts find an important pattern and want to make the public aware of it, the designer needs to create a simple map that dramatically portrays the pattern. Include the minimum number of layers to provide context and highlight the subject, and make good use of graphic hierarchy.

This chapter provided graphic design principles to accomplish thematic map design, but right away you also saw that the choice of map layers for thematic maps is divided into two straightforward parts: (1) what layer or layers are needed to represent the subject, and (2) what spatial context layers are needed to orient the map reader to recognize locations and patterns of the subject features.

Key terms

analogous colors: Adjacent colors on the color wheel, used to depict association or harmony.

basemap: A map available from governments or GIS vendors that provides an infrastructure or costly but shared resources for GIS applications. Basemap layers commonly include streets, boundaries (political, legal, administrative, and physical), and so forth.

break values: Points chosen along the range of a quantitative attribute for creating nonoverlapping, exhaustive intervals. The intervals make the attribute discrete so it can be represented as a bar chart or a choropleth map.

cartogram: A thematic map whose features are distorted or altered to be directly proportional to a selected variable.

cartography: The art of choosing map layers and graphic elements to yield a map composition that meets a specified purpose.

chart junk: Graphic elements and symbols that do not add value to charts, maps, graphs, or other graphic designs. Chart junk wastes ink and clutters maps.

choropleth maps: Polygon map layers that have fill (such as shading or a pattern) using color value to signify the magnitude of an attribute.

color ramp: A particular sequence or continuum of colors designed to represent numeric quantities. Monochromatic or dichromatic color ramps are useful for analytical mapping.

color spectrum: The sequence of colors determined by the increasing frequency of visible-range electromagnetic waves, seen as light from a prism or a rainbow.

color value: The amount of white or black in a color. In relation to white paper or a white computer screen, white has low value and black has high value.

color wheel: A color-choosing guide, shaped like a wheel, that arrays colors in order of the color spectrum. Violet, the shortest-wavelength color, is adjacent to red, the longest-wavelength color.

complementary colors: Opposite colors on the color wheel. They combine a warm and cool color that look good together and provide more visual differentiation.

contrast: The difference in luminance or color that makes a map feature distinguishable from another feature.

dichromatic color scale: Two monochromatic scales joined together with low color value in the center and color value increasing toward either end. Such a scale is used for attributes that have a natural center, such as the value 0 for measures of increasing and decreasing values.

dot density map: A type of thematic map that uses a point symbol to visualize the geographic distribution of features that are scattered randomly in polygons.

equal intervals: Intervals with equal widths, such as 0–5, 5–10, 10–15, and so on.

exponential scale: A numeric scale with break values that follow an exponential sequence, such as 2*n* or 3*n*, where *n* takes on values 1, 2, 3, and so on. Often, the value 0 is included if the corresponding attribute's data values include zeros.

figure: A graphic feature given a bright color, distinctive boundaries, or other graphic designs to draw attention to it. Graphic features in figure are the subjects being investigated or those of importance.

graphic design: The choice of graphic features and elements yielding a map or other graphic display that meets an intended purpose.

graphic elements: The graphic variables used to impart meaning to graphic design, such as shape, size, width, and color.

graphic hierarchy: A design principle that dictates the use of color, strong edges, and other graphic elements to direct the viewer's attention to important parts of a map, chart, or other graphic.

ground: A graphic feature given dull colors, dashed lines, or other graphic designs to place it in the background. Ground features provide context and supplemental information and are secondary to graphic features in figure.

hue: The essence or distinguishing feature of color—for example, the blue in light blue and dark blue.

increasing interval widths: A sequence of intervals covering the range of a variable that accommodates long-tailed representations in bar charts and choropleth maps.

long-tailed distributions: Samples or populations whose distribution deviates from the normal, bell-shaped curve by having one tail elongated. Athletic performance and computer programming are examples of such distributions, with long tails on the right side of the distribution, as are many entities in nature.

median: The middle member of a distribution, with 50 percent of the sample smaller and the other 50 percent larger in magnitude.

mimetic symbols: Graphic symbols that resemble what they represent, such as a cross-hatched line for a railroad on a map.

monochromatic color scale: A series of colors of the same hue with color value varied from low to high—for example, the value ranges from white to black on a monochromatic grayscale, from light to dark green in a green monochromatic scale, and so on.

numeric intervals: Nonoverlapping and exhaustive intervals covering the range of data values for an attribute, such as those associated with bars on a bar chart.

quantiles: Numeric intervals for the range of an attribute that have equal numbers of members in each interval. The intervals are constructed by sorting an attribute and choosing break values along the sorted list of values that result in an equal number of data points in each interval.

quartiles: Quantiles that have four intervals, each with 25 percent of an attribute's data values.

reference map: A map that shows boundaries and locations of geographic areas—for example, accidents in relation to streets. Reference maps use conventional symbols and colors to represent features.

saturation: A color scale that ranges from a pure hue to gray or black—for example, the closer to black, the more saturated the color.

spider diagram: A graphic display to show the relationship between two kinds of points on a map. For example, a spider diagram may be used to study a person's residence by using a straight line between the residence and a hospital where they were admitted. Generally, the result for each person's residence to the hospital has the appearance of a spider's web.

thematic map: A map that focuses on a specific subject or theme. Unlike reference maps, which show many features, a thematic map highlights a specific topic, such as the rate of a disease.

value: The relative lightness or darkness of a color.

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