be the processes by which each new level of representation is generated, the implications of these processes for map symbolization and design, and the corresponding implications of symbolization and design decisions for the success at which reasonable cognitive representations are achieved.

**NOTES**

1. We may even find that the intense efforts of the past decade by cartographers to understand map generalization closely parallel some of the work by information-processing researchers to understand visual cognition. The cartographic principles developed may inform theories of mental image formation (at least in relation to maps and other abstract visual scenes) and work by cartographers and others on visual cognition may suggest some new approaches to those trying to develop a more unified theory of map generalization (rather than the fragmented element-by-element approaches characteristic of most work thus far).

2. A variety of theories have subsequently been proposed to explain how parts are categorized and identified; see, for example, Biederman (1987) and Hoffman and Richards (1984).

3. The VSSP is proposed as a temporary storage location in which (a shelf on which) visual information can be briefly stored until needed by the “central executive.” The VSSP complements an “articulatory loop” where phonetic material can be stored (see Baddeley, 1988, for details).

4. For an overview of one cartographic attempt to evaluate the relative impact of specific Gestalt grouping variables, see Chapter 3.

5. See Part III for detailed discussion of computer-assisted visualization in a geographic context.

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**CHAPTER THREE**

**How Maps Are Seen**

A key aspect of Marr's (1982) approach to vision is his contention that there are three levels of explanation from which to address an information-processing system. The computational level focuses on the what and why. Considering vision at this level, and recognizing that vision involves a series of representations and processes that interpret those representations and build new ones, we begin the task of understanding how maps are seen by asking what the purpose of seeing is. According to Marr, this purpose ultimately focuses on recognizing and identifying shapes in the real world. At intermediate stages, however, there are representation-specific purposes that can be identified. In moving from the initial visual scene as sensed by the retina of the eye to Marr's primal sketch, the purpose can be defined as extracting contrast information (related to differences in intensities and wavelengths) and grouping this information to form edges, regions, and shapes. The purpose of the process leading up to Marr's 2½-D sketch (or Pinker's visual description level) is to make the depth, orientation, and junctions of visible surfaces explicit.

In relation to maps, these two goals imply that the way we establish contrast among map features will be critical at the initial level of vision. At this level, according to Marr, no higher level processes come into play, and therefore the only information available to the map viewer is contrast (from pixel to pixel of the retinal image). Although others have argued that top-down cognitive processes can have an effect even at this early stage of vision, it is clear that applying this top-down control is an effortful process. Sorting out components of a map display will be accomplished most efficiently if the cartographer creates contrasts among those
map elements that are most important for the viewer to notice immediately. The second goal, associated with the next stage of perceptual representation, suggests that Gestalt principles of perceptual grouping will play an important role. Again, although top-down processes might be able to facilitate Gestalt grouping (or may interfere with it), the most successful map (at this stage of processing) will be one that elicits grouping that links map elements in logical ways (e.g., areas are seen as homogeneous regions rather than disaggregated individual point features—as might happen with use of a pattern made up of noncompatible elements spaced too far apart).

Cartographically, the goal of research directed to low-level visual–cognitive processes is to understand how the stages of physiological–conceptual representation of a map scene interact with symbolization and design variables. Ultimately, we would like to be able to predict what symbol variables or design choices make differences noticeable (in particular situations or for particular tasks), attract viewer attention, are seen as having equal salience, have an intuitive order, or induce grouping or formation of figures on backgrounds. Vision should, on evolutionary grounds, be good at extracting object shape from the visual scene, assessing depth and relative size, and noticing movement. It must perform these functions from information about contrast on a roughly pixel-by-pixel basis at a retinal level, using neurological hardware to process the retinal image. This hardware appears to rely heavily on spatial filtering and enhancement procedures operating simultaneously at several scales. These filtering procedures take into account sensations received by groups of cells. A key feature of this system is that it emphasizes contrast more than absolute illumination (as it must do if we are to recognize an object as the same at dawn and midday). The system has many more cells devoted to value/brightness difference than to hue or saturation, although those cells devoted to these “color” differences are concentrated in central vision and are agglomerated less as they pass signals to cells in the brain’s visual cortex. This concentration means that we have relatively higher acuity for hue (hundreds of differences are discriminable) than for value (tens of differences or less are discriminable). A second key feature of the system is an ability to group the elements that the neurological image processing achieves into “objects,” or shapes that higher level processes can match to memory representations.

Within this context, this chapter begins with a brief look at our visual hardware that has evolved to meet the above goals. Once in possession of the basic ideas about how this visual hardware has evolved to meet the needs of vision in general, we can speculate about the limits that it imposes for the abstract task of “seeing” a map. The bulk of the chapter, then, considers selected low-level perceptual processes and the potential implications of cartographic use of the visual variables (i.e., the building blocks of map design) to create contrasts between and relations among map elements. While there is continuing debate about whether the low-level processes discussed in this chapter operate in a completely bottom-up, preattentive fashion, or are controlled (at least in part) by top-down processes, the key commonality of the processes discussed here is that they are fast (measured in milliseconds) and probably occur in parallel. It is this fast parallel processing that makes visualization such a potentially powerful tool for science in an era of data excess (see Part III).

**EYE-BRAIN SYSTEM**

The intent of this section is to provide a brief sketch of the eye–brain system’s major features and to suggest a few examples of how the eye–brain system puts constraints on the way we see symbols and read maps. Knowing the limits, constraints, and idiosyncrasies of vision allows us to avoid presenting map readers with processing tasks that are difficult or impossible to perform. Understanding why such limits exist and what our visual system has evolved to accomplish can give us clues about how we might facilitate processing of map information and also clues about the implications of our decisions concerning symbol form, color, size, texture, and so on, for how the information will be processed. The examples provided may also serve to suggest some possible avenues for cartographic research that draws directly upon the quickly expanding knowledge base concerning how human vision works as an information-processing system.

How human vision works is, of course, incompletely understood. What has become clear, however, is that the system does not transfer little pictures of the world from the eye to the brain. Our “perceptions” are constructed (or reconstructed) from a multitude of fragmentary information, some of which is organized spatially (i.e., a direct mapping from positions in the environment to positions in the brain) and some of which is organized according to the attributes of the stimulus (e.g., color, orientation, texture, movement, etc.). Vision is a complex parallel-processing system in which hundreds of millions of sensing cells react to input of light through the lens of our eyes. Through multiple interconnections, these reactions cause subsequent reactions among the tens of billions of cells in our brain that are devoted to vision. Both psychophysical and neurophysiological research indicates that considerable preconscious processing of the signals occurs between the initial incidence of light on the cornea of the eye and the ultimate perceptual experience.
The Eye

Some common conceptions about how the eye–brain system works evaporate quickly when we take a close look at the structure of the eye. A camera analogy is frequently applied. Like the lens of a camera, the human eye is arranged so that reflected and emitted light passes through a lens and results in an “image” of what is observed on a receiving surface. The extent of the image on the eye’s receiving surface is a direct function of the size of the object viewed and its distance from the lens. In comparison to many cameras, the eye contains a rather wide angle lens (focal length of 14–17 millimeters), allowing representation of a scene that extends 60° to either side of the central focus to which vision is directed. Although the camera analogy tells part of the story, it can be very misleading. As the complexity and interconnections of cells in the eye become clear, the camera analogy becomes less useful. The fact that we do not have the sensation of looking at the world through a fish-eye lens is one clue to the complexity of image processing that happens between the eye and our conscious sensation of seeing.

An analogy to image analysis systems used in digital remote sensing might prove useful, at least to cartographers trying to understand implications of the eye–brain system for how map symbolization is “seen.” Marr’s (1982) computational models of vision will, in fact, sound quite familiar to those conversant with image analysis. His hypothesis is that one of the principle steps in vision is the extraction of “shape contours,” and he describes how these contours might be extracted through spatial filtering procedures.

With a camera, a lens focuses an image directly onto a flat piece of film. With the eye, light must pass through a complicated tangle of semitransparent cells on its way to the receptors at the back of the eye, and these receptors lie on a curved surface (Figure 3.1). In addition, unlike a camera, with the eye focusing is achieved by changing the shape of the lens, rather than the distance from the lens to the receiving surface. Receptors in the eye’s receiving surface (the retina) vary in density, with substantially more in central vision, and contain distinct kinds of receptor cells that respond to different input.

Two major categories of cells line the retina: rods and cones. The rods are more numerous than cones (about 120 million and 5 million, respectively, in each eye) and will respond to very small changes in intensity of light, but not when light is very bright (Figure 3.2). Rods are insensitive to differences in wavelengths of that light, and therefore to color. Cones need greater illumination in order to react but are sensitive to differences in wavelength. Cones are concentrated in a very small area in the center of the retina (the macula). The fovea, a position that is directly exposed to light entering the eye, is located at the center of the macula. This is the location of greatest visual acuity and contains no rods, only cones. Cones, by their dominance here, are responsible for our ability to see fine detail.

Cone cells, in persons with normal color vision, can be further distinguished on the basis of the wavelengths of light they respond to. These cone types are generally referred to as L cones (sensitive to long wavelengths), M cones (sensitive to medium wavelengths), and S cones (sensitive to short wavelengths). These different cone cells are unevenly distributed in the eye as well. As a result, the eye’s sensitivity to different wavelengths of light varies spatially. Maps of retinal sensitivity to various wavelengths present a complex overlapping picture in which we find, for example, that sensitivity to green is confined to a relatively small hori-
horizontally extending band, while that to yellow occurs across a considerably larger, and nearly circular, portion of the eye (Figure 3.3). Sensitivity to blue, although covering a greater area of the retina than red or green, is lowest overall (in magnitude), which makes blue a poor color for small map features.

The retina is the first of three cell layers in the eye (Figure 3.4). The second consists of bipolar, horizontal, and amacrine cells. These in turn connect the receptor cells (i.e., rods and cones) to the ganglia. Many bipolar cells form direct connections. Horizontal cells, however, connect receptors with more than one bipolar cell, and amacrine cells link more than one bipolar to individual ganglion cells. These interconnections mean that a ganglion will not transmit an impulse based on stimulus of a single location on the retina; instead, it summarizes the signals received from a number of inputs, the ganglion’s “receptive field.” Most of these fields, in humans (as well as other mammals), are roughly circular with sufficient overlap for the foveal areas to overlap slightly (Figure 3.5).

To relate the size of receptive fields to the size of discriminative features in the visual field, the “angle subtended” by the feature is referred to. This is the angle formed from the lens of the eye to the top and bottom of the feature attended to. The angle equals that covered by the image of the feature on the retina (Figure 3.6). If, for example, you were viewing one of the pictorial symbols on a National Park Map (4 millimeters high) from normal reading distance of (approximately 460 millimeters), the image on the retina will cover 30 minutes of arc.

Ganglion cell receptive fields vary in size from the fovea to peripheral areas of the retina. Receptive field centers exhibit particularly systematic enlargement from center to periphery. Near the fovea, where the receptive field can be as small as a single receptor cell, the cells are spaced about 0.5 minutes of arc apart (2.5 micrometers). This corresponds to our greatest visual acuity. An example of a single feature that subtends 0.5 minutes of arc is a 0.13-millimeter-wide line on a map at normal reading distance (e.g., representing a road) or a 1-millimeter boundary line on a wall map viewed from about 22 feet away. In contrast to this, receptive field centers near the eye’s periphery can be a degree or more. The result is sharply decreasing acuity from the center of vision to the periphery. For maps, this means that a small map symbol, identifiable when we look directly at it, will be less and less clear the further in the periphery it is. For symbols to be recognizable in peripheral vision, then, they need to be larger (Figure 3.7).

If images or parts of images (e.g., skates on the feet of the figure in the National Park Service symbol for skating area) are to be seen and discriminated in peripheral vision, symbols must be considerably larger than required for discrimination with foveal vision. If differences between two symbols are small, therefore, we will require a “fixation” on the symbol to discriminate it from others and identify what it is.1 In addition, the color sensitivity maps above suggest that the ability to see and recognize a symbol in specific regions of peripheral vision will vary with its hue.

This variation in acuity from central to peripheral vision has express implications for designing general reference and topographic map symbols. On a highway map, for example, map users often try to find particular kinds of features (e.g., points of interest, airports, universities, etc.). Symbols that are clearly distinguishable to the cartographer next to each other in the legend (when both are in the foveal area of vision) may not be different enough to be distinguishable when the map user scans across the map looking for them.

Like most neurons in the brain (discussed below), the ganglia collecting signals from receptive fields of the retina generate impulses of a constant magnitude. What varies is their rate of firing. They exhibit a steady (resting) rate until the combined input from their receptive field reaches a threshold, at which point they either cease firing impulses or increase their firing rate. Whether the firing rate of a ganglion increases or decreases will be a function of the kind of ganglion cell stimulated, together with the spatial characteristics of the stimulus. Most ganglia react differently to stimuli near the center and periphery of the receptive field and, as a result, are termed “center-surround” cells. Both ON-center and OFF-center cells exist. With ON-center cells, a stimulus near the center of the receptive field stimulates an increase in firing rate, while a stimulus from the outer cells of the receptive field inhibits firing. With OFF-center cells, this pattern is reversed.

A constant stimulus that covers an entire ganglion's receptive field will result in competing signals that will partially cancel each other with (usually) a net result of slight inhibition on the ganglion's firing rate. If, on the other hand, the cell's receptive field is exactly centered on a small enough stimulus or it crosses an edge of some type, resulting in a different stimulus for the center and surround, the signals of center and surround can reinforce each other.

An interesting example, relevant to selection of area patterns for maps, of how this center-surround system and the size of receptive fields interact is an illusion called the Hermann grid (Figure 3.8). Most people when viewing this grid "see" dark spots at the intersections of the grid,
unless they look right at those intersections. If we make use of peripheral vision, the ganglia being used have relatively large receptive fields (about the size of each grid zone). ON-center ganglia with receptive fields centered on the grid intersections will have the same reactions from their central areas as do ON-center cells centered over intermediate points, but an increased inhibition from the surround, resulting in the sensation of a dark spot. If you look directly at the intersection area, the receptive fields for the ganglia now involved are much smaller, and the illusion disappears. While artists sometimes make use of this effect to achieve a feeling of motion or instability in an image, we seldom want such a reaction to maps. We can prevent these distracting effects on maps by avoiding the relatively coarse patterns that match up with peripheral ganglion receptive fields.

In addition to having overlapping receptive fields, ganglia are interconnected and can inhibit each other's firing rate in the same way that a single cell's surround can inhibit the firing rate of its interior. These lateral inhibitory connections are thought to be responsible for the phenomena of "Mach bands," the illusion of shifts in brightness that cause the appearance of two vertical lines in Figure 3.9. Simultaneous contrast is also due to lateral inhibition of ganglion cells. As shown in Figure 3.10, the counties highlighted on the inset map appear to differ in degree of darkness even though they are the same.

Lateral inhibition is important in cartography because it will help accentuate differences between adjacent patterns or between symbols and background. On the other hand, it will make one pattern appear darker when next to a light pattern than when next to a darker pattern. This is one reason that there is an apparently smaller range of gray tones that people can distinguish on a map versus in gray patch experiments typical of gray scale research (MacEachren, 1982). Evidence of lateral inhibition clearly leads to the prediction that fewer shades of gray will be distinguishable on a map (where context within which any particular gray tone appears will vary) than in side-by-side comparison of pairs of gray patches. Only these out-of-context, side-by-side comparisons, however, have been used in formulating gray-tone selection guidelines. There has been a failure to test gray tones on actual maps because of the expectation that the spatial aspects of gray tone perception might confound results. As a result, cartographers have devised some tightly controlled "clean" experiments resulting in gray scales having unknown applicability for use on maps.

The only attempt that I am aware of to measure gray tone perception on actual maps was an undergraduate term project by one of my students (Terry Idol) several years ago. The experiment used a gridded 20-class choropleth map with gray tones assigned randomly to cells. Subjects (college students) were asked to estimate the actual value (as a percent of black from 0 to 100) of specified cells. The gray scale derived from this experiment was more linear than any of the gray patch-based scales cited in the literature. Because of some printing flaws in the test maps and the small sample used in the study, 1 would not consider this isolated map-based gray scale experiment conclusive. If replicated, however, the interpretation would be that 0% and 100% anchor the gray scale and simultaneous contrast on actual maps tends to make light grays look lighter and dark grays look darker, thus at least partially compensating for the apparent perceptual underestimation of differences so often cited in the litera-

![Figure 3.9](image_url)  
(a) The illusion of Mach bands—the dark vertical line toward the left of the illustration and the light vertical line toward the right. These apparent lines do not exist when luminance is measured with a light meter. (b) This illusion causes lower tints on isarithmic maps to appear to gradually change in value in the wrong direction (i.e., between any two isarithms, regions that should have a lower data value will end up with an apparently darker color value than regions with a high data value).

![Figure 3.10](image_url)  
An illustration of simultaneous contrast for two map zones surrounded by predominantly light versus predominantly dark zones. Both counties (highlighted in the inset map) have the same data value and are filled (on the main map) with the same shade of gray.
ture. A much more linear gray scale may apply to choropleth maps than we have suspected thus far, one that bottoms out at about 20% reflectance (or 80% black).

In addition to producing simultaneous contrast effects, lateral inhibition between adjacent ganglion cells has a major role in color perception. Ganglion receptive fields for the three types of cone cell include various opponent relationships of center and surround cells. The three general categories of relationships are (1) red-green opponent cells that include ON- and OFF-center arrangements of L and M cells, (2) blue-yellow opponent cells that include ON- and OFF-center arrangements of S with combined L + M input, and (3) dark-light opponent cells that seem to be stimulated by all three cone types. Proponents of opponent-process theory (OPT) argue that these opponent relationships are responsible for our full range of hue sensation (Hurvich and Jameson, 1957). The theory predicts that there are four unique hues (blue, yellow, green, and red) and that all other hues result from mixtures of these four basic colors. The theory was developed in the 19th century with neurophysiological support coming in the latter half of the present century. At least one cartographer (Eastman, 1986) has attempted to apply the theory to selection of hue ranges for choropleth maps. This application will be discussed in the next chapter.

The most comprehensive look at one result of lateral inhibition (simultaneous-contrast or surround-induced changes) in relation to color use on maps is Brewer’s (1991) dissertation (which dealt specifically with this topic in the context of color maps). Her initial premise was that induction will cause colors on maps to shift in appearance toward the complement of the surround hue. She devised an experiment to determine whether this assumption was in fact true and, if so, whether a quantitative model of simultaneous contrast could be used as an aid to selection of easily identified map colors. The opponent-process approach to color was selected as the best starting point for modeling induction. Brewer found the expected shifts in color appearance toward the complement of the surround (e.g., a red surround makes a central color appear more green). An unexpected finding, however, was that center-surround combinations with low contrast exhibited larger shifts than those with high contrast. This result seemed to be related to color saturation. Saturation shifts turned out to be the largest shift identified in the research. Based on her experiments, Brewer devised a model of the buffer around each color that represents its potential appearance with various surrounds. The model, designed to accommodate 90% of potential map viewers, was judged a success. With this model, a cartographer can ensure that colors for map categories are not confused by selecting only colors whose color-space buffers do not overlap.

As we have with visual acuity, we tend to take for granted the similarity of the color-processing system from person to person. Some of the individual variability may, however, be critical to map design (which is why Brewer chose a 90% target rather than designing for the average map reader). As Judy Olson (1989) pointed out, for example, a significant proportion of the population has some level of color deficiency. The deficiency is usually due to the absence of or the failure to function of one or more of the cone types found in the eye. Males are particularly likely to suffer from some level of color deficiency (about 8% for males vs. 0.4% for females). Recent evidence suggests that females, in addition to being less susceptible to color deficiencies of this type, sometimes actually have an extra category of cone in their retina, thus giving them an extra dimension of color vision not shared by any male counterparts. Although about 12% of females may have this extra category of cone, the necessary experiments to determine what impact it has on their color vision have not as yet been conducted.

Eye to Brain

From the ganglia, axons extend that connect these composite signals to the next step in the process: the optic nerves. The optic nerves serve as the connecting link between the eyes and the brain. One of their primary functions seems to be the spatial amalgamation of signals from each eye. After leaving the eye, the optic nerves converge at the optic chiasma where they divide so that information from one side of each eye is directed to the same side of the visual cortex in the brain. Since the image on the retina is reversed, this sends information from each half of our visual field to the opposite side of the brain (Figure 3.11).

There are less than 1 million optic nerve fibers leading from the ganglion cells. In the outer part of the retina, up to 600 rods might be connected to one optic nerve fiber through one or more ganglion cells. In the fovea there is close to a one-to-one match of cones and optic fibers. This is one reason for more acute vision at the center of the visual system.

Brain

In the 1960s neurophysiology predicted the ability to understand thought by understanding our neurophysiological hardware. The slow progress since the breakthroughs that found cells with apparently specific functions (e.g., recognizing edges at specific orientations, and possibly even recognizing faces) has led to a realization that neurophysiological and
neuropsychological evidence about vision will provide only part of the answer to how vision works. Following Marr's ideas, neuropsychological hardware is best considered as a mechanism that has evolved to meet the needs of vision, rather than as a fixed system that our visual abilities were adapted to. It does, however, exert limits on visual tasks that are not part of everyday behavior in the world (relatively recent visual tasks that human vision has not had time to evolve special procedures for). Reading maps seems to be one such unnatural task, with its typically abstract, twodimensional static depiction. From a cartographic point of view, then, we are interested in features of how the brain processes visual signals not because this knowledge is likely to tell us how maps work, but because these processes put limits on what symbolization and design variations might work.

As indicated above, the signals sent to the brain by the ganglion cells result from a complex interaction of signals from each cell's receptive field together with the inhibitory interconnections of individual ganglion cells. Cells first reach the lateral geniculate nucleus (LGN) in the brain where neurons behave similarly to ganglia. Receptive fields still correspond to concentric regions in the retina. The LGN is arranged in six layers, each of which contains cells that respond to only one eye. For reasons that are as yet not understood, the six layers are arranged, from the top down, in a left, right, left, right, left, right eye sequence.

Once signals reach the visual cortex at the rear of the brain, linkages back to the retina become much less simplistic. Like the network of ganglia, cells within the visual cortex emphasize the signals coming from the macula. Approximately 50% of each side of the visual cortex is devoted to these signals. In contrast to neurons of the eye, however, those in the visual cortex have been found to be more specialized. Some appear to respond to particular visual elements such as line widths, angles, orientations, and so on, and some to the hue and brightness distinctions found with ganglion cells. The overall consensus of recent work in neurophysiology is that the visual system is composed of a sequence of processes capable of initially detecting edges, lines, and patterns (the processes Marr associated with extraction of the prim sketch) and subsequently analyzing these to result in more complex structures (Marr's 2½-D and 3-D representations).

This research has recently begun to result in maps of the brain in which the spatial arrangements of cells associated with specific functions are depicted (Figure 3.12). It seems particularly apt for a book about how maps work to include maps of the brain as a piece of evidence concerning how the brain might process maps.

Clinical observation beginning in the 19th century was responsible for the first crude mappings of the brain's major sections. It was not until the 1950s, however, when single-cell recording techniques began to yield information about individual and groups of cells that the complexity and intricacy of the neural interactions began to be recognized. Kuffer (cited in Hubel, 1988), in 1952, demonstrated the existence of the center-surround cell receptive fields described above. Much of what we now know

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**FIGURE 3.11.** A depiction of the pathways connecting receptor cells in the eyes to the primary visual cortex in the brain. Derived from Hubel (1988, p. 60) and Wade and Swanson (1991, Fig. 3.22, p. 70).

**FIGURE 3.12.** Activity maps (derived from positron emission tomography scans) that suggest the varied landscape of functions mapped out across the brain. After Raschle (1991, color plate 3-1). Reprinted with permission from Mapping the Brain and its Research: Enabling Technologies into Neuroscience Research. Copyright 1991 by the National Academy of Sciences. Courtesy of the National Academy of Sciences Press, Washington, DC.
PERCEPTUAL ORGANIZATION
AND ATTENTION

If an information-processing approach to vision and visual cognition is
accepted as a useful conceptual structure, then derivation of meaning
from maps can be viewed as a linked series of processing modules. A
number of authors have made this point and offered their versions of how the
overall process should be divided. The first such categorization was prob-4
ably Olson’s (1976) level-of-processing approach in which she delineated
three levels: (1) comparing symbol pairs, (2) recognizing characteristics
of symbol groups, and (3) using symbols as signals to information about
what is represented. Both Phillips (1984), with a “low-level”/“high-level”
categorization, and Dobson (1985), with a distinction between “visual-
search guidance”/“cognitive-search guidance,” emphasize a break between
preattentive and attentive or perceptual and cognitive processing. Both
posit that map design will have more impact on the lowest level of pro-
cessing because it is at this level that the system is virtually overwhelmed
with input and expert knowledge is least likely to apply. As certain optical
illusions demonstrate, early perceptual reactions can often be hard (or
impossible) to ignore—an indication that top-down processing (i.e.,
knowledge) has less control at this level and perhaps in some cases no
control at all (Figure 3.17).

Although I do not agree with Dobson that cartographers should di-
rect most of their research energy to the influence of symbolization and
design decisions on low-level processes—the higher level processes such
as derivation of meaning and decision making are what maps are really
about—I do agree that failure of a map at this level can make it difficult
or impossible to use. A complete understanding of how meaning is de-
derived from maps, then, must begin with an appreciation for the selectiv-
ness of vision in giving us a representation to think about. The informa-
tion theory approach (that treated cartography as a communication
system) focused on vision as an information filter with the cartographer’s
goal being to limit the amount of information that was filtered out in the
communication process. This perspective treated perceptual representa-
tions as imperfect translations of reality. In contrast, the approach taken
here is that perceptual representations are not fuzzy copies of the world,
but interpretations of that world. The cartographer’s goal is to determine
what kind of representation her maps produce and how symbolization
and design decisions influence the processes leading to those representa-
tions.

The remainder of this chapter, then, considers these initial visual
processes from a perspective of how symbolization and design decisions
interact with them.  

Gestalt psychologists in the early part of this century laid the
groundwork for our current understanding of the perceptual organization
of visual scenes. The Gestalt approach emphasized the holistic nature
of human reactions to sensation. According to Wertheimer (quoted in Ellis,
1955, p. 2), “There are wholes, the behavior of which is not determined
by that of their individual elements, but where the part processes are
themselves determined by the intrinsic nature of the whole.” More spe-
cific attention to pattern is seen in Kohler’s (1947, p. 103) statement that
“the organism responds to the pattern of stimuli to which it is exposed;
and that this answer is a unitary process, a functional whole, which gives,
in experience, a sensory scene rather than a mosaic of local sensations.”
Wertheimer’s initial emphasis was on defining principles of grouping, and
he mentions the segregation of figure and ground only briefly at the end of his article. Köhler and Kohler, Wertheimer’s contemporaries, however, extended the initial thoughts on formation of figures. Köhler (1947, p. 145), for example, argued that “sometimes it seems more natural to define a principle of grouping not so much in terms of given conditions as in terms of the direction which grouping tends to take.” This viewpoint is specifically linked to figure formation in his statement that “a homogeneous field in visual space is practically uniform and, being without points, there are no relations between points within this field. When Gestalten appear we see firm, closed structures, standing out in lively and impressive manner from the remaining field” (quoted in Ellis, 1955, p. 35).

For several decades while the behaviorists held sway in psychology (particularly in the United States), Gestalt psychology and its principles of perceptual organization were ignored by experimentalists. More recently, particularly in response to the needs of computational vision research and the attention to form and structure in vision that it has stimulated, Gestalt principles are being re-examined. Uttal (1988, p. 146), for example, contends that “human visual perception is powerfully driven by the global organization of form.” Recent research in psychology that incorporates Marr’s basic contentions (that human vision is an information-processing system and that information-processing systems can only be understood if examined at a combination of computational, algorithm-representational, and hardware levels) have drawn heavily upon Gestalt principles as a source of ideas for understanding grouping in early vision and figure–ground separation associated with object and pattern recognition (see Roth and Frisby, 1986, and Bruce and Green, 1990, for overviews of this work).

Pomerantz (1985) points out that the distinction of Gestaltists, between processes of grouping and of figure–ground separation, is significant from an information-processing perspective. Although there is a clear connection between principles of grouping and formation of figures, grouping of as yet unidentified edges, blobs, terminations, and the like, is a requisite step in deriving a primal sketch. Once edge segments are grouped into contours, then it becomes possible for vision to sort out figure from ground. There is considerable evidence that the initial grouping stages are almost entirely preattentive with little or no input from higher level processes. Research results concerning figure–ground segregation are mixed, with some evidence that figures can spontaneously “pop out” of a background, together with demonstrations that input from stored knowledge or expectations does (in some circumstances) effect both the initial appearance of figure and the stability of the figure–ground relationship.

From a cartographic perspective, low-level issues of grouping seem most relevant for exploratory cartographic visualization in which limited attention will be directed to any one map view and the goal is to notice patterns and relationships. Exploratory visualization implies that the outcome is not known, and that knowledge and expectations therefore may often be absent or wrong. Obtaining an immediate impression, before conscious application of knowledge schemata take over, is likely to play a major role in whether the visual displays lead to insight or simply are used to confirm expectations.

Perceptual organization operating at higher levels is important in those situations where particular information is to be emphasized while other information is suppressed. When goals are to create an imagable map (Peterson, 1987) or to ensure that a particular region becomes the focus of attention (Dent, 1972; MacEachren and Mistrick, 1992), issues of selectivity, associativity, and figure–ground become relevant. Most of the references to Gestalt principles by cartographers have been in relation to figure–ground segregation, with only limited attention paid thus far to the underlying processes of grouping.

Grouping

The “pattern of stimuli” mentioned by Kohler occurs due to grouping of elements in the sensory field. In relation to Marr’s theory, these elements might be edge parts, blobs, and the like. For maps, viewing these edges and “blobs” will occur in the primal sketch representation in response to map symbols such as points, lines, or elemental parts of textures. Their grouping will determine whether symbols are seen as intended and which kinds and scales of patterns are noticed. Wertheimer (1923; translated in Ellis, 1955) set out the rules for such perceptual grouping in his classic paper, “Laws of Organization in Perceptual Forms.” He defined the following factors or rules:

1. Proximity: Objects close together form groups. In the abstract, the factor holds that in any array of individual elements, those that are closest together will be seen as part of a group (Figure 3.18). Cartographically, as detailed below, proximity has been postulated to account for the appearance of regions on maps (Figure 3.18). A particularly intriguing part of Wertheimer’s argument, in light of current interest in dynamic and animated maps, is his contention that the factor of proximity holds for sound as well as sight. Sounds close together in time will form perceptual groups. This issue (without reference to Gestalt principles) is alluded
to by Krygier (1991) in his identification of the audio variable *rhythm* as “the grouping and ordering of sounds.”

2. **Similarity**: Like objects form groups. As presented by Wertheimer, similarity relates to nonlocational characteristics of perceptual units. He specifically mentions color, form, and sound. From a cartographic perspective, we might consider the similarity of all graphic variables (color hue, color value, shape, etc.), as well as tactual and audio variables (Figure 3.20). Wertheimer (1923; translated in Ellis, 1955) points out that similarity is not absolute, but can occur in degrees. Thus, judging “more and less dissimilar” becomes an issue in how people experience map symbols.

3. **Common fate**: Objects moving together are seen as a group. For this factor, Wertheimer points out that already grouped units that move together may hardly be noticed, but that units from separate groups moving together can be “confusing and discomforting” and will most certainly be noticed. It is postulated that common movement of units from separate (static) perceptual groups will override proximity, similarity, or other factors to achieve a new group held together by their “common fate.” Cartographically, of course, this factor applies only to animated or dynamic maps. In this context, however, it may play a particularly strong role in what groups are perceived. A corollary to Wertheimer’s common fate in relation to map animation is that objects that change together (even when they do not move) are seen as a group. In our map animation research at Pennsylvania State University, we have used this principle to animate static maps that depict existence of a feature with a fixed location (Figure 3.21). Similarly, Monmonier (1992) has employed what he called “blinking” as a method to emphasize the spatial pattern (or lack of it) in the proportion of public officials who are female. Blinking, in this context, involves having a choropleth map class (with values for the United States grouped by quintiles) blink on and off while other classes are turned off. Thus, one at a time, the states in successive quintiles are visually grouped so that the viewer can easily identify regional patterns in exclusion of females from public office.

4. **Pragnanzstufen**: Perceptual groups are characterized by regions of “figural stability.” This factor is difficult to translate, but implies that grouping has discrete cases. In relation to proximity, for example, there will be a relative threshold distance at which units will be seen to group or to occupy space in an undifferentiated way. Wertheimer’s example sug-
gests that for a row of dots we will see an ab–cd–ef–gh–ij grouping, no grouping at all, or an a–bc–de–fg–hi–j grouping at different possible regular spacings of the dots (Figure 3.22). This concept seems to match with anchor-effect theories of magnitude estimation (discussed below) and ideas about prototype categories (discussed in the next chapter).

5. 

Objective set: With change, there will be a tendency toward stable groups. Following from the above factor, the idea here is that if a set of perceptual units is initially seen as a group and that over time the position of those units changes, perception will try to retain the initial group. In addition, there will be a tendency to see a limited number of states (e.g., grouping A, undifferentiated scene, grouping B). Wertheimer’s example is based on a scenario in which seven pairs of dots gradually change relative positions (refer to Figure 3.22). Again, cartographically, this factor applies to animation. The implication is that throughout a movement perception tries to maintain a stable state, resulting in a greater likelihood that we will see a constant grouping on a set of change maps if they are presented dynamically than if they are presented on a page as small multiples. This would be an interesting hypothesis to test. The possibility to be concerned with is that “a certain (objectively) ambiguous arrangement will be perfectly definite and unequivocal when given as part of a sequence” (Wertheimer, 1923; translated in Ellis, 1955, p. 80). The issue here is one of visualization quality and how to determine when a pattern is “real” or illusory (MacEachren and Ganter, 1990).

6. 

Good continuation: Elements that follow a constant direction group. This factor applies not only to straight-line arrangements, but to curves, as illustrated in Figure 3.23. Cartographically, this factor allows contours on a black and white map to be seen as separate curved lines differentiated from roads or rivers that they might cross (Figure 3.24).

7. 

Closure: Closed objects form wholes. There is a tendency to see bounded perceptual units as wholes. Even when bounding edges overlap, there is a likelihood that the factor of good continuation cited above will allow us to see the separate bounds as units and apply closure to isolate their edges as groups defining wholes. The critical role of good continuation, and its potential dominance over closure was dramatically illustrated by Wertheimer (1923; translated in Ellis, 1955) (Figure 3.25). Cartographically, closure has clear applications to situations such as graduated symbol maps where it has been demonstrated that circle overlap does not prevent readers from seeing the circle segments as whole circles, or from judging circle size (Groop and Cole, 1978). In addition, a variety of graphic methods for emphasizing the closure of a map region have been examined.

8. Simplicity: Objects will group in the simplest form. Wertheimer did not specify simplicity as a specific factor, but mentioned it in relation to what he called “good Gestalt.” This concept was a basis of

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**FIGURE 3.22.** Grouping due to Wertheimer’s Pragnanzstufen factor. If shown as a time series, the original groups (top row) will be seen at time 4, even though all distances are equal at this time.

**FIGURE 3.23.** Grouping by good continuation. On the top, we “see” a long line with two short lines attached, rather than a short line with two angular attachments. On the bottom, we “see” two smooth curves crossing.

**FIGURE 3.24.** Good continuation helps map viewers sort out intersection lines on maps. Even in the absence of other contrasts, we can visually separate the contours from the county boundaries.
Wertheimer's "Law of Prägnanz," which Koffka (1935, p. 138) described as follows: "Of several geometrically possible organizations that one will actually occur which possesses the best, simplest and most stable shape." An example relevant to cartography is found with the tendency to interpret ambiguous situations (such as Figure 3.26) as interposition of simple figures rather than more complex adjacent figures.

9. Experience or habit. Familiar shapes or arrangements form groups. Many subsequent authors have focused on Wertheimer's contentions that past experience was not essential to perception of groups and that proving a role for past experience would be difficult. As a result, these authors have (mistakenly) characterized Gestalt psychology as disallowing the possibility for knowledge to play a role in both perceptual grouping and figure-ground perception. Wertheimer did, however, contend that experience or habit, in the form of "repeated drill," could play a role and at times cause groups to be seen that are at odds with what the other factors might dictate. Although he placed more emphasis on preconceptual processes, Wertheimer did not rule out the possibility of what we consider in the next chapter as "knowledge schemata" playing a role, even at early low-level stages of visual processing.

A number of cartographers have cited the above Gestalt "laws" (Wood, 1968, 1972; Dent, 1972; Mc Cleary, 1981). For the most part, they have been treated as laws, with attention directed to devising logical guidelines for incorporating the laws into map design. Few cartographers have questioned the principles or considered their relative influence on grouping of map elements. This tendency to take the Gestalt laws for granted is even apparent among psychologists (e.g., Kosslyn, 1989, uses some of the laws as given in developing a procedure for assessing graphic acceptability). Pinker (1990), like Kosslyn, contends that Gestalt principles have a role in the process of translating the initial visual scene to a visual description of a graph (a representation of entities and relationships among those entities). He goes on to suggest, however, that we do not at this point understand how to apply these principles because there has been little empirical research about the situations in which they hold or their relative importance.

Among psychologists, Pomerantz (1985) has provided perhaps the most explicit analysis of Gestalt grouping principles and their interrelations, as separate from the issue of figure-ground segregation. He begins with a convincing argument that grouping is "logically prior to figure-ground segregation" (p. 128). We must group perceptual units into objects and regions before a choice can be made among objects or regions concerning which are the focus of attention.

Although no cartographers, to my knowledge, have explicitly mentioned Gestalt principles in relation to perceptual grouping of map elements, a few have incorporated the principles in their work without crediting them to Gestalt psychology. Olsen (1976) alludes to the cartographic importance of grouping with her three-tiered hierarchy of mental processing in map use. Her second level deals with recognizing properties of symbol groups. To recognize these group properties, of course, the visual process must provide groups for which properties can be compared by higher level processes. Olsen considers (but does not test) the possible impact of symbol scaling (for graduated circle and dot maps) on regions that might be identified, as well as the role of value contrast among different symbols and between them and the background. In the former examples, the variable of proximity is manipulated and in the latter case similarity is used.

In a somewhat more direct examination of the applicability of Gestalt grouping laws to map reading, Slocum (1983) investigated visual clustering on graduated circle maps. Slocum's stated goal, formulated in behavioral terms, was to develop a method to predict perceived map groups using a combination of the psychological principles he felt were relevant to the problem. He hypothesized that proximity, similarity, and good continuation would play a role in the visual groups seen on graduat-
ed circle maps. He was unable to devise a measure of good continuation in the absence of eye movement recordings, so it was not actually tested. In addition to grouping factors, Slocum hypothesized that "figure-ground" would play a role in visual grouping. Figure-ground was limited for purposes of his experiment to a measure of value contrast, with dark areas expected to be seen as figure. The incorporation of this measure was based on prior evidence by Jenks (1975) that value difference had an effect on the groups seen, and its interpretation in terms of "figure-ground" seems to be based on Dent's (1972) emphasis on value contrast as a figure-ground variable.

Slocum's (1983, p. 61) experiment involved having subjects outline sections of graduated circle maps that they "saw" as "visual clusters"—"groups of circles that appeared to belong together and form a visual unit." His analysis indicated that a combination of proximity and figure (defined as relatively dark sections of the maps) provided a reasonable prediction. In fact, 92% of the individual circles on his 10 test maps were correctly classified as in or out of a cluster. Similarity of circle sizes had virtually no effect upon groups seen (Figure 3.27).

Eastman (1985b) has also investigated an aspect of perceptual grouping but, unlike Slocum, did so following a cognitive information-processing approach. Specifically, he examined the effect of several design variations of a typical reference map on the perceptual organization of the map. The goal was to determine whether proximity of locations, similarity of symbolization for those locations, regional inclusion (which can be associated with the closure of country boundaries or road segments), or linear linkage (determined by road connections between cities and at least loosely associated with "good continuation") influenced how map items were grouped in memory. Eastman found that the maps stimulated five different groupings, each of which was primarily associated with one or two of the map designs. All five grouping strategies led to hierarchical memory structures. A comparison of subject groups that grouped map elements differently did not support Eastman's hypothesis that different grouping strategies would lead to differences in learning speed or memory accuracy. Graphic organization of the maps, however, did appear to have an impact, both on how maps were perceptually organized and on whether organization was easy. Lack of graphic organization led to grouping by proximity or horizontal partitions. A map with regions delineated led to regional chunking (Figure 3.28). The map with no graphic organization also proved to be much harder to learn than the rest.

In addition to these relatively direct applications of Gestalt grouping principles to cartography, grouping has been considered less directly in studies of map regionalization. Muller (1979), for example, demonstrated that map viewers arrived at similar regions or groups when asked to delineate regions of high, medium, and low population density on continuous tone choropleth maps. In spite of being presented with many more color values than could be discriminated, subjects were able to group similar values into categories in a consistent way. In contrast to Muller, who asked subjects to delineate high, medium, and low regions, McCleary

![FIGURE 3.27. Grouping as predicted by Slocum (gray region) in comparison to grouping produced by his subjects (outlined region). After Slocum (1983, Fig. 9, no. 13, p. 71). Adapted by permission of the American Congress on Surveying and Mapping.](image)

![FIGURE 3.28. Eastman's graphically undifferentiated map (top) compared to the map leading to the most consistent grouping strategies (bottom). For subject groups viewing each map (at left), the gray shading represents consensus first- and second-order chunks (middle maps and right maps, respectively). After Eastman (1985b, Figs. 2, 8, 9, 12, and 13, pp. 5, 15, 16). Adapted by permission of the American Congress on Surveying and Mapping.](image)
(1975) had subjects delineate any regions they saw on a set of dot maps. An intriguing result of this task was that although grouping by proximity seemed to be at work in all cases, his subjects fell into two quite distinct types that he termed "atomists" and "generalists" (Figure 3.29). The atomists focused on local details. According to McCleary (1975, p. 247), they "seemed obsessed with detail and may have lost sight of the overall pattern of density." For the generalists, on the other hand, "lines are schematic and the 'attitude' expressed by the boundary line drawn suggests a reductionist view of the image." This finding has not been pursued in the cartographic literature but has interesting implications for our current concern with use of cartographic visualization for exploratory data analysis. It is important to determine whether McCleary's atomists and generalists represent general categories of map viewers and whether these tendencies are altered with training or expectations.

What We Attend To

Perceptual grouping is thought to work, at least in part, at a preattentive level. Based on Marr's speculations, some amount of grouping (into edges, blobs, etc., of the primal sketch) is a prerequisite to all seeing. Grouping will interact with visual attention in complex ways. Where our gaze is directed will limit what can be grouped (only global features of a scene in peripheral vision vs. details in central vision). The results of grouping will control what can be attended to and where our gaze might travel next. Where we direct our attention can, of course, also be consciously controlled. As a complement to issues of grouping, then, we must consider the combination of processes that fall under the heading visual attention. An important issue that Wertheimer considered in relation to grouping is the possibility of more than one factor acting at the same time. Such interaction may enhance visual grouping or may act in opposition to inhibit it (Figure 3.30). In addition to the effect on grouping, the interaction of multiple variables of perceptual units can influence the separability of features of the unit. This has obvious implications for how multivariate symbols are perceived, particularly for which aspects of a multivariate map symbol we can attend to together or separately.

Selective Attention and Separability of Visual Dimensions

Recent research on perceptual organization has emphasized the notion of selective attention as a way to measure the role of different features in the visual scene on perceptual grouping (Pomerantz, 1985). "Selective attention" refers to the ability to attend to one dimension of a display and ignore another. If dimensions or variables can be segregated in this way, they are not grouped. If, on the other hand, it is difficult or impossible to selectively attend to the separate dimensions, they are considered to be perceptually grouped. In a series of experiments, Pomerantz and his colleagues examined selective attention to features of compound stimuli. Their results, in addition to informing us about general perceptual processes relevant to map reading, are likely to be particularly relevant to design of multivariate symbols for maps.

Many of Pomerantz's experiments used sets of simple parenthesis-like symbols that were paired in various ways. These pairings were designed so that some should lead to groups (based upon Gestalt principles

FIGURE 3.29. Sample subjects from McCleary's dot map regionalization experiment illustrating the grouping strategies of atomists (left) and generalists (right). Reproduced from McCleary (1975, Fig. 4, p. 246).

FIGURE 3.30. Similarity and proximity acting together to enhance grouping (left) and in opposition resulting in ambiguous grouping (right). Derived from Slocum (1983, Fig. 9, no. 13, p. 71).
of good continuation, similarity, symmetry, and proximity) and others should resist grouping. One set of stimuli are shown in Figure 3.31.

A typical experiment would match a control case in which subjects had to sort two stimuli (e.g., the top row of each box in Figure 3.31) versus a selective attention case in which subjects had to sort all four stimuli (e.g., the two pairs on the right of each box in Figure 3.31 in one category and the two pairs on the left in the other) (Pomerantz and Garner, 1973). In both cases the task could be completed by focusing on only the left-hand element of the parenthesis pair. If subjects could selectively attend to this element and ignore the other, both groups should accomplish sorting at the same rate. Subjects in Pomerantz’s selective attention group, however, took longer to sort their stimuli. This is an indication that the pairs were processed as groups. The control case subjects had the easy task of sorting these perceptual groups into a symmetrical and an asymmetrical category. The selective attention group was forced to treat the four stimuli separately because, as groups, the two columns of parenthesis pairs do not form Gestalt categories (in fact, symmetrical vs. asymmetrical units form categories counter to the ones required by the sorting task). When the same experiment was run with stimuli that should, according to Gestalt principles, not group, there was no difference in response time between the experimental groups. The parentheses did not form perceptual units, and therefore the right-hand parenthesis could be ignored and sorting accomplished by focusing attention on the left parenthesis only. Thus both groups had a two element categorization task and completed it at the same rate.

Cartographically, Bertin (1967/1983) has focused upon issues similar to those that interest Pomerantz, but has not investigated his contentions experimentally. Bertin’s hypothesis (which he treats as fact) is that the visual variables can be independently judged on the basis of what he calls selectivity and associativity, and that these designations are discrete (i.e., a visual variable is either selective or nonselective in all applications). His selectivity is similar to Pomerantz’s selective attention. Where Pomerantz focuses on whether conjunctions of two or more objects proximate to one another are seen as a whole (a group), Bertin is interested in whether objects (map symbols) spread across the map can be formed into visual groups. Visually grouping, or attending selectively to, a particular value, for example, seems easier than attending to a particular shape (Figure 3.32). Bertin’s concept of selectivity is limited to grouping by similarity (although he does not define it in these terms). The emphasis is on whether visual grouping is “immediate” (a term that can probably be taken to mean preattentive) for all symbols in a category identified by a specific variation of one visual variable (e.g., all blue symbols on a map compared with symbols in various hues). Bertin posits that location, size, color value, texture, color hue, and orientation (of point and line symbols only) are selective variables.

There is empirical evidence for some of Bertin’s claims (although not derived from explicit attempts to test those claims). In relation to orientation, for example, Olson and Attnave (1970) demonstrated that a difference in orientation of simple line symbols can cause regions to be discriminated quickly (Figure 3.33). There is even a neurological (hardware level) explanation for why orientation is selective. Research by DeYoe et al. (1986) with monkeys has demonstrated that there are cells in the monkey’s cortex (regions VI and V2) that respond to pattern edges defined by differences in orientations of the texture elements making up the patterns. For this differentiation to occur, orientation differences must be in the center and surround portions of the cell’s receptive field.

Notodurft (1992) found that with limited variation within pattern areas, differences in orientation of as little as 20° were sufficient for a 75% success rate for preattentive pattern segregation. As variability in orientation of individual elements making up the pattern increased, the necessary difference in mean orientation of line segments in the two regions (required to achieve a 75% preattentive selection rate) increased in a roughly linear fashion. Beyond 30% variability in orientation within the individual patterns, pattern discrimination was unsuccessful regardless of magnitude of between-pattern orientation difference.

In contrast to Bertin’s sweeping claim, other evidence exists that the

![FIGURE 3.31. Test stimuli with good (left) and poor (right) grouping. Reproduced from Pomerantz (1973, Fie. 6.1, p. 129). Copyright 1973 by the Psychonomic Society. Reprinted by permission of the author.](image1)

![FIGURE 3.32. Value (right) seems to be selective while shape (left) is not.](image2)
key selective variable is symbol slope rather than orientation. If a symbol is used that has an internal orientation, it becomes clear that we can distinguish (mathematically) between orientations that are 180° apart, but that this orientation difference is not selective in Bertin’s terms (Figure 3.34). With Bertin’s line segment examples, it was not obvious that 180° rotations were not selective because they could not even be detected.

Not all of Bertin’s visual variables have been tested for selectivity; and the only empirical tests thus far have been by psychologists (who have not specifically set out to test graphic variables but to study the phenomenon of selective attention). In addition to slope, there is evidence for selectivity of color hue and color value. For both, Julesz (1975) found that regions were easily segregated if distinct value or hue differences exist. An interesting factor for these visual variables was that when pattern elements are small, vision seems to respond to an average signal. A region of mostly black and dark gray squares having a few white and light gray ones mixed in (and as a result mostly dark) is easily segregated from a region of mostly white and light gray squares having a few dark gray and black ones mixed in. Similarly, wavelengths of colors seem to be averaged so that a region of red and yellow squares (and a few green and blue) is clearly discriminated from one of green and blue squares (and a few red and yellow). A red-green region, however, is not easily discriminated from a blue-yellow region. Evidence also exists to support Bertin’s contention that shape is not selective, at least in the case of different shapes that have the same number of line segments and terminators (Figure 3.35).

At least one graphic variable that Bertin ignored has also been demonstrated to be selective. Julesz (1965) demonstrated that what he called “granularity” of a pattern (discussed in Part II of this book as pattern arrangement) leads to easy segregation of regions. The general success of Bertin’s selectivity claims, along with some discrepancies uncovered by empirical research in psychology, suggests that cartographers need to take a closer look at Bertin’s ideas. Studies that empirically test Bertin’s hypotheses and investigate the magnitude of differences required along specific dimensions of visual variables (including additional variables that others have added to Bertin’s original set) are clearly called for.

Bertin considers visual variables largely in isolation and does not discuss their potential interaction on a map. Experiments along the lines of those conducted by Pomerantz might be used to determine how vision will react to multivariate symbols that are designed to convey redundant information for emphasis and to enhance discrimination or separate information so that interrelationships can be noticed. In the first case, we would want to apply visual variables for which selective attention is difficult; in the latter case we would want the opposite.

No cartographic research (to my knowledge) has been conducted in relation to the issue of selective attention to visual variables in multivariate map symbols. Shortridge (1982) has, however, provided an overview of evidence from psychology and suggested possible applications to map symbolization. In particular, she considered the issue of integral versus separable dimensions (i.e., visual variables). Separable dimensions are ones for which selective attention is easy; integral dimensions tend to be seen

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**FIGURE 3.34.** It appears that slope of parts rather than orientation of an overall shape must differ (in some cases) for orientation to be selective in Bertin’s sense.

**FIGURE 3.35.** Shape, with other variables held constant, is not selective. After Julesz (1981, Fig. 6, p. 95). Copyright 1981 by Macmillan Magazines Limited. Adapted by permission of the author and Nature.
as wholes, and therefore selective attention is hard. As an example, consider a map that uses line size to indicate temperature at weather recording stations and line orientation from horizontal to vertical to indicate precipitation amount (Figure 3.36). If the two dimensions (e.g., symbol size and line orientation) are separable, selective attention will be possible and a viewer should be able to compare two stations on temperature or precipitation quickly—and not be able to judge temperature–precipitation correspondence easily (a contention that seems to be supported by Figure 3.36).

As Shorridge (1982) points out, psychologists began to distinguish between integral and separable dimensions as a way to explain results of visual search tasks that sometimes indicated processing of multiple stimuli in parallel and sometimes in a serial self-terminating manner (i.e., one symbol at a time until a target is found, at which point processing is halted). For serial searches, if a target is not present the search is exhaustive (relatively long) and will increase in length as the number of stimuli in the scene is increased. When a target is present (and a serial search is used), it will be found (on average) after half of the stimuli have been processed (response times will be 0.5 times that of target-absent cases). If stimuli are processed in parallel (all at once) then processing times will not be affected by the number of stimuli that must be processed. Although predicting whether a serial or a parallel process will be invoked does not seem easy, attention to this question led psychologists to notice the differences between compound stimuli that seemed to differ in the likelihood of serial versus parallel processing. Recognition that some symbol dimensions are integral (i.e., difficult or impossible to attend to separately) led to a holistic account of processing as an alternative to the serial–parallel possibilities. This account suggests that integral symbol dimensions create a whole that is processed as a single unit. Evidence for such holistic processing comes from research by Lockhead (1970) and Pomerantz and Schwartzberg (1975), both of whom found that certain conjunction tasks, in which subjects had to discriminate or categorize symbols on the basis of the conjunction of two dimensions, were performed faster than discrimination or categorization on the basis of either dimension individually.

**Divided Attention and Variable Conjunctions**

In their research on conjunction tasks Pomerantz and Schwartzberg (1975) used measures of *divided attention* as a complement to previous selective attention studies of perceptual grouping. They reasoned that if selective attention to parts failed, implying that they were grouped, viewers should find it easier to attend to the groups as a unit. This hypothesis was tested by having subjects try to sort stimuli (of the kind used in their initial experiments—see Figure 3.31) according to groups that were similar while ignoring elements within those groups that would suggest alternative groupings. They found that when Gestalt attributes of element pairs (e.g., combinations of symmetry, closure, similarity) indicated that grouping of the elements into a single whole was likely, sorting by groups was faster than sorting by individual element. When, on the other hand, individual elements did not form "good" Gestalt groups, sorting by individual elements was easy and sorting by group was extremely difficult.

The above evidence indicates that various combinations of map symbol attributes may lead to integral or separable symbol dimensions which in turn may facilitate divided or selective attention. Knowing which will occur in particular cases is clearly crucial to making effective map symbolization choices. Integral combinations should be useful in univariate map applications where the goal is to enhance discrimination while reinforcing appearance of order for quantitative information. One example would be the combination of color value and saturation for area fills on a choropleth map of population density. By combining these variables to produce a wide range of area fills (e.g., from a light, desaturated blue to a dark, fully saturated blue), it may be possible to extend the practical number of categories that can be used. Multivariate symbols with separable dimensions, on the other hand, seem suited to the depiction of multivariate data (either qualitative or quantitative) in which the viewer will want to extract various components of the data separately. Examples include the temperature–precipitation map cited above or a map showing relationships between soils and geology (e.g., Wakanusa quad, Campbell and Davis, 1979). In the latter case, color was used for one variable and pattern for the other. Each was, in fact, a combination of visual variables.
and neither the combinations nor the conjunctive of the color-pattern sets have been examined for selective attention.

In response to our current lack of knowledge concerning how visual variables interact in multivariate symbols, Shortridge (1982) suggests a program of research to evaluate whether specific combinations of visual variables combine in integral versus separable ways. She considers creating a classification scheme based on symbol properties a useful goal. In addition, she presents a hypothesis that integral versus separable conjunctions of visual variables may not be discrete categories, as presented in most psychological literature to date, but may be two ends of a continuum. This proposal allows for some level of integrality to occur between size and color value, a conjunction that Shortridge used with graduated circles to demonstrate the potential advantages of variable redundancy with a quantitative map sequence (but one that psychologists have labeled as separable). Dobson (1983) provides evidence that this particular conjunction of variables (size and value) does improve processing over using size alone. Dobson conducted three experiments in which subjects viewed a graduated circle map of the western United States and responded to tasks requiring location (counting the number of states in a particular category), categorization (identifying the category for a particular state), and comparative judgment (determining which of a pair of states had the higher data value). A control group viewed a map in which black circles scaled by area was presented and the redundant symbol group viewed a map of the same data in which color value as well as circle area was used to represent data values (Figure 3.37). Response times as well as accuracy of responses both indicated significant processing improvements for the size-value conjunction over size alone, an indication that those variables are at least partially integral.

Some psychologists working with integral versus separable conjunctions to study perceptual group work have recognized a third category of conjunctions that fits between integrality and separability (Pomeranz and Garner, 1973). This intermediate category is termed "configural." Where integral conjunctions refer to two physical dimensions that correspond to a single perceptual code and separable conjunctions refer to two physical dimensions that lead to distinct perceptual codes, configural conjunctions maintain separate perceptual codes, but also code a relational or "emergent" dimension. Both integral and configural dimensions lead to "filtering interference" (interference of the second, nonrelevant attribute in tasks requiring attention to only one attribute) and "condensation efficiency" (improvement on tasks requiring both attributes to be considered as a unit). Integral dimensions differ from configural ones, however, in exhibiting "redundancy gains" (improvements in speed of performance on tasks in which both attributes provide the same information).

Based on the above definitions, the size-value conjunction that improved performance on Dobson's experiments would be considered integral, but evidence from at least five psychological studies that Shortridge (1982) cites indicates that size and value are at least configurational (if not separable). One difference between the psychological studies and Dobson's research is that Dobson’s subjects had to assign stimuli to one of five rather than one of two categories. Another difference was that Dobson's subjects had to locate a named state and its circle from the map display containing 11 circles, while the subjects in the psychological studies only saw one stimulus at a time. The apparent redundancy gain in Dobson's experiment may therefore be associated with search time rather than with categorization time. Another possibility, of course, is that Shortridge's continuum hypothesis is correct and that a size-value conjunction is somewhere between the separable and integral extremes.

The concept of an integral-separable continuum of symbol conjunctions has found some support in the psychological literature. Cheng and Pachella (1984) in particular have argued that most phenomenon already categorized as integral or separable actually exhibit "degrees of nonseparability." Further support comes from a recent study by Carswell and
Wickens (1990). They examined 13 stimulus sets involving conjunctions. All were derived from existing graphics. They found that 2 of the 13 commonly used symbol conjunctions contained separable variables, 2 contained configural variables, and the other 9 could not be classified. Rather than interpreting their results as support for a continuum, Car- 
swell and Wickens favor three distinct categories: integral, configural, and separable.

In addition to examining separability of variable conjunctions, Car-
swell and Wickens (1990) considered whether or not conjunctions were homogeneous or heterogeneous and whether they used object integration. Homogeneous conjunctions are those in which the same visual variable (e.g., location in space, as on a graph, or orientation as in a wind rose) is used for both (or all) variables. Object integration is the merging of two attributes into a single object (Figure 3.38). Garner (1976) has argued that object integration is more likely to lead to integral or configural conjunctions than will two distinct spatially contiguous objects (e.g., paired bars on a bar chart). Following from these ideas, we might expect that the Carr et al. (1992) bivariate NO$_2$-SO$_2$ map (which uses homogeneous conjunctions and object integration) would result in configural conjunctions for which individual attributes and their relationships can be easily extracted from the line slopes, their direction agreement (both up, both down), or the angle between them (Figure 3.39).

**FIGURE 3.38.** An example of the use of an ellipse as a map symbol in which the horizontal and vertical axes represent different (but presumably related) variables.

**FIGURE 3.39.** Bivariate map of NO$_2$ and SO$_2$ trends. The original Carr et al. version of this map used a wheel with eight spokes, rather than a simple dot, as the center of each glyph. When large enough, this added feature facilitates judgment of specific values. After Carr et al. (1992, Fig. 7a, p. 234). Adapted by permission of the American Congress on Surveying and Mapping.

**Associativity of Graphic Variables**

As described in Chapter 2, associativity exists for a visual variable if variations within that variable (or, in Bertin’s terms, the “levels” of the dimension) can be ignored, allowing the units using that visual variable to form a perceptual group. Bertin demonstrates the difference between associative and dissociative variables with a bivariate map composed of point symbols that vary in size (which he considers a disassociative variable) along one axis and shape plus orientation (a pair of associative variables) along the other (Figure 3.40). As is clear here, and for Bertin’s original somewhat more complex conjunction of three variables, it is easier to attend to different shapes of the same size than different sizes of the same shape. Bertin’s claim is that different levels of particular visual variables retain sufficient similarity that symbols to which these various levels are assigned can be seen as a visual group regardless of proximity. Bertin contends that for his associative variables, this grouping will occur “immediately.”

Just as Bertin’s (1967/1983) contentions about the selectivity of the visual variables are related to psychological work on selective attention,
his arguments concerning associativity are related to research on divided attention. In the case of Pomerantz and Schwitzeberg's (1975) divided attention study, divided attention was easy for pairs of shapes that were in close proximity and formed Gestalt groups. As distance between the elements increased, however, attention to the feature pairs as units became more and more difficult (after 2° of arc separation, response times for divided attention rise markedly). This evidence makes Bertin's contentions about associativity seem unlikely. At the least, associativity will depend upon proximity, decreasing as proximity among symbols increases. At this point, we have no information to suggest the shape of this relationship (whether it might be linear, geometric, or stepped with one or more thresholds), nor do we know whether the associativity-proximity relationship will look the same for all of the visual variables that Bertin claims are associative. Shortridge (1982) suggested that we examine whether the integrity or separability of pairs of visual variables is a discrete phenomenon or is better represented as a continuum. We should perhaps extend this suggestion to all aspects of visual variable combinations and examine whether Bertin's selectivity and associativity concepts also represent continua.

Indispensable Variables

There seem to be differences in dominance among both visual variables and Gestalt grouping principles in various contexts. That position, in both space and time, has a dominant overall role in perceptual organization is the contention of Kubovy's (1981) concept of "indispensable" variables. Both Pinker (1990) in relation to graph understanding and Bertin (1967/1983) in relation to map understanding have chosen to ignore time, the second of Kubovy's indispensable variables. Considering the current attention to map animation and dynamic visualization, however, we can no longer afford to do so.

In a map context, Slocum's (1983) analysis of proximity and similarity as factors in groups seen on graduated circle maps supports the contention that spatial location (in the form of proximity) is a more dominant variable than similarity (of size). In Slocum's study, in fact, circles of different size were more likely to be seen in the same group than those of the same size. His subjects attended to relative location of circles and ignored similarity of size. In the context of multivariate dot maps, however, Rogers and Groop (1981) found that proximity did not overpower color hue. Their subjects were able to identify univariate regions as effectively on trivariate dot maps using different color dots for each of the three variables as they could on individual dot maps. While this result does not necessarily counter the claim that location is an indispensable variable, it does indicate that grouping by a conjunction of color hue plus proximity works as well as grouping by proximity alone.

Humans appear able to segregate the visual scene in terms of both position in X-Y (or the plane of the retinal image) and position in Z (or depth). Research on visual search for objects having conjunctions of two or more variables, for example, has demonstrated that perception can segregate a scene on the basis of depth planes and position in these planes. Nakayama and Silverman (1986) presented subjects with displays in which stereo disparity was used to produce a near and a far visual plane containing colored items. In their experiment, all nontarget items in each plane were a single color hue (e.g., near = red and far = blue). Targets were the opposite color of the depth plane in which they appeared. Subjects were told to locate the colored target and their response times were measured for displays having various densities of nontarget items. The display density did not affect search times, indicating that search was accomplished in parallel (i.e., all potential targets were attended to at once). Since the depth plane that did not contain a target had items of the same color as the target, this result means that subjects were able to direct their attention to one position in Z and ignore the potentially distracting objects at another position in Z.

Following from these results for position in 3-D space, we might predict that position in space-time will be easily distinguishable (and more noticeable) than position in static space or aspatial time. This makes sense on evolutionary grounds. Our ability to attend to moving objects can be thought of as an ability to focus attention on position in space-time. If the position of an object changes over time, it is very difficult to avoid attending to it. This "fact" is the basis for the Gestalt principle of common fate, which Wertheimer (1923; translated in Ellis, 1955) argued was often dominant over grouping by proximity. Humphreys and
Bruce (1989) cite a number of related studies in which various combinations of locational with nonlocational visual variables were tested. It is clear from these studies that visual scenes can be segregated by disparity in both depth and motion (across space over time) and that these aspects of location are dominant over nonlocational variables such as color, form, orientation, or size. Both motion and disparity in depth also seem to dominate position in the plane as a factor in forming perceptual groups. One counterpoint to the argument that disparity in depth is more noticeable than differences in color, texture, and the like, is that natural camouflage of animals and artificial camouflage of military equipment both seem to be effective in concealing, in spite of the presence of depth due to binocular parallax—until movement occurs.

Where We Attend

In relation to visual attention, we began by considering what humans attend to when we look at a particular map (or spatial display) location. In this section, we move on to consider various factors that determine where we look when viewing a map. Two aspects of this question are considered, location within the visual scene and the scale of attention.

Location

Attention to items in the visual scene has been likened to a spotlight that highlights a small area making it more visible than its surroundings (Posner, 1980) (Figure 3.41). This spotlight can be directed away from our fixations to objects or events in peripheral vision (without changing the direction of fixation). It is therefore somewhat independent of eye move-

![Figure 3.41](image.png)

**Figure 3.41.** The attention spotlight as a viewer scans a map. Each ellipse represents the region of emphasis by each eye.

ments. In fact, it is probable that the ability to change the spotlight (or location) of attention without eye movement may be how the visual system determines where the next eye movement should fixate (Humphreys and Bruce, 1989).

The view of attention as a spotlight with a focus, a margin, and a fringe can be traced to William James in 1890 (1890/1960), but has regained popularity due to a variety of recent response time studies that show response time decreases for appearance of stimuli at locations anticipated due to a cue and increases for appearance at locations away from location cues (Humphreys and Bruce, 1989). It has also been demonstrated that when subjects were prompted to locate targets (letters) of a given color or a given shape, other nearby letters were more likely to be recalled than letters of the same color or shape that were not adjacent to the target. They contend that their findings “strengthen and extend the notion that attention operates as a spotlight” (p. 19).

We seem able to narrow the focus of the spotlight more in the foveal area of vision than in the periphery (Downing and Pinker, 1985). Evidence also suggests that the focus of attention may begin with a wide aperture (but low resolution) and gradually change to a more focused, higher resolution (Eriksen and Murphy, 1987). As a consequence, the analogy of a zoom lens has been offered as an improvement on the original spotlight analogy. This multiscale feature of attention with its apparent tendency to begin with a broad view corresponds to evidence for a dominance of global versus local processing of visual scenes (Navon, 1977) and to Marr’s contention that 3-D model representations are hierarchical, making recognition of membership in a category possible before recognition of individuals (see Chapter 2 for details).

Cartographically, a key aspect of the way attention works is that initial views, if they take in large segments of a map, will be able to process only gross features. This processing will then guide the narrowing of attention to particular features and objects in order to examine details. Particularly in a visualization context, therefore, graphic design impacts upon the initial wide-scope global view of the map and may dictate what specific details are seen. Also, in the case of reference and travel maps, the ease with which point features, labels, and other small map items can be found by scanning across the map is likely to be controlled to a large extent not by the discriminability of separate features of symbols or text, but by the higher level appearance of symbols and words as a whole and by the overall map structure that may influence attention and thereby guide where attention will be directed (Phillips and Noyes, 1977—see discussion in the “Scanning the Visual Scene” section below).

There is evidence that attention can be directed to objects as well as locations. Duncan (1984), for example, demonstrated that subjects could
more easily attend to two attributes of one object (rectangle length plus position of a gap in the rectangle or line type and its orientation) than to elements of two different objects (length of a rectangle plus line orientation). In his experiment, the objects were superimposed, and therefore location was the same. That we can attend to features of objects when location is restricted to foveal vision, however, does not discount the role of location in attention. As mentioned in Chapter 2, when more than one object at more than one location is presented to us, we are more able to attend to a particular location (and to all objects at that location) than to a particular category of objects regardless of position. To attend to an object, we must first attend to its position. It is only then that the features of the object begin to be clear enough to guide our attention to them.

Scale

In the previous section, it was suggested that visual attention may begin with a broad extent but relatively coarse resolution, and then, based on cues obtained from this initial perspective, be redirected to another location or focus in on a particular area or object. Humphreys and Bruce (1989) contend that overall spatial structure is probably available more quickly than is the structure of local details. Humphreys and Quinlan (1987) suggest that both pattern and object recognition might rely on descriptions available from relatively low spatial frequencies—the global features—because patterns at this frequency are more stable over time.

Neurophysiological evidence complements the view of multiple spatial scales of visual processing. Wilson et al. (1990, p. 240) cite research with cats and macaque monkeys indicating that “at each stage of the visual pathway cells with receptive fields in the same part of the visual field can respond to different ranges of spatial frequency.” In addition, they contend that “spatial frequency selectivity becomes progressively narrower moving up the system from retinal ganglion cells to LGN cells to simple cortical cells.”

The idea of multiple scales of attention is closely associated with research concerning global-local precedence—whether global holistic properties or local components or parts are perceived more readily (Watt, 1988). The divided attention studies of Pomerantz and his colleagues provide one piece of evidence for global structures taking precedence over individual features. As noted above, their results demonstrate that in categorization tasks, certain arrangements of parts are processed more quickly as a unit (a whole) than are either of the individual parts (Pomerantz and Schwartzberg, 1975). These results seem to support global precedence for “good” Gestalt groups, and local precedence for “poor” groups.

The experiments, however, focus only on the issue of global versus local processing of small perceptual units that are easily attended to because they appear in foveal vision, exactly where they are anticipated. Their concern, then, is not spatial but object-based and their research has little to say about the relative spatial scope of attention and how it is controlled.

In examining a map or other visual scene, one role of visual attention is to determine where to look. Because attention can be directed to various locations at various scales, the issue of whether perception usually begins with a spatially global or a spatially local perspective becomes important. Most studies of global-local precedence seem to implicitly accept the roving zoom-lens analogy for visual attention and have focused on the question of the scale of feature that is most easily attended to initially.

In a now classic study that has stimulated much of the subsequent research, Navon (1977, p. 354) investigated the postulate that “perceptual processes are temporarily organized so that they precede from global structuring towards more and more fine grained analysis [local structuring].” His experimental stimuli (compound letters), were selected so that global and local components could be manipulated independently (Figure 3.42). The stimuli were composed of small letters organized in arrangements to create large letters with the small and composite letters being either the same or different. Subjects were asked to identify either the local stimuli (small letters) or the global stimuli (large letters), and the speed with which they could do so was measured. What Navon found was that identification of global features was faster than identification of local features, and that conflicts between local and global letters interfered with identification of local letters, but not with identification of global letters. Navon’s interpretation of his findings was that global processes must necessarily be prior to local ones. What is not clear from this research is whether identification of global stimuli requires a prior grouping (as yet unidentified local stimuli).

Subsequent research by Paquet and Merikle (1988) has considered situations in which the visual scene is composed of more than one element set. They again used compound letters as stimuli, but presented sub-

![Figure 3.42](image-url)
jects with pairs of them rather than a single set (Figure 3.43). Subjects were asked to attend to one of the pair (identified by a surrounding circle or square) and, as in Navon’s study, to identify either the local or the global letter. Their results confirmed that the global letters were identified faster and that the global aspect of the attended form was harder to ignore than the local aspect. Beyond this confirmation, however, they found that both global and local aspects of the unattended stimulus could influence identification speed, with local features having an influence if a local identification was requested and global features having an influence if a global identification was requested. Further, Paquet and Merikle (1988, p. 98) found that “it was impossible for observers to ignore the category of the global aspect of the nonattended object.” This latter finding seems to add even more support to the idea that space is an indispensable variable—because we anticipate features near one another to be related.

If the zoom-lens analogy for visual attention and the idea that attention varies in acuity from central focal point to its fringes are correct, we can anticipate extensions and modifications to Navon’s original ideas about global–local precedence. First, since it is clear that people can attend to local details when directed to, we might anticipate that global precedence will be strongest when we are not already cued to expect some local feature. Second, global precedence can be expected to be stronger on the periphery of attention where the resolution of attention (and of vision) is not sufficient to resolve local details. Third, we might expect to find limits on scale of global elements that will be attended to quickly—if they are too large, the elements will be beyond the bounds of our attentional zoom lens, and if they are too small, they will be local details.

All of the above possibilities have been supported to some extent by empirical research. In an experiment using compound letter stimuli similar to Navon’s, Pomerantz (1983) dealt with the first issue. Half of his subjects had to respond to either the global or the local letter when it appeared on the screen at random locations. For the remaining subjects, presentation was always at the center of the screen. For both certain and uncertain presentation locations, global letters were easier to identify than local ones, but the difference was greater for uncertain than for certain locations. In a related experiment, Lamb and Robertson (1988) had subjects fixate on the center of the screen before presentation of a compound letter. Presentation could be central or to either side of center. They found that the global-identification speed advantage was greatest for peripheral presentations.

That size of perceptual units has an impact on global–local precedence is supported in a variety of studies. In research with compound stimuli composed of geometric shapes rather than letters, Kinchi (1988) found that the number of local elements making up the global shape interacted with the strength of global precedence (Figure 3.44). Specifically, when the number of elements was small, thereby making the global figure small, global processing was faster whether or not local and global shapes agreed. With larger global stimuli, composed of more local elements, global processing was faster in situations where there was conflict, but not in situations where the shapes agreed. More direct evidence that the size of a global figure must be within some limit in order to receive attention precedence can be found in research by Kinchi and Wolfe (1979) with compound letter stimuli and research by Antes and Mann (1984) with pictorial stimuli. For the compound letters, Kinchi and Wolfe found that compound figures larger than 8° of visual angle (roughly the size of the United States on a page-sized map of North America at normal reading distance) resulted in a reversal of attention to local prece-
At this point, we can only speculate upon the implications of global-local research for map understanding. There has been no cartographic research to date that has extended directly from these studies. As Mistick (1990) points out, however, results of the global-local processing research support the concept that extraction of meaning from visual scenes uses hierarchical structuring of information at multiple spatial scales. This view corresponds quite well to Marr and Nishihara's (1978) ideas concerning how primal sketches are derived from a retinal array and to research directed at higher levels of processing that indicates hierarchical structures for memory encoding of spatial knowledge. As discussed in Chapter 8, issues of global-local precedence may have particular relevance to exploratory visualization with maps—a situation in which an analyst is not entirely certain what patterns to expect and a situation for which dynamic manipulation of display scale will be a significant part of the analysis.

### Scanning the Visual Scene

Both what is attended to and the scale of that attention interact with the process of visually exploring a map or other graphic display. It seems clear that both global views and peripheral attention act to steer eye movements toward important information in a visual scene and away from unimportant information. As early as the 1970s, cartographers investigated the use of eye movement recordings as a tool for understanding the visual-cognitive process of map reading and the impact of both changes in map design and training on that process (see Steinke, 1987, for a comprehensive review). In addition, cartographers have studied a variety of visual search problems on maps in an effort to determine how to facilitate search for specific kinds of features (e.g., placenames, point symbols, etc.). Much of the early work in both visual search and eye movement analysis by cartographers suffered from a lack of theoretical perspective. As Steinke (1987, p. 57) noted in relation to eye movement research, early work seemed driven by a "let's see what happens when we put a map in front of somebody and photograph their eyes" approach. Only recently has cartographic research dealing with visual scanning of maps begun to build on a firm theoretical base grounded in perceptual-cognitive theory. Looking back from an information-processing perspective, however, we can identify some links between early cartographic eye movement research and the perspectives, presented above, on vision as a modular system for processing increasingly interpreted representations.

Both Marr's model of vision and Gestalt principles suggest that edges are important elements of visual scenes that are processed early in vision.
Steinke (1987) cites eye movement research by both Thomas and Lansdown (1963), with medical images, and Gratzer and McDowell (1971), with landscape photos, in which foveal attention to edges in the scene was demonstrated to be a common tendency, in spite of highly individualistic scan paths. In the Gratzer and McDowell study, edges defined by the skyline, ridgelines, shorelines, and vegetation boundaries all received particular attention. Not all edges, however, seem to be equal in attracting foveal attention. Mackworth and Morandi (1967), for example, provides evidence that simple contours are noticed using peripheral vision and largely ignored by foveal fixations. It is unpredictable edges, or edges with unusual details, that seem to attract foveal attention.

Although cartographers employing eye movement techniques are clearly aware of psychological research showing attention to edges, no cartographic research based on this knowledge seems to have been done. On maps, eye movement techniques might be used to determine the relative “goodness” of the contour established by different methods of creating contrast between map regions. Alternatively, analysis of eye movements might be used to assess techniques for enhancing the identification of map regions. Although Jenks (1973) found little similarity in map viewers’ scan paths when viewing a dot map, he did identify commonalities in relative attention to different parts of a map. He did not, however, examine fixation times in relation to regional edges delineated by his subjects. The one example that he does provide of a subject’s fixation times for map cells suggests that more attention was given to the edges of dot clusters than to the core of those clusters (Figure 3.45). Dobson (1979a) also found correspondence among subjects about relative attention to different parts of a test map. In examining his data, he found a high correlation between the “informativeness” of map sections and visual attention to those locations. Both Jenks’s and Dobson’s results suggest that eye movement analysis might be applicable to assessment of the distinctiveness of regions on thematic maps. Measuring attention to transition zones around a region or between regions could be used to assess the strength of regional edges.

One common feature of early cartographic research using eye movement analysis was that subject attention to maps was observed in the absence of defined tasks. Castner and Eastman (1985) point out that we should expect quite different perceptual and cognitive processes to be at work in this situation, which they called “spontaneous looking,” and in “task-specific viewing.” With spontaneous looking, location of attention will be influenced primarily by the properties of individual map symbols, Gestalt properties of symbol groups, and reader attitudes or expectations about the stimulus and the experimental situation. For this kind of viewing (perhaps typical of early exploratory visualization), then, map design changes are likely to be particularly important. On the other hand, Castner and Eastman contend that for task-specific viewing, cognitive processes will exert a much stronger control over eye movements and attention. In these cases, eye movement analysis might be used to distinguish different problem-solving strategies or application of different schemata. Recent evidence by Morita (1991), however, demonstrates that while task-specific viewing can lead to greater similarity in eye movement parameters than spontaneous looking, design alterations can still play a major role. He found very distinct differences in patterns of visual search on schematic maps in which numerical information was symbolized by seven different graphic variables (see Figure 2.14).

Most cartographic research using eye movement analysis has focused on questions of where foveal vision is directed. The technique can also provide information relevant to the issue of global–local precedence. A graduate research project by Guyot (1971; cited in Steinke, 1987) provides one example. Guyot was interested in how map patterns are compared. In an experiment in which subjects were required to select one of two maps that was most like a third, eye movement recordings were used to measure which of the two maps was attended to first, as well as which received the most and the longest fixations. The finding that the first map looked at was generally selected as the most similar to the referent.
map suggests that peripheral vision played a key role in pattern comparison for these maps. This in turn suggests that global processing of map patterns is quite sophisticated and that it directs eye movements, at least in a task-specific viewing situation.

Recent uses of eye movement analysis in cartography have focused on task-specific viewing. This focus is driven, in part, by the lack of consistent results of past "spontaneous looking" experiments and by the desire to achieve particular application goals. The map-use task to which eye movement evidence seems most applicable is visual search. Phillips and his colleagues in the Psychology Department of University College in London (with input from cartographers Bickmore and DeLucia) were among the first to use eye movement techniques to examine strategies of visual search for information on maps. They focused on the influence of map design on search and gave particular attention to the problem of searching for names on maps (see Phillips and Noyes, 1977). They proposed that reducing either the number of fixations or the duration of individual fixations would speed searches for place labels, and that reducing the number of fixations should be more effective. Three map-design procedures were suggested to reduce the number of fixations: generalization that reduced the total number of names on the map, categorization and visual coding of names so that only a subset had to be attended to, and use of a map grid that could direct attention to a limited section of the map. Adjustments to type placement were used to control individual fixation times. Both procedures reduced search times, but the three techniques that reduced the number of names considered were (as predicted) more effective. Of these, using small map grids had the most dramatic effect.

Eye movement analysis has not proved to be as powerful a tool for cartographic research as originally anticipated by Jenks and others (Steinke, 1987). This limited success is due to both practical and conceptual issues. From a practical point of view, eye movement analysis has been difficult and expensive. Conceptually, it suffers from the problem that there is no simple way to determine whether a fixated location is also attended to. Because of these problems, the question of visual scanning (particularly visual search) has been investigated in a number of other ways. The two most commonly used measures in visual search experiments (other than eye movement analysis) are the accuracy and the speed with which targets are identified. Accuracy is assessed by the number of correct identifications compared to the number not found and/or misidentified.

In the only cartographic study to consider the role of figure-ground in visual search, Lloyd (1988) compared perceptual and imagery processes involved in determining the presence or absence of pictorial point symbols on a simple map like display (Figure 3.46). The display had a central green area surrounded by a blue area and symbols in yellow were dispersed relatively evenly across the map's surface. The central green area (presumably due to centrality, surroundedness, and slightly smaller size) was expected to be a figure on the blue background. Subjects in the perception condition had the task of determining whether or not two different symbols both appeared on a display. Symbols were either both absent, both on the figure, both on the ground, or one on the figure and one on the ground. Lloyd predicted that when both symbols were on the figure they would be found more quickly because the figure was expected to draw the subjects' initial attention. When both symbols were on the ground he expected opposite results, and with one symbol on the ground and one on the figure he expected intermediate results. Although mean response times exhibited this ordering, differences were not significant. The explanation provided, and one that could be predicted from Gestalt principles, is that the yellow point symbols (due to small relative size and greater contrast with either area than the areas had with each other) were the dominant figures seen and that for most subjects both the green and blue areas became ground.

Treisman et al. (1990) (building on work by Cavenagh, 1987, 1988) proposed a model in which five independent visual pathways—luminance, motion, binocular disparity, color, and texture (Figure 3.47)—process different attributes of the visual scene. This model is supported in

**FIGURE 3.46.** Simulation of the test map from Lloyd's experiment. After Lloyd (1988, Fig. 4, p. 366). Adapted by permission of the American Congress on Surveying and Mapping.
part by neurophysiological findings that provide evidence for separate color-form and motion pathways and neuropsychological evidence from brain-damaged patients that shows luminance operating separately from either color or motion. Experiments using visual search tasks, examination of after-effects, and identification of shape from contours have confirmed the separate pathways for color, luminance, and motion, and have provided evidence that early vision must also process texture and binocular disparity separately. Each of these visual pathways seems able to code size and orientation information which, in turn, may function as shape primitives.

The model led to Treisman's (1988) feature integration theory (FIT) that posits a series of “feature maps” with one set for each pathway plus one for size and one for orientation. Each set of feature maps consists of individual layers (analogous to the structure of a GIS) to code possible variations along the specific dimension (e.g., red, yellow, and blue color maps or orientation maps for various angles). If the Treisman model is correct, it can explain why some visual search tasks can be conducted in parallel while others require serial processes. If a target differs from other elements of the scene along one dimension or feature, a parallel holistic process can be used. When the search is for a conjunction target that can share features with nontargets, however, location of potential targets must be relied upon to link separate feature maps before determining whether the conjunction occurs. This location-based linking can only proceed in serial.

Recently, Cave and Wolfe (1990) suggested a modification of Treisman's FIT that seems relevant to visual search for map symbols. As originally conceived, FIT predicts that if a target (such as a map symbol) differs from all distractors by a single feature, parallel processes should be able to detect it. If, on the other hand, the target is defined by a conjunc-

![Figure 3.47](image)

**FIGURE 3.47.** Treisman's five-pathway model for processing of the visual scene. Derived from Treisman et al. (1990, Fig. 16, p. 294).
ure is thinglike and shaped, ground is more like empty space, amorphous and unshaped."

Figures are defined by their contour or the boundary between object and nonobject. The contour operates on only one field or the other, but not both (Arnheim, 1974). When it is unclear which region of a scene the contour belongs to, an ambiguous figure results in which first one, then the other, part of the field becomes figure (Figure 3.48). Such ambiguity is what cartographers strive to avoid.

Most cartographers who have considered the issue of figure-ground segregation on maps have turned to Gestalt psychology for guidance. This is a good place to start because Gestalt psychology has made the greatest contribution to our current understanding of figure-ground. Gestalt psychology alone, however, does not answer all of the cartographically relevant questions. The discussion that follows will begin with a brief overview of some of the more important Gestalt ideas relating to figure-ground and will then explore more recent psychological and cartographic research that has attempted to extend from this base.

Gestalt psychologists' initial approach to figure-ground began with principles of perceptual grouping because, to see a figure, a perceptual unit must exist and grouping produces perceptual units. All grouping factors have a potential role in defining regions of a visual scene, and the scene must be differentiated in order for figures to appear. Extending from the fundamental grouping principles, a set of related principles has been devised to deal with the visual strength of perceptual groups as figures segregated from a background. Some were suggested directly by Gestalt psychologists and others were derived more recently by researchers following similar logic. The factors below seem to be the most relevant to establishing symbols and regions as figures on maps.

1. Heterogeneity: A visual field must be differentiated to form groups before one part of the field can stand out as figure. While not one of Wertheimer's (1923; translated in Ellis, 1955) grouping principles, this idea was offered (with no label assigned) at the end of his paper. The main guiding principles offered for establishment of figure were that an enclosed shape for which there was a color difference between the shape and the background will stand out as a distinct figure. This basic idea was elaborated by a number of other Gestalt psychologists. Among them was Koffka (1935) who introduced the concept of articulation as a figure-ground principle (see below for more details).

2. Contour: Objects are more easily seen as figure the more definite the edge between object and nonobject. The establishment of contour follows directly from establishment of heterogeneity. A noticeable difference between areas creates an edge, boundary, or contour between them. If differences are due to relatively coarse features, the edge will be rather fuzzy and the contour (and the experience of figure) may be weak (Figure 3.49). If the differences consist of fine-textured fills or solid colors, however, (or a distinct line separates the regions) the contour will be stronger, as will the experience of Figure (Figure 3.50).

3. Surroundedness: Completely surrounded objects tend to be seen as a unit and thus as figure (Bruce and Green, 1990). That is why, even with weak contour, the white area of Figure 3.49 is seen as figure. This principle is probably the single most useful in creating figure-ground distinctions on maps. As a number of conflicting experiments recounted below make clear, it is hard to avoid ambiguity about figure versus ground in displays that do not have a surrounded figure. Centrally located surrounded shapes will enhance figure formation.

4. Orientation: Objects with a horizontal or vertical orientation are seen as figure (Bruce and Green, 1990). A rotation of areas on a hypothetical map illustrates this point (Figure 3.51). It is likely that this tendency has to do with relationships between visual displays and real-world visual scenes in which most figures are upright (as are humans, trees, etc.) or aligned with the horizon.

5. Relative size: The smaller of two areas is more likely to be seen as figure. This factor is essentially a corollary to the factor of surroundedness cited above. It is particularly relevant when the larger area completely surrounds the smaller. Assuming the object has sufficient size to be easily detected, the smaller the object relative to its surround, the more it is seen as a figure (Figure 3.52).

FIGURE 3.48. An ambiguous map in which subjects were asked to determine which area was the figure. Half of the subjects picked light and half picked dark. Derived from Mistry (1990, Fig. 3.3, p. 60).

FIGURE 3.49. A central figure that fades into the background due to a weak contour.
6. Convexity: Convexity will be seen as figure. A schematic map of England, for example, has greater convexity than a map using a detailed but smoothed boundary. As a result, it should be more likely to stand out as figure (Figure 3.53).

Heterogeneity

Of the factors thought to lead to “good” figures, it is the first, heterogeneity, that has been given the greatest attention. Issues of contour, surroundedness, orientation, symmetry, and convexity have typically been considered as complements to a primary focus on heterogeneity. Both psychologists and cartographers have investigated how segregation of figure and ground is influenced by various methods of creating heterogeneity between areas. Psychologists have primarily been interested in what figure–ground reactions to differences in texture, value, temporal frequency, and so on, tell us about the visual and cognitive processes underlying perceptual organization of visual scenes. Cartographers, on the other hand, have been most interested in developing guidelines for use of area fills on maps that will lead to consistent identification of specified portions of the map as figure. Psychological research has used a rather limited range of possible area fills, limiting the generality of their findings, and cartographers, while they have tested more kinds of area fills, have not linked their research to psychological theory beyond that of the Gestalt principles developed in the 1920s and 1930s. The discussion below provides an overview of some of the work from both disciplines (with an emphasis on the role of brightness differences) and uses an experiment by one of my graduate students as an example of how we might integrate these two research streams more effectively.

Both cartographers and psychologists have given considerable attention to the role of brightness (i.e., color value) differences in figure–ground. On maps, it is a particularly important tool because all other means of creating heterogeneity between areas (with the exception of color hue) have a tendency to interfere with other map information (e.g., texture differences require one area to have a coarse enough texture to be noticeable as texture—and coarse-textured area fills make text difficult to read). In psychology, attention to brightness as a figure–ground factor began in the 1920s, with Wever (1927) among the first to address the issue.

In relation to brightness, Wever (1927, p. 222) contended that “a minimum brightness difference is necessary for the experience of figure and ground. As brightness-difference increases, the ‘goodness’ of the experience increases, though at a constantly diminishing rate.” This contention was based on research in which subjects viewed irregular forms presented tachistoscopically. In his experiment subjects viewed 1,060 different black forms on white backgrounds with illumination varied, result-
ing in differences in contrast between brightness of the white and black areas.

Much of the psychological research subsequent to Wever has used variations on a simple pie-wedge stimulus. This stimulus allows researchers to experimentally manipulate the actual value of parts of each stimulus, the number of components to the stimulus, their relative size, and the background upon which the stimulus appears. One of the first uses of this stimulus was made by Goldhamer (1934) who examined the influence of relative size on the appearance of white versus black wedges on a gray background (Figure 3.54). He showed that for equal-sized regions, black tended to be seen as figure, but when size varied, it was the smaller shapes that were regarded as figure, regardless of brightness. Oyama (1960) used similar stimuli but came up with somewhat conflicting conclusions. The difference in his experiment was that the surrounds for the stimuli were either white or black rather than gray. Half of the wedges were gray (of varying shades for different stimuli) and half were the opposite of the surround (Figure 3.55). He found that the sectors opposite in brightness to the surround tended to be seen as figure, and that this tendency was strongest when the alternate wedges were closest in brightness to the surround. The situation in which surround and one set of wedges are similar resulted in the other set of wedges appearing as small shapes on a relatively homogeneous background. That the wedges of opposite brightness to the background appeared as figure in this case agrees with Goldhamer and with general Gestalt principles about small surrounded areas being seen as figure. When the alternating wedges were closer (in color value) to each other than either was to the background, however, the white wedges with black surround (and grey alternate wedges) were seen as figure more often than the black wedges with white surround (and grey alternate wedges). This disagrees with Goldhamer’s finding that black shapes stand out as figure when size does not differ.

Overall, studies of brightness difference using the pie-wedge stimuli have produced equivocal results. There has been a consistent finding that the smaller of the areas are seen as figure regardless of brightness and that horizontal-vertical wedges are more likely to be seen as figure than diagonal wedges (Bruce and Green, 1990).

Most of the remaining psychological research on brightness as a figure-ground variable has made use of stimuli similar to the Rubin’s vase-face ambiguous figure (Figure 3.56). This stimuli is somewhat more similar to the situation on a map in which land-water areas are adjacent and the cartographer wants one to be seen as figure. Harrower (1936) created an experimental setting similar to Goldhamer’s, but with the vase-face figure on a surround. He used the following combinations: black surround, black face, white vase; black surround, white face, black vase; white surround, black face, white vase; white surround, black face, white vase. Whether there was a light or a dark vase or face did not seem to matter. The figure proved to be whichever differed from the surround, although there was a slight tendency toward face as figure. Harrower also examined a range of brightness differences assigned to surround, vase, and face. In this case, the face part of the stimulus was mounted on a track that allowed the halves to be pulled apart. The subject’s task was to attend to the face as figure as long as possible. Results indicated that the face was held as figure longer as brightness difference was increased. Again, it did not matter whether the vase or the face was darker.

More recently, Lindauer and Lindauer (1970) used the Rubin’s vase-face figure in a similar experiment involving brightness contrast. They compared a control (an unshaded outline drawing of the vase-face figure) with versions in which one area was white and the other was filled with a 20%, 40%, 60%, 80%, or 100% black pattern. In the unshaded control, the face was seen as figure, a finding that the authors attribute to
familiarity. For the test stimuli, responses to the shaded area as figure increased as the contrast between areas increased.

Building upon the rather mixed psychological findings, there have been a small number of published cartographic studies of the influence of brightness on figure–ground segregation. The first was by Dent (1972) as one component of his dissertation. He used bipartite squares, stimuli that were simpler than any of those used in previous psychological studies (Figure 3.57). As part of a larger study, his stimuli used various combinations of area fills on the two sides of the square. These were created with both dot and line patterns, in some cases texture was apparent because Dent was testing for it as well as for brightness. Dent’s experiment, unlike the psychological research, was not based on response times (to identify figure or hold particular areas as figure). Instead, his subjects were asked to examine each stimulus and to mark the side of the square that they saw as figure (or that visually stood out). In general, Dent found the coarser areas to be seen as figure (as the Gestalt concept of articulation would predict). When both areas were shaded with similar-sized dots, however, the finer textured, darker pattern was seen as figure—an indication that brightness might be more important than texture.

On a follow-up to the figure–ground test, Dent assessed subject preferences for maps in which a central focus area (e.g., North America) was shaded and the surround was white. For four different maps he found preference for the shaded maps over unshaded maps ranging from 71% of subjects to 96%. Wood (1976) also examined the “most desirable” brightness differences for maps. In this case all maps used some shading with relative brightness of figure, ground, and surround varied across the range of 16 test maps. Regardless of surround, maps with figures lighter than the ground were preferred.

The two preference studies by Dent and Wood suggest that heterogeneity of value for areas is preferred to homogeneity, but that preferences for lighter or darker areas as figures are inconsistent. Neither study directly addressed the issue of how value differences on maps influence the likelihood of map areas appearing as either figure or ground. Mstrick (1990) designed a study to do just that. In essence, she replicated a portion of Dent’s (1970) initial figure–ground choice study using stimuli that were more maplike than his bipartite squares.

Mstrick’s test maps, as we reported in our paper on brightness contrast as a figure–ground variable (MacEachren and Mstrick, 1992), depicted the land–water border along the coast of Korea (see Figure 3.48). The test maps were cropped so that the map border was square and the land and water areas of the map both occupied 50% of the area included. A pretest had shown that without labels the coastline was recognized by few students at Pennsylvania State University (the source of subjects for the experiment). The test stimulus, then, was a real map but due to the lack of familiarity with it, prior experience was not a factor in determining figure–ground segregation. In addition, the lack of familiarity allowed the map to be presented at four orientations with any change in response to it attributable to relative position of features and their concavities rather than to variations in recognizability of the map.

Mstrick’s (1990) test map was created at four orientations with six combinations of area fill (white–dark gray; dark gray–white; white–light gray; light gray–white; light gray–dark gray; dark gray–light gray) applied to the land and water areas respectively (Figure 3.58). Each subject viewed only one map and indicated the region seen as figure. Two hundred forty subjects participated, half of whom saw unlabeled maps and half of whom saw maps with the labels “land” and “water” outside the map border next to these respective areas. The land–water labels had no effect on identification of one area as figure in relation to the other.

FIGURE 3.58. The complete set of maps used in Mstrick’s study (at greatly reduced size). Reproduced from MacEachren and Mstrick (1992, Fig. 6, p. 96). Reprinted by permission of The Cartographic Journal.
Somewhat surprisingly, in relation to Dent's earlier findings with bipartite squares, the darkness of area fills had no effect on figure-ground segregation. Exactly half of the subjects identified the relatively darker area as figure and half identified the relatively lighter area. This "negative" finding does, however, seem to agree with previous cartographic interpretations of Gestalt "rules" by Wood (1968), Spiess (1978), and McCleary (1981) that advocated relative value contrast (heterogeneity) between figure and ground but did not suggest that absolute value of area fills is relevant to what is seen as figure.

That contrast influences figure-ground segregation independently of the direction or sign or the difference is logical on "hardware" grounds. Shapley et al. (1990, p. 348) cite neurophysiological evidence that "fundamental neural mechanisms of pattern recognition are essentially non-linear because these mechanisms ignore the sign of the contrast." They go on to contend that "form depends on the magnitude of contrast at a border while brightness depends on its sign." They demonstrate the implications of this fact with an illusory contour demonstration which reveals that contour-sensing processes do not rely upon the sign of contrast (Figure 3.59). In a similar vein, Barlow (1990) cites evidence that different sets of brain cells are specialized for light, for dark, and for value contrast. These contentions of independent brightness and form processing at a neurological level support the argument that Mistrick and I make (MacEachren and Mistrick, 1992) that contrast should be much more important in establishing figure on maps than specific brightness relationships.

In addition to research on heterogeneity due to brightness differences in relation to figure-ground, a number of psychological studies have considered heterogeneity created by contrast in spatial and temporal frequency of areal fills. This research has been closely linked to information-processing and computational-vision assumptions about how early vision represents visual scenes.

The influence of spatial frequency (or focus) on figure-ground segregation has been addressed in several psychological studies. Wong and

**FIGURE 3.59.** Two Kanizsa squares illustrating the dominance of contrast over brightness in establishing figure-ground.
that subjects must have separated figure from ground, then made a decision about in or out. This contention derives from the Gestalt view that only figures have form, and thus an inside or an outside. Kienker and Sznajdowski (1986, p. 198) go on to contend that the speed of processing Ullman found compared to time scales for neural processing and "suggests that figure-ground separation is computed in parallel over the visual field." Based on this evidence, figure-ground segregation is (or at least can be) a preattentive, bottom-up process.

There seems little doubt that figure can be found without input from higher level processes. Marr's information-processing approach suggests that the extraction of figure is one of the functions of early visual processing which, in the form of the $2\frac{1}{2}$-D sketch, provides higher level processes with the input about object surfaces and orientations needed in order to recognize the objects. He demonstrated that, computationally, bounding edges and surfaces could be extracted from a scene with no input of prior knowledge (Marr, 1982).

The fact (if it is one) that figure-ground segregation can occur preattentively with no input from higher level processes, of course, does not prove that attention and top-down processing cannot sometimes play a role in figure-ground segregation. The ability of most people to consciously control figure-ground reversal when viewing Rubin's vase-face or other similar figures attests to this. In relation to ambiguous figures, Tsai and Kolbert (1985) have demonstrated empirically that figure-ground segregation is affected by attention.

Another related piece of evidence concerning the possible influence of top-down processes on figure-ground segregation comes from research by Peterson et al. (1991). She and her colleagues began by addressing the potential role of object recognition in figure-ground reversals of ambiguous figures. They had subjects view inverted and upright versions of Rubin's-like ambiguous figures. Their test figures were designed so that one orientation (upright) had highly denotive surrounds (viewers agreed on a specific shape represented) while an inverted version was not denotive (they were not recognized as a particular object) (Figure 3.60). Subjects continually reported which of the two regions appeared as figure during 30-second trials. They found that surrounds were more easily held as figure when they were upright (when the surround orientation was seen as denoting a particular identifiable object). Convergent evidence from four experiments led to the contention that "figure-ground reversal computations weigh inputs reflecting the goodness of fit between stimulus regions and orientation-specific structural memory representations" (Peterson et al., 1991, p. 1066). This finding agrees with Marr's model of shape recognition that posits that perceptual descriptions of shape structure (at the $2\frac{1}{2}$-D sketch level) are matched to the best fitting structural memory representation (defined as a memory representation that specifies parts of a shape and their relative locations with respect to a canonical orientation for the object). Peterson et al. also interpret their findings to demonstrate that orientation-independent shape representations had no influence on figure-ground reversals.

Although Peterson et al. (1991) support Marr's views on matches with structural memory representations, there is disagreement about whether this matching can occur before figures are isolated. Peterson et al. (1991) contend that their results suggest a mechanism by which object recognition may facilitate initial figure segregation, as well as figure reversals. As they point out, the view seems to create a paradox: How can experience with shapes influence figure-ground organization given that no shape description should exist until figure-ground organization is determined? Their hypothesis is that contours may be evaluated from both sides simultaneously before figure is determined. A parallel set of experiments by Peterson and Gibson (1991) support this contention. In this set of experiments, full and half-versions of figures with denotive surrounds were used and presented in both upright and inverted orientations. The figures created were designed to meet Gestalt principles for establishing the central area as figure in the full versions but to be ambiguous (according to Gestalt principles) for the half-versions. Their expectations were that (1) for the ambiguous half-figures, there would be an exposure duration at which the denotive region of upright versions would be chosen as figure more often (indicating that shape recognition input can facilitate figure-ground segregation when Gestalt variables are missing or ambiguous), and (2) for upright stimuli a dominance of Gestalt variables would lead to an initial identification of the center as figure; a lack of Gestalt variables would lead to initial identification of the surround as figure—for the upright cases; and if both Gestalt variables and shape recognition work together there will be equally many identifications of center and surround as initial figure. Interactions of display time, uprightness, and Gestalt goodness of the central shape were found. Evidence indicated that shape-recognition routines required about 150 milliseconds and that if Gestalt variables were not strong enough to have
isolated figure from ground in this time that shape recognition played a role.

Both Marr (1982) and Gregory (1990) concede that cognition (top-down processing) can be employed to deal with ambiguous situations. Gregory contends that there would be an evolutionary advantage to a system that worked in parallel with preattentive perception coming up with a quick interpretation that is usually (but not always) correct and conceptual processes (sometimes) modifying that initial impression. Such a parallel system seems to be well supported by Peterson et al. (1991) and is the process behind the pattern identification model of cartographic visualization cited above (MacEachren and Ganter, 1990). Based on this model and ideas about grouping and figure–ground segregation detailed here, we can predict that manipulating any design variables that influence strength of contour or heterogeneity of regions will have a dramatic effect on the patterns noticed. This issue will be considered further in Chapter 8.

**Visual Levels**

Closely related to the issue of figure–ground segregation is the concept of visual levels in graphic illustrations. The theory behind visual levels is that a viewer of a graphic depiction can group sets of objects into common wholes that are seen as occupying different visual (or conceptual) planes. The concept is related to Bertin’s (1967/1983) selective and associative principles in that viewers are believed to see different objects as sufficiently similar that they become a unit and different units as sufficiently different that they are visually segregated. Robinson (1960) may have been the first to discuss the principles involved in creating visual levels on maps (although he did not use this term). To introduce novice map designers to how a map might be structured so that items will appear at “differing position on the scale of visual significance,” Robinson (1960, p. 223) used an analogy to hierarchical outlines for organizing written essays. He then went on to discuss how contrasts of lines, shapes, colors, and value can be manipulated to achieve this structuring.

Michael Wood (1968) took one of the first systematic looks at the idea of visual levels applied to cartography. Wood’s (1968, p. 61) objective was to derive principles that would allow a cartographer to place information “on an imaginary scale of distance planes.” The “distance” between these planes (i.e., levels), according to Wood, should be based on the similarity of the data occupying them. The separation into planes is required to “provide for focused attention and a good ‘gestalt.’” Wood interpreted the concept of visual planes directly in terms of depth perception (which allows humans to segregate a three-dimensional visual field into many depth planes). Wood’s goal was to draw on psychological literature to derive principles for simulating depth planes on two-dimensional maps. Building on research discussed by Vernon (1962), Gibson (1950), and others, Wood proposed ways in which graphic variables such as texture, hue, and value could be used to create depth cues on two-dimensional maps. Although he was able to develop some suggestions for creating visual planes on maps, Wood saw these suggestions as an interim solution to a question that required empirical research to answer more fully. In subsequent work, Wood (1972) specifically considered the application of several Gestalt principles of figure–ground segregation as they relate to separation of visual levels on maps. He cautions, however, that the map viewer’s knowledge and assumptions “can easily reverse” the levels intended by the cartographer.

A number of cartographers followed Wood’s lead in looking to psychological literature for ideas about how visual levels might be created on maps (e.g., Dent, 1970; Spiess, 1978; McCleary, 1981). Dent (1970) also looked to the graphic design literature, particularly Bowman’s Graphic Communication (1968). Dent cites Bowman’s concept that graphic depiction can have one of three categories of visual depth organization: planar, multiplane, or continuous. Dent then proposes that most maps should use a multiplane strategy in which information is organized into a small set of discrete visual planes. Following Bowman’s lead, Dent suggests that techniques employing contrast, aerial perspective (Bowman’s dissimilar focus), and overlay can be used to segregate two-dimensional map information into multiple visual levels. He even goes as far as to propose a formula for predicting how contrast and contour sharpness (an aerial perspective cue) interact to produce position in visual depth:

\[ PVH_j = f(l_j, ES_j) \]

where \( PVH_j \) is the position in the visual hierarchy of object \( j \), \( l_j \) is the intensity of object \( j \), and \( ES_j \) is the edge “sharpness” of object \( j \). This hypothesized formula was never empirically tested. Based on more recent evidence concerning brightness contrast cited above, at least one major flaw in the hypothesis seems apparent without testing. An understanding of visual organization suggests that perception of individual features on a map will not happen in isolation from other map elements. Perceptual representations are inferences based on processing relative intensities in the visual field. The intensity (i.e., brightness) of an object, therefore, is probably not related directly to prominence in the visual field. Contrast
in intensity of an object from its surroundings should, instead, be used. In spite of this flaw, the formula Dent offered is intuitively appealing and could be tested quite easily, but no one has yet done so.

Another untested hypothesis concerning visual levels on maps was proposed by Spiess (1978) and included in the ICA-sponsored text on Basic Cartography (Spiess, 1988). Spiess (1988) contends (as if it were a fact) that no more than three visual levels should be attempted on maps. This view challenges earlier cartographic proposals by both Wood (1968) and Dent (1970) who suggest that at least four visual levels are possible and Bowman’s (1968) contention in relation to information graphics in general that continuous as well as multiplane organization is both possible and useful in some cases (Figure 3.61). Particularly in light of recent technological developments that allow binocular depth cues to be added to the cartographic toolkit, three visual levels for maps seems unduly restrictive. Whether we claim three, four, or more visual levels as a practical maximum, however, visual hierarchies can clearly exist within each level (e.g., a road crossing a stream). We could easily make a case (based on this kind of evidence) for ignoring visual levels altogether and treating visual hierarchy as a continuum. As considered in Part II, however,

**FIGURE 3.61.** An example of a map with four (or more) visual levels: a base, areas on the base, point symbols on the areas, and a legend (which has its own levels) in "front" of all map elements.

grouping categories of features into a small number of levels facilitates a semiotic approach to development of a map syntax (see Chapter 6).

**PERCEPTUAL CATEGORIZATION AND JUDGMENT**

Underlying perceptual organization are processes of categorization. Hoffman (1989, p. 84) contends that “whatever else it does, the brain must be able to simplify and categorize the structures in the patterns it processes.” At the most fundamental level, a bipartite categorization into same-different (i.e., discrimination) is required for early vision to isolate perceptual objects and organize them into groups. All Gestalt principles for grouping or figure-ground segregation are dependent upon heterogeneity of perceptual objects. If there are no differences between objects and background, we will see no objects. If differences are absent among objects, there will be no groups (Figure 3.62).

When vision discriminates between elements of the visual scene, it also generally orders those elements in some way (e.g., one is lighter than another, of coarser texture, longer, closer, etc.). This tendency to order is related to perceptual organization research devoted to visual attention. Items that appear higher on some ordered scale are likely to be more noticeable and thus are probably more often attended to. Eye movement research with maps, for example, has documented the intuitive notion that large map symbols attract more attention than small ones. In addition to these perceptual units, psychophysical tests suggest that the judgment of magnitude is also a preattentive process, at least for size and brightness.

The output of perceptual organization can also be the input for further categorization processes. Detection and discrimination among perceptual objects and groups as well as identification of order or relative magnitude are required if features of a visual scene (i.e., map symbols) are to be assigned to more specific categories. From the perspective of an in-

**FIGURE 3.62.** A map from research by Slocum for which subjects produced no consistent regionalization (i.e., groupings of circles). In this case, differences exist, but they are small. Reproduced from Slocum (1983, Fig. 9, no. 13, p. 71). Adapted by permission of the American Congress on Surveying and Mapping.
formation-processing approach to vision and visual cognition, then, detection, discrimination, and ordering on maps are important in relation to perceptual organization of map marks making up symbols, patterns, and regions and in relation to categorization of map symbols (an issue addressed in more detail in Chapter 4).

Cartographers have directed attention to the empirical examination of map symbol discriminability and have devoted considerable energy to a search for "laws" by which judgment of order and estimation of magnitude are performed. The driving force behind these efforts has been the map engineering goals of determining "least practical differences," making the order of ranked information intuitively obvious, and scaling symbols to match perceptions. These goals, first identified by Robinson (1952), have been approached from a communication perspective—for example, if a cartographer wishes to communicate that there is a categorical difference between two map elements, what physical difference is required to ensure that most people will notice it (and interpret it correctly). In spite of this limited perspective, past results can, to some extent, be put in a broader information-processing context where they might inform work in perceptual organization of maps as well as work dealing with symbol categorization, identification, and interpretation. No attempt is made here to provide a comprehensive review of cartographic research on discriminability, apparent order, or magnitude judgments. What is provided are a few key examples to illustrate how this research might be fit into a broader (thus potentially more useful) context. A sampling of recent ideas from the psychological literature is also described to help link the psychophysical approach taken in much of the cartographic research with the overall cartographic-representation perspective presented in this book.

Detection

Discrimination is the ability of vision to recognize a difference. Detection is, in essence, a discrimination problem in which a viewer must discriminate between some signal and the background on (or in) which that signal appears. For some purposes, however, it is useful to distinguish between detection (the ability to notice the presence of an object or feature) and discrimination.

For areas, there is at least one detection issue that has been of interest: detecting texture of area fill patterns. This is an issue because most area fills on maps to be printed (even if the final appearance is of a solid color) are made up of a textured pattern.9

One of the things that has become clear from both neurophysiological and psychophysical research is that the visual system is relatively insensitive to high frequency (fine) patterns. This allows us to create the impression of flat gray tones from patterns made up of fine dots. Castner and Robinson (1969) were among the first cartographers to investigate the perceptual thresholds involved. If patterns are coarser than about 40 lines (or dots) per inch, we see them as predominantly a pattern (at normal reading distance) (Figure 3.63). Patterns between 40 and 85 dots per inch are ambiguous (as with ambiguous figures in figure-ground research, these fills can be seen as either gray or textured, but not both at once). We can recognize the pattern easily, however, it does not dominate our impression, and we can see a value difference as well. Above 85 dots per inch we no longer notice the texture (unless we are consciously trying to see it—as you probably are now). We see these patterns generally as a color value or a gray tone. If a viewer is consciously trying to detect a texture, however, we have to go to almost 300 dots per inch before our visual system becomes incapable of detecting individual dots in figure-ground vision.

In contrast to Castner and Robinson's thorough examination of texture detection, cartographers have given little attention to questions of point or line symbol detection. Keates (1982) discusses the issues and suggests that detection will be a combined function of symbol size and contrast with the background it appears on (generally a contrast of color value or hue). Viewing distance is an additional factor that is often ignored because it is assumed to be normal reading distance (an incorrect assumption for route maps posted in public places, slide presentations, etc.). At normal reading distance with high-contrast symbols (e.g., black on white), size is not an issue because lines or symbols too small to be seen cannot be consistently printed (at least on normal porous paper). It is when color hue or value differences are used that detection of point and line symbols can be compromised. Although Keates (1982), Spiess (1988), and most authors of cartographic texts caution cartographers to use symbols with sufficient contrast to the backgrounds they appear on, no guidelines exist because little empirical testing has been done.

Noting the importance of low-level vision to any higher level pro-

![Figure 3.63. Map regions with 35 lines/inch dot fills (a), 65 lines/inch dot fills (b), and 133 lines/inch dot fills (c).](image-url)
cessing of map information, Dobson (1985) advocates a concerted effort by cartographers to investigate questions of symbol "conspicuousness." Vision research offers a few hints about potential detection problems on maps, as well as about particular issues that deserve empirical research. The structure of our eye results in a rapid decrease in visual acuity from the fovea to the periphery. Detection will obviously be best for features (e.g., map symbols) that we are looking directly at. With map search tasks, however, in which the map user wants to find an occurrence of a particular feature, symbols must be detectable with peripheral vision if the search is not to be painfully slow. Engel (1977) has demonstrated that increased contrast can increase detectability in peripheral vision.

For maps, black symbols on white backgrounds are usually detectable. It is when color is added that detection problems become likely. Travis (1990), for example, points out that about 8% of men are congenitally red-green color deficient. For these map viewers, detection of symbols on backgrounds and discrimination between symbols can at times be impossible if this problem is not taken into account. Thus far, Olson (1989) seems to be the only cartographer to explore the issue of color deficiency empirically. Based on her research, she devised some guidelines for color choice that should limit hue detection and discrimination problems for the color deficient.10

Beyond issues of color deficiency, all humans have differences in acuity for different hues. Because our eyes have no blue cones in the fovea, our ability to detect blue map symbols is reduced over other hues. As Robinson (1967) noted, the traditional choice of blue for coastlines and depth contours is a poor one in situations for which quick discrimination of these features from their backgrounds is critical (e.g., navigation charts). For logical reasons, and some not so logical, cartography is a tradition-bound discipline. We are therefore unlikely to see a sudden change in color of depth contours or coastlines, in spite of empirical (and neuro-physiological) evidence favoring such a change. In producing a detailed map of Georges Bank, for example, cartographers at Woods Hole Oceanographic Institution conducted extensive tests of detectability and discriminability of various point and line symbol colors on a range of background colors, but did not even bother to test anything other than blue for depth contours (Woods Hole Oceanographic Institute, 1982).

Humans are particularly sensitive to motion. We can detect motion of a few seconds of arc (Mowafy et al., 1990). This ability can be put to use in animated displays—if time is available. Similarly, humans are quite sensitive to aspatial change. As Travis (1990, p. 431) notes, "From neon signs in Las Vegas to the blue light atop an ambulance, flickering lights are used in our society to gain attention." On otherwise static maps, blinking symbols can be used in symbolic ways to highlight important features (MacEachren, 1994b). Examples of blinking symbols have been used by a number of animation authors (DiBlase et al., 1992; Monmonier, 1992).

**Discrimination**

Discrimination (in its usual sense of noticing a difference between two perceptual units rather than between one unit and its background) has been investigated by both psychologists and cartographers using two experimental paradigms, one based on same-different tasks for stimulus pairs, the other on visual search tasks for a target on a background of similar features. Visual search tasks are a less direct measure of discrimination in situations for which the target is both conceptually and visually different from the non-targets. When differences are strictly visual, however, search tasks provide a direct measure of discriminability (Uttal, 1988).

Using visual search methods, psychologists have uncovered a rather unexpected aspect of how vision discriminates. There appear to be natural categories (e.g., circles) from which vision will "notice" differences more readily. Discrimination seems to be asymmetrical. Within a dimension or feature class, some values appear more likely than others. Deviations from these standard values are more noticeable in relation to the standard than the reverse. For example, curved lines among straight lines are discriminated more quickly than straight among curved lines as are tilted lines among verticals, circles with gaps among whole circles, and ellipses among circles (Treisman et al., 1990).11

**Text Discrimination**

For maps, the same-different experimental method has been particularly useful in studies of place labels. Shortridge (1979) used this method to develop guidelines for the minimum point size difference necessary for text labels to be noticeably different (Figure 3.64).12 In collaboration with Welch (Shortridge and Welch, 1980, 1982), she went on to investigate how both the experimental methodology and the features of town labels other than point size influenced discriminability. In the first follow-up study, they focused on discriminability of dot symbols of different size used to indicate town location. They found that larger size differences were required for discrimination if a simple same-different task was posed than if the task was for subjects to indicate the larger dot. In addition, if subjects were led to expect some dot pairs to be the same (as they would when viewing a typical map), the difference required for discrimination...
search for those point features. Quinlan and Humphreys (1987), for example, compared search tasks in which subjects searched for a single-feature target, two different single-feature targets, and a conjunction target combining the two features. Their evidence demonstrated that the rate of conjunction searches is influenced by discriminability of features, but the kind of search process used is not. Regardless of how discriminable the features, they found conjunction searches to proceed in serial fashion, while single-feature searches were executed in parallel when symbols were sufficiently different. Treisman (1988), however, offers some evidence that when two highly discriminable sets of distractors are present, attention can be directed to subgroups of items as a whole and, using inhibition of feature categories that cannot be the conjunction sought, can limit the search in such a way that a parallel process can be used.

There have been several studies that have dealt more directly with discriminability of positional symbols for maps. Most of these studies have measured “confusability” of symbols—a measure that does not separate discrimination from identification (assigning a label to symbols). An example of this kind of study is Johnson’s (1983) empirical evaluation of the National Park Service point “symbol” set. He had subjects match symbols with labels (both with and without a legend present). A confusability index of sorts was devised based on the number of misidentifications for each symbol (Figure 3.65). Subjects were then presented with a visual search task in which the number of correct identifications in a limited time was determined. Those symbols that were highly confusable and were judged to be so because they look alike (rather than because they refer to similar things) also rated low on the visual search task (e.g., the

Point Feature Discrimination

Discriminability of text could be considered a special category of discrimination of point features on maps. A number of psychologists have looked at the interaction between point feature discriminability and visual

FIGURE 3.65. The part of the National Park Service symbol set that was tested, with number of misidentifications per symbol indicated. Derived from Johnson (1983; Fig. 23, p. 112).
lighthouse and the service station symbols). In a similar study with four alternative sets of symbols for tourist maps, Forrest and Castner (1985) found that iconic symbols took longer to locate than abstract symbols, but that fewer identification errors resulted. In addition, they found that the advantages of iconicity (for identification) and of simple abstract shapes (for visual search) could be combined by bounding iconic symbols with geometric frames (triangles, circles, and squares).

**Pattern Discrimination**

Discriminability of point features is probably most critical in situations where visual search is demanded. In contrast, discriminability of map patterns is probably most important when map readers are faced with general tasks related to pattern analysis (e.g., identification of homogeneous regions).

Based on Gestalt grouping principles, we would expect similar elements in close proximity to group and be seen as a whole. In order for patterns to be discriminable, then, grouping must occur for subsections of the visual scene. Patterns in which one feature (i.e., visual variable) is altered in an obvious way are usually quite discriminable, but patterns differing on a conjunction of features or rearrangement of subcomponents of elements composing them are not (Beck, 1966; Treisman, 1985). For patterns made up of coarse textures of the type used to depict qualitative data on maps, there seems to be a good understanding. Because of their probable importance in early vision (leading to Marr's primal sketch) considerable attention has been directed to how texture boundaries are identified and to algorithmic approaches to solving the same problem in computer vision. Malik and Perona (1990) compared the results of visual search measures of pattern element discriminability with a computational approach to texture discrimination and found nearly perfect correspondence (Figure 3.66).

Julesz (1975) has developed perhaps the most complete theory of texture discrimination. He postulates three levels of discrimination (Figure 3.67). First is discrimination on the basis of darkness (or percent area inked). Second is discrimination of the characteristics of pattern arrangement. Both of these processes operate at the global level of the whole pattern. At a third level is discrimination of local geometry. Area patterns for maps, then, could be expected to be most discriminable if differences exist at all three levels. Global-level differences should allow quick parallel processes to be used in discrimination. Patterns that differ only at the local geometry level should be rather difficult to discriminate and will probably require serial processes in which patterns are closely examined one at a time.

Julesz (1981) has formalized the mathematical description of his three levels of texture differentiation and demonstrated that the pretentious visual system is unable to process statistical information beyond the second order. It is possible, however, to create patterns that are discriminable even though they have identical first- and second-order statistics. Discrimination in these cases involves local conspicuous features that Julesz calls "textons" (elongated "blobs" of specific widths, orientations, and aspect ratios). This research, which Julesz has linked to Marr's

**FIGURE 3.66.** A comparison of texture discriminability determined by experiment and by computations. Texture pairs are those evaluated by both Krüse (1987) and Malik and Perona (1990), using experimental and computational procedures, respectively. The most discernible texture pair is shown as an inset on the graph and elements making up all texture pairs appear as labels on the X-axis. Derived from Cleveland (1993, Table 1, p. 335).

**FIGURE 3.67.** Discrimination of two map areas by value (a), by pattern arrangement (what cartographers would term orientation) (b), by local pattern geometry (c), and by the combination of all three (d).
primal sketch model, offers a sound basis from which patterns for use in interactive visualization might be devised (see Chapter 8 for discussion of one attempt to do just that).

Issues of texture discrimination have particular implications for design of area fills to be used in depicting qualitative information on maps. In this case, cartographic and perceptual logic suggests that patterns should avoid the use of differences in percent area inked because these will be seen as ordered. Without percent area inked, however, only pattern arrangement and local geometry are available.

Color Discrimination

In relation to color discrimination, Luria et al. (1986) point out that while color hue discrimnability is “truly astronomical,” the discriminable number of colors drops rapidly as their number in the scene goes up. These authors cite results of 98% correct discrimination among 10 colors, dropping to 72% for 17 colors. In spite of the fact that color discrimnability may be orders of magnitude more limited than simple same-different experiments have suggested, there is considerable evidence that for visual search tasks, symbols that differ from others by hue are much more discriminable than those differing by either shape or size (Williams, 1967). In addition, for symbol conjunctions of color and shape or color and size, color seems to act as the dominant cue (Eriksen, 1952). Williams (1967) has provided evidence from eye movement studies that for these conjunction searches, subjects fixate on targets of the specified color to determine whether they are the correct size or shape rather than fixating on targets of a specified size or shape to check their color. Quinlan and Humphreys (1987), in a visual search experiment involving conjunction targets, came to a similar conclusion.

In graphic applications, Lewandowsky and Spence (1989) have demonstrated that discrimination of different variables on a multivariate scatterplot is higher for point symbols of three different colors than for three different geometric shapes or three different letters. When subjects were asked to estimate the correlation of variable pairs on the graphs, this difference in discriminability resulted in novices having more accurate correlation estimates with scatterplots using color than experts had for scatterplots using three letters (that were not individually very discriminable).

In relation to maps, Forrest and Castner (1985) cite an unpublished study by DeBraties confirming the dominance of color in discrimination of point symbols for visual search tasks on maps. Although Forrest and Castner, along with other cartographers, argue that varying hue of point symbols will be a particularly good idea on maps where visual search is expected (e.g., travel maps, navigation charts, etc.), none have considered the fact that there is a pronounced male–female difference in color acuity, and that for both males and females that acuity drops with age.

Neurophysiological evidence suggests that discrimination on the basis of color or luminance contrast is a lower level visual process than is estimation of luminance. Shapley et al. (1990) argue that early vision computes contrast (not reflectance as Land and McCann, 1971, had predicted). Experimentation with cats (a species whose visual processes are considered quite similar to those of humans) has indicated that “the response of retinal, lateral geniculate and some primary cortical neurons is proportional to contrast over a low-to-medium contrast range, and then may saturate at high contrast” (Shapley et al., 1990, p. 435). This emphasis of early vision on contrast rather than reflectance helps explain phenomenon such as color constancy (that we see a color as the same under various lighting conditions), simultaneous contrast (that perception of a color or shade will change due to the background it is on), and assimilation (the additive effect on brightness of an object produced by the brightness of its background). The emphasis on contrast over reflectance may also relate to the important role contrast appears to have in segregation of figure from ground and the equivocal results that have been obtained when attempts are made to determine whether light or dark areas are most likely to be seen as figures (see discussion of figure-ground above).

Motion Discrimination

As we would predict based on the idea of indispensable variables discussed earlier in this chapter, human vision is very sensitive to motion (for which both location and time are changing). In relation to motion, the Gestalt principles suggest that the common fate of objects moving together will allow a viewer to visually group those objects and discriminate them from their background. Just as we can visually group objects moving together, however, evidence suggests that humans are very sensitive to constancy of spatial distance between moving edges (Mowafy et al., 1990). Their results indicate that discrimination between coherent and uncorrelated motion can be achieved with similar levels of accuracy to the ability for detecting any motion at all (i.e., changes of a few seconds of arc). Mowafy et al. (1990, p. 591) contend that “processing relative movements in the environment is a fundamental characteristic of human motion perception.” Therefore the evidence for this ability to discriminate coherent motion has good evolutionary support. Ability to detect
motion and discriminate between coherent and noncoherent motion has obvious implications for the design of animated maps. For example, on a map depicting flows, we might expect viewers to be attracted to even small deviations (in speed or direction) of a single moving arrow from the flow of a group. No cartographic research has been directed to this or related issues.

**Judging Order**

According to Shapley et al. (1990), one of several fundamental “facts” of perception is that if objects or patterns can be discriminated, we can usually also assign an order. Another “fact” (that they admit they have little scientific evidence for) is that there are “natural continua” along which discriminations are easy (e.g., larger–smaller, left–right), and that we can expect discrimination to be hard along non-natural continua (e.g., alphabetical order).

For maps and other graphics, Bertin (1967/1983) contends that humans find inherent order in spatial location, size, color value, and texture. DiBiase et al. (1992) point out that time is inherently ordered as well, and that for animation temporal order provides one of three dynamic variables, all of which are intuitively ordered (the other two being duration and rate of change). In Some Truth with Maps (MacEachren, 1994a), I suggest that color saturation and focus are ordered graphic variables that Bertin omitted from consideration and that color hue and orientation are marginally ordered. Few of these contentions, however, have been examined experimentally.

Most of the attention to whether various graphic variables used on maps are intuitively ordered has been directed to color hue, color saturation, and color value for area fills. The cartographic goal of the research has been to determine color sequences appropriate for choropleth and other quantitative maps. Experimental tasks used in this research have not allowed preattentive processes to be segregated from attentive ones. Whether the process of seeing the order of various hue-value sets is a logical–cognitive one or a purely visual one, therefore, cannot be determined from the evidence. Results do support the contention that color value and color saturation are ordered and that hue is not (Cuff, 1973; Gilmartin, 1988). In contrast to Cuff’s empirical results, the phenomenon of advance and retreat is expected to cause red to appear to be located on a visual plane in front of blue. Travis (1990) offers three physiological explanations for this effect: (1) that because of chromatic aberration the eye’s lens causes short wavelengths to have a shorter focus than long wavelengths, (2) that the visual and optical axes of the eyes do not coin-

cide, and (3) that the apparent brightness of light depends on the point of entry through the pupil. He contends that using saturated red and blue will make objects literally “stand out” from the display.

A recent study, by students of mine, seems to favor the advance and retreat hypothesis and contradict Cuff’s findings (Bemis and Bates, 1989). For hypothetical temperature maps, subjects were found to consistently see an order in shaded isotherm maps using a bipolar range of colors (with blues at one end and reds at the other). They proposed an interesting explanation for the contradiction between their results and Cuff’s. Since 1973 when Cuff collected his data, a blue–red range has become much more common for temperature maps (e.g., on television news and in many newspapers). Bemis and Bates (1989) contend that the logic of the order has been learned, an explanation that is intuitively appealing. A further test of this hypothesis would be to assess the relative order seen in value versus spectral series using reaction-time methods. If an identification of order for color value is a preattentive process while identification of order in a color hue sequence is a cognitive process, reaction times to judge “higher” values should be faster than reaction times to judge “higher” hues, and the presentation time threshold at which order can first be judged should be much less for value than for hue.

Although several studies have found value ranges to be judged as ordered (with dark values usually seen as the high end of the scale), this ordering is not perfect even for simple maps. McGranaghan (1989), for example, had subjects judge which of two states on a map of the western United States had the higher data value. While the darker of the states was selected as “more” in a majority of cases, only 30% of the subjects consistently saw darker as “more.” Most of the inconsistent ordering occurred when the map’s background was gray or black rather than white, with the black background resulting in about twice as many intransitivities as the white and the gray resulting in about four times as many.

**Judging Relative Magnitude**

Early perceptual research in cartography was devoted almost exclusively to attempts at deriving functional relationships between physical magnitude of different aspects of map symbols and psychological magnitude. McCleary (1970) reviewed this research and suggested that the one generalization that seemed to apply across the board was that map readers underestimate differences between map symbols. The precise functional relationship seemed, at first, to depend primarily upon the particular stimuli being tested and the questions asked (e.g., Olson, 1976). It gradually became clear that there is also substantial individual (subject) varia-
tion in magnitude judgments (McCleary, 1975; Griffin, 1985) and that map context created further problems (Gilpin, 1981).

Based on the extensive testing Flannery did in 1956 and repeated in 1972, Robinson et al., (1984) and other authors of cartographic texts adopted the guideline of adjusting scaling on graduated circle maps to account for underestimation of differences. Others (e.g., Cox, 1976) have suggested that we might be better off simply providing more anchors (in the form of legend circles). The among-experiment and among-subject variatations together with context effects have made many practitioners suspiscious of the empirically derived guidelines for perceptual scaling and today it is doubtful whether many cartographers actually use them.

In relation to gray tones for quantitative maps, there seems to be a bit more consensus. Kimerling (1985) was able to demonstrate a correspondence among what were apparently divergent results and showed that usable gray scales could be devised. The two most significant issues he considered are the interaction between area fill texture and perception of value and the interaction between judgment task and value perception. In terms of texture, Kimerling found that the finer the texture, the more curvilinear the relationship between perceived and actual gray tone. The implications of this finding are that a different set of gray tones is required for maximum discriminability if a map is produced on a laser printer (with dots spaced at about 60 lines per inch) versus on a film recorder (with dots at 100 or 120 lines per inch) (Figure 3.68). Judgment was also found to be dependent upon the visual task, with a different actual-perceived gray tone function for judgment of percent black versus a partitioning task or tasks leading to a set of maximally discriminable gray tones.17

PERCEIVING DEPTH FROM A TWO-DIMENSIONAL SCENE

Closely related to concepts of judging order and magnitude (as well as to the visual levels discussed above) is the simulation of depth in two-di-

![Gray Scale](image)

**FIGURE 3.68.** A gray scale designed for maximum between-category contrast with production on a 100 lines/inch image setter (top) compared to the same grays produced at 45 lines/inch resolution (typical of laser printers) (middle), and to grays adjusted in color value to achieve maximum contrast at the coarser resolution (bottom).

dimensional displays.18 Vision is designed to deal with a three-dimensional world. Interpreting depth in a visual scene is a complex process that appears to be facilitated by a large number of interdependent cues. For good evolutionary reasons, vision does not require all depth cues to be present in order to interpret features of a scene as being at varied distance from the observer. This makes it possible to trick vision into interpreting a map or other display as three-dimensional by combining some of these cues in appropriate ways. How vision interprets depth cues is relevant to cartography because cartographers are often faced with the problem of simulating three-dimensional information on a two-dimensional display (when depicting terrain, but also for more abstract multivariate information).

A Taxonomy of Depth Cues

Kraak (1988) provides a taxonomy of cues for depth perception and a review of the cartographic literature relevant to each. His taxonomy distinguishes between "physiological" and "psychological" depth cues. Some authors have called the latter "pictorial." Since this latter term puts emphasis on characteristics of the display rather than on the cognitive processing of that display, it is adopted here. The physiological depth cues have to do with the physical processes of vision as it reacts to the real three-dimensional environment. Pictorial cues, in contrast, are those related to the object's structure and the way that structure organizes visual input. In the context of computer graphics, Wanger et al., (1992) provide a list of depth cues similar to those cited by Kraak. Each of these sources includes pictorial cues (or subcategories of cues) omitted by the other and disagree on whether motion parallax should be considered a physiological or a pictorial cue (with Kraak opting for the former, and Wanger et al. for the latter). If we look to the art literature, we find additional depth cues not included in either the cartographic or the computer graphic taxonomies (along with some differences in terms for cues in common) (Metzger, 1992). A composite of these sources results in the following taxonomies of depth cues that may be relevant to maps:

**Physiological**

**Accommodation:** A change in thickness of the eye's lens as it focuses on an object.

**Convergence:** The difference in angle of gaze by the two eyes focused on the same object.

**Retinal disparity:** The difference in image (visual array) derived by each eye (which has a slightly different point of view).
Pictorial

Perspective: Kraak (1988) subdivides perspective into four components, and we will follow this subdivision here.

Oblique projection: Representation of a scene from a viewpoint that is not an elevation (profile) or plan view (overhead) suggests a three-dimensional solid, thus depth.

Linear perspective: Lines that are parallel in reality seem to converge with distance (e.g., a pair of railroad tracks).

Retinal image size: Objects appear smaller the farther away they are.

Texture gradient: Texture appears to decrease with distance.

Motion: Movement (actual or simulated) of the observer's point of observation produces changes in the relative retinal displacement of objects at different distances. Successive presentation of static images in which objects are displaced relative to one another can (particularly in the presence of other cues) also result in a sensation of depth.

Interposition: Using Gestalt principles of good continuation, vision will assume that whole objects juxtaposed with what appear to be part objects are really whole objects blocking our view of other whole objects farther away.

Shadow: A cue to obstruction or overlap, indicating that one object is blocking light from falling on another object.

Shading: Illumination gradient can indicate the shape and orientation of a surface.

Color:

Chromostereopsis (also called color stereoptic effect or, more commonly, advance-and-retract): The differences in wavelength of colors are thought to result in apparent differences in distance (with reds appearing closer than blues at the same true distance).

Aerial perspective: With distance colors become less distinct (less saturated) and lighter (higher value), often with a bluish tint due to atmospheric scattering.

Detail: With distance detail becomes less visible and edges become blurred.

Reference frame: In order to judge relative size, vision must match retinal size to some frame of reference—apparent distance will therefore vary with what an object is compared to.

Not surprisingly, the bulk of cartographic attention to depth perception and how specific cues might prompt this perception is related to terrain mapping. Terrain is three-dimensional and cartographers have struggled with collapsing those three dimensions onto a two-dimensional page since the earliest maps were made. Although contour lines involve no depth cues, virtually all other methods of depicting relief rely on one or more of the cues listed above. Simulation of three dimensions on maps can be grouped into techniques that involve physiological cues, that rely on perspective, that use static nonperspective pictorial cues, and that include motion. For motion to cue depth, the user must assume a perspective view (but linear perspective is not essential). Since the possibility of motion as a depth cue requires a dynamic display, further discussion of these cues will be postponed until Chapter 8 in the context of geographic visualization environments (which, as they will be defined here, are dynamic).

Applying Depth Cues to Maps

Physiological Approaches

Computer technology has facilitated production of displays that make direct use of binocular parallax as the primary depth cue. Such displays consist of pairs of representations, usually perspective views, that depict the mapped area from slightly different points of view (simulating the different points of view resulting from the spacing of our eyes). Seeing depth in stereo pair maps usually requires that the observer's head does not change position while viewing, and/or that special glasses be worn. One technique, referred to as anaglyph plots, uses opponent colors of red and green to produce two overlapping views. When an observer wears glasses having one red and one green lens (if she has normal color vision) the two views will be separated with one seen by each eye. This technique was used for maps at least as early as 1970 in the Surface II package that could generate anaglyph fishnet maps.

Perspective Approaches

Included here are the four perspective cues of oblique projection, linear perspective, retinal size, and texture gradient. These cues are typically manipulated together on perspective view maps, with oblique projection common to all. Different representational techniques can put uneven emphasis on the remaining three perspective cues. The well-known fishnet plot (Figure 3.69), for example, emphasizes texture gradient. In contrast, layered contours (Figure 3.70) and block diagrams emphasize linear
perspective and size disparity, and solid modeling (Figure 3.71) emphasizes linear perspective with shading and shadow as additional (nonperspective) depth cues. All of the methods mentioned make use of interposition as an additional cue (e.g., fishnet plots are rarely generated without hidden line removal). I have uncovered no empirical comparisons among the various styles of perspective map, but some attention has been given to perception of fishnet plots.

That fishnet plots, with their strong texture gradient, do work was convincingly demonstrated by Rowles (1978). She found that subjects were able to judge relative height quite accurately, even when the point of view for the perspective was as high as 75° (nearly overhead) or as low as 15° (Figure 3.72). The view from 15°, however, results in considerable occlusion of map sections, something that probably helps to cue depth but can make the map much less useful (unless it can be dynamically oriented to allow hidden locations to be uncovered).

Nonperspective Approaches

Whether or not fishnet and other perspective view maps are effective, they all suffer from two problems. No matter what point of view is taken, there will be some hidden features and (if linear perspective is used) scale will change across the map. To avoid these issues, considerable attention has been given to use of nonperspective depth cues with the goal of an effective plan-view relief representation that suggests depth. Most cartographic attempts to create the illusion of depth without perspective use shading and/or color.

With shading, there is a long history of manual techniques using pencil, airbrush, and other tools. The procedures for what is termed "plastic relief" borrow from principles of light and shadow in art and psychological principles of depth perception, but to be effective must also incorporate considerable knowledge of geomorphic structure of the terrain.
being represented. Imhof (1965/1982) provides the most comprehensive account of these methods. One of the things that has been learned (primarily from long experience and years of marginal success at computerizing the process rather than from empirical research) is that perception is sensitive to what might be called the texture of shading as well as to its value. Humans can immediately recognize the difference between a perfect match of shading with slope-aspect values and shading that looks real. Not only do real surfaces not reflect light as perfectly as a virtual computer surface can, the real environment has complex interactions of direct with reflected light that our visual system has evolved to expect. For terrain shading to look real, it must incorporate at least some of the subtle variation from perfect reflectance that occurs in the real environment. Many theories have been proffered for the ideal reflectance model, but little empirical research has been done to determine their relative merits. In spite of the lack of empirical research, plastic shading has developed to the point in cartography that it has been successfully modeled with computer software (Figure 3.73). Perhaps the most impressive result thus far is Pike and Thelin's (1989) digital relief map of the United States, described by Lewis (1992) as a "cartographic masterpiece."

One issue that all disciplines interested in shading as a depth cue seem to agree upon is that the simulated light source needs to be from above the scene, and above-left is usually cited as best. This phenomena seems to be based upon a schema (or expectation) that light in the environment is from above. When applied to art (e.g., in the representation of a vase of flowers on a table or a figure in repose) this light-from-above rule is quite logical. On a map, the rule results in light from the north-west, a direction that is at odds with reality in the northern hemisphere. In spite of the physical impossibility of the scene, humans consistently treat terrain shading on maps in the same way that they treat shading on a painting. This reaction is so strong that a map produced with terrain illuminated from the south will appear inverted, with the hills looking like valleys and the valleys like hills.

In an effort to represent terrain aspect information clearly while also creating effective relief shading, Moeller and Kimerling (1990) developed a unique color-rendering process that has subsequently been labeled MKS-ASPECT™ (Moeller, 1993). They started with the assumption that aspect is a nominal (qualitative) phenomenon for which color hue differences provide a suitable representation. They set out to devise a color-matching system that would allow observers to visually separate terrain regions with different aspects while also providing appropriate depth cues leading to interpretation as a three-dimensional surface. The system relies heavily on OPT (described above in the discussion of eye and
brain). As noted above, OPT predicts four unique hues from which all others are derived. It also predicts that certain hue combinations are not possible: those across the diagonals of the square color space (red-green or blue-yellow). The four unique hues are considered to be the maximally discriminable hues (when at maximum saturation and medium lightness). One guideline that Moellerling and Kimberling arrive at from OPT is that aspect should be grouped into four, eight, sixteen, and so on, classes using the four unique hues or these four plus their first order combinations, second order combinations, and the like. They argue that the resulting hues (for eight or more classes) should be seen as a circular progression of related colors.

Moellerling and Kimberling (1990) had the primary goal of depicting aspect classes clearly. Initially they matched the four unique hues with cardinal directions. Although a discriminable map was obtained, the resulting representation prompted a number of inversions of features (e.g., ridges seen as valleys). Their technique (unlike true relief shading) does not take into account a light source or reflectance due to that light source. The impression of relief obtained is due entirely to slope aspect. Moellerling and Kimberling were able to achieve a reasonable impression of depth by rotating the unique colors so that yellow (the highest value color) was aligned with the standard light source azimuth (315° or northwest), and the value of all other hues was adjusted to match the deviation of azimuth from northwest. It is claimed that the MKS-ASPECT™ system eliminates one of the most severe problems with standard gray tone relief shading: that the visual interpretation of the scene will be highly dependent upon the exact angle of illumination for the hypothetical light source (Moellerling, 1993). By not relying on color value alone, identification of ridge lines or valleys is not as dependent upon how their alignment matches with that of the illumination. No empirical test of Moellerling's claims has yet been undertaken.

Recently Brewer (1993) has developed an alternative color scheme for mapping slope and aspect in conjunction. This scheme uses a hue range to represent aspect, with yellow as the anchor hue aligned with northwest. Other hues were selected so that a value progression was achieved in each direction from yellow, and each of the eight distinct aspect categories would have a sufficient saturation range for three saturation steps (plus unsaturated gray) to be discernable. Slope categories were depicted with these saturation steps; the higher the saturation, the steeper the slope. Its main advantage over Moellerling and Kimberling's MKS-ASPECT™ system is that Brewer's color scheme results in a much more effective depiction of the terrain form, while still providing easily interpreted aspect information and adding three categories of slope.

An alternative use of color hue as a depth cue in terrain representat-
inks give the appearance of reflecting more light than is incident on the page. Again, Eyton provides anecdotal evidence, indicating that few students saw a fluorescent ink map as having depth, but the same map with black contours appeared to be three-dimensional to almost all the students. A final variation on the maps was obtained by adding hill shading (in gray) to the fluorescent ink maps. The added cue seemed to aid the perception of depth, but again the effect was strongest when contours were included as well.

A final depth-cue technique for static plan view maps worth noting is the "Tanaka method." Tanaka (1932) made use of shadow rather than shading (or color) to produce a sensation of depth in contour maps. The basis of the technique is to treat contours as if they represented a three-dimensional "layer-cake" model of terrain which in a perspective view would result in a layered contour depiction of the sort discussed in Crawford and Marks (1973). Tanaka's technique simulated the appearance of a layered contour map by putting white and black contours on a gray background. Contours toward the light source are in white with those away from the light source in black (Figure 3.74). Width of contours "varies

FIGURE 3.74. Representation of Tanaka's layer-cake method of terrain depiction. After Japan Cartographers Association (1980, Fig. 4, p. 162).

with the cosine of the angle θ between the horizontal direction of the incident ray and the normal to the contour at the point under consideration" (Japan Cartographers Association, 1980, pp. 162-163). Although the ability of Tanaka's method to provide a 3-D appearance is clear from examining a color version of a map using the Tanaka method (Japan Cartographers Association, 1980, f. 162), no empirical evaluation of the method exists nor any empirically derived guidelines on appropriate maximum widths for the variable contours.

SUMMARY

The goal of this chapter has been to provide an overview of a range of issues relevant to visual processing of maps. Perspectives from neurophysiology, psychology, cognitive science, human factors engineering, and cartography are woven together in an effort to build an understanding of how maps are seen that can serve as a framework for research on and guidelines for map symbolization and design. It is only by understanding what vision is for and its limits that we can hope to comprehend the complex process involved in "seeing" a map.

Vision has been treated as a complex information-processing system that generates a succession of "representations." At the lowest level are representations of the visual scene on the retina of the eye. These are processed by our neurological hardware through a series of stages leading toward an organization of input into a coherent description of the visual scene in a form that can be interrogated by higher level cognitive processes.

After briefly reviewing the neurophysiological hardware issues and the limits that they place on map displays, the bulk of the chapter emphasized perceptual organization and perceptual categorization and judgment—two areas that have received considerable attention in the cartographic literature of the past four decades. In terms of perceptual organization of map information, the topics of perceptual grouping, attention, visual search, and figure-ground are emphasized. Psychological, cartographic, and other research on these topics is considered in relation to Bertin's contentions about the fundamental graphic variables available for creating map symbols. Although a great deal of cartographic research of the 1960s and 1970s dealt with issues of magnitude estimation, it is now clear that other aspects of perception are more relevant to map design. In the section on perceptual categorization and judgment, the emphasis, therefore, was placed on what we know about discrimination of symbols and patterns and about the propensity of the visual system to distinguish differences in kind and differences in order, two topics that seem particularly relevant to design of interactive visualization tools. Finally,
the chapter concludes with a section devoted to the simulation of three dimensions on flat two-dimensional maps. This is an area of cartography with a long history, but one in which the integration of psychological principles and cartographic practice has been minimally addressed. Again, the topic of simulating the third dimension has become more important than ever in the context of visualization.

The perceptual emphasis in this chapter sets the stage for discussion of how knowledge is linked to perceptual input in the interpretation and use of maps. We pick up this thread in the next chapter, where the emphasis is on cognitive processes of mental categorization and spatial knowledge representation. These topics are the design of interactive visualization tools intended to facilitate visual thinking as well as to the formalization of spatial knowledge that will be required by expert systems for map generalization, symbolization, and design.

NOTES

1. A fixation is a brief focus on a small section of the visual field where the item at the center of the fixation is “seen” by the foveal area of the retina and the cells connected to it.

2. The sections below are ordered because language requires order. The processes, however, are interdependent and are as likely to occur simultaneously as in the order presented or any other order. Some detection differences, for example, are necessary for grouping and attention. On the other hand, some grouping is required for objects to be isolated for discrimination and some attention to particular locations is needed to note differences between these locations.

3. Although Slocom did not specifically mention Gestalt psychology, he provides standard examples of the laws of similarity, proximity, and good continuation and directs the reader's attention to Arnheim (1974) and Woodworth (1938) as sources.

4. Eastman never cites the graphic organization variables he considered as Gestalt principles. To put his study in the context of the present discussion, however, I have made this link to Gestalt theory explicit in my review of Eastman's research.

5. This finding supports OPT, which would predict that wavelength averaging can happen for red-yellow and green-blue but cannot happen for red-green and blue-yellow mixtures. These mixtures are not possible (according to OPT) because there is no neurological mechanism for mixing across the diagonals of opponent color space.

6. The term “divided attention” is potentially misleading. Pomerantz and Schweitzer (1975) use it as an antonym for selective attention. Attention is not really divided (in time) between parts, as the term might imply, but is directed to the whole created by relationship of the parts. Thus “holistic” attention might be a more appropriate term.

7. Each of these hypotheses has implications for the development of visual-
CHAPTER FOUR

How Maps Are Understood

VISUAL ARRAY → VISUAL DESCRIPTION
  ↔ KNOWLEDGE SCHEMATA
  ↔ COGNITIVE REPRESENTATION

To examine the next major stage in human-map interaction, how maps are understood, we must consider how visual descriptions of map displays (that result from how maps are seen) interact with existing knowledge and the form that knowledge takes. The perspective taken here is that existing knowledge, in the form of propositional, analog, and procedural representations, is brought to bear on the interpretation of visual scenes through knowledge schemata that serve as an interface between visual descriptions and knowledge representations. These schemata act to structure what we know about objects, concepts, relationships, and processes in the world. As a result, they also structure what we see by making certain groupings, categorizations, patterns, and so on, more likely than others. In a complementary fashion what we see (in the sense outlined in Chapter 3) provides input to generalized schemata. These complementary processes allow us to make sense out of the visual scene.

In order to understand the complex interactions among the visual array resulting from perception of a map, the visual description that provides structure to what is seen when studying the map, and the knowledge schemata that provide an interface with previous knowledge and a structure for conceptualizing about the input, we must consider the forms that knowledge schemata might take. There seem to be three possibilities that are probably used to some extent by all humans. These three are propositional, image, and event schemata. Each will be described in detail below.

Underlying our human ability to form and make use of knowledge schemata, of whatever form, is the human propensity to categorize. How we mentally categorize (what things are grouped together through what kinds of relationships) determines the elements and kinds of relationships available to knowledge schemata. Most entities in knowledge schemata are categories to which we "map" individuals that are encountered. Thus in order to understand how knowledge schemata link information acquired by visual (or other) senses to stored knowledge, we must first consider the nature of conceptual categories.

MENTAL CATEGORIES

"Without the ability to categorize, we could not function at all" (Lakoff, 1987, p. 6). If we accept this premise, the logical cartographic corollary is: Without categorization, maps would not be possible. Like Lewis Carroll’s story of a map produced at larger and larger scale until it was the same scale as the environment (quoted in Muehrcke and Muehrcke, 1978, p. 22), a map without any categorization would be more cumbersome than using the environment as its own map. Maps depict categories rather than individuals. As such, to understand how maps work, we must understand categorization. To make maps that work, we must depict categories using methods that match the structures of human mental categorization. Human mental categorization processes are, of course, relevant to map interpretation as well as to map creation. Maps depict information that has the potential to be categorized by viewers in a variety of ways that relate to their goals, interests, backgrounds, and so on. How stimuli in a visual scene are grouped into categories can be dependent upon relationships among the complete set of stimuli (see Handel et al., 1980).

The classical approach to mental categories assumes that categories exist in the world and that we can discover them. These natural categories are taken to be clearly defined and mutually exclusive. Cartographers have accepted this proposition (at least in part) and assumed that there are optimal (or correct) categories to be uncovered in any mappable information. Following from this perspective on categories, cartographers (and their geographic colleagues in climatology, soil science, etc.) have devoted considerable energy to developing optimal categorization (or optimization) methods for category delineation (e.g., Jenks, 1977). Map categories derived by such methods are typically defined with precision, resulting categories are mutually exclusive, and the category system is
comprehensive (i.e., everything fits into a category). The failure to use "optimal" classification procedures (by noncartographers) has lead to critiques (by cartographers) of maps produced to represent disease and other topics. The assumption that optimal categories for statistical maps are possible has led to conflicts between cartographers and their map author clients of the kind cited by Krygier (forthcoming).

The classical approach to mental categorization that cartographers and others have accepted as fact has come under increasing attack in the linguistic, philosophical, and psychological literature. Championed by the empirical efforts of Rosch (1973), a convincing body of evidence has been produced to support a view that few mental categories fit the classical mold. It is now clear that many of the scientific categorization systems that had been taken as evidence of the classical view of categories do not, in fact, support that view. Lakoff's (1987) *Women, Fire, and Dangerous Things: What Categories Reveal about the Mind* provides perhaps the most compelling account of what a shift from classical categorization theory entails in relation to both mental categorization itself and, more generally, how the mind organizes knowledge. A few researchers in the GIS community have begun to grapple with what this new view of mental categorization means for natural language approaches to GIS user interfaces and to GIS information structures (e.g., Pequen, 1988; Mark and Frank, 1991; Bjorklund, 1991; Usery, 1993). Also, from the perspective of databases for GIS, Suchan (1991) describes the implications of alternatives to classical categories in the context of land-use classification. It is time that cartographers also begin to question past approaches to categorization for maps and to consider what has been learned about mental categorization in relation to how information should be presented on, and is derived from, maps.

To understand the implications of recent evidence about mental categorization, we must begin with the classical approach to categories. From Aristotle to the present, two basic tenets were taken for granted by most disciplines: (1) Categories are like containers (with things either inside or outside) and (2) Individual things are assumed to be in the same category if and only if they have certain properties in common. A third assumption that usually goes along with classical categories is that natural categories exist, and that if we are diligent and resourceful we can discover them. Biological taxonomies and color are often cited as evidence for this last proposition, but as we will see below, neither is independent of the human observers who developed the categories.

The classical approach to categories was not based on empirical study; it was assumed to be so obvious that a priori philosophical speculation was sufficient to consider the tenets as fact, rather than theory subject to verification. One implication of the acceptance of classical cate-

gories is that any element in a category must, by definition, be as representative of the category as any other element. This perspective is applied in cartography when we produce choropleth maps, soils maps, climate maps, and so on, in which all map units falling in a particular category are depicted with identical symbolization. On a choropleth map not only are we implying homogeneity within geographic units, but homogeneity among units in the same category. Several spatially adjacent units that are grouped in the same numerical category, therefore, are taken to represent a homogeneous region that is assumed to differ from other regions on the map. The cartographic concept of a choropleth map depends upon the classical theory of categorization being "correct." The understanding derived from choropleth maps based on classical categories depends upon how the categories are interpreted by users (i.e., in terms of classical or alternative categorization systems).

Elenore Rosch (1973, 1975a, 1977, 1978; Rosch et al., 1976) has been the primary force behind a dramatic change in how we view human categorization, and by implication how we view the human mind and human reason. She was among the first to view classical theory as just that, a theory, and to seriously question its assumptions. Two of these assumptions were specifically addressed in research by Rosch and her collaborators: (1) If categories are defined by properties that all members share, no members should be more representative of the category than others; (2) if categories are defined by properties inherent in their members, then categories should be independent from characteristics of humans doing the categorizing (e.g., neurophysiology, perception, culture, etc.). What Rosch and others found was that neither assumption held in practice. Most categories investigated consisted of individual members judged to be more or less representative of the category, and the characteristics of the humans doing the categorizing were fundamental to the categories defined. The alternative to classical categories that is supported by empirical evidence collected by numerous researchers in varied disciplines over the past two decades has been termed prototype theory in reference to one of its basic premises, that category membership is determined not by a match to a fixed set of properties, but by similarity to a prototype representing the most typical category member.

Prototype Effects

The central feature of Rosch's theory of categorization is this concept of a prototype. Prototypes have been variously defined as abstract mental concepts of a typical (but not necessarily existing) member of a category, as exemplars (or "best") members of a category, or as collections of fea-
tures (and relationships among them) that are most strongly associated with the concept. In differentiating her approach from classical category theory, Rosch (1975b) initially advocated a conception of prototypes as a kind of abstract mental composite of the most typical members of a category. At least with common objects such as fruit, however, this mental composite idea of a prototype does not work well (e.g., it is difficult to conceive of what a composite of apples, oranges, and bananas might be like—other than as a fruit salad—or how this composite might be used to judge the "fruitiness" of another potential, but less typical, category member such as a tomato). The idea that prototypes for a category are simply the most typical members that a person has encountered has similar problems explaining how the prototype could be used to judge whether new objects or concepts fit in the category. In addition, exemplars are likely to be highly individualistic, and therefore to be too idiosyncratic to be useful in interpersonal interaction.

A view of prototypes based on features of category members seems to be most plausible. This view differs from classical accounts of categories (also based on features) in that the features are not expected to be common to all category members. Rather, the feature lists of a prototype are assumed to represent those features that together represent the most typical and distinctive characteristics of the category (Roth and Frisby, 1986). Smith and Medin (1981) propose a "probabilistic" model as one mechanism for using features to establish the relative "goodness" of entities as category members. This model matches the probability that two entities are in the same category with the degree to which they share features. It discounts the notion of a common core of critical properties that are necessary for membership in the category. As Murphy and Medin (1985) point out, however, a limitation of the probabilistic approach is that it cannot determine which features form possible concepts (prototypes) and which form incoherent ones. By itself, therefore, a probabilistic model might be able to describe the structure of a particular category (in relation to entities that people tend to assign, or not assign, to the category), but we need something further to understand what qualifies as a category in the first place. Murphy and Medin argue that concepts are fundamentally linked to "theories" about the world, and claim that these theories are the "glue" that holds concepts together.7

In the realm of maps, Downs et al. (1988) found that the category "map" itself demonstrates prototype effects. Both children and adults shared a concept of a prototypic map (with the Weekly Reader World Political Map being a good example), but children chose a much narrower range of displays that they were willing to categorize as a map than did adolescents or adults. Vasilev et al. (1990), in a similar experiment, found that the category "map" was defined by a set of characteristics that in various combinations determine "mapness." This finding seems to agree with the feature-list approach to prototypes described above.

Family Resemblance

As early as the 1950s, evidence began to accumulate that classical categories having clear boundaries and common properties did not fit all situations. Wittgenstein (1953; cited in Lakoff, 1987) used the category "game" as an example of a category that does not conform to classical theory. As a category, games do not share a common set of properties. Some are based on competition and others are not, some depend on chance (e.g., dice), while others depend on skill (e.g., darts). Some games are for amusement (e.g., pinball), while others have an educational goal (e.g., SimCity). The main point made by Wittgenstein is that some categories are defined not by common properties, but by family resemblance. In people or animals, members of a family resemble each other in various ways (e.g., hair color, shape of the face, build, height, etc.). To be recognized as part of the family does not require sharing all characteristics with other members. Closer members in a family tend to share more features, while distant members may share none but still be identified as in the same family by virtue of sharing separate features with a more central member (e.g., Joe has Uncle Harry's eyes while Sally has Uncle Harry's sense of humor).

Category membership defined by family resemblance is much more flexible than are classical categories. It allows individual entities to maintain category links to multiple categories. In addition, the concept of family resemblance provides a logical mechanism by which potential new category members can be added over time (as evolving knowledge and technology generates them). Historically, the category "numbers" exhibited this growth, beginning with integers and subsequently extending to include rational numbers, real numbers, complex numbers, and so on (Lakoff, 1987). As Stephen Hall's (1992) overview of mapping technology applications makes apparent, the category "map" is being extended into new domains as a result of computer technology producing spatial depictions (i.e., maps) of new frontiers in medicine, biology, physics, mathematics, and astronomy. This expansion of the category "map"—due to the flexibility of the concept of family resemblance—has the potential to expand the bounds of the category "cartography" as well. If maps are not restricted to depictions of the earth's surface or the surfaces of other celestial bodies (a restriction found in the 1973 International Cartographic Association [ICA] definition of cartography) the definition of cartography will have to be rethought. In 1987, the ICA actually began
an attempt to redefine the field by redefining "cartography." The revised definition is most significant in its shift of emphasis from "making maps" to "organization and communication of geographically related information" (Board, 1989; cited in Taylor, 1991). Such a formal redefinition, however, is unlikely to prove satisfactory unless cartographers accept the idea that the object of their interest, the map, is a category in constant flux (rather than a static classical category).

One of the most important aspects of the concept of family resemblance for cartography is that it allows for category members that share no properties. This is exactly the approach recently taken in attempts to derive optimal categorization procedures for quantitative statistical maps (e.g., Jenks, 1977; Coulson, 1987). Jenks's statistically optimal classification procedures delineate categories in which all members are more similar (numerically) to some central prototype (a mean or median that may not actually exist in the data set) than to the central prototype of adjacent categories. Jenks's optimal categorization scheme does not (as would a classical categorization scheme) require that all elements of a category share some common property. If a map user misinterprets the resulting categories in classical terms, however, the map as a whole will be misinterpreted (Figure 4.1).

**Fuzzy Categories**

Some categories like "large cities" have no clear bounds. As city size decreases, the certainty that a city is large will probably decrease, but there is unlikely to be a distinct boundary above which an individual classifies cities as large and below which cities are classed as small. "Map" as a category, in addition to an apparent structure based on family resemblance,

![3-class](image1)

![n-class](image2)

**FIGURE 4.1.** The potential for misinterpretation is apparent if we compare an optimally classed three-class choropleth map with its n-class counterpart (a map in which each data value is given a shade of gray corresponding to its position in the data range). The clear regions with sharp edges apparent in the classed map are not really there.

has been demonstrated to have fuzzy bounds (Downs et al., 1988; Vasiliev et al., 1990).\(^3\) Downs and Liben (1987) specifically measured the fuzziness of "map" as a category by asking subjects to respond to a series of examples with one of three answers: Yes, I think it is a map; No, I think it is not a map; or I am unsure or can't decide whether this is or is not a map. Vasiliev et al. (1990) posed a similar task using a 5-point scale from "definitely a map" to "definitely not a map." Both experiments demonstrated fuzziness or uncertainty concerning category bounds. Both also point out that scale is a factor in "mapness," with national scale more typically a map than city scale. Downs and Liben (1987) found this scale factor to be particularly important for children, only slightly over half of whom accepted a "map" of Philadelphia as a map (while 100% of the adults did so).

The phenomenon that some categories appear to have fuzzy boundaries was initially investigated by Labov (1973). Using drawings of household objects as stimuli, he attempted to determine whether the assignment of an object to a category could be influenced by the context within which the object is presented. Such a context effect would, of course, be at odds with classical category theory that assumes all categories have clear-cut and stable boundaries. His drawings all depicted objects that could be considered vessels for holding things. These were presented in one of four contexts: neutral—where subjects were to imagine someone holding the object in their hand; coffee—where subjects were to imagine someone holding the object and drinking coffee from it; food—where subjects were to imagine the object filled with mashed potatoes and sitting on the dinner table; and flower—where subjects were to imagine the object on a shelf filled with cut flowers. As the appearance of the drawing was less and less cuplike (broader and shallower), responses that it was a cup declined in all four contexts. A clear context effect, however, was present. For the neutral and coffee cases, the identification of objects as a cup decreased much less markedly across the set of examples than it did for the food and flower cases (Figure 4.2). Labov's (1973) research, and subsequent findings by Barsalou and Sewell (cited in Barsalou, 1985) among others, suggest that people's perception and structuring of categories does not reflect invariant properties of the categories. Category structuring appears to be highly dynamic and context-dependent.

Stephen Hall's (1992) Mapping in the Next Millennium may provide cartographic examples of context effects. Because this book is purportedly about mapping, and he uses the term "map" when referring to visual depictions of the brain, DNA, atoms, galaxies, and fractals, readers undoubtedly accept them as such. The same readers, however, in a different context, might be more likely to categorize the depictions presented as medical images, star charts, diagrams, or perhaps abstract art.
A mechanism for conceptualizing and working with fuzzy categories such as those Labov found was developed nearly a decade earlier by Zadeh (1965). With this method, known as fuzzy set theory, membership in a category is not a binary decision of in or out. Values between 0 and 1 are allowed. At its most basic level, fuzzy set theory allows operations on sets that are generalized from the analogous operations on ordinary sets. Within the area of spatial representation, versions of fuzzy set theory have been used in an effort to simulate the uncertainty in category assignment within a GIS.

Typicality Effects

One of the key initial findings underpinning prototype theory as an alternative to classical category theory was the identification of typicality effects in category structure. Some categories, although they may have relatively clear bounds (e.g., trees), have a graded internal structure resulting in differences in terms of how typical an individual example is of the category (e.g., oak vs. mulberry). Rosch (1973; Rosch and Lloyd, 1975) demonstrated typicality effects within categories convincingly in a series of experiments in which subjects rated potential category members according to their goodness as an example of a specified category. Categories tested were furniture, vehicle, weapon, carpenter's tool, toy, sport, fruit, vegetable, and bird. In all cases, subjects found the task easy and there was substantial agreement on the ratings given. Results provide clear evidence that, at least for these common categories, membership is not a simple binary choice but involves a grading from typical to atypical.

A chair or sofa, for example, represent highly typical members of the category "furniture," while lamp and stool are clearly within the category, but much less typical. Other items, such as vase and telephone, are atypical.

If we consider a standard cartographic topic such as land use or land cover, it seems likely that we will find a similar graded range of members at all levels of classification. As an example, an avocado orchard is probably less typical of "agricultural land" for most people than is a wheat field and a 100-acre cattle ranch is probably more typical than a 2-acre biointensive herb farm (although both may generate similar income identified as "farm" by the IRS). As noted above, the category "map" itself exhibits prototype effects, and these seem to include typicality. Some maps while clearly within the category are less suitable as exemplars of the category than others.

Among the best known empirical demonstrations of typicality effects (and fuzzy boundaries) is Berlin and Kay's (1969) research on color categories, a topic of increasing cartographic relevance in an age of virtual color CRT maps. They conducted a series of empirical tests of the generally accepted notion that different languages can partition color in arbitrary ways. What they found was that a set of basic color terms exist across languages (names consisting of a single morpheme: yellow vs. sun-colored, not contained in another color—yellow vs. gold, applicable to a broad context—yellow vs. blond, and generally known—yellow vs. saffron). Not all languages examined had the same number of basic terms, but when languages had a specified number, they were typically the same (e.g., those languages having only three basic color terms use terms for white, black, and red; yellow or green are added in four- and five-color languages; blue is added in six-color languages; and brown is added in seven-color languages). The complete set of what Berlin and Kay identified as basic color terms is black, white, red, yellow, green, blue, brown, purple, pink, orange, and gray. Obviously, since I was able to list all colors in single English words, English contains all eleven. A key feature of the basic color terms is that when individuals were asked to select (from a set of color chips) the best example of any color included as a basic color for their language, they were very consistent in selecting the same color. In addition, this color choice corresponded across languages, even when languages had different numbers of basic colors (e.g., for all languages having blue as a basic color, the same blue was picked).

For each basic color, therefore, there is a central member considered to be the best example of the category and the category grades away from this central color. While Berlin and Kay found consistency in the prototypic color representing each basic color category, they did not find similar consistency in identifying category bounds. Colors seem to be fuzzy
categories with the fuzzy set size for specific basic colors varying from language to language, resulting in lack of consistency for color boundaries. This cultural difference suggests potential problems in trying to select colors for maps used in cross-cultural contexts or default colors in mapping systems for a multinational market (e.g., tourist maps).

In an attempt to explain the phenomenon of basic color categories, Kay and McDaniel (1978) looked to neurophysiological evidence of opponent color processes in vision (see Chapter 3) combined with an adaptation of fuzzy set theory. They cite DeValois and Jacobs (1968) as evidence for opponent processes based on blue, yellow, red, and green, plus light and dark. According to an opponent process model, human vision is expected to react to these six distinctions in a direct way. Kay and McDaniel (1978) point out that these six neurophysiologically basic colors are the first six basic colors that appear in language. That these colors are basic, they contend, is due primarily to human neurophysiology. This view has subsequently been disputed by Ratner (1989) whose results suggest that cognitive as well as neurophysiological mechanisms may play a role even for these most common focal colors. The remaining basic colors are thought to come from combinations of the first six based on cognitive mechanisms making use of something akin to fuzzy set theory. Orange is derived from a fuzzy set intersection of red and yellow, purple from blue and red, pink from red and white, brown from black and yellow, and gray from white and black. As Lakoff (1987, p. 29) rightly notes, “Color categories result from the world plus human biology plus a cognitive mechanism that has some of the characteristics of fuzzy set theory plus a culture-specific choice of which basic color categories there are.”

Map as a Radial Category

Lakoff (1987), in combining the ideas of prototypes, family resemblance, fuzzy bounds, and typicality effects, suggests the concept of a radial category. Radial categories have a clearly defined center or prototype. The center of the category is predictable from family resemblance to prototypic members. Noncentral members are not predictable from prototypes, but, according to Lakoff, are motivated by family resemblances to them. By “motivated,” Lakoff seems to mean that there is a cognitive economy in recognizing similarity on some criteria (e.g., appearance, function, etc.) between the potential category member and the central prototype. For maps, we are motivated to consider a contour plot of brain cell activity (see Figure 3.13) to be a map because this allows us to interpret the display as we would a topographic surface, thus immediately “recognizing” peaks and troughs in density of active cells.

The category “map” seems to be a clear case of a radial category. Its category space can be defined by two orthogonal axes. One is the grading of mapness due to scale identified by both Downs et al. (1988) and Vasiliev et al. (1990). The other involves map abstraction. John Ganter and I have argued that spatial displays form an abstractness continuum from images to graphics (or diagrams) (MacEachren and Ganter, 1990). Typical maps occupy a middle ground along this continuum. Combining the ideas of a prototypic scale and abstractness for maps gives us a map category space within which a variety of spatial depictions can exist (Figure 4.3).

The fact that “map” is a fuzzy and radial, rather than a precisely defined, category is important because what a viewer interprets a display to be will influence her expectations about the display and how she interacts with it. Prototype maps, being at the midpoint of the scale axis of this space, are probably more readily interpreted and more readily accepted as objective depictions (than are maps at the atomic or astronomic extremes) because they depict reality at a scale closer to human experience. Considering the other axis, graphs and diagrams are often viewed with some suspicion due to their abstract nature, while images (i.e., photos) are generally accepted as unbiased depictions of what can be seen from a particular vantage point. The prototypic map, lying between the image

FIGURE 4.3. The radial category map, illustrating two possible axes of the category space.
and diagram extremes, clearly involves some processing, and therefore some potential for bias (but also becomes functional due to this processing). The idea that function is often a defining feature of categories is stressed by Lakoff (1987) and others. A depiction is considered a map if it can function like one (e.g., be used to plan a trip).

**Basic-Level Categories**

Lakoff (1987) credits research by Brown (1958) as the first to note that categories are organized hierarchically. Certain labels within the hierarchy of category names have a higher status, and these categories are correlated with actions (e.g., “flower”—can be sniffed—compared to the more generic “plant”; “ball”—can be bounced—compared to “sports equipment”). This distinctive level of categorization has come to be termed the basic level. It was the anthropological research by Berlin (1972) that first explored basic-level categories in detail and served as the impetus for Rosch et al. (1976), Tversky and Hemenway (1984), and others to extend the idea of basic-level categories to all kinds of mental categorization (including categories of events as well as objects).

Berlin examined, in considerable detail, the plant names used by the Tzeltal Indians of Mexico. The categories that they routinely identified were found to correspond with categories at a particular level of scientific taxonomy for plants, the level of genus. Berlin argued that there was cognitive economy in grouping plants at this level because the genus is the highest level at which many visually distinctive attributes are held in common by most members of the category—plants that look alike therefore are likely to be in the same category when categories are defined at the level of the genus. Lakoff (1987) points out that the correlation between the folk classification at this basic level and the scientific level of the genus was not a coincidence. Linnaeus built his taxonomic system around the level of genus, and similarity in some readily apparent characteristic (e.g., shape of fruit) was his key criterion for grouping at this level. As Lakoff makes clear, therefore, the scientific classification system (at what Linnaeus considered the most important level) was grounded in folk categorization emphasizing visual similarity.

Tversky and Hemenway (1984) argue, using evidence from psychology, linguistics, and anthropology, that for all category systems (not just biological ones), there will be a basic level at which a variety of aspects of perception, behavior, and communication converge. These basic-level categories are the most general categories for which we can form a single image. They contend that the basic level is distinctive primarily because there are relatively large numbers of attributes (parts) associated with it and because these attributes share both perceptual and functional features. “Car” and “table,” for example, are cited as more basic categories than “vehicle” or “tool” because most people can define more attributes of the former than of the latter and because many of those attributes have both form and function (e.g., tires on a car). This important role for the function of attributes shared by category members is echoed in Lakoff’s (1987, p. 12) contentions that properties of certain categories depend upon human capacities and experience of functioning in the environment, and that concepts that are “used” are more fundamental than those that are simply “understood intellectually.”

Lakoff (1987) reviews much of the evidence for basic-level categories. From this review he contends that basic-level categories are basic in at least four respects:

1. **Perception**: Basic-level categories are the highest level categories having similar overall perceived shape, a single mental image, and fast identification.
2. **Function**: They are the highest level categories for which a person uses similar motor activities to interact with them (e.g., sitting on chairs vs. standing on furniture).
3. **Communication**: Basic category labels are the shortest, most commonly used, and most contextually neutral words; they are the first learned by children; and they are the first to enter the lexicon.
4. **Knowledge organization**: The basic level is the level at which most of our knowledge is organized and for which the most attributes are stored.

The search for a basic level of categorization is related to cartographic questions surrounding quantitative data classification for choropleth maps and the issue of when, or if, classification is appropriate (vs. use of unclassed maps). As mentioned above, Jenks's so-called optimal classification makes use of one of the aspects of prototype theory, that categories can be delineated on the basis of family resemblance such that variation internal to the categories is minimized and that variation among categories is maximized. Jenks and Caspall (1971) seem also to have anticipated the idea of basic-level categories in arguing that comparing variance for a hierarchical series of classifications is a good way to identify the most efficient position in that hierarchy. Specifically, they advocated computing a “goodness-of-variance-fit” for two through n categories, graphing the results, and determining the number of categories at which the graph levels out (Figure 4.4). This number of categories should be the most cognitively efficient for the map reader. With a more detailed cate-
FIGURE 4.4. A plot of decreasing classification variance with increasing numbers of categories. Such plots typically suggest a decreasing accuracy return on the cognitive investment of processing more and more differences.

gorization, cognitive effort to process the increasing number of categories would continue to increase, while within-category variance would improve only marginally.\(^{11}\)

Building from the extensive research on basic-level categorization in a variety of contexts, then, we arrive at an argument in support of classed choropleth maps over unclassed maps based on features that have been identified for basic-level categorization, such as cognitive efficiency and enhanced memorability. My research on memorability of choropleth and isopleth map patterns supports this contention by demonstrating that even if we give map readers more detailed maps (with up to 11 categories), they seem to “remember” at what may be the basic level of three categories (high, medium, and low) (MacEachren, 1982). The alternative argument is, of course, that if readers are capable of seeing basic-level categories in a map display having subordinate categories, we can provide more detail to the readers without interfering with their ability to ferret out the basic-level structure. This argument is supported to some extent by Muller’s (1979) demonstration that subjects asked to regionalize n-class choropleth maps grouped enumeration units into roughly the same groups as did Jenks’s statistically optimal data classification procedure (when both subjects and Jenks’s algorithm were asked for three classes) (Figure 4.5). As we will discuss below, however, different map readers bring different schemata to the map interpretation task and these differences may result in differences in what is identified as a basic-level categorization.

Cartographically and geographically, we often categorize the world on the basis of spatially contained regions. This process of geographic regionalization differs from standard choropleth categorization and much of the natural object categorization that Tversky and Hemenway (1984) and others studying basic-level categories have addressed. The primary difference is the interaction of spatial location with nonspatial attributes. Tversky and Hemenway (1984) offer an extension to the idea of basic-level categories that may be relevant to geographic regionalizations. In their emphasis on the role of parts in basic-level categories, Tversky and Hemenway distinguish between what they term taxonomies and partonomies. Taxonomies involve organization by kinds (i.e., grouping things that are similar), while partonomies involve organization by parts (i.e., grouping things containing similar parts or attributes). In relation to geographic regions, a taxonomy could group locations that were similar in spatial position and overall appearance (e.g., sparsely populated rolling hills dominated by livestock pastures), or some composite measure of characteristics (e.g., a politically conservative, agrarian economy, with an aging population). A spatial taxonomy, then, might serve to divide the world into spatially bounded categories that are organized hierarchically such that inferences about the largest regions can be applied to subregions within them. A partonomy, in contrast, would focus on region parts (or attributes) and identification of region cores based on locations with the greatest number of shared attributes. Regionalization by partonomy, in contrast to the spatial taxonomic regionalization described above, may be spatially quite fragmented with ill-defined (fuzzy and perhaps overlapping) spatial bounds.

My own research on the role of map compilation exercises in influencing regional images supports the spatial taxonomy–partonomy distinction (MacEachren, 1991a). I found that spatial and attribute components of regional images were at least somewhat independent. Subjects in an initial survey exhibited considerable location mismatch between the location they associated with a major regional (the Midwest) and where the attributes they associated with the region actually are. The task of compiling maps of these attributes led to changes in the location component of regional images to correspond more closely with attribute location (Figure 4.6). The category “Midwest” was therefore shown to exist in two separate but interrelated cognitive models that can conflict and can influence one another when those conflicts are brought to the indi-
individual's attention. That the locationally based categorization of the "Midwest" was altered to correspond more closely to the attribute-based categorization seen on cartographic maps is evidence for the importance assigned to "map" as a category. The depictions classed as "real" cartographic maps were accepted as more valid than the subject's own mental maps of regional image location.

Regional images represent a "folk" classification in that they are derived by nonspecialists for use in everyday spatial decision making and behavior. Like plant taxonomies, many presumably objective geographic regionalizations (e.g., climate zones) are based in part on folk categorization, presumably at the basic level. Climate categories, for example, in order to be functional, must relate to issues of human comfort and/or productivity (e.g., the ideal temperature and moisture conditions for agricultural crops). This structuring of regionalizations around a functional basic level of categorization has proved effective, even if we were not conscious of using a fundamental process of human mental categorization when we devised the categories.

In relation to socioeconomic factors, folk classifications (of high-income neighborhoods, ghettos, etc.) combine space and attributes in ways similar to the physical regionalizations of climate and soils. Why, then, do we ignore space when classifying data for a choropleth map? Jenks's statistical classification procedures seem to have (if only coincidentally) taken into account the principle of basic-level categories. The next step in our evolution of quantitative data classification, then, should be to add space to the equation. Jenks, in fact, attempted to do this in a "contiguity-biased" data-classification procedure that he developed in collabora-

**Figure 4.6.** A composite Midwest location based on responses from 32 students (left), a composite map of the location of Midwest attributes identified and compiled from existing maps by those same 32 students (right), and a composite map of the Midwest location as specified by those 32 students 10 weeks after completing the Midwest attribute map compilation exercise (middle). Shading on all maps corresponds to the percentage of students for whom a cell was identified as in the Midwest (for the two location maps) or for whom a cell contained two or more Midwest attributes (for the attribute map). After MacEachren (1991a, Fig. 1, p. 153). Adapted by permission of The Cartographic Journal.

**Natural versus Cultural Category Structures**

Classical categorization assumes that the world is divided into categories that it is our task to discover. Anthropologists, who were among the first to find flaws in classical category theory, came to the conclusion that structure does not exist in the world: it is imposed by cognitive processes of the human mind (Leach, 1964). They came to this conclusion by observing the variety of ways different cultures categorized the natural world (e.g., languages that had from two to 11 basic color terms; those that group plants on the basis of appearance, kind of propagation mechanism, or medicinal use, etc.).

Rosch, the most influential critic of classical categorization theory and proponent of prototype theory, took a middle ground. Her initial view (Rosch et al., 1976) was that the world has structure and that this structure influences how the mind divides things into categories. She contended that there are natural correlations of properties of things in the world that tend to go together (e.g., wings with feathers). These natural correlations influence, but do not determine, the groupings we observe and find useful. Characteristics of human perception and cognition were
seen to interact with these natural structures to highlight some and to bypass others. Kay and McDaniel's (1978) explanation for the existence of a structured but variable set of basic colors in the world's languages fits this conception. In subsequent research Rosch (1978) saw flaws with this realistic view. In particular, it became clear to her that many categories could not exist independently of the observer doing the categorization. Certain attributes of categories (e.g., "seat" for a chair) could only be applied after knowledge of the object as a particular category was established, others (e.g., "large" for a piano) were meaningful only in terms of a superordinate category (furniture vs. built object), and yet others were functional attributes that depended upon how humans interact with the world (e.g., humans eat, therefore we have developed the category of "food").

Lakoff (1987) places particular emphasis on this interactional nature of many category properties. He contends that properties are "the result of our interactions as part of our physical and cultural environments given our bodies and our cognitive apparatus" (p. 51). He suggests that interactional properties often seem objective or natural when we consider basic-level categories because humans perceive certain aspects of the environment very accurately at the basic level. Lakoff contends that cognitive models that structure thought and are used in forming categories are either directly embodied or linked directly to embodied models. By "directly embodied," he means that the models are based upon human biological capacities and experiences of functioning in a physical and social environment. Part of our cognitive model for understanding a road map, for example, includes a basic understanding of front and back in relation to the human body, and origins, paths, and destinations in relation to everyday movement.

Multiple Representations

Classical categorization assumes that there is always a single correct way to categorize any phenomenon. Prototype theory with its typicality grading, fuzzy category bounds, family resemblance, and hierarchical category structure presents a more flexible view that allows for multiple representations of individual concepts.

Dual Representations: Common and Scientific

It is easy to demonstrate that there are differences between scientific and common categorizations of the world. As Roth and Frisby (1986) point out, common categories are often clear-cut (e.g., male–female, life–death). Scientifically (and legally) there is often considerable debate about the boundaries of such categories. Nonexperts tend to focus on the core of categories and shared characteristics while experts may focus on category divisions and distinctive features. In addition to this expert–nonexpert distinction, individuals often hold more than one kind of representation of a concept suited to different applications. A cartographer, for example, may accept digital databases as being "maps" at a conceptual level, but when she goes to the local bookstore looking for the map section in preparation for a trip abroad, she would probably be surprised (and not very happy) to be led to a rack of floppy disks containing Digital Data Bank of the World files.

An important issue that cartographers must begin to grapple with is the choice of category representation. Up to now, we have taken a view that there is one "objective" way to categorize any data set and have tended to rely more and more heavily on quantifiable attributes of categories to achieve this objectiveness. As Krygier (forthcoming) points out, this model for what maps are and how they should depict is at odds with the philosophical perspective of much of modern human geography. There is a need to explore the possibility of varying levels of categorization for different goals, applications, and perspectives, and to explore how our maps might incorporate some of the less precisely defined (but no less truthful) ways of categorizing the world. The distinction is not just one of common versus scientific categories, but also occurs among scientific categories based upon differing philosophical foundations (e.g., see Yapa, 1992, on the category GNP).

Fuzzy Representations of Well-Defined Concepts

Many kinds of categories can be demonstrated to be ill-defined or fuzzy categories. Categories like "map" are fuzzy categories at both common and scientific levels because there is no precise definition (either an embodied functional one or an arbitrary formal one) that allows us to clearly identify whether an object is in or out of the category. Other categories can be quite well defined. Roth and Frisby (1986) offer the triangle (a category defined quite precisely as an object having three and only three sides) as an example of a particularly well-defined domain. Cartographically, a "railroad" on a map is a similar unambiguously defined concept (although its position may not be well defined). Armstrong et al., (1983) have provided evidence that even for well-defined categories people often have a fuzzy representation. This happens even when they know, intellectually, that the category is not a matter of degree. Roth and Frisby (1986) sug-
suggest that the tendency to have fuzzy representations of well-defined domains is cognitively efficient because these fuzzy representations provide a means for fast judgments. This notion of fuzzy representation relates to the pattern recognition model for cartographic visualization that John Ganter and I have devised (see Chapters 2 and 10) (MacEachren and Ganter, 1990). In that model, we suggest that use of maps as visualization tools is effective because of a human tendency to see (or notice) patterns quickly that are usually correct or significant, then reason about them to determine how accurate this initial noticing actually was. Recognizing that a display has some similarity to a likely prototype is often enough to result in an initial categorization of an object or pattern noticed on a map. This initial categorization will remain accepted until evidence to the contrary is encountered, or until a reasoning-why process determines that an alternative categorization has a higher probability. These fuzzy categories also allow objects or concepts that have some similarity to the prototype for a category to be linked with that prototype even without meeting some formal criterion for category membership. Figure 4.7, for example, can be classed as triangular even though it is not geometrically a triangle.

**KNOWLEDGE REPRESENTATION**

Mental categories occupy a fundamental level of human knowledge. Without categories, we would be quickly overwhelmed with specific unique elements of information (for color alone, as an example, humans are capable of discriminating more than 7 million colors). At the level of mental categories and above, we are faced with the issue of how knowledge in general is organized. Such knowledge includes (in addition to category structures) spatial and aspatial relationships among categories or category members, procedures for action, and more. A number of theories of knowledge organization or representation exist. The one I will draw upon here is that offered by Rumelhart and Norman (1985) in which they present a typology that divides knowledge representations into three types: propositional, analogical, and procedural.

**Kinds of Knowledge Representation**

There has been considerable debate among psychologists concerning the form that cognitive spatial representations take. The competing theoretical positions were described by Lloyd (1982) as ranging from radical image theory (see Kosslyn, 1981) through dual-coding theory (see Paivio, 1969) to conceptual-proposition theory (see Pylyshyn, 1981). The distinction among the theories arises from the role that imagery is thought to play in the coding, storage, and retrieval of spatial information. Conceptual-proposition theory contends that all knowledge exists as conceptual propositions and that images, if they are accepted as existing at all, are an epiphenomenon with no real function in thought. Radical-image theory, at the other extreme, posits that images exist, are used in thought, and are stored in an analog form. Although there is little hard evidence to support the idea of this “pictures-in-the-head” view, there is considerable evidence that images are a real phenomenon that can be mentally manipulated and used in abstract thought (see the discussion of “Processing of Imagery” in Chapter 2). In addition, imagery seems to use some of the same processes as seeing because imagery cues have been demonstrated to help detection (Peterson and Graham, 1974). While most psychologists and neurophysiologists scoff at the picture-in-the-head idea, a more schematic map-in-the-head view has growing support. The maps of activity in the brain presented in Chapter 3 (Figure 3.13) provide one piece of evidence for this view. Neurobiologist John Allman (1990; cited in Hall, 1992, p. 16) contends that one of the most distinctive differences between human brains and those of other animals is the size of our neocortex and that one form of learning, which he calls “perceptual memory,” is stored within “maps” in the neocortex. Stephen Hall (1992, p. 17) in reference to work by Allman and others speculates that “it may be that the human brain not only perceives but stores the essentials of a visual scene using the same geometrical, quasi-symbolic, minimalist vocabulary found in maps.”

Both propositional and analogical representations appear to be applicable to encoding concepts or static scenes. In relation to maps and the geography they depict, it seems that propositional knowledge representation might be most suited to the organization of what Golledge and Stimson (1987) refer to as “declarative knowledge,” knowledge about objects, attributes, and places. Analog representations seem suited to orga-
nization of configurational knowledge about space—knowledge of spatial relationships among entities in space. In relation to environmental learning, Golledge and Stimson contend that declarative knowledge is at a lower level of cognitive processing with configurational knowledge achieved through a developmental-like process with increasing experience in an environment (Figure 4.8). I have found that learning can be facilitated by simulating this developmental sequence by presenting a map as a hierarchically structured set of route segments that gradually build toward a configurational representation (MacEachren, 1992a). As Lloyd (1989) has shown, however, when a map is the source of information, configurational knowledge can be acquired quickly (10 minutes of map study resulted in more accurate distance and direction knowledge than 10 years of living in an environment). In the study of sequenced presentation of map components (cited above) I found evidence that different kinds of knowledge representations can be stimulated by different knowledge-presentation procedures (MacEachren, 1992a). It is likely that map reading involves reliance upon knowledge structures dealing with both declarative and configurational knowledge and that the process of map reading can generate or alter both propositional and analogical knowledge representations.

What the bipartite approach to knowledge representation suggested by the proposition–imagery debate leaves out is what Golledge and Stimson (1987), in an environmental learning context, refer to as procedural knowledge, knowledge of the sequence of steps needed to get from one place to another. More broadly, procedural knowledge is considered simply knowledge of how to do something. Rumelhart and Norman (1985) contend that procedural representations are a distinct category of knowledge representation; that propositional, analog, and procedural representations all play a role in human knowledge organization; and that they interact in complex ways. Evidence from research by Golledge et al. (1992) suggests that procedural knowledge obtained during route learning is difficult to transform into a configurational (analogue) representation. Frequent reports of traveler frustration with maps (that probably induce an analog representation) suggest that transformation in the opposite direction (analogue to procedural) is equally difficult. This implies that alternative navigational aids that provide procedural rather than configurational information may have an advantage over traditional maps for some travel needs, particularly for following a route once it has been selected (McGranaghan et al., 1987).

That cognitive representations, exhibiting both propositional and analog characteristics, can be generated from maps has been demonstrated by a number of authors (Garling et al., 1983; Peterson, 1985; MacEachren, 1992a). It has been argued by some that map-derived representations are typically analog (image) in form and it has even been suggested that these can be picture-like (Levine et al., 1982). Corresponding to the likelihood that maps generate analog representations, research supports a view that mental imagery plays some role whenever information learned from maps must be recalled and applied to solving specific map-use tasks (e.g., Steinke and Lloyd, 1983a; Lloyd and Steinke, 1985; Rice, 1990). Steinke and Lloyd (1983a), for example, demonstrated that images can be formed of maps and that these images can be transformed (i.e., mentally rotated). Two colleagues and I (Goldberg et al., 1992), however, found that when dealing with perspective terrain maps, only a small portion of subjects seemed to use mental rotation as a strategy for comparing map views. Our results suggest that a variety of problem-solving strategies can be used in map comparison tasks and that some of these strategies involve interrogation of a propositional rather than an analog representation. My research on the role of maps in environmental knowledge acquisition supports a hypothesis that individuals differ in the tendency to organize map-derived knowledge in an analog versus a propositional (and/or maybe a procedural) form (or in the tendency to retrieve knowledge in that form) (MacEachren, 1992a).

As a whole, cartographic evidence supports Rumelhart and Norman's (1985) contention that there are separate propositional and image representations. At this point, whether or not maps can stimulate procedural representations remains an open question. It seems likely, however, that dynamic real-time navigation aids based on moving-window map displays are likely to do so. That usable cognitive representations of some kind can be generated from such displays has been demonstrated by Ford (1985). Whether or not the representations generated are procedural, it is clear that map-derived knowledge must interface with procedural representations in the process of wayfinding (e.g., Crampton, 1992a).
Kinds of Knowledge Schemata

Regardless of how knowledge is represented in long-term memory, whether in propositional, analog, or procedural form, we must have some way to interface between visual descriptions (and other temporary sensory input stores, such as those for acoustic input) and these knowledge representations. The dominant view in the psychological literature is that some structuring mechanism or mechanisms exist that provide a common format for organizing sensory input and information retrieved from long-term knowledge representations. These structuring mechanisms have been given a variety of labels depending upon the kind of knowledge they are hypothesized to deal with and the proclivities of the author suggesting them (e.g., schemata, frames, scripts, mental models, idealized cognitive models, etc.). Although there are some fundamental differences implied by these labels (and among authors who use the same label), for simplicity in discussing how map understanding may depend upon these cognitive structures I will adopt a single term, schema, to refer to them.

Following from the introduction of schemata in Chapter 2, schemata will be defined here in rather general terms as structures for representing and organizing concepts. These structures can be conceived of as models containing slots (or nodes) and links among them. The slots represent categories or attributes of categories and the links specify the possible relationships that can hold among the categories or attributes. Mental categorization of elements in a visual description is influenced by potential relationships specified by a schema that an observer brings to bear on a situation—such as understanding a map. Conversely, human mechanisms for categorization, identified as aspects of prototype theory, will control how unknowns of knowledge schemata can be filled in (i.e., instantiated). An important feature attributed to schemata by most theorists is that they are active devices—"plans for finding out about objects and events" to quote Neisser (1976) again.

In one of the few attempts thus far to consider schema theory in a cartographic context, Eastman (1985a) emphasizes the hierarchical, embedded nature of schemata. He equates schemata with cognitive structures that define prototype cases and points out that each schema consists of concepts or entities (each of which is a category that may be described by a prototype structure of its own) connected by relations. Eastman uses this argument of hierarchical schemata to contend that there is really no difference between schemata and "chunks" other than the typical use of the latter term to label the more primitive structures contained in a schema at a particular level of description.

Schemata are hypothesized (by various authors) to exist for dealing with all three kinds of information suggested by the typology of propositional, analog, and procedural representations. In the psychological literature schemata are typically assumed to be propositional models or organizing structures, even when they are applied to procedures or images (Rumelhart and Norman, 1985). I suggest, however, that different schemata are likely to exist for interfacing with different knowledge representations. A categorization of schemata as propositional schemata, image schemata, and event schemata seems appropriate. The idea that schemata serve as a structure to interface between sensory representations and long-term memory representations is derived from work by a number of cognitive psychologists, cognitive scientists, and linguists. I believe, however, that the proposal offered here is unique in suggesting three categories of schemata as cognitive structures matched with the three categories of knowledge representation delineated above.

As organizing structures, schemata can be embedded one within the other, representing knowledge at all levels of abstraction. These embedded complexes of schemata can include combinations of all three kinds identified. For most maps, we can expect at least propositional and image schemata to interact in map understanding. According to Neisser (1976, p. 53), an important function of schemata in seeing is to direct exploratory movements of the head and eyes. In visual search of maps for items such as placenames or point symbols, propositional schemata may guide search strategy and image schemata may control precognitive decisions about whether a name or a symbol is likely enough to be the one searched for to warrant closer examination. In exploratory analysis of complex map patterns, propositional and image schemata in combination may determine what spatial relationships we initially see. Whenever a map depicts a dynamic event (particularly with dynamic or animated symbols) or is used dynamically as a decision-making tool (e.g., in wayfinding), procedural schemata are likely to play a role.

This typology of schemata and the contention that each higher level schema can include subordinate schemata of more than one type parallels (to some extent) Lakoff's conception of an idealized cognitive model (ICM). An ICM as presented by Lakoff (1987, p. 126) offers "a conventionalized way of comprehending experience in an oversimplified manner. It may fit real experience well or it may not." ICMs can use any of four structuring principles: propositional, image-schematic, metaphorical, and/or metonymic. In Lakoff's view, ICMs that deal directly with automatic, normal functioning (functionally embodied concepts) have primacy. Lakoff devotes most of his attention to concepts related to "things." Procedures are given minimal consideration and no separate procedural category is proposed. Although procedures are omitted from Lakoff's view, the concepts of metaphor and metonymy are added as structuring "models." These concepts seem to be at a different level than proposi-
tional or image-schematic models (or than my typology of schemata). Both metaphor and metonymy deal with the way one thing or concept is able to stand for another and, as Lakoff presents them, are structures internal to ICMs or that serve as links among elements of different ICMs.

Like Lakoff's ICMs, schemata as presented here are conceived of as simplified structures that can include imagistic and propositional concepts (as well as procedural ones). Lakoff's concept of an ICM (or schema) as a structure that is prototypic of a concept or set of relations, rather than being a template that must be matched exactly, parallels the perspective that John Ganter and I took in our pattern recognition model for cartographic visualization. In that context we contended that when scientists apply a pattern identification schema to visual analysis of a cartographic display, "There is seldom an exact match, instead we do a sort of curve-fitting to get an approximate answer—very quickly" (MacEachren and Ganter, 1990). A similar position is also found in Uttal (1988, p. 29) who states that "humans generate approximate solutions to geometry of the stimulus on the basis of soft rules of approximate inference."

The most completely developed formulation of schemata applied to interpretation of visual information displays is Pinker's (1990) conceptualization of a graph schema. Although Pinker's approach to graph schemata, highlighted in Chapter 2, offers an attractive starting point for conceiving of how people understand graphs (or maps), there is something intuitively uncomfortable about trying to explain graph or map understanding while relying exclusively upon propositional structures. Pinker's propositional-based approach may work quite well for computational models in which all information must ultimately be processed linearly. For human map understanding, however, Arnheim's (1985) contention that humans can reason imagistically as well as verbally (propositionally) seems undeniable. Basic concepts involved with all three kinds of schemata are outlined below. This outline will then be built upon in a proposal for how map schemata might be formed and used.

Propositional Schemata

Some cognitive theorists contend that all knowledge is fundamentally propositional in nature. The major proponents of schema theory seem to have held this perspective because most attempts to formalize the idea of schemata for thinking and knowledge acquisition have modeled schemata in propositional terms. Rumelhart and Norman (1985), for example, discuss schemata and frames as subcategories of organizing structures for propositional representations. They contend that schemata exist for concepts underlying "objects, situations, events, sequences of events, action and sequences of action" (Rumelhart and Norman, 1985, p. 36). They go on to describe schemata as "packets of information that contain variables." In their view, each schema has a "fixed part" corresponding to characteristics that are (usually) true of exemplars and a "variable part" that deals with those characteristics that are likely to be unique to individuals. The variable parts are assumed to have default values (information about what to assume when incoming information is left unspecified). They offer a schema for the category "dog" as an example (Figure 4.9). Among the fixed parts of the schema would be "four-legged animal." Variable parts would include color, size, and so on (with defaults possibly set to match an individual dog with which the person is familiar).

A similar example schema for a map symbol interpretation might be associated with activity location symbols on a National Park Service (NPS) map (Figure 4.10). The fixed part of the schema might involve the concept of a small, black, roughly square symbol. The variable part would involve shape of the symbol (e.g., skiing). The default value for the variable might be the pump tent or picnic table. The concept that schemata are active devices (proposed by Neisser, 1976, and by Rumelhart and Ortony, 1977) is significant here. According to this view of schemata, they are not only a structure for interfacing with visual descriptions but have the embedded goal of determining their own goodness of fit to the visual description. Seeing an NPS-style camping symbol used on
a non-NPS map, for example, might activate an NPS symbol schema resulting in an expectation that other symbols encountered on the map will also correspond to the NPS symbol set. This, in turn, would lead to attempts to match other symbols to this schema, a strategy that might lead to confusion if all point symbols on the map did not come from the NPS set. Following this logic, we could predict map-reading problems in any situation for which map symbols associated with a particular map type are mixed with other symbols.

Of the attempts to formalize the concept of propositional schemata, Pinker's graph schema introduced in Chapter 2 comes closest to the kind of schema that might underlie at least some components of map understanding. I will, therefore, use it as an exemplar of propositional schemata and fill in some of the details omitted from the discussion in Chapter 2.

Pinker introduces his conception of a graph schema by diagramming the potential interface role (see Figure 2.12). The graph schema as depicted in this diagram serves as a model that has three roles: (1) to determine the kind of interpretation possible from the visual description, (2) to structure conceptual questions (queries) in a format that is compatible with the structure of the visual description, and (3) to allow different visual descriptions to be categorized (as particular graph types). It seems, then, that the first stage of graph understanding (and map understanding if it is analogous) is to draw upon aspects of a schema that process the visual description at a global level, allowing particular categories of the object to be recognized. This recognition (e.g., that the visual description is of a histogram or a choropleth map) allows the system to access lower level schemata that provide for more precise interpretation. At both global and local levels, the schemata are active in that they include a goal of assigning elements of what is seen to conceptual categories. These, in turn, allow links to be made with knowledge organized according to these categories.

A nonspatial but map-related example may be useful to present the formalisms incorporated in Pinker's propositional schemata. Consider the numbering system for interstate highways in the United States and how we can interpret those numbers to derive more than an arbitrary label. A schema is diagrammed in Figure 4.11 in a manner similar to that used by Pinker for telephone numbers. The schema contains slots or parameters

![Figure 4.10](image1.png)

**Figure 4.10.** A possible schema diagram for interpretation of National Park Service point symbols.

![Figure 4.11](image2.png)

**Figure 4.11.** A schema for interpreting U.S. Interstate Highway numbers. Pinker terms the rectangles in schema diagrams such as this "message flags" because they contain the definitions and relational information needed to derive knowledge, which he terms "conceptual messages." When instantiated with values from the visual depiction, the message flag on the left is interpreted as follows: When A is present, a connecting or bypass route is indicated and B then represents the primary route it is linked to. The right-hand message flag has the following possible interpretations when instantiated: (a) If B1 is an even number, the route is a dominantly east-west one and the magnitude of B1 represents the position north-south in the United States (the higher the number, the farther north); (b) if B1 is an odd number, the route is a dominantly north-south one and the magnitude of B1 represents the position east-west in the United States (the higher the number the farther east).
for as yet unknown information to be matched against a visual description containing constants in place of the parameters. What the interstate numbering system allows us to determine (if we have the appropriate schema) is (1) whether the highway labeled is a primary route, a regional connector, or an urban beltway; (2) if a through route or connector, whether the route is predominantly east–west or north–south; and (3) if an urban route, whether it is a circular beltway or a crosstown expressway. The schema works because it includes fixed knowledge (that interstate numbers have two or three digits, that two-digit numbers are primary routes, etc.) and variable knowledge that can be filled in from a limited number of possibilities. With this schema, you can recognize that a route labeled M1 is not a U.S. interstate (it is the British equivalent). The recognition is accomplished at the level of individual parameters (in this case representing slots that can be occupied by single alphanumeric characters), with M1 being rejected because the interstate numbering schema limits each parameter to the set of one-digit integers. The number 270, however, passes the recognition test as a possible interstate number because each of the three schema parameters could be replaced by one of the three digits (or numerical predicates).

Pinker goes on to develop a rather elaborate schema for interpretation of bar graphs. The schema contains a fundamental separation of the overall graph framework (L-shaped) from the pictorial content (bars) (Figure 4.12). These elements, however, are linked in two places with the vertical part of the framework joined to the bar heights depicting data values and the horizontal component of the framework joined with the categorical information that provides information on what each bar represents. Because Pinker has devised an explicit formalism for representing graph schemata, I will quote at length from his description of the realization of this schema so that the notation used can be interpreted.

The height and horizontal position of each bar are specified with respect to coordinate systems centered on the respective axes of the framework, and each bar is linked to a node representing its nearby text. An asterisk followed by a letter inside a node indicates that the node, together with its connection to other nodes, can be duplicated any number of times in the visual description. The letter itself indicates that each duplication of the node is to be assigned a distinct number, which will appear within the message flags attached to that instance of the node.

The message flags specify the conceptual information that is to be "read off" the instantiated graph schema. They specify that each bar will contribute an entry to the conceptual message. Each entry will equate the ratio value of the first variable (referred to in the description as "IV," for Independent Variable) with the horizontal posi-

![FIGURE 4.2. Pinker's bar graph schema diagram and the kind of bar graph it is intended to deal with. After Pinker (1990, Fig. 4.17, p. 98, and Fig. 4.18, p. 100). Adapted by permission of Ablex Publishing Corporation.](image)

tion of the bar with respect to the abscissa, and will equate the ratio value of the second variable (the "DV" or Dependent Variable) with the bar's height with respect to the ordinate. In addition, the absolute value of the independent variable for an entry will be equated with the meaning of whatever label is printed below it along the abscissa. Finally, the referents of each variable will be equated with the meaning of the text printed alongside its respective axis. (Pinker, 1990, p. 97)

Pinker (1990) hypothesizes that the process of applying the graph schema to a particular graph understanding context involves four proce-
Pinker in an elaboration of his initial information-processing diagram (Figure 4.13).

In addition to proposing schemata that provide the structure necessary to interpret specific graphs, Pinker (1990) also advances the concept of a general schema (Figure 4.14). A general schema is a more abstract, less detailed schema that might be considered a prototypic schema. It includes those parameters and relations found in typical graphs but does not necessarily represent knowledge about any particular graph type. The main purposes of general schemata, according to Pinker, are to allow entities never before encountered (a new graph type) to be recognized as belonging to a particular category (a kind of graph) and to provide an initial structure that can be modified and added to in order to develop a specific schema for understanding this new entity. The hierarchical structure of Marr's 3-D model representation (described in Chapter 2) allows us to recognize categories without recognizing individuals because information about arrangement of parts of one size is segregated from information about internal organization of those parts. This same ability at a higher level of processing is what Pinker seems to be suggesting with his general schema. The notion of a general graph schema translates easily to the context of maps. In Figure 4.15, the main attributes of Pinker's general graph schema are listed along with the corresponding attributes that I would propose for a general map schema.  

Pinker's propositionally based schema for graph understanding explains many facets of how graph readers can link their knowledge with sensory input to interpret this abstract form of representation. Many of the key relations specified in Pinker's graph schema, however, are spatial. The kinds of spatial relationships Pinker encodes in propositional form (e.g., relative height, proximity, etc.) are just the kinds of relations that Lakoff argues are more logically represented via image schemata. In dis-
cussing where graph schemata come from, in fact, Pinker presents what might be interpreted as a strong case for image schemata as the core feature of his graph schema. He cites Lakoff and Johnson's (1980) work when he states that "a great many abstract concepts seem to be mentally represented by structures originally dedicated to the representation of space and the movement of objects within it, a phenomena that manifests itself in language in many ways. ... In particular, abstract quantities seem to be treated mentally as if they were locations on a spatially extended scale" (Pinker 1990, pp. 105-107). It is to this issue of the indispensability of space and the potential role of image schemata that we now turn our attention.

Image Schemata

Lakoff (1987) suggests that image schemata provide a format for encoding information from vision and language simultaneously. If Lakoff (1987, p. 440) is correct when he says, "I believe that they [image schemata] structure our perceptions and that their structure is made use of in reasoning," image schemata must occupy a more fundamental level than propositional schemata in how we interact with concrete visual representations such as maps. This perspective is complemented by John Allman's contention that the brain extracts information from a noisy environment "by making maps that accentuate the useful information" (quoted in Hall, 1992, p. 16). He goes on to suggest that these maplike structures are not only generated by the brain, but retained in the neocortex for repeated use. Thus, there seems to be not only a functional-evolutionary argument for image schemata, but a neurophysiological one as well.

Our capacity for basic-level Gestalt perception is at the core of our everyday interaction with the world. Lakoff (1987, p. 270) asserts that research on basic-level categorization demonstrates that our experience is preconsciously structured at the basic level and that "basic-level concepts correspond to that preconceptual structure and are understood directly in terms of it." Basic-level preconceptual structures arise due to our capabilities for dealing with part–whole structure in real-world objects via Gestalt perception, motor movement, and the formation of mental images. Complementary to basic-level preconceptual structures, Lakoff (1987) hypothesizes preconceptual image-schematic structures that can be independent of any concepts. Johnson (1987) makes a strong case for embodied kinesthetic image schemata as the basis of this alternative preconceptual structuring, and Lakoff (1987) elaborates upon this contention. He points out that the logic of image schemata can be represent-
ed in formal logic using predicate calculus notation, but the flaw in doing so is that this formalism produces a set of meaning postulates composed of symbols having no inherent meaning but which would be "given meaning" by the set theoretic models they are specified in. According to Lakoff, however, image schemata are inherently meaningful. Lakoff's point seems to be that some concepts that can be described with abstract propositionally based formalisms emanate from inherently meaningful schemata or relations that derive their meaning directly from human experience with the environment—what he and Johnson refer to as "embodied image schema."

Lakoff (1987) identifies a container schema as one of the best examples of an embodied image schema. The schema consists of a boundary distinguishing interior from exterior; these distinctions can be understood directly in relation to our own bodies which take in air and breath it out, ingest food and excrete, and so on. The container schema is applied to a vast array of experiences in both a literal and a metaphorical sense. Johnson (1987), for example, cites 21 cases in which an in–out schema plays a role in the first few minutes of a typical person's day (e.g., waking out of a deep sleep, going out of the bedroom into the bath, taking the toothpaste out of the medicine cabinet and putting the toothbrush into your mouth, etc.). Lakoff goes on to describe how the container schema is transferred metaphorically to a variety of contexts. Among the metaphorical translations relevant to maps is the understanding of the visual field in terms of a container with things coming into and going out of view. Beyond this, the container schema plays a direct role in many aspects of mapping: most maps include bounded areas that define an inside and an outside (e.g., lakes, forests, counties, environmental impact zones), individual symbols are interpreted as being in or out of particular regions, and so on.

While these are all fairly literal applications of the container schema, it is also applied in a metaphorical sense to all information depicted on a map. A given population density or soil type, for example, is considered either in or out of a particular map category. The fact that such map categories are prototypic rather than classical categories has been recently recognized by those concerned with visualizing data quality (e.g., Fisher, 1994; MacEachren, 1992b). In an effort to communicate the probabilistic nature of being in a soils category and typicality effects within these categories, Fisher (1994) has devised a dynamic soils map that directly depicts the ambiguity of the categories. On this map, individual cells or pixels are shown as in a category (by having a particular hue) for lengths of time proportional to the likelihood that the categorization is correct. Such a dynamic display seems more effective than written documentation of category ambiguity in overcoming the inflexible in–out container schema that we normally bring to interpretation of map categories.

Kinesthetic image schemata are distinguished by Lakoff (1987) from context-bound specific conscious effortful rich images of the sort investigated by psychologists (Kosslyn, 1980; Shepard and Cooper, 1982) and cartographers (Steinke and Lloyd, 1983; MacEachren, 1992a). Instead of representing particular objects, kinesthetic image schemata are models or prototypes dealing with fundamental spatial relations (in-out, up-down, etc.). Like other schemata described here, kinesthetic image schemata can be considered interfaces for matching sensory input to knowledge representations or for structuring thought processes that make use of information retrieved from knowledge representations. Conscious mental images of the sort studied by most cartographers thus far are specific instantiations of a cognitive representation in working memory, consciously generated to solve a particular task. It could be hypothesized, however, that mental images of the sort that can be consciously scanned or rotated rely upon a complex of schemata to generate them from propositional, analog, and procedural representations, with kinesthetic image schemata likely to dominate. In addition, image schemata seem to derive from repeated use of a particular imagistic structure. Over time with repeated use, therefore, we might expect experts to transform context bound rich images into image schemata. In addition to this conversion of mental images to image schemata through repeated use, Kosslyn and Koenig (1992) contend that we often used imagery directly as an aid in symbolic reasoning. In this case, Kosslyn and Koenig contend that reasoning makes use of a mapping of nonspatial problems onto an image (e.g., locating your assessment of people's intelligence along an imagined yardstick). This "mapping" of nonspatial concepts to a spatial framework seems analogous to Lakoff's ideas about metaphorical transfer of spatial relationships into nonspatial situations.

Beyond the container schema, Lakoff (1987) details a number of common image schemata that he contends operate at a preconceptual level as structuring devices for processing sensory input as well as for general processes of reasoning. Among these are part–whole, link, center–periphery, source–path–goal, and linear order schemata. All of these schemata seem to have direct application to maps. The link schema, for example, is based on the fact that human interaction is structured via physical and metaphorical links (from the umbilical cord and holding a parent's hand to establishing social ties or a desire for freedom because we object to being tied down). On maps, physical links between places are depicted with symbols representing highways, air routes, and so on, and metaphorical links extend these basic symbol conventions to flow maps depicting topics such as fiscal transfers or fishnet plots of AIDS incidence (that suggest
a continuous surface linking isolated locations where the disease is present. Any locations on a map with a continuous symbol stretching out between them are assumed to be linked in some way.

The linear order schema suggested by Lakoff (1987) is particularly important in relation to how people grapple with abstractions of space, such as occur with strip travel maps (Figure 4.16). In this case, the map is reinterpreted from the prototypical map schema in which two-dimensional map space represents two-dimensional environmental space. With a strip map, the map space represents a linear sequence or order of decision points along a route between an origin and a destination. An even more abstract metaphorical extension of the linear order schema occurs for quantities depicted on maps. Quantitative information is interpreted as ordered and cartographers attempt to use a variety of graphic means to prompt viewers to recognize the order (to prompt them to apply a linear order schema). Legends on graduated circle and choropleth maps, for example, appear as isolated object groups in which the categories are arrayed in numerical order and symbols are assigned in what is expected to be an intuitively logical order (e.g., by size or value as found in Figure 3.38). A common objection by cartographers to maps of quantities produced by noncartographers is that these maps often ignore the importance of the linear order schema and employ a sort of eye-catching (but randomly ordered) hues. Sometimes the hues are ordered, but according to wavelength of the hue. Wavelength ordering is not immediately recognized by our visual system, and therefore is unlikely to prompt the appropriate linear order schema on the part of the viewer.

Many of the image schemata identified by Lakoff (1987) seem to underlie propositional schemata. For example, container schemata are the basis of both classical and common notions of conceptual categories. The prototype theory of categorization presented in this chapter, however, does not “map” to container schema perfectly.

At least one image schema, the source-path-goal schema, may underlie what are identified below as event schemata. The source-path-goal schema is based on the fact that whenever we move anywhere, there is a starting location (a source), a destination (the goal), and a sequence of contiguous locations that we traverse in achieving the destination. The strip map illustrated above is one of the most obvious cartographic examples of a map designed to match this schema. In keeping with Lakoff’s view that image schema are embodied, a more appropriate label for the underlying schema might be origin-path-destination. The source-path-goal schema is actually the metaphorical extension of this basic spatial movement schema to purposes of any kind.

All of the image schemata described by Lakoff are thought to be based on a structuring of bodily experience preconceptually. These embodied structures have a basic logic and they “motivate metaphors that map logic into abstract domains” (Lakoff, 1987, p. 278). This ability to map image-schematic structures (which are taken to be inherently meaningful) into abstract domains is, according to Lakoff, at the root of human conceptualizing capacities. He goes as far as contending that, “image schemata define most of what we commonly mean by the term ‘structure’ when we talk about abstract domains” (1987, p. 283).

Of direct relevance to cartography and to geographic visualization is Lakoff’s contention that much of our technology is aimed at facilitating this mapping of embodied schemata into abstract domains in order to make those abstract domains seem more like the environment we are used to interacting with (e.g., through the use of tools that can enlarge or reduce objects to human dimensions or can depict nonspatial relationships in terms of familiar spaces).

Elaborating on the role of image schemata in human reasoning abilities, Lakoff (1987, p. 283) offers what he terms a spatialization of form hypothesis. This hypothesis includes the following points:

- Categories (in general) are understood in terms of container schemata.
- Hierarchical structure is understood in terms of part-whole schemata and up-down schemata.
- Relational structure is understood in terms of link schemata.
- Radial structure in categories is understood in terms of center-periphery schemata.
- Foreground-background structure is understood in terms of front-back schemata.
- Linear quantity scales are understood in terms of up-down schemata and linear order schemata.

Overall, then, image schemata, in addition to having directly understood structures of their own, are used metaphorically to structure most abstract concepts. As indicated above, for example, image schemata probably form the basis for our apparent ability to consciously form con-
text-bound rich mental images. Such image-schemata-based mental images seem to underlie some aspects of wayfinding, scientific problem solving, and other endeavors in which geographic space must be conceptualized or for which space serves as a convenient media within which to grapple with abstract concepts.

Lakoff (1987) contends that science has come to rely on tools that extend basic-level perception in ways that allow image schemata to be applied in the manner detailed in his spatialization of form hypothesis. Technology provides “ways of extending basic-level categorization by extending the means for gestalt perception and for the manipulation of objects” (Lakoff, 1987, p. 302). Extensions of basic-level perception and manipulation “makes us confident that science provides us with real knowledge” (Lakoff, 1987, p. 298). This may be one explanation for the early development of maps in the history of civilization and the important role they have played (and continue to play) in attempts to understand the environment. It may also explain why recent advances in computer graphics that made Scientific Visualization possible were so rapidly accepted as viable tools for doing science.

Lakoff cites chemistry’s use of plots from nuclear magnetic resonance (NMR) spectrometers to demonstrate how concrete representations of abstract concepts can be such complete metaphorical mappings of embodied schemata that they come to be treated as the phenomenon itself rather than a representation of it. The NMR spectrometer produces a spectrogram, in the form of a curve, to represent a substance. Chemists using NMR have come to accept the resulting curve as a property of the substance on a par with its crystal configuration and more revealing than the substance’s color. This extended basic-level perception has come to be regarded as primary data.

Maps are a means to extend basic-level perception to places too distant, too large, or too complex to be experienced directly. That maps functioning as an extension of basic-level perception are often also treated as primary data is one of the main arguments behind Harley’s (1989) call for “deconstructing the map” (an issue to be dealt with more directly in Chapters 7 and 10). Essentially, his argument is that cartographers have (perhaps unconsciously) conspired to present maps as a direct window on the world rather than a highly processed representation of selected aspects of it.

Event Schemata (Scripts and Plans)

As we made a case above for distinguishing procedural representations from both propositional and analog representations, it is useful to consider event schemata as a separate category. In practice (when reading a map or walking from home to work) it is likely that we employ multiple schemata to build hierarchical structures for interfacing between “the world out there” and our various kinds of cognitive representation. Following from the contentions that schemata are hierarchically organized and different kinds of schemata can link in complex ways within the hierarchies, it is probable that event schemata include sub-schemata of image or propositional form. The point of describing event schemata separately is that they are schemata with separate goals and with primary links to a different kind of knowledge representation. In contrast to propositional schemata (which, as described here, structure knowledge about objects, concepts, and categories) and image schemata (that deal exclusively with fundamental spatial relationships), event schemata are structures that place primary emphasis on time, sequence, and process. In understanding the role of the three kinds of schemata proposed here, an analogy to spatial databases is helpful. In spatial-database terms, we would associate propositional schemata with database attributes, image schemata with specification of location in space, and event schemata with specification of location in time. While both propositional and image schemata seem to have a role in all map understanding, application of event schemata to map understanding is probably limited to maps that depict dynamic processes, maps used to initiate or guide a process (e.g., wayfinding), or maps that use dynamic symbols or interaction as a tool to reveal features and relations in the data.

Among the first to direct attention to what I have labeled event schemata were Schank and Abelson (1977) with their concept of scripts. Like other schemata, scripts are structures that include variables (slots, parameters, or placeholders for categories of things), requirements about what can fill the variables, and relations among them. In Schank and Abelson’s formulations, a distinction is made between variables that must be filled by people (called roles) and those filled by objects (called props). When we consider the propensity of humans for metaphor, however, this distinction is quickly blurred. In abstract conceptualizations, objects are often assigned characteristics of humans and could fill a “role” rather than a “prop” position in a script. For example, consider a forest-succession simulation and the “role” of a non-native tree species introduced in a forest as it gradually transforms the competitive balance of species and takes over most of the territory from a native species. With many map-reading situations for which event schemata are applicable, then, roles will be filled metaphorically by an element of the map theme.

Schank and Abelson (1977) direct their attention to scripts in a less abstract context: those that deal directly with human events. They focused particularly on describing potential scripts that might guide common kinds of social events. A restaurant script, for example, was devised to explain how the event of going to a restaurant might be structured.
The script includes props (e.g., table, food, bill, etc.), roles (customer, waiter, cook, etc.), entry conditions (a hungry customer with money), and results (a transfer of money and cessation of hunger). As we might find with a script for a play, Schank and Abelson’s scripts are divided into scenes that represent sequences of linked events (entering the restaurant, ordering, eating, and exiting).

A key point that Schank and Abelson (1977) make about scripts is that the structure of a script is an interconnected whole with the contents of any variable affecting all others. In addition to being a whole (or a gestalt), scripts are considered to be stylized or stereotypes representing a sequence of actions defining some well-known situation. As with other schemata, then, scripts will have approximate fits to particular events and the script applied will be the one that has the highest goodness-of-fit to the situation. One of the advantages (and sometimes disadvantages) of scripts (or event schemata) serving as prototypic models of events is that certain variables and actions will be assumed even when sensory input does not indicate them directly (or instantiate them in the schemata). For example, a script to handle driving an automobile will include the role of a driver for any other automobile on the highway and assumptions about the driver’s behavior. The script’s assumptions would probably include an expectation that both the individual with the script and all other drivers (using similar scripts) will stop at stop signs. This commonly held script allows traffic to flow in an efficient manner down through streets having no stop signs, but can lead to accidents when an unlicensed teenager takes a car for a joyride and ignores the script (or uses an alternative based on other assumptions).

While the standard driving schema (and potential flaws in it) may inform efforts to create real-time cartographic navigation aids, it is in more abstract domains that event schemata are likely to be most important in cartography. On an animated weather map, for example, change in location of the jet stream shortly before initiation of a midlatitude cyclone will probably be interpreted in cause-and-effect terms. This interpretation is likely because standard event schemata probably include an assumption that the order of scenes in an event corresponds to an underlying process. In this case, the schema is likely to lead to a reasonable conclusion, but often it will not.

There are at least two kinds of cartographic applications where event schemata have a potential role. The most obvious, perhaps, is in relation to interpretation of maps that depict dynamic events. Szegö (1987) has provided an elaborate account of temporal cartographic events and the key features of these events that we attempt to map. He structures his analysis around a theater metaphor with stage = geographic setting, play = spatiotemporal event, and actors = objects of the map theme. Beyond consideration of how dynamic events are depicted on maps, however, attention to event schemata is relevant cartographically in relation to human-map interaction with virtual maps and hypertext/hypergraphic environments. Monmonier (1989b) has borrowed directly from Schank and Abelson (1977) in an attempt to develop prototypic scripts for narratives that lead a viewer through an exploration of data—what Monmonier calls an Atlas Tour. Both Szegö and Monmonier’s work will be considered in more detail in Chapter 6 when we look at how formalized cartographic systems for structuring maps can be matched to human perceptual-cognitive structuring systems.

**DEVELOPMENT AND APPLICATION OF COGNITIVE MAP SCHEMATA**

As noted in Chapter 2, cartographers have directed only limited attention to the concept of knowledge schemata and how they may serve to mediate between sensory input and long-term knowledge representations. Therefore, the ideas presented below are speculative with a view to identifying the questions we should pose rather than to supplying answers. The appeal of exploiting the concept of map schemata is that the approach offers a way to bring together ideas about perception of map symbols, cognitive processing of map-derived information, and the roles of knowledge, experience, practice, and training on the part of map readers. I conclude our look at “How Meaning Is Derived from Maps,” then, with a brief consideration of how map schemata might develop, how a particular map schema is selected to match individual map-reading situations, and how map schemata may be used.

It would be impossible to delineate all potential sources and uses of map schemata. This section will instead focus on a prototypic case: schemata for interpreting arithmetic representations of terrain. Terrain representation provides a good example of how map schemata might work because the representational techniques devised for terrain depiction have been adapted (through metaphorical extension) to so many topics (from atmospheric chemical concentrations, to population density, to neurophysiology of the brain, to molecular structure, to abstract mathematical concepts).

**How Map Schemata Are Developed**

It is Lakoff’s (1987) belief, and I share it, that human abilities to understand and conceptualize about the world around us (including the ability
Physiological Bases for Map Schemata

One potential physiological basis for a map schema can be found in the advance and retreat theory mentioned in the introduction to this section. Cartographers advocating a red-to-blue range of color for elevation maps have argued that this color sequence matches the prediction that long wavelength reds will advance toward a viewer while short wavelength blues will retreat away. If this neurophysiological response does occur, we might expect an image schema to have evolved that makes use of it. If such a red = near–blue = far image schema does exist, adapting it to the map-specific case would be quite easy.

A related potential physiological source for image schemata that may be incorporated in map schemata can be found in opponent process theory for color vision. Eastman (1986) (as noted in Chapter 3) speculates that opponent processes of color might lead to tendencies to see certain color combinations as ordered mixtures of two variables (what he called balance scales) with others seen as bipolar scales. This speculation suggests two possible extensions of linear order schemata, one a metaphorical extension to ordered mixtures, the other a more direct application to order in two directions (as locations along two paths from the same physical place might be ordered). An alternative schema that could underlie bipolar scales is a front–back schema, which deals directly with position in two directions from some central point. The fact that Eastman's hypotheses about opponent color processes was at least partly confirmed in empirical testing implies one of two possibilities. The first is that Eastman's subjects did have image (or propositional) schemata that linked the physiology underlying opponent process theory to a front–back order schema. Alternatively, repeated exposure to the kinds of color combinations used may have produced the more specific map schema that specifies these relationships as a default when an area fill map is encountered. In either case, Eastman's finding that value differences dominated a hue sequence supports a contention that a light–dark schema is more likely to exist.

In addition to explaining aspects of hue perception, OPT takes into account the presence of light–dark opponent cells. Our eyes are, in fact, dominated by cells that react only to light–dark differences. This physiological propensity to recognize light versus dark (and a range of grays in between) combines in our everyday lives with experiencing a daily order from dark to light to dark. The light–dark schema implied may, of course, itself be derived from the more general linear order schema. Evidence for metaphorical extension of the light–dark image schema to maps is relatively strong, with Cuff's (1973) and Gilmartin and Shelton's (1989) findings that value ranges suggest an order even when no legend is provided. Whether application of the light–dark schema to quantitative maps is preconceived or conscious is not clear at this point. Only in cases where the map's background is intermediate to the light–dark range, however, is a light–dark schema not consistently applied (McGranaghan, 1989).

The potential sources of schemata noted above are just a sample of those that are possible. In relation to use of layer tints on terrain maps, we have at least three (but probably many more) potential physiologically based image schemata that might be applied separately or in combination. A color range crossing a unique color might activate a linear order image schema extending in two directions from the perceptually unique color in the center of the range (which might be used to indicate sea level); a color range from red to blue might activate a front–back image schema (which could be used, as many cartographers have, to indicate mountains to valleys); and a value range might activate both a linear order image schema and a more = up image schema (with the value range "mapped" to the elevation range and more ink mapped to more elevation). Evidence seems to suggest that a value range is most consistent in prompting application of the appropriate image schema.

Developmental Bases for Map Schemata

There are several developmental issues that underlie the ability to generate the kind of general map schema described above. First, an individual must grasp the idea that a two-dimensional graphic display can stand for
some portion of the world, what Downs et al. (1988) term a holistic stand-for relationship. The holistic stand-for relationship requires, at a general level, an ability to achieve metaphorical mappings between domains (the environment and the map). This ability seems to be achieved between 3 and 6 years of age. In an empirical examination of what constitutes a map, Downs et al. (1988) found that children of kindergarten age and older recognized certain prototypic maps as place representations, but that younger children frequently misidentified some maps as object representations of various kinds (e.g., a Washington, DC, tourist map was seen as a cage or spaceship by some children). This inconsistency indicates that even when an ability to grasp holistic stand-for relationships is achieved by children, appropriate cues must be present in a particular display before a map schema is selected by the child as the appropriate vehicle for understanding. The ability to recognize certain objects in a display as map cues appears to develop with age and probably relates to the second category of stand-for relationships cited by Downs et al. (1988), componential stand-for relationships. A conception of these relationships is required to recognize map symbols as something other than what they appear.

Beyond stand-for relationships, general and specific map schemata depend upon the development of image schemata and metaphorical mappings that deal with space in a variety of ways. To cope with plan views, an individual must be able to mentally project themselves to a vantage point and understand space in a Euclidean sense such that distance and direction can be inferred from relative position. In addition, to deal with geographic hierarchy, the individual must have developed container, linear order, up-down, and part-whole schemata, have the capacity to metaphorically extend these schemata to abstract situations, and have the ability to relate them to one another in an integrated structure. Based on most theories of development, all of the above abilities evolve gradually. We can, therefore, expect that children have quite different map schemata than do adults and that their map schemata will be continually adapting as their ability to cope with space, scale, and representation increases.

The prototypic map, for both children and adults, seems to be a plan view of relatively small scale—for example, a political map of the world showing countries as bounded places identified by varying colored fills (Downs and Liben, 1987). Thus, if we assume that it matches the prototype reasonably well and that it allows maps to be understood rather than misunderstood, the general map schema must include an expectation of a plan view and transformations that allow the world to be split open and flattened (in terms of both sphere to plane and 3-D to 2-D). It is, of course, possible that these elements are absent from some individuals'

map schemata. When they are missing, we would expect that individual to make some characteristic misinterpretations of the map (e.g., assuming that the distance from the United States to Japan is much farther than it really is because, on a Euro-centered world map, they are at opposite ends of the world). That young children accept a world map as prototypic of maps does not, of course, prove that they have a map schema that includes a full understanding of plan views and map projection. It seems, on the basis of developmental theory, that the ability to incorporate these ideas in a general map schema must wait until the child develops projective and Euclidean spatial concepts, an ability that preoperational children do not have and one that develops only gradually with topological spatial concepts coming first. Children without projective and Euclidean spatial concepts who recognize a world political map as a typical map must do so through application of a very different general map schema than that assumed to operate for adults.

Developing projective spatial concepts are suggested by Wood (1977) to underlie the gradual evolution of children's depiction of topographic relief. His investigation offers support for the notion that as children progress toward adulthood, an ability develops to deal with projective spatial concepts and that this ability allows for inclusion of plan views as a basic feature of the developing map schema. Downs and Liben (1987), however, provide a variety of evidence to indicate that even many college students do not have all of the spatial abilities that Piagetian theory suggests they should have. In particular, projective spatial concepts are not universally developed. If projective spatial concepts underlie the inclusion of plan views as a component of general map schemata (as hypothesized here), we must assume that many young adults will be unable to make use of maps effectively.

In addition to plan views, understanding of geographic hierarchy is critical to a fully developed general map schema. Geographic hierarchy, according to Downs et al. (1988, p. 694), "refers to the structural arrangements of places which result from the recursive spatial partitioning of larger areal units into smaller ones, creating a series of nested spaces." To understand that objects can simultaneously exist as independent objects and be in another object clearly depends upon development of a container schema and the ability to map it into abstract domains. In addition, however, geographic hierarchy requires a part-whole schema, a linear order schema, and an up-down schema to recognize the part-whole relationships of embedded and superordinate regions and the ordering and dominance implied by the hierarchy. Piagetian theory contends that the operations of class inclusion (knowing that if A is in B, B cannot be in A) and transitivity (knowing that if A is in B and B is in C, then A is in C) are fundamental to comprehension of geographic hierarchy, and that
these operations do not emerge until children reach the concrete operational stage of development, at about 7 years (Downs et al., 1988). We should anticipate, then, that children in kindergarten and first grade will not include concepts of geographic hierarchy in their general map schema, and as a result will typically have trouble dealing with maps in which embedded geographic regions appear.

The conventional wisdom, derived from Piagetian theories of development, is that by the time children reach a level of formal operations (beginning at about age 12 and continuing through adolescence) all of the basic abilities described above should be present. From this perspective, then, we would assume that all adult map readers will have developed the same set of core image schemas and abilities to metaphorically and metonymically extend them to abstract domains. Differences among adults in map schemata should be due to different causes than differences between children and adults (e.g., the extent to which particular schemata are used on a routine basis or specific training in concepts underlying general or specific map schemata). As noted above, however, conventional wisdom might be wrong. There may be a segment of college-age people who have not yet achieved full development of projective spatial concepts.

**General-to-Specific Map Schemata**

I propose that humans possess a general map schema comparable to the general graph schema hypothesized by Pinker. Such a schema would draw upon noncartographic schemata derived for and from everyday experience. A general map schema is, in fact, more likely for most humans than a general graph schema because, as Hall (1992, p. 17) points out, “geography is essential to survival—to finding food, to migration, to reproduction and nurturing” and mapping behaviors have been evident in all cultures for the past two millennia. Wood (1992) contends that even cultures that do not make many tangible maps exhibit active mapping behavior. General map schemata will also be closer to real-world experience than graph schemata are because map schemata rely upon space to represent space.

A general map schema, as I envision it, must include at least the following principles (which extend upon those outlined in Figure 4.15): (1) position on a map is linked to position in space via some coordinate system; (2) the map space represents a geographic space within some size range (probably city to globe); (3) the space depicted is continuous and hierarchically structured such that features within the bounds of an area on the map are within that area in the world, features adjacent on the map are adjacent in the world, features connected on the map are connected in the world, and relative distances are consistent throughout the space; (4) point, line, area (and maybe volume) objects exist in this space and are represented in the schema as generic point, line, area, or volume variables or slots; (5) graphic primitives linked to these variables represent the category of point, line, area, or volume object; (6) relationships exist among the graphic primitives such that locations whose symbols look alike are expected to be alike in some recognizable way, locations that look different are expected to be different, and graphic primitive differences are expected to be meaningfully related to actual differences (e.g., differences can be in kind or in order/amount); and (7) scale of map marks (objects + graphic primitives) is independent of the scale at which the geographic space is depicted.

A subordinate schema that might be termed a general notational schema underlies (or is embedded within) the last two features of the map schema as defined here. This notational schema is derived from Kosslyn's (1989) interpretation of Goodman's (1976) theory of symbols. The notational schema makes use of a container schema at two levels, that of the symbols and of the phenomenon, what Kosslyn identifies as the syntactic and the semantic requirements of notational systems. The two syntactic requirements are that a given map mark (an object + graphic primitive combination) should map into only one symbol category and that discriminable differences will exist between these map marks such that it is possible to decide into which symbol category that map mark falls. At the semantic level, the notational schema includes the rule that each symbol category will map into one and only one phenomenon category (what Goodman called “a compliance class” and Kosslyn termed the “referent”) and that it will be possible to identify the phenomenon category into which each symbol category should be placed.21

The general map schema (and notational subschema) outlined is presumed to be held in varying levels of detail by most adults. It requires an ability to understand both holistic and componential stand-for relationships—an ability that, as Downs et. al. (1988) point out, develops gradually in children. Particularly below the second- or third-grade level, then, children are anticipated to hold a very different general map schema if they have one at all. An initial general map schema for a preoperational child, for example, might be “lines on a flat surface” with lines seen as defining the shape of objects on an unspecified surface (or areas to be colored with a crayon).

For adults, specific map schemata can be develop by using a general map schema to recognize that the object of interest is a map, then to note those features that do not match or are missing from the general schema. Developing a specific map schema, then, will be a process of modifying,
expanding, and filling in the details of the general schema (or possibly modifying another specific schema that is a reasonable but not perfect fit to the situation at hand). This process can be achieved by being told how, observing map use and inferring how, applying other schemata from related domains that seem appropriate to the situation (e.g., red on washroom faucets means hot and blue means cold; therefore red on a climate map indicates hot and blue indicates cold), or simply by trial and error (e.g., assuming that a blue line on a highway map is a connecting link between two towns and that this link is a road—until it proves to be a river at which point "rivers are blue" might be added to the schema).

Certain specific map schemata—for reading an area cartogram or an isochrone map—require metaphorical mapping of spatial aspects of the general schema into an abstract domain. For a map that depicts categorization uncertainty directly, on the other hand, the general notational schema described above would need to be modified to include the possibility of fuzzy assignment of symbolic categories to phenomenon categories (see the discussion of visualizing uncertainty in Chapter 10).

While most adults probably have a general map schema including at least some of the components cited above, most will have only a few specific map schemata (perhaps for road maps, weather maps, and geopolitical [atlas] maps). Schemata for understanding less common map forms are likely to be accumulated only by experts in some field that makes use of those map types on a routine basis (e.g., geologists develop a geologic map schema that allows them to interpret individual symbols as well as complex color and pattern combinations in an automatic or nearly automatic way, seismic sounding map schema that allows them to translate contours into a three-dimensional image of the density of subsurface layers, etc.). The point is that although they may be based on basic-level categories and/or image schemata (some of which may be innate), specific schemata are learned. Cartographers need to consider the fact that not all potential map users will have the appropriate schema with which to interpret a particular category of map. As a result, attention to training geared toward developing appropriate schemata may lead to more significant improvements in how maps work than our more frequent attempts to improve the maps.

Chang et al. (1985) examined the differences in strategies used by experts and novices for interpretation of topographic maps. They point out that "a common method of teaching topographic map reading is through illustrations of contour patterns made by specific landform features. The idea is that, when map readers become familiar with those contour patterns, the process of map reading would be just a matter of detection and identification" (Chang et al., 1985, p. 88). This suggests a procedure in which there is development of prototypes for landform categories together with a structuring of relations among these prototypes to form a schema. This schema can be used to guide map examination and the categorization of what is encountered. Chang et al. (1985) go on to draw an analogy between schemata that are used to guide map interpretation and patterns stored by chess experts and used to guide decision making concerning potential moves. The authors speculate that the ability to form the initial patterns is related to general abilities for pattern recognition. A study by McGuigan (1957) is cited in which contour interpretation ability was found to be highly correlated with general pattern recognition aptitude.

To make some of the ideas presented about schemata more concrete in relation to map understanding, 1 describe an idealized specific map schema for layer tint terrain map understanding—referred to for convenience as the hypsometric map schema.22 The schema builds from the general map schema described above to include categories and relationships necessary to deal with both the abstract features of this particular map symbolization and with the nature of the phenomenon underlying the symbolization. At the level of the phenomenon, the schema turns into account the three-dimensional nature of terrain by including extensions of up-down image schema to directly indicate height above a base level. In addition, a source-path-goal schema is used to deal with the potentially circuitous route needed to travel between places while avoiding major terrain features. In relation to the symbolization method itself, linear order and light-dark schemata are linked to the up-down schema in order to map the value range onto the elevation range. In addition, a center-periphery schema will be invoked to interpret closed contours and their indication of a peak or pit at the center of an area with gradually differing elevations.

One of the notable points about the hypsometric map schema suggested is that it makes fairly direct use of several of the kinesthetic image schemata that Lakoff identified as preconceptual embodied schemata, and it does so with only modest metaphorical extension of these concepts. The up = more schema, for example, is interpreted directly and the symbolization indicates it through a straightforward mapping of other image schemata onto the up-down schema. This interpretation has interesting implications for statistical maps of enumeration unit data. A shaded isopleth map, for example, is a minor modification from a layer tint elevation map. In terms of schemata, the only difference is the acceptance of a metaphorical extension of up-down and link schemata to abstract derived quantities (e.g., population density). For readers using the appropriate schema, then, isopleth maps may be remembered better than
choropleth maps, not, as I once suggested (MacEachren, 1982), because they are inherently simpler in a geometric sense, but because they are interpreted with an inherently simpler cognitive map schema.

As we move farther from general map schemata toward schemata for specific categories of maps, we can expect more complex mapping of embodied schemata into increasingly abstract domains. Schemata for specialized maps typically depend upon sophisticated domain knowledge that has become so ingrained that these schemata begin to take on properties of embodied image schemata. As with the chemists' use of NMR spectrometer plots cited above, map users can come to accept quite abstract symbolic representations as properties of the environment represented because they develop schemata (derived from embodied image schemata) that allow for preconceptual processing of what is seen.

How Map Schemata Are Selected

We can see in an illustration only what we know to look for (i.e., what the schema allows us to see). Cues in the sensory input will prompt a choice (or adaptation) of schemata having the highest goodness-of-fit. This choice can only be from among schemata held by the individual experiencing the sensory input and will be influenced by elements of the display that generates the visual array and subsequent visual description to which our visual system tries to find an appropriate match.

To some extent, the selection and possible modification of a schema to match sensory input will be an individualistic act. The knowledge that a person holds along with experience in dealing with a particular kind of sensory input will determine, in part, the choice of schema that a goodness-of-fit can be evaluated for. Lakoff (1987), however, argues that at the most fundamental level, humans share a common image-schematic structuring of bodily experience. This is essentially an argument that we all possess linear order, container, source–path–goal, and other basic image schemata and that these are the most likely schemata to be initially applied to sensory input. As our visual and cognitive system processes input, a series of increasingly more specific schemata will be applied and it is at this stage that significant differences among individuals in the schemata selected for a particular situation will arise.

Judging from anthropological research on differences in basic-level categories across cultures, we can expect both schema development and schemata matching (to particular sensory input) to be influenced by cultural as well as individual factors. The fact that different cultures divide color hues into a different number of named categories, for example, suggests that people from these cultures would bring different schemata to the act of map reading. A culture whose language includes only the distinction between light and dark, for example, is unlikely to find it easy to develop a schema to deal with a full-spectral, layer tint elevation map.

Beyond the cultural influences and individual limits on the store of schemata available, some evidence suggests that what might be called "global cognitive styles" can influence visual input–schemata matching. For example, an interesting difference in apparent schemata applied to dot maps was identified by Mc Cleary (1975) in his dot map regionalization experiment cited in Chapter 3 (although he does not discuss it in terms of schemata). Mc Cleary had subjects identify regions on dot maps by outlining groups of dots forming those regions. He noted two quite different approaches (i.e., cognitive styles), the identification of many small tight clusters of dots versus a few large general regions (see Figure 3.30). He labeled individuals following the two approaches atomists and generalists, respectively. In relation to issues of schemata, Mc Cleary's results could be interpreted as two different extensions of a container schema. In both cases, regions are viewed as areas in which elements are either in or out. The difference seems to be in how this container schema is adapted to the dot map context and how it interacts with Gestalt grouping principles. Atomists seem able to extend the container schema to situations in which a boundary between in and out is clearly defined by presence or absence of dots. Generalists, on the other hand, seem able to extend this image schema farther. They are able to see regions of similar dot density as units, with the container boundary identified as a change in dot density. Whether the atomist–generalist difference might be due to individual differences at a genetic or environmental level, or to broader cultural differences, is not clear. That these differences exist, however, is certain to influence the impact of interactive visualization tools for different users (see Part III).

No matter how individual or group differences might influence schemata selection, the schemata applied to a particular sensory input also depend upon how the information is presented to us and at what scale (Antes and Mann, 1984). It is these issues, of course, that are the most concern to cartographers because we have more control over how information is presented than over the schemata available to a reader.

Eastman's (1981) research on symbolic indications of map scale suggests that adults make assumptions about the abstractness of metaphorical mapping used that do not always match those intended by map authors. He found that detailed depictions of base information lead to assumptions that the map is at large scale with relatively unaggregated data. Generalized base information, on the other hand, suggests generalization of, or uncertainty about, the theme. Eastman proposes that we might take advantage of the tendency to assume a similarity in the ab-
strictness of metaphorical mapping throughout the map. By adopting this schema as a map design guideline, for example, we might help viewers grapple with scale change in dynamic interactive data exploration environments that computers are allowing us to create.

In addition to making use of likely schemata, we can also manipulate our map designs to act as a catalyst for specific schemata. There has been one particularly interesting investigation that addresses the issue of how we might prompt appropriate schemata for terrain map reading (although, again, the authors did not present their investigation in these terms). This experiment by DeLucia and Hiller (1982) focused on the role of legends in understanding layer tint elevation maps. Specifically, they devised what they termed a natural legend and evaluated it against a standard legend. With the standard legend, sample area fills are arrayed in labeled boxes next to the map. The natural legend, in contrast, depicted in a somewhat generalized form a section of the map in which all area fills were present (Figure 4.17). DeLucia and Hiller tested two groups of subjects on a series of map interpretation tasks selected to represent typical data acquisition and terrain visualization tasks. For the data acquisition tasks, their subjects performed slightly better with standard legends. For visualization, however, subjects with the natural legends had substantially better performance, leading the authors to conclude that their natural legend noticeably enhanced subjects’ ability to visualize a landscape.

In relation to schemata as interfaces between visual descriptions and knowledge representations, DeLucia and Hiller’s natural legends have one substantial advantage over the standard box legends. While the box legends can help invoke a linear order schema by arraying categories in order and an up = more schema by putting the symbol for the highest elevation at the top of a column of boxes, a natural legend adds a cue for link and center-periphery schemata as well. These additional schemata are necessary to understand a layer tint terrain map completely because it is essential to recognize that enclosed contours are peaks (or pits) at the center of a region that either rises (or falls) from this central point and that the elevation categories on the map are always linked in the order depicted by the legend (i.e., you cannot move from 100 feet to 300 feet without passing 200 feet). Link and center-periphery schemata would not be required in order to use the map effectively for comparing spot elevations, but would be necessary to accomplish visualization tasks such as determining intervisibility between locations. DeLucia and Hiller’s results are precisely what this application of schema theory would predict: there was no between-group difference in accuracy for spot height comparisons, but for terrain visualization tasks, the group using natural legends performed significantly better.

How Map Schemata Are Used

Although I do not share Pinker’s (1990) opinion that graph (or map) schemata will be exclusively propositional, I do agree with him that schemata (in whatever form they take) will be part of an iterative process of seeing, organizing, interpreting, and interrogating a visual description. The number of iterations required to extract particular information from a visual description will be a function of both the visual description itself and the appropriateness and completeness of the schemata brought to the viewing process.

In detailing his concept of a graph schema, Pinker considers some of the factors that may cause graph comprehension difficulty and how aspects of the graph schema predict these difficulties. In addition, he speculates on how idealized graph schemata can provide clues to training procedures that might reduce graph-reading difficulty in certain cases. He bases his argument on a Graph Difficulty Principle that he defines as follows (Pinker, 1990, p. 108): “A particular type of information will be harder to extract from a given graph to the extent that inferential
processes and top-down encoding processes, as opposed to conceptual message look-up, must be used." This is essentially the equivalent of Bertin's (1983) distinction between maps to be seen and maps to be read. A map to be seen allows immediate apprehension of particular relations, while a map to be read requires conscious data extraction.

Pinker argues that two factors will influence whether a particular kind of information will be present in a conceptual message on initial interaction with a graph. The information can only be present if “the visual system encodes a single visual predicate that corresponds to the quantitative information” (1990, p. 108). Complementary to this low-level perceptual control on what information makes it into the visual description and becomes available to be matched with a graph schema, is the encoding likelihood that particular predicates will be attached to the graph schema. Those patterns that are highly practiced (or that the reader is prompted to look for) are more likely to be specified in the graph schema, and are therefore more easily extracted from the scene. Together, these two factors allow a prediction that certain graphic constructions will be recognized in an almost effortless way, without the need for top-down queries to prompt the visual system to extract more details.

To support his contentions, Pinker (1990) cites his own empirical work and that by Simcox (1983) related to interpretation of bar graphs, line graphs, and a novel graph form (using length and angular change of linked line segments). Simcox examined the hypothesis that line graphs facilitate encoding of overall trend information while bar graphs facilitate encoding of individual magnitudes or comparisons between magnitudes. Simcox found, in a sorting experiment, that height of individual bars (in a pair) could be selectivity attended to regardless of slope between the two bars. Slope between the bars, however, could not be attended to without interference from relative bar height. For lines, the opposite was true. Sorting by height of a line segment endpoint was slowed by variation in height of the other endpoint, but sorting by slope of the segment was not affected by the overall height of the line. This difference at the level of perceptual organization transferred to tasks in which subjects were asked to extract specific kinds of information from bar and line graphs. Subjects were faster at extracting slop information from line graphs than bar graphs, but faster at magnitude judgments with the bar graphs. The explanation for these results is that schemata for different graph types have different default encoding likelihoods for particular kinds of information.

Cleveland (1991) provides a simple, but dramatic, example that gives further support to this view. His example focuses on the issue of whether comparison of two data sets can be accomplished most efficiently using overlay of the two variables or through merging the data into a single depiction. In his example, the data are depicted with overlaid line graphs, making relative magnitude estimates for various points in the time series hard to judge (Figure 4.18). Pinker (1990) suggests that line graphs are ill-suited to extraction of specific values (or value comparisons between lines or between places on the line) because Gestalt grouping principles cause us to process each line as a whole unit. The schema used by the typical analyst interpreting these bivariate line graphs is missing a key constraint. To interpret the relationship between lines correctly, the schema must include the constraint that comparison is only valid perpendicular to the dependent variable (i.e., parallel to the Y-axis) (Figure 4.19). Using a bar graph instead of a line graph minimizes incorrect comparison because it emphasizes differences in the Y-direction, thus prompting the appropriate schema component. With a bar graph, however, the advantage for judging relative difference between variables is balanced against making the individual slopes hard to extract.

Pinker (1990, p. 121) summarizes the hypothesis that is the basis of his overall theory of graph understanding as follows: “Graphs will be easy to comprehend when the visual system naturally encodes the geometric features of the graph with visual predicates that stand in one-to-one correspondence (via the graph schema) with the conceptual message that the reader is seeking.” Graphic constructions seem to work well for par-

![Figure 4.18](image-url)  
**FIGURE 4.18.** Example of the difficulty of extracting relative value information from line graphs that depict two variables independently. On the top graph, the impression obtained by most viewers is that the two variables become quite similar by 1755 and remain so. If, however, we look at the plot of differences between the variables (bottom graph), it is apparent that the decrease in difference reverses itself about 1760, reaching a peak in 1762. After Cleveland (1991, Fig. 4). Adapted by permission of the author.
and least well from layer tints (that put emphasis on trend direction) seems to match Pinker’s results for tables compared to bar and line graphs. The reverse pattern for a visualization task (that focuses attention on slope and trends) also corresponds to Pinker’s graph results.

In extending his theory from quantitative graphs to qualitative charts and diagrams, Pinker (1990, pp. 122–123) contends that the ease with which charts will be processed will depend upon whether the visual system parses them into “important chunks of conceptual information.” This argument is similar to the one made by Eastman (1985b) in relation to how people learn maps information. Eastman examined the impact of various design changes on how information from a typical reference map was chunked in memory. He found that design differences did influence chunking, but had little effect on subsequent recall of information (see Figure 3.29). He did not, however, examine whether the variations in visual chunking of map information induced by design differences matches with any hypothesized map understanding schema or whether these chunking differences made it more or less easy for map readers to solve different categories of map use task (e.g., route planning vs. relative distance estimation vs. intervisibility estimates).

CONCLUSION

The processes and relationships underlying mental categories interact with knowledge schema complexes to allow humans to interpret the world. When dealing with a map or other graphic display, the human propensity to categorize and to apply knowledge structures to sort out what is seen leads to both the great advantages and (often hidden or overlooked) disadvantages of visual tools as a prompt to thinking.

Graphic displays can be designed to take advantage of human perceptual organization tendencies leading to nearly automatic identification of certain relationships via a mental structuring ability (defined here as schemata). This contention echoes that of a number of other writers who have examined why graphics are effective at communicating relationships and prompting visual thinking. Larkin and Simon’s (1987, p. 92), for example, propose that “diagrams and the human visual system provide, at essentially zero cost, all the inferences we have called ‘perceptual.’” Bertin (1967/1983), in relation to diagrams, networks, and maps, contends that there are specific uses of his set of graphic variables that are immediately apparent to viewers. He distinguishes between maps to be seen and maps to be read. The distinction translates to a difference in viewing efficiency, or the mental cost that the viewer must expend to extract information, with maps to be seen extracting a low cost and maps to
be read a high cost. Bertin has gone as far as to devise what he terms “standard schemata” to guide the information designer in producing efficient graphics.

Merging Pinker’s and Bertin’s perspectives would lead to the hypothesis that information displays will be most effective when the information designer uses a logical schema to organize the display and the viewer employs an identical schema when viewing the display. Improvements in information design (for maps and/or other graphics) could be expected to result through user training in the schemata employed by information designers and by information designers developing design schemata that match the general schemata of potential viewers in intuitive ways so that they find it easy to adapt their general schemata to the particular case at hand. In Part III of this book these issues will be addressed from the perspective of the cartographic information designer faced with questions of design for interactive geographic visualization. Before doing so, however, Part II will focus specifically on the rule structures (schemata) of information designers from the perspective of semiotics.

NOTES

1. Virtually everything on a map is a representation of a category, not of an individual entity. The categorization may be one imposed by the cartographer or by the context within which the map is being produced (e.g., industrial, residential, agricultural land use). Categorization may also simply be that imposed by language (e.g., tree, house, road, etc.).

2. Some of the most interesting critiques were never published. These involved reactions by cartographers to medical maps presented at the 1976 Workshop on Automated Cartography and Epidemiology and the 1980 Auto-Carto IV meeting (with its theme of Cartography and Computing: Applications in Health and Environment). In both cases, cartographers were adamant in condemning choropleth maps with quantile, equal interval, and arbitrary data classes, along with those in which raw totals were depicted.

3. Krygier (forthcoming) recounts an experience in which a client (a historian) objected to “optimal” data classification because it did not reveal the pattern that she “knew” was there.

4. To begin addressing the latter issue, we can look to evidence from psychological literature concerning the impact on mental categorization of interaction between characteristics of the scene and of the individual (Barsalou, 1983, 1985; Handel et al., 1980).

5. Jenks’s (1967) “data model” concept, as applied to choropleth maps, is founded upon this view of categories.

6. Rosch later backed away from the view that her research supported a theory of mental representation, emphasizing prototypes as “goodness judgments” people make about category membership (Rosch, 1978).

7. They use “theory” broadly to include both formal scientific models and common sense knowledge of how the world works—both of which can at times be wrong.

8. Within the category of maps, specification of large versus small scale, thematic versus reference, and so on, are also fuzzy categories.

9. Eco (1985a) presents a semiotic argument for culture as a major variable in colors that are actually defined by various groups.

10. Lakoff’s (1987) “motivation” can be considered analogous to Murphy and Medlin’s (1985) “theories.” Both provide explanations for the choice of criteria on which similarity is judged, and for which similarities are actually noticed.

11. In the terminology to be developed more fully in the next section, categorization of a display as a map is likely to bring various aspects of our cognitive map schemata to bear on interpretation of the display.

12. See Dobson (1973), Muller (1979), and Peterson (1979) for the debate.

13. Cartographers have frequently used the well known 7±2 limits of short-term memory to argue for a maximum of about six or seven classes on choropleth maps, regardless of where the curve levels out. This argument assumes, however, that for a person to remember a map pattern long enough to compare it to another, she must convert it to some kind of propositional representation. Research by Phillips (1983), Buddeley (1988), and others suggests that this conversion might be unnecessary. What a viewer sees on a map can be retained in the short-term visual store (or the visuospatial scratch pad) for which the 7±2 limits do not apply.

14. Philosophers Mark Rollins (1989) contends that although evidence for image storage as pictures may not exist, neither does evidence that images are not stored as pictures.


16. The use of the term “procedural” knowledge representation is somewhat broader in the context of spatial cognition/environmental psychology than in that of skill acquisition. In the latter, “procedural” is reserved for fully acquired skills in which knowledge of procedures reaches a level at which it can be accessed without conscious effort (see Anderson, 1982). From this perspective, simply knowing the sequence of steps required to accomplish a wayfinding task would be considered declarative knowledge. It would be considered procedural at the point where a person can negotiate a trip without paying direct attention to the route (as happens when someone travels the same route to work everyday).

17. The idea that a map itself is an ICM will be taken up in Part II, where we will consider how cartographers and cartographic practice provide maps with meaning.

18. Although Pinker does not discuss category theory, his view of dynamic active schemata that can adapt to new input and evolve with experience seems