4

Principles of Symbolization

OVERVIEW

The purpose of this chapter is to cover basic principles of symbolizing geographic phenomena. An overarching goal is to assist you in selecting among four common thematic mapping techniques: ***choropleth***, ***proportional symbol***, ***isopleth***, *and* ***dot***. *For example, imagine that you wish to map the spatial pattern of income in Washington, DC, and that you have collected data on the annual income of all families in each census tract of the city. You might wonder which of these four techniques would be appropriate. Determining the appropriate technique will require that we first consider (1) the spatial arrangement of geographic phenomena, (2) the various levels at which we can measure geographic phenomena, and (3) the types of symbols that can be used to represent spatial data.*

Section 4.1 discusses the spatial arrangement of geographic phenomena. One way to think about spatial arrangement is to consider a phenomenon's extent or ***spatial dimension****—whether a phenomenon can be conceived of as* ***points***, ***lines***, ***areas***, *or* ***volumes***. *For example, water well sites in a rural area constitute a point phenomenon, whereas a city boundary is representative of a linear phenomenon. Another way of thinking about spatial arrangement is to contrast discrete and continuous phenomena.* ***Discrete phenomena*** *occur at isolated point locations, whereas* ***continuous phenomena*** *occur everywhere. For example, water towers in a city would be discrete, but the distribution of solar insolation during the month of January is continuous. Discrete and continuous phenomena can also be classified as* ***smooth*** *or* ***abrupt***. *For instance, rainfall and sales tax rates for states are both continuous in nature, but the former is smooth, whereas the latter is abrupt (varying at state boundaries). In thinking about the arrangement of geographic phenomena, we need to distinguish between a phenomenon that exists in the real world and the data that we use to represent that phenomenon.*

Section 4.2 considers ***levels of measurement***, *which refers to the various ways of measuring a phenomenon when a data set is created. For instance, we might specify the soil type of a region as an entisol, as opposed to a mollisol; such a categorization of soils would be termed a nominal level of measurement. We consider four basic levels of measurement:* ***nominal***, ***ordinal***, ***interval***, *and* ***ratio***. *The latter two levels are commonly combined into numerical data, which is the focus of this book.*

The term ***visual variables*** *is commonly used to describe the various perceived differences in map symbols that are used to represent spatial data. For example, the visual variable spacing involves varying the distance between evenly spaced marks (e.g., horizontal lines). Section 4.3 covers a host of visual variables, including* ***spacing***, ***size***, ***perspective height***, ***orientation***, ***shape***, ***arrangement***, ***hue***, ***lightness***, ***saturation***, *and* ***location***.

Section 4.4 introduces four common thematic mapping techniques (choropleth, proportional symbol, isopleth, and dot) and considers how a mapmaker selects among them. We will see that the selection is a function of both the nature of the underlying phenomenon and the purpose for making the map. Section 4.4 also introduces the notion of ***data standardization*** *to account for the area over which data are collected; here we will consider the most direct form of standardization, which involves dividing* ***raw totals*** *by the areas of enumeration units (e.g., dividing acres of wheat for each county by the area of each county).*

Section 4.5 considers the issue of selecting an appropriate visual variable for choropleth mapping, which has traditionally been the most common thematic mapping method. Selecting an appropriate visual variable requires *creating a logical match between the level of measurement of the data and the visual variable (e.g., if data are numerical, the visual variable should appear to reflect the numerical character of the data).*

4.1 SPATIAL ARRANGEMENT OF GEOGRAPHIC PHENOMENA

4.1.1 Spatial Dimension

One way to think about the spatial arrangement of geographic phenomena is to consider their extent or **spatial dimension**. For our purposes, we consider five types of phenomena with respect to spatial dimension: point, linear, areal, $2^1/_2$-D and true 3-D.

Point phenomena are assumed to have no spatial extent and are thus termed "zero-dimensional." Examples include weather station recording devices, oil wells, and locations of nesting sites for eagles. Locations for point phenomena can be specified in either two- or three-dimensional space; for example, places of religious worship are defined by x and y coordinate pairs (longitude and latitude), whereas nesting sites for eagles are defined by x, y, and z coordinates (the z coordinate would be the height above the earth's surface).

Linear phenomena are one-dimensional in spatial extent, having length, but essentially no width. Examples include a boundary between countries and the path of a stunt plane during an air show. Locations of linear phenomena are defined as an unclosed series of x and y coordinates (in two-dimensional space), or an unclosed series of x, y, and z coordinates (in three-dimensional space).

Areal phenomena are two-dimensional in spatial extent, having both length and width. An example would be a lake (assuming that we focus on its two-dimensional surface extent). Data associated with political units (e.g., counties) can also fit into this framework, because the location of each county can be specified as an enclosed region. In two-dimensional space, areal phenomena are defined by a series of x and y coordinates that completely enclose a region (computer systems generally require that the first coordinate pair equal the last).

When we move into the realm of volumetric phenomena, it is convenient to consider two types: $2^1/_2$-D and true 3-D. The first of these, **$2^1/_2$-D phenomena**, can be thought of as a surface, in which geographic location is defined by x and y coordinate pairs and the value of the phenomenon is the height above a zero point (or depth below a zero point). Probably the easiest example to understand is elevation above sea level, because we can actually see the surface in the real world; here height above a zero point is the elevation of the land surface above sea level. A more abstract example would be precipitation falling over a region over the course of a year; in this case the height of the surface would be the total amount of precipitation for the year.

Another way of thinking about $2^1/_2$-D surfaces is that they are single-valued in the sense that each x and y coordinate location has a single value associated with it. In contrast, **true 3-D phenomena** are multivalued because each x and y location can have multiple values associated with it. With true 3-D phenomena, any point on the surface is specified by four values: an x coordinate, a y coordinate, a z coordinate (which is the height above, or depth below, sea level), and the value of the phenomenon. Consider mapping the concentration of carbon dioxide (CO_2) in the atmosphere. At any point in the atmosphere, it is possible to define longitude, latitude, height above sea level, and an associated level of CO_2. Color Plate 4.1 illustrates a true 3-D phenomenon: geologic material underneath the earth's surface. Although we should ideally distinguish true 3-D phenomena from $2^1/_2$-D phenomena, in this book we sometimes refer to a map of either as a *3-D map*.

It is important to realize that map scale plays a major role in determining how we handle the spatial dimension of a phenomenon. For example, on a **small-scale map** (e.g., a page-size map of France) places of religious worship occur at points, but on a **large-scale map** (e.g., a map of a local neighborhood) individual buildings would be apparent, and thus the focus might be on the area covered by the place of worship. Similarly, a river could be considered a linear phenomenon on a small-scale map, but on a large-scale map, the emphasis could be on the area covered by the river.

4.1.2 Models of Geographic Phenomena

The notion of spatial dimension is just one way of thinking about how geographic phenomena are arranged in the real world. Another approach is to consider the arrangement of geographic phenomena along discrete–continuous and abrupt–smooth continua. In this section we define the terms associated with these continua and show how they provide a useful set of *models of geographic phenomena*, a notion developed by Alan MacEachren and David DiBiase (1991).

The terms "discrete" and "continuous" are often used in statistics courses to describe different types of data along a number line; here we consider their use by cartographers in a spatial context. **Discrete phenomena** are presumed to occur at distinct locations (with space in between). Individual people living in a city would be an example of a discrete phenomenon; for an instant in time, a location can be specified for each person, with space between individuals. **Continuous phenomena** occur throughout a geographic region of interest. The examples presented previously for $2^{1}/_{2}$-D phenomena would also be considered continuous phenomena. For instance, when considering elevation, every longitude and latitude position has a value above or below sea level.

Discrete and continuous phenomena can also be described as either abrupt or smooth. **Abrupt phenomena** change suddenly, whereas **smooth phenomena** change in a gradual fashion. This concept is most easily understood for continuous phenomena. The number of electoral votes for each state in the United States would be considered an abrupt continuous phenomenon because although each enumeration unit (a state) has a value, there are abrupt changes at the boundaries between states. In contrast, the distribution of total precipitation over the course of a year for a humid region would be a smooth continuous phenomenon because we would not expect such a distribution to exhibit abrupt discontinuities.

Figure 4.1 provides a graphic portrayal of a variety of models of geographic phenomena that result when we combine the discrete–continuous and abrupt–smooth continua. We'll discuss these models in detail because considering the nature of geographic phenomena is extremely important in selecting an appropriate method of symbolization. First, consider the continuous phenomena shown in the bottom row of Figure 4.1. Percent sales tax is an obvious *abrupt* continuous phenomenon, as it changes suddenly at the boundary between enumeration units (e.g., one state's sales tax is different from another).

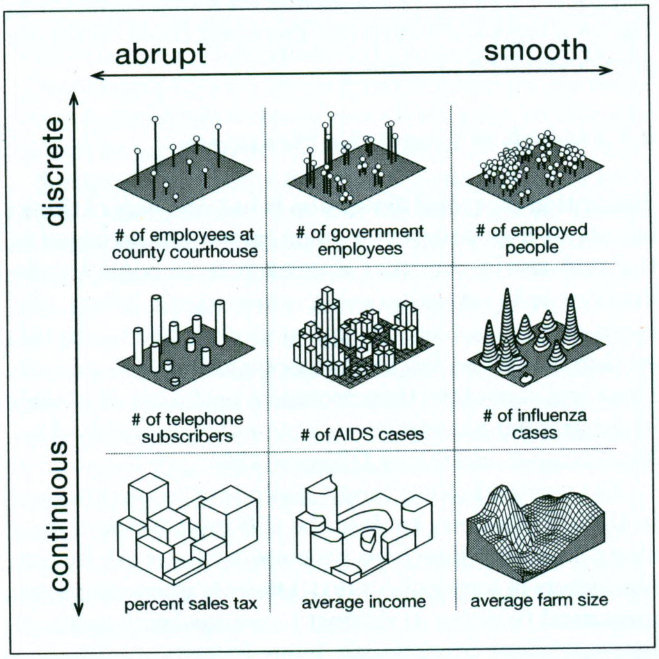


FIGURE 4.1 Models of geographic phenomena arranged along discrete–continuous and abrupt–smooth continua. (After MacEachren 1992, 16; courtesy of North American Cartographic Information Society and Alan MacEachren.)

In contrast, average farm size is an example of a *smooth* continuous phenomenon because we would expect it to vary in a relatively gradual fashion (as the climate becomes drier, we would expect the average farm size to increase). Average income falls somewhere between percent sales tax and average farm size on the abruptness–smoothness continuum. In some cases, average income would exhibit the abrupt changes of percent sales tax (as at the boundary between urban neighborhoods), while in others it would exhibit a more gradual change (as one moves up a hill toward a region of more attractive views, average income should increase).

In contrast to the bottom row, the top row of Figure 4.1 represents a range of discrete phenomena. The number of employees located at county courthouses is clearly an *abrupt* discrete phenomenon, as there can be only one value for a county and it occurs at an isolated location. In contrast, the number of employed people (based on where they live, as opposed to where they work) is a *smooth* discrete phenomenon, because it gradually changes over geographic space. The number of government employees (again, based on where they live) falls somewhere between these; it might exhibit an abrupt character in the sense that government employees might live near government offices, but it will not exhibit the extreme abruptness of the courthouse example.

The middle row of Figure 4.1 represents phenomena that can be classified as not clearly continuous or discrete, and that also span the abruptness–smoothness continuum. This row is probably most easily understood by considering the influenza case first. Because influenza is an infectious disease, it should exhibit a smooth character. Although individual influenza cases could be represented at discrete locations, it makes sense to suggest some degree of continuity if we wish to stress the potential of infection. At the other end of the row is the number of subscribers to a particular telephone company. Competition between telephone companies could lead to a distribution that changes abruptly but that exhibits continuity between the lines of abrupt change. Finally, the number of people with AIDS is in the middle of the diagram. AIDS occupies a more abrupt position than influenza because of its mode of transmission (sexual intercourse, sharing of needles, and blood transfusions).

4.1.3 Phenomena versus Data

When mapping geographic phenomena, it is important to distinguish between the actual *phenomenon* and the *data* collected to represent that phenomenon. For example, imagine that we wish to map the percentage of forest cover in South Carolina. If we try to visualize the phenomenon, we can conceive of it as smooth and continuous in some portions of the state where the percentage gradually increases or decreases. In other areas, we can conceive of relatively abrupt changes where the percentage shifts very rapidly (when, say, an urban area is bounded by a hilly forested region).

One form of data that we might use to represent percentage of forest cover would be individual values for counties, which can be found in the state statistical abstract for South Carolina (South Carolina State Budget and Control Board 1994, 45). We might consider mapping these data directly by creating the **prism map** shown in Figure 4.2B. Note that in this case there are abrupt changes at the boundaries of each county. Such a map might be appropriate if we wished to provide a typical value for each county, but it obviously hides the variation within counties and misleads the reader into thinking that changes take place only at county boundaries.

Potentially, a better approach would be the smooth, continuous map **(fishnet map)** shown in Figure 4.2A; this map indicates that the percentage of forest cover does not coincide with county boundaries, but rather changes in a gradual fashion. A still better map would be one that shows some of the abrupt changes that are likely to occur. Creating such a map would require detailed information about the location of forest within the state, as might be available from a remotely sensed image. Our purpose at this point in the text is not to create the most

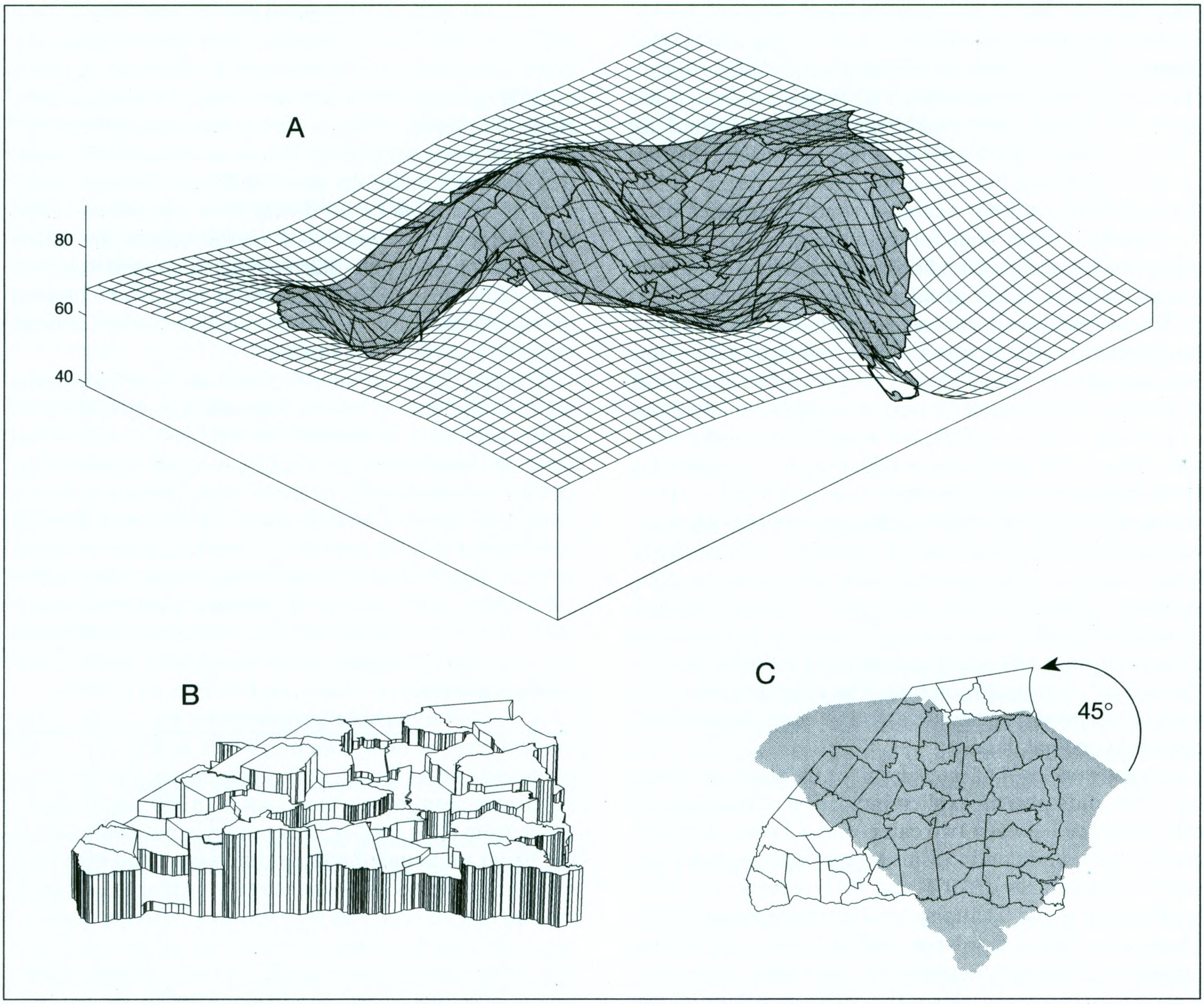


FIGURE 4.2 Approaches for mapping a data set of percentage of forest cover by county for the state of South Carolina: (A) The data are treated as coming from a smooth continuous phenomenon; (B) the data are treated as an areal phenomenon. Map C illustrates that maps A and B have been rotated 45° from a traditional north-oriented map. For A, values outside the state are extrapolated, and thus must be treated with caution. (Data Source: South Carolina State Budget and Control Board 1994.)

representative map of the phenomenon, but to stress that the mapmaker must carefully distinguish between data that have been collected and the phenomenon that is being mapped. Which type of map is used will be a function of both the nature of the underlying phenomenon and the purpose of the map. We consider this issue in greater depth in section 4.4.

4.2 LEVELS OF MEASUREMENT

When a geographic phenomenon is measured to create a data set, we commonly speak of the **level of measurement** associated with the resulting data. Conventionally, four levels of measurement are recognized—nominal, ordinal, interval, and ratio—with each subsequent level including all characteristics of the preceding levels. The **nominal** level of measurement involves grouping (or categorization), but no ordering. The classic example is religion, in which individuals might be identified as Catholic, Protestant, Jewish, or other; here each religious group is different, but one is not more or less in value than another. Another example would be classes on a land use/land cover map; for example, grassland, forest, urban, water, and cropland differ from one another, but one is not more or less in value.

The second level of measurement, **ordinal**, involves categorization plus an ordering (or ranking) of the data. For example, a geologist asked to specify the likelihood of finding oil at each of 50 well sites might be unwilling to provide numerical data, but would feel comfortable specifying a low, moderate, or high potential at each site. Here three categories (low, moderate, and high) are provided, with a distinct ordering among them. Another example of ordinal data would be rankings resulting from a map comparison experiment. Imagine that you constructed dot maps for 10 different phenomena and asked people to compare these maps with another dot map (say, of population) and to rank the maps from "most like" to "least like" the population map. The 10 maps ranked by each person would constitute a distinct ordering, and thus represent ordinal data.

An **interval** level of measurement involves an ordering of the data plus an explicit indication of the numerical difference between two categories. Classic examples are the Fahrenheit and Celsius temperature scales. Consider temperatures of 20°F and 40°F recorded in Fairbanks, Alaska, and Chattanooga, Tennessee, respectively. These two values are ordered, and they reveal the precise numerical difference between the two cities. One characteristic of interval scales is the arbitrary nature of the zero point. In the case of the Celsius scale, 0 is the freezing point for pure water, whereas on the Fahrenheit scale, 0 is the lowest temperature obtained by mixing salt and ice. A result of an *arbitrary zero point* is that ratios of two interval values cannot be interpreted correctly; for example, 40°F is numerically twice the value of 20°F, but it is not twice as warm (in terms of the kinetic energy of the molecules). An example of an interval scale familiar to academics is SAT scores, which range from a minimum of 200 to a maximum of 800. Note that it is not possible to say that an individual scoring 800 on an SAT exam did four times better than an individual scoring 200; all that can be said is that the individual scored 600 points better. A geographical example of interval-level data is elevation, where the establishment of mean sea level represents an arbitrary zero point.

A **ratio** level of measurement has all the characteristics of the interval level, plus a *nonarbitrary zero point.* Continuing with the temperature example, the Kelvin scale is ratio in nature because at 0°K all molecular motion ceases; thus, a temperature of 40°K is twice as warm as 20°K (in terms of the kinetic energy of the molecules). Ratio data sets are more common than interval ones. For example, a perusal of maps shown in this text will reveal that most are based on ratio-level data. Because many symbol forms can be used with both interval and ratio scales, these two levels of measurement are often grouped together and referred to as **numerical data**. The basic scales that we have discussed can also be divided into *qualitative* (nominal data) and *quantitative* (ordinal, interval, and ratio data) scales.

The four levels of measurement we have considered are the only ones normally covered in geographic textbooks. Nicholas Chrisman (1998; 2002, 25–33) argues that these are insufficient for working with geographic data, and so has proposed several extensions. One is to create a separate level of measurement for data sets that are constrained to a fixed set of numbers, such as probability (the range is 0 to 1) or percentages (the range is 0 to 100). Chrisman terms this an *absolute* level of measurement, as no transformations are possible that could retain the meaning of measurement. We instead use the term **constrained ratio** recommended by Forrest (1999b).

A second extension proposed by Chrisman is the **cyclical** level of measurement, which is appropriate for phenomena that have a cyclical character. For instance, angular measurements have a cycle of 360°, with angle x as far from 0° as 360°–x. This notion is not dealt with in the linear unbounded number line associated with ratio measurements. As another example, the seasons are cyclical and can be specified with different starting points—we could specify spring–summer–fall–winter–spring or fall–winter–spring–summer–fall. A third extension is the notion of **counts**, in which individual objects, such as people, are counted. Although counts have a nonarbitrary zero point, Chrisman argues that they cannot be rescaled as readily as ratio scales because we cannot conceive of a fraction of an object (e.g., half of a person).

A final extension is the notion of **fuzzy categories.*** Normally, we think of individual items as falling wholly within a particular nominal category; for instance, an individual is either a Protestant or not (in terms of church membership). In practice, category memberships are often fuzzy, as it might not be entirely clear whether an item is within a particular category. A good illustration of fuzzy categories is some remote sensing classification procedures, which produce a probability that each pixel falls in a particular land use (e.g., a pixel might have an 85 percent probability of being wheat and a 15 percent probability of being corn). Increasingly race and ethnicity can be considered "fuzzy" in that individuals identify themselves with more than one race. In fact, the 2000 Census, for the first time, allowed for multiple ethnicity.

Another extension to the basic levels of measurement is the three kinds of numerical data proposed by J. Ronald Eastman (1986): bipolar, balanced, and unipolar. **Bipolar data** are characterized by either natural or meaningful dividing points. A *natural* dividing point is inherent to the data and can be used intuitively to divide the data into two parts. An example would be a value of 0 for percentage of population change, which would divide the data into positive and negative percent changes. A *meaningful* dividing point does not occur inherently in the data, but can logically divide the data into two parts. An example would be the mean of the data, which enables differentiating values above and below the mean. **Balanced data** are characterized by two phenomena that coexist in a complementary fashion. An example is the percentage of English and French spoken in Canadian provinces—a high percentage of English-speaking people implies a low percentage of French-speaking people (the two are in "balance" with one another). **Unipolar data** have no natural dividing points and do not involve two complementary phenomena. Per capita income associated with countries of Africa or states of the United States would be an example of unipolar data.

4.3 VISUAL VARIABLES

The term **visual variables** is commonly used to describe the various perceived differences in map symbols that are used to represent geographic phenomena. The notion of visual variables was developed by the French cartographer Jacques Bertin (1983) and subsequently modified by others, including McCleary (1983), Morrison (1984), DiBiase et al. (1991), and MacEachren (1994a). Our approach is similar to that of MacEachren, but differs primarily in the inclusion of $2\frac{1}{2}$-D and true 3-D phenomena and the use of the perspective-height visual variable.

In this chapter, we consider only visual variables for static maps. Additional visual variables for animated maps and for depicting uncertainty are covered in Chapters 20 and 23, respectively. In Chapter 25, we consider **abstract sound variables**, which utilize sound to communicate spatial information (e.g., a louder tone at a particular map location could represent a greater magnitude of the phenomenon at that location). We will find that abstract sound variables can be especially useful for visually impaired map users.

The visual variables that we discuss are illustrated in Figure 4.3 and Color Plate 4.2. Note that the visual variables appear in the rows, and the columns represent the dimensions of spatial phenomena discussed in the preceding section. In discussing the visual variables, we sometimes need to distinguish between the overall *symbol* and the *marks* making up the symbol. For example, note that the spacing visual variable shown for point phenomena consists of circular symbols, and that each circle is composed of parallel horizontal marks.

4.3.1 Spacing

The **spacing** visual variable involves changes in the distance between the marks making up the symbol (Figure 4.3). Cartographers traditionally have used the term *texture* to describe these changes (e.g., Castner and Robinson 1969), but we use the term spacing because texture has varied usages in the literature.

4.3.2 Size

Cartographers have used size as a visual variable in two different ways. One has been to change the size of the entire symbol, as is shown for the point and linear phenomena (Figure 4.3). Another is to change the size of individual marks making up the symbol, as for the areal, $2\frac{1}{2}$-D, and true 3-D phenomena. This inconsistency might be a bit confusing, but the term *size* seems to reflect the visual differences that arise in each case. Note that for areal phenomena, the size of the entire areal unit could also be changed, as is done on cartograms, to be discussed in Chapter 19.

4.3.3 Perspective Height

Perspective height refers to a perspective 3-D view of a phenomenon (Figure 4.3). It is interesting to consider some of the potential applications of this visual variable. In the case of point phenomena, oil production at well locations might be represented by raised sticks (or lollipops) above each well, with the stick height proportional to well production. For linear phenomena, total traffic flow between two cities over some time period

* Chrisman terms this extension "graded membership in categories."

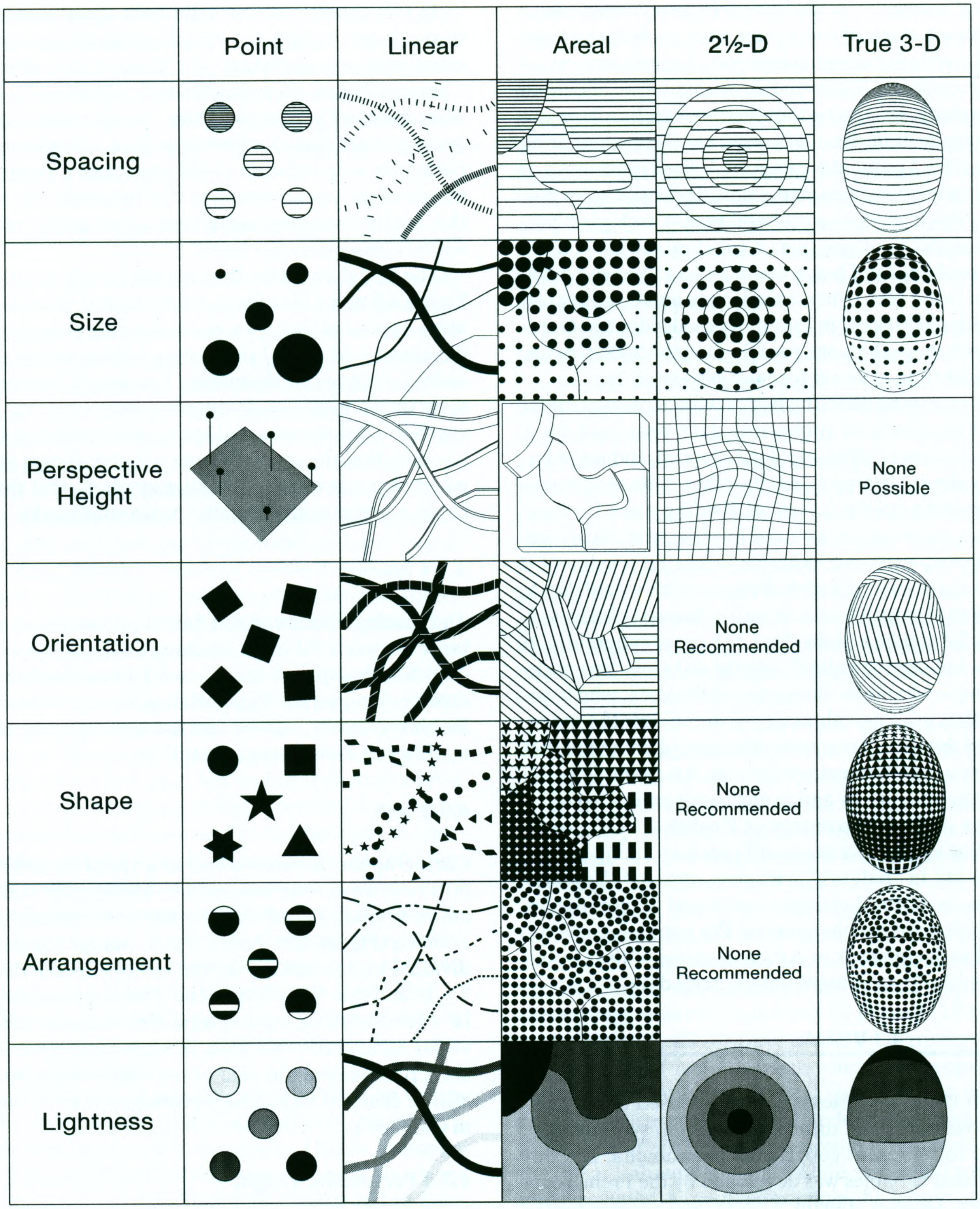


FIGURE 4.3 Visual variables for black-and-white maps. For visual variables for color maps, see Color Plate 4.2.

could be represented by a fencelike structure above each roadway, with the height of the "fence" proportional to traffic flow. In the case of areal and $2\frac{1}{2}$-D phenomena, we have already discussed examples for the forest cover data in South Carolina (Figure 4.2). Perspective height cannot be used for true 3-D phenomena because three dimensions are needed to locate the phenomenon being mapped.

4.3.4 Orientation and Shape

As with the size visual variable, the character of the **orientation** visual variable is a function of the kind of spatial phenomena. For linear, areal, and true 3-D phenomena, orientation refers to the direction of individual marks making up the symbol. In contrast, for point phenomena, orientation refers to the direction of the entire point symbol (Figure 4.3). (Marks of differing direction could be applied to point symbols, but the small size of point symbols often makes it difficult to see the marks.) Because orientation is most appropriate for representing nominal data, we do not recommend using it for $2\frac{1}{2}$-D phenomena, which are inherently numerical. Note that the **shape** visual variable is handled in a fashion similar to orientation.

4.3.5 Arrangement

Understanding the **arrangement** visual variable requires a careful examination of Figure 4.3. For areal and true 3-D phenomena, note that arrangement refers to how marks making up the symbol are distributed; marks for some areas are part of a square arrangement, whereas marks for other areas appear to be randomly placed. For linear phenomena, arrangement refers to splitting lines into a series of dots and dashes, as might be found on a map of political boundaries. Finally, for point phenomena, arrangement refers to changing the position of the white marker within the black symbol.

4.3.6 Hue, Lightness, and Saturation

The visual variables hue, lightness, and saturation are commonly recognized as basic components of color.* **Hue** is the dominant wavelength of light making up a color (the notion of wavelengths of light and the associated electromagnetic spectrum will be considered in detail in Chapter 10). In everyday life, hue is the parameter of color most often used; for example, you might note that one person has on a red shirt and another a blue shirt. Color Plate 4.2 illustrates how various hues can be used to depict spatial phenomena.

Lightness (or **value**) refers to how dark or light a particular color is, while holding hue constant; for example, in Color Plate 4.2, different lightnesses of a green hue are shown. Lightness also can be shown as shades of gray (in the absence of what we commonly would call color), as in Figure 4.3.

Saturation (or **chroma**) can be thought of as a mixture of gray and a pure hue. It is the intensity of a color; for instance, we might speak of different intensities of colorful shirts. This concept is illustrated in Color Plate 4.3, where the areal symbols shown for saturation in Color Plate 4.2 are arranged along a continuum from a desaturated red (grayish red) to a fully saturated red (while holding lightness constant).

4.3.7 Some Considerations in Working with Visual Variables

You should bear in mind that Figure 4.3 and Color Plate 4.2 depict only a fraction of the many symbols that could be used to depict the visual variables; for example, either circles or squares might be used to depict point phenomena for the size visual variable. A major group of symbols not shown in the figures are **pictographic symbols**, which are intended to look like the phenomenon being mapped (as opposed to **geometric symbols** such as circles). For instance, Figure 4.4 illustrates the use of different-sized beer mugs to represent the number of microbreweries and brewpubs in each U.S. state. Pictographic symbols are often used in children's atlases.

Also keep in mind that the visual variables can serve as basic building blocks of more complex representations. For example, Figure 4.5 illustrates how the visual

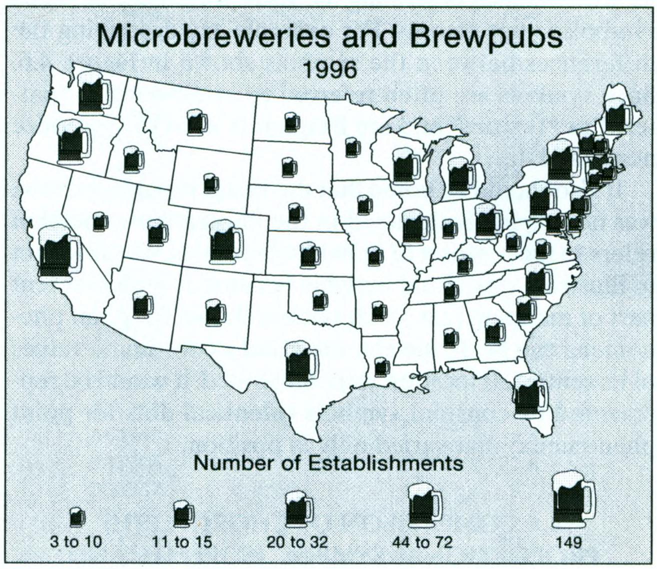


FIGURE 4.4 Using a pictographic visual variable (beer mugs) to represent the number of microbreweries and brewpubs in each U.S. state. (For similar data, see *http://brewpubzone.com.*)

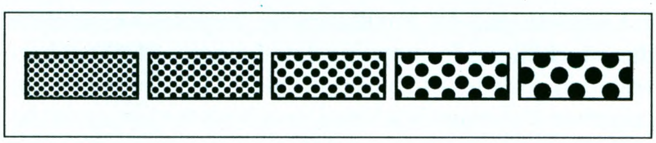


FIGURE 4.5 Combining the visual variables spacing and size. (After MacEachren 1994a, p. 26.)

* See Brewer (1994a) for a discussion of terminology associated with color.

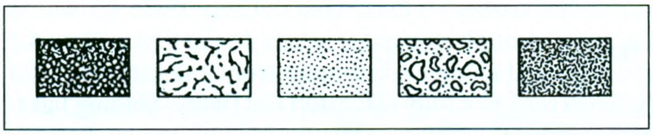


FIGURE 4.6 Different "patterns" or "textures" that can be created to portray nominal information. Note that these are not readily described in terms of the visual variables shown in Figure 4.3.

variables spacing and size might be combined. MacEachren (1994a, 27) called the resulting symbol a form of texture. In our opinion, such an approach produces a rather coarse-looking map, but it can highlight various aspects of a distribution (for an example, see Figure 2.19 of MacEachren's work).

In Figure 4.3 and Color Plate 4.2, the term for each visual variable used appears to be a clear expression of the visual differences that we see; for example, in the case of the orientation visual variable for point phenomena, we see that one square is at a different orientation than another. Moreover, if we wanted, we could compute a mathematical expression of this difference (that one square is rotated 40° from a vertical, whereas another is rotated 50°). Sometimes, describing the visual difference between symbols is not so easy. For example, try describing the differences between the symbols shown in Figure 4.6. Such symbols are often referred to as differing in "pattern" or "texture" and are frequently used to symbolize nominal data.

It also should be noted that the visual variable location was not explicitly depicted in the illustrations. **Location** refers to the position of individual symbols. We chose not to illustrate this visual variable because it is an inherent part of mapping (e.g., each symbol shown for point phenomena can be defined by the *x* and *y* coordinate values of its center). If location were illustrated, it would be represented by constant symbols (identical dots for point phenomena) that varied only in position.

4.4 COMPARISON OF CHOROPLETH, PROPORTIONAL SYMBOL, ISOPLETH, AND DOT MAPPING

In this section, we define and contrast four common thematic mapping techniques: choropleth, proportional symbol, isopleth, and dot. For illustrative purposes, we examine these techniques by mapping data for acres of wheat harvested in counties of Kansas (Table 4.1). Selecting an appropriate technique is a function of both the nature of the underlying phenomenon and the purpose for making the map. Here we consider a basic introduction to these mapping techniques; more advanced concepts are covered in subsequent chapters (13 for choropleth, 16 for proportional symbol, 14 for isopleth, and 17 for dot).

4.4.1 Choropleth Mapping

A **choropleth map** is commonly used to portray data collected for enumeration units, such as counties or states. To construct a choropleth map, data for enumeration units are typically grouped into classes and a gray tone or color is assigned to each class. The choropleth map is clearly appropriate when values of a phenomenon change abruptly at enumeration unit boundaries, such as for state sales tax rates. Choropleth maps might also be appropriate when you want the map reader to focus on "typical" values for individual enumeration units, even though the underlying phenomenon does not change abruptly at enumeration unit boundaries. For example, politicians and government officials might use this approach when stressing how one county or state compares with another. Although choropleth maps are commonly used in this fashion, it is important to recognize two major limitations: (1) Such maps do not portray the variation that might actually occur within enumeration units, and (2) the boundaries of enumeration units are arbitrary, and thus unlikely to be associated with major discontinuities in the actual phenomenon.*

An important consideration in constructing choropleth maps is the need for **data standardization**, in which **raw totals** are adjusted for differing sizes of enumeration units. To understand the need to standardize, consider map A of Figure 4.7, which portrays a hypothetical distribution consisting of three distinct regions: S, T, and U. Note that regions S and T have equal-sized enumeration units, each 16 acres in size. In contrast, region U has enumeration units four times the size of those in S and T, or 64 acres in size.

Let's presume that the number of acres of wheat harvested from enumeration units in each region is as follows: 0 in S, 16 in T, and 64 in U (these numbers are shown within each enumeration unit in Figure 4.7A). The acres of wheat harvested from each enumeration unit represent raw totals. Mapping these raw totals with the choropleth method produces the result shown in Figure 4.7B (note that higher data values are depicted by a darker gray tone). A user examining this map would likely conclude that because region U is the darkest, it must have more wheat grown in it. Unfortunately, this conclusion would be inappropriate because we have not accounted for the size of enumeration units. One approach to adjust (or standardize) for the size of enumeration units is to divide each raw total by the area of the associated enumeration unit; the resulting values are 0/16, or 0 for region S; 16/16, or 1 for

* See Langford and Unwin 1994 for a more detailed discussion of these limitations.

TABLE 4.1 Wheat harvested in Kansas counties 1993

County	*Acres Harvested*	*Area of County (in acres)*	*% of Land in Wheat*
Allen	35200	324735	10.8
Anderson	36600	373075	9.8
Atchison	12300	278937	4.4
Barber	150200	727904	20.6
Barton	199400	576390	34.6
Bourbon	14800	409210	3.6
Brown	26600	365894	7.3
Butler	80700	926707	8.7
Chase	15000	497369	3.0
Chautauqua	15500	412610	3.8
Cherokee	78000	377881	20.6
Cheyenne	147800	651910	22.7
Clark	93100	626576	14.9
Clay	99400	420435	23.6
Cloud	107700	461204	23.4
Coffey	31400	419001	7.5
Comanche	92000	506214	18.2
Cowley	125600	725741	17.3
Crawford	41100	380157	10.8
Decatur	133200	572289	23.3
Dickinson	153600	546094	28.1
Doniphan	9000	254242	3.5
Douglas	15700	304118	5.2
Edwards	108400	397693	27.3
Elk	11600	416442	2.8
Ellis	132800	575971	23.1
Ellsworth	97700	463260	21.1
Finney	224800	833658	27.0
Ford	226100	701190	32.2
Franklin	14500	369251	3.9
Geary	17700	259175	6.8
Gove	162400	685862	23.7
Graham	96400	575048	16.8
Grant	123300	368538	33.5
Gray	190700	555865	34.3
Greeley	175900	498307	35.3
Greenwood	11100	736333	1.5
Hamilton	160000	637046	25.1
Harper	281100	512292	54.9
Harvey	125000	345324	36.2
Haskell	126800	369004	34.4
Hodgeman	136900	551464	24.8
Jackson	17500	421717	4.1
Jefferson	8900	354557	2.5
Jewell	126300	585604	21.6
Johnson	11300	306957	3.7
Kearny	144100	557439	25.9
Kingman	216800	554529	39.1
Kiowa	116300	464185	25.1
Labette	66200	421057	15.7
Lane	155200	459018	33.8
Leavenworth	11400	303572	3.8
Lincoln	106000	460879	23.0
Linn	16000	387873	4.1
Logan	179800	688192	26.1
Lyon	16000	549098	2.9
Marion	142200	610675	23.3
Marshall	92500	578662	16.0
Mcpherson	226300	576316	39.3
Meade	121000	627167	19.3
Miami	10800	378094	2.9

Continued

TABLE 4.1 *Continued*

County	*Acres Harvested*	*Area of County (in acres)*	*% of Land in Wheat*
Mitchell	150000	459022	32.7
Montgomery	54000	413768	13.1
Morris	46000	449145	10.2
Morton	78100	466625	16.7
Nemaha	31000	459537	6.7
Neosho	45000	369610	12.2
Ness	171600	687891	24.9
Norton	139400	563491	24.7
Osage	19500	459872	4.2
Osborne	107400	572513	18.8
Ottawa	103400	460748	22.4
Pawnee	153400	482433	31.8
Phillips	103700	572563	18.1
Pottawatomie	17300	551123	3.1
Pratt	163100	469889	34.7
Rawlins	160100	686637	23.3
Reno	292500	813939	35.9
Republic	96600	459717	21.0
Rice	160400	466673	34.4
Riley	17800	397742	4.5
Rooks	71500	573454	12.5
Rush	154000	459719	33.5
Russell	98100	576143	17.0
Saline	121500	459756	26.4
Scott	170500	459183	37.1
Sedgwick	262300	646618	40.6
Seward	98400	410803	24.0
Shawnee	14500	354420	4.1
Sheridan	120300	573394	21.0
Sherman	185400	675725	27.4
Smith	126000	573619	22.0
Stafford	160200	508439	31.5
Stanton	134100	436392	30.7
Stevens	101600	465830	21.8
Sumner	443700	758976	58.5
Thomas	235400	687149	34.3
Trego	119500	575635	20.8
Wabaunsee	15000	511601	2.9
Wallace	123800	584778	21.2
Washington	88000	575534	15.3
Wichita	152300	460170	33.1
Wilson	52400	367770	14.2
Woodson	18800	322672	5.8
Wyandotte	700	99196	0.7

region T; and 64/64, or 1 for region U. Mapping these values with the choropleth method results in Figure 4.7C; note that regions T and U are now identically shaded and thus have the same density of wheat harvested.

In a similar fashion, the Kansas wheat data can be standardized by dividing the acres harvested within each county by the area of the corresponding county. Because the wheat harvested data and the area of the county are both in acres, dividing the two produces a proportion (or percentage when we multiply the result by 100; see Table 4.1). Figure 4.8 portrays maps of both the unstandardized and standardized Kansas wheat data. The difference between the maps is not as dramatic as the hypothetical example because the areas of counties in Kansas are similar in size, but we can still note areas where the patterns differ.

Standardization not only adjusts for the differing sizes of counties but also provides a very useful attribute, namely, the proportion (or percentage) of each county from which wheat was harvested. Such an attribute provides an indication of the probability that one might see wheat being cut at harvest time while driving through the county. The standardized map is shown in Figure 4.9A for comparison with the other methods of mapping discussed in this section. (Note that the *lightness* visual variable has been used for the choropleth map.)

4.4.2 Proportional Symbol Maps

A **proportional symbol map** is constructed by scaling symbols in proportion to the magnitude of data occurring at

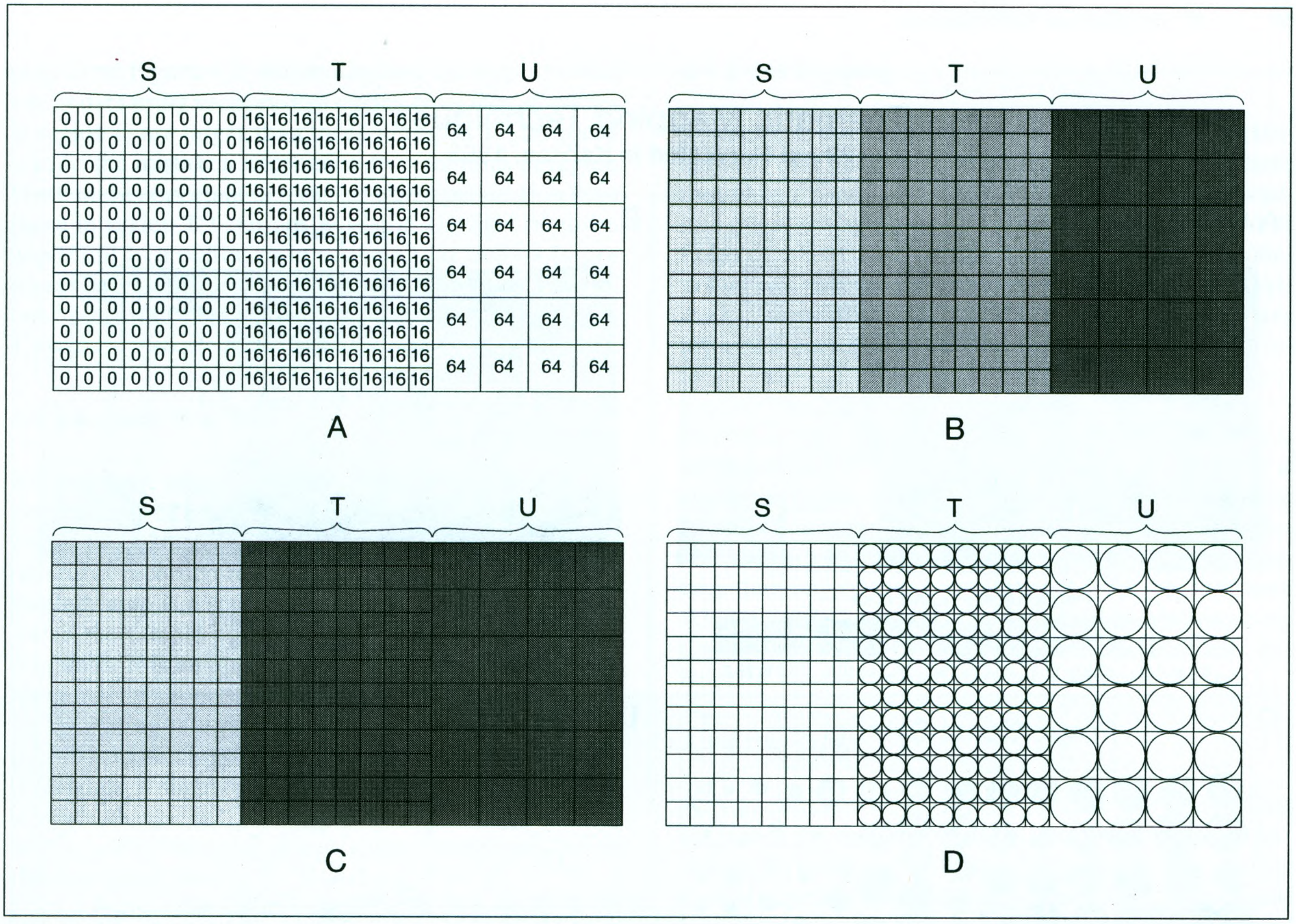


FIGURE 4.7 A hypothetical illustration of the effect of data standardization: (A) raw totals—number of acres of wheat harvested in each enumeration unit; (B) a choropleth map of the raw totals; (C) a choropleth map of standardized data achieved by dividing the raw totals by the area of the corresponding enumeration unit; and (D) a proportional circle map of the raw totals.

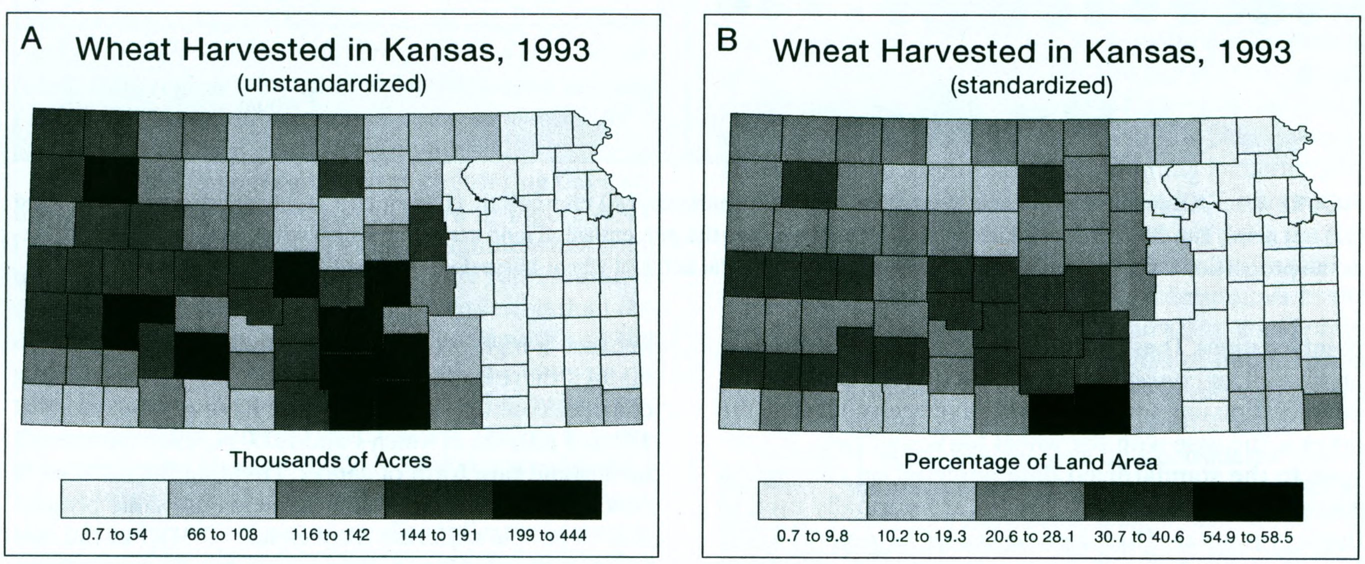


FIGURE 4.8 Standardizing wheat harvested in Kansas counties in 1993: (A) a map of the number of acres harvested; and (B) a standardized map resulting from dividing number of acres harvested by the area of each county. (Data Source: Kansas Agricultural Statistics 1994.)

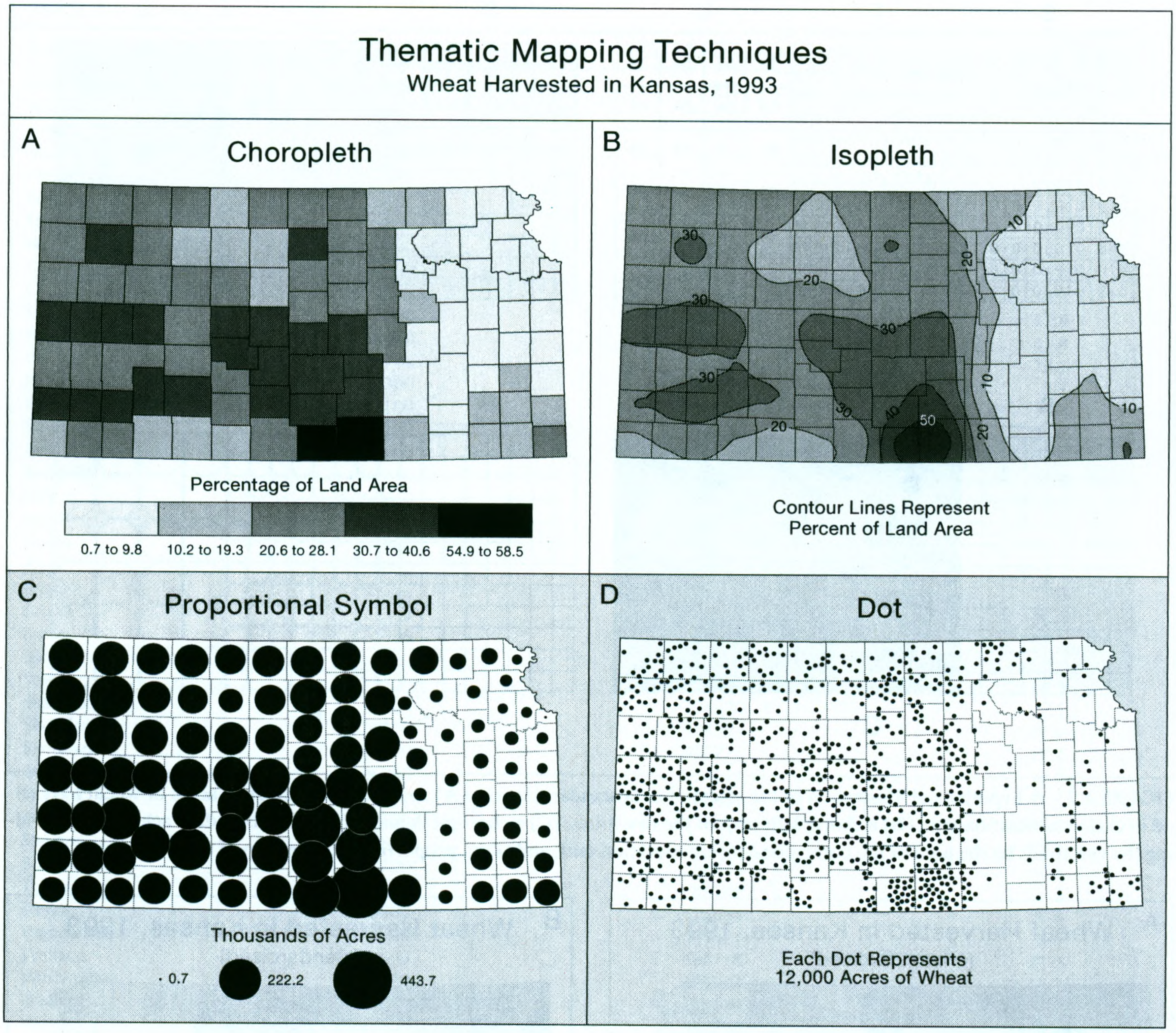


FIGURE 4.9 A comparison of basic thematic mapping techniques: (A) choropleth, (B) isopleth, (C) proportional symbol, and (D) dot maps. The choropleth and isopleth maps are based on the percentage of land area from which wheat was harvested, whereas the proportional symbol and dot maps are based on the total acres of wheat harvested.

point locations. These locations can be *true points,* such as an oil well, or *conceptual points,* such as the center of an enumeration unit for which data have been collected; the latter is the case with the wheat harvested data. In contrast to the standardized data depicted on choropleth maps, proportional symbol maps are normally used to display raw totals. Thus, the magnitudes for acres of wheat harvested are depicted as proportional circles in Figure 4.9C. (Note that the visual variable used here is *size.*)

The raw totals depicted on proportional symbol maps provide a useful complement to the standardized data shown on choropleth maps. Raw totals are important because a high proportion or rate might not be meaningful if there is not also a high raw total. As an example, consider counties of the same size having populations of 100 and 100,000, in which 1 and 1,000 people, respectively, have some rare form of cancer. Dividing the number of cancer cases by the population yields the same proportion of people suffering from cancer (0.01), but the rate for the less populous county would be of lesser interest to the epidemiologist.

Although the proportional symbol map is a better choice than the choropleth map for depicting raw totals, care should be taken in using it. To illustrate, consider map D of Figure 4.7, which displays the hypothetical wheat data using proportional circles. Note that all circles in region U are larger than those in region T. This could lead to the mistaken impression that counties in region U are more important in terms of wheat production than those in region T. Counties in region U might be more important to a politician in assigning tax dollars (more wheat harvested indicates a greater tax is appropriate), but in terms of the density of wheat harvested, regions T and U are identical.

4.4.3 Isopleth Map

An **isarithmic map** (or **contour map**) is created by interpolating a set of isolines between sample points of known values; for example, we might draw isolines between temperatures recorded for individual weather stations. The **isopleth map** is a specialized type of isarithmic map in which the sample points are associated with enumeration units. It is an appropriate alternative to the choropleth map when one can assume that the data collected for enumeration units are part of a smooth continuous ($2\frac{1}{2}$-D) phenomenon. For example, in the case of the wheat data, it might be argued that the proportion of land in wheat changes in a relatively gradual (smooth) fashion, as opposed to changing just at county boundaries (as on the choropleth map).

In a fashion similar to a choropleth map, an isopleth map also requires standardized data. Referring again to the hypothetical raw totals shown in Figure 4.7A, imagine drawing contours through such data. High-valued contour lines would tend to occur in region U, where there are high values in the data; but as has already been shown for the choropleth case, region U is really no different from region T. Dividing the raw totals by the area of each enumeration unit would result in standardized data that could be appropriately contoured.

The isopleth map resulting from contouring the standardized Kansas wheat data is shown in Figure 4.9B. (Again, note that the visual variable lightness has been used.) Although this map might be more representative of the general distribution of wheat harvested than the choropleth map, the assumption of continuity and the use of county-level data produce some questionable results. For example, note the island of higher value near the center of the extreme southeastern county (Cherokee). In reality, it seems unlikely that you would find a higher value here; the high value is more likely a function of the fact that the centers of counties were used as a basis for contouring and Cherokee's value was higher than any of the surrounding counties. Note that a similar problem occurs within two northern counties (Figure 4.9B). The dot map could be a solution to this type of problem.

4.4.4 Dot Mapping

To create a **dot map**, one dot is set equal to a certain amount of a phenomenon, and dots are placed where that phenomenon is most likely to occur. The phenomenon might actually cover an area or areas (e.g, a field or fields of wheat), but for the sake of mapping, the phenomenon is represented as located at points. Constructing an accurate dot map requires collecting ancillary information that indicates where the phenomenon of interest (wheat, in our case) is likely found. For the wheat data, this was accomplished using the cropland category of a land use/land cover map (the detailed procedures are described in Chapter 17). The resulting dot map is shown in Figure 4.9D. (In this case, the visual variable *location* is used.) Clearly, the dot map is able to represent the underlying phenomenon with much more accuracy than any of the other methods we have discussed. Also note that parts of the distribution exhibit sharp discontinuities that would be difficult to show with the isopleth method (which presumes smooth changes).

4.4.5 Discussion

An examination of Figure 4.9 reveals that each of the four maps provides a quite different picture of wheat harvested in the state of Kansas. Which method is used should depend on the purpose of the map. If the purpose is to focus on "typical" county-level information, then the choropleth and proportional symbol maps are appropriate. The choropleth map provides standardized information, whereas the proportional symbol map provides raw total information. It must be emphasized that neither map depicts the detail of the underlying phenomenon, which is unlikely to follow enumeration unit boundaries.

When data are collected in the form of enumeration units, the dot and isopleth methods should be considered as two possible solutions for representing an underlying phenomenon that is not coincident with enumeration unit boundaries. In the case of the wheat data, the dot method is probably the more appropriate approach because it can capture some of the discontinuities in the phenomenon. The isopleth method, however, could probably be improved on with a finer grid of enumeration units (e.g., townships);* of course, this would also be true of the choropleth and proportional symbol maps.

It must be noted that we have only considered four of the more common methods of thematic mapping. One alternative would be a **dasymetric map**, which, like the dot map, can show very detailed information, but uses standardized data. We will cover the dasymetric map in

* Data at the township level are not released to the general public to protect the confidentiality of individual farm production.

Chapter 17. Another alternative would be to modify the proportional symbol map by making the area of the circle that is filled in proportional to the percent of land area from which wheat is harvested—this creates what is called a **pie chart**. Finally, we should keep in mind that if maps are to be viewed in an interactive graphics environment, the mapmaker will have the option of showing several of them, thus providing the user with various perspectives on the distribution of wheat harvested in Kansas.

4.5 SELECTING VISUAL VARIABLES FOR CHOROPLETH MAPS

In the preceding section, the visual variable lightness was utilized for the choropleth map. An examination of Figure 4.3 and Color Plate 4.2 reveals that there are a number of other visual variables that might be used to represent a phenomenon that is treated as areal in nature. This section considers how we might select among these visual variables. The basic solution is to select a visual variable that appears to "match" the level of measurement of the data. For illustrative purposes, we again use the Kansas wheat data.

The specific visual variables we discuss are illustrated in Figure 4.10 and Color Plate 4.4. In examining these figures, note that they depict classed maps using *maximum-contrast symbolization,* which means that symbols for classes have been selected so that they are maximally differentiated from one another. An alternative approach would be to create an unclassed map in which symbols are directly proportional to the value for each enumeration unit (as in Figure 1.6B). The maximum-contrast approach is used here because it is common and more easily constructed (particularly in the case of the size visual variable).

In addition to discussing Figure 4.10 and Color Plate 4.4, we also consider Figure 4.11, which summarizes the use of visual variables for various levels of measurement. Note that the body of this figure is shaded and labeled to indicate various levels of acceptability: Poor (P), Marginally effective (M), and Good (G). MacEachren (1994a, 33) developed a similar figure, which he appeared to apply to all kinds of spatial phenomena. We use Figure 4.11 only for areal phenomena; as an exercise, you might consider developing such a figure for other kinds of phenomena.

We'll consider the perspective height and size visual variables first because they have the greatest potential for logically representing the numerical data depicted on choropleth maps. Use of perspective height produces what is commonly termed a *prism map* (Figure 4.10A). In Figure 4.11, note that perspective height is the only visual variable receiving a "good" rating for numerical data. The justification is that an unclassed map based on perspective height can portray ratios correctly (a data value twice as large as another will be represented by a prism twice as high), and that readers perceive the height of resulting prisms as ratios (Cuff and Bieri 1979).

There are two problems, however, that complicate the extraction of numerical information from prism maps. One is that tall prisms sometimes block smaller prisms. A solution to this problem is to rotate the map so that blockage is minimized; for example, the map in Figure 4.10A has been rotated so that the view is from the lower valued northeast. A second solution to the blockage problem is to manipulate the map in an interactive graphics environment. If a flexible program is available, it might even be possible to suppress selected portions of the distribution so that other portions can be seen. A third solution is to use the perspective height variable but also symbolize the distribution with another visual variable; for example, Figure 4.10D might be displayed in addition to Figure 4.10A.

Another problem with prism maps is that rotation might produce a view that is unfamiliar to readers who normally see maps with north at the top. This problem can be handled by showing a second map (as suggested earlier) or by using an overlay of the base to show the amount of rotation (as in Figure 4.2C).

The size visual variable is illustrated in Figure 4.10B; note that here the size of individual marks making up the areal symbol has been varied. Size can be considered appropriate for representing numerical relations because circles can be constructed in direct proportion to the data (a data value twice another can be represented by a circle twice as large in area). Furthermore, readers should see the circles in approximately the correct relations. (However, we will see in Chapter 16 that a correction factor might have to be implemented to account for underestimation of larger circles.)

Although some cartographers (most notably Bertin) have used this sort of argument to promote the use of the visual variable size on choropleth maps, two problems are apparent. First, it is questionable whether map users actually consider the sizes of circles when used as part of an areal symbol. Users might analyze circle size when trying to acquire specific information, but it seems unlikely that they would do so when analyzing the overall map pattern. Rather, it is more likely that they would perceive areas of light and dark, in a fashion similar to the lightness visual variable. Second, many cartographers (and presumably map users) find the coarseness of the resulting symbols unacceptable—they would prefer the fine tones shown in Figure 4.10D. The latter problem in particular caused us to give the size variable only a moderate rating for portraying numerical data (Figure 4.11).

Note also that we have given both perspective height and size only moderate ratings for portraying ordinal data. The logic is that if such variables are used to illustrate numerical relations, users might perceive such relations when only ordinal relations are intended.

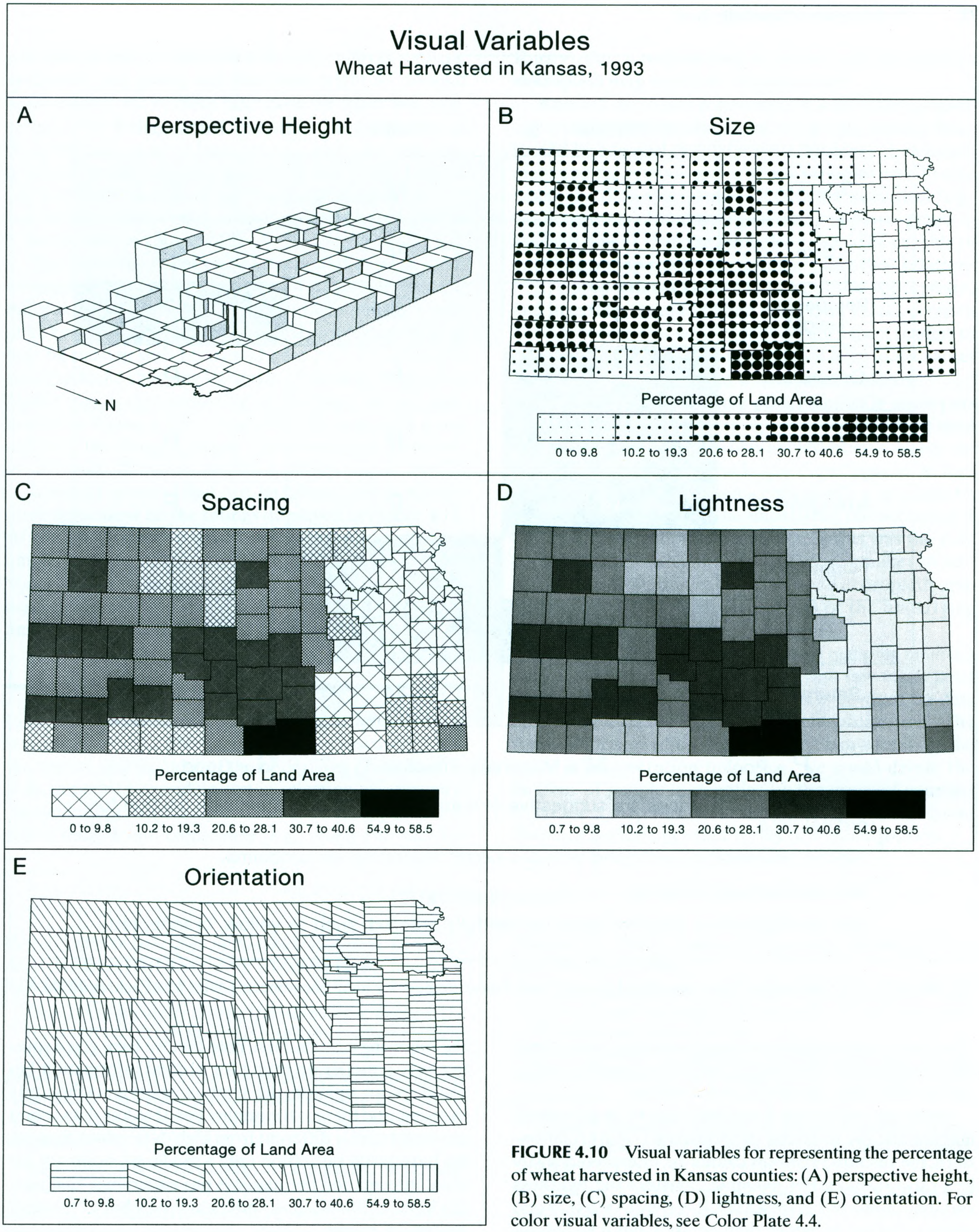


FIGURE 4.10 Visual variables for representing the percentage of wheat harvested in Kansas counties: (A) perspective height, (B) size, (C) spacing, (D) lightness, and (E) orientation. For color visual variables, see Color Plate 4.4.

	Nominal	Ordinal	Numerical
Spacing	P	M[c]	M[c]
Size	P	M	M
Perspective Height	P	M[a]	G[b]
Orientation	G	P	P
Shape	G	P	P
Arrangement	G	P	P
Lightness	P	G	M
Hue	G	G[d]	M[d]
Saturation	P	M	M

P = Poor M = Marginally Effective G = Good

[a] Since height differences are suggestive of numerical differences, use with caution for ordinal data.

[b] Hidden enumeration units and lack of a north orientation are problems.

[c] Not aesthetically pleasing.

[d] The particular hues selected must be carefully ordered, such as yellow, orange, red.

FIGURE 4.11 Effectiveness of visual variables for each level of measurement for areal phenomena. (After MacEachren 1994a, 33.)

Obviously, both variables are inappropriate for nominal data because different heights and sizes suggest quantitative rather than qualitative information.

Although other visual variables can be manipulated mathematically to create proportional (ratio) relationships, the resulting symbols cannot be interpreted easily in a ratio fashion. For example, consider the lightness variable shown in Figure 4.10D. It is easy to see that one shade is darker or lighter than another, but it is difficult to establish proportional relations (that one shade is twice as dark as another). Similar comments can be made for the visual variables spacing, saturation, and hue, with the following caveats. First, note that we have given spacing only a moderate rating for ordinal information because, in our opinion, the symbols are not aesthetically pleasing, and there is the implication that low data values are qualitatively different from high data values. Second, we have given saturation only a moderate rating for ordinal information because it is our experience that people have a difficult time understanding what a "greater" saturation means.

We have rated hue as "good" for both nominal and ordinal data because some hues work well for nominal data, and other hues work better for ordinal data. For example, to display different soil types (alfisols, entisols, mollisols), red, green, and blue hues might be deemed appropriate (one of these hues does not inherently represent more than another). For ordinal and higher level data, logically ordered hues are necessary; for example, a yellow, orange, and red scheme (Color Plate 4.4B) is one possibility because orange is seen as a mixture of yellow and red (based on opponent process theory, a topic to be covered in Chapter 10).

The remaining visual variables (orientation, shape, and arrangement) are only appropriate for creating nominal differences. As an example, consider the orientation variable. You might try to create a logical progression of symbols by starting with horizontal lines for low values and then gradually changing the angle of the lines so that the highest class is represented by vertical lines, but an examination of Figure 4.10E reveals that this approach is not effective; the changing angle of the lines appears to create nominal differences, and the resulting map is "busy."

It should be noted that cartographers are not in complete agreement on the ratings displayed in Figure 4.11, so you might develop slightly different ratings. For example, one of our students rated the orientation variable "poor" (even for nominal data) because he felt it lacked aesthetic quality and that it was difficult to discriminate among different orientations.

SUMMARY

In this chapter, we have covered basic principles for symbolizing geographic phenomena. We have discovered that the spatial arrangement of the underlying phenomenon is an important consideration in selecting an appropriate symbology. For example, if the underlying phenomenon is **smooth** and **continuous** (e.g., yearly snowfall for Russia), then a **contour map** would be appropriate, but a **choropleth map** would be inappropriate.

Another important consideration in selecting symbology is the **level of measurement** of the data. Ideally, there should be a logical match between the level of measurement and the symbology (or **visual variable**) used to represent the data. For instance, if data are numerical (e.g., the magnitude of electrical generation at power plants in kilowatt hours), then the symbology should be capable of enabling a map reader to visualize numerical relations (e.g., a **proportional symbol map** would be appropriate) and in certain cases to obtain exact data values. Keep in mind, however, that we generally do not expect readers to acquire precise numerical information from maps; rather maps are primarily used to show spatial patterns.

Although the underlying phenomenon is an important consideration in selecting symbology, we have seen that map purpose can also play an important role. For example, if the mapmaker wishes to show "typical" values for enumeration units, then a choropleth map might be appropriate even when the underlying phenomenon is not coincident with enumeration units, as was the case with wheat harvested in Kansas. The mapmaker should realize, however, that in this instance a choropleth map might lead to incorrect perceptions of the underlying phenomenon.

We have also learned that for some mapping methods **data standardization** is important, that **raw totals** need to be adjusted to account for the area over which the data have been collected (typically an enumeration unit). The simplest form of adjustment is to divide raw totals by the areas of enumeration units (e.g., we could divide the number of people in counties by the areas of counties to create a map of population density). In subsequent chapters, we look at other forms of standardization.

FURTHER READING

Bertin, J. (1983) *Semiology of Graphics: Diagrams, Networks, Maps*. Madison, WI: University of Wisconsin Press. (Translated by W. J. Berg)

Chapter 2 of this widely cited text focuses on visual variables. The text is a bit difficult to read as it has been translated from French to English.

Brewer, C. A. (1994a) "Color use guidelines for mapping and visualization." In *Visualization in Modern Cartography*, ed. by A. M. MacEachren and D. R. F. Taylor, pp. 123–147. Oxford: Pergamon.

Pages 124–126 cover terminology for using color. We consider Brewer's work more fully in Chapter 13.

Burrough, P. A., and McDonnell, R. A. (1998) *Principles of Geographical Information Systems*. Oxford: Oxford University Press.

Chapter 2 provides an alternative view of geographic phenomena by contrasting *entity* and *continuous field* approaches.

Chrisman, N. (2002) *Exploring Geographic Information Systems*. New York: Wiley.

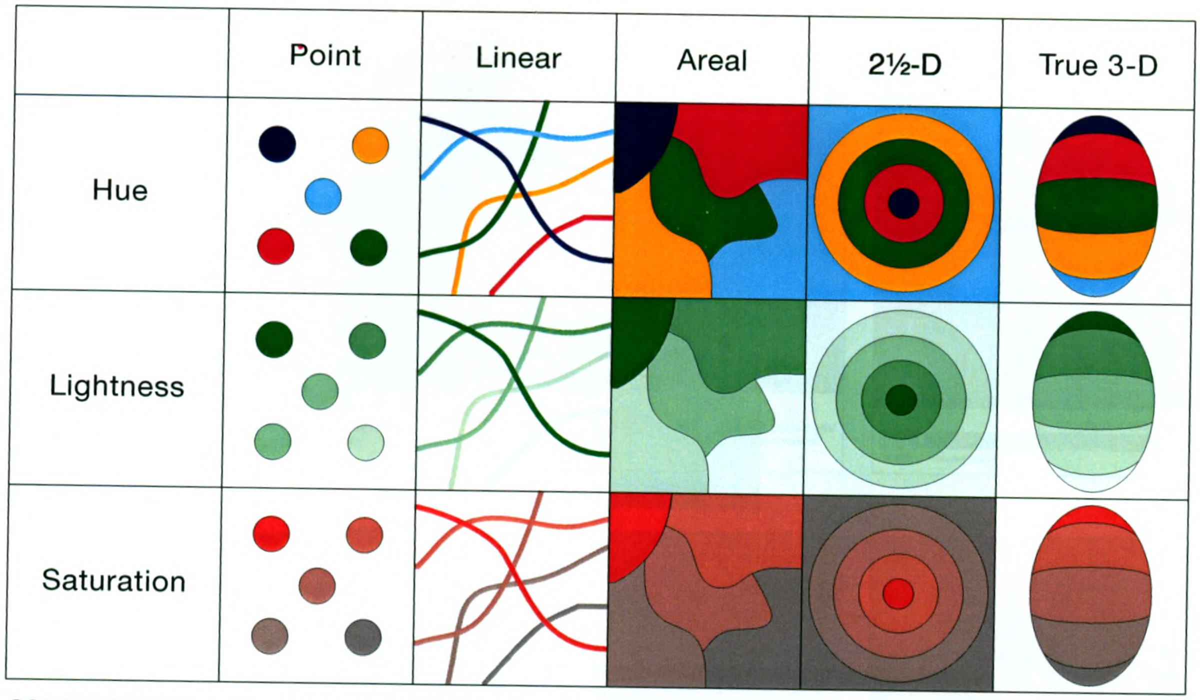
Discusses several extensions to the four standard levels of measurement (nominal, ordinal, interval, and ratio). For a theoretical discussion, see Chrisman (1998).

Forrest, D. (1999b) "Geographic information: Its nature, classification, and cartographic representation." *Cartographica* 36, no. 2:31–53.

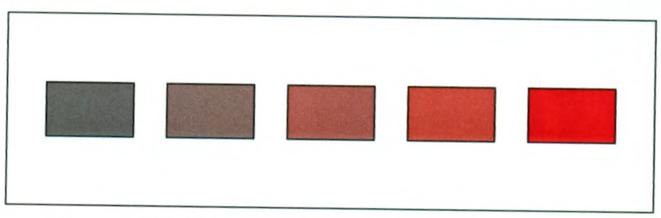
Presents a sophisticated approach for selecting symbology as a function of the phenomena, the spatial data, and the level of measurement.

MacEachren, A. M. (1994a) *Some Truth with Maps: A Primer on Symbolization and Design*. Washington, DC: Association of American Geographers.

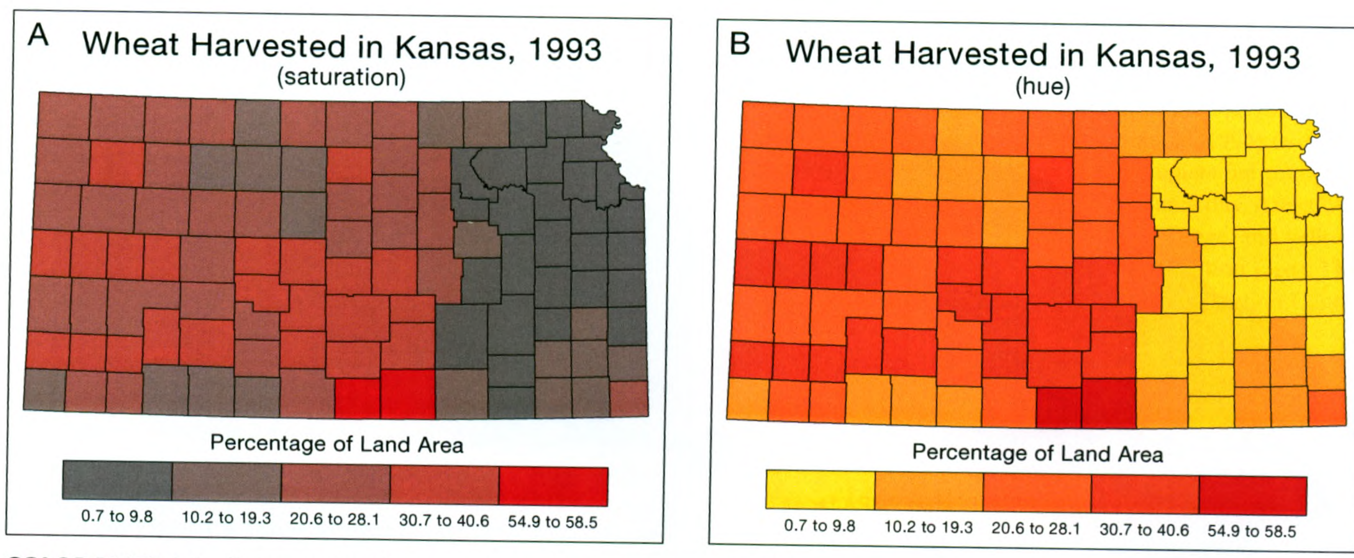
Spatial arrangement of geographic phenomena, levels of measurement, and visual variables are covered in pages 13–34.



COLOR PLATE 4.2 Visual variables for colored maps. For visual variables for black-and-white maps, see Figure 4.3.



COLOR PLATE 4.3 An illustration of saturation, holding hue and value constant. The area symbols shown for saturation in Color Plate 4.2 are arranged from a desaturated red (gray) to a fully saturated red.



COLOR PLATE 4.4 Representing the percentage of wheat harvested in Kansas counties using different visual variables: (A) saturation, (B) hue. For black-and-white visual variables, see Figure 4.10.