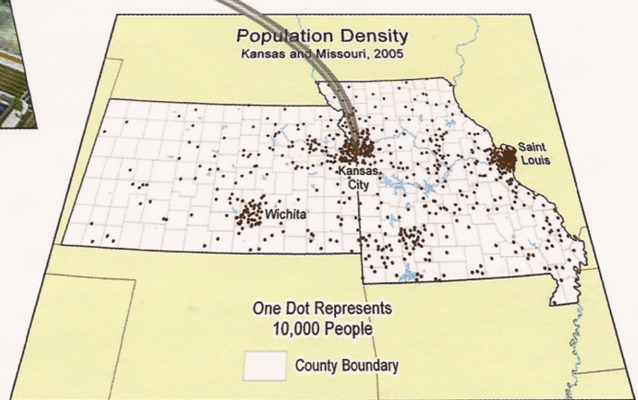
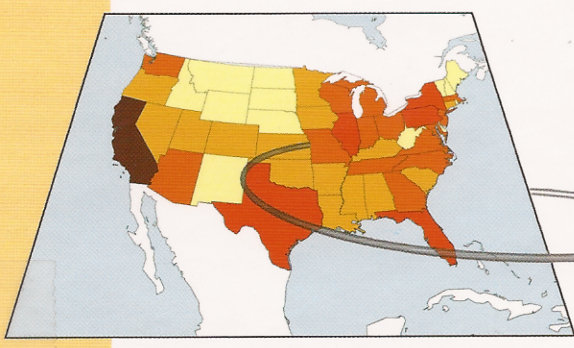
Prentice Hall Series in Geographic Information Science

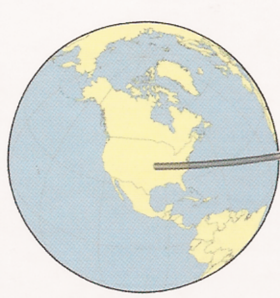
KEITH C. CLARKE, *Series Editor*

Thematic Cartography and Geovisualization

Third Edition







Terry A. Slocum
Robert B. McMaster
Fritz C. Kessler
Hugh H. Howard

1

Thematic Cartography and Geovisualization

OVERVIEW

This book covers thematic mapping and the associated expanding area of geographic visualization (or "geovisualization"). A ***thematic map*** *(or* ***statistical map****) is used to display the spatial pattern of a theme or* ***attribute****. A familiar example is the temperature map shown in daily newspapers; the theme (or attribute) in this case is the predicted high temperature for the day. The notion of a thematic map is described in section 1.1 and contrasted with the* ***general-reference map****, which focuses on geographic location as opposed to spatial pattern (e.g., a topographic map might show the location of rivers). In section 1.2 the different uses for thematic maps are described: to provide* ***specific information*** *about particular locations, to provide* ***general information*** *about spatial patterns, and to* ***compare patterns*** *on two or more maps.*

An important function of this book is to assist you in selecting appropriate techniques for symbolizing spatial data. For example, imagine that you wish to depict the amount of forest cleared for agriculture in each country during the preceding year, and have been told that the number of acres of forest cleared by country is available on the Web. You wonder whether additional data (e.g., the total acres of land in each country) should be collected and how the resulting data should be symbolized. Section 1.3 presents steps that assist you in tackling such problems, and ultimately that enable you to communicate the desired information to map readers. These steps are as follows: (1) consider the real-world distribution of the phenomenon, (2) determine the purpose for making the map, (3) collect data appropriate for the map purpose, (4) design and construct the map, and (5) determine whether users find the map useful and informative. Despite some criticism of the appropriateness of such steps, they are helpful in avoiding the design blunders that can result from using the most readily available data and software.

Like many disciplines, the field of cartography has undergone major technological changes. As recently as the 1970s, most maps were still produced by manual and photomechanical methods, whereas today, nearly all maps are produced using computer technology. Section 1.4 considers some of the consequences of this technological change, including (1) the ability of virtually anyone to create maps using personal computers; (2) new mapping methods, such as ***animated maps****; (3) the ability to explore geographic data in an interactive graphics environment; (4) the ability to link maps, text, pictures, video, and sound in* ***multimedia*** *presentations; (5) the ability to create realistic representations of the environment (****virtual environments*** *or* ***virtual reality****) and the related notion of* ***augmented reality*** *(i.e., enhancing our view of the real world through computer-based information); and (6) the ability to access maps and related information via the Web.*

In section 1.5 we consider the origin and definition of geographic visualization. The term "visualization" has its roots in ***scientific visualization****, which was developed outside geography to explore large multivariate data sets, such as those associated with medical imaging, molecular structure, and fluid flows. Borrowing from these ideas, geographers have created the notion of* *geographic visualization* (or *geovisualization*), *which can be defined as a private activity in which unknowns are revealed in a highly interactive environment.* ***Communication*** *on traditional printed maps involves the opposite: It is a public activity in which knowns are presented in a noninteractive environment.*

Although our emphasis in this book is on cartography, we want you to be aware of developments in the broader realm of geographic information science (GIScience), which can be considered to include cartography and the techniques of geographic information systems (GIS), remote sensing, and quantitative methods. In section 1.6, we consider the increased capability provided by GIS and remote sensing, which allow us to create detailed maps more easily than was possible with manual techniques. GIS accomplishes this through its extensive spatial analysis capabilities, and remote sensing allows us to "sense" the environment, particularly outside our normal visual capabilities (e.g., detecting previsual levels of vegetation stress). The major development in quantitative methods relevant to cartography is that of exploratory spatial data analysis (ESDA), which has close ties with the notion of data exploration that cartographers utilize.

While technological advances have had a major impact on cartography, the discipline has also experienced changes in its philosophical outlook. Section 1.7 deals with the increasing role that **cognition** *now plays in cartography. Traditionally, cartographers approached mapping with a behaviorist view, in which the human mind was treated like a black box. Today cartographers take a cognitive view, in which they hope to learn why symbols work effectively. Section 1.8 deals with social and ethical issues in cartography—there we will see that maps often have hidden agendas and meanings, and that our increasing technological capability provides tremendous opportunity, but also is fraught with potential problems (e.g., the notion of* **geoslavery***).*

1.1 WHAT IS A THEMATIC MAP?

Cartographers commonly distinguish between two types of maps: general-reference and thematic. **General-reference maps** are used to emphasize the location of spatial phenomena. For instance, topographic maps, such as those produced by the U.S. Geological Survey (USGS), are general-reference maps. On topographic maps, readers can determine the location of streams, roads, houses, and many other natural and cultural features. **Thematic maps** (or **statistical maps**) are used to emphasize the spatial pattern of one or more geographic **attributes** (or *variables*), such as population density, family income, and daily temperature maximums. A common thematic map is the **choropleth map**, in which **enumeration units** (or data-collection units such as states) are shaded to represent different magnitudes of an attribute (Color Plate 1.1). A variety of thematic maps are possible, including proportional symbol, isarithmic, dot, and flow (see Figure 1.1). A major purpose of this book is to introduce you to these and other types of thematic maps, as well as to methods used in designing and constructing them.

Although cartographers commonly distinguish between general-reference and thematic maps, they do so largely for the convenience of categorizing maps. The general-reference map also can be viewed as a thematic map in which multiple attributes are displayed simultaneously; thus, the general-reference map can be termed a *multivariate thematic map*. Furthermore, although the major emphasis of general-reference maps is on the *location* of spatial phenomena, they can also portray the *spatial pattern* of a particular attribute (e.g., the pattern of drainage shown on a USGS topographic sheet).

1.2 HOW ARE THEMATIC MAPS USED?

Thematic maps can be used in three basic ways: to provide **specific information** about particular locations, to provide **general information** about spatial patterns, and to **compare patterns** on two or more maps. As an example of specific information, map A of Color Plate 1.1 indicates that between 8.8 and 12.0 percent of the people in Louisiana voted for Ross Perot in the 1992 U.S. presidential election. As another example, Figure 1.1 indicates that approximately 2 million slaves were transported from Africa to Spanish America between 1700 and 1870. Obtaining general information requires an overall analysis of the map. For example, map B of Color Plate 1.1 illustrates that a low percentage of people voted for Perot in the southeastern United States, whereas a higher percentage voted for him in the central and northwestern states; and Figure 1.1 indicates that the bulk of the slave trade between 1700 and 1870 occurred outside North America.

A pitfall for naive mapmakers is that they often place inordinate emphasis on specific information. Map A of Color Plate 1.1 is illustrative of this problem. Here one can discriminate the data classes based on strikingly different colors and thus determine which class each state belongs in (as we did for Louisiana), but it is difficult to acquire general information without carefully examining the legend. In map B, the reverse is true: Determining class membership is more difficult because the classes are all blue shades, but the spatial pattern of voting is readily apparent because there is a logical progression of legend colors.

As an illustration of pattern comparison, consider the **dot maps** of corn and wheat shown in Figure 1.2. Note that

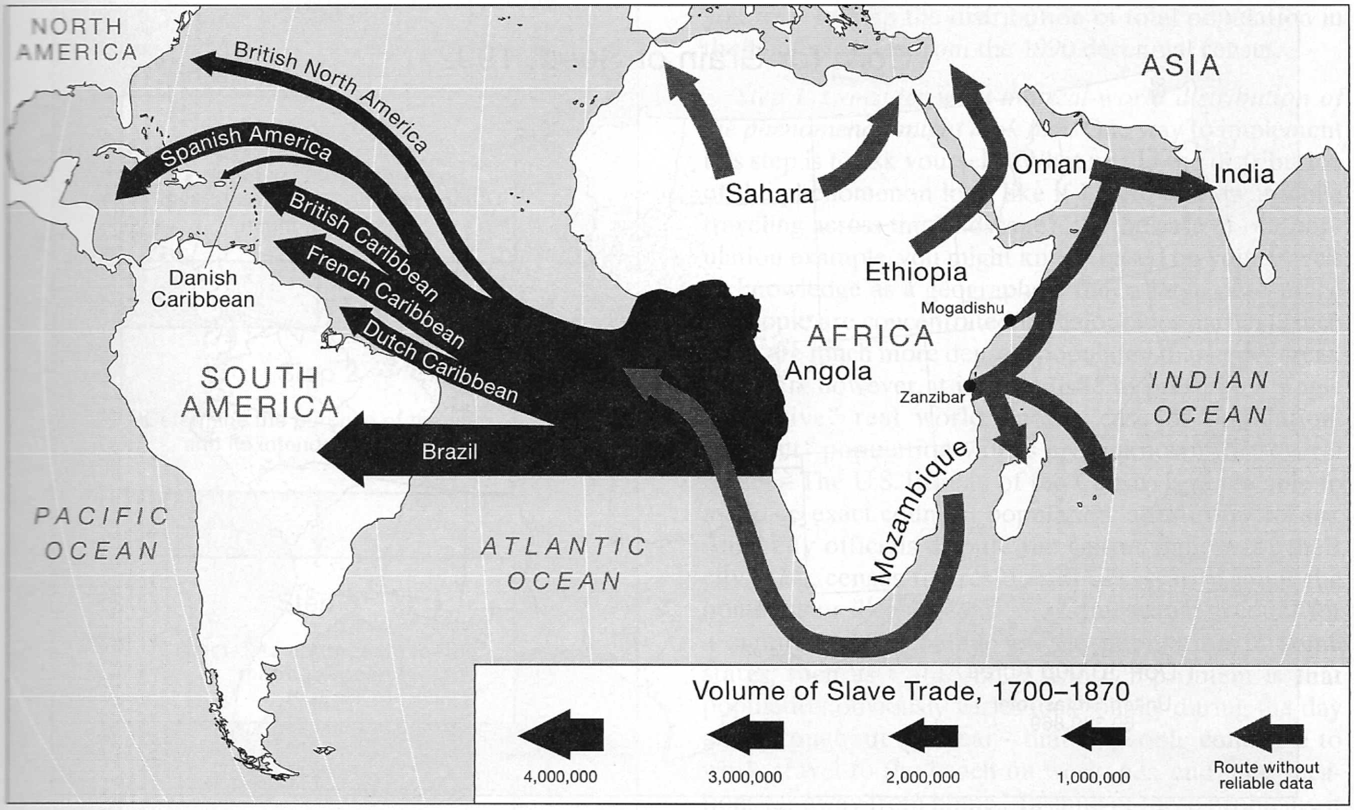


FIGURE 1.1 A flow map: an example of a thematic map. (From BERGMAN, EDWARD F., *HUMAN GEOGRAPHY: CULTURE, CONNECTIONS, AND LANDSCAPES,* 1st Edition, © 1995, pg. 167. Reprinted by permission of Pearson Education, Inc., Upper Saddle River, NJ.)

the patterns on these two maps are quite different. Corn is concentrated in the traditional Corn Belt region of the Midwest, whereas wheat is concentrated in the Great Plains, with a less notable focus in the Palouse region of eastern Washington. Conventionally, a comparison of patterns such as these was limited by their fixed placement on pages of paper atlases, but interactive graphics now allow us to readily compare arbitrarily selected distributions.

Two further issues are important when considering the ways in which thematic maps are used. First, one should distinguish between **information acquisition** and **memory for mapped information.*** Thus far, we have focused on information acquisition, or acquiring information while the map is being used. We can also consider memory for map information and how that memory is integrated with other spatial information (obtained through either maps or fieldwork). For example, a cultural geographer might note that houses in a particular area are built predominantly of limestone. Recalling a geologic map of bedrock, the geographer might mentally correlate the spatial pattern of limestone in the bedrock with the pattern of limestone houses.

A second important issue is that terms other than *specific* and *general* can be found in the cartographic literature. We have used *specific* and *general* (developed by Alan MacEachren 1982b) because they appear frequently in the literature. Others have developed a more complex set of terms. For example, Philip Robertson (1991, 61) distinguished among *three* kinds of information: values at a point, local distributions characterized by "gradients and features," and the global distribution characterized by "trends and structure"; Robertson argued that these levels corresponded closely with Jacques Bertin's (1981) elementary, intermediate, and superior levels.†

1.3 BASIC STEPS FOR COMMUNICATING MAP INFORMATION

In this section, we consider basic steps involved in communicating map information to others. For instance, imagine that you wish to create a map for a term paper

* Technically, memory for mapped information would be equivalent to what psychologists term *long-term memory,* but for simplicity, the word *memory* is normally used.

† Additional terminology can be found in Olson (1976a) and Board (1984).

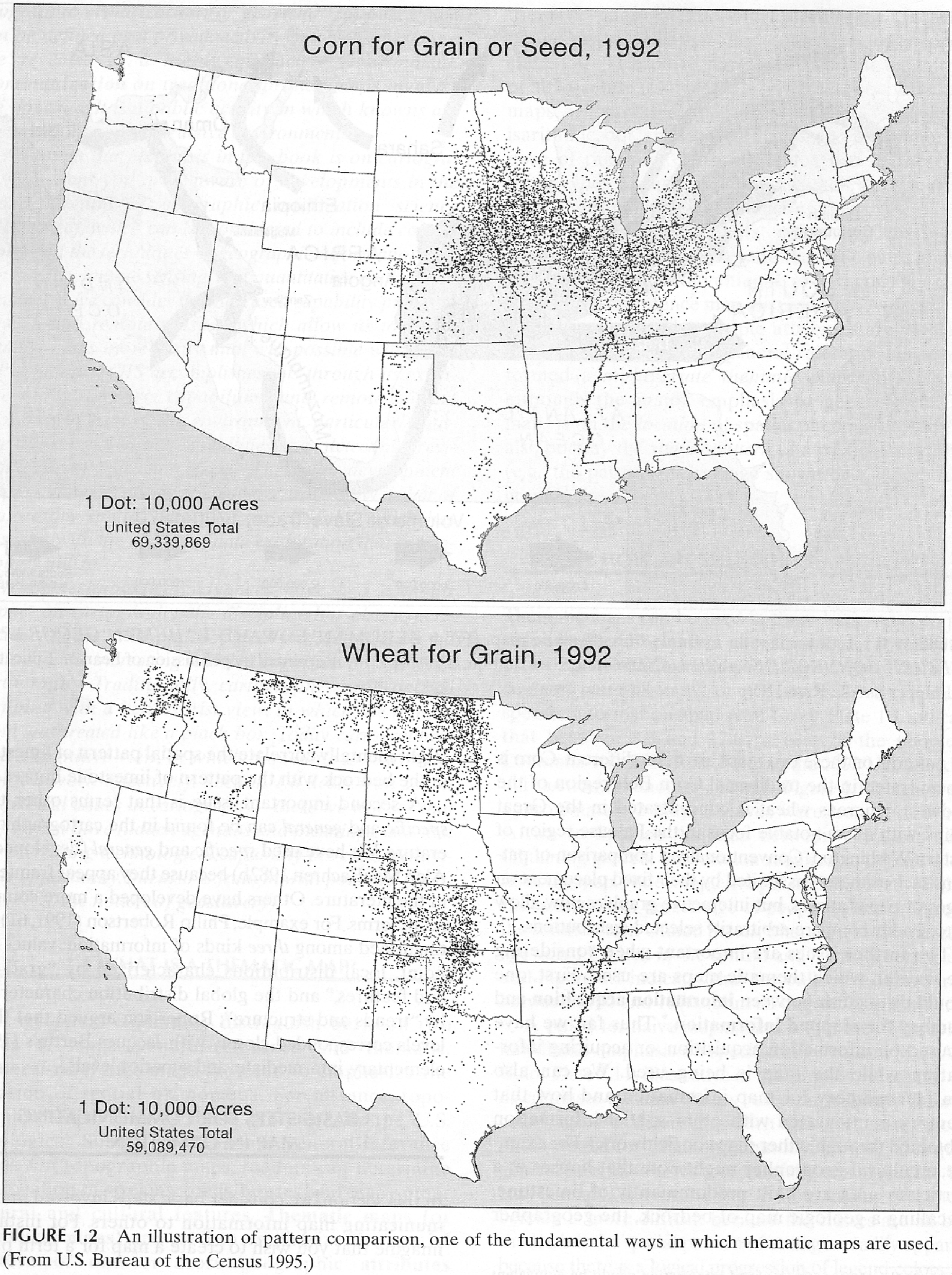


FIGURE 1.2 An illustration of pattern comparison, one of the fundamental ways in which thematic maps are used. (From U.S. Bureau of the Census 1995.)

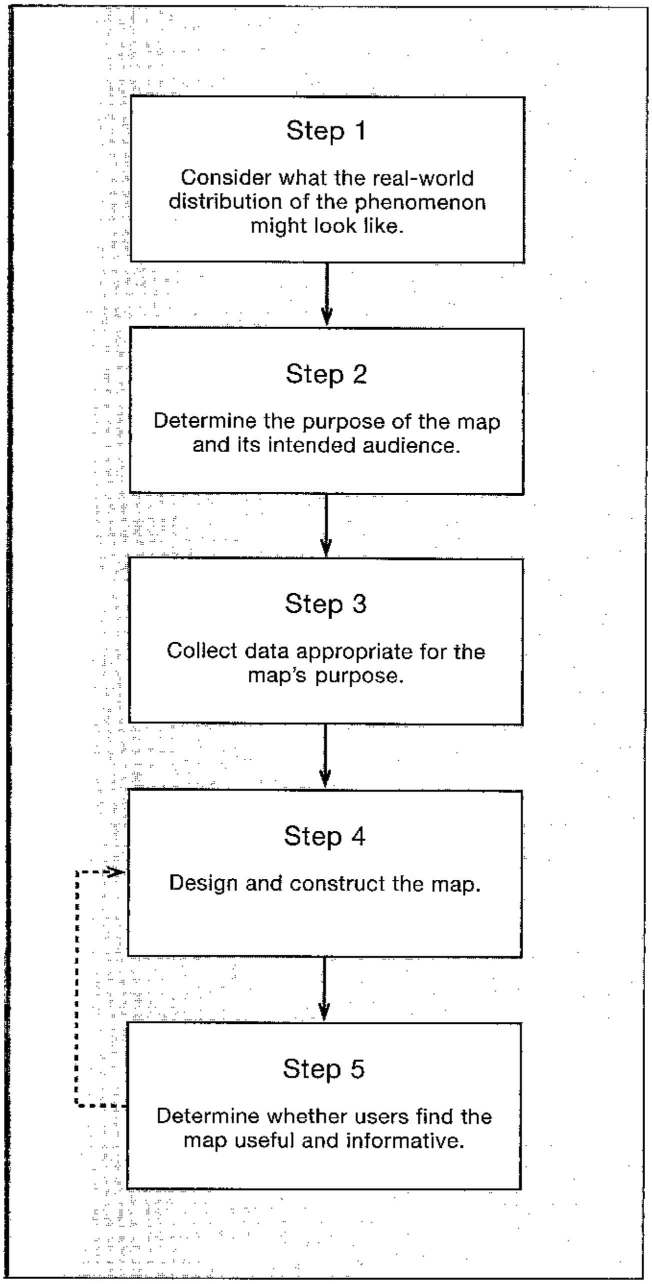


FIGURE 1.3 Basic steps for communicating map information to others.

or that you are working for a local newspaper and need to create a map for a major news story. Traditionally, the basic steps for communicating map information were taught within the framework of map communication models (e.g., Dent 1996, 12–14; Robinson et al. 1984, 15–16). Although such models have received criticism (e.g., MacEachren 1995, 3–11), their use often leads to better designed maps. The map communication model that we use is shown in Figure 1.3 as a set of five idealized steps. Let's examine these steps by assuming that you wish to map the distribution of total population in the United States from the 1990 decennial census.

Step 1. Consider what the real-world distribution of the phenomenon might look like. One way to implement this step is to ask yourself, "What would the distribution of the phenomenon look like if I were to view it while traveling across the landscape?" In the case of our population example, you might know (based on your travels or knowledge as a geographer) that a large percentage of people are concentrated in major cities and that such cities are much more densely populated than rural areas.

Often, however, it is unrealistic to presume a single "objective" real world. In the case of population, "correct" population values are unknown for several reasons. The U.S. Bureau of the Census is never able to make an exact count of population; after every census, some city officials dispute the census figures for their city. Also, census figures do not necessarily count the homeless or illegal aliens (the latter would account for a significant percentage of the population in some states, such as California). Another problem is that population obviously varies locationally during the day and throughout the year—that is, people commute to work, travel to the beach on weekends, and take vacations far away from home.* In spite of these problems, it is useful to think of a "real-world" distribution. Such an approach forces you to think about the distribution at its most detailed level, and then to decide what degree of generalization meets the purpose of the map.

Step 2. Determine the purpose of the map and its intended audience. One purpose would be to attempt to match the real world as closely as possible (within the constraints of the map scale used). In the case of population, you might want to distinguish clearly between urban and rural population. Another purpose might be to map the distribution at a particular geographic level (say, the county level); such views are often sought by government officials for political reasons. From your viewpoint as a mapmaker, it is important for you to realize that mapping at a particular geographic level can introduce error into the resulting map because each enumeration unit is represented by a single value, and thus the variation within units cannot be portrayed. This error might be unimportant if the focus is on how one enumeration unit compares to another, but it can be a serious problem if readers infer more from the map than was intended; for example, readers might erroneously assume that the population density is uniform across a county on a choropleth map. A key point is that mapmakers often display data at the level of a convenient political unit (e.g., county, state, or nation) because data are available for that level, rather than consider the purpose of the map.

* For a statistical approach for handling mobile populations, see li (1998).

The nature of your intended audience may also play an important role in designing the map. For instance, if you are utilizing thematic maps in a grade school textbook, you might utilize symbols that are particularly suggestive of the phenomenon being mapped (e.g., pizzas to represent the amount of pizza consumed in census tracts throughout a city). In many instances, however, it is difficult to anticipate exactly who will read the map (such as when designing maps for a daily newspaper).

Step 3. Collect data appropriate for the map's purpose. In general, spatial data can be collected from primary sources (e.g., field studies) or secondary sources (e.g., Census data). For something close to the real-world view of population, you would likely consult the U.S. Census of Population for information on urban and rural population; additionally, you would collect ancillary data that could assist you in locating the population data within rural areas. For a county-level view of population, the Census figures for individual counties would suffice.

Step 4. Design and construct the map. Designing and constructing the map involves not only selecting an appropriate symbology (e.g., using a dot map rather than a choropleth map), but also selecting and positioning the various map elements (e.g., title, legend, and source) so that the resulting map is both informative and visually pleasing. This step is a complex one that involves assessing the following questions:

1. How will the map be used? Will it be used to portray general or specific information?
2. What is the spatial dimension of the data? For instance, are the data available at *points*, do they extend along *lines*, or are they *areal* in nature?
3. At what level are the data measured—nominal, ordinal, interval, or ratio?
4. Is data standardization necessary? If the data are raw totals, do they need to be adjusted?
5. How many attributes are to be mapped?
6. Is there a temporal component to the data?
7. Are there any technical limitations? For example, a journal might not be willing to reproduce maps in color.
8. What are the characteristics of the intended audience? Is the map intended for the general public or for professional geographers? What limitations might particular members of the audience have (e.g., do any have color vision impairments)?
9. What are the time and monetary constraints? For example, creating a high-quality dot map will cost more than creating a choropleth map, regardless of the technical capabilities available.

A full consideration of these questions will occupy the rest of this book. For now, consider two maps that could result from efforts to create a population map of the United States: a combined proportional symbol–dot map (Color Plate 1.2) for the real-world view, and a choropleth map for the county-level view (map A in Figure 1.4). The proportional symbol–dot map is particularly illustrative of how one can attempt to match the mapped spatial distribution to the real world. Note that the overall population is split into urban and rural categories, and that urban population is further subdivided into "urbanized areas" and "places outside urban areas."

Step 5. Determine whether users find the map useful and informative. Possibly the most important point to keep in mind is that you are designing the map *for others,* not for yourself. For example, you might find a particular color scheme pleasing, but you should ask yourself whether others also will find it attractive. Ideally, you should answer such questions by getting feedback about the map from potential users. Admittedly, time and monetary constraints make this task difficult, but it is necessary to undertake because you could discover not only whether a particular mapping technique works, but also the nature of information that users acquire from the map. Moreover, if you plan to employ the map to illustrate a *particular* concept (as for a class lecture), then you will want to know whether users acquired this concept when using the map.

If your analysis reveals that the map is not useful and informative, then you will need to redesign the map. This possibility is shown as a dashed line in Figure 1.3. It is also conceivable that you might have to return to an earlier step, but it is more likely that you will have to modify some design aspect, such as the color scheme.

Unfortunately, naive mapmakers are unlikely to follow the five steps we have outlined. Instead, their decisions are frequently based on readily available data and mapping software. As an example, imagine that for a term paper, a student wished to map the distribution of population that we have been discussing. Rather than considering steps 1 and 2 of the model, the student might simply use state totals, either because fewer numbers would have to be entered into the computer or because the data are readily available (as on a Web site). Furthermore, in step 4 the student might choose a choropleth map (map B of Figure 1.4) because software for creating choropleth maps is readily available. Presuming that the student had collected data in raw-total form, the choropleth map would be a poor choice because it requires standardized data (as we will see later in this chapter and in Chapter 5). Cartographers would argue that a proportional symbol map (map C of Figure 1.4) would be a better choice if raw totals were to be mapped.

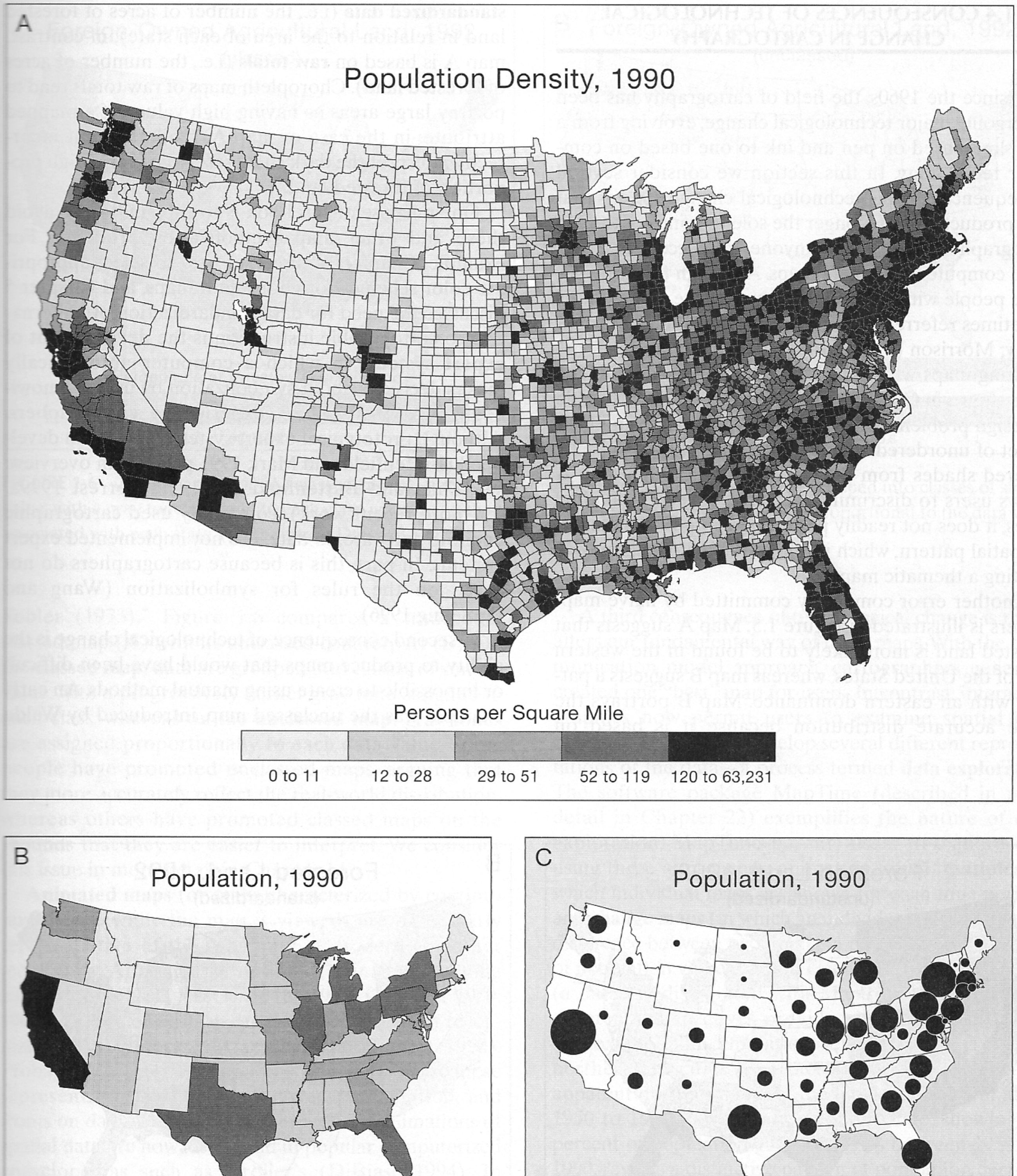


FIGURE 1.4 Potential maps of the population distribution in the United States in 1990: (A) a standardized choropleth map at the county level; (B) an unstandardized choropleth map at the state level; and (C) a state-level proportional symbol map. (Data source: U.S. Bureau of the Census 1994.)

1.4 CONSEQUENCES OF TECHNOLOGICAL CHANGE IN CARTOGRAPHY

Ever since the 1960s, the field of cartography has been undergoing major technological change, evolving from a discipline based on pen and ink to one based on computer technology. In this section we consider several consequences of this technological change. One is that map production is no longer the sole province of trained cartographers, as virtually anyone with access to a personal computer can create maps. Although this provides more people with the opportunity to make maps (this is sometimes referred to as the **democratization of cartography**; Morrison (1997)), there is no guarantee that the resulting maps will be well designed and accurate. The maps shown in Color Plate 1.1 illustrate a good example of design problems that can arise. Map A uses an illogical set of unordered hues, whereas map B uses logically ordered shades from the same hue. Although map A allows users to discriminate easily between individual states, it does not readily permit perception of the overall spatial pattern, which is one of the major reasons for creating a thematic map.

Another error commonly committed by naive mapmakers is illustrated in Figure 1.5. Map A suggests that forested land is more likely to be found in the western part of the United States, whereas map B suggests a pattern with an eastern dominance. Map B portrays the more accurate distribution because it is based on **standardized data** (i.e., the number of acres of forested land in relation to the area of each state); in contrast, map A is based on **raw totals** (i.e., the number of acres of forested land). Choropleth maps of raw totals tend to portray large areas as having high values of a mapped attribute; in the case of map A, readers might incorrectly interpret the dark shades as indicating a high proportion of forested land.

One purpose of this book is to explain how to avoid these and other map symbolization problems. For example, Chapter 14 discusses how to select appropriate color schemes for choropleth maps, and Chapter 5 discusses the need for data standardization. An alternative to cartographic instruction is the development of **expert systems** in which a computer automatically makes decisions about symbolization by using a knowledge base provided by experienced cartographers. Although prototypical expert systems have been developed (Buttenfield and Mark 1991 provide an overview; see Zhan and Buttenfield 1995, and Forrest 1999a, for more recent work), commonly used cartographic and GIS software, to date, has not implemented expert systems. In part, this is because cartographers do not agree on the rules for symbolization (Wang and Ormeling 1996).

A second consequence of technological change is the ability to produce maps that would have been difficult or impossible to create using manual methods. An early example was the unclassed map, introduced by Waldo

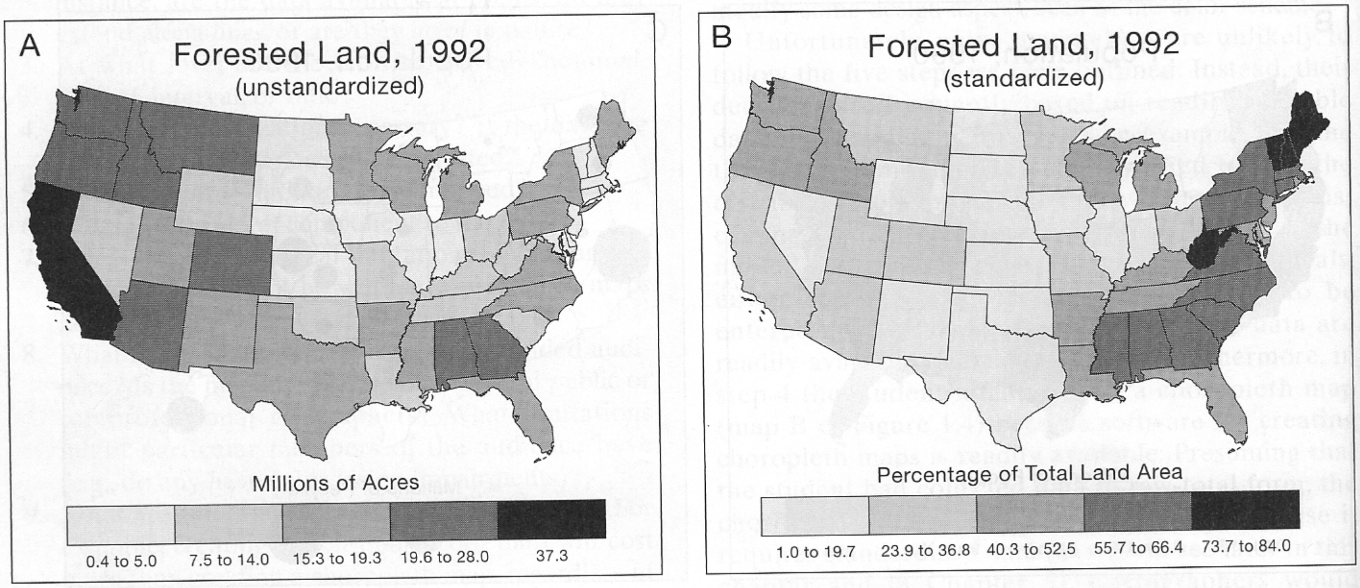


FIGURE 1.5 A comparison of the effect of data standardization. Map A is based on raw totals (i.e., the number of acres of forested land), whereas map B is based on standardized data (i.e., the number of acres of forested land relative to the area of each state). Map A is misleading because states with large areas tend to have more forest. (Data source: Powell et al. 1992.)

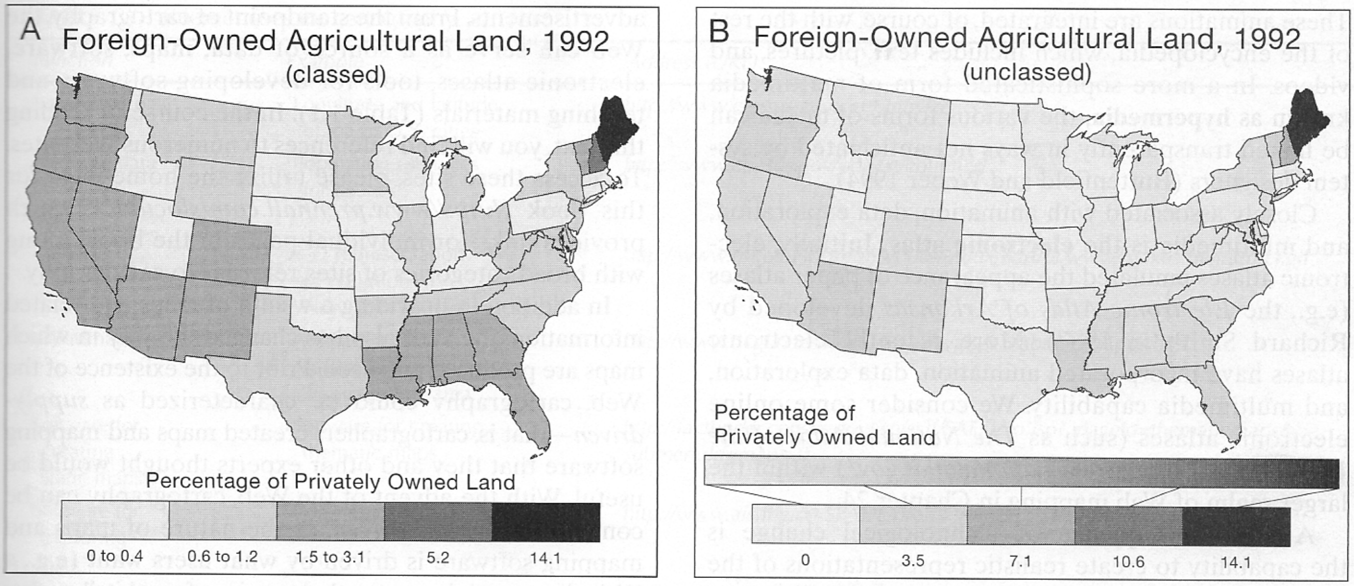


FIGURE 1.6 A comparison of (A) classed and (B) unclassed maps. On the classed map, states are grouped into classes of similar value, with a gray tone assigned to each class, whereas on the unclassed map, gray tones are selected proportional to the data value associated with each state. (Data source: DeBraal 1992.)

Tobler (1973).* Figure 1.6 compares a traditional classed map (A) with its unclassed counterpart (B). On the **classed map**, data are grouped into classes of similar value, with a progressively darker gray tone assigned to each class, whereas on the **unclassed map**, gray tones are assigned proportionally to each data value. Some people have promoted unclassed maps, arguing that they more accurately reflect the real-world distribution, whereas others have promoted classed maps on the grounds that they are easier to interpret. We consider this issue in more detail in Chapter 14.

Animated maps (or maps characterized by continuous change while the map is viewed) are particularly representative of the capability of modern computer technology. Although the notion of animated mapping has been around at least since the 1930s (Thrower 1959; 1961), only recently have cartographers begun to recognize its full potential (Campbell and Egbert 1990). Probably the most common forms of animation are those representing changing cloud cover, precipitation, and fronts on daily television weather reports. Animations of spatial data are now also found in popular computerized encyclopedias such as Grolier's (DiBiase 1994). In Chapter 21, we consider a variety of animations that geographers and other spatial scientists have developed; for example, we consider an animation that Lloyd Treinish (1992) developed for visualizing the formation of the ozone hole over Antarctica (see Color Plate 21.2).

A third consequence of technological change is that it alters our fundamental way of using maps. With the communication model approach, cartographers generally created one "best" map for users. In contrast, interactive graphics now permit users to examine spatial data dynamically and thus develop several different representations of the data—a process termed **data exploration.** The software package MapTime (described in more detail in Chapter 22) exemplifies the nature of data exploration. MapTime permits users to explore data using three approaches: animation, **small multiples** (in which individual maps are shown for each time period), and **change maps** (in which an individual map depicts the difference between two points in time). The examination of population values for 196 U.S. cities from 1790 to 1990 (a data set distributed with MapTime) illustrates the different perspectives provided by these approaches. For example, an animation reveals major growth in northeastern cities over most of the period, with an apparent drop for some of the largest cities from about 1950 to 1990. In contrast, a change map, showing the percent of population gains or losses between 1950 and 1990, reveals a distinctive pattern of population decrease throughout the Northeast (Color Plate 1.3). One of the keys to data exploration is that displays such as these can be created in a matter of seconds.

A fourth consequence of technological change is that it enables mapmakers to link maps, text, pictures, video, and sound in **multimedia** presentations. For example, in the Grolier encyclopedia already mentioned, animations include sound clips to assist in understanding.

* The earliest choropleth maps were actually unclassed, but they rapidly gave way to classed maps (see Robinson 1982, 199).

These animations are integrated, of course, with the rest of the encyclopedia, which includes text, pictures, and videos. In a more sophisticated form of multimedia known as **hypermedia**, the various forms of media can be linked transparently in ways not anticipated by system designers (Buttenfield and Weber 1994).

Closely associated with animation, data exploration, and multimedia is the **electronic atlas**. Initially, electronic atlases emulated the appearance of paper atlases (e.g., the *Electronic Atlas of Arkansas* developed by Richard Smith in 1987). More recently, electronic atlases have incorporated animation, data exploration, and multimedia capability. We consider some online electronic atlases (such as *The National Atlas of the United States*; *http://www.nationalatlas.gov/*) within the larger realm of Web mapping in Chapter 24.

A fifth consequence of technological change is the capability to create realistic representations of the Earth's natural and built environments. To illustrate, Color Plate 1.4 is a frame taken from a fly-through animation of a portion of Lawrence, Kansas, that was created by geography students at the University of Kansas. Such realistic fly-throughs provide users a sense of being immersed in a 3-D landscape. When users are able to navigate through and interact with a realistic 3-D environment, we term this a **virtual environment** or **virtual reality**. For instance, in Chapter 25 we describe Virtual Puget Sound, a system in which users don a **head-mounted display (HMD)** and examine water movement, the behavior of tides, and salinity levels in Puget Sound. The notions of visual realism and virtual environments certainly challenge our traditional thoughts about what cartography is. Normally, we have thought of maps as consisting of abstract symbols; now we need to extend our notion of maps to include realism.

Closely aligned with virtual environments is the notion of **augmented reality**, in which computer-based information is used to enhance our view of the real world. For instance, imagine that you are a physical geographer studying vegetation changes in a particular region, and you wish to examine the current vegetation in the field and compare it with past vegetation patterns. Traditionally, you would accomplish this by taking maps into the field and comparing them with current vegetation patterns. With augmented reality, however, you can don a *wearable computer* (and associated specialized viewing hardware) and actually *see* historic vegetation patterns overlaid on the present-day landscape. We consider this evolving technology in Chapter 25.

A sixth consequence of technological change is the ability to access maps and related information via the World Wide Web (WWW, or simply "the Web"), which is part of the larger Internet. The Web has, of course, changed our daily lives as evidenced by the common listing of Web addresses in newspaper and television advertisements. From the standpoint of cartography, the Web can serve as a source of data, maps, software, electronic atlases, tools for developing software, and teaching materials (Table 1.1). In the course of reading this text, you will find references to numerous Web sites. To access these sites, please utilize the home page for this book (*http://www.prenhall.com/slocum/*), which provides links for individual pages in the book, along with broad categories of sites relevant to cartography.

In addition to providing a wealth of maps and related information, the Web also has changed the way in which maps are produced and used. Prior to the existence of the Web, cartography could be characterized as *supply-driven*—that is, cartographers created maps and mapping software that they and other experts thought would be useful. With the advent of the Web, cartography can be considered *demand-driven*, as the nature of maps and mapping software is driven by what users want (e.g., a Web site containing maps that receives few "hits" probably is not particularly useful or desirable).* As part of this demand-driven character, users might want to design their own maps. User-designed maps were possible prior to the Web with mapping software, but now there are millions of Web users, whose cartographic abilities obviously vary. As we have already suggested, this raises the possibility of millions of poorly designed maps. Poorly designed maps are problematic even if only the individual making the map will use that map, because the individual might derive incorrect information as a function of poor design.

A distinct advantage of the Web is that it provides the general public with access to spatial information that they normally might not have access to. For example, imagine that officials are planning to build a bypass around the city that you live in, and that the city has hired a consulting firm to model the anticipated impact on the city. If the consulting firm makes its predictions available via the Web, you should be able to examine them from the comfort of your home; you might even be able to run their models under different scenarios—for example, you might wonder what would happen if the bypass were located north as opposed to south of the city. The ability of the general public to work with such spatial information is commonly termed *public participation GIS* (PPGIS).†

One aspect of the Web (and associated Internet technology) that has received considerable interest is mapping the technology and its associated information spaces. For instance, Color Plate 1.5 is an example of mapping the technology itself—in this case, early Internet traffic. The red balls, and the white lines connecting them, represent the backbone of NSFNET in 1991 (NSFNET formed the basis for the present-day

* The terms *supply-driven* and *demand-driven* were taken from the work of Kraak and Brown (2001).

† For an overview of PPGIS, see Sieber (2006).

TABLE 1.1 Internet uses for cartography

Function	Example	Address (URL)
Locational data	Longitude and latitude of major U.S. cities	*http://www.census.gov/cgi-bin/gazetteer*
Attribute data	Population estimates for counties	*http://www.census.gov/popest/counties/*
Maps		
Static	3-D representation of pollution in New York Harbor	*http://www.rpi.edu/locker/69/000469/dx/harbor.www/maxus.dieldrin.cr.gif*
Animated	Animation of urban sprawl in the San Francisco Bay area	*http://www.ncgia.ucsb.edu/projects/gig/v2/About/abApps.htm*
Software for creating static maps	Software for creating thematic maps	*http://factfinder.census.gov/jsp/saff/SAFFInfo.jsp?_pageId=thematicmaps&_submenuId=maps_0*
Software for exploring data	CommonGIS	*http://www.ais.fhg.de/SPADE/products/index_eng.html*
Electronic atlases	The Atlas of Canada	*http://atlas.nrcan.gc.ca/site/index.html*
Tools for developing software	GeoVISTA Studio	*http://geovistastudio.sourceforge.net/*
Teaching materials for students	The Geographer's Craft	*http://www.colorado.edu/geography/gcraft/contents.html*
Teaching materials for instructors	Cartography: The Virtual Geography Department	*http://www.colorado.edu/geography/virtdept/contents.html*

Internet). The colored vertical lines depict inbound data to each of the nodes of the backbone, with low and high amounts of data depicted by purple and white, respectively. Figure 1.7 is an example of mapping the information space of the Internet. Here, more than 900 online news reports of the Kosovo crisis of the late 1990s have been "mapped" using the isarithmic method; dark peaks represent similar commonly occurring news topics. Note that this is not a map in the conventional sense because we are mapping abstract space. Numerous examples of mapping the Internet and its associated information spaces can be found in Martin Dodge and Rob Kitchin's *Atlas of Cyberspace* (2001a) and on Martin Dodge's Web site (*http://www.cybergeography.org/atlas/*).

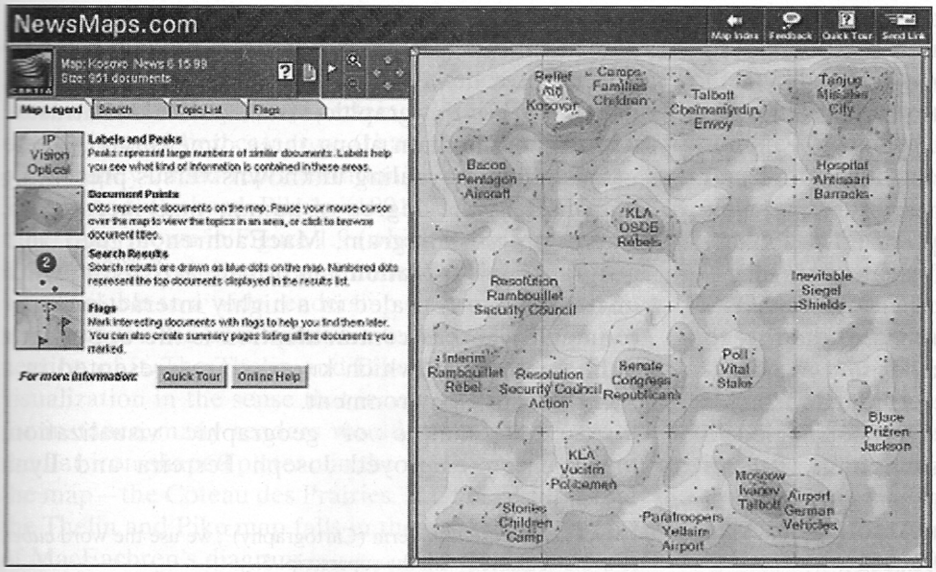


FIGURE 1.7 An example of mapping the information space of the Internet. The relationship and frequency of topics associated with more than 900 online news reports of the Kosovo crisis are depicted using the isarithmic method. (Originally produced by Newsmaps, Cartia, Inc.; the software used to create this figure is now known as ThemeView and is produced by the Pacific Northwest National Laboratory (*http://infoviz.pnl.gov/technologies.html*)).

An excellent recent example of the capability provided by the Web is Google Earth (*http://earth.google.com/index.html*) and the companion product Google Maps (*http://maps.google.com/*). By draping high-resolution, remotely sensed imagery on a digital elevation model and permitting users to zoom in or fly over the landscape, Google Earth provides breathtaking, realistic views of the Earth's landscape, all of which are free in the basic version. In Chapter 24, we'll discuss Google Earth in detail and consider numerous other examples of maps available via the Web.

1.5 GEOVISUALIZATION

Outside geography, the term *visualization* has its origins in a special issue of *Computer Graphics* authored by Bruce McCormick and his colleagues (1987). To McCormick and his colleagues, the objective of **scientific visualization** was "to leverage existing scientific methods by providing . . . insight through visual methods" (p. 3). Today, scientific visualization generally involves using sophisticated workstations to explore large multivariate data sets (Color Plate 1.6). Work in scientific visualization extends far beyond the realm of spatial data, which geographers deal with, to include topics such as medical imaging and visualization of molecular structure and fluid flows. Peter and Mary Keller (1993) provided numerous examples of the use of scientific visualization. The most recent developments in scientific visualization can be found in the proceedings of the Institute of Electrical and Electronics Engineers (IEEE) Visualization conference, which has been held every year since 1990.

The notion of **information visualization** is closely related to scientific visualization. Information visualization focuses on the visual representation and analysis of nonnumerical abstract information. The "map" of online news reports of the Kosovo crisis shown in Figure 1.7 is an example of information visualization. In Chapter 1 of their book *Readings in Information Visualization: Using Vision to Think*, Stuart Card and his colleagues (1999) provide numerous examples of information visualization. In Chapter 26, we look at some ongoing developments in information visualization in geography.

Although those outside geography were the first to popularize visualization, the idea has existed in cartography at least since the 1950s (MacEachren and Taylor 1994, 2). As a result, cartographers have struggled to define the term. Thus far, two basic definitions have emerged. The first is a broad one that encompasses both paper and computer-displayed maps. According to Alan MacEachren and his colleagues (1992, 101):

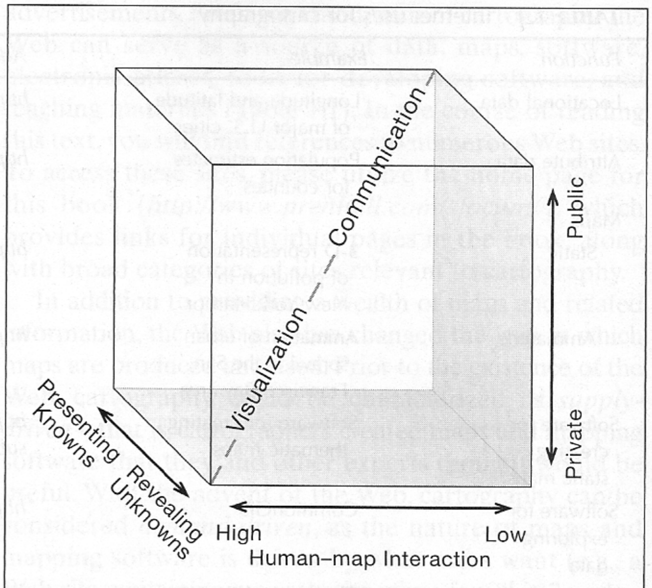


FIGURE 1.8 A graphical representation of how maps are used. Note that visualization is contrasted with communication along three dimensions: private versus public, revealing unknowns versus presenting knowns, and the degree of human–map interaction. (After MacEachren 1994b, 7.)

> Geographic visualization [can be defined] as the use of concrete visual representations—whether on paper or through computer displays or other media—to make spatial contexts and problems visible, so as to engage the most powerful human information-processing abilities, those associated with vision.

Using this definition, geographic visualization could be applied to the visual analysis of a paper map created by pen-and-ink methods or to the visual analysis of a map created on an interactive graphic display.

The second, and narrower, definition is based on MacEachren's (1994b, 6) cartography-cubed representation of how maps are used, which is shown in Figure 1.8.* In this graphic, visualization is contrasted with communication along three dimensions: private versus public, revealing unknowns versus presenting knowns, and the degree of human–map interaction. Based on this diagram, MacEachren argued that **geographic visualization** is a private activity in which unknowns are revealed in a highly interactive environment, whereas **communication** is the opposite: a public activity in which knowns are presented in a noninteractive environment.

As an example of geographic visualization, MacEachren employed Joseph Ferreira and Lyna

* MacEachren used the term (Cartography)^3; we use the word *cubed* to avoid confusion with the superscript 3.

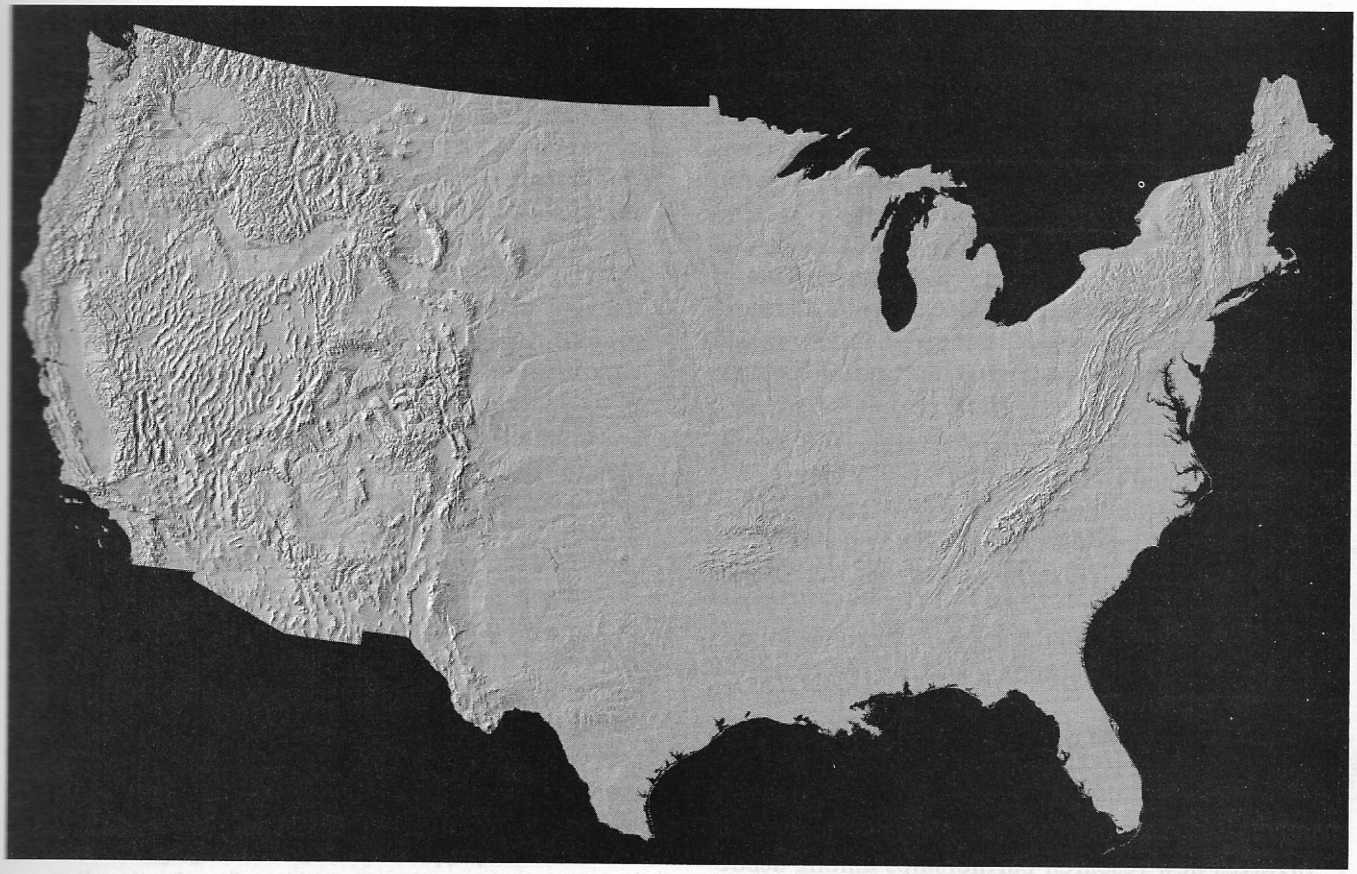


FIGURE 1.9 A small-scale version (1:21,400,000) of the USGS map *Landforms of the Conterminous United States: A Digital Shaded-Relief Portrayal*, developed by Thelin and Pike (1991). (Courtesy of Gail P. Thelin.)

Wiggin's (1990) "density dial," in which class break points on choropleth maps were manipulated to identify and enhance spatial patterns. The idea is that users of the density dial could discover previously unknown spatial patterns. In contrast, MacEachren argued that communication is exemplified by the "you are here" maps used to locate oneself in a shopping mall. MacEachren stressed that certain map uses do not fit neatly into either category (thus the need for the cartography-cubed representation). For example, Gail Thelin and Richard Pike's (1991) dramatic shaded relief map shown in Figure 1.9 (which we will discuss in Chapter 20) fits into the communication realm because it is available to a wide readership (making it "public") and because the user cannot interact with the paper version of it. The Thelin and Pike map, however, fits visualization in the sense that it can reveal unknowns; for instance, many readers would be unfamiliar with the flat-iron-shaped plateau in the north central part of the map—the Coteau des Prairies. The net result is that the Thelin and Pike map falls in the upper right corner of MacEachren's diagram.

The notions of map communication models and data exploration introduced previously can be associated with communication and visualization, respectively, in MacEachren's cartography-cubed representation. Thus, when using the five steps of the communication model presented in section 1.3, the intention generally is that the map is being made for the general public, there will be low human–map interaction, and the focus is on presenting knowns. In data exploration, the emphasis is on revealing unknowns via high human–map interaction in a private setting; in this sense the word "exploration" could easily be substituted for "visualization" in MacEachren's graphic.

On an informal basis, visualization has been used to describe any recently developed, novel method for displaying data. Thus, cartographers have placed animation and virtual environments under the rubric of "visualization." Additionally, novel methods that might result in static maps (e.g., Daniel Dorling's cartograms; see Chapter 19) are also placed under the heading of "visualization." More recently, MacEachren has simplified the term *geographic visualization* to **geovisualization** (e.g., MacEachren et al. 1999c). We will follow MacEachren's lead and use the term geovisualization throughout the remainder of the book.

One limitation of the term geovisualization is its implication that our interpretation of spatial patterns is solely a function of our sense of vision. As we will see in Chapter 26, however, cartographers have begun to explore how our other senses (e.g., sound, touch, and even smell) might be used to interpret spatial patterns. Thus, it would seem desirable to use a term that is more inclusive. One term that has been proposed (by Fraser Taylor) is **cybercartography**, which, he argued, includes the following elements:

- Is multisensory, using vision, hearing, touch, and eventually smell and taste;
- Uses multimedia formats and new telecommunications technologies such as the World Wide Web;
- Is highly interactive and engages the user in new ways;
- Is applied to a wide range of topics of interest to society, not only location finding and the physical environment;
- Is not a stand-alone product like the traditional map but is part of an information/analytical package;
- Is compiled by teams of individuals from different disciplines;
- Involves new research partnerships among academia, government, civil society, and the private sector. (Taylor 2003, 407)

A number of these elements overlap with the notion of geovisualization (e.g., "Is highly interactive and engages the user in new ways"), while others suggest a broader view (e.g., "Involves new research partnerships . . ."). As an example of the latter, Taylor and his colleagues have been developing the *Cybercartographic Atlas of Antarctica* (Pulsifer et al. 2007), which includes a broad range of partnerships (Taylor 2003, 414). Although the term cybercartography has not been widely adopted by cartographers, it seems clear that ultimately we will need a term that is more inclusive than geovisualization.

1.6 RELATED TECHNIQUES

The picture of cartography today would not be complete without including the broader realm of geographic information science (GIScience), which can be considered to include cartography and the related techniques of geographic information systems (GIS), remote sensing, and quantitative methods. In this section, we consider not only how cartographers can use these techniques, but also how knowledge of cartography can provide those working with these techniques the ability to create more effective cartographic products.

GISs are computer-based systems that are used to analyze spatial problems. For example, we might use a GIS to determine optimal bus routes in a school district, or to predict the likely location of a criminal's residence based on a series of apparently related crimes. Traditionally, most digital thematic maps were created using so-called **thematic mapping software** (e.g., MapViewer).* Today, GIS software typically has considerable thematic mapping capability, in addition to its inherent spatial analysis capabilities. These spatial analysis capabilities also enable GIS to handle more sophisticated mapping problems than traditional thematic mapping software. Dot maps (such as those shown in Figure 1.2) provide a good illustration of the capability of GIS software. Ideally, dots on a dot map should be located as accurately as possible to reflect the underlying phenomenon. Thus, in the case of the wheat map, we would want to place dots where wheat is most likely to be grown (say, on level terrain with fertile soil) and not where it cannot be grown (in water bodies). Traditional thematic mapping software did not accomplish this, as dots would normally be based solely on the basis of enumeration units (e.g., counties). In contrast, GIS software enables a large number of factors (or *layers*, in GIS terminology) to be accounted for. We consider this process further in Chapters 15 and 17.

The basic purpose of remote sensing is to record information about the Earth's surface from a distance (e.g., via satellites and aircraft). For instance, we might use remote sensing to determine temporal changes resulting from forest fires (e.g., acreage burned, effects of erosion, and regrowth) or the health of crops. The importance of remote sensing to cartography can be illustrated by again presuming that we wish to map the distribution of wheat across the United States. Rather than use a GIS approach, in which layers of related information are considered, we could use remote sensing to directly determine the precise location of wheat fields. For instance, Stephen Egbert and his colleagues (1995) found that wheat fields could be identified with an accuracy as high as 99 percent by using remotely sensed imagery for three time periods. In Chapters 15 and 17, we'll consider how remotely sensed imagery can be used to enhance both dasymetric and dot mapping, respectively.

Quantitative methods are used in the statistical analysis of spatial data. For instance, we might develop an equation that relates deaths due to drunk driving to various attributes that we think might explain the spatial variation in the death rate, such as the severity of laws that penalize drunk driving, the extent to which the laws are enforced, the percentage of the population

* MapViewer is still marketed as a thematic mapping tool, but now has some GIS analytic capability.

that are members of various religious groups, the traffic density, and many other attributes. The major development in quantitative methods relevant to cartography is that of exploratory spatial data analysis (ESDA), which refers to data exploration techniques that accompany a statistical analysis of the data. As an example, we might explore a map of predicted deaths due to drunk driving to see how the pattern is affected by various attributes that we include in the model. We only touch on ESDA in this book (in Chapter 22) because a thorough understanding requires a more complete background in statistics than is typical for the introductory cartography student.

Thus far, we have considered how cartographers can benefit from knowledge of other geographic techniques. We argue that those working with these other techniques can also benefit from a knowledge of cartography. For example, imagine that you are working in the GIS department of a city and wish to examine the distribution of auto thefts, and so you create a choropleth map depicting the number of auto thefts for each census tract in the city. Based on the high incidence of auto thefts in a contiguous set of census tracts, you recommend to the police department that they focus their patrols in those areas. Unfortunately, your solution might be inappropriate, because you failed to consider the population (and possibly the number of cars owned) in each census tract. Instead of mapping the raw number of auto thefts, you probably would want to adjust for the population (or number of cars owned) in each tract. This is another example of the data standardization problem that we mentioned earlier. Effective use of GIS requires an understanding of basic cartographic principles such as these.

As another example of how those working in other areas can benefit from cartography, imagine that you are a remote sensor working on the GreenReport (*http://koufax.kgs.ku.edu/kars/kars_map.cfm*), which uses remotely sensed images to depict the health of crops and natural vegetation throughout the United States. Color Plate 1.7A illustrates a basic greenness map that you might use to represent current vegetation conditions. One can argue that this is a logical color scheme because dark green represents "High Biomass" whereas dark brown indicates "Low Biomass." Color Plate 1.7B depicts a change map that might be used to compare current conditions to those two weeks earlier. Note that in this case, the "Little or no Change" category is similar to some of the categories on the basic greenness map, which could confuse a map reader. An improved symbology would be to use a gray tone for the "Little or no Change" category, as shown in Color Plate 1.7C. An alternative symbology would be to use completely different colors to represent the changes in greenness; for example, Color Plate 1.7D uses shades of blue to represent increased greenness and orange and red shades to represent decreased greenness. The latter symbology would be desirable because users could associate certain colors with the raw image and a different set of colors with the changes.

1.7 COGNITIVE ISSUES IN CARTOGRAPHY

Understanding the role that cognition plays in cartography requires contrasting cognition with perception. *Perception* deals with our initial reaction to map symbols (e.g., that a symbol is there, that one symbol is larger or smaller than another, or that symbols have different colors). In contrast, *cognition* deals not only with perception but also with our thought processes, prior experiences, and memory.* For example, contour lines on a topographic map can be interpreted without looking at a legend because of one's past experience with such maps. Alternatively, one might correlate the pattern of soils on a particular map with the distribution of vegetation seen on a previous map.

The principles of cognition are important to cartographers because they can explain why certain map symbols work (i.e., communicate information effectively). Traditionally, cartographers were not so concerned with why symbols worked but rather with determining which symbols worked best. This was known as a *behaviorist view*, in which the human mind was treated like a black box. Today, cartographers are more likely to utilize a *cognitive view*, in which they hope to determine *why* symbols work effectively. A cognitive view provides a theoretical basis for map symbol processing that not only assists in explaining why particular symbols work, but also provides a basis for evaluating other map symbols, even those not yet developed.

To illustrate the difference between the behaviorist and cognitive views, consider an experiment in which a cartographer wishes to compare the effectiveness of two color schemes for numerical data: five hues from a yellow-to-red progression and five hues from the electromagnetic spectrum (red, orange, yellow, green, blue). Let us presume that the results of such an experiment reveal that the yellow–red progression works best. The traditional behaviorist would report these results but probably would not provide any indication as to why one sequence worked better than another. In contrast, the cognitivist would consider how color is processed by the eye–brain system, possibly theorizing that the yellow–red progression works best because of opponent process theory (see Chapter 10). Effectiveness of the spectral hues might be emphasized on the grounds

* For a more in-depth discussion of perception and cognition, see Goldstein (2007) and Matlin (2006), respectively.

that different hues will appear to be at slightly different distances from the eye and thus will form a logical progression (e.g., red will appear nearer than, say, blue, as discussed in Chapter 16). Spectral hues might also be considered effective because of their common use on maps, and the likelihood that readers have experience in using them.

An important concept of cognition is the three types of memory: iconic memory, short-term visual store, and long-term visual memory (Peterson 1995). **Iconic memory** deals with the initial perception of an object (in our case, a map or portion thereof) by the retina of the eye (see Chapter 10 for a detailed discussion of the retina). Calling this "memory" is somewhat of a misnomer, because it exists for only about one-half second and because we have no control over it. Visual information initially recorded in iconic memory is passed on to the **short-term visual store**. Only selected information is passed on at this stage; for example, the boundary of Texas shown in Figure 1.10 will likely be simplified to some extent in moving from iconic to short-term visual store. Keeping information in short-term visual store requires constant attention (or activation). This is accomplished by rehearsal of the items being memorized (e.g., staring at the map of Texas and telling yourself to remember its shape).

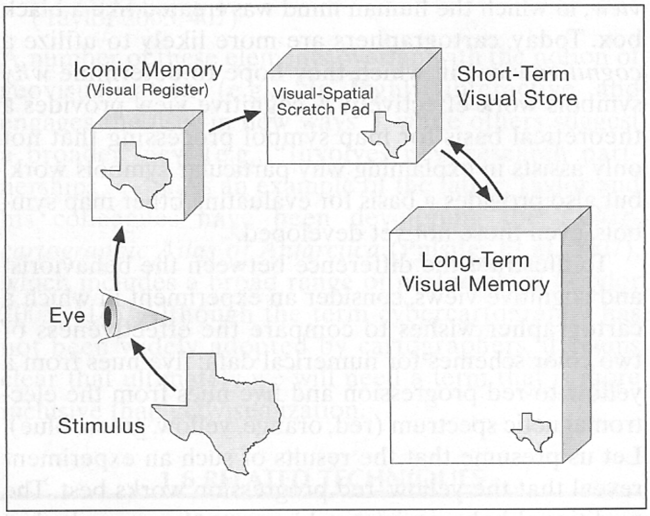


FIGURE 1.10 Three forms of memory used in cartography. A perceived map is initially stored in iconic memory (the retina of the eye). The image is then passed to the short-term visual store in the brain (where it is rehearsed). Finally, information is stored for later use in long-term visual memory in the brain. (From PETERSON, MICHAEL P., *INTERACTIVE AND ANIMATED CARTOGRAPHY*, 1st Edition, © 1995, pg. 27. Reprinted by permission of Pearson Education, Inc., Upper Saddle River, NJ.)

After the information has been rehearsed in the short-term visual store, it is ultimately passed on to **long-term visual memory** (Figure 1.10). Note that arrows are shown going in both directions between short-term visual store and long-term visual memory. When something is initially memorized, information must be moved from the short-term store to long-term memory; when something is retrieved from memory, the opposite is the case. As an example of the latter, imagine that you are shown a map of Texas and asked to indicate which state it is. To make your decision, you must retrieve the image of Texas from long-term memory and compare it with the image in the short-term store to make your decision. We have covered here only some of the basic concepts of cognitive psychology that are necessary for understanding this text. For a broader overview, see Peterson (1995, Chapter 2) and MacEachren (1995).

1.8 SOCIAL AND ETHICAL ISSUES IN CARTOGRAPHY

Although maps, and especially interactive digital maps, have tremendous potential for visualizing spatial data, we should also consider various social and ethical issues associated with their use. The notion of social and ethical issues in cartography was first developed in the context of *postmodernism*. Those who subscribe to a postmodernist view believe that problems can best be approached from multiple perspectives or viewpoints; for example, in a study of an urban neighborhood, a postmodernist would want to acquire not only the perspective of those in positions of political and economic power, but also the perspectives of as wide a sample of inhabitants as possible: men and women, children, the elderly, each of the social classes, ethnic and racial groups, or any others who might shed light on the dynamics of the neighborhood (Cloke et al. 1991, 170–201).

An important notion of postmodernism is that a text (or map) is not an objective form of knowledge, but rather has numerous hidden agendas or meanings. **Deconstruction** enables us to uncover these hidden agendas and meanings. Brian Harley (1989, 3) stated:

> Deconstruction urges us to read between the lines of the map . . . to discover the silences and contradictions that challenge the apparent honesty of the image. We begin to learn that cartographic facts are only facts within a specific cultural perspective.

As an example of deconstruction, consider Mark Bockenhauer's (1994) examination of the official state highway maps of Wisconsin over a seven-decade period. Although the major purpose of highway maps is presumably to assist a motorist in getting from one place to another, Bockenhauer (17) argued that "three dominant 'cultures' [could] be identified as factors influencing the map product: a transportation/modernization culture, a culture of promotion, and a subtle, beneath-the-surface culture of dominion." As an example of the transportation/modernization culture, Bockenhauer recounted the removal of surfaced county roads from recent editions of the map, and thus the greater emphasis on "getting us from here to there by encouraging travelers onto the freeways" (p. 21). An illustration of highway maps as promotional devices was their use by government officials; for example, in the 1989–1990 edition, Governor Tommy Thompson showcased himself next to a replica of a Duesenberg automobile. Finally, an example of the culture of dominion was the portrayal of women on the maps: "Among the most common and prominent images appearing on the . . . maps . . . are those of women in swim suits and fishermen. Nearly all of the photos of people enjoying Wisconsin fishing . . . are of white men. . . . [The] women seem to be part of the package of 'pleasure' offered to white men in Wisconsin" (p. 24). Although some would disagree with Bockenhauer's interpretations of these maps, it is clear that maps can convey information other than their supposed primary purpose.

Although we do not focus on postmodernism and map deconstruction in this book, both mapmakers and map users need to recognize their importance. Mapmakers must realize that maps can communicate unintended messages, and that the data they have chosen to include on a map or the method of symbolizing that data might be a function of the culture of which they are a part. Conversely, map users must recognize that a single map might depict only one representation of a spatial phenomenon (e.g., a map of percent forest cover is only one representation of vegetation).

Note that there is some overlap between the notions of data exploration and postmodernism because both promote the notion of multiple representations of data. In the context of data exploration, "multiple representations" refers to the various methods of symbolizing the data (e.g., using MapTime to display population data as both an animation and a change map). The postmodernist would likely support this approach because it concurs with the notion that there is no single, "correct" way of visualizing data. Additionally, however, the postmodernist would be interested in the multiple meanings and potentially hidden agendas found in a particular thematic map.

The notions of postmodernism and map deconstruction led to an examination of the social and ethical implications of the broader field of GIScience (Sui 2004); today, an examination of such issues is known as **critical GIS** (Harvey et al. 2005). Early on, those taking a critical view were concerned that, because of its quantitative and empirical nature, GIS failed to properly consider the everyday world that individuals live in, that the cost and complexity of GIS software prevented access by the full range of the population, and, consequently, that GIS was largely under the control of those in positions of political and economic power. To understand the nature of such concerns, consider the role that GIS might play in tracking the whereabouts of individuals. The Digital Angel Corporation (*http://www.digitalangelcorp.com/*) markets a wristband that can be affixed to an individual and locked or unlocked remotely, enabling another party to track the movement of that individual in real time via the global positioning system (GPS) and GIS. Although such technology is arguably useful for tracking children and the elderly, its availability raises interesting ethical questions. For instance, what if a child does not wish to be tracked (not surprising for a teenager)? And should spouses be able to track one another? Jerry Dobson and Peter Fisher (2003) are particularly wary of such technology, noting that if a transponder were added to the wristband, it would be possible to administer a form of punishment to the individual. They term the net result **geoslavery**, suggesting that the results would be far worse than George Orwell's *1984*, as one "master" could potentially monitor and enslave thousands of people.

Although those involved with critical GIS are concerned about the potential misuse of GIS, they also note that effective visualizations can be produced if GIS is used with care. For instance, in a paper dealing with feminist visualization, Mei-Po Kwan (2002) describes how she has mapped the spacetime paths of a sample of African-American women in Portland, Oregon. Kwan argues that "not only do the homes and workplaces of these women concentrate in a small area . . . but their activities' locations are much more spatially restricted when compared to those of all other gender/ethnic groups." (p. 654). As another example, Jeremy Crampton (2004) has criticized the traditional choropleth map because "it produces a view of human life as crammed into pre-given political units." Utilizing the work of Holloway and his colleagues (1999), Crampton illustrates how a consideration of ancillary information such as land use/land cover can be used to create a much more detailed dasymetric map. We will consider more recent dasymetric mapping efforts in Chapter 15.

FURTHER READING

Board, C. (1984) "Higher-order map-using tasks: Geographical lessons in danger of being forgotten." *Cartographica* 21, no. 1:85–97.

Discusses issues relevant to the kinds of information that can be acquired from maps.

Buttenfield, B. P., and Mark, D. M. (1991) "Expert systems in cartographic design." In *Geographic Information Systems: The Microcomputer and Modern Cartography*, ed. by D. R. F. Taylor, pp. 129–150. Oxford: Pergamon.

Although a bit dated, this work provides a good summary of the potential for using expert systems in map design; for more recent work, see Zhan and Buttenfield (1995) and Forrest (1999a).

Campbell, C. S., and Egbert, S. L. (1990) "Animated cartography: Thirty years of scratching the surface." *Cartographica* 27, no. 2:24–46.

An overview of early work in animated cartography, along with some suggestions for the potential of animation.

Cartographica 40, no. 4, 2005 (entire issue).

This special issue focuses on critical GIS; also see *Cartographica* 39, no. 1, 2004 (entire issue).

DiBiase, D. (1990) "Visualization in the earth sciences." *Earth and Mineral Sciences* 59, no. 2:13–18.

Discusses visualization and its role in geographic research.

Dodge, M., and Kitchin, R. (2001a) *Atlas of Cyberspace*. Harlow, England: Addison-Wesley.

Provides numerous examples of mapping the Internet and its associated information spaces.

Environment and Planning B: Planning and Design, 28, no. 6, 2001 (entire issue).

This special issue deals with public participation in GIS. Also see vol. 25, no. 2, 1998 of *Cartography and Geographic Information Science*.

Hallisey, E. J. (2005) "Cartographic visualization: An assessment and epistemological review." *The Professional Geographer* 57, no. 3:350–364.

Considers epistemological issues in geovisualization (what Hallisey terms "cartographic visualization").

Keller, P. R., and Keller, M. M. (1993) *Visual Cues: Practical Data Visualization*. Los Alamitos, CA: IEEE Computer Society Press.

Provides examples of visualization from a wide variety of disciplines.

Koláčný, A. (1969) "Cartographic information: A fundamental concept and term in modern cartography." *The Cartographic Journal* 6, no. 1:47–49.

Presents a cartographic communication model that MacEachren (1995) claimed had "the greatest initial impact on cartography" (p. 4).

Kraak, M.-J., and Brown, A., eds. (2001) *Web Cartography: Developments and Prospects*. London: Taylor & Francis.

Provides a broad overview of issues related to the Web.

MacEachren, A. M. (1994b) "Visualization in modern cartography: Setting the agenda." In *Visualization in Modern Cartography*, ed. by A. M. MacEachren and D. R. F. Taylor, pp. 1–12. Oxford: Pergamon.

Discusses definitions for visualization.

MacEachren, A. M. (1995) *How Maps Work: Representation, Visualization, and Design*. New York: Guilford.

An advanced treatment of cognitive issues in cartography.

MacEachren, A. M., and Kraak, M.-J. (1997) "Exploratory cartographic visualization: Advancing the agenda." *Computers & Geosciences* 23, no. 4:335–343.

Provides an alternative view of MacEachren's cartography-cubed model.

McCormick, B. H., DeFanti, T. A., and Brown, M. D. (1987) "Visualization in scientific computing." *Computer Graphics* 21, no. 6 (entire issue).

A classic early work on visualization.

Monmonier, M. S. (1985) *Technological Transition in Cartography*. Madison, WI: University of Wisconsin Press.

A text dealing with technological change in cartography.

Monmonier, M. (2002) *Spying with Maps: Surveillance Technologies and the Future of Privacy*. Chicago: University of Chicago Press.

Presents myriad ways in which modern GPS and GIS technologies can be used for surveillance and discusses related privacy issues; also see Monmonier (2003).

Peterson, M. P. (1997) "Cartography and the Internet: Introduction and research agenda." *Cartographic Perspectives* no. 26:3–12.

An overview of the Internet and its role in cartography. Other articles in this issue also deal with the Internet. The complete issue can be found at *http://maps.unomaha.edu:16080/NACIS/cp26/*. For more recent work, see Peterson (2003).

Rundstrom, R. A., ed. (1993) "Introducing cultural and social cartography." *Cartographica* 30, no. 1 (entire issue).

A set of articles dealing with postmodern issues in cartography.

Taylor, D. R. F., ed. (2005) *Cybercartography: Theory and Practice*. Amsterdam:Elsevier.

An edited volume dealing entirely with the theory and practice of cybercartography.

Wood, D., and Fels, J. (1992) *The Power of Maps*. New York: Guilford.

An extensive essay on postmodern issues in cartography. Also see Wood and Fels (1986).