CHAPTER 10

Data Display

Tables, Graphs, Maps, Visualizations

Learning Objectives:

- What are tables best used for, and what are some design alternatives for their construction?
- What are graphs best used for, and what are some design alternatives for their construction?
- What are some principles for good graphing?
- What are some of the special powers of maps, and what are some of their special pitfalls?
- How are new computer technologies being applied to displaying data in innovative and powerful ways?

In Chapter 13, we point out that scientific communication occurs not only verbally but also graphically. In Chapter 9, we similarly pointed out that data analysis includes not just mathematical techniques but also graphical techniques. We refer to these graphical techniques for communication and analysis as **data display**. Data displays *depict* data patterns rather than literally *describe* them. This gives data displays exceptional power to help us understand and communicate data. The spatial medium of graphical representation takes advantage of the human visual and spatial cognitive systems, including perception and memory, and the unique semiotic qualities of spatiality—the particular way it symbolically represents information. When depicting information about phenomena that *are* inherently spatial, as geographers so often do, data displays can do this at whatever scale and viewing perspective is convenient—you can see it all in a glance. Even nonspatial and

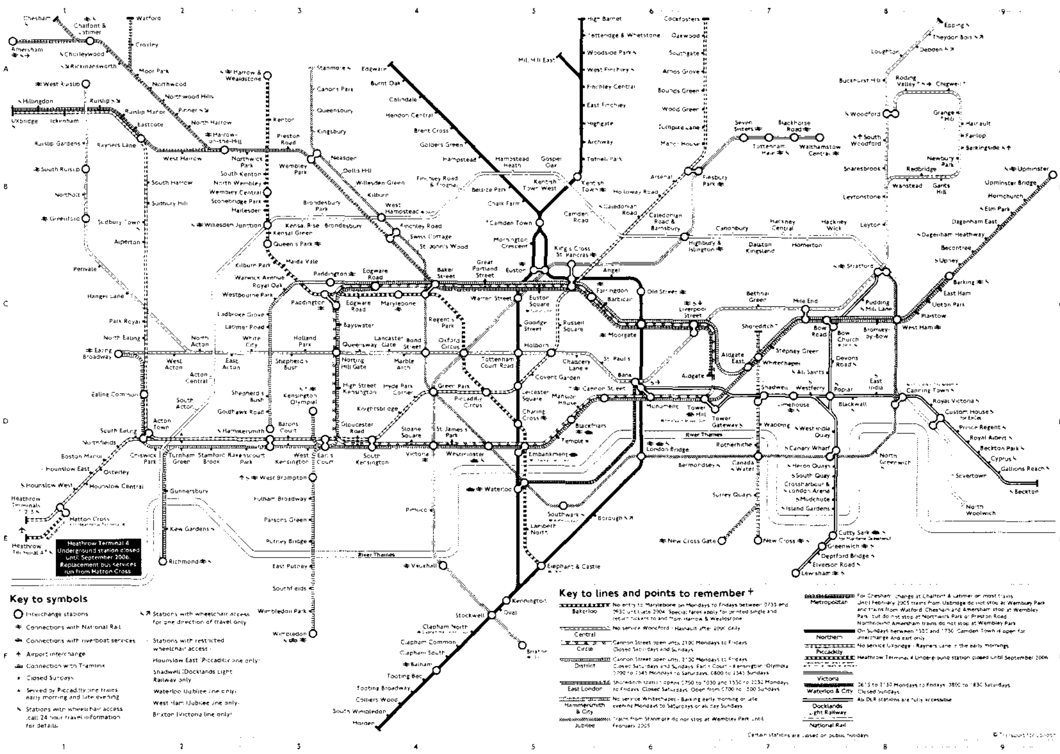

Figure 10.1 The London tube (subway) map. By focusing on line connections and stop sequences, this famous image exemplifies the power of graphical displays to highlight and clarify the relevant while omitting or downplaying the irrelevant, all in the interest of serving human communication. (Reprinted by permission of the Transport for London.)

nonperceptible information can be spatially and visually displayed. What's more, data displays allow us to highlight and clarify the relevant properties of phenomena and omit or downplay the irrelevant. The London tube (subway) map and countless others like it around the world provide a wonderful example of this point (Figure 10.1).

Scientific researchers use data displays for several purposes: to examine data initially, to interpret their meaning, and to communicate the data and their meaning to others. As part of their initial examination, researchers use displays to begin the process of intuitively grasping patterns in their data. How are the different variables statistically distributed, how are different values of the variables spatially distributed, and how do pairs or larger sets of variables relate to each other? Data display is quite useful for initially evaluating how "well-behaved" your data are. Are statistical assumptions about distributions, such as normality or homogeneity of variance, viable? Do the values of variables more or less fit the values you expect them to have? Are there unusual or extreme values—**outliers**—in your data? Do variables take on values that should be impossible, which is a signal that data have been miscoded or misrecorded somehow?

Initial examination merges with data interpretation as data display and examination continues. Dive right in—think of this process as "submersing" yourself in your data. Look at your data in an as many different ways as you can think of. Constructing a variety of tables can help, but for most people, the true power of data display derives from turning values into pictorial (graphical) displays. Try several different types of displays, including and excluding different variables and ranges of values, in a flexible manner that highlights different aspects of your data. Modern computing software and hardware makes this relatively easy to do. During the 1970s, this submersive, graphical, and ad hoc approach to data interpretation was dubbed **exploratory data analysis**. There is now a great deal of interest in this approach to data interpretation in many scientific disciplines, especially those like geography that generate very large amounts of data that are spatially and temporally distributed. In any event, whether you enthusiastically advocate exploratory data analysis or not,[1] the wisdom of exploratory submersion in your data as *part* of the total process of data interpretation and analysis has always been solid and commendable scientific practice. At the end of the chapter, we discuss recent computer display techniques that facilitate exploratory analysis and the interpretation of complex spatio-temporal data.

Of course, data displays are also invaluable for the communication of data to other people. They are a critical part of both written and oral communication in science, including published articles and books, theses and other student papers, grant applications, talks given at conferences and job interviews, and so on. As compared to displays made for initial examination and interpretation, those made for communication, especially if they are to appear in published scientific literature, function in a more "archival" fashion. They will be viewed more frequently, by more different people, and as relatively permanent records. Thus, displays made for final communication should be made with greater care, following more closely the guidelines for the design of effective displays we cover below.

The question arises as to whether one can ever use *too many* data displays. The answer is yes. Data displays are powerful in part because they are relatively concrete,

[1]A potentially important criticism of the exploratory analysis approach is that it is largely an ad hoc data-driven approach to science rather than an a priori theory-driven exercise. The exploratory approach definitely risks capitalizing on chance findings, even when findings are established to be statistically significant. Clearly, such an approach should offend anyone who advocates "hypothetico-deductive" reasoning in science, in which prior theories predict empirical results that can subsequently confirm or disconfirm the theories. It is true that patterns found via exploratory analysis maintain a definite conditional status until their further replication and confirmatory analysis. However, as we pointed out in Chapter 1, it is historically inaccurate to claim that scientists have ever stuck purely to one logical approach to theoretical and empirical reasoning and activity, and we do not believe any single approach is advisable or even feasible. Just remember that exploratory data analysis is but *part* of an optimal approach to data analysis and scientific progress.

so if you want to communicate something more abstract, words are often a better choice. Displays also consume quite a bit of space on a page, so you should not use them if they are only communicating a small amount of information. We recommend that you use displays when you have more than a handful of data values to report, whether the values are raw scores or aggregate measures like averages. That is, a general rule, which should sometimes be broken, is to use tables or graphs or maps when you need to communicate more than three or four values. If you are reporting fewer than this, most of the time it works best simply to list them verbally or numerically in the body of your text. "There were 35 inches of rain this season, which is far above the normal rainfall of 19 inches." Does that call for a table or picture? Could you make a good display for this information that would take up less space than the sentence does? Even if you have more than a handful of values to report, it may be best to communicate highly familiar information or information that can be summarized easily in verbal form. "Average annual precipitation follows a smooth gradient decreasing from east to west across the plains region of the U.S. and Canada, whereas temperature follows a smooth gradient decreasing from south to north." Would you prefer a picture of that?

Finally, as we note in Chapter 13, scientists do not use graphic displays, or **figures**, only to depict data. A variety of figures, including photographs and drawings, are used to communicate information other than data patterns. They are also used in scientific communication to depict the equipment and material employed in research, procedures followed, settings, example cases, the structure of models of all kinds, and more. As we suggest in Chapter 13, graphical displays are especially nice to use during oral presentations, and not just because they communicate efficiently and concretely; they also entertain and stimulate audience members by allowing them to activate other parts of their minds besides the verbal system. Indeed, we use figures in most chapters of this book to communicate things besides data patterns.

Guidelines for Designing Displays

We have seen that data displays help in the initial examination and ultimate interpretation of data, not just in their final communication to others. But even the examination and interpretation of data are really examples of communication—they are essentially processes of *self*-communication. Therefore, guiding principles for the design and use of data displays really boil down to one idea: effective communication.[2] Communication is about transferring ideas to, or stimulating ideas in, sentient or information-processing entities. In our case, those entities are individual human beings or groups, like families, communities, or policy-making bodies.

[2] In the past, the archival function of data displays was quite important; they served to store information of various kinds. This function has largely been subsumed by digital files and databases. Graphical displays are now almost exclusively about facilitating human communication.

To communicate effectively is to communicate a great deal of truthful and relevant information that a person or group should know, or wants to know, as quickly and easily as possible. That is, displays should be designed to depict valid and relevant information, in a manner that is clear, accurate, and unambiguous, and in a manner that is as efficient as possible. Displays should give access to the complex; they should not complicate the simple.[3]

The design of displays unquestionably affects what and how well they communicate. A particularly consequential example of how graphic design can make the simple complex and thereby influence communication is provided by the voting ballot for the 2000 U.S. presidential election in Palm Beach County, in the state of Florida. Palm Beach County employed a double-column or "butterfly" ballot (see Figure 10.2) instead of the much more common single-column ballot. George W. Bush, the top candidate on the left side, won the election in that county by a small margin; he was eventually declared the victor in an extremely close Florida vote count and consequently, in an extremely close national election. Some commentators observed that a surprisingly large number of votes were cast in Palm Beach County for Pat Buchanan, the top candidate on the right side—surprising considering the demographics of the county and the outcome of a previous election in which Mr. Buchanan ran. A look at the ballot suggests—at least it did to us the first time we saw it—that it would probably cause confusion for some voters. In order to vote for the *second* candidate on the left side, Al Gore, one would have to punch the *third* hole; punching the second hole would count as a vote for Mr. Buchanan. Even given the arrows that apparently indicated to most voters how to negotiate the confusing ballot layout, a significant minority of voters apparently did vote mistakenly for Mr. Buchanan when they intended to vote for Mr. Gore. In fact, experimental research conducted shortly after the election provided evidence that such a ballot would indeed cause confusion for some voters.[4] As a consequence, graphical miscommunication likely had a large effect on the outcome of this extremely close election (various other kinds of measurement errors certainly influenced vote counts elsewhere, although perhaps not with such a dramatic influence on the final outcome).

What about the role of aesthetics in data displays? Stressing communication like we do has sometimes been criticized as leading to a disregard for aesthetics. This may be somewhat true, but perhaps it reflects a misunderstanding of the power of beauty to increase the effectiveness of communication. Attractiveness induces people to look at a display more, which enhances communication. And displays that are cognitively effective in their communication tend for that reason also to be aesthetically pleasing. A quality piece of music or a quality piece of pie share something in common with a quality graph or map—they have a purity of focus on a meaning, whether sensory, emotional, or cognitive, and they avoid irrelevant and distracting ingredients that don't harmonize and contribute to that meaning. So we believe that beauty is valuable to data displays, but we don't think a display can be beautiful *as a*

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[3]As noted by Wainer (1997).

[4]Sinclair, R. C., Mark, M. M., Moore, S. E., Lavis, C. A., & Soldat, A. S. (2000). An electoral butterfly effect. *Nature, 408*, 665–666.

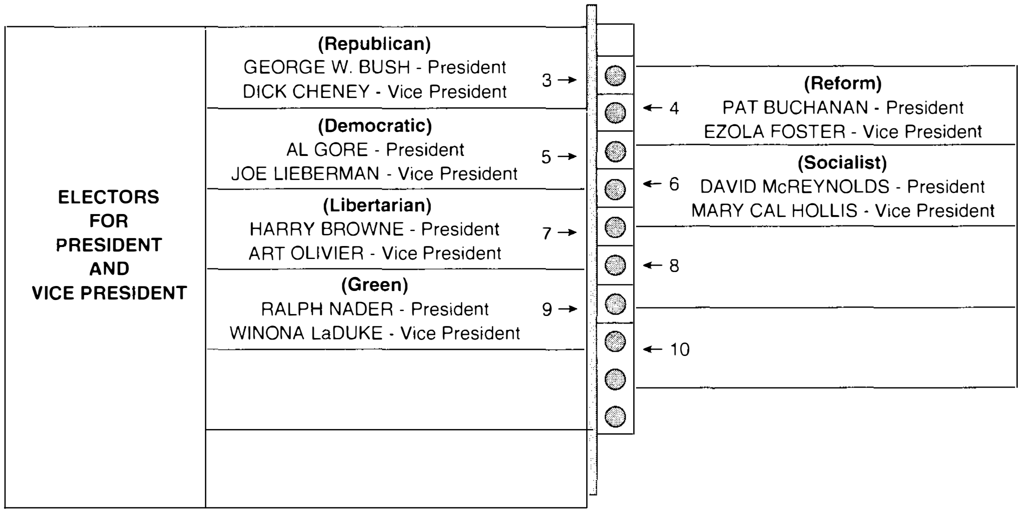

Figure 10.2 Recreation of the relevant portion of the 2000 presidential double-column "butterfly" ballot from Palm Beach County, Florida, U.S. A variety of evidence (as well as graphical logic) suggests a significant minority of voters who intended to vote for the *second* candidate on the left list punched the *second* hole from the top, which was actually a vote for the top candidate on the right list.

data display if it doesn't facilitate communication of the data's meaning. Below, we consider some display adornments that are, in the end, "unattractive" in this way.

Tables

Tables are organized lists, arrays, or matrices of data. They show data values directly with numbers (or class labels for nominal variables), and unlike the other display types we discuss in this chapter, tables make only minimal use of spatiality. For instance, data values are often sequentially ordered in table space according to their numerical magnitudes, and variables usually correspond to spatial dimensions. That is, distributions of single variables map directly onto one-dimensional lists (vectors), and joint distributions of two variables together map directly onto two-dimensional arrays or matrices. Given the two-dimensional "flatness" of tables, joint distributions of three or more variables have to be shown indirectly with hierarchically articulated two-dimensional displays, such as two neighboring tables that represent the two levels of a third variable. With respect to spatiality in tables and graphs, the **stem-and-leaf display** is an interesting case in point (see Figure 10.3). Unlike a standard table, it uses spatial magnitude (line length) to communicate perceptually the frequencies of values in particular ranges of the data. This is the kind of communication device a graph uses, and for that reason, we think of the stem-and-leaf display as "hybrid" between tables and graphs.

As we advised above, when you have only a handful of values, you should probably just verbally state the values without a data display. If you decide you do want

Ozone Concentration in Hundreds of PPB
Downunder, Queensland
October 11–December 5, 2003

Stems	Leaves
0	477
1	002559
2	0114577889
3	000112344566689
4	1224569
5	026
6	01578
7	245799
8	3
9	–

Figure 10.3 A stem-and-leaf display, essentially a hybrid display between tables and graphs. The fictitious data values are daily ozone concentrations in hundreds of parts per billion for the equally fictitious town of Downunder in Australia.

to display data, tables are often a good display choice when you want to show data values precisely and in detail, although even this becomes hard to do effectively with a table when you have a very large number of data values to communicate. In fact, although it is useful to record data values precisely and in detail when the table is functioning archivally, it is usually not so useful when tables function to communicate. One more often wants to communicate general patterns of data. As such, values in tables should be adequately rounded in order to support effective communication of general patterns. At the least, the spurious precision defined in Chapter 2 should be avoided in tables. Believe it or not, one almost never cares to see the fifth digit after the decimal, perhaps not even the first or second.

Tables depict data in one of two ways. The first is to present the overall distribution of the data by showing all of the values in the data set and how many scores have each value. That is, such **distribution tables** show the **frequency** of data values; alternatively, they can show **relative frequency** (as proportions or percentages), **cumulative frequency**, or **cumulative relative frequency**. Distribution tables can also present data in terms of derived scores, such as percentiles or *z* scores (see Chapter 9). A special type of distribution table called **contingency tables** can show relationships between nominal variables or metric variables that can be grouped into discrete classes; they show the frequencies of cases across levels of one variable cross-tabulated against frequencies of a second variable. The second way tables depict data is to present summary descriptive indices calculated on the data. Such **descriptive index tables** can present measures of central tendency, variability, relationship, and so on.

As we suggested in Chapter 9, the limiting example of a table is an unorganized printout of raw data values. Most people would not consider this much of a table until the data values were organized or summarized in some informative way. A typical way to do this is simply to order the values from lowest to highest, or vice versa. When displaying nominal variables, there is no natural numerical order to the data, even if the nominal classes have been given numerical labels. You can use arbitrary ordering; with some nominal variables, it might make sense to use an alphabetical ordering. But often, you can communicate more effectively by ordering the nominal classes according to the magnitudes of frequency within the classes or some other logic; you might organize country names according to country proximity, for example.

Finally, metric-level data values in tables as well as graphs are often grouped into classes or intervals in order to facilitate efficient communication of the pattern of the data. For example, one often sees incomes expressed in terms of something like "less than \$20,000," "at least \$20,000 but less than \$40,000," "at least \$40,000 but less than \$60,000," "at least \$60,000 but less than \$80,000," "at least \$80,000 but less than \$100,000," and "over \$100,000." There are a great variety of ways to create these **class intervals**. To begin, there is the question of how many classes there should be. It is not possible to answer this formulaically, but there should probably be at least three or four classes but no more than 10 or so; more can sometimes be appropriate, however. Either all intervals are bounded with minimum and maximum values, or upper or lower intervals may be open-ended, as in our example above. All intervals may be of the same width or different widths. Likewise, intervals may contain the same number of cases or different numbers. The widths and frequency counts of intervals depend on the design rule you use to construct the intervals.[5] For example, if you decide to let the data pattern itself dictate where interval breaks go (so-called natural breaks), you are almost certain to have intervals of varying widths *and* counts. Often, when constructing classes for variables that are bounded on only one end, such as a ratio-level variable with a zero value on one end like in our income example, interval widths should perhaps increase in a nonlinear fashion as one moves toward the unbounded end. After all, the effective difference, whether economic, social, or psychological, between making \$20,000 and \$40,000 is greater than between \$80,000 and \$100,000.

Graphs

Graphs are pictorial representations of data. They show data values by metaphorically mapping them onto the spatial and nonspatial properties of images. For example, a higher value in the data is usually shown as being higher on the graph image, or a particular vegetation region is shown by a particular line pattern. Graphs typically include numerical and verbal symbols as well. But the use of spatial properties such as location, size, distance, and direction to represent data is at the heart of what a graph is and how it functions. Well-made graphs are particularly effective for communicating general rather than precise patterns of data values, although some researchers place precise data values redundantly on their graphs, next to the symbol whose properties also encode the data values. Using graphs to communicate data patterns is especially useful with large data sets.

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[5]In a cartographic context, the way class intervals are created is recognized as an especially important issue because it affects the visual impression created by, especially, choropleth maps. In the case of choropleth maps, however, perceptual considerations definitely keep the effective, and therefore recommended, number of classes down to around seven.

Table 10.1 lists some principles of good graphing, organized into three dictums. The first is to clearly and sufficiently label the graph and its parts. This includes labeling the units of variables on the axes with **tic marks.** It is possible to use too few or too many tic marks and labels; you want to be adequately informative while avoiding unnecessary clutter. As Table 10.1 points out, a general rule is to aim for something like 4–10 tics. The second dictum is to avoid uninformative and content-free graphic marks. Graphs should draw attention to their data rather than themselves. The third dictum is to fill the graph space with data marks. This should be done whenever there is no constraint on what values should be placed at the lower and upper ends of the axes. It stretches the data pattern out as far as possible, facilitating the display of variation over the graph space. Of course, if you want to emphasize a lack of variation, you should ignore our advice and choose axis values far above and/or below the values in your data.

In other words, you can manipulate the range of your axes in order to exaggerate or minimize data variation. Is that propaganda? Yes, trying to direct people to focus on what you want them to focus on and away from what you don't want them to focus on is at least "impression management." But, arguably, there is no way to avoid directing people like this, accidentally if not intentionally. It doesn't seem insidious to us as long as your ultimate objective is communicating truth, as you understand it. And as long as you have followed the other principles of good graphing, particularly those under the first dictum to label clearly and sufficiently, you are not deceiving consumers of your graph. At this point, people often recall the quote attributed to the statesmen Benjamin Disraeli: "There are three kinds of lies—lies, damned lies, and statistics." It is certainly true that statistics (data) can be displayed in ways that communicate deceptively. However, although amusing, we find this quote misleading. Data don't lie to people; *people* lie to people—with intentionally poor data collection, analysis, and especially display.

There are a variety of more or less standard graph styles available to the researcher, and new styles continue to be invented. Here are some guidelines for choosing among them; as *guidelines,* they should probably be ignored on occasion. The first consideration is whether you are graphing the distribution of one or more variables, or the relationship between two or more variables. **Distribution graphs** depict the distributions of variables, most often employing a two-dimensional space whose mapping onto data values is defined by two axes that meet at a right angle[6] (but see our discussion below of dimensionality in graphs). The values or ranges of values of the variable are typically displayed on the horizontal **X-axis** or **abscissa.** The frequency (or relative frequency, and so on, as discussed above with tables) of each value or range of values is displayed on the vertical **Y-axis** or **ordinate. Relationship graphs** depict the form and strength of relationships between pairs of variables, again most often with a two-dimensional space. The values or ranges

[6]Not all graphs should use the standard **Cartesian coordinate axes** (X and Y) meeting at right angles. When you have cyclic data, such as directions in space or measurements in repeating time periods, you may want to use **polar coordinate axes.** The fact that normal Cartesian axes meet at a right angle implies that X and Y are uncorrelated. If they are in fact somewhat correlated, you can suggest that by using oblique Cartesian axes.

Table 10.1 Principles of Good Graphing

Dictum 1: Label Clearly and Sufficiently.

- Always include a title or caption (sometimes put in a caption).
- Always label the variables that are expressed on each axis, and their units (as appropriate).
- Mark each variable's units on its axis (stay away from excessive precision); label the class names of nominal variables and the numerical values, or ranges of values, of ordinal and metric values.
- Indicate positions of the values of variables on the axes with tic marks; as a general rule, aim for something like 4–10 tics.

Dictum 2: Avoid Uninformative and Content-Free Graphic Marks.

- Marks should provide useful or necessary information, not just "decoration."
- This includes dots, lines, patterns, labels, and so on
- Reduce the size, brightness, and attention-grabbing hues of less important marks that do not show data patterns of central importance.
- Avoid visual clutter, vacuous complexity, moiré patterns, 3D symbols for 2D data.

Dictum 3: Fill the Graph Space with Data Marks.

- Stretch out the data pattern as much as reasonable within the graph space.
- Do this by choosing minimum and maximum units on the axes so there are values somewhere within the graph near the lowest and highest values on the axes.
- Use nonlinear axes when appropriate (for example, logarithmic scales)
- Truncate axes to help accomplish this, as appropriate; if a truncated axis represents a ratio-level variable (a metric variable with a true "0"), use **interruption tics** (something like "+") on the axis to indicate that it has been truncated.
- When two or more graphs are to be directly compared, use identical graph formats to facilitate their direct comparison (for example, small multiples).

of values of one variable are displayed on the X-axis; those of the other variable are displayed on the Y-axis. More complex relationships, such as the relationship between two variables separately for each level of a third variable, can be displayed by using three spatial dimensions, using nonspatial symbols like color hue, showing separate two-dimensional graphs for each level of a third variable, and so on.

Two additional considerations when choosing a graph style are whether variables are discrete or continuous, and the level at which they were measured. We present these together because their meanings, including the way they influence graph choice, are partially related; remember from Chapter 2 that nominal and ordinal variables must be discrete, but interval and ratio (metric) variables can be either discrete or continuous. Figure 10.4 shows schematic examples of various common graph styles. Distribution graphs of nominal or ordinal variables should generally be made with a discrete graph style, such as the **bar graph** (bar chart). Like tables of nominal variables, graphs of nominal variables should also order values according to some useful communication logic such as class magnitudes. Distribution graphs of discrete metric-level variables can use a discrete graph style such as the **histogram**, which is a bar chart whose bars' widths represent the range of a quantitative class interval for a metric variable. For example, spectral frequency data generated by remote sensing are traditionally graphed with a histogram densely filled with bars. A style of distribution graph that necessarily shows relative frequencies (proportions) is the **circle diagram**, known by many people as the "pie chart." They are a poor choice for variables above the nominal level because they force a confusing circular logic onto the linear sequential logic of ordinal and metric variables; cyclic variables such as measurements over 360° of direction or 12 months of a year might work fine, however. Distribution graphs of continuous variables should generally use continuous graphing styles, the most common of which is the **line graph** (polygon or "connect-the-dot" graph). That deserves emphasizing: *Line graphs are strictly correct only for graphing continuous variables.* That's because a line itself is continuous, so that as a visual metaphor it implies continuously filled intervals between any two data values; it's probably a good idea for those filled intervals to be conceptually possible. Finally, we should point out that distribution graphs sometimes show a statistical model of a distribution that has been fitted to the data (Chapter 9), perhaps by overlaying a line or bar graph over the data itself; these are **curve-fitting graphs.**

In addition to styles for distribution graphs, there are a few graph styles specifically appropriate for relationships. Showing relationships between two classed variables, especially nominal variables, is almost always done with the contingency table we mentioned above instead of a graph. If the *Y*-variable is metric, either bar or line graphs can be used to show relationships, depending on whether the *X*-variable is classed or continuous. Probably the most common way to graph relationships with any type of data is the **scatterplot**. A dot is placed at the intersection of imaginary lines emanating from each data point's values on the X- and Y-axes. This produces a "scatter" of dots; as shown in Figure 9.3 of the previous chapter, the width and shape of this scatter indicates relationship strength and form. As Figure 9.3 also shows, relationship models are sometimes depicted on scatterplots by overlaying straight or curved lines on the dots.

There is one specialized relationship graph appropriate specifically for showing relationships among three variables that are mutually interdependent so that their proportions must sum to 100%. This is the **ternary diagram**, also known as the "trilinear" or "triangle" plot. It is the standard way to show the relative proportions of sand, silt, and clay that determine soil texture (Chapter 4). Ternary diagrams manage to depict three spatial dimensions of information with a two-dimensional figure, and because of this, they can be tricky to interpret at first. As Figure 10.5 shows, there are three Y-axes on a ternary diagram, one for each of the three variables whose proportions are shown. The three axes are not the three sides of the triangle, however; they are the three intersecting bisector lines within the equilateral triangle. To read off the proportion of sand in a particular batch of soil, for example, focus on the bisector line that starts from the center of the side labeled "Sand." That line starts at soil with 0% sand and ends at the opposite vertex, which is soil with 100% sand; it makes sense that a vertex represents 100% of one of the components because

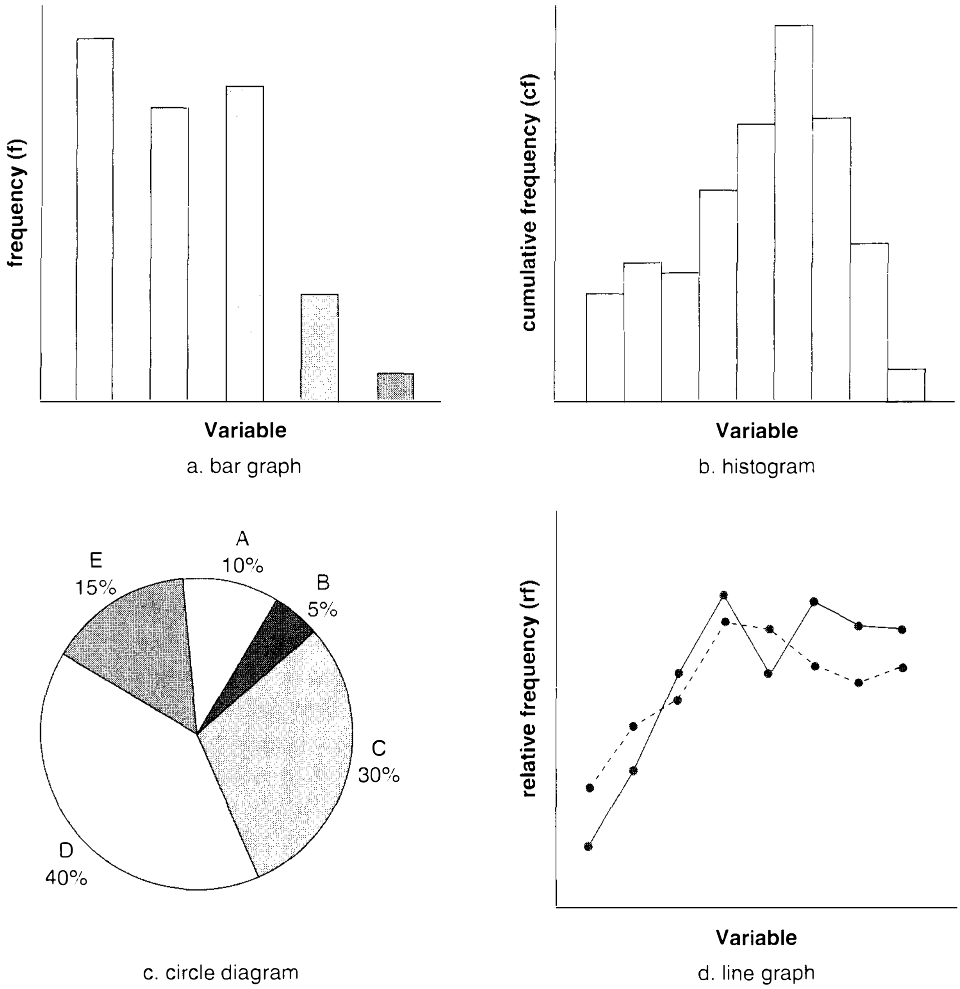


Figure 10.4 Schematic examples of graph styles (real graphs need captions, labels, and so on, as described in the text).

vertices are always at the 0% baseline of the other two variables. Any line parallel to the sand baseline shows all soils with intermediate proportions of sand, according to where that line intersects the vertical sand axis. Likewise, the proportions of silt and clay in a particular soil can be read off the vertical axes that bisect from the center of those sides. When these vertical bisector lines are left out of the diagram, as is sometimes done, interpreting ternary graphs can become confusing for the novice, who typically tries to interpret the sloped sides of the triangle as axes.

Above, we pointed out that the typical graph employs two dimensions of space, as coded by the two axes X and Y. In fact, even traditional flat graphs have three dimensions of space available to encode data, and any number of additional dimensions that can be thematically encoded. Spatially three-dimensional graphs are sometimes made, and sometimes they are a good idea, but not too often. Perceptually,

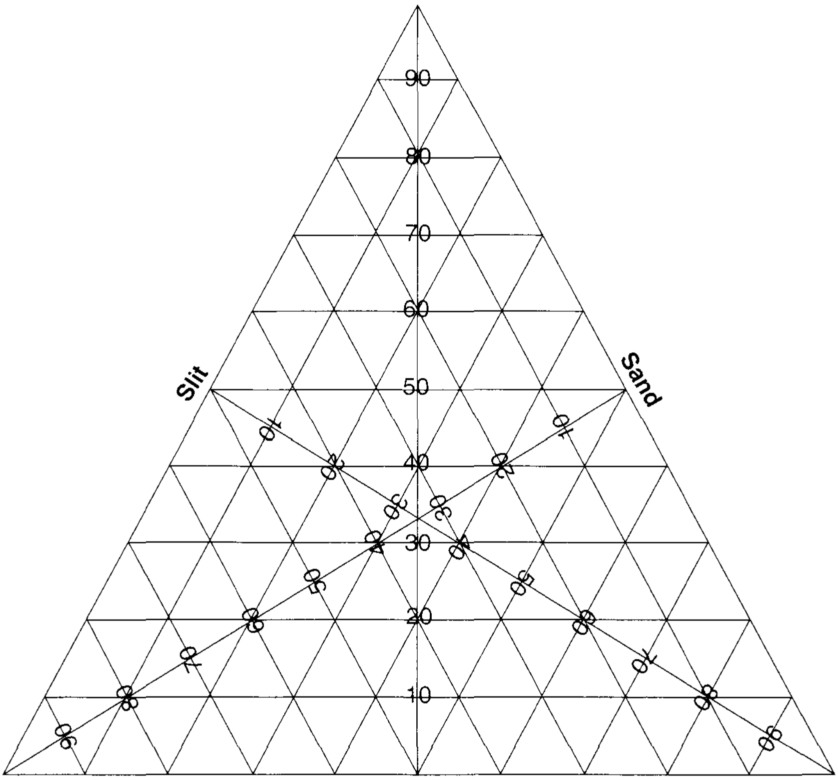


Figure 10.5 The classic example of a ternary diagram showing the relative components of sand, silt, and clay that determine soil texture (graphic by M. V. Gray).

locations displayed on the X- and Y-axes are seen quite differently than locations on the protruding/receding "Z-axis" of the third dimension. For example, there is foreshortening of the third dimension. Graphically, it is challenging to display information on the "virtual" third spatial dimension of a two-dimensional image, whether paper or CRT screen, in the same way it can be displayed on the "real" first and second dimensions. Using three spatial dimensions to depict information probably works much better on a dynamic display that can be manipulated by the viewer, because which dimension plays the role of Z can be alternated. On a static image, it is usually a better idea to depict a third variable by the use of hierarchically grouped bars, multiple lines, or various thematic codes such as size, colors, patterns, or texture[7] (yes, we know size is a spatial property but not one that requires locational coding on a graph axis). A particularly effective graphing style for geographic

[7]We do not like **stacked bar graphs** as a way to show more variables of data, however. They obscure direct comparisons across classes except for the class at the bottom of the bars, because only that class starts at the same baseline location on each bar.

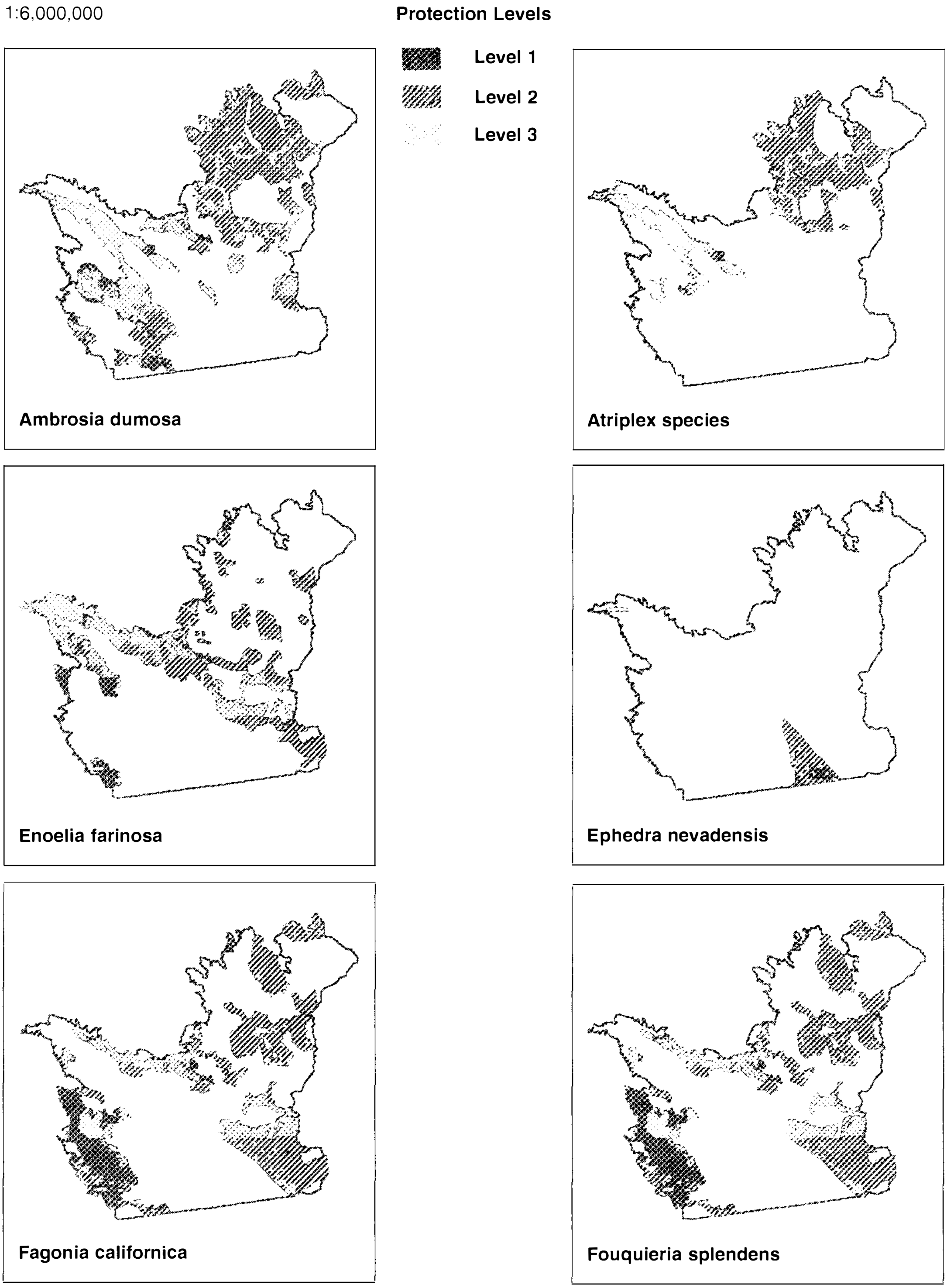


Figure 10.6 Example of a small multiples graph/map; depicts the management status for species of desert-scrub shrubs in the Colorado (Sonoran) Desert of southeastern California. (Graphic by M. V. Gray. Reprinted with permission.)

data in many situations is the **small multiples** graph (Figure 10.6), which is really a type of thematic map when its repeating graph space is an earth-surface base map like in this figure.

We offer a final admonishment about graph dimensionality. Many people, especially new researchers, have a predilection for graphing data with three spatial dimensions when they are only depicting two dimensions of information. For example, just about any graph style can be converted into **simulated 3D**; 3D bar graphs using rectangular prisms are a common example. We agree with the advice of most graphical experts, such as those whose books are included in the Bibliography, that the use of the third dimension in this way for purely "decorative" purposes, when it carries no information, is bad graphing practice.

Maps

Maps are graphic displays that depict earth-referenced features and data (geographic information), using a graphic space that represents a portion of the earth's surface.[8] The earth surface depicted in this graphic space is designed to resemble the actual earth surface more or less closely. But either way, as a map rather than a graph, the actual spatial layout of features on the earth's surface is always shown directly as a spatial layout on the map. Maps are obviously the quintessential geographic display, and geographers, specifically cartographers, are the experts of the map as a data display tool. Therefore, just as we apprised you of the need to take specific data analysis courses in Chapter 9, we urge you to take at least one course that focuses on cartographic display and interpretation. There's much more worth learning about designing and using maps than we cover here.

There is an important distinction between reference maps and thematic maps. **Reference maps** focus on depicting a variety of actual earth-surface features as accurately and precisely as possible. In an effort to achieve general-purpose functionality, reference maps tend to show the most significant features that a person could potentially perceive directly while moving about the planet. Feature locations are encoded with a **coordinate system**; the latitude-longitude **graticule** is just one of many. "Significant" features are typically things that are large, relatively stable over space and time, relevant to the basic shape of the earth's surface from a human perspective, and so on. Standard examples include ground surface topography, water bodies of sufficient size, forested areas, cities, transportation networks, and so on. In truth, though, whatever individual or organization chooses what to include and what to exclude on a map is intentionally or inadvertently working from a

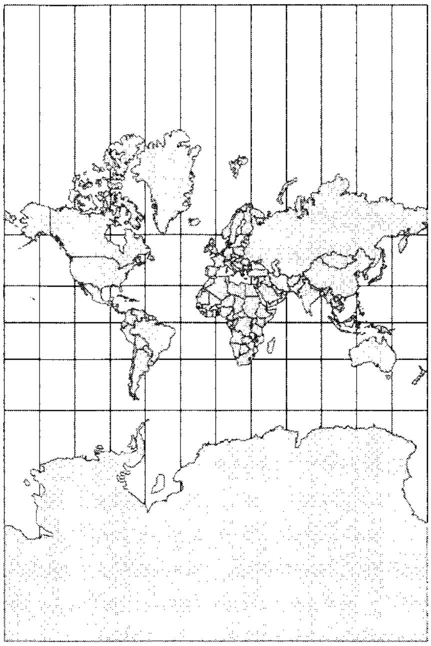
[8] We refer here to a traditional conception of a cartographic map. Terms like "map" and "mapping" are extremely broad and are used in many disciplines to refer to a spatial or structural representation of information of any type. Not only are there maps of other planets, of the universe, of molecules and electrical circuits, there are "maps" in the mind and in the brain, in families, in cultures, in administrative and economic institutions, in the genetic code, and so on. Indeed, central intellectual and informational concepts such as symbol, representation, semantics, and metaphor all involve a notion of "mapping" from one thing to another.

conception of what map viewers do or do not need to see, or should or should not be allowed to see. As with graphs, you can call it propaganda or call it informational impression management.

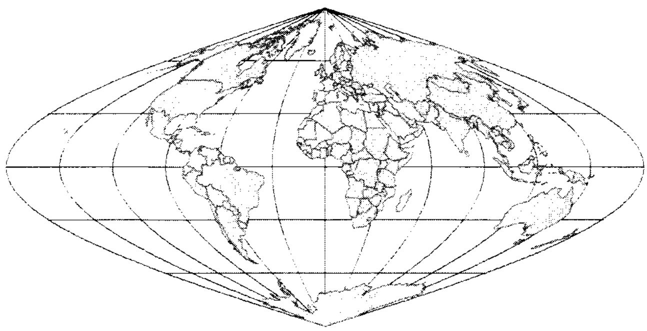
Thematic maps, in contrast, are special-purpose displays. They focus on showing the spatial distribution of one or a few thematic variables, often variables like "AIDS incidence" or "average insolation" that are not easily perceptible from a single place or at a single moment, if at all. Unlike reference maps, thematic maps depict very little actual earth-surface detail, and locational accuracy and precision tend not to be their strengths. Thematic maps are really hybrid "map-graphs" that use a simple geographic base map for the graphic space so that thematic variables can be "geo-referenced" (Chapter 12). See Figure 10.8 for an example of a thematic map; we discuss the map further below.

Having said that maps always depict aspects of spatial layout directly is not to claim that this spatial layout is necessarily undistorted on the map—far from it. Maps always distort the earth's surface and the features and variables arrayed thereon, including spatial layout and virtually all other properties and attributes. Perhaps foremost, maps always require **selectivity**. There is no way to show all the details of a portion of the earth's surface on a map, no matter how big your supercomputer is, so decisions must always be made as to what to include and what to exclude. Even to the degree it is possible to include great detail on a map, it is typically unwise to do so. That's because selectivity and carefully applied distortion is a considerable source of the effectiveness of maps as communication displays. Remember the London tube map in Figure 10.1?

Even if it did not serve the purpose of communication, all spatial properties of earth features, including size, shape, distance, direction, and connectivity, would never be shown accurately on a map. That's because they *cannot* be. It has been proven, and it may strike you as intuitively evident if you think about it, that you cannot flatten the curved earth surface onto a piece of paper or a computer screen without distorting one or more of the spatial properties listed above. The standard demonstration of this is to imagine peeling an orange in one piece and then flattening it on a table—you will have to tear the peel up pretty well to get it all flat. The topic of cartographic **projection** concerns the many different ways of "developing" (flattening) the earth surface, or any portion thereof, and the patterns of spatial distortion that result. Figure 10.7 shows just two examples of projections, the Mercator and the sinusoidal, and their patterns of distortions. There are in fact more than a hundred projections that cartographers have studied over the centuries, and an infinite number are possible. Don't be misled by the fact that our figure shows *global* projections. It is true that necessary spatial distortion is greater as more of the earth surface is depicted (smaller cartographic scale), but all maps distort spatiality, even maps of your neighborhood. It's just that the necessary distortion is so small on very large-scale maps that you don't see it. Different projections should be chosen for different map uses, so that important information is relatively undistorted or distorted in acceptable ways, whereas less important information can be more distorted. The Mercator map was created for use by navigators on the high seas, because it shows constant compass directions as straight lines on the map. To achieve this considerable benefit, it must greatly exaggerate the size of landmasses toward the poles relative to those toward the equator; did you know that Brazil is actually a little over four



a. Global Mercator projection.



b. Global sinusoidal projection.

Figure 10.7 Two examples of global map projections, (a) Mercator and (b) sinusoidal. The Mercator greatly distorts the size of landmasses relative to each other, and the sinusoidal greatly distorts their shapes (both projections distort other spatial properties too). (Graphic by Sarah Battersby. Reprinted with permission.)

times *larger* than Greenland? Because of this exaggeration, the Mercator is a poor choice as a general world map for atlases or K–12 education, a job to which it has unfortunately been put at times in many parts of the world.

Maps distort spatial and nonspatial properties for other reasons than projection. As we mentioned above, maps cannot avoid simplifying reality, and we wouldn't have it any other way. **Generalization** refers to the amount of detail included on features as they are mapped. It is essentially an issue of simplification, but also includes aspects of selection and enhancement of features of particular interest. For example, maps show rivers with fewer meanders and coastlines with fewer crenulations than they actually have. Thematic maps show regions, such as climate or cultural regions, as much more homogeneous and crisply bordered than they actually are. Furthermore, there tends strongly to be more simplification of detail as one represents larger portions of the earth surface, that is, as one makes smaller-scale maps. Features are also exaggerated for graphic legibility and to direct attention to more relevant information. Take a look at a road map of a country or continent. Measure the width of the highway and use the scale factor to translate it to the actual width it would have in the real world at that graphical width. You'll come up with an answer in the miles or tens of miles. But if it were shown at accurate scale, it would be hard to see.

The symbols on maps can be relatively easy or difficult to interpret, and when they are interpreted, they are often *mis*interpreted to some degree. Maps represent features and properties of the earth using spatial and nonspatial graphic properties, including location, size, shape, patterns, textures, color hue, color value, and more. Above, we pointed out how maps resemble the reality they represent more or less closely. That is, symbolic representation on maps is relatively **iconic** (mimetic) or **abstract** (conventional). The fact that maps show spatial layout on the earth with spatial layout on the image is an iconic aspect of how they represent. More distant features are usually shown as further apart on the map, features that are connected are usually shown as connected, and features to the southwest of other features are usually shown to the lower left (assuming a north-up map orientation). Other symbols are more or less iconic. Larger **graduated circles** represent larger cities, green represents vegetation and blue represents water, and a pick and shovel represents a mine. Some symbols, in contrast, are quite abstract. A bunch of contour lines does not look like a hillside, a checkered pattern does not look like high fertility, and a small square does not resemble the scene of a tornado touchdown. Even vegetation does not always look green, and water certainly does not look blue all the time. The most abstract of symbols on maps are the words on it. How does the phrase "tourist attraction" look like Carhenge, a simulated Stonehenge in western Nebraska made from buried automobiles?

Just as there are principles of good graphing, there are principles of good mapping. In fact, such principles are more complex for maps and harder to present as a simple list. That is why we urge you to take a course or two that covers cartographic design and read books like those we list in the Bibliography. The rationale behind good map design is the same as it is behind the design of other displays. Maps should be designed to facilitate effective and efficient communication to one's self and other people. A variety of general pieces of advice about map design follow from this, including that you should choose relevant and high-quality data, show them clearly and truthfully, highlight the important and downplay the less important, focus on the data and not on mere decoration, and so on. One of the central issues in the design of maps, especially thematic maps, is to make good choices for map symbols to represent data variables and their values. This is the same concern we have with graphs when we choose a bar graph over a line graph, or vice versa, because of the nature of the underlying variables being graphed. But the issues are more involved when it comes to maps. For example, graphs usually do not incorporate color except for decorative purposes, whereas maps nearly always involve various aspects of color (**hue**, **value**, **saturation**) as communication symbols, or **visual variables**. And of course, graph space is abstract and shows metaphorical "data space," whereas map space always corresponds to earth-surface space, with greatly varying amounts of detail, precision, and realism called for. Because maps show the earth, they require more sophisticated spatial annotation, such as compass roses, distance scale factors, and coordinate system grids. These features are called **map elements** because they describe basic characteristics of the mapped portion of earth surface.

Take the example of **choropleth maps**. This is a widely used style of thematic mapping in which discrete regions, such as countries or census tracts, are filled with colors, shades of gray, or textures that represent the values of some quantitative variable (see Figure 10.8). Since a finite number of classes are mapped, the data must be grouped into classes or intervals; if you try to avoid the grouping by mapping a continuous visual variable onto a continuous data variable, your visual system will do the grouping anyway, resulting in a *de facto* set of about 5–10 classes that your visual system decides how to create. All the usual questions result about how many and which classes to use. What visual variables should be used? Hue (red, yellow, blue, and so on) is usually a poor choice here, with some notable exceptions, because people generally interpret it to correspond to qualitatively different classes rather than quantitatively spaced amounts; in other words, hue is good for nominal variables, as in Figure 10.8. Area patterns like dots or hatchings are usually a poor choice for the same reason. Color or gray tone values typically work well. However, choropleth maps are not too good if you are mapping a thematic variable that is assessed on something other than spatial area. It's fine for precipitation because that variable is assessed per areal unit like square kilometers. It's not good for population-based variables, such as birth or death rates, because large areas with low populations (such as Siberia) are given far too much visual emphasis compared to small areas with high populations (such as the city of Moscow). Many authors recommend an alternative in these cases, such as the **population cartogram** shown in Figure 10.8.

New Trends in Scientific Visualization

Humans have made forms of reference maps for several thousand years. In comparison, thematic mapping is a rather modern invention, having been around only since the 18th century or so. But since the 1970s and 1980s, there has been a bloom of innovation in the display of geographic information—indeed, in the display of all types of information. These innovations have of course been spurred on primarily by computer hardware and software. Computer technologies, and other technologies dependent on the computer, have made possible a variety of computationally intensive analytic techniques, and a variety of new display formats and "information interfaces." They have also led to a stunning increase in the amount and complexity of data and other information we have to comprehend and communicate in the first place. This has provided us with great challenges even as it has provided us with great opportunities.

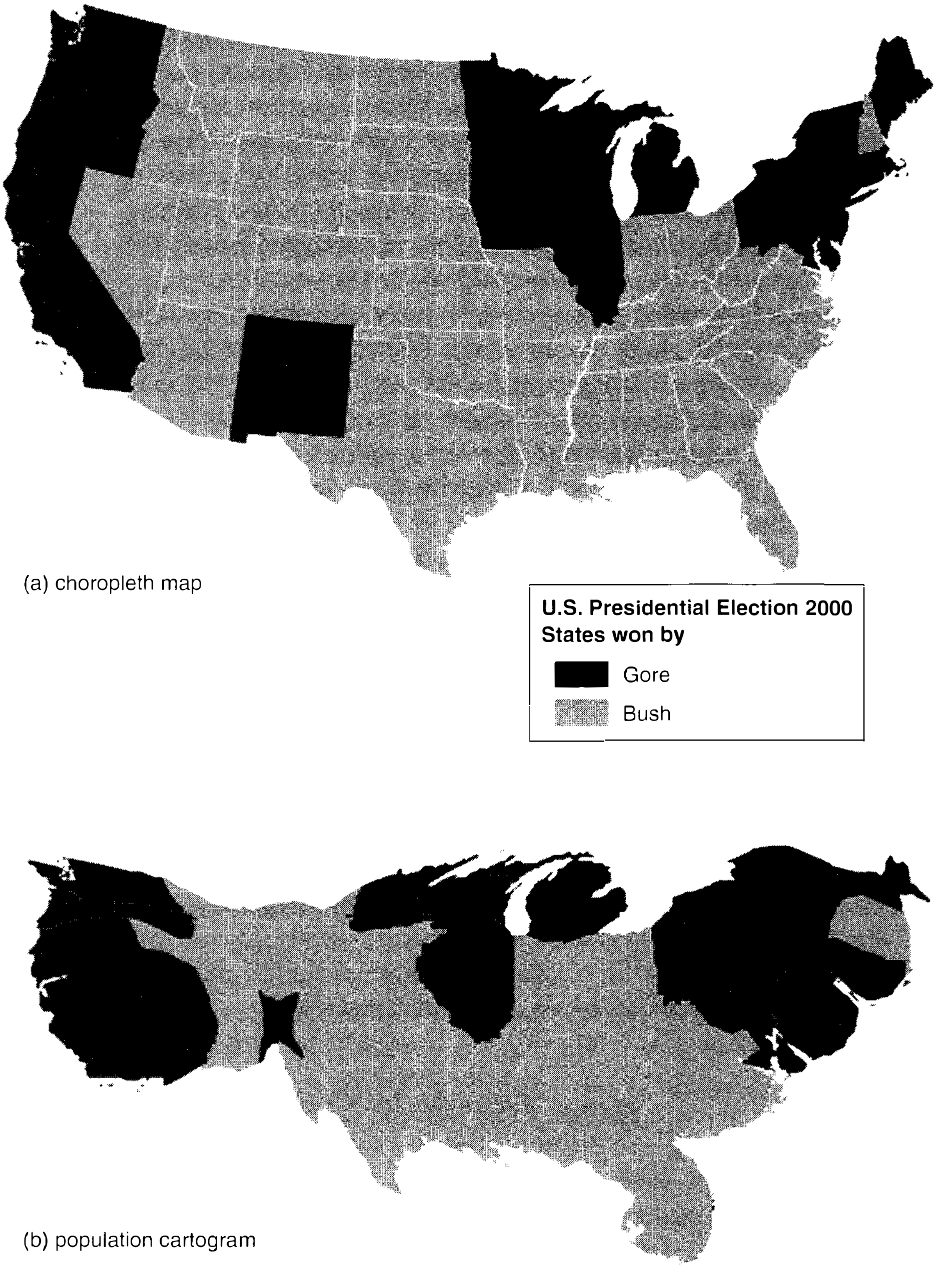


Figure 10.8 Thematic maps of the conterminous United States showing the breakdown of the electorate by state in the 2000 U.S. presidential election. The top map (a) is a traditional choropleth map showing geographic areas accurately but distorting each state's population. The bottom map (b) is a population cartogram map showing each state's population accurately but distorting geographic areas. Cartographic principles would suggest using less saturated colors, but intense red and blue have become standard symbols for the Republican and Democratic parties in the United States since this election. (Graphic by Sara Fabrikant. Reprinted with permission.)

We noted above that geographers and other scientists are quite interested in the techniques of exploratory data analysis. **Information visualization** is a key to exploratory data analysis. Such techniques are especially valuable with large data sets that are spatially and temporally distributed. In Chapter 12, we discuss the power of visualizing information against its geographic background with the help of computer geographic information systems; this is often called **geo-visualization.** Given the power that spatiality lends to the search for patterns in data, as when graphs display numerical information pictorially, it has been proposed that the interpretation of very large data sets that are not necessarily spatial (such as a corpus of news stories) could benefit from display in spatial and even geographic form, such as in the form of simulated landscapes; this technique is called **spatialization.** Other technologies of the last couple decades allow researchers to generate multiple views of data, at multiple scales and from multiple perspectives, relatively quickly and easily. The speed with which the visualizations can be created is important, because the nature of human perception and working memory requires that information must be accessed within particular time parameters if it is to be mentally integrated, compared, and so on, by an analyst.

Technologies allow some truly novel ways of looking at data. Manipulable or interactive graphics can be made, graphics that incorporate pop-up menus, "slider bars," "brushes," "magic lenses," and more; see texts listed in the Bibliography. **Animations** allow dynamic displays so data that include change over time can be directly visualized. In fact, even nontemporal information can be expressed with temporal visual variables, allowing us to increase the information dimensionality of our displays by adding rate, rhythm, regularity, and other temporal properties to our toolbox of visual variables. **Augmented reality** combines digital displays of data superimposed and appropriately keyed and updated to the actual surrounds in which researchers find themselves; it might be viewed via electronic "data goggles." This could give researchers access to data and analysis in new ways and in new situations, for instance, while they are in the field. Going further, **virtual reality (VR)** is a way of simulating places in natural or built environments that offers the prospect of allowing people access to places without the cost of actually traveling there. As a research tool for data collection in human behavioral geography, VRs also allow one to exert empirical control (see Chapter 7) over variations in places that is difficult or impossible to achieve otherwise. There are a variety of such interactive, real-time, 3D graphical displays that display information from a first-person perspective and change appearance appropriately in response to movements by users (so-called **active control**). Various virtual systems include desktop displays, projected displays, "caves," and fully immersive systems. And while we're at it, why stop at *visual* display? There is great interest in the development of nonvisual and multisensory display technologies, and not just for people with visual disabilities. Researchers who specialize in studying and developing geographic information techniques have developed or at least proposed **sonifications** (sound displays), **tactilizations** (touch displays), and more ("smell maps" anyone?).

Of course, there is no guarantee that all of these technological possibilities really work well as display techniques. In fact, we are confident that some of the proposed and developed techniques do not work well. Remember, effective and efficient communication to humans is the point. Novelty and the "gee whiz!" factor might help you get funding, but by themselves, they are not adequate reasons to actually use something to interpret and communicate data. Educated, talented, and thoughtful judgment can certainly help decide whether a display method is a good idea. Researchers who specialize in studying and developing display techniques, including geographers, are also applying a scientific approach to help understand and evaluate the display innovations of today and tomorrow.

Review Questions

- What is data display, and what are some purposes of data display in research?
- What should we consider when deciding whether to use displays, as opposed to other forms of communication?
- What does the design principle of "effective communication" mean, and what are some considerations that stem from this principle?

Tables

- When does it make most sense to use tables to display data, rather than other forms of displays?
- What are distribution and contingency tables? What are frequency, relative frequency, cumulative frequency, and cumulative relative frequency?
- What are some choices for how to organize metric-level data into class intervals?

Graphs

- When does it make most sense to use graphs to display data, rather than other forms of displays?
- What are some principles of good graphing and specific design guidelines that derive from them?
- What are distribution and relationship graphs, and what are specific styles of each?
- What are the basic issues of dimensionality in graphing (including spatial, temporal, and thematic dimensionality)?

Maps

- When does it make most sense to use maps to display data, rather than other forms of displays?
- What is the distinction between reference and thematic maps, and why is it so important to considerations of map design?
- Selectivity, projection, generalization, and varying symbol abstractness are always involved in mapping. Why are they always involved, and why are they potentially misleading to map viewers?

New Trends in Scientific Visualization

- What is information visualization (including geo-visualization), and how does it go beyond the traditional graphical display methods of graphing and mapping?
- What are animation, augmented reality, virtual reality, sonification, and tactilization?

Key Terms

abscissa: the horizontal axis on a Cartesian coordinate graph; also known as the X-axis

abstract symbols: map representations not resembling the earth phenomenon they stand for; also known as conventional symbols

active control: property of information displays that change appearance appropriately in response to movements by users

animation: information visualizations in which change over time or other properties of data are displayed with moving or changing displays

augmented reality: interactive, real-time, graphical displays that display information superimposed over a person's actual surroundings as seen in the visual field

bar graph: graph style for discrete variables showing the frequencies or some other variable for each value on the X-axis by means of the heights of rectangular bars; also known as a bar chart

Cartesian coordinate axes: standard graph dimensions consisting of X- and Y-axes that meet at a right angle

choropleth map: widely used style of thematic mapping in which discrete regions are filled with colors, gray shades, or textures that represent the values of a quantitative variable

circle diagram: distribution graph for nominal variables showing relative frequencies; also known as a pie chart

class intervals: categories constructed to group metric-level data values into discrete ranges

contingency table: table showing relationships between discrete variables by cross-tabulating frequencies of the individual variables against each other

coordinate system: mathematical system for coding locations on the earth surface, particularly on reference maps

cumulative frequency: the frequency of each value in a data set accumulated as one moves from the lowest to the highest value, so that the frequency of the final value is the total number of scores in the data set

cumulative relative frequency: the relative frequency of each value in a data set accumulated as one moves from the lowest to the highest value, so that the relative frequency of the final value is 1.0 or 100%

curve-fitting graph: graph showing a statistical model that has been fitted to a data set

data display: graphical techniques for data communication and analysis, including tables, graphs, maps, and other visualizations

descriptive index table: tables presenting summary descriptive indices, such as central tendency, variability, or relationship

distribution graph: graph presenting the distribution of a data set by showing all of its values and their frequencies, relative frequencies, or cumulative frequencies

distribution table: tables presenting the distribution of a data set by showing all of its values and their frequencies, relative frequencies, or cumulative frequencies

exploratory data analysis: submersive, graphical, and ad hoc approach to data interpretation that emerged during the 1970s

figures: pictorial graphics used in scientific communication, including data displays, drawings, and photographs

frequency: how many scores have each possible value in a data set

generalization: the amount of detail included on features as they are mapped; primarily a function of simplification, it also includes aspects of selection and feature enhancement

geo-visualization: geographic information visualizations that include depictions of the earth-surface context of the information

graduated circles: common thematic map symbol in which a circle is placed at a location on the map so that its area is equivalent to the value of a quantitative variable

graphs: pictorial representations of data that metaphorically map data values onto the spatial and nonspatial properties of images

graticule: the latitude-longitude coordinate system on the earth or a representation of the earth

histogram: bar chart whose bars' widths represent the range of a quantitative class interval for a metric variable

hue: quality of color corresponding to its wavelength or mixture of wavelengths, including red, yellow, blue, and so on

iconic symbols: map representations resembling the earth phenomenon they stand for; also known as mimetic symbols

information visualization: any graphical or pictorial technique for displaying data, especially referring to computer techniques that take advantage of the computer's capabilities to create displays difficult or impossible to simulate on a traditional flat and static image

interruption tics: small marks used to indicate that a ratio-level Y-axis has been truncated

line graph: graph style for continuous variables showing the frequencies or some other variable for each value on the X-axis by means of the heights of points connected by straight line segments; also known as a polygon graph

map: graphic display depicting earth-referenced features and data with a graphic space that represents a portion of the earth's surface

map elements: symbols on maps, such as compass roses and coordinate grids, that describe basic characteristics of the portion of earth surface mapped

ordinate: the vertical axis on a Cartesian coordinate graph; also known as the Y-axis

outliers: unusual or extreme values in a data set

polar coordinate axes: circular graph dimensions consisting of a radius axis of varying length and angle; appropriate for cyclic data, such as directions in space or measurements in repeating time periods

population cartogram: style of thematic mapping in which discrete regions are expanded or shrunk so their areas represent the values of a quantitative variable

projection: geometric or mathematical solution to developing (flattening) the earth surface on a map

reference map: type of map that focuses on depicting a variety of significant earth-surface features as accurately and precisely as possible, with the intent of achieving general-purpose functionality

relationship graph: graph depicting the form and strength of relationships between variables

relative frequency: the frequency of each value in a data set, as a proportion or percentage of all the scores

saturation: quality of color corresponding to the brightness or intensity of its hue, varying from a pure gray tone to a pure chromatic hue

scatterplot: common way to graph relationships with any type of data; for each case, a dot is placed in the graph space at the intersection of each pair of values of the variables placed on the X- and Y-axes

selectivity: the fact that maps must necessarily depict less than all possible detail in the world

simulated 3D: graphing data with three spatial dimensions that depict only two dimensions of information; most authors advise against the practice, even though most computer graphics packages facilitate it

small multiples: type of graph or thematic map that repeats a framework graphic space several times in order to show the same variables according to instances of some repeating factor, such as data at several times or in several places

sonification: information visualization that incorporates sound as a symbolic medium

spatialization: information visualization using a simulated spatial entity, such as a geographic landscape, to metaphorically represent nonspatial information

stacked bar graph: bar graph simultaneously showing the distributions of two discrete variables by breaking each bar of the X-axis variable into the classes of a second variable

stem-and-leaf display: hybrid table-graph displaying a list of data values with the second digit of data precision (the leaves) arrayed in a line whose length spatially communicates frequencies, like a bar graph

tables: organized lists, arrays, or matrices of data

tactilization: information visualization incorporating haptic stimuli, such as texture or pressure, as a symbolic medium

ternary diagram: specialized three-variable relationship graph showing three dimensions arranged as the three intersecting bisector lines of an equilateral triangle, appropriate when the three variables are mutually interdependent proportions that must sum to 100%; also known as a trilinear or triangle plot

thematic map: special-purpose type of map that focuses on depicting the spatial distribution of one or a few thematic variables, usually with limited spatial accuracy and precision; essentially a hybrid graph-map

tic marks: very short line segments like hyphens indicating where particular data values fall along graph axes

value: quality of color corresponding to its lightness, varying from pure white through various shades of gray to pure black; characterizes both chromatic (with hue) and achromatic (black-to-white tones) tones

virtual reality (VR): interactive, real-time, 3D graphical displays displaying information from a first-person perspective and changing appearance appropriately in response to movements by users

visual variables: spatial and nonspatial properties of the appearance of map symbols that symbolically represent values of mapped variables

X-axis: the horizontal axis on a Cartesian coordinate graph; also known as the abscissa

Y-axis: the vertical axis on a Cartesian coordinate graph; also known as the ordinate

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