CHAPTER 10

DATA DISPLAY AND CARTOGRAPHY

CHAPTER OUTLINE

Maps are an interface to GIS (Kraak and Ormeling 1996). We view, query, and analyze maps. We plot maps to examine the results of query and analysis. And we produce maps for presentation and reports. As a visual tool, maps are most effective in communicating geospatial data, whether the emphasis is on the location or the distribution pattern of the data.

Common map elements are the title, body, legend, north arrow, scale bar, acknowledgment, and neatline/map border (Figure 10.1). Other elements include the graticule or grid, name of map projection, inset or location map, and data quality information. Together, these elements bring the map information to the map reader. The map body is the most important part of a map because it contains the map information. Other elements of the map support the communication process. For example, the title suggests the subject matter and the legend relates map symbols to the mapped data. In practical terms, mapmaking may be described as a process of assembling map elements.

Data display is one area in which commercial GIS packages have greatly improved in recent years. Desktop GIS packages with the graphical user interface are excellent for data display for two reasons. First, the mapmaker can simply point and click on the graphic icons to construct a map. In comparison, a command-line driven package requires the user to become familiar with many commands and their parameters before making a map. Second, desktop GIS packages have incorporated some design options such as symbol choices and color schemes into menu selections.

For a novice mapmaker, these easy-to-use GIS packages and their "default options" can re-

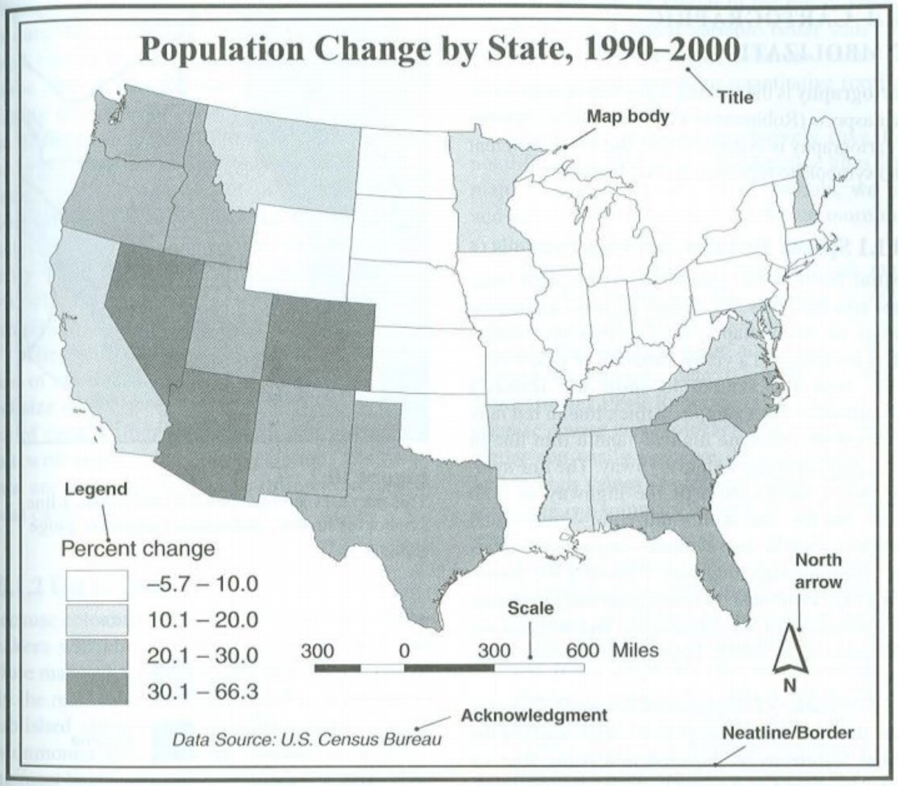


Figure 10.1
Common map elements.

sult in maps of questionable quality. Mapmaking should be guided by a clear idea of map design and map communication. A well-designed map can help the mapmaker communicate geospatial information to the map reader, whereas a poorly designed map can confuse the map reader and even distort the information.

Chapter 10 emphasizes maps for presentation and reports. Maps for data exploration and 3-D visualization are covered in Chapters 11 and 14, respectively. Chapter 10 is divided into the following five sections. Section 10.1 discusses cartographic symbolization including the data–symbol relationship, the use of color, and data classification. Section 10.2 considers different types of maps by function and by map symbol. Section 10.3 provides an overview of typography, the selection of type variations, and the placement of text. Section 10.4 covers map design and the design elements of layout and visual hierarchy. Section 10.5 examines issues related to map production.

10.1 Cartographic Symbolization

Cartography is the making and study of maps in all their aspects (Robinson et al. 1995). A basic element of cartography is symbolization, the use of different map symbols to represent spatial features.

10.1.1 Spatial Features and Map Symbols

Spatial features are characterized by their locations and attributes. To display a spatial feature on a map, we use a map symbol to indicate the feature's location and a visual variable, or visual variables, with the symbol to show the feature's attribute data. For example, a thick line in red may represent an interstate highway and a thin line in black may represent a state highway. The line symbol shows the location of the highway in both cases, but the line width and color—two visual variables with the line symbol—separate the interstate from the state highway. Choosing the appropriate map symbol and visual variables is therefore the main concern for data display and mapmaking (Robinson et al. 1995; Dent 1999; Slocum et al. 2005).

The choice of map symbol is simple for raster data: the map symbol applies to cells whether the spatial feature to be depicted is a point, line, or area. The choice of map symbol for vector data depends on the feature type (Figure 10.2). The general rule is to use point symbols for point features, line symbols for line features, and area symbols for area features. But this general rule does not apply to volumetric data or aggregate data. There are no volumetric symbols for data such as elevation, temperature, and precipitation. Instead, 3-D surfaces and isolines are often used to map volumetric data. Aggregate data such as county populations are data reported at an aggregate level. A common approach is to assign aggregate data to the center of each county and display the data using point symbols.

Visual variables for data display include hue, value, chroma, size, texture, shape, and pattern (Figure 10.3). The choice of visual variable de-

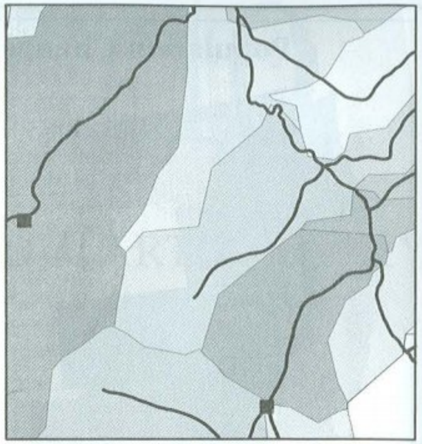


Figure 10.2
This map uses area symbols for watersheds, a line symbol for streams, and a point symbol for gauge stations.

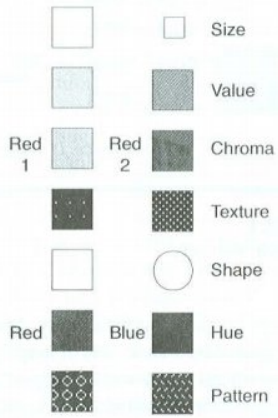


Figure 10.3
Visual variables in cartographic symbolization.

pends on the type of data to be displayed. The measurement scale is commonly used for classifying attribute data (Chapter 9). Size and texture (the spacing of symbol markings) are more appropriate for displaying ordinal, interval, and ratio data. For example, a map may use different-sized circles to represent different-sized cities. Shape and pattern are more appropriate for displaying nominal data. For example, a map may use different area patterns to show different land-use types. The use of hue, value, and chroma as visual variables is covered in Section 10.1.2. Most GIS packages organize the selection of visual variables into palettes so that the user can easily select the variables that make up the map symbols. Some packages also allow custom pattern designs.

The choice of visual variables is limited in the case of raster data. The visual variables of shape and size do not apply to raster data because of the use of cells. Using texture or pattern is also difficult with small cells. Display options for raster data are therefore limited to different colors in most cases.

10.1.2 Use of Color

Because color adds a special appeal to a map, mapmakers will choose color maps over black and white maps whenever possible. But color is probably the most misused visual variable, according to published critiques of computer-generated maps (Monmonier 1996). The use of color in mapmaking must begin with an understanding of the visual dimensions of hue, value, and chroma.

Hue is the quality that distinguishes one color from another, such as red from blue. Hue can also be defined as the dominant wavelength of light making up a color. We tend to relate different hues with different kinds of data. **Value** is the lightness or darkness of a color, with black at the lower end and white at the higher end. We generally perceive darker symbols on a map as being more important, or greater in terms of magnitude (Robinson et al. 1995). Also called saturation or intensity, **chroma** refers to the richness, or brilliance, of a color. A fully saturated color is pure, whereas a low saturation approaches gray. We generally associate higher-intensity symbols with greater visual importance.

The first rule of thumb in the use of color is simple: hue is a visual variable better suited for qualitative (nominal) data, whereas value and chroma are better suited for quantitative (ordinal, interval, and ratio) data.

Qualitative mapping is relatively easy. It is not difficult to find 12 or 15 distinctive hues for a map. If a map requires more symbols, we can add pattern or text to hue to make up more map symbols.

Quantitative mapping has received much more attention than qualitative mapping. Over the years, cartographers have suggested general color schemes that combine value and chroma for displaying quantitative data (Cuff 1972; Mersey 1990; Brewer 1994; Robinson et al. 1995). A basic premise among these color schemes is that the map reader can easily perceive the progression from low to high values (Antes and Chang 1990). The following is a summary of these color schemes.

- The single hue scheme. This color scheme uses a single hue but varies the combination of value and chroma to produce a sequential color scheme such as from light red to dark red. It is a simple but effective option for displaying quantitative data (Cuff 1972).
- The hue and value scheme. This color scheme progresses from a light value of one hue to a darker value of a different hue. Examples are yellow to dark red and yellow to dark blue. Mersey (1990) finds that color sequences incorporating both regular hue and value variations outperform other color schemes on the recall or recognition of general map information.
- The diverging or double-ended scheme. This color scheme uses graduated colors between two dominant colors. For example, a diverging scheme may progress from dark blue to light blue and then from light red to dark red. The diverging color scheme is a natural choice for displaying data with positive and negative values, or increases and decreases. But Brewer et al. (1997) report that, even in cases where the map reader is

asked to retrieve information from maps that do not include positive and negative values, the diverging scheme is still better than other color schemes. Divergent color schemes are found in many maps of Census 2000 demographic data prepared by Brewer (2001) **http://www.census.gov/population/www/cen2000/atlas.html).**

- The part spectral scheme. This color scheme uses adjacent colors of the visible spectrum to show variations in magnitude. Examples of this color scheme include yellow to orange to red and yellow to green to blue.
- The full spectral scheme. This color scheme uses all colors in the visible spectrum. A conventional use of the full spectral scheme is found in elevation maps. Cartographers usually do not recommend this option for mapping other quantitative data because there is no logical sequence between hues.

10.1.3 Data Classification

Data classification involves the use of a classification method and a number of classes for aggregating data and map features. A GIS package typically offers different data classification methods. The following summarizes five commonly used methods:

- Equal interval. This classification method divides the range of data values into equal intervals.
- Equal frequency. Also called quantile, this classification method divides the total number of data values by the number of classes and ensures that each class contains the same number of data values.
- Mean and standard deviation. This classification method sets the class breaks at units of the standard deviation (0.5, 1.0, etc.) above or below the mean.
- Natural breaks. Also called the Jenks optimization method, this classification method optimizes the grouping of data values (Slocum et al. 2005). The method uses a computing algorithm to minimize differences between data values in the same class and to maximize differences between classes.
- User defined. This method lets the user choose the appropriate or meaningful class breaks. For example, in mapping rates of population change by state, the user may choose zero or the national average as a class break.

With changes in the classification method, the number of classes, or both, the same data can produce different-looking maps and different spatial patterns. This is why mapmakers usually experiment with data classification before deciding on a classification scheme for the final map. Although the decision is ultimately subjective, it should be guided by map purpose and map communication principles.

10.2 Types of Maps

Cartographers classify maps by function and by symbolization. By function, maps can be general reference or thematic. The **general reference map** is used for general purposes. For example, a U.S. Geological Survey (USGS) quadrangle map shows a variety of spatial features, including boundaries, hydrology, transportation, contour lines, settlements, and land covers. The **thematic map** is also called the special purpose map, because its main objective is to show the distribution pattern of a theme, such as the distribution of population densities by county in a state.

By map symbol, maps can be qualitative or quantitative. A qualitative map uses visual variables that are appropriate for portraying qualitative data, whereas a quantitative map uses visual variables that are appropriate for communicating quantitative data. The following describes several common types of quantitative maps (Figure 10.4) (Robinson et al. 1995; Dent 1999; Slocum et al. 2005).

The **dot map** uses uniform point symbols to show spatial data, with each symbol representing a unit value. One-to-one dot mapping uses the unit value of one, such as one dot representing one crime location. But in most cases, it is one-to-many dot mapping and the unit value is greater than one. The placement of dots becomes a major consideration in one-to-many dot mapping (Box 10.1).

The **choropleth map** symbolizes, with shading, derived data based on administrative units (Box 10.2). An example is a map showing average household income by county. The derived data are usually classified prior to mapping and are symbolized using a color scheme for quantitative data.

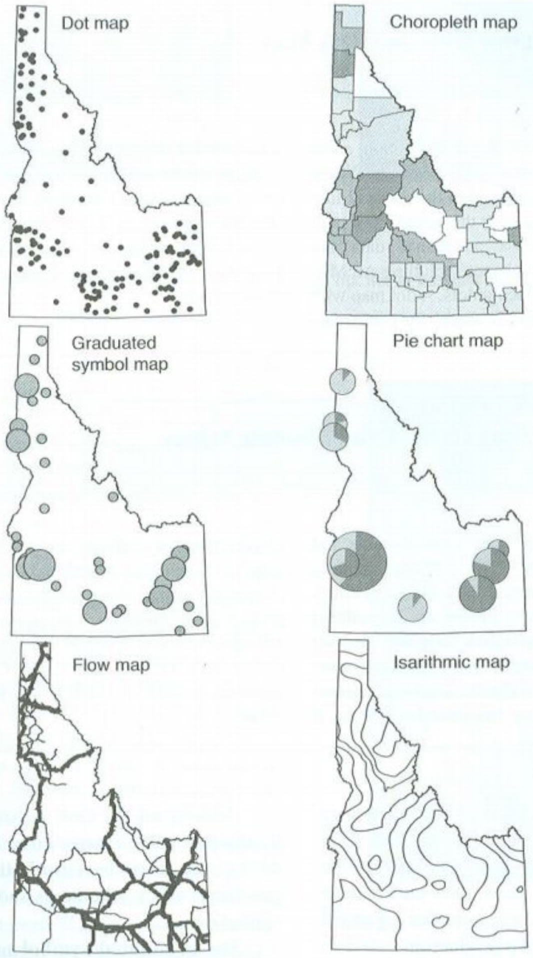


Figure 10.4
Six common types of quantitative maps.

Box 10.1 Locating Dots on a Dot Map

Suppose a county has a population of 5000, and a dot on a dot map represents 500 persons. Where should the 10 dots be placed within the county? Ideally the dots should be placed at the locations of populated places. But, unless additional data are incorporated, most GIS packages including ArcMap use a random method in placing dots. A dot map with a random placement of dots is useful for comparing relative dot densities in different parts of the map. But it should not be used for locating data. One way to improve the accuracy of dot maps is to base them on the smallest administrative unit possible. Another way is to exclude areas such as water bodies that should not have dots. ArcMap allows the use of mask areas for this purpose.

Box 10.2 Mapping Derived and Absolute Values

Cartographers distinguish between absolute and derived values in mapping (Chang 1978). Absolute values are magnitudes or raw data such as county population, whereas derived values are normalized values such as county population densities (derived from dividing the county population by the area of the county). County population densities are independent of the county size. Therefore, two counties with equal populations but different sizes will have different population densities, and thus different symbols, on a choropleth map. If choropleth maps are used for mapping absolute values such as county populations, size differences among counties can severely distort map comparisons (Monmonier 1996). Cartographers recommend graduated symbols for mapping absolute values.

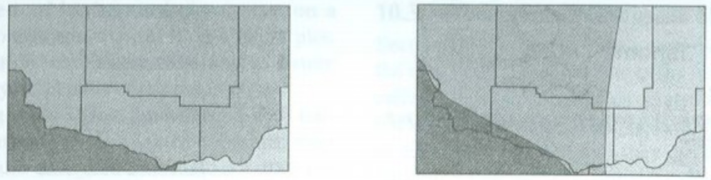
Therefore, the appearance of the choropleth map can be greatly affected by data classification. Cartographers often make several versions of the choropleth map from the same data and choose one—typically one with a good spatial organization of classes—for final map production.

The **dasymetric map** is a variation of the simple choropleth map. By using statistics and additional information, the dasymetric map delineates areas of homogeneous values rather than following administrative boundaries (Robinson et al. 1995) (Figure 10.5). Dasymetric mapping used to be a time-consuming task, but the analytical functions of a GIS have simplified the mapping procedure (Holloway et al. 1999; Eicher and Brewer 2001; Holt et al. 2004).

A GIS package such as ArcGIS uses the term **graduated color map** to cover the choropleth and dasymetric maps because both map types use a graduated color scheme to show the variation in spatial data.

The **graduated symbol map** uses different-sized symbols such as circles, squares, or triangles to represent different ranges of values. For example, we can use graduated symbols to represent cities of different population ranges. Two important issues to this map type are the range of sizes and the discernible difference between sizes. Both issues are obviously related to the number of graduated symbols on a map.

A **proportional symbol map** is a map that uses a specific symbol size for each numeric value



(a) (b)

Figure 10.5
Map symbols follow the boundaries in the choropleth map (*a*) but not in the dasymetric map (*b*).

rather than a range of values. Therefore, one circle size may represent a population of 10,000, another 15,000, and so on.

The **chart map** uses either pie charts or bar charts. A variation of the graduated circle, the pie chart can display two sets of quantitative data: the circle size can be made proportional to a value such as a county population, and the subdivisions can show the makeup of the value, such as the racial composition of the county population. Bar charts use vertical bars and their height to represent quantitative data. Bar charts are particularly useful for comparing data side by side.

The **flow map** displays different quantities of flow data such as traffic volume and stream flow by varying the line symbol width. Similar to the graduated symbols, the flow symbols usually represent ranges of values.

The **isarithmic map** uses a system of isolines to represent a surface. Each isoline connects points of equal value. GIS users often use the isarithmic map to display the terrain (Chapter 14) and the statistical surface created by spatial interpolation (Chapter 16).

GIS has introduced a new classification of maps based on vector and raster data. Maps prepared from vector data are the same as traditional maps using point, line, and area symbols. Most of Chapter 10 applies to the display of vector data. Maps prepared from raster data, although they may look like traditional maps, are cell-based (Figure 10.6). But raster data can also be classified as either quantitative or qualitative. The color schemes for qualitative and quantitative maps described in Section 10.1.2 can therefore be applied to mapping raster data as well.

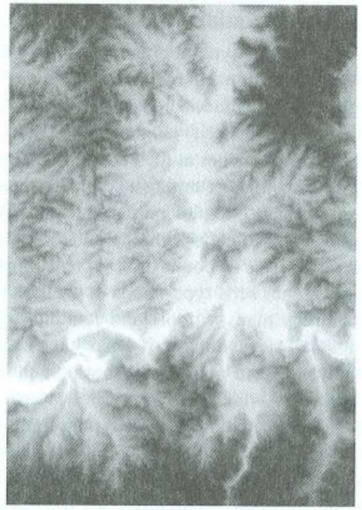


Figure 10.6
Map showing raster-based elevation data. Cells with higher elevations have darker shades.

10.3 Typography

A map cannot be understood without text on it. Text is needed for almost every map element.

Times New Roman

Tahoma

Figure 10.7
Times New Roman is a serif typeface, and Tahoma is a sans serif typeface.

Mapmakers treat text as a map symbol because, like point, line, or area symbols, text can have many type variations. Using type variations to create a pleasing and coherent map is therefore part of the mapmaking process.

10.3.1 Type Variations

Type can vary in typeface and form. **Typeface** refers to the design character of the type. Two main groups of typefaces are **serif** (with serif) and **sans serif** (without serif) (Figure 10.7). Serifs are small, finishing touches at the ends of line strokes, which tend to make running text in newspapers and books easier to read. Compared to serif types, sans serif types appear simpler and bolder. Although rarely used in books or other text-intensive materials, a sans serif type stands up well on maps with complex map symbols and remains legible even in small sizes. Sans serif types have an additional advantage in mapmaking because many of them come in a wide range of type variations.

Type form variations include **type weight** (bold, regular, or light), **type width** (condensed or extended), upright versus slanted (or roman versus italic), and uppercase versus lowercase (Figure 10.8). A **font** is a complete set of all variants of a given typeface. Fonts on a computer are those loaded from the printer manufacturer and software packages. They are usually enough for mapping purposes. If necessary, additional fonts can be imported into a GIS package.

Type can also vary in size and color. Type size measures the height of a letter in **points,** with 72 points to an inch. Printed letters look smaller than what their point sizes suggest. The point size is supposed to be measured from a metal type block, which must accommodate the lowest point of the descender (such as p or g) to the highest part of the

Helvetica Normal

Helvetica Italic

Helvetica Bold

Helvetica Bold-Italic

Times Roman Normal

Times Roman Italic

Times Roman Bold

Times Roman Bold-Italic

Figure 10.8
Type variations in weight and roman versus italic.

ascender (such as d or b). But no letters extend to the very edge of the block. Text color is the color of letters. In addition to color, letters may also appear with drop shadow, halo, or fill pattern.

10.3.2 Selection of Type Variations

Type variations for text symbols can function in the same way as visual variables for map symbols. How does one choose type variations for a map? A practical guideline is to group text symbols into qualitative and quantitative classes. Text symbols representing qualitative classes such as names of streams, mountains, parks, and so on can vary in typeface, color, and upright versus italic. In contrast, text symbols representing quantitative classes such as names of different-sized cities can vary in type size, weight, and uppercase versus lowercase. Grouping text symbols into classes simplifies the process of selecting type variations.

Besides classification, cartographers also recommend legibility, harmony, and conventions for type selection (Dent 1999). Legibility is difficult to control on a map because it can be influenced not only by type variations but also by the placement of text and the contrast between text and the background symbol. As GIS users, we have the additional problem of having to design a map on a computer monitor and to print it on a larger plot. Experimentation may be the only way to ensure type legibility in all parts of the map.

Type legibility should be balanced with harmony. As a means to communicate the map content, text should be legible but should not draw too much attention. Mapmakers can generally achieve harmony by adopting only one or two typefaces on a map (Figure 10.9). For example, many mapmakers use a sans serif type in the body of a map and a serif type for the map's title and legend. The use of conventions can also lend support for harmony. Conventions in type selection include italic for names of water features, uppercase and letter spacing for names of administrative units, and variations in type size and form for names of different-sized cities.

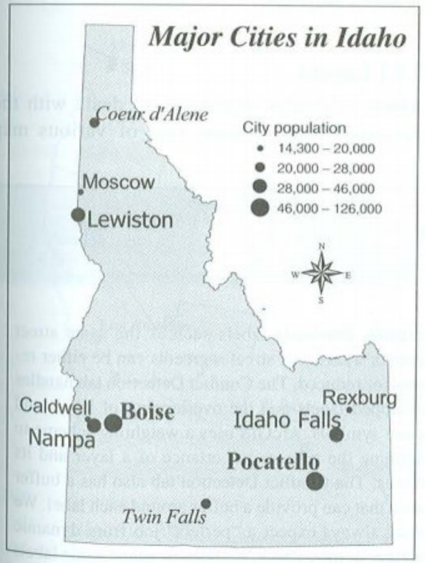


Figure 10.9
The look of the map is not harmonious because of too many typefaces.

10.3.3 Placement of Text in the Map Body

Section 10.3.3 focuses on the placement of text in the map body. Text elements in the map body, also called labels, are directly associated with the spatial features. In most cases, these labels are names of the spatial features. But they can also be some attribute values such as contour readings or precipitation amounts. Other text elements on a map such as the title and the legend are not tied to any specific locations. Instead, the placement of these text elements (i.e., graphic elements) is related to the layout of the map (Section 10.4.1).

As a general rule, a label should be placed to show the location or the area extent of the named spatial feature. Cartographers recommend placing the name of a point feature to the upper right of its symbol, the name of a line feature in a block and parallel to the course of the feature, and the name of an area feature in a manner that indicates its area extent. Other general rules suggest aligning labels with either the map border or lines of latitude, and placing labels entirely on land or on water.

Implementing labeling algorithms in a GIS package is no easy task (Mower 1993; Chirié 2000). Automated name placement presents several difficult problems for the computer programmer: names must be legible, names cannot overlap other names, names must be clearly associated with their intended referent symbols, and name placement must follow cartographic conventions. These problems worsen at smaller map scales as competition for the map space intensifies between names. We should not expect labeling to be completely automated. Some interactive editing is usually needed to improve the final map's appearance. For this reason many GIS packages offer more than one method of labeling.

As an example, ArcGIS offers interactive and dynamic labeling. Interactive labeling works with one label at a time. If the placement does not work out well, the label can be moved immediately. Interactive labeling is ideal if the number of labels is small or if the location of labels must be exact. Dynamic labeling is probably the method of choice for most users because it can automatically label all or selected features. Using dynamic labeling, we can prioritize options for text placement and for solving potential conflicts (Box 10.3). For example, we can choose to place a line label in a block and parallel to the course of the line feature. We can also set rules to prioritize labels that compete for the same map space. By default, ArcGIS does not allow overlapped labels. This constraint, which is sensible, can impact the placement of labels and may require the adjustment of some labels (Figure 10.10).

Dynamic labels cannot be selected or adjusted individually. But they can be converted to text elements so that we can move and change them in the same way we change interactive labels (Figure 10.11). One way to take care of labels in a truly congested area is to use a leader line to link a label to its feature (Figure 10.12).

Perhaps the most difficult task in labeling is to label the names of streams. The general rule states that the name should follow the course of the stream, either above or below it. Both interactive labeling and dynamic labeling can curve the name if it appears along a curvy part of the stream. But the appearance of the curved name depends on the smoothness of the corresponding stream segment, the length of the stream segment, and the length of the name. Placing every name in its correct position the first time is nearly impossible (Figure 10.13). Problem names must be removed and relabeled using the **spline text** tool, which can align a text string along a curved line that is digitized on-screen (Figure 10.14).

10.4 Map Design

Like graphic design, **map design** is a visual plan to achieve a goal. The purpose of map design is to enhance map communication, which is particularly important for thematic maps. A well-designed map is balanced, coherent, ordered, and interesting to look at, whereas a poorly designed map is confusing and disoriented (Antes et al. 1985). Map design is both an art and a science. There may not be clear-cut right or wrong designs for maps, but there are better or more effective maps and worse or less effective maps.

Map design overlaps with the field of graphic arts, and many map design principles have their origin in visual perception. Cartographers usually study map design from the perspectives of layout and visual hierarchy.

10.4.1 Layout

Layout, or planar organization, deals with the arrangement and composition of various map

Box 10.3 Options for Dynamic Labeling

When we choose dynamic labeling, we basically let the computer take over the labeling task. But the computer needs instructions for placement methods and for solving potential problems in labeling. ArcGIS uses the Placement Properties dialog to gather instructions from the user. The dialog has two tabs. The Placement tab deals with the placement method and duplicate labels. Different placement methods are offered for each feature type. For example, ArcGIS offers 36 options for placing a label relative to its point feature. The default placement method is usually what is recommended in the cartographic literature. Duplicate labels such as the same street name for a series of street segments can be either removed or reduced. The Conflict Detection tab handles overlapped labels and the overlapping of labels and feature symbols. ArcGIS uses a weighting scheme to determine the relative importance of a layer and its features. The Conflict Detection tab also has a buffer option that can provide a buffer around each label. We cannot always expect a "perfect" job from dynamic labeling. In most cases, we need to adjust some labels individually.

Figure 10.10
Dynamic labeling of major cities in the United States. The initial result is good but not totally satisfactory. Philadelphia is missing. Labels of San Antonio, Indianapolis, and Baltimore overlap slightly with point symbols. San Francisco is too close to San Jose.

Figure 10.11
A revised version of Figure 10.10. Philadelphia is added to the map, and several city names are moved individually to be closer to their point symbols.

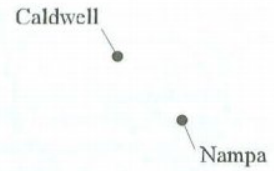


Figure 10.12
A leader line connects a point symbol to its label.

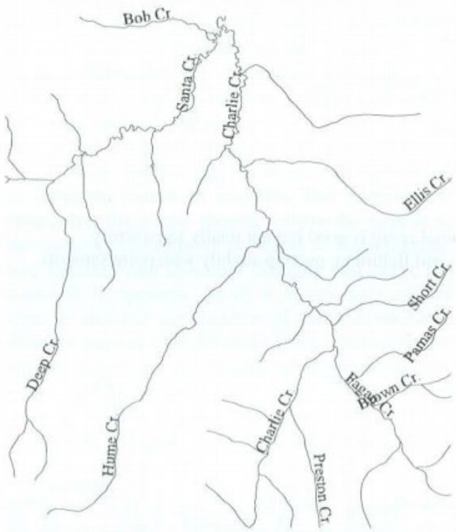


Figure 10.13
Dynamic labeling of streams may not work for every label. Brown Cr. overlaps with Fagan Cr., and Pamas Cr. and Short Cr. do not follow the course of the creek.

elements. Major concerns with layout are focus, order, and balance. A thematic map should have a clear focus, which is usually the map body or a part of the map body. To draw the map reader's attention, the focal element should be placed near the optical center, just above the map's geometric center. The focal element should be differentiated from other map elements by contrast in line width, texture, value, detail, and color.

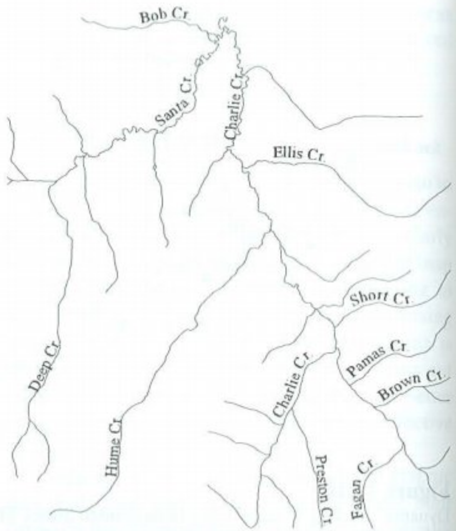


Figure 10.14
Problem labels in Figure 10.13 are redrawn with the spline text tool.

After viewing the focal element, the reader should be directed to the rest of the map in an ordered fashion. For example, the legend and the title are probably the next elements that the viewer needs to look at after the map body. To smooth the transition, the mapmaker should clearly place the legend and the title on the map, with perhaps a box around the legend and a larger type size for the title to draw attention to them (Figure 10.15).

A finished map should look balanced. It should not give the map reader an impression that the map "looks" heavier on the top, bottom, or side (Figure 10.16). But balance does not suggest the breaking down of the map elements and placing them, almost mechanically, in every part of the map. Although in that case the elements would be in balance, the map would be disorganized and confusing. Mapmakers therefore should deal with balance within the context of organization and map communication.

Cartographers used to use thumbnail sketches to experiment with balance on a map. Now they

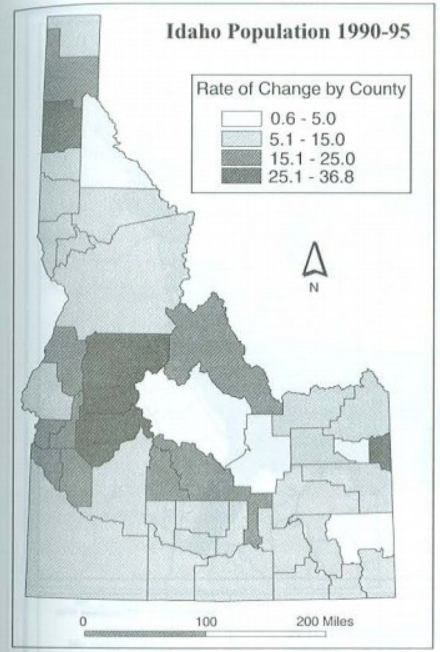


Figure 10.15
Use a box around the legend to draw the map reader's attention to it.

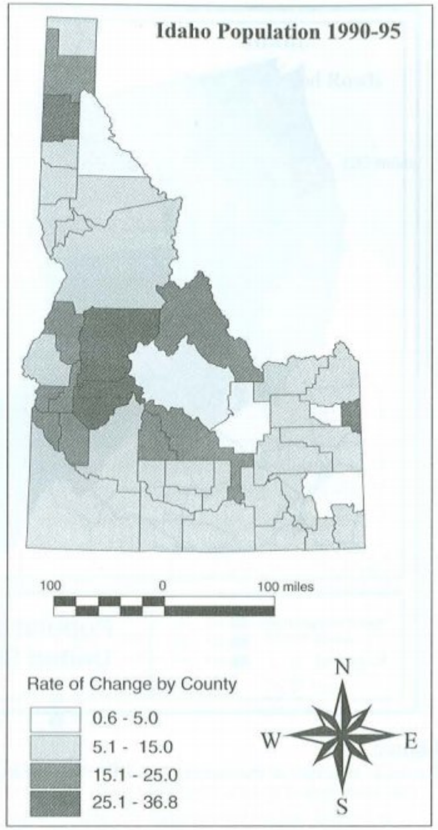


Figure 10.16
A poorly balanced map.

use computers to manipulate map elements on a layout page. ArcGIS, for example, offers two basic methods for layout design. The first method is to use a layout template. These templates are grouped as general, industry, USA, and world. Each group has a list of choices. For example, the layout templates for the United States include USA, conterminous USA, and five different regions of the country. Figure 10.17 shows the basic structure of the conterminous USA layout template. The idea of using a layout template is to use a built-in design option to quickly compose a map.

The second option is to open a layout page and add map elements one at a time. ArcGIS offers the following map elements: title, text, neatline, legend, north arrow, scale bar, scale text, and the graticule (Box 10.4). The user can choose one of these map elements, place it on the layout page, and manipulate it graphically. For example, the user can change the type design of the title, enlarge or reduce it, and move it around the layout. A layout design created using the second option can be saved as a template for future use.

Regardless of the method used in layout design, the legend deserves special consideration. The legend includes descriptions of all the layers that make up a map. For example, a map showing different classes of cities and roads in a state requires

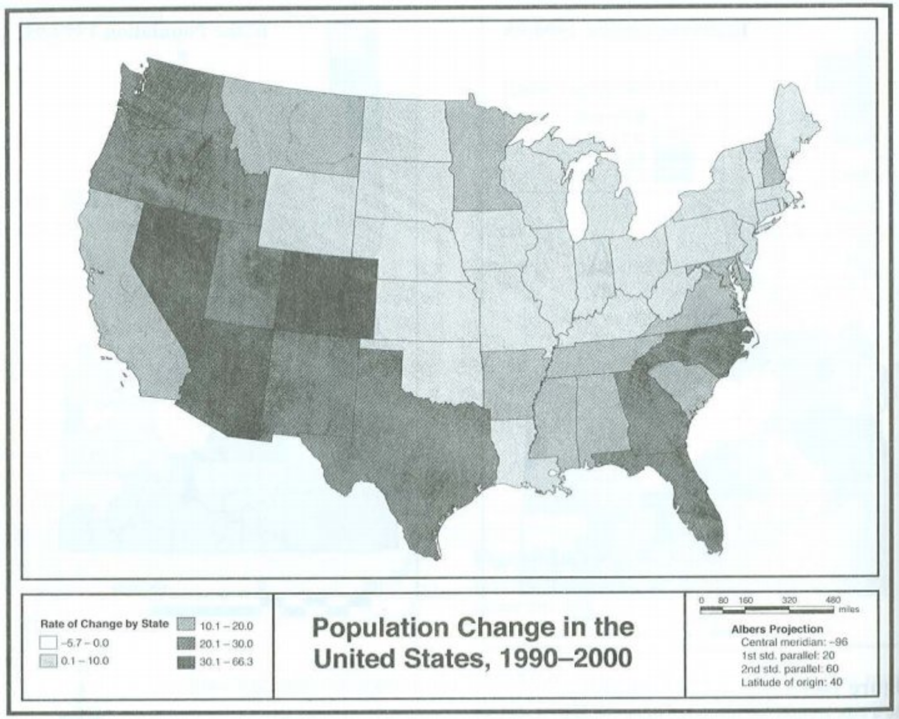


Figure 10.17
The basic structure of the conterminous USA layout template in ArcMap.

Box 10.4 Wizards for Adding Map Elements

ArcMap provides wizards and selectors for adding map elements to a map. The Grids and Graticules wizard is one of them. The graticule refers to lines or tics of longitude and latitude. The grid can be a measured grid or a reference grid. A measured grid shows lines or tics of projected coordinates. A reference grid divides a map into a grid for spatial indexing. The Grids and Graticules wizard guides the user through a series of dialogs to choose the intervals, symbol design, and placement option. Wizards are useful for the beginner but can be tedious and limiting for experienced users. We can choose to turn off the wizard and to work directly with the main property dialog of a map element.

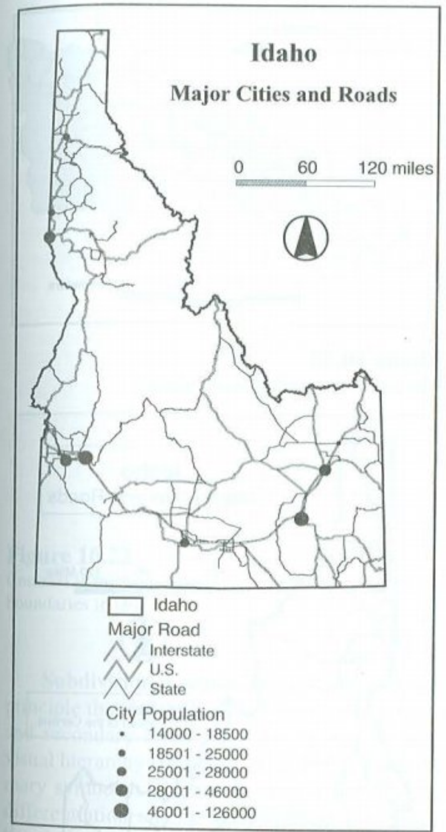


Figure 10.18a
A lengthy legend is confusing and can create a problem in layout design.

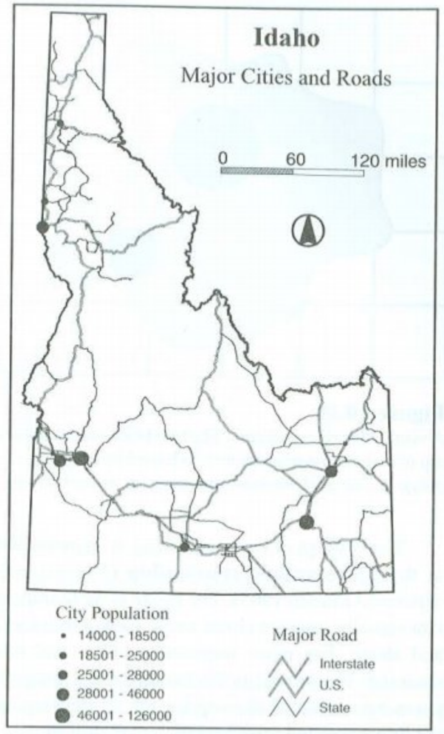


Figure 10.18b
The lengthy legend in Figure 10.18a is separated into two parts. Also, the unnecessary outline symbol is removed from the legend.

a minimum of three layers: one for the cities, one for the roads, and one for the state boundary. As default, these descriptions are placed together as a single graphic element, which can become quite lengthy with multiple layers. A lengthy legend presents a problem in balancing a layout design (Figure 10.18a). The solution is to break the legend into two or more columns and to remove useless legend descriptions such as the description of an outline symbol (Figure 10.18b).

10.4.2 Visual Hierarchy

Visual hierarchy is the process of developing a visual plan to introduce the 3-D effect or depth to maps (Figure 10.19). Mapmakers create the visual hierarchy by placing map elements at different visual levels according to their importance to the map's purpose. The most important element should be at the top of the hierarchy and should appear closest to the map reader. The least important element should be at the bottom. A thematic map may consist of three or more levels in a visual hierarchy.

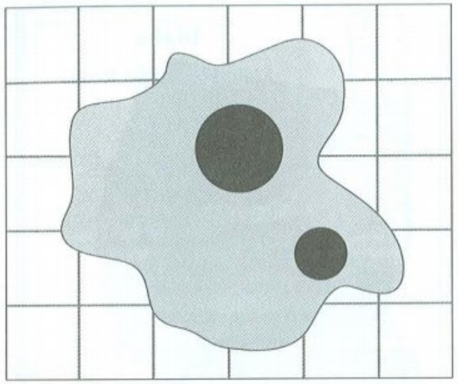


Figure 10.19
A visual hierarchy example. The two black circles are on top (closest to the map reader), followed by the gray polygon. The grid, the least important, is on the bottom.

The concept of visual hierarchy is an extension of the **figure–ground relationship** in visual perception (Arnheim 1965). The figure is more important visually, appears closer to the viewer, has form and shape, has more impressive color, and has meaning. The ground is the background. Cartographers have adopted the depth cues for developing the figure–ground relationship in map design.

Probably the simplest and yet most effective principle in creating a visual hierarchy is interposition or superimposition (Dent 1999). **Interposition** uses the incomplete outline of an object to make it appear as though it is behind another. Examples of interposition abound in maps, especially in newspapers and magazines. Continents on a map look more important or occupy a higher level in visual hierarchy if the lines of longitude and latitude stop at the coast. A map title, a legend, or an inset map looks more prominent if it lies within a box, with or without the drop shadow. When the map body is deliberately placed on top of the neatline around a map, the map body will stand out more (Figure 10.20). Because interposition is so easy to use, it can be overused or misused. A map looks confusing if several of its elements compete for the map reader's attention (Figure 10.21).

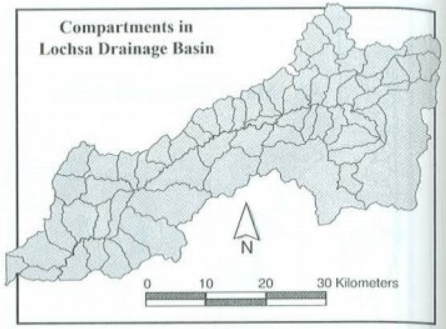


Figure 10.20
The interposition effect in map design.

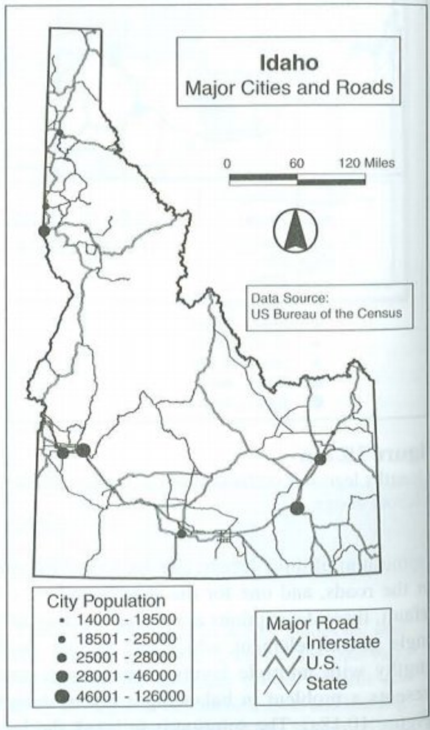


Figure 10.21
A map looks confusing if it uses too many boxes to highlight individual elements.

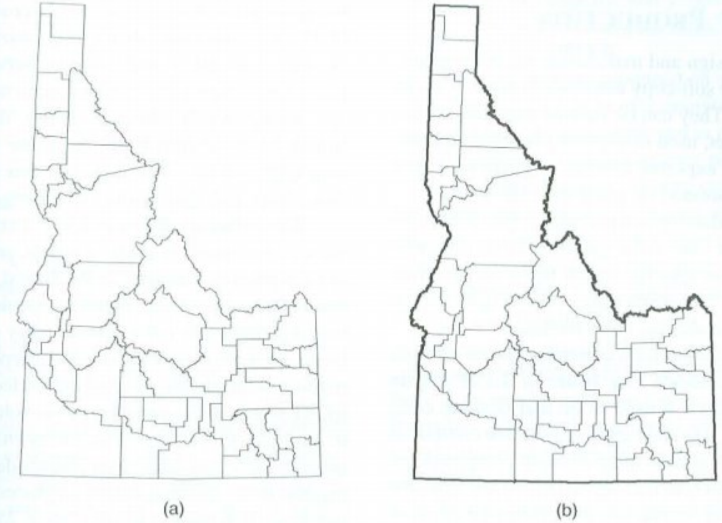


Figure 10.22
Contrast is missing in (*a*), whereas the line contrast makes the state outline look more important than the county boundaries in (*b*).

Subdivisional organization is a map design principle that groups map symbols at the primary and secondary levels according to the intended visual hierarchy (Robinson et al. 1995). Each primary symbol is given a distinctive hue, and the differentiation among the secondary symbols is based on color variation, pattern, or texture. For example, all tropical climates on a climate map are shown in red, and different tropical climates (e.g., wet equatorial climate, monsoon climate, and wet–dry tropical climate) are distinguished by different shades of red. Subdivisional organization is most useful for maps with many map symbols, such as climate, soil, geology, and vegetation maps.

Contrast is a basic element in map design, important to layout as well as to visual hierarchy. Contrast in size or width can make a state outline look more important than county boundaries and larger cities look more important than smaller ones (Figure 10.22). Contrast in color can separate the figure from the ground. Cartographers often use a warm color (e.g., orange to red) for the figure and a cool color (e.g., blue) for the ground. Contrast in texture can also differentiate between the figure and the ground because the area containing more details or a greater amount of texture tends to stand out on a map. Like the use of interposition, too much contrast can create a confusing map appearance. For instance, if bright red and green are used side by side as area symbols on a map, they appear to vibrate.

A tool that many GIS packages offer for data display is called **transparency,** which controls the percentage of a layer that is transparent. Transparency can be useful in creating a visual hierarchy by "toning down" the symbols of a background layer. Suppose we want to superimpose a layer showing major cities on top of a layer showing rates of population change by county. We can apply transparency to the county layer so that the city layer will stand out more.

10.5 Map Production

GIS users design and make maps on the computer screen. These soft-copy maps can be used in a variety of ways. They can be printed, exported for use on the Internet, used in overhead computer projection systems, exported to other software packages, or further processed for publishing (Box 10.5).

Map production is a complex topic. We are often surprised that color symbols from the color printers do not exactly match those on the computer screen. This discrepancy results from the use of different media and color models.

Data display on the computer screen uses either **CRT (cathode ray tube)** or **LCD (liquid crystal display).** It used to be that desktop computers used CRTs and laptop or portable computers used LCDs. But now more desktop computers are also using LCDs to take advantage of the thin, flat screen. A CRT screen has a built-in fine mesh of pixels, and each pixel has colored dots called phosphors. When struck by electrons from an electron gun, a dot lights up and slowly grows dim. An LCD screen uses two sheets of polarizing materials with a liquid crystal solution between them. Each pixel on an LCD screen can be turned on or off independently. Besides being thinner and lighter, LCD screens have two other advantages over CRT screens: they consume less power, and they produce sharper, flicker-free images.

With either a CRT or an LCD, a color symbol we see on a screen is made of pixels, and the color of each pixel is a mixture of **RGB** (red, green, and blue). The intensity of each primary color in a mixture determines its color. The number of intensity levels each primary color can have depends on the number of bit-planes assigned to the electron gun in a CRT screen or the variation of the voltage applied in an LCD screen. Typically, the intensity of each primary color can range over 256 shades. Combining the three primary colors produces a possible palette of 16.8 million colors (256 × 256 × 256).

Many GIS packages offer the RGB color model for color specification. But color mixtures of RGB

Box 10.5 Working with Soft-Copy Maps

When completed, a soft-copy map can be either printed or exported. Printing a map from the computer screen requires the software interface (often called the driver) between the operating system and the print device. ArcMap uses Enhanced Metafiles (EMF) as the default and offers two additional choices of PostScript (PS) and ArcPress. EMF files are native to the Windows operating system for printing graphics. PS, developed by Adobe Systems Inc., in the 1980s, is an industry standard for high-quality printing. Developed by ESRI, Inc., ArcPress is PS-based and useful for printing maps containing raster data sets, images, or complex map symbols.

One must specify an export format to export a computer-generated map for other uses. ArcMap, for example, offers the export formats of JPEG (Joint Photographic Experts Group), TIFF (tagged image file format), AI (Adobe Illustrator format), BMP (bitmap), GIF (graphics interchange format), EMF, EPS (encapsulated PostScript), PDF (portable document format), SVG (scalable vector graphics), and PNG (portable network graphics).

Offset printing is the standard method for printing a large number of copies of a map. A typical procedure to prepare a computer-generated map for offset printing involves the following steps. First, the map is exported to separate CMYK PostScript files in a process called color separation. CMYK stands for the four process colors of cyan, magenta, yellow, and black, commonly used in offset printing. Second, these files are processed through an image setter to produce high-resolution plates or film negatives. Third, if the output from the image setter consists of film negatives, the negatives are used to make plates. Finally, offset printing runs the plates on the press to print color maps.

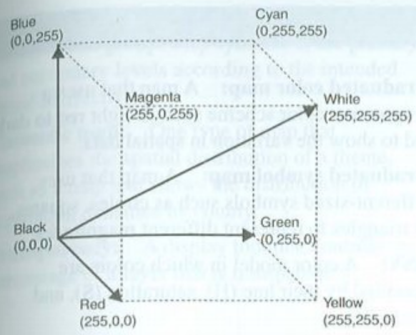


Figure 10.23
The RGB (red, green, and blue) color model.

are not intuitive and do not correspond to the human dimensions of color perception (Figure 10.23) (MacDonald 1999). It is difficult to perceive that a mixture of red and green at full intensity is a yellow color. This is why other color models have been developed to specify colors that are based on the visual perception of hue, value, and chroma. ArcGIS, for example, has the **HSV** (hue/saturation/value) color model in addition to the RGB color model for specifying custom colors.

Printed color maps differ from color displays on a computer screen in two ways: color maps reflect rather than emit light; and the creation of colors on color maps is a subtractive rather than an additive process. The three primary subtractive colors are cyan, magenta, and yellow. In printing, these three primary colors plus black form the four process colors of **CMYK.**

Color symbols are produced on a printed map in much the same way as on a computer screen. In place of pixels are color dots, and in place of varying light intensities or voltages are percentages of area covered by color dots. A deep orange color on a printed map may represent a combination of 60% magenta and 80% yellow, whereas a light orange color may represent a combination of 30% magenta and 90% yellow. To match a color symbol on the computer screen with a color symbol on the printed map requires a translation from the RGB color model to the CMYK color model. As yet there is no exact translation between the two, and therefore the color map looks different when printed (Fairchild 2005; Slocum et al. 2005). The International Color Consortium, a consortium of over 70 companies and organizations worldwide, has been working since 1993 on a color management system that can be used across different platforms and media (**http://www.color.org/**). Until such a color management system is developed, we must experiment with colors on different media.

Map production, especially the production of color maps, can be a challenging task to GIS users. Box 10.6 describes ColorBrewer, a free Web tool that can help GIS users choose color symbols that are appropriate for a particular mode of map production (Brewer et al. 2003).

Box 10.6 A Web Tool for Making Color Maps

A free Web tool for making color maps is available at **http://ColorBrewer.org.** Funded initially by the National Science Foundation's Digital Government Program, the website is maintained by Cindy Brewer of Pennsylvania State University. The tool offers three main types of color schemes: sequential, diverging, and qualitative. One can select a color scheme and see how the color scheme looks on a sample choropleth map. One can also add point and line symbols to the sample map and change the colors for the map border and background. Then, for each color selected, the tool shows its color values in terms of CMYK, RGB, and other models. And, for each color scheme selected, the tool rates its potential uses including photocopy in black and white, CRT display, color printing, LCD projector, and laptop LCD display.

KEY CONCEPTS AND TERMS

Cartography: The making and study of maps in all their aspects.

Chart map: A map that uses charts such as pie charts or bar charts as map symbols.

Choropleth map: A map that applies shading symbols to data or statistics collected for enumeration units such as counties or states.

Chroma: The richness or brilliance of a color. Also called *saturation* or *intensity*.

CMYK: A color model in which colors are specified by the four process colors of cyan (C), magenta (M), yellow (Y), and black (K).

Contrast: A basic element in map design that enhances the look of a map or the figure–ground relationship by varying the size, width, color, and texture of map symbols.

CRT (cathode-ray tube) screen: A display device for a personal computer that uses electron guns and color dots.

Dasymetric map: A map that uses statistics and additional information to delineate areas of homogeneous values, rather than following administrative boundaries.

Dot map: A map that uses uniform point symbols to show spatial data, with each symbol representing a unit value.

Figure–ground relationship: A tendency in visual perception to separate more important objects (figures) in a visual field from the background (ground).

Flow map: A map that displays different quantities of flow data by varying the width of the line symbol.

Font: A complete set of all variants of a given typeface.

General reference map: One type of map used for general purposes such as the USGS topographic map.

Graduated color map: A map that uses a progressive color scheme such as light red to dark red to show the variation in spatial data.

Graduated symbol map: A map that uses different-sized symbols such as circles, squares, or triangles to represent different magnitudes.

HSV: A color model in which colors are specified by their hue (H), saturation (S), and value (V).

Hue: The quality that distinguishes one color from another, such as red from blue. Hue is the dominant wavelength of light.

Interposition: A tendency for an object to appear as though it is behind another because of its incomplete outline.

Isarithmic map: A map that uses a system of isolines to represent a surface.

Layout: The arrangement and composition of map elements on a map.

LCD (liquid crystal display) screen: A display device for a personal computer that uses electric charge through a liquid crystal solution between two sheets of polarizing materials.

Map design: The process of developing a visual plan to achieve the map's purpose.

Point: Measurement unit of type, with 72 points to an inch.

Proportional symbol map: A map that uses a specific-sized symbol for each numeric value.

RGB: A color model in which colors are specified by their red (R), green (G), and blue (B) components.

Sans serif: Without serif.

Serif: Small, finishing touches added to the ends of line strokes in a typeface.

Spline text: A text string aligned along a curved line.

Subdivisional organization: A map design principle that groups map symbols at the primary and secondary levels according to the intended visual hierarchy.

Thematic map: One type of map that emphasizes the spatial distribution of a theme, such as a map that shows the distribution of population densities by county.

Transparency: A display tool that controls the percentage of a layer that is transparent.

Typeface: A particular style or design of type.

Type weight: Relative blackness of a type such as bold, regular, or light.

Type width: Relative width of a type such as condensed or extended.

Value: The lightness or darkness of a color.

Visual hierarchy: The process of developing a visual plan to introduce the 3-D effect or depth to maps.

REVIEW QUESTIONS

1. What are the common elements on a map for presentation?
2. Why is it important to pay attention to map design?
3. Mapmakers apply visual variables to map symbols. What are visual variables?
4. Name common visual variables for data display.
5. Describe the three visual dimensions of color.
6. Use an example to describe a "hue and value" color scheme.
7. Use an example to describe a "diverging" color scheme.
8. How does a general reference map differ from a thematic map?
9. Define the choropleth map.
10. ArcMap offers the display options of graduated colors and graduated symbols. How do these two options differ?
11. Suppose you are asked to redo Figure 10.9. Provide a list of type designs, including typeface, form, and size, that you will use for the four classes of cities.
12. What are the general rules for achieving harmony with text on a map?
13. ArcGIS offers interactive labeling and dynamic labeling for the placement of text. What are the advantages and disadvantages of each labeling method?
14. Figure 10.17 shows a layout template available in ArcMap for the conterminous USA. Will you consider using the layout template for future projects? Why, or why not?
15. What is visual hierarchy in map design? How is the hierarchy related to the map purpose?
16. Figure 10.20 shows an example of using interposition in map design. Does the map achieve the intended 3-D effect?
17. What is subdivisional organization in map design? Can you think of an example, other than the climate map example in Chapter 10, to which you can apply the principle?
18. Explain why color symbols from a color printer do not exactly match those on the computer screen.
19. Define the RGB and CMYK color models.