(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

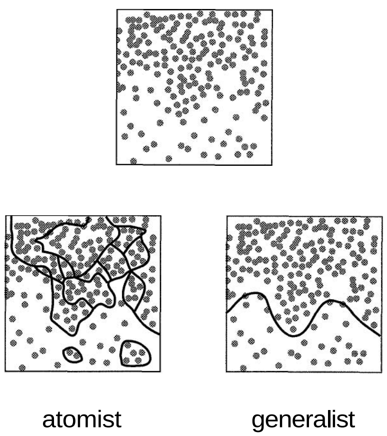

FIGURE 3.29. Sample subjects from McCleary's dot map regionalization experiment illustrating the grouping strategies of atomists (left) and generalists (right). *Reproduced from McCleary (1975, Fig. 4, p. 246).*

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

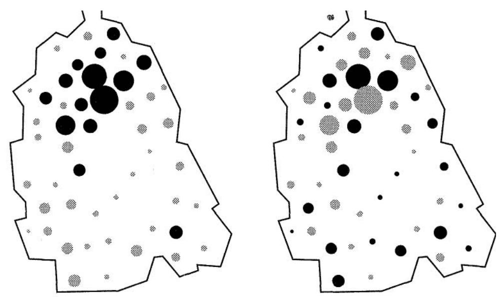

FIGURE 3.30. Similarity and proximity acting together to enhance grouping (left) and in opposition resulting in ambiguous grouping (right). *Derived from Slocum (1983, Fig. 9, no. 13, p. 71).*

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 satne 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 (196711983) 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 Attneave (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 V1 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.

Nothdurft (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 unsucessful regardless of magnitude of between-pattern orientation difference.

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

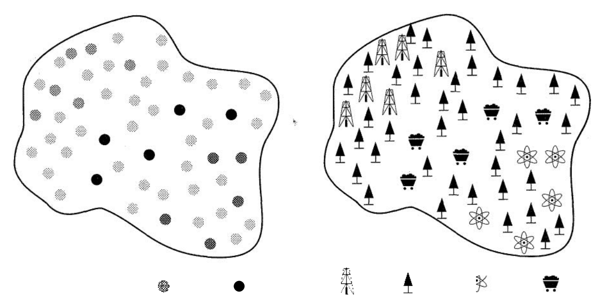

FIGURE 3.32. Value (right) seems to be selective while shape (left) is not

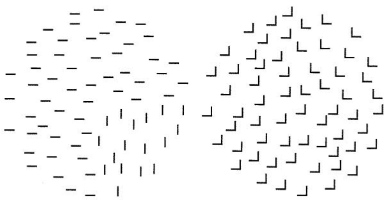

FIGURE 3.33. Differences in orienta. tion result in visual groups, but differences in alignment do not. *Derived from Bruce and Green (1990, Fig. 6.16, p. 117).*

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 orientation-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.[5] Evidence also exists to support Bertin's contention that shape is not selective, at least in the case of different shapes

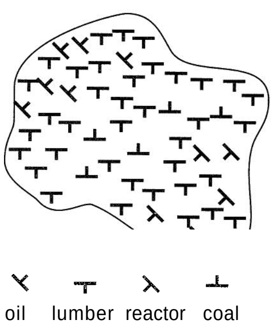

FIGURE 3.34. It appears that slope of parts rather than orientation of an overall shape must differ (in some cases) for orientation to be selective in Bertin's sense.

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

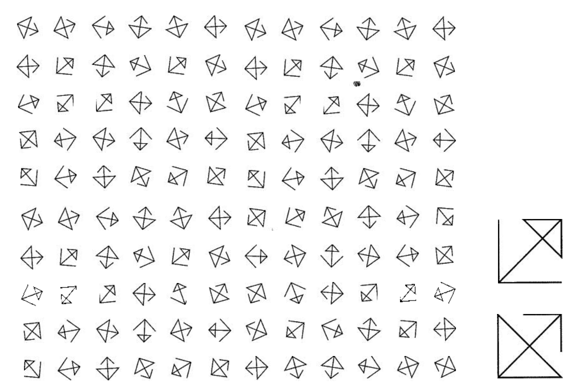

FIGURE 3.35. Shape, with other variables held constant, is not selective. *After Julesz (1981, Fig. 6, p. 95). Copyright 1981 by Macmillan Magazines Limited. Adapted by permission of the author and* Nature.

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 Shortridge (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 effected 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

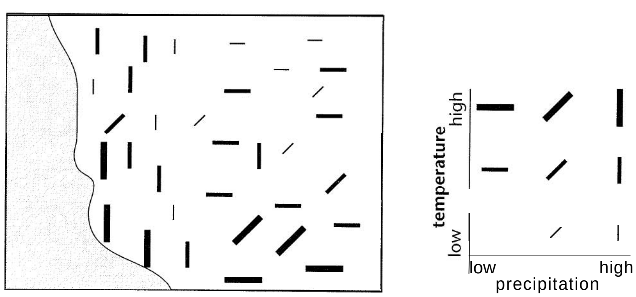

FIGURE 3.36. A map of temperature and precipitation using symbol size and orientation to represent data values on the two variables

such holistic processing comes from research by Lockhead (1970) and Pomerantz and Schwaitzberg (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 Schwaitzberg (1975) used measures of divided *attention* as a complement to previous selective attention studies of perceptual grouping.[6] 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 sortings. 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., Wakarusa 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 conjunction of the color–pattern sets have been exatnined 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 treating 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 grouping have recognized a third category of conjunctions that fits between integrality and separability (Pomeranti 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

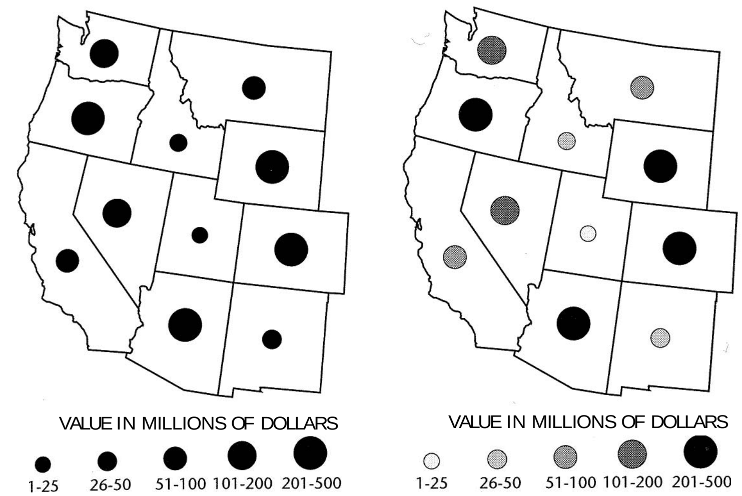

FIGURE 3.37. A pair of Dobson's maps. Reproduced from Dobson (1983, Fig. 7.1, pp. 156–157). Reprinted by permission of John Wiley & Sons, Ltd., from Graphic Communication and Design in Contemporary Cartography. Copyright 1983 by John Wiley & Sons, Ltd.

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 configural (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, Carswell and Wickens favor three distinct categories: integral, configural, and separable.

In addition to examining separability of variable conjunctions, Carswell 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_3–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).

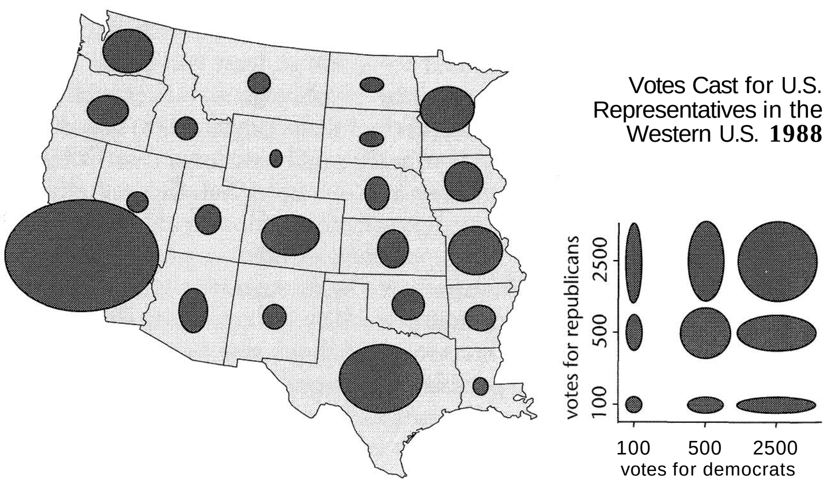

FIGURE 3.38. An example of the use of an ellipse as a map symbol in which the horizontal and vertical axes represent different (but presumably related) variables.

FIGURE 3.39. Bivariate map of NO_3 and SO_4 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 disassociative 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 (196711983) contentions about the selectivity of the visual variables are related to psychological work on selective attention,

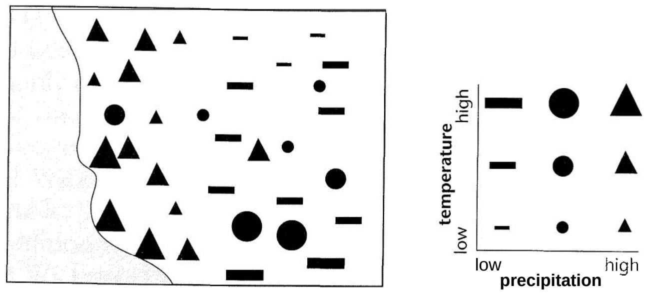

FIGURE 3.40. The bivariate temperature–precipitation map of Figure 3.36, this time using point symbols that vary in shape and size to represent the two quantities.

his arguments concerning associativity are related to research on divided attention. In the case of Pomerantz and Schwaitzberg'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 integrality 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 (196711983) 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 to 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 conjunctions 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 inotion and disparity in depth also seem to dominate position in the plane as a factor in forming pe ceptual 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 sotnewhat independent of eye move-

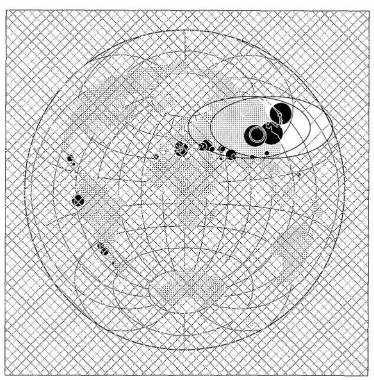

FIGURE 3.41. The attention *spotlight* as a viewer scans a map. Each ellipse represents the region of emphasis by each eye.

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). Tsal and Lavie (1988) have also 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 doininance 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 inay 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 Schwaitzberg, 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 cotnponents 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 (of 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-

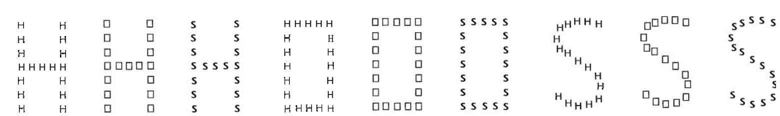

FIGURE 3.42. An example of the kind of compound letters used by Navon and other psychologists studying global–local precedence. *Derived from* Navon (*1977, Fig. 5, p.* 365).

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.

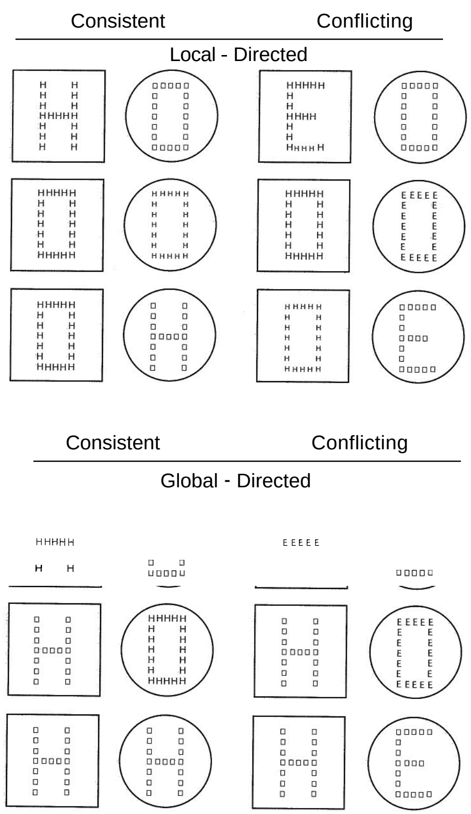

FIGURE 3.43. Sample compound letter stimuli. Derived from *Paquet* and Merikle (1988, *Fig.* 1, *p.* 91).

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, Kimchi (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 Kinchla and Wolfe (1979) with compound letter stimuli and research by Antes and Mann (1984) with pictorial stimuli. For the compound letters, Kinchla 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-

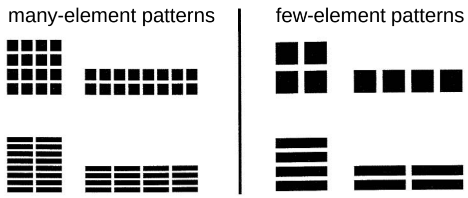

FIGURE 3.44. Nonalphanumeric compound symbols used in testing for global versus local precedence. *Derived from Kimchi* (1988, *Fig.* 1, *p.* 191).

dence over global. For pictures, Antes and Mann found that global precedence existed for pictures subtending 4°, local precedence occurred for pictures subtending 16°, and neither global nor local precedence was found for scenes subtending 8".

An interesting feature of the Antes and Mann study is that their picture stimuli contain global–local dependencies (at a semantic level) not found in the compound letter stimuli. Identification of global scenes in pictures can depend (in part) on identification of local details (e.g., one of their pictures is a farm scene that would be quite difficult to distinguish from many other landscapes unless a local detail, the barn, is recognized). In spite of this interdependency, results concerning the effect of scale on global–local precedence is consistent with that for the compound letter stimuli, for which local and global levels are independent. This comparability of results suggests that global–local precedence effects processing of representations at multiple processing levels (e.g., the low-level primal sketch and subsequent 3-D model representation where recognition can occur).

Most global–local research in psychology, like virtually all cartographic research, has been directed to static displays. There is, however, evidence of global–local processing in the temporal as well as the spatial dimension. The research on temporal context might be considered an extension of the Gestalt grouping principle of "objective set" (that humans tend toward stability over time in perceptual grouping). Objects grouped at one time remain grouped over time, even when changes in proximity would result in no groups or different groups in a static scene. Palmer (1975) examined a similar idea in relation to the effect of temporal context on identification of objects. He hypothesized that global scenes in a temporal sequence would influence the identification of local details presented in subsequent scenes. Palmer found that "appropriate" prior scenes facilitated object recognition and "inappropriate" prior scenes (e.g., a kitchen prior to presentation of a mailbox) impeded recognition. When the subsequent object was similar in appearance to one more logically part of the scene (e.g., a loaf of bread) misidentification was likely.

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 Mistrick (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 infortnation. 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.