5

Thematic Mapping

5.1 Fundamental Elements of Maps

Do you use maps often? Are there any characteristics that different maps have in common? Most maps represent features of the Earth (such as roads, buildings, and lakes) from a viewpoint directly above those features. That is, planimetric (or 2D) representations of geographic features are common in maps, although the Earth is three dimensional. To represent features in spatially constrained and flat media such as a sheet of paper or computer screen, cartographers have to select, simplify, project, and symbolize the features of interest at a reduced scale. Therefore, cartographic maps (except for physical 3D models) have the following common denominators:

- map scale: how much a map reduces features on the ground
- map projection: how features on the curved Earth are flattened
- cartographic abstraction: how features are cartographically represented using visual variables such as color, shape, size, shading, etc.

In other words, a map is a reduced, flattened, and abstracted version of selected features on the Earth's surface.

Suppose you are given the topographic map shown in Figure 5.1 and are asked to determine the 2D distance between Belknap Crater and Black Crater on the ground, marked with a purple bidirectional arrow in the middle of the map. To do this, you would first measure the distance between the two craters using a ruler. If the distance is 1 in., you could then mark the distance (1 in.) in the scale bar at the bottom of the map, to find out how this map distance corresponds to the distance on the ground. The scale bar shows that the distance between the two craters is 5 miles. This means that 1 in. on the map represents 5 miles (=316,800 in.) on the ground. In other words, 316,800 units on the ground are reduced to 1 unit on the map. Therefore, the map scale can be expressed as 1:316,800, where the number on the left (1) represents a unit on the map and the number on the right (316,800) represents a unit on the ground. Although the scale ratio is 1:250,000 in this map, the actual map scale of this map is 1:316,800 because the map is digitally reduced to the image shown in Figure 5.1. This means that scale ratio would not be valid if the map image was resized (enlarged or reduced). It is always a good practice to go by the scale bar because the scale bar (unlike scale ratio) is resized in proportion to the map image when maps are resized.

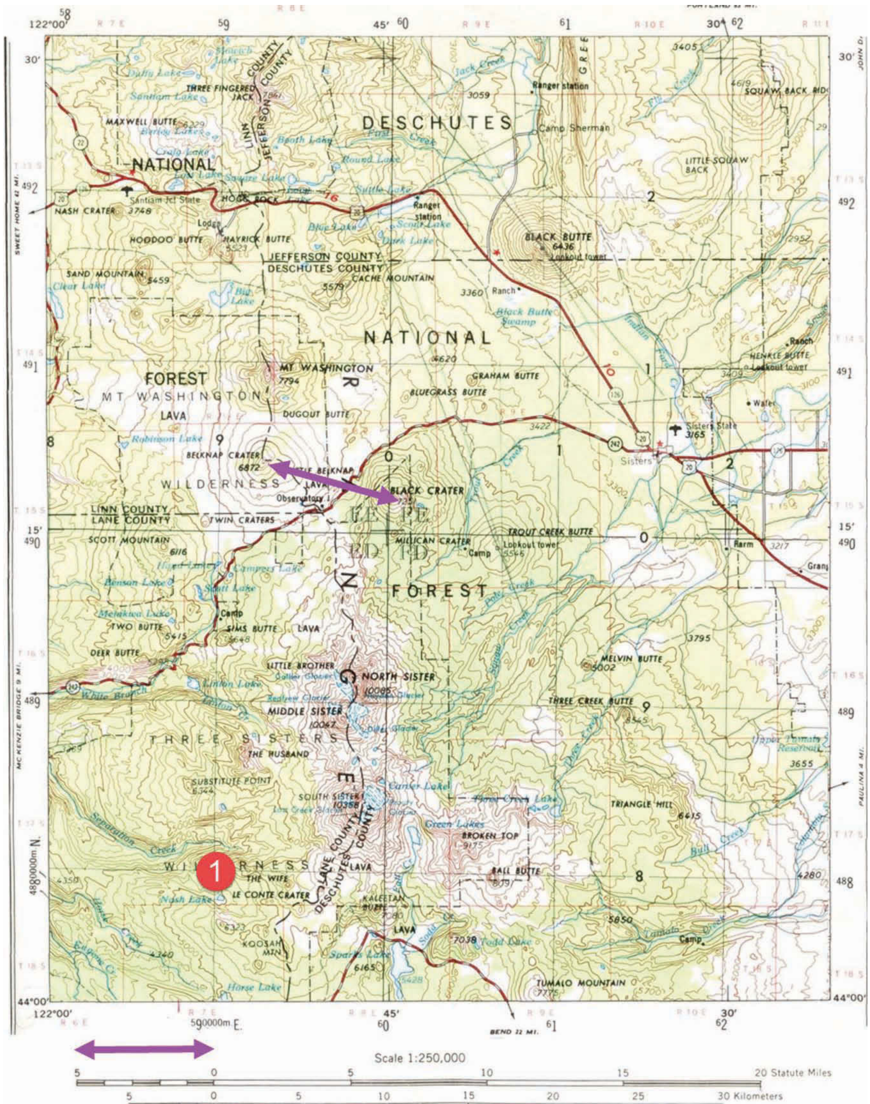

FIGURE 5.1
Topographic map used as a reference map showing the location of natural and cultural features (from US Geological Survey).

Compare 1:1,000,000 to 1:24,000. Which do you think is smaller? The former (1/1,000,000) is smaller than the latter (1/24,000). Therefore, it is correct to say that the former is a small-scale map while the latter is a large-scale map. In cartographic terms, a small-scale map shows a large area with less detail (like US maps), and a large-scale map shows a small area with more detail (like neighborhood maps). This distinction is often used when classifying topographic map series. Some geospatial data is derived from topographic maps and thus the scale of source topographic maps is an important factor influencing the quality of that geospatial data. All else being equal, the larger the map scale the more precise and accurate the geospatial data derived from the map will be.

You can use topographic maps to determine location. In the lower-left corner of the map shown in Figure 5.1, you might read 44° and 122° latitude and longitude of that corner. The topographic map also shows location in Universal Transverse Mercator (UTM) coordinates. For example, the location of the red symbol with the number 1 is read 10N 590,000 Easting (x) 4,880,000 Northing (y) in UTM coordinates. You can infer a UTM zone number based on longitude since the UTM zone number increases every 6 degrees longitude from the international dateline.

Mapmakers rely on cartographic conventions to reduce ambiguity. For instance, in Figure 5.1 the names of natural features (like lakes and mountains) are displayed in italics, and place names are displayed in upright text. Primary highways (e.g., route # 20) and secondary highways (e.g., route # 242) are displayed using standardized symbols. Some maps are easier to read and more informative than other maps even when the same data is mapped. Cartographers apply cartographic principles to design and create effective maps. Unlike nonvisual media such as letters, many factors that dictate the appearance of a map—such as the colors and symbols used and how the data is classified—can significantly affect map reading. We will address some of the principles of cartographic design in later sections, but first we will explore the types of maps available for use.

5.2 Gallery of Maps

There are two types of cartographic maps: reference maps and thematic maps. A reference map shows as many features as possible as long as the map size allows. A topographic map (Figure 5.1) showing both natural and cultural features belongs to a reference map. In contrast, a thematic map picks a particular theme or variable (e.g., primary language, population density, GDP by country) and depicts the spatial distribution of the variable. A population density map (Figure 5.2) is an example of a thematic map. A reference map works like an encyclopedia, and a thematic map is more like an

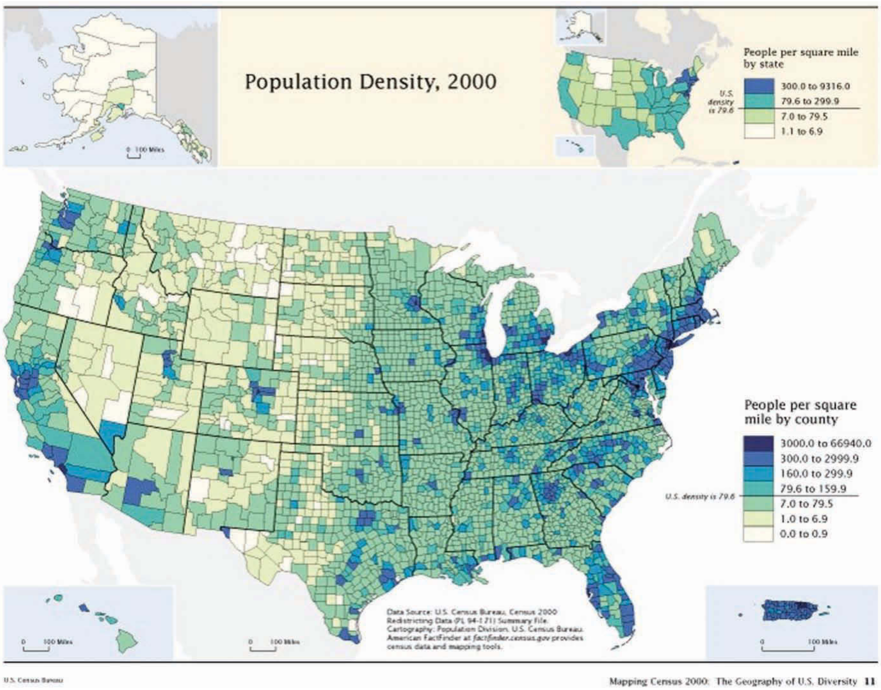

FIGURE 5.2
Choropleth map as a thematic map (from US Census Bureau).

essay due to its emphasis on a particular topic. In the following we focus on thematic maps because they can be easily created based on field values from the attribute table in GIS.

In Figure 5.2, people per square mile is depicted as graduated shades at the level of counties (areal units), where the darker shades indicate higher population density. This type of map is called a choropleth map. "Choro" means area (region) and "pleth" means value. Hence, a choropleth map depicts "values assigned or constrained to areas" (e.g., population density by county). A choropleth map is also referred to as a graduated color map in GIS software. The population density map uses insets to show Alaska, Hawaii, and Puerto Rico. These three insets have different map projections and map scales as indicated by the different scale bars in each of those insets. The legend on the right shows that the population density values are grouped into seven classes. This method of dividing quantitative data into classes is referred to as data classification in GIS, and will be discussed in a later section.

There are two types of thematic maps: qualitative maps and quantitative maps. The former maps categorical data (such as land cover and primary language), and the latter maps quantitative data (such as population density and temperature). Some maps only show the locations of features. These types of maps are called point maps. Figure 5.3 shows an example of a point map that depicts the location of UN cultural heritage sites in South America.

The qualitative map shown in Figure 5.4 represents language families (categorical data) as color. Maps depicting categorical data for boundaries that exhaustively cover an entire area of interest are called categorical maps. Example categorical maps include maps showing geology type, ethnicity, and climate regions where boundaries are delineated based on the homogeneity of attribute values within each boundary. In contrast, in choropleth maps attribute values are assigned to pre-existing areal units. This type of map is also referred to as a unique value map.

There are several other commonly used quantitative thematic mapping techniques. Figure 5.5 shows AIDS cases in July of 1989 and December of 1995. In this map, one dot represents 30 AIDS cases as shown at the bottom of the map. In Montana, AIDS cases increased from zero to 120 cases from 1989 to 1995 as shown by the four dots in Montana in the 1995 map. A large number of dots indicates high density. The type of map that scales the number of dots in proportion to numerical data is called a dot density map. Both dot density maps and choropleth maps depict data that are aggregated at the level of areal tabulation units (such as counties and states). In GIS software, dots are placed randomly within an areal unit because it is not

FIGURE 5.3
Point map showing the location of geographic features.

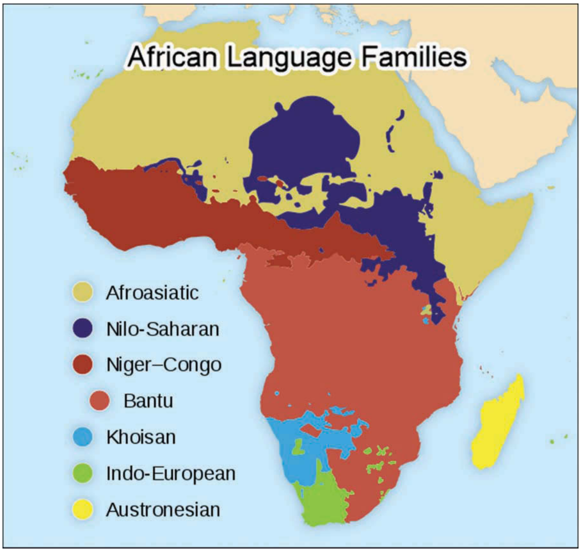

FIGURE 5.4
Categorical map showing language families. (From Eric Gaba, Wikimedia Commons User: Sting, retrieved from https://commons.wikimedia.org/wiki/File:Map_of_African_language_families.svg).

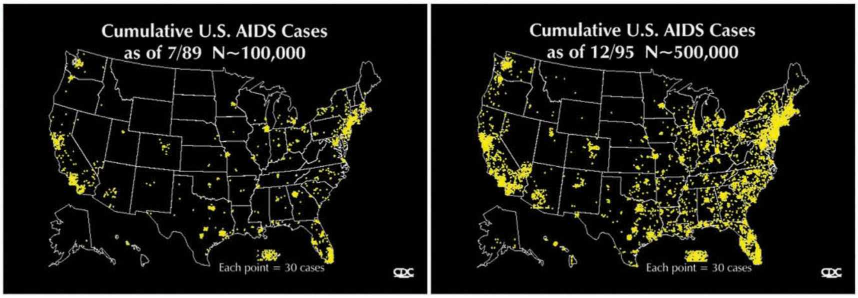

FIGURE 5.5
Dot density map depicting AIDS cases (from US Centers for Disease Control).

known exactly where individual AIDS cases occurred within the areal unit. Thus, the placement of dots should not be considered as the actual location of events. The smaller the areal unit, the more accurately dots will be placed.

Figure 5.6 shows where green building projects were implemented in the Washington, DC region. In this map, the size of a circle is scaled in proportion to the square footage of the green building project. This type of map is called a proportional (graduated) symbol map. Similar to a choropleth map, in a proportional symbol map the data (in this case the square footage of the green building projects) can be grouped into classes (there are four classes in

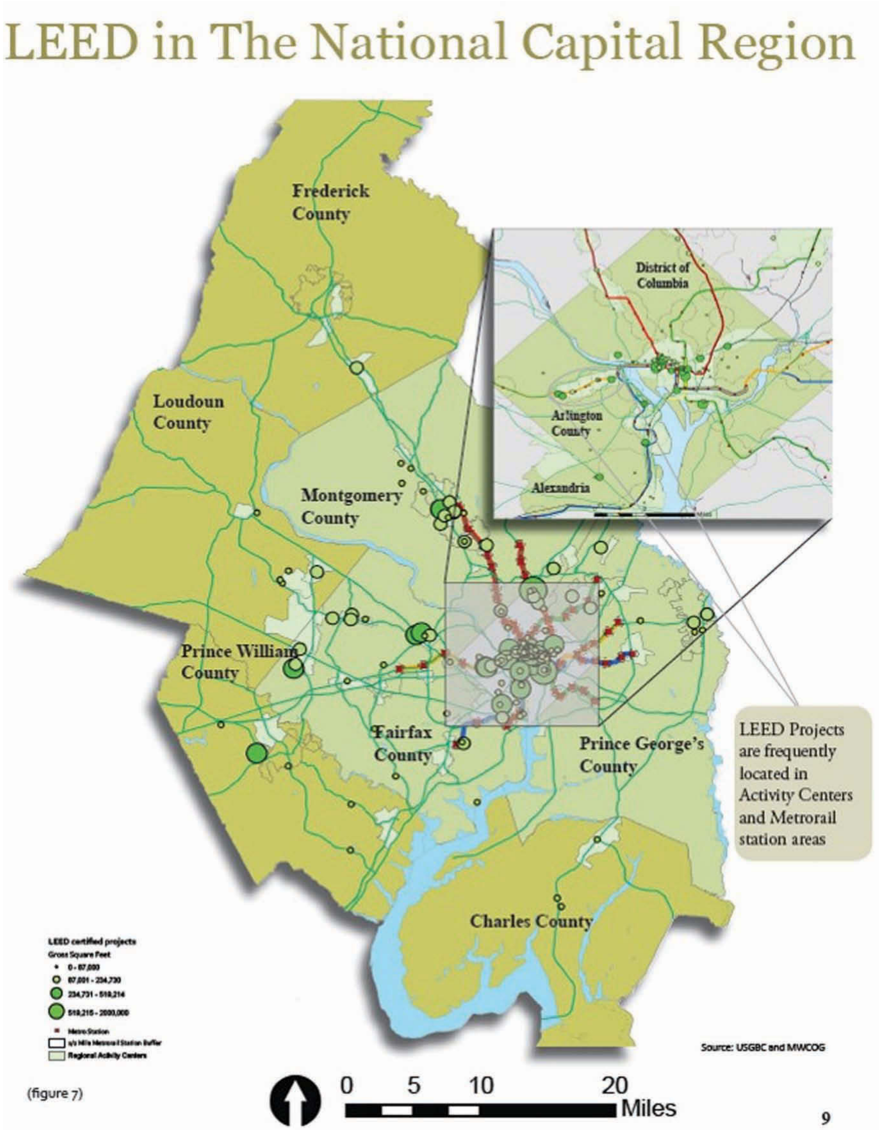

FIGURE 5.6
Proportional symbol map portraying Leadership in Energy & Environmental Design (LEED) buildings in the Washington metropolitan area (from US Green Building Council).

Figure 5.6). A proportional symbol map is good for visualizing quantitative data at point locations. A proportional symbol map can also be used to map quantitative data at areal units. Figure 5.7 shows the number of microbreweries and brewpubs by state. If a proportional symbol map is used to map areal data, the exact location of breweries is not of interest because the aim

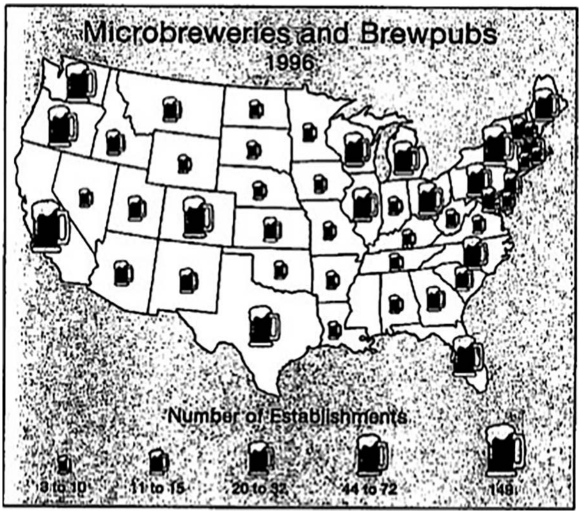

FIGURE 5.7
Proportional symbol map that shows data tabulated at the level of areal units (states).

is to show numerical data representatively by areal units (states). This type of proportional symbol map is often used to depict non-normalized data (such as the number of microbreweries) to complement a choropleth map that is good for depicting normalized data (such as microbreweries per 1,000 population).

Another widely used quantitative thematic map is an isarithmic map. Figure 5.8 shows an isarithmic map that depicts temperature using a spectral (rainbow) color scheme. An isarithmic map is the most appropriate way to visualize continuous geographic phenomena with smooth variation, such as temperature, elevation, and carbon dioxide. To create an isarithmic map using GIS software, you need to use a spatial interpolation tool that creates a continuous surface from sample point data. There are two types of isarithmic maps: isometric maps and isopleth maps. An isometric map depicts data collected at physical point locations (e.g., temperature at weather monitoring stations). An isopleth map, on the other hand, depicts data collected at perceptual or representative locations (e.g., poverty rate by census tracts). Figure 5.9 shows an isopleth map with the median home value to complement the choropleth map. Isarithmic maps should only be used when similar values cluster together (i.e., positive spatial autocorrelation).

The world air travel map in Figure 5.10 depicts the number of international flights per year along the major air routes. Data is represented by the thickness of the two directional arrows. The thicker the arrow the more international flights. This type of map depicting the amount of flow between origin and destination is referred to as a flow map. This map also depicts two more variables: traffic in passenger miles at the origin airport by choropleth

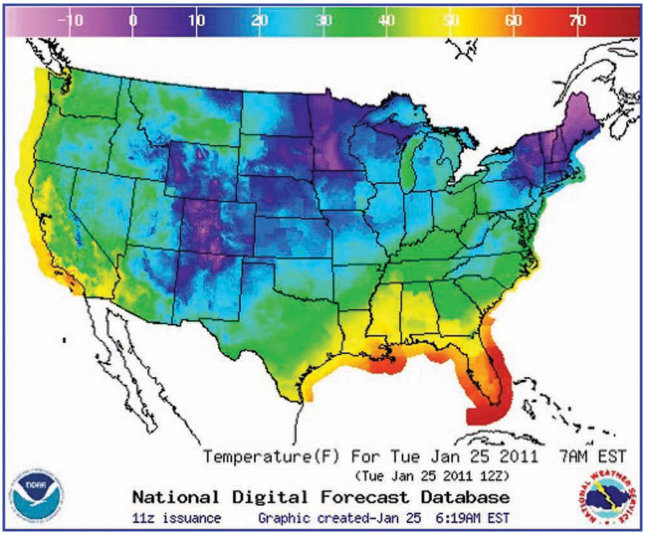

FIGURE 5.8
Isarithmic map showing temperature in the contiguous United States.

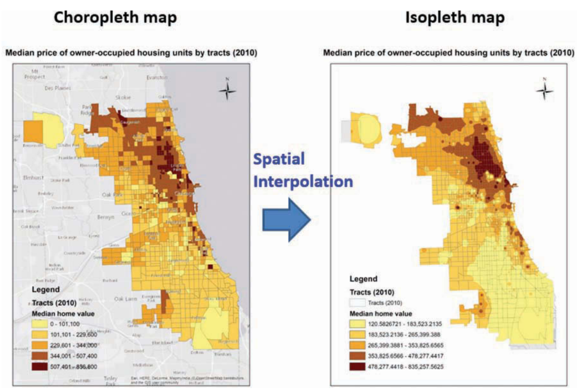

FIGURE 5.9
Isopleth map depicting median home price by census tracts in Chicago (2010).

mapping, and the number of passengers at major airports by proportional symbol mapping. In contrast to a proportional symbol and choropleth map that shows spatial distribution at a particular location, a flow map depicts the amount of spatial interaction between places. It is interesting to note that Fuller map projection is employed to map air traffic that is centered around the north pole.

Figure 5.11 shows how population density by county changed over time in the western United States. A map that represents numeric data using perspective height is called a prism map. Note that the same data classification

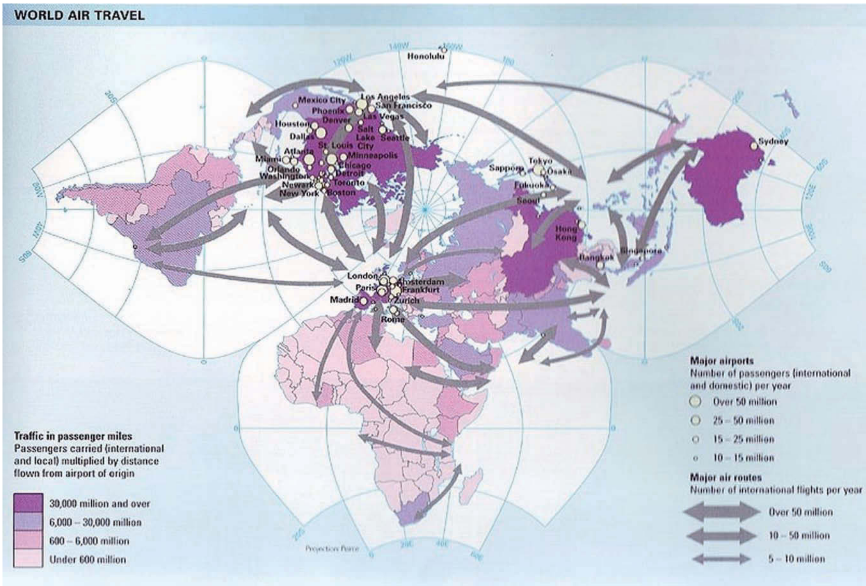

FIGURE 5.10
Flow map showing air traffic in the world.

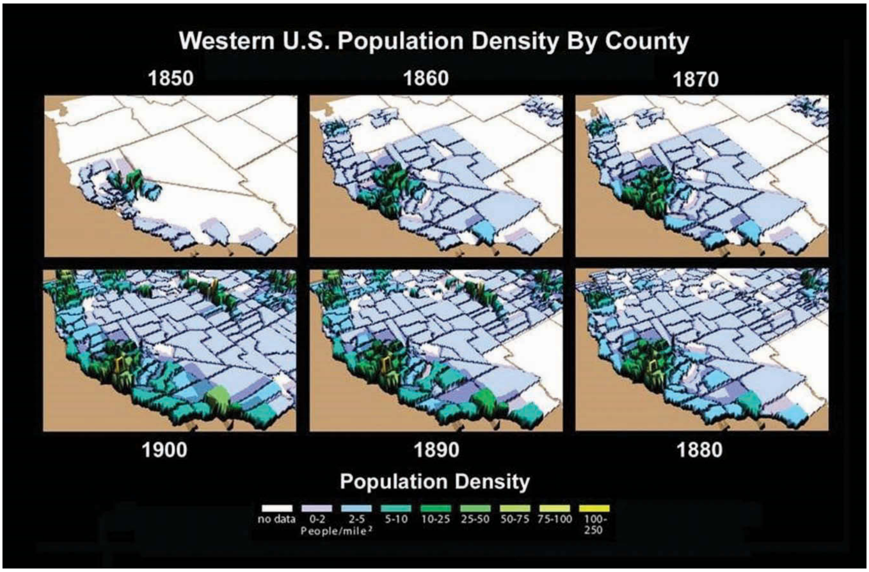

FIGURE 5.11
Prism map showing population density in the western United States from 1850 to 1900.

is used to facilitate comparison across different years. To make a prism map, the GIS software should have 3D modeling and visualization capabilities. ArcGIS, for example, provides this functionality through ArcScene.

We have examined many thematic maps that represent data aggregated at areal units. A choropleth map, dot density map, proportional symbol map, and isopleth map all represent such data. While these maps use different visual variables (e.g., color shading, the number of dots, size of symbol), the geometric properties (e.g., the size of areal unit) do not change. However, some thematic maps do modify geometric properties in proportion to the data being used. This type of thematic map is called a cartogram. The cartogram shown in Figure 5.12 scales the size of the areal units (countries) in proportion to the per capita consumption (translated as land area using the ecological footprint framework) by country. Although the distortion of geometric properties (e.g., sizes and shapes of countries) can make it challenging to read this type of map, global inequality of consumption is effectively conveyed due to the unfamiliar appearance of the map.

Thus far we have looked at thematic maps depicting one variable at a time (univariate maps). But sometimes it is useful to map charts comprised of multiple variables at a particular location. For example, the map in Figure 5.13 depicts age structure by tracts, where the height of each bar represents the population counts by different age groups. This map shows that the elderly population is more concentrated near Lake Michigan compared to other age groups in Uptown, Chicago. A bar chart map is good for visualizing related variables that are ordered (e.g., income group, population by year). In contrast, a pie chart map can most effectively show the relative share of related categorical variables that make up the whole. In Figure 5.14 a pie chart is created in areal units (tracts) to represent ethnic composition. It is important to note that

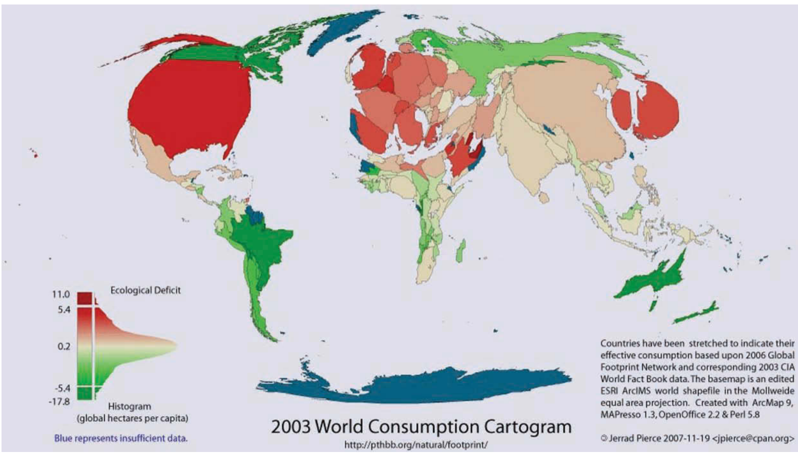

FIGURE 5.12
Cartogram that portrays consumption level by country in the world (2003).

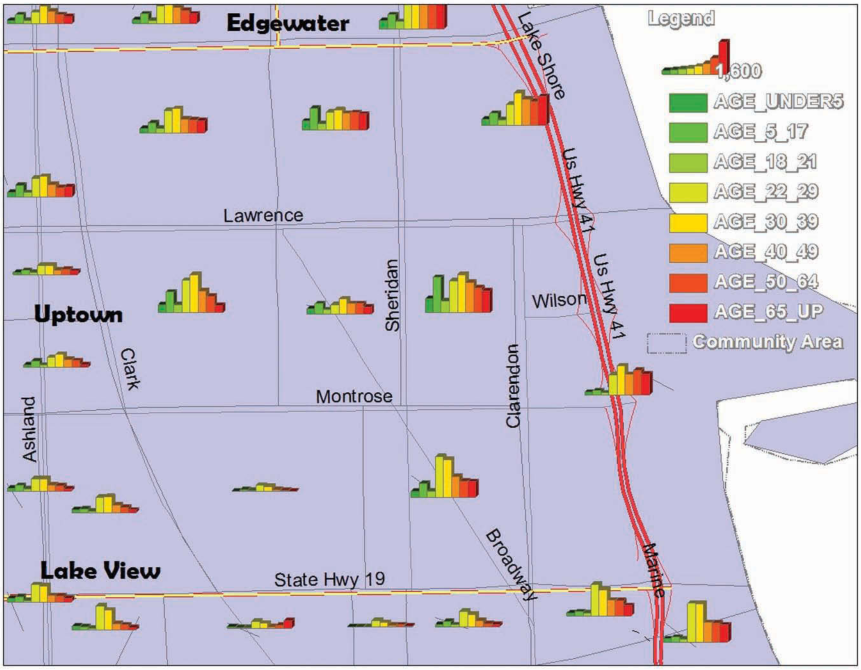

FIGURE 5.13
Bar chart map showing age composition by tracts in Uptown, Chicago; from Copyright © 2018 Esri, ArcGIS, ArcMap, and the GIS User Community. All rights reserved. With Permission.

categories that make up slices of a pie chart are mutually exclusive. For example, in Figure 5.14 the Hispanic population is not shown in the pie chart map because it is subsumed in the White population according to the census ethnic category. Figure 5.14 also shows that tracts that border the intersection between Sheridan and Lawrence appear to be most diverse in Uptown, Chicago.

5.3 How Data Representation Affects Map Reading and Interpretation

All four of the choropleth maps shown in Figure 5.15 represent the same data (median house value by tracts in a Seattle metropolitan area in 2000), but they all look different. Map readers will likely draw different conclusions from those maps. In those maps data values are grouped into five to seven classes using different data classification methods. You can compare data classification methods by referring to a histogram and noting where classes are divided in the histogram.

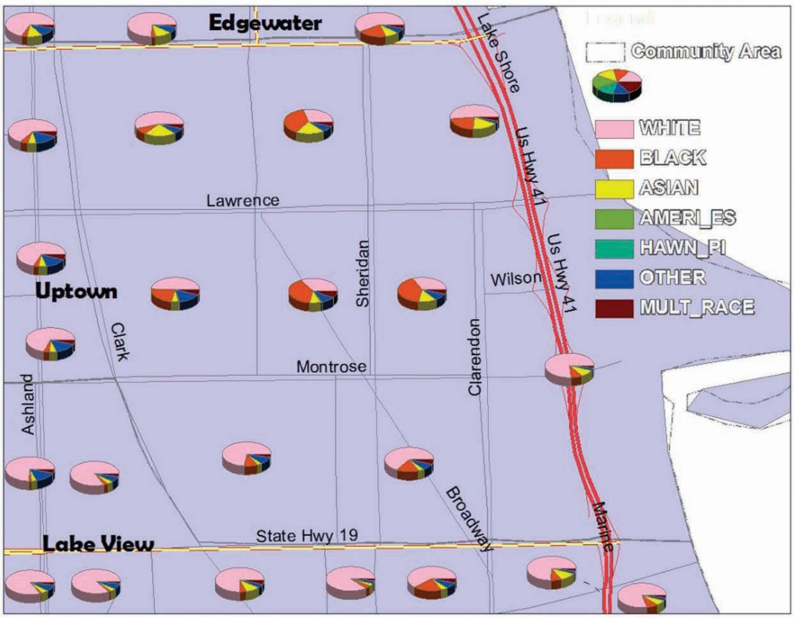

FIGURE 5.14
Pie chart map showing ethnic composition in Uptown, Chicago; from Copyright © 2018 Esri, ArcGIS, ArcMap, and the GIS User Community. All rights reserved. With Permission.

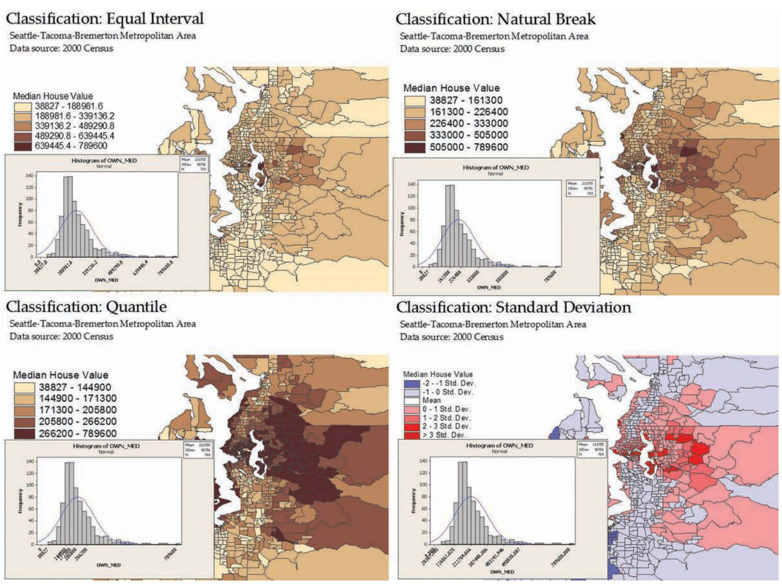

FIGURE 5.15
Effect of data classification methods on map reading; from Copyright © 2018 Esri, ArcGIS, ArcMap, and the GIS User Community. All rights reserved. With Permission.

In an equal interval map (upper left of Figure 5.15), the data values are divided into five classes with equal intervals. To determine the intervals, you divide the range (maximum value minus minimum value) by the number of classes. Classes are equally divided at the interval 150,154 (=750,773/5). The fifth class has the range $639,445–$789,600 in an equal interval map. While the equal area method is easy to understand, it does not fairly represent data when the data is highly skewed. For example, in the equal area map in Figure 5.15 the fourth and fifth classes are overrepresented despite the low frequency of the data.

A quantile map (lower left of Figure 5.15) divides data in terms of percentiles. If data is grouped into five classes, the first class ($38,827–$144,900) represents the 0–20th percentile, the second class represents the 20–40th percentile, and the fifth class ($266,200–$789,600) represents the 80–100th percentile. In a quantile map, an equal number of ordered cases (units of observation) is placed in each class. The histogram in the lower left of Figure 5.15 shows that the breaking points are close to each other in the second, third, and fourth classes because many cases are concentrated in those values in the range $144,900–$266,200. The result is that the remaining data is grouped into the fifth class in the large range $266,200–$789,600. This works to mask internal variation in the range $266,200–$789,600, but data in the range $144,900–$266,200 are more precisely depicted.

The natural break method (also known as Jenk's method) divides data into the most homogeneous classes. Notice that the fifth class ($505,000–$789,600) in the natural break map is internally homogeneous and is distinct from the other classes. Breaking points are determined through a clustering algorithm that maximizes intra-class similarity and inter-class difference. The default option for data classification in many GIS software is natural break because natural break organizes data in itself, and works in most (if not all) cases.

Standard deviation calculates the mean and standard deviation from data, and determines breaking points by subtracting multiples of standard deviation from the mean. The standard deviation method is useful when it is important to convey how much data deviates from the average for each areal unit. In contrast to the equal interval and quantile methods, natural break and standard deviation take into account the frequency distribution of data. Using GIS software, you can also set your own breaking points to meet map requirements. For example, it would make sense to group data into classes manually when you need to visualize income data by income tax brackets.

Data should be normalized as needed before mapping. Data normalization is intended to facilitate comparison of data values that are often measured in different units. For example, if you are studying how prevalent obesity is in a community, it would be more useful to look at obesity rates than the number of obese persons because variations in base populations across communities make it hard to compare obesity prevalence equally. Examples of normalized data include mortality rate, rate of population change, median household income, and average SAT score.

Consider the two choropleth maps in Figure 5.16. The map on the left (A) depicts raw population count by tract, and the map on the right (B) shows population density (population per square mile) in Cook County, Illinois. Cook County contains the City of Chicago at the center right. Do you see any difference between these maps? Which map do you think more accurately represents the spatial distribution of the population? Map A may give you the false impression that there are many people living in the suburbs and relatively few people living in the city. But note that tract sizes are typically large in suburbs and small in a city. When mapping raw count at areal units remember that the size of areal units varies greatly, and thus mapping non-normalized data (such as raw count) may simply reflect the size of areal units rather than the actual data being mapped. Similarly, if you map the number of deaths instead of the mortality rate, the number of deaths will most likely reflect the base population as well. When interpreting a map showing non-normalized data, it is easy to be unfairly influenced by varying areal sizes or base populations.

To illustrate this concept further, suppose that you will choropleth map trees that are evenly distributed (or are planted at equal intervals) in a study area divided into two sections, where the first section is 10 acres and the second section is 5 acres. If you map raw count (the number of trees), the first section will look darker than the second section in the map because the first section is larger than the second section, giving a false impression higher density of trees in the first section than in the second section. Mapping

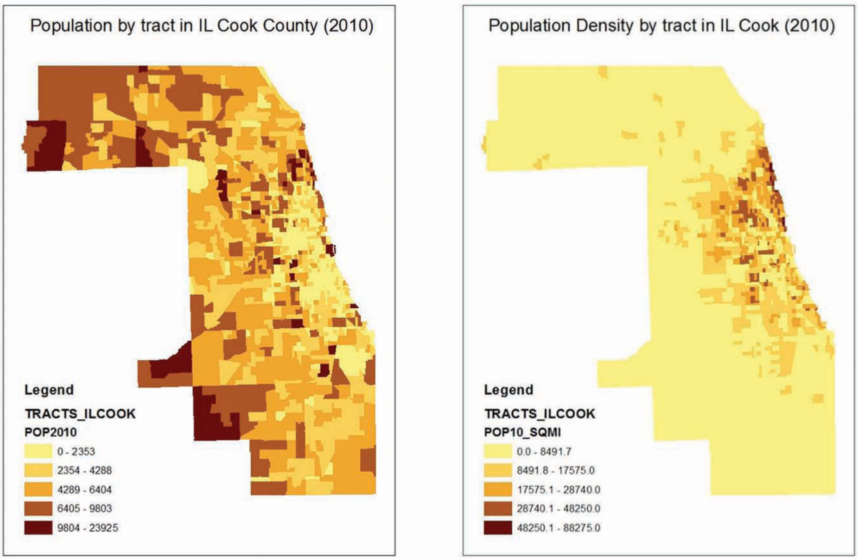

FIGURE 5.16
Effect of data normalization on map reading; from Copyright © 2018 Esri, ArcGIS, ArcMap, and the GIS User Community. All rights reserved. With Permission.

normalized data (e.g., the number of trees per acre) will show that the two sections have the same density (equal distribution). Mapping normalized data can help map readers neutralize the effects of varying areal sizes and base populations.

Moreover, shading is usually interpreted as intensity (e.g., population density or crime rate). That is, map readers tend to associate darker tints with higher intensity (or density). Map B in Figure 5.16 gives the correct impression that there are more people in the city than the suburbs by naturally associating dark tints with high intensity. Further, map B is more effective at portraying spatial distribution of population than map A because additional information (e.g., area, base population) that helps compare data among different areal units is taken into account, and a relative measure facilitates comparison among cases. It is important to consider data normalization to create an effective choropleth map that is not misleading.

Consider the two maps in Figure 5.17. The map on the left (A) shows the crude death rate and the map on the right (B) shows the age-adjusted death rate. The crude death rate is simply the number of deaths per 100,000 population. The age-adjusted death rate is adjusted for differences in age distribution. To calculate age-adjusted death rates, you multiply the age-specific crude death rate by the national standard proportion for each age group (as weight), and sum the products over all age groups. That way, the age-specific death rate of the state with a high proportion of elderly population will be deflated. Age adjustment is a common procedure in calculating the rates of health statistics to allow communities with different age structures to be compared. There are higher crude death rates in a few states (e.g., Pennsylvania, Maine, Florida) compared to other parts of the country because there are

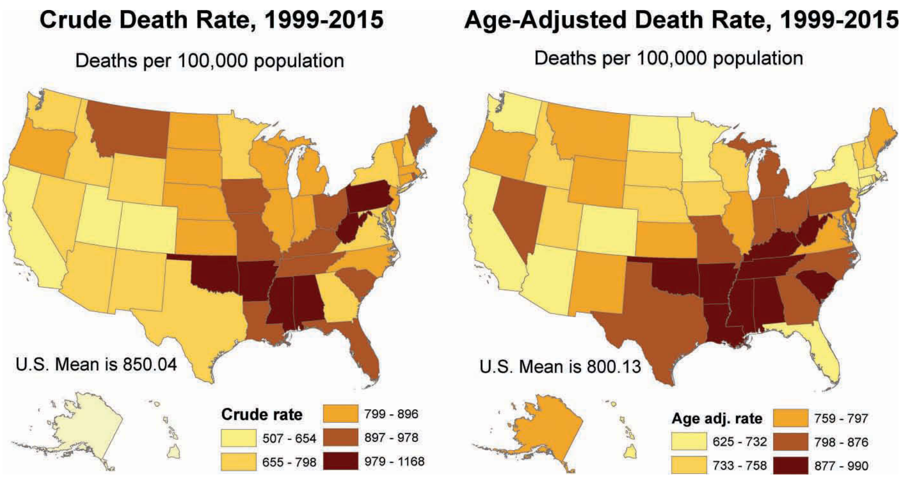

FIGURE 5.17
Effect of data normalization methods on map reading.

relatively more elderly people in those states. The map of the age-adjusted death rate gives a different pattern than the map of the crude death rate. Figure 5.17 shows that map interpretation can be significantly influenced by how data is normalized. It is important to consider an appropriate method for data normalization that meets the requirements of the map being created.

5.4 Choosing Symbology (Visual Variables)

The previous three sections focused on how to read cartographic maps in an informed and critical manner. After familiarizing yourself with how features and attributes are cartographically represented, you know that making maps involves numerous choices regarding cartographic parameters. What symbology should you use? What thematic mapping technique would be most appropriate for a given data and problem? Should you normalize data? If so, how? What data classification method would be most effective? How can you make a map easy to read? In the following we consider some of the following mapmaking questions:

- What symbology should be used?
- What thematic mapping technique should be used?
- How should thematic contents be organized?

Compare the two maps in Figure 5.18. Both maps depict the percentage of multiple races by state in the United States. Which map do you think is more effective at depicting the spatial distribution of multiple races? What is wrong with the other map? One of the problems with the map on the left is that the visual representation is not logically aligned with the characteristics of data. In contrast, the visual representation from light shade to dark shade

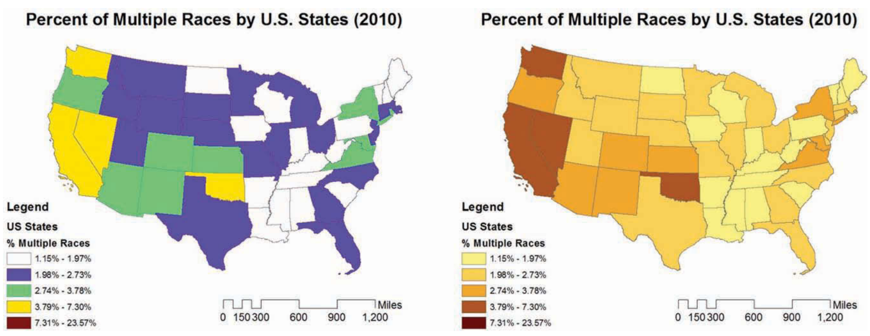

FIGURE 5.18
Choosing visual variables: use color value (lightness) for quantitative data.

is naturally in line with the graduation of data values (from low percentage to high percentage of multiple races) in the map on the right.

Consider the two maps in Figure 5.19 showing presidential election results. Which map do you think is more effective at depicting election results, and why? Why did you choose that map over the other one? The map on the right exploits the symbolic connotation of color; red is associated with the Republican political party, and blue is associated with the Democratic political party. The two colors (red and blue) are well suited to depict categorical differences. In contrast, dark green and light green in the map on the left can be perceived as data with different weights, where dark green potentially looks more important than light green. In other words, visual representation that suggests ordinal difference is not naturally aligned with data that suggests qualitative difference.

Consider the two maps in Figure 5.20. The map on the left shows the number of active hate groups by state, and the map on the right shows the dominant hate groups by state. Which map do you think is poorly designed, and how would you improve it? The number of active hate groups would have

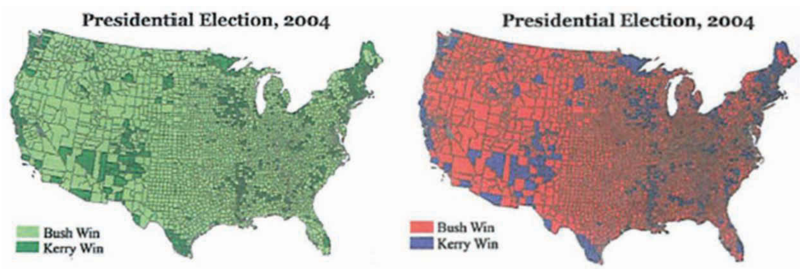

FIGURE 5.19
Choosing visual variables: use color hue for categorical data. (Reprinted with permission from Krygier, J. and Wood, D. *Making Maps: A Visual Guide to Map Design for GIS*, 1st Edition, The Guilford Press, 2005.)

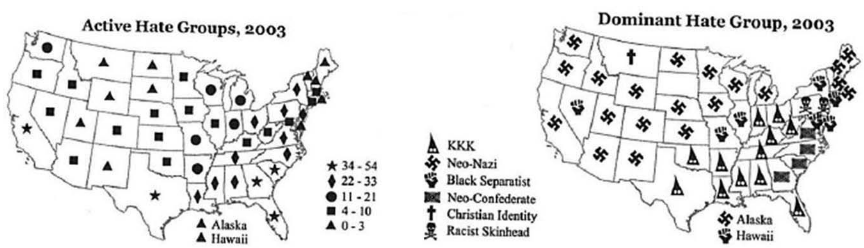

FIGURE 5.20
Choosing visual variables: use shape for categorical data. (Reprinted with permission from Krygier, J. and Wood, D. *Making Maps: A Visual Guide to Map Design for GIS*, 1st Edition, The Guilford Press, 2005.)

been better represented by the same shape (a circle rather than various geometric shapes) in graduated size, where the number of active hate groups is depicted by the size. The map on the right is logically designed as different pictorial map symbols that suggest qualitative difference are used to represent qualitative data (dominant hate groups).

The human eye can perceive differences in map elements or symbology, such as color, symbol size, and shape. Those visual aspects that result in perceived differences are called visual variables (or graphic elements) in cartography. Figure 5.21 shows shape, size, color and perspective height, the visual variables commonly used in mapmaking. Humans perceive three dimensions of color: hue, brightness (value), and saturation (intensity). Hue refers to what we commonly think of as color, such as red, blue, and green. We can perceive a varying degree of brightness within a color hue, like dark blue to light blue. Humans can also distinguish between pure (more saturated) blue and impure (less saturated) blue by adding or subtracting gray.

Each of the visual variables has its own inherent logic. Some visual variables suggest qualitative difference, and some visual variables suggest quantitative difference. Suppose you are given cards with different color hues (blue, red) and are asked to order them. If you can order them, they are quantitative. Otherwise, they are qualitative. Thus, visual variables are classified

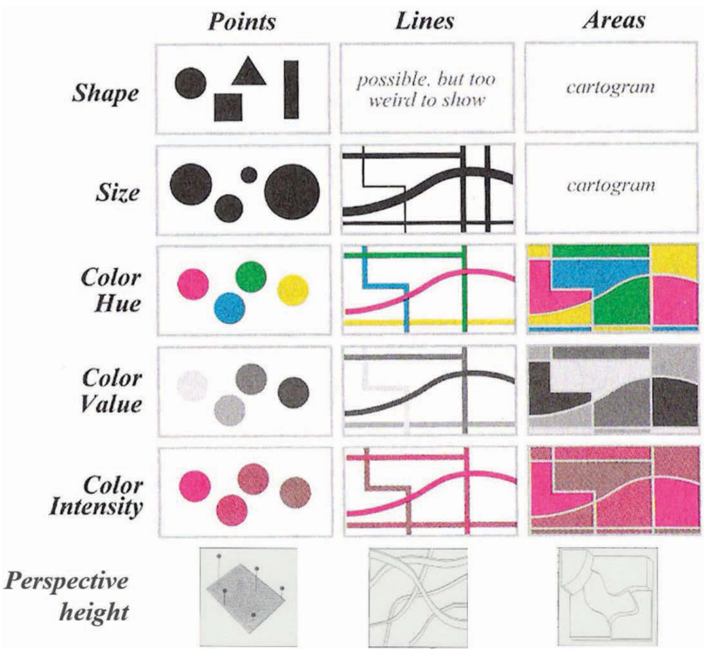

FIGURE 5.21
Visual variables used for map design. (Reprinted with permission from Krygier, J. and Wood, D. *Making Maps: A Visual Guide to Map Design for GIS*, 1st Edition, The Guilford Press, 2005.)

TABLE 5.1

Two Types of Visual Variables

	Qualitative (No Order)	Qualitative (Ranked)
Shape	x	
Size		x
Color hue	x	(x)
Color value		x
Color intensity	(x)	x
Perspective height		x

into two categories, qualitative (no order) or quantitative (ranked), as shown in Table 5.1. Shape and color hue suggest difference in kind or category and hence are qualitative visual variables. Size, color value, color intensity, and perspective height are quantitative visual variables because they can be ordered, suggesting a difference in quantity. Although color hue is mostly qualitative, color can be grouped into warm colors and cool colors, and there is some perceived order within that category. For example, we can order yellow, orange, and red within a group of warm colors. Similarly, color intensity is in most cases quantitative (pure to impure red), but the most impure color or achromatic color (e.g., white, black, gray) is qualitatively different from chromatic color (e.g., red, blue, green). Hence, color intensity can be used to suggest qualitative difference if achromatic colors and chromatic colors are used together.

When choosing visual variables you should match the type of visual variables with the nature of the data. That is, you should use qualitative visual variables if you are mapping categorical data such as the dominant hate group, but you should use quantitative visual variables when mapping ordinal or numeric data such as earthquake magnitude or the percentage of multiple races. Figure 5.22 uses a qualitative visual variable—shape (coffee cups and coffee bags)—to represent categorical data (coffee consumption and coffee production). This map also uses a quantitative visual variable—size—to represent quantitative data (the relative share of coffee consumption and production). Pictorial symbols—in this case, cups and bags—make it easy to recognize two categories (here, coffee consumption and production).

Even when working with the same raw data, you will often need to choose different visual variables to meet different map requirements. For instance, Figure 5.23 shows age-adjusted death rate in two different color schemes—sequential vs. diverging color schemes. While the sequential color map in Figure 5.23 is good to show death rate in natural sequence, the diverging color map would be effective if map requirements are to show how data (death rate) deviates from mean. The diverging color map in Figure 5.23 divides data into two categories—data below mean, and data above mean—to represent two categories in color hues (blue and red), and amount of deviation within each category in color value (or lightness). In general,

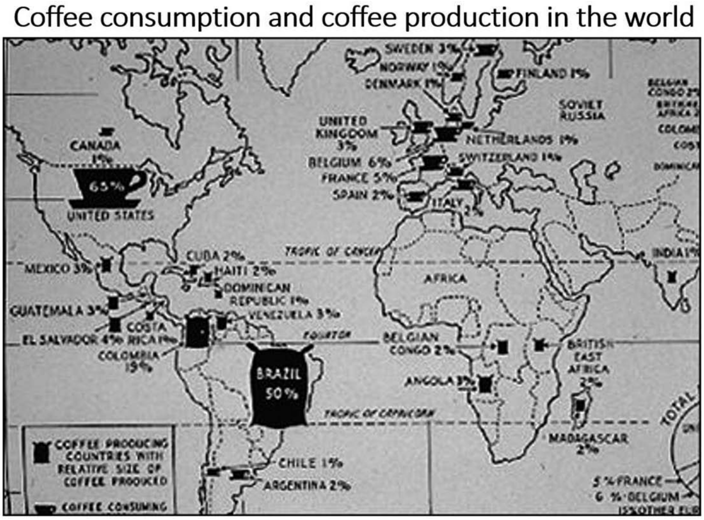

FIGURE 5.22
Choosing visual variables: shape for categorical data and size for numerical data.

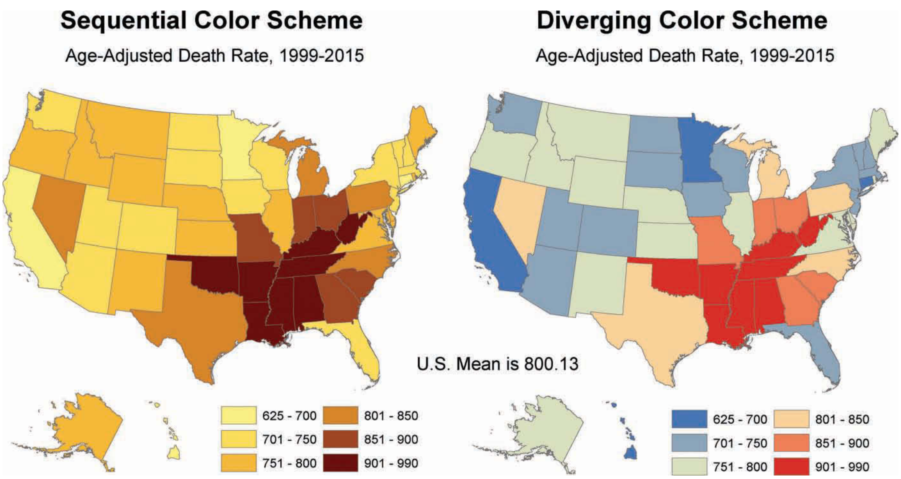

FIGURE 5.23
Sequential color scheme vs. diverging color scheme.

a diverging color scheme would be appropriate for depicting data with a natural breaking point (or baseline) such as population growth which can be positive or negative. Color Brewer 2.0 (http://colorbrewer2.org) provides color specifications for suggested sequential, diverging, and qualitative color schemes.

5.5 Choosing a Quantitative Thematic Mapping Technique

The previous section provided guidance on choosing thematic mapping techniques based on measurement levels of data. A unique value map (qualitative thematic map) that uses color hue as a visual variable was created to map election results (qualitative data) in Figure 5.19. A point map that uses shape (pictorial symbol) as a visual variable was created to map dominant hate groups in Figure 5.20. However, matching the type of visual variables with the nature of the data provides little guidance on choosing among the different quantitative thematic maps—namely, choropleth maps, dot density maps, proportional symbol maps, and isarithmic maps. Suppose you need to map the following four quantitative data in a metropolitan area:

- Precipitation, where data is collected at weather monitoring stations
- Hospital discharge rates for diabetics, where data is aggregated at the level of zip code
- Revenue of shopping malls
- Population (raw counts), where data is aggregated at the level of census block

What thematic mapping techniques would you consider for each of the above data types, and why?

In cartography data used can be classified depending on whether it is continuous or not (y axis) and how data values vary (x axis), as shown in Figure 5.24. In a y axis, data is spatially continuous if the data values exist at all locations and are seen as a continuous surface filled with values. Temperature, elevation, and precipitation are good examples. Data is spatially discrete if the values exist at discrete locations and do not occur between those locations. Examples include buildings, trees, and traffic accidents. Population is considered discrete data as each data point falls into

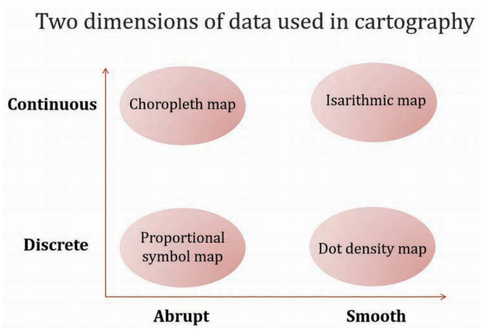

FIGURE 5.24
Matching thematic mapping techniques with data characteristics.

each person at discrete location and no values exist between two persons. Population density is considered continuous data because the value calculated for a given area occurs at all locations as if it fills the entire area continuously. Normalized data for an areal unit such as SAT score by school district, median household income by tract, and mortality rate by county are considered continuous data.

In an x axis, data is considered smooth if discrete data points occur relatively frequently or continuous data varies smoothly in the geographic space. Data is considered abrupt if discrete data points occur rather infrequently or continuous data does not vary smoothly in the geographic space. If you compare shopping malls and buildings in a metropolitan area, shopping malls are on the abrupt side and buildings are on the smooth side. Temperature would have a smooth variation whereas population density would have an abrupt variation as the level of population density varies abruptly across boundaries of areal enumeration units.

In summary, data used for quantitative thematic mapping can be organized into the phenomenon space in two dimensions of continuity (y) and variation (x), and the phenomenon space can be matched with the symbolization space as shown in Figure 5.24. An isarithmic map is the best way to depict continuous phenomenon with smooth variation, such as precipitation, temperature, elevation, and ozone level. A dot density map is well suited for portraying discrete phenomenon that occurs frequently, such as population count, number of jobs, number of churches, and acreage of cropland harvested by county subdivision. A proportional symbol map works well for depicting discrete phenomenon that does not occur frequently, such as the number of cases of the West Nile virus, revenue of shopping malls, enrollment by universities, and the number of visitors to national and state parks. Obviously, the map scale or study area influences the variation factor in an x axis. For example, enrollment by university in Chicago may be abrupt, but enrollment by university in the United States may be smooth. A choropleth map is suitable for depicting continuous phenomenon whose value abruptly changes across areal units, such as average SAT score by school district, median household income by tracts, hospital discharge rates for diabetics by zip code, and population density by county. Two dimensions of cartographic data (continuity and variation) can be considered along with map purposes and audience when choosing the right quantitative thematic mapping technique.

5.6 Organizing Thematic Content

After you choose your visual variables and a thematic map, next you need to consider how to organize thematic content. Consider the two maps shown in

Figure 5.25. The purpose of these maps is to show where the Black Heritage Trail is located. Which map do you think serves the purpose more effectively? The map on the left is less effective than the map on the right because the Black Heritage Trail, the most important thematic content, is not emphasized. "Black Heritage Trail" in the title should have been emphasized more than "Eli County, VA" as the map is about "Black Heritage Trail," and a mapping area is secondary to the trail. The map on the right clearly emphasizes the trail. Unlike the former map, the trail stands out relative to other content such as topography, place names, and other trails.

The two maps in Figure 5.26 show the Latino population using a dot density map. The only difference is the visual representation of dots and boundaries. The map on the right is more effective than the map on the left because the most important thematic content (dots) stand out most while less important content (tracts boundary) are deliberately toned down. Consider how the AIDS maps in Figure 5.5 would have looked if the background color was orange instead of black. Black was chosen because it helps the yellow dots representing AIDS cases stand out. In the AIDS map, good contrast is achieved using color saturation as well, where dots (yellow) are highly saturated and a backdrop color (black) is unsaturated (achromatic). In a well-designed map, visual weight corresponds to importance of map content.

Map design uses visual hierarchy to reflect varying levels of intellectual importance of map content by exploiting the figure-ground relationship. Figure-ground relationship refers to a perceptual grouping necessary for recognizing objects through vision. When you see a guinea pig in Figure 5.27, you will distinguish a guinea pig as a figure from the background. In an effectively designed map, more important content stands out to map readers and less important content retreats to the background. This is illustrated in the figure on the right (Figure 5.27) in which darker visuals are seen more clearly by map readers, and lighter visuals are de-emphasized. The two maps (Black Heritage Trail and Latino population) on the right in Figures 5.25 and 5.26, respectively, are effective because the thematic content is hierarchically

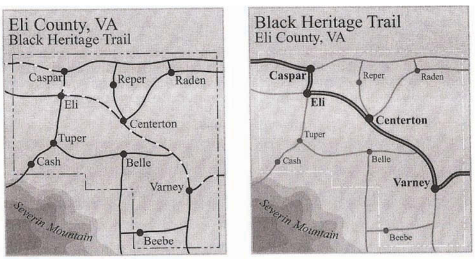

FIGURE 5.25
Visual hierarchy can be achieved by highlighting important elements. (Reprinted with permission from Krygier, J. and Wood, D. *Making Maps: A Visual Guide to Map Design for GIS*, 1st Edition, The Guilford Press, 2005.)

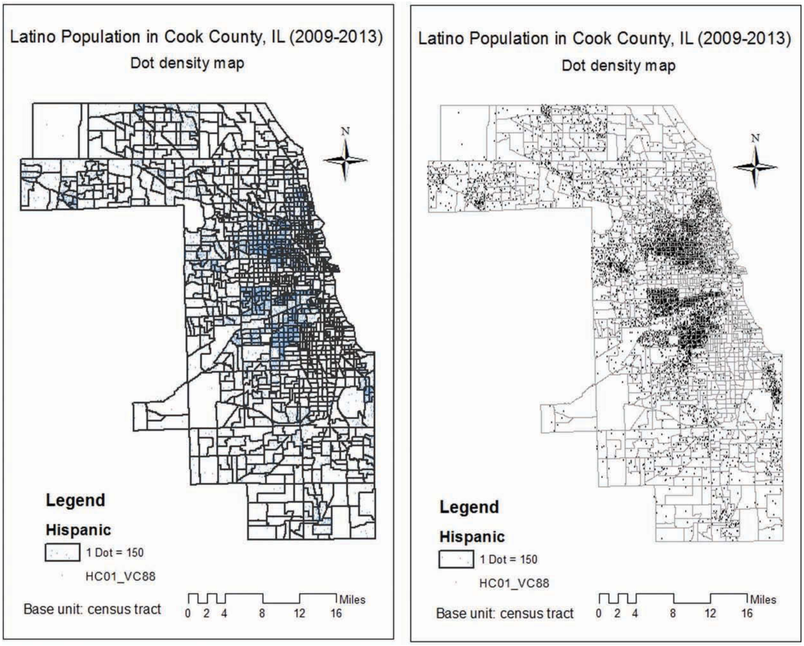

FIGURE 5.26
Visual hierarchy can be achieved by toning down less important elements.

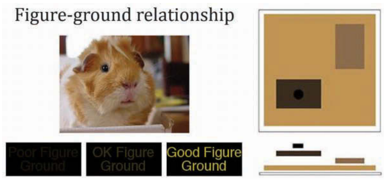

FIGURE 5.27
Figure-ground relationship. (Reprinted with permission from Krygier, J. and Wood, D. *Making Maps: A Visual Guide to Map Design for GIS*, 1st Edition, The Guilford Press, 2005.)

organized and depth is added through visual hierarchy. Compare these maps to those on the left, which look flat and do not immediately convey what is important in the map.

While there are many cartographic conventions at your disposal, many of them rely on your cognitive capacity to determine the best choices for your map content. The human brain is incredibly efficient at processing visual information but has limited short-term memory with a tendency to organize fuzzy constructs into discrete ones. Cartographers understand this and group data into no more than seven classes because humans can only process limited amount of information at once. Cartographers also make use of the figure-ground relationship to organize content.