14

Designing the Map

14.1 SYMBOLIZATION IN CONTEXT

A *map* can be defined as a graphic depiction of all or part of a geographic realm in which the real-world features have been replaced with symbols in their correct spatial location at a reduced scale. This definition highlights the importance of the symbolization process in cartography, because the transformation determines not only the esthetic look of the map, but also how effectively it communicates the map's spatial information content to the user or interpreter.

In Part III we saw that the process of mapping can be seen as a series of states at which maps exist in various forms, plus a series of transitions or transformations between these states. The entire sequence of stages begins with the least abstract, with the cartographic and spatial phenomena as they exist in the real world. It continues with the specific steps taken to portray the data that represent these phenomena as objects inside the computer via graphic elements and symbols on a map. The symbolization transformation is unique, first because it produces something tangible (the real map), and second because the tangible map communicates information to its user about the distillation of the part of the world's geography it represents.

A first reference point is the part of the real world that the intended map represents.The term *world* is used loosely, because maps of other planets, moons, and imaginary places are just as cartographic. In the first transformation, a geographic subset of the world is selected, often the area bounded by parallels and meridians or the area defined as a nation, region, or area of interest. Sufficient information about this area is selected from existing maps, or by direct measurement (often from satellite images or air photos), or perhaps by reference to a survey, census, atlas, almanac, or other source of information.

In this initial state, we distill the necessary information needed to compile the map; in other words, we complete the map research and the map at this stage may consist of an existing map, a folder of notes, an air photo, a satellite image, a computer tape, or the correct volume of the census for which we intend to map data.

The first transformation is the process of geocoding, defined and discussed in Chapter 4 (see Figure 14.1). The result is the spatial objects as digital numbers, stored and structured as discussed in Chapters 4, 5, 7, and 8. Attribute data are structured as in Chapter 9. The next transformation is either a map-based or a data structure transformation, as discussed in Chapters 11 and 12. The map data are now ready for symbolization, the subject of this part, and the result is a "real" map. This is not the final stage, however. Significant research in cartography has examined the map-to-map–reader transformation, one that is perceptual and somewhat subjective, but nevertheless important for mapping. This research has led to improvements in design and a better understanding of how people retrieve and then use spatial information from maps.

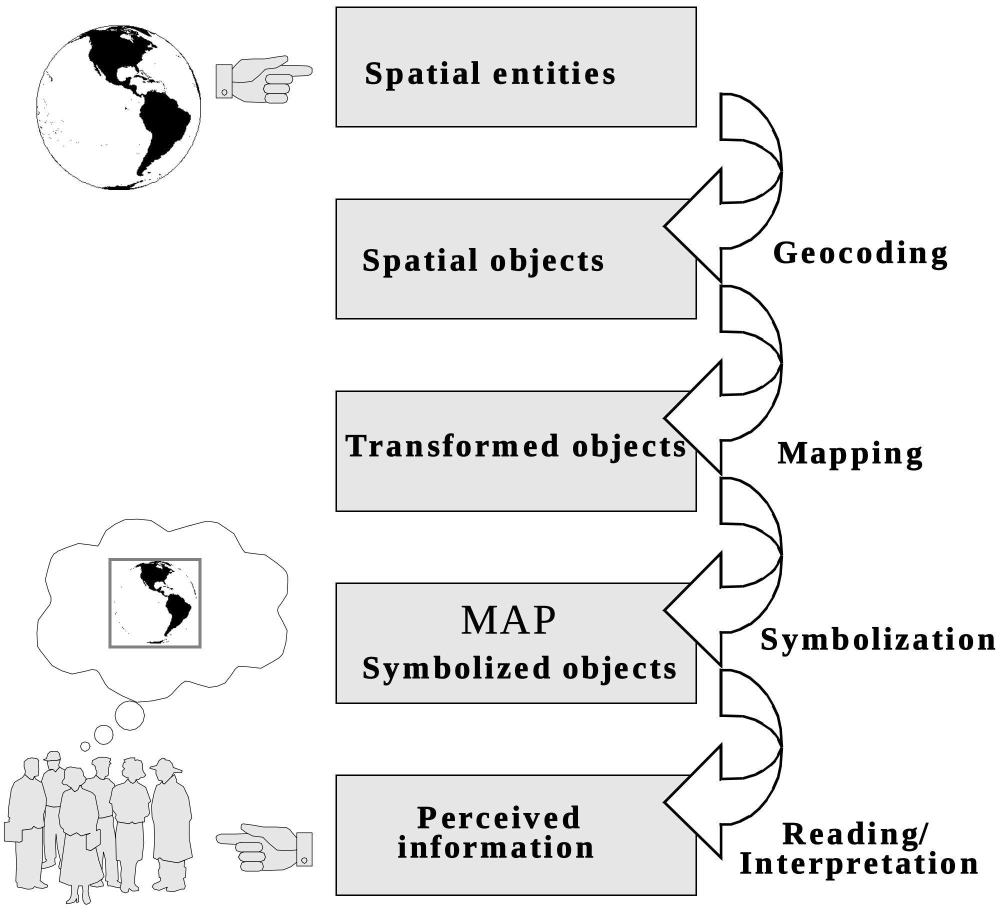

Figure 14.1 States and transformations in a model of the mapping process.

14.2 THE SYMBOLIZATION TRANSFORMATION

Symbolization is itself a set of states and state transformations. The input to the overall process is the map data, transformed into the correct geometry, generalized to the appropriate scale, and clipped to the area of interest. These data define a virtual map, because they could be realized in many different types of symbolizations. The output from the process is a real map, with a selected means of representation or type of map (for example, choropleth or isoline), a given design chosen by the cartographer to facilitate map use, and a set of symbols used to represent the cartographic objects. If the whole set of transformations is completed successfully, the real map will be accurate, effective, esthetically attractive, and useful.The transformation as a whole can be seen in Figure 14.2. Four individual transformations make up the symbolization process: *compilation*, *representation*, *design*, and *symbol selection*. Each contributes its own set of modifications to the map data, and represents

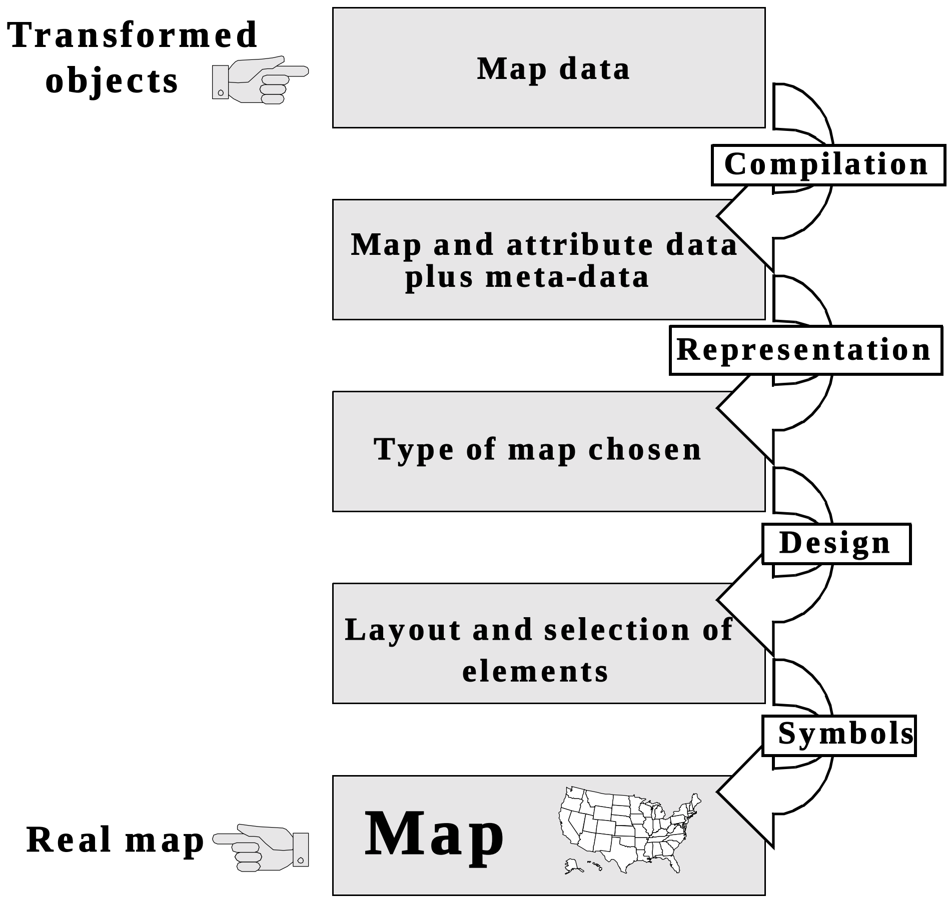

Figure 14.2 States and transformations in the symbolization process**.**

a successive narrowing in the number of possible virtual maps until just one real map emerges. As the process evolves, the geometry of the map changes from that of world coordinates—in the system of the figure or map area of the map—into the “device” or workstation coordinates of the real map. In the design and symbolization stages, the map space coordinates are used predominantly, and the world coordinates remain only as georeferences into the map figure itself.

14.2.1 Map Compilation

The first of the symbolization transformations is compilation. In this stage, map layers are coregistered at the correct scale and projection, data are selected and converted into the correct form (for example, perhaps county populations are divided by county area to give county population density or objects visible in an air photo are classified), and checks are made to deal with data limitations, missing information, data with different dates, and the reliability of the source information. Selection implies leaving data out, and significant data volume and information loss can occur at this stage.

Compilation involves research including updating and verification, because both the map data and the attribute data should be up to date and correct. The attribute data should be assembled and processed, if necessary, and other metadata, such as the source and date, the type of coordinates and map projection, the data lineage information, and the pertinent accuracy information should be compiled and prepared for use. Primarily, compilation affects how the map data finds a way into the “figure” of the map, one of the cartographic elements considered under design in subsection 14.2.3.

14.2.2 Representation

After compilation, we arrive at the point when we at last have assembled all the information required to make the map. At this stage, the map may be a series of base maps, a set of converted data files, tables, and text data. The representation phase is one in which the cartographer has to choose the type of map that is to be produced. Unwin discussed map types as relating directly to the types of data, in terms of their dimension and scaling. In addition to Unwin’s map types of dot, symbol, graduated symbol, network, flow, colored area, ordered area, choropleth, and contour map, cartographers have designed a plethora of different methods for representation.

Two standard cartographic texts that cover design are Robinson et al. (1984) and Dent (1993). These sources yielded a set of representational methods to supplement Unwin’s. Figures 14.3 and 14.4 give a sense of how to choose between methods based on the characteristics of the map data.

A basic outline or *reference map* shows the simplest properties of the map data. An example would be a world outline map, with named continents and oceans. A *dot map* uses dots to show the location of features and may show a distribution such as population against a base map. A *picture symbol* map uses a symbol, such a the silhouette of a skier, to locate features such as ski resorts. The *graduated symbol map* is the same, except that the size of

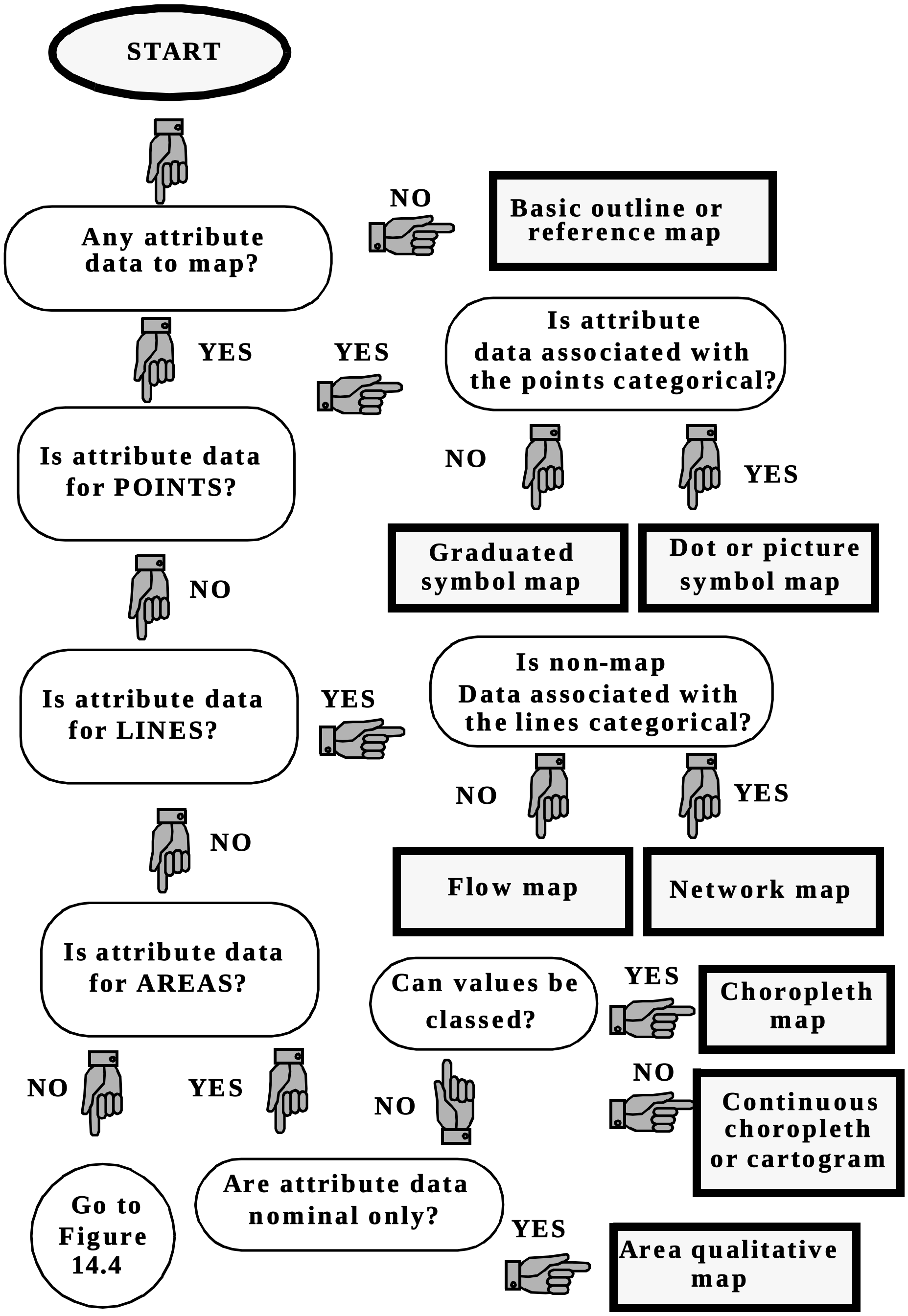

Figure 14.3 Guide to selecting a representational method (Part 1).

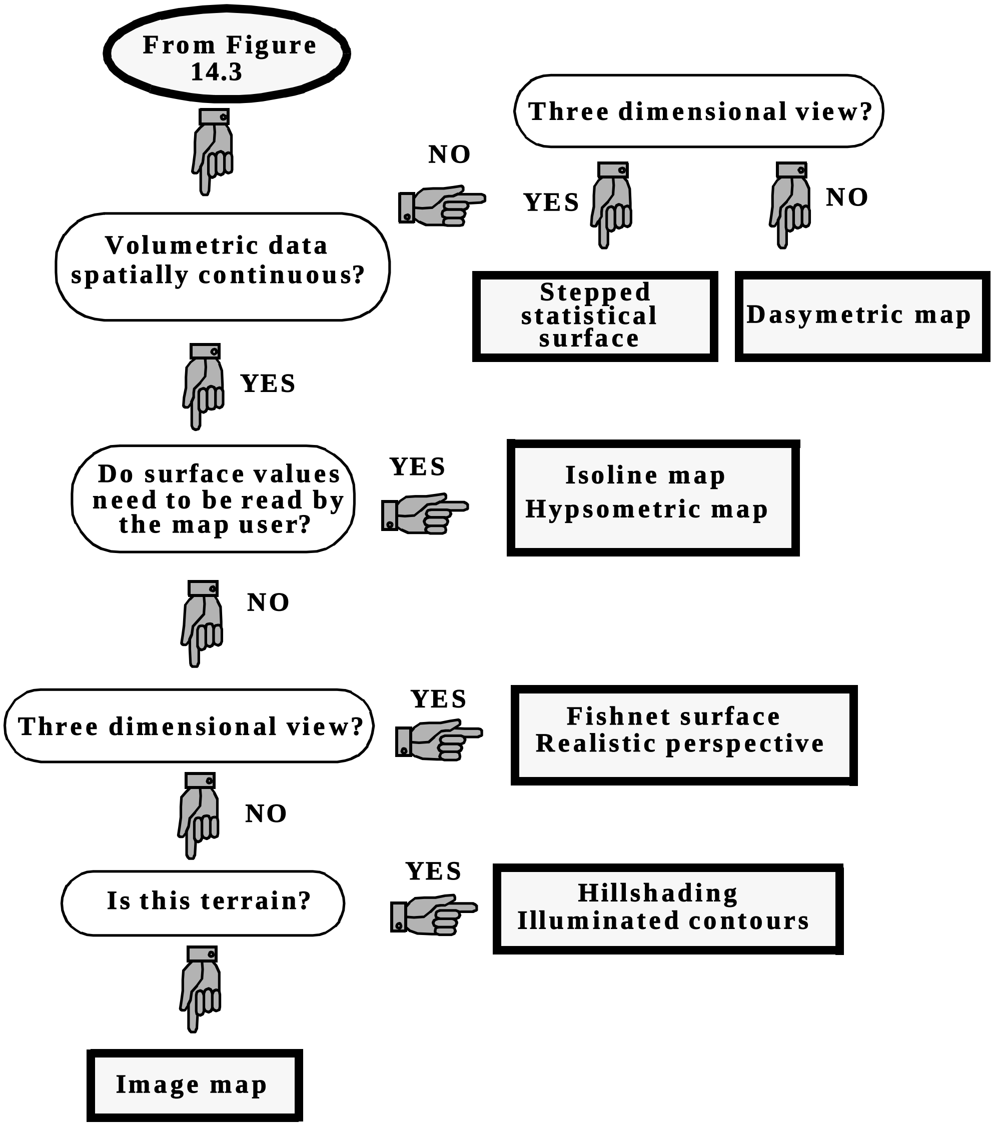

Figure 14.4 Guide to selecting a representational method (Part 2).

the symbol is varied with the value of the feature. Typically, geometric symbols such as circles, squares, triangles, or “spheres” are used.

A *network map* shows a set of connected lines with similar attributes. A subway map, an airline route map, or a map of streams and rivers are examples. The *flow map* is the same, but it uses the width of the line to show value, for example, to show the air traffic volume or the amount of water flow in a stream system.

A *choropleth map* is the familiar shaded map where data are classed and areas such as states or countries are shaded or colored more or less densely according to their value. A variation on this, the unclassed choropleth, uses a continuous variation in tone or color rather than the steps which result from classes. An *area qualitative map* simply gives a color or pattern to an area, for example the colors of rocks on a geological map, or the land-use classes derived from image classification in remote sensing.

Volumetric data can be shown in several ways. Discontinuous data are often shown as a *stepped statistical surface* a block type diagram viewed in perspective. A *dasymetric map* closely resembles an isoline map, without the constraint that values must be sequential. Thus breaks in value are permitted. An example would be a map of rock ore content, which would break sharply at linear fault lines but be smoother elsewhere.

The standard *isoline map* is simply a map with lines joining points of equal value. Surface continuity is assumed, meaning that sharp breaks are usually smoothed. The terrain equivalent is the contour map, with its characteristic datum and contour interval. A variant is the *hypsometric map* in which the space between contour lines is filled with color using a sequence designed to illustrate variation. Often image maps and schoolroom topography maps use this technique.

Three-dimensional views of surfaces rendered in perspective can be either a *gridded fishnet,* as discussed in Chapter 13, or a *realistic perspective,* when an image or shaded map is draped over the surface. The latter technique is often used in animations. Map views of terrain are often represented using *simulated hill shading,* where illumination of shadowing is simulated by the computer and a gray scale or a colored map is used to show the surface. A variant is illuminated contours, in which the shading algorithm is applied only to the contours themselves. Alternatively, apparent hillshading can be produced using inclined contours.

The final map type considered here is the *image map,* in which a value is depicted as variation in tone on a color or monochrome grid. Most raw and false-colored satellite images maps fall into this category, as does the orthophoto map.

This listing is far from exhaustive. A full listing of all representational methods would require an exhaustive survey of the work of thousands of individual cartographers over thousands of years, a virtually impossible task. Cartographers are continuously devising new representational methods, improving the existing methods, and rediscovering methods that are no longer in use. Many of these techniques are attributable to the advent of the digital computer, because their complexity and demands of computation made them impossible to imagine or to implement until the computer came along. Although many of the techniques covered here date back millennia, about half have originated since 1960.

The analytical cartographer should view the representational choice process as a procedure that can be measured, modeled, and improved by automation. Although many of the decisions involved here are subjective, many such problems have been solved using expert systems and neural networks.

One wonders how long it will take before the selection of the mapping method is also fully automated. A computer mapping system can make many of the decisions involved. More difficult, however, will be the automation of map design.

14.2.3 Design

The third transformation in the symbolization process is the conversion of the map data into a map design. Some characteristics of the design are predetermined by the choice of representational method. Primarily, however, the design stage consists of devising a balanced and effective set of cartographic elements with which to construct the map. The interrelationship between the design and the following stage, the choice of symbols, is strong, and it is at this stage where the use of the design loop, a trial-and-error interplay between a map design and a symbol set comes into play. This is because particular symbol sets,such as a set of colors, influence how the map is viewed, read, and interpreted.

A distinct advantage of computer cartography, as previously pointed out, is that this design loop is easily traversed, with a soft-copy or displayed virtual map as the intermediate step. Often, the virtual map is the means by which the design is constructed on-screen in a design software package such as CorelDraw!, Freehand, or Adobe Illustrator. These packages allow the user to preview the map in color, or with its final symbol set, at any time, or even continuously, effectively eliminating the distinction between design and choice of symbols.

Dent (1993) probably gives the most comprehensive overview of map design, oriented primarily toward manual or photomechanically produced maps and thematic cartography. Dent defines the map or cartographic elements as the title and subtitle, the legend, the scale, the credits, the mapped and unmapped areas (figure and ground in Robinson's terminology), the graticule, borders and neat lines, map symbols, and place names and text (Figure 14.5). Dent states that "the task of the designer is to arrange these into a meaningful, aesthetically pleasing design—not an easy task."

Figure 14.5 shows a set of cartographic elements. The *border* is the part of the display medium (paper, computer screen, or other media) that shows beyond the neat line of the map. In special circumstances, additional information can be provided in this space, such as the map copyright, the name of the cartographer, or permissions information. The *neat line* is the visual frame for the map and is usually a bold single or double line around the map that acts as a rectangular frame. From a design standpoint, the neat line provides the basis for the map (that is, cartographic device) coordinate system, in display units such as inches or centimeters on the page.

The two basic parts of the map are the *figure* and *ground*. The figure is the body of the map data itself and is the part of the map referenced in world coordinates. The *graticule* or *grid* (not shown in Figure 14.5) is the reference link between the two coordinate systems on the final map. Also part of both the figure and the ground or legend are the symbols, to be covered in the next subsection. The *legend* translates the symbols into words by collocating text and the symbols in the map coordinate space.

Text information is an integral part of a map, and no map is complete without it. Text figures in the *title* (whose wording sets the theme and the "feeling" for the map), in *place names*, in the *legend*, and in the *credits* and *scale*. The scale is a visual expression of the relationship between the world coordinate space and that of the map space. Because representative fractions change as the map is rescaled into the device space, a graphic scale is preferred. Place names follow a strict set of placement rules, both on the figure and related to features, and within the map space (Imhoff, 1975). These rules have been successfully .

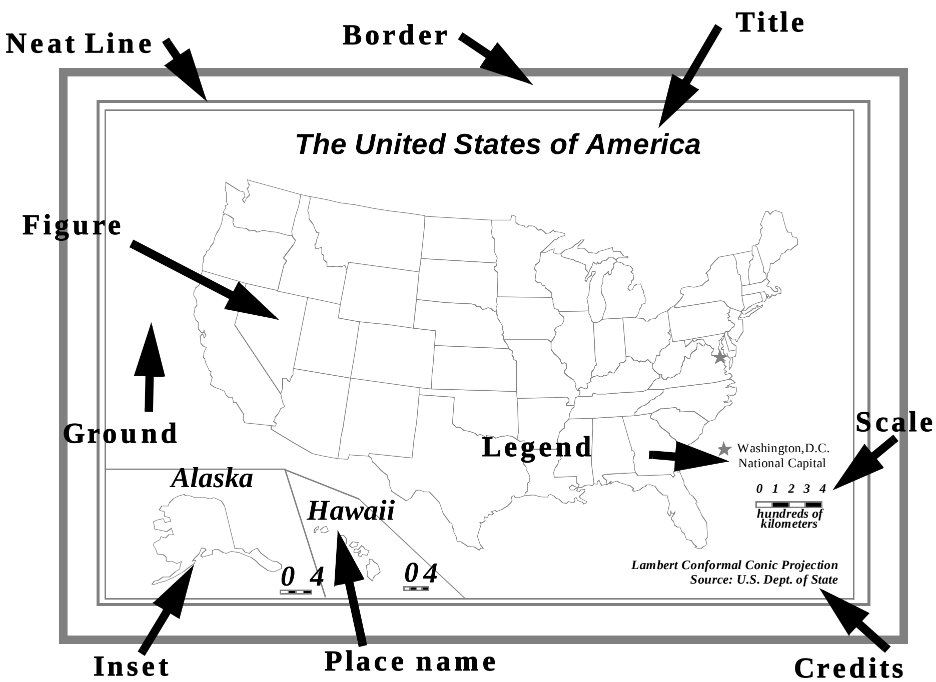

Figure 14.5 Cartographic elements.

automated, but as yet have not been incorporated in computer mapping systems (Ahn, 1984; Doerschler and Freeman, 1992)

Finally, an *inset* is either an enlarged or a reduced map designed to place the map into geographic scale context or to enlarge an area of interest whose level of detail is too specific for the main map scale. An inset should have its own set of cartographic elements, although it is usually highly generalized and many elements may be omitted. Because confusing the figure and ground of the main map with those of the inset is common, the inset should be clearly distinguishable from the figure and ground of the main map. Many Americans, for example, believe that Alaska and Hawaii are islands off of San Diego.

Having named the elements, the next stage is to place them correctly. Actual placement of the elements is usually accomplished in one of two ways: first, by interacting with the map in a visual design loop; and second, by editing a set of macrolike commands that move elements to specific places in the map space. The latter technique is less efficient and involves many traverses through the design loop. Most cartography texts state that the cartographer should aim for harmony and clarity in the composition. This comes from experience and an esthetic sense only and can take years to perfect. For a concise summary of the design literature for the beginning cartographer, the reader is referred to MacEachren (1994).

Obviously, the major facts to bear in mind to balance the elements are (1) that the “weight” of the elements can change when a symbol set (for example, line widths, colors, text fonts and so forth) are chosen, (2) that the elements act in concert with each other in a visual hierarchy (that is some elements naturally stand out from or "above" others, and that using deliberately exaggerated contrast to enhance this hierarchy is usually most effective), and (3) that the combined effect of all the elements is to draw the eye to the center of gravity of the elements. The latter point implies an analytic solution, because the output from many computer mapping systems is a raster file, for which the moment of each pixel around the center of gravity can be computed, along with statistics of trend and dispersal. Cartographic theory implies that the "visual center" of the map should be placed 5% of the map height below the geometric center. Again, computation of the mean and visual center implies an interactive or even fully automated analytic solution to this aspect of map design.

14.2.4 Symbol Selection

The fourth transformation—the symbol selection—changes this map design into a specific set of map symbols, and in this process the cartographer executes the technique to produce the map, with all text, color, linework, and so forth, in final form. The output from this stage is a real map. The map may take many forms and could be a page in a book, a map supplement to a journal, a page in an atlas, a sheet map, an image on a workstation or television screen, a piece of microfilm, a hologram, or a film negative.

The symbolization aspect of design has been studied in detail, and more than a few rules of thumb exist. Some symbolization methods are simply not suitable for certain types of maps and certain map data configurations. For example, a frequent misuse of color is on choropleth maps, especially when the computer gives access to thousands of possible colors (Mersey, 1990). Choropleth maps usually establish value by shading, by pattern, or by color intensity, but rarely by hue alone. Thus a sequence from light to dark red, with a slight hue change looks right, but a sequence of hues from red to blue across the rainbow makes the map look like a decorated Easter egg! Hue changes are appropriate to distinguish between opposites on the same map, such as a surplus/deficit or above/below a statistical average, or two party election results.

Even on general purpose maps, the color balance is essential. Computer displays use pure color, to which the eye is not usually subjected. Less saturated colors, if available, are more suitable for mapping. In addition, convention should be followed. Ground colors are usually white or cyan, not black or bright blue. Contours are frequently brown, water features cyan, roads red, vegetation and forest green and so forth. Failure to follow these conventions is particularly confusing to the map reader. Imagine, for example, a globe with green water and cyan land.

14.2.5 Visual Variables

Most cartographers realize that only a finite set of "visual variables" can be used to generate sets of mapping symbols. This set, first suggested by Bertin (1983), consists of *form, size, color, value, pattern/texture,* and *orientation* (Figure 14.6). Each of the visual variables comes into play during the map symbolization process. The form of cartographic symbols

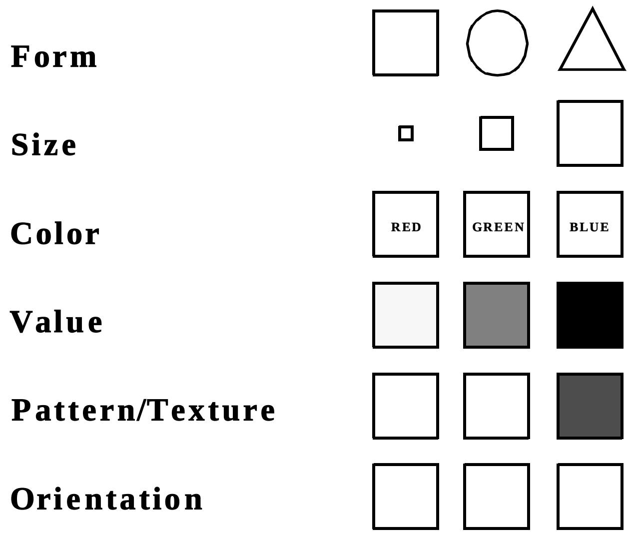

Figure 14.6 Bertin's visual variables.

is directly equivalent to the attributes assignable to GKS primitives. Lines can be dotted or dashed, point symbols can be different shaped polymarkers, polygon boundaries can be lines or transparent. The size of symbols can be used as the means of showing data, as in graduated symbol mapping, for example, where again the size is an attribute of the polymarker. Line size or width is sometimes called weight and is one area where contrast can be enhanced to solve figure/ground problems. Color is a more complex visual variable. Colors are often expressed as red, green, blue triplets (RGB) or sometimes as hue, saturation and intensity (HSI). These values are either integers determined by the hardware device (for example, 8 bit color allows a total of 256 colors from any of $256 \times 256 \times 256$ combinations of individual values of RGB), or, as in GKS, are floating point values of HSI between zero and one. It is possible to translate directly between the RGB and HSI representations of color. Whereas RGB values are simply the degree to which the respective colored phosphors emit light, HSI is closer to the way humans perceive color.

Hue corresponds to the wavelength of light, going from red at the long wave end of the visible light spectrum to blue at the other end. Saturation is the amount of color per unit display area, and intensity is the illumination effect or brightness of the color. Cartographic convention dictates that hue is assigned to categories and that saturation or intensity is assigned to numerical value. When several hues appear in juxtaposition on a map, the colors are perceptually altered by the eye, a phenomenon known as *simultaneous contrast.* Thus maps that use several hues, even as background and line color, should be designed with caution. In addition, the eye's ability to resolve contrast varies significantly with hue, highest in red and green and lowest in yellow and blue.

Value corresponds inversely to saturation and directly to intensity. Because many maps have to appear in black and white, value can be an important visual variable. The eye finds contrasts at low values (near black) much harder to resolve than those at high values. As a result, values are usually assigned to categories or classes. Symbols usually appear with extreme values (for example, white lines on black, black lines on white), but variations can help in setting the visual hierarchy.

Pattern, texture, and orientation are somewhat related, patterns simply consisting of repetitive textures. When patterns are used, they are either conventional (for example, the brick pattern for limestone, the marsh symbol for swamps), or are varied to achieve contrast. In GKS many different patterns are possible using the cell array with duplicated patterns. Pattern should be aligned across features and with the neat line or graticule. A common pattern is the dot sequence to simulate value on printers (for example, in PostScript) and the random or triangular dot pattern (actually a texture) used to reproduce continuous tone in newspapers. Neither pattern nor texture should be used to depict numerical value. Even with classes, a very busy map can result if pattern is varied.

To summarize, the design of a map is a complex process. Good design can be facilitated by planning, by achieving visual balance between map elements, by following conventions, by taking advantage of the design loop, and by the correct use of symbols and map types. Without consideration of design, and certainly without having all the required map elements however impressive it may look on a computer screen, the product is simply not an effective map (MacEachren, 1994).

A well-designed map becomes more than simply an object to be used for communicating map information, it is a reflection of the expertise of the cartographer and the capabilities of the technology of map production, and as such has value beyond its original purpose. The desire to produce computer maps at any cost, or plain ignorance, has often led cartographers to abandon these basic design principles, and as a result we have few beautiful computer-produced maps to show. On the other hand, the means to produce such maps is now easily within reach, if cartographers pay attention to design.

14.3 MAP USE AND ANALYSIS

We now switch from map making to map use. The next reference point is the map reader, who is usually not the cartographer and who may have no cartographic training. The last transformation involves reading the map, and the amount of information lost here can exceed that lost in all the stages up to this. Many cartographers study this transformation, using the term *map perception* to label the stage. This transformation can take place in the field, at night, in a vehicle, or during a location search, and it is usually of great importance in determining the success of the map.

The map-reading transformation uses the real map as source data, either for analysis or interpretation (for example, a farmer measuring the size of fields, or a geologist looking for fault lines) or to simply gain an image in the mind of what it is that the map depicts. If the map is successful, the reader of the map can get locational information as required and without errors,and the interpreter and analyst can do the same. We could say that the information that describes the piece of the world from the beginning of the mapping process has survived the mapping process intact, perhaps it has even been enhanced by the process. In this way, the map can be thought of as delivering a message. If there is only one message, the map is a *thematic map,* that is it shows a single theme. The more information kept as part of the symbolization, the more the map serves the function of storing or preserving generic information. A map showing multiple themes is a *general-purpose map*.

A single pass through the mapping process produces a tangible map and gives it value to the user. As such, the permanent version of the map is a valuable snapshot of the knowledge, skill, beliefs, and objectivity of the cartographer, as well as the technology used in each of the transformations. It is not surprising, therefore, to find map libraries and a healthy trade in old and interesting maps. The study, analysis, and interpretation of historical maps is a very important part of cartography, and is recommended for all those interested in computer mapping. Thematic maps are judged effective if they can communicate to the map reader the fundamental properties and essential characteristics of the particular statistical distribution that they depict. General-purpose maps, however, act as storehouses of locational information and are used for hiking, driving, planning, and even as data sources themselves.

The final transformation in the mapping process encompasses both map reading and map interpretation. Map reading is the inverse of the symbolization process. Locations, text, and symbols are used to rebuild the local geography in the mind of the map reader. The effectiveness of this translation is a result of the accuracy of the map, the legibility of the text, the clarity of the symbols and legend, and the suitability of the chosen mapping technique. Also, however, the effectiveness is the result of the training of the map reader. Map reading can be taught, as it is to navigators, members of the armed forces, foresters, hikers, and planners. Studies show that the more geographic training a person has, the better that person is able to read maps.

In addition, the final mapping transformation includes the analysis of map information. This sometimes involves measurement of location, areas, length, elevations and so forth. Especially important is the calculation of distances and bearing for cross-country movement. Map-related direct measurement is known as *cartometry* (Muehrcke, 1986; Campbell, 1993). Many mechanical devices for map measurement can be replaced in computer cartography if the map data are retained by the mapping system, as in a GIS, although the tools of the map user, the compass, the altimeter, the hand-held Global Positioning System receiver, and the planimeter, for example, will remain in use as long as there are sheet maps.

Last of all, the map user interprets the information from the map. Map interpretation assumes that the user has knowledge in addition to the "where" that is the primary concern of the cartographer. For example, the cartographer may be interested in accurately showing contours and streams in a landscape, while the structural geologist is searching those same contours and streams shown on the map for information about underlying geology, structure, and geomorphology (Miller and Westerback, 1989). The final transformation is not outside of the cartographer's interest, however, since this is the result of a logical and consistent cartographic treatment of the data throughout the mapping process. Cartographers can learn much from using their own and other cartographer's maps in the field.

4.4 THE MAPPING PROCESS AND THE COMPUTER

No part of the mapping process has escaped the impact of the digital computer. We use the computer to assist in map research, map compilation, map design, map production, finding their location in map libraries, and even in writing textbooks on cartography! Although this book focuses on the computer as a means of producing maps, we should not forget that the computer's impact is widespread, from the digital theodolite, to the digital satellite image, to the microprocessor-controlled process camera, to the statistical study of historical maps. This widespread nature of the technology makes the computer unique as a cartographic technology and means that the study of contemporary cartography is impossible without the study of the computer's impact.

We began this book by placing the computer in context as the current technology with which maps are made. This was to demonstrate that the computer is the current logical mapping technology and that its influence upon cartography has been truly revolutionary. Coupled with the data management capabilities of the GIS and linked to the technology of navigation and location-finding through GPS, a highly productive technology-led synthesis of disciplines has taken place, and indeed continues to take place in the mapping sciences.

Balchin (1976) has argued that maps are a component of a graphical form of communication that is a distinct alternative to the more familiar forms of spoken language (articulacy), written language (literacy) and symbolic numerical expression (numeracy and math), which he termed *graphicacy*. Although not everyone uses maps and graphics as a means of reasoning, maps are an extremely powerful tool for the communication of ideas.

The understanding of maps, at least as simple forms, is intuitive to humans, and map interpretation is rapid and efficient. Compare, for example, a text file composed of a regional description (a few kilobytes), a digital sound recording of the same file (maybe a megabyte), and a table of numbers describing the natural and human characteristics of the region (a megabyte at most) with the hundreds of megabytes needed to store imagery and digital map data for a whole region. Yet the user of a GIS can browse through and interpret the spatial information content of the maps in a fraction of the time it would take to read, let alone digest, the text information. Extending this argument, if the goal of a means of communication is to reason and persuade, then no other form of communication can come close to the map. Map logic is a powerful and currently underused tool of communication.

Users of the tools and theory of analytical and computer cartography have the opportunity to play a new role in the information age. Maps have power without doubt. The challenge is to use the power for the benefit of everyone. Effective use of mapping science technology in management and decision making will allow not only the solution of some of the problems that have been traditionally seen as intractable, but also will provide for the more effective use of existing, rather than new, resources.

To use maps effectively for these challenges requires both the practical (computer) and the theoretical (analytical) sides of cartography, for as time advances, cartographic theory becomes cartographic practice. The challenges also require a stream of new cartographers, flexible enough to cross disciplinary boundaries as the technology becomes universal, willing to take up the gauntlet, and intellectually capable of designing and making better maps.

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