journal of the North American Cartographic Information Society

# cartographic perspectives

Number 32, Winter 1999

## in this issue



## *messages*

**LETTER FROM THE PRESIDENT**

As I look back through my set of *Cartographic Perspectives*, I come to a slim dark red issue labeled Number 1 from March 1989. Ten years ago, CP was 24 pages with one featured article on radar video mapping at NOAA. It was chock full of cartographic news about software (Adobe Illustrator for PC platforms had just been announced), cart labs (Wisconsin was seeking advice about color separation with these new-fangled computer tools), reviews of fugitive literature (Alan MacEachren reviewed an article on the first interactive classification system he had come across), and lists of new maps, upcoming events, and more.

Back then, CP selected featured articles through a competition held at the annual meeting, and this 1989 issue contains the call for papers for the next meeting in Ann

*(continued on page 72)*

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# cartographic perspectives

**journal of the**
**North American Cartographic Information Society**

ISSN 1048-9085
*Cartographic Perspectives* is published triannually



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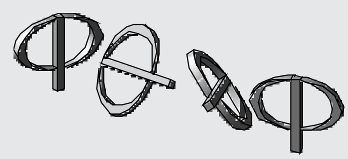
***about the cover***



The cover design was created by Steven R. Holloway. Steven is with the Department of Geography at the University of Montana in Missoula, Montana.

This map is the first in a series of four reflecting on North 47º 56' West 110º 30' and on lines by Korzbsky; "A map is not the territory it represents, but, if correct, it has a similar structure to the territory, which accounts for its usefulness". The location of the series is the juncture of the Missouri and Marias Rivers near Loma, Montana. Cover scale is approximately 1:46200 with a west orientation. This is where on their westward journey, Captains M. Lewis and Wm. Clark "Camped the 2–12 of June 1805 to determine the proper river."

*essay*

# The Web, Cartography and Trust

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The web's facility for sharing maps and digital cartographic data brings to the fore a timeless cartographic question: Why trust maps? The easy excnange, duplication, and modification of digital representations in web-based cartography, coupled with the ephemeral nature of these maps and the generally unknown provenance of maps from this media would seem to make them particularly suspect; yet people seem to be using maps from the internet in great numbers. It is argued here that trusting maps, web-based or other, is a pragmatic response.

The web is an amazing development in human communication. It is at once both a convenient library and a prolific vanity press. It simultaneously increases access to information, and reduces familiarity with it. Web content sometimes seems accessible, uncontrolled, unedited, and idiosyncratic. Anyone with a modicum of technical savvy can "publish" any content they wish on the internet, without the editorial and market constraints which ostensibly encourage accurate, well-crafted content in traditional media.

*"Anyone with a modicum of technical savvy can "publish" any content they wish on the internet, without the editorial and market constraints which ostensibly encourage accurate, well-crafted content in traditional media."*

Much of the web's content is cartographic and more involved than simple locator maps. Peterson (1997) indicates that 10 million maps a day are delivered via the internet. Libraries and museums have begun to put digital versions of significant historic and archival maps on the web. Government agencies from the US Census Bureau, US Geological Survey, and NIMA down to local planning offices as well as private companies supply a range of spatial data, aerial photographs, satellite imagery, and maps via the web. Microsoft's Terra-Server offers access to several terabytes of imagery and map data. Crampton (1998) notes that MapQuest alone produces more than 1.5 million maps a day without the intervention of trained cartographers.

Digital maps seem different from printed ones. The ease with which digital maps, indeed any digital data, are duplicated, changed, and transmitted is at the heart of the apparent difference. Easy duplication and editing are a great part of why digital media are popular, but at the same time lead to concerns about information verity. Easy duplication allows greater access and redundant storage. Digital data are also malleable. They can be altered to reflect a changed understanding of the world. They also are susceptible to inadvertent mutation and malicious change. Data entropy and version control are problems. Managing distributed, changing data is a daunting task.

But many of these differences from previous technologies are differences in degree rather than in kind. Manuscript maps can be copied by hand; printing allows faster and more faithful reproduction. Digital reproduction permits exact copies of other digital materials, but only approximations to manuscript originals. Concern with changing content and lineage uncertainty are not new. Sixteenth century European cartographers (archetypal early "content providers") compiled from and improved upon each other. Cartographic databases, whether stored on copper plates or optical disks, evolve as knowledge about the world changes, sometimes incorporating errors but more often (hopefully) incorporating improvements. Keeping track of the changes may not be as important as making more useful maps. There are also similarities too in the permanence of the cartographic record: history is replete with maps that once existed in quantity but of which not a single copy survives, so redundant hardcopy storage does not guarantee a permanent record. Oddly, the very ease of digital duplication-on-demand may discourage redundant stores of cartographic data. It is sobering to speculate that for maps stored centrally and distributed on demand via the web, a single disk failure could be like the burning of the library at Alexandria. Map provenance may not be so different either. While the web permits essentially anonymous distribution of maps, we often have little or no idea which cartographic databases were used, or who compiled, edited, or checked the data, or what processing might have modified the information.

*"While the web permits essentially anonymous distribution of maps, we often have little or no idea which cartographic databases were used, or who compiled, edited, or checked the data, or what processing might have modified the information."*

On the surface, it may seem that current technological capabilities, enthusiasm for convenience, notions about the impossibility of truth, and acceptance of ignorance as inescapable, place the possibility of cartographic (or any other) communication in jeopardy. If there is so little reason to expect that maps reflect the state of geographic space, why would one use them at all? Why would any one ever trust a map? Especially one from an apparently uncontrolled, unstable, and rapidly evolving media such as the web?

The fundamental issue is that we find maps useful. They communicate locations and distributions in geographic space and we believe, that is trust, maps until we have reason not to. We expect that the maps (and for that matter other communications) we receive from others are produced in a good faith effort to communicate accurately even while knowing that they may not be. We do this in other domains — we buy and use software with the hope and expectation that it will function even though software licenses routinely refuse to warrant it to be fit for use. Trusting a map is accepting that the cartographer has tried to communicate accurately and was capable of doing so to some adequate approximation. It may be a leap of faith, but it is not taken blindly: we know that there are problems with communication and have methods of working around them.

*"Trusting a map is accepting that the cartographer has tried to communicate accurately and was capable of doing so to some adequate approximation."*

Trust is balanced by rational skepticism and tempered by familiarity. When we can, and especially when the risks associated with miscommunication are high, we check the map for consistency with other knowledge of the world, perhaps gathered through experience or through other maps. In this context, the emergence of a national spatial data infrastructure (NSDI) that can serve as a thoroughly tested and constantly corrected standard is a good idea. Reputation can encourage trust. If others' experiences have been good, we infer that ours stand a good chance of being so. If others have had bad experiences, we infer that ours will be similar. Familiarity encourages trust. Repeated, fruitful map use increases familiarity and adds psychological security, but, of course, this inductive inference is no guarantee that the next use will not reveal flaws. There is always the possibility that inconsistency will arise and require a reassessment of the map, the cartographer's intent, or our understanding of the world.

Crampton calls for cartographers to be internet activists in developing web content. This activism is consistent with the meticulous care and attention to detail in the recording and transmission of cartographic information that have long guided cartographers in the production of useful, accurate and well designed maps. Web-based maps should be no exception. Despite their apparent impermanance, easy accessibility, and low cost, web-based maps must be made to be trustworthy. In the end, a mixture of initial trust based on necessity and a leap of faith guided by critical assessment is all we have; indeed, it's all we've ever had to establish trust in maps.

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# Using Selective Attention Theory to Design Bivariate Point Symbols

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**The research discussed in this paper applies the theory of selective attention to graphic variables used in designing map symbols. Selective attention contends that our ability to analyze a symbol's graphic variables (i.e., color, size) is affected by other graphic variables present in the same symbol. Psychological research suggests that certain combinations of graphic variables can enhance or restrict selective attention. In this literature, variables are described as either separable (capable of being attended to independently of other dimensions), integral (cannot be processed without interference from other dimensions), or configural (shows characteristics of both integrality and separability and may also form new, emergent properties). For example, sometimes it may be desirable for a map user to focus individually on separate symbol dimensions when using a bivariate or multivariate map, whereas under other conditions it may be advantageous for him/her to integrate the graphic variables visually for interpretation. Without empirical evidence describing such interactions for various combinations of graphic variables, cartographers cannot truly evaluate the functionality of the symbols they use on maps. The research reported here is the result of the first of a set of four inter-related experiments. Combinations of graphic variables were examined in an abstract setting using a speeded-classification task. Response data and accuracy data were used to provide an initial assessment of the levels of integrality, separability and configurality of several graphic combinations. Findings from this study will be integrated into subsequent map-using experiments, the results of which will assist cartographers in the design of complex map symbols.**

## INTRODUCTION

*"Designing symbols that effectively represent geographic phenomena is one of the primary challenges in cartographic production."*

Designing symbols that effectively represent geographic phenomena is one of the primary challenges in cartographic production. As with many other aspects of cartography, there are guidelines that facilitate this task, but few firm rules upon which decisions may be based. Dent (1996: 82) begins his discussion of map symbols by stating that the selection of symbols is ". . . based on a compelling system of logic tied to both the type of geographic phenomenon mapped and certain graphic primitives or variables." One of the earlier works in which such primitives are described is Bertin's *Semiologie Graphique* (1967). Bertin devised a set of six graphic variables (size, value, texture, color, orientation, and shape) that he considered to be the basic building blocks of all maps. For each of these variables, he proposed a set of rules that outlined how to best use them in conjunction with the type of data being mapped. One of Bertin's interests was in determining whether symbols, composed of various combinations of graphic variables, could be visually grouped across map space. Although his work established hypotheses about the groupings of these variables, Bertin performed little research to empirically verify his ideas. His hypotheses merit further consideration, especially given the recent interest in visualizing multivariate spatial data. One key issue, for example, is how these visual groupings interact with attentional processes. Will certain combinations of graphic variables enhance or inhibit a map user's ability to parcel out information in complex visual representations?

Psychological research in this area has emphasized the theory of *selective attention* as a way of measuring the perceptual grouping of features in a visual image. Selective attention, simply defined, is the ability to focus on a single dimension in a visual image, such as the size or value of a group of symbols, while ignoring all other symbol dimensions. Dimensions that are capable of being attended to independently of all others are *separable*; those that cannot be attended to without processing another symbol dimension as well are *integral*. A third category, *configural*, is reserved for those dimensions that may be attended to individually, but that also interact to form a relational or emergent property that takes perceptual precedence over the original dimensions.

*"Psychological research . . . has emphasized the theory of selective attention as a way of measuring the perceptual grouping of features in a visual image."*

The objective of this research was to empirically assess the perceptual groupings of various combinations of Bertin's graphic variables. The combinations selected were representative of those commonly found in the design of bivariate point symbols for thematic maps. The results presented here are the first in a series of four experiments designed to address the utility of selective attention for designing bivariate symbols for mapping. The overarching goal of this set of experiments is to examine combinations of graphic variables for several types of bivariate map symbols, and to do this in both non-map and map settings. The data gathered in the non-map settings is intended to replicate and expand upon previous studies conducted in psychology; the results will be used to direct the subsequent studies conducted in map settings.

Evidence from psychological studies suggests that various combinations of graphic variables may facilitate or inhibit selective attention. Such findings, if they also hold true for the perception of map symbols, would be crucial to making effective multivariate symbolization choices. Symbols composed of separable graphic variables, for example, would be expected to be effective for different types of tasks than symbols composed of integral or configural graphic variables. Cartographers have long struggled to devise effective means for graphically representing bivariate and multivariate spatial data. This research contributes to that endeavor by establishing which combinations of graphic variables are most effective for the different tasks facing the map reader in a bivariate mapping environment.

*"Evidence from psychological studies suggests that various combinations of graphic variables may facilitate or inhibit selective attention. Such findings, if they also hold true for the perception of map symbols, would be crucial to making effective multivariate symbolization choices."*

RELEVANT LITERATURE

**Selective Attention Theory**

The origins of Selective Attention Theory can be traced back to the late 1950's and early 1960's, when a number of psychological researchers (Torgerson, 1958; Attneave, 1962; Shepard, 1964) recognized that

> "the structure of the perceived relations between multidimensional stimuli depends on whether the stimulus dimensions are integral or separable, the distinction phenomenologically being between dimensions which can be pulled apart, seen as unrelated, or analyzable, and those which cannot be analyzed but somehow are perceived as single dimensions" (Garner and Felfoldy, 1970: 225).

The classic experimental task used to evaluate the interaction of stimulus dimensions is the *speeded-classification task*. In speeded classification, stimuli typically contain two graphic dimensions, where each dimension can have one of two levels. Subjects are presented with these stimuli one at a time and are asked to sort them using one of four types of discrimination tasks. In the *baseline* tasks, only one of the two dimensions (the relevant one) must be attended to in order to make a discrimination; the irrelevant dimension is always held constant. In the *filtering* tasks, the ability to sort stimuli again depends on attending to only the relevant dimension. The irrelevant dimension, however, is no longer held constant, so the

*"The classic experimental task used to evaluate the interaction of stimulus dimensions is the speeded-classification task."*

subject must filter out that information to perform these tasks as quickly as the baseline tasks. The *redundant* tasks are those in which both dimensions vary simultaneously; thus, discrimination can be made by attending to either dimension or by attending to both dimensions. The last task is the *condensation* task, and it requires that the subject attend to both of the stimuli dimensions to make a correct sorting decision (Bennett and Flach, 1992).

*"Reaction-time performance across . . . four types of discrimination tasks provides the basis for defining three different relationships between stimulus dimensions: integral, separable, and configural."*

Reaction-time performance across these four types of discrimination tasks provides the basis for defining three different relationships between stimulus dimensions: integral, separable, and configural. Two dimensions must be interdependent to be defined as integral. This interdependency is marked by such a strong interaction that the ". . . unique perceptual identities of the independent dimensions are lost" (Bennett and Flach, 1992). When such interdependency occurs, reaction times for the redundant tasks, where the two dimensions are correlated, will be faster than those for the corresponding baseline tasks (known as a *redundancy gain*). Furthermore, reaction times for the baseline tasks will be faster than those for the filtering and condensation tasks, where attention to only one or to both of the individual dimensions is required (Bennett and Flach, 1992). The former relationship is called *filtering interference* and the latter is known as *poor condensation efficiency* in the selective attention literature. Researchers using this experimental method have identified several integral stimulus dimensions (see Figure 1 for examples). One of the earlier studies, Garner and Felfoldy (1970), examined the dimensions of value and chroma and reached this conclusion. Their results have since been confirmed by Gottwald and Garner (1975), Kemler and Smith (1979), Smith and Kilroy (1979), Schumann and Wang (1980), and Smith (1980). In addition to value and chroma, psychological research has also established that the following dimensions are integral: horizontal and vertical dot position (Garner and Felfoldy, 1970; Schumann and Wang, 1980), height and width of rectangles (Felfoldy, 1974; Monahan and Lockhead, 1977; Dykes and Cooper, 1978; Dykes, 1979), and pairs of vertical lines (Lockhead and King, 1977; Monahan and Lockhead, 1977).

*"Two dimensions must be interdependent to be defined as integral. This interdependency is marked by such a strong interaction that the ". . . unique perceptual identities of the independent dimensions are lost"."*

Under the speeded-classification paradigm, two dimensions are defined as separable when reaction times on the baseline, filtering, and redundant tasks are equivalent. This equivalency across tasks indicates that the irrelevant dimension in each case did not interfere with subjects' abilities to attend to the relevant dimension. Since there is no interaction between the dimensions, performance on the condensation task suffers accordingly (Bennett and Flach, 1992). Psychological studies suggest that the following stimulus dimensions are separable: size and value (Handel and Imai, 1972; Gottwald and Garner, 1975; Garner, 1977; Kemler and Smith, 1979; Smith, 1980), size of circle and angle of diameter (Garner and Felfoldy, 1970; Schumann and Wang, 1980), the tilt of a line within a form (Egeth, 1966), color and orientation (Carswell and Wickens, 1990), and the orientation of multiple lines (Carswell and Wickens, 1990).

*". . . two dimensions are defined as separable when reaction times on the baseline, filtering, and redundant tasks are equiva-*

The third type of dimensional interaction identified in psychological studies is the configural relationship, which is viewed as an intermediate level of interaction that bridges the separable/integral continuum. In this instance, two dimensions interact to form an emerging property. Subjects can use this property ". . . as the sole basis for the classification, and thus the decision can be made more quickly than if each parent dimension were being processed sequentially" (Carswell and Wickens, 1990: 158). With this type of interaction, sorting times will again show evidence of filtering interference, but will not show evidence of redundancy gains. Furthermore, configural dimensions will facilitate the condensation task because

*""". . . the configural relationship . . . is viewed as an intermediate level of interaction that bridges the separable/integral continuum."*

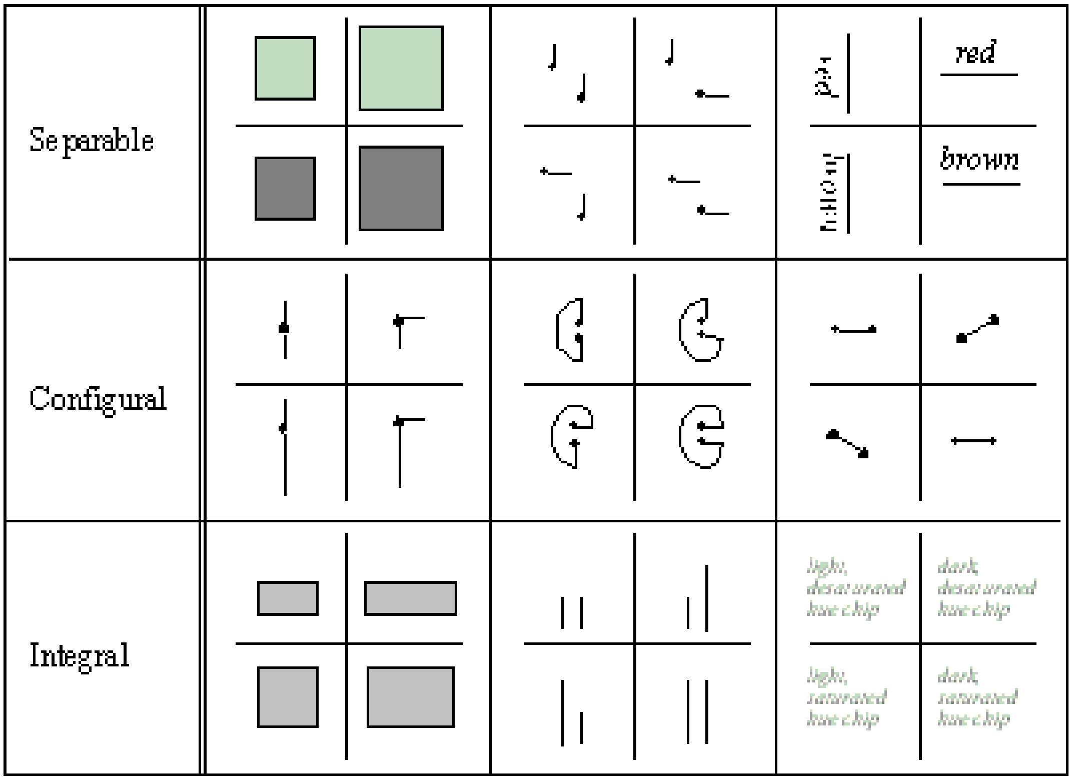


*Figure 1. A few examples of stimuli tested in psychology experiments and their classification (variation in object colors is denoted by italicized labels).*

the emerging property can be used as the basis for classification (Bennett and Flach, 1992). Psychological research has found that the repeated used of the same dimension promotes configurality (Garner, 1978; Carswell and Wickens, 1990). Other stimulus dimensions that have been identified as configural include vertical symmetry and parallelism (Pomerantz and Garner, 1973; Pomerantz and Pristach, 1989), as well as the vertical extents of line graphs and the orientations of folding fans (Carswell and Wickens, 1990).

**Symbol Design in Cartography**

Both Shortridge (1982) and MacEachren (1995) have discussed the potential relevance of selective attention to map design. Shortridge (1982: 163) notes the following about the topic:

> Psychologists expend little effort in assigning new stimuli into the separable and integral categories, but rely instead upon a small group of stimuli that already have been identified as belonging to one or the other of these categories. . . .The concepts have yet to be tested under a variety of more realistic, applied conditions, including the processing of map symbols.

MacEachren (1995) has stated that the existence of integral or separable symbol dimensions might facilitate divided or selective attention. If true, "[k]nowing which will occur in particular cases is clearly crucial to making effective map symbolization choices" (MacEachren, 1995:87).

*". . . cartographers have not, to date, directly tested the theory of selective attention in research on map symbolization . . ."*

Although cartographers have not, to date, directly tested the theory of selective attention in research on map symbolization, they have produced a number of related studies. Those relating directly to the design of point symbols fall into one of three categories: (1) those that propose designs

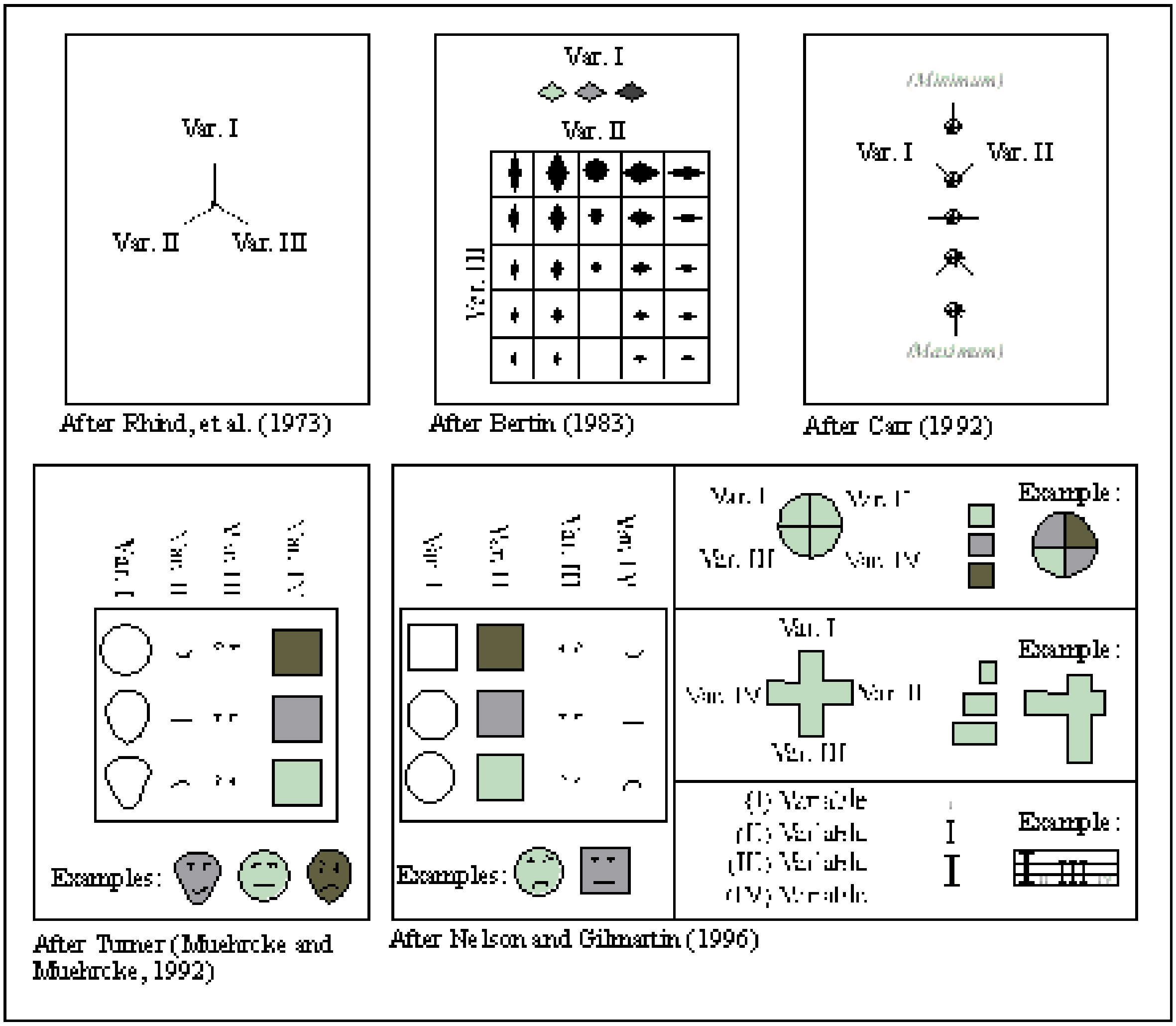


*Figure 2. A few examples of multivariate symbol designs in cartography.*

of multivariate point symbols; (2) those that examine the effectiveness of representing two or more variables using point symbols; or (3) those that investigate the merits of redundant coding (e.g., using two visual dimensions to symbolize one variable). These studies are reviewed below.

A number of authors have simply proposed designs for multivariate point symbols, but have not tested their effectiveness (see Figure 2 for examples). Carlyle and Carlyle (1977), for example, designed an ellipse that represented three variables. The number of sheep sold at various markets in Scotland was symbolized by the length of the semi-major axis of the ellipse; the distance the sheep had been transported to market was indicated by the length of the semi-minor axis; and the proportion of sales accounted for by various breeds was denoted by shading sectors of the ellipse. Bertin (1983) also discussed several ways in which multivariate data could be symbolized. Using point symbols that varied in size, value, shape, and orientation, he constructed a map that showed the distribution of three anthropomorphic characteristics of Europeans. Turner (reproduced by Muehrcke and Muehrcke, 1992: 162) created a map using Chernoff faces to symbolize four socio-economic variables for Los Angeles. A similar map showing nine quality-of-life variables for the United States was published by Wainer (1979). Bivariate ray-glyph point symbols were used by Carr to symbolize trends in sulfate and nitrate deposition in the eastern United

*"A number of authors have . . . proposed designs for multivariate point symbols, but have not tested their effectiveness."*

States (Carr, 1991; Carr, et al., 1992). Each symbol in this design consisted of two line segments joined end to end. One ray pointed left to represent sulfates, and one pointed right to indicate nitrates. The angle of the lines away from vertical symbolized the rate of increased or decreased deposition per year. Dahlberg (1981) combined circle size and shading value in a bivariate point symbol to illustrate the number of course offerings in cartography and the relative importance of cartography programs at U.S. colleges and universities.

Two studies have investigated the effectiveness of quantitative multivariate point symbols from an empirical perspective. Rhind, et al. (1973) designed a three-arm wind-rose type symbol for summarizing geochemical data. The length of each arm represented the concentration of copper, lead, and zinc in stream sediments, with symbol location on the map indicating where the sediment samples had been collected. The authors used both counting and estimation tasks to determine how well the symbol would function under varying scale and background conditions. Results of their study suggested that none of the experimental variables had much effect and that subjects performed poorly under all conditions.

*"Two studies have investigated the effectiveness of quantitative multivariate point symbols from an empirical perspective."*

Nelson and Gilmartin (1996) evaluated four different multivariate point symbol designs by measuring how quickly and accurately map readers could retrieve either an individual value from a symbol or interpret the symbol's overall (composite) value. They also asked map readers to discern regional trends by examining groups of these symbols. The symbols evaluated included two abstract, geometric designs (crosses and circles), Chernoff Faces, and a rectangular symbol containing graduated alphabetic characters that represented the mapped variables. Results of their study suggested that subjects could answer questions using all symbol types with the same level of accuracy, if given enough time. There was a clear hierarchy, however, in how difficult each symbol was to process. Subjects found it easiest to reach a correct answer using the boxed letters and most difficult to reach a correct answer using the Chernoff Faces. Furthermore, reaction times for questions about specific parts of both Chernoff Faces and boxed letters were processed more quickly than questions that required the subject to process each symbol as a whole. This suggests that subjects could focus more quickly on an individual component of these symbols than on their composite image. The opposite held true for the geometric symbols tested.

*"Other cartographers have examined the efficacy of redundant coding in map symbolization."*

Other cartographers have examined the efficacy of redundant coding in map symbolization. Dobson (1983), for example, investigated the utility of redundant coding on graduated symbol maps. He added gray-tone shading to proportional circles to assess whether varying the value as well as the size of a map symbol would improve map interpretation. The greater the quantity represented by the circle, the larger the circle was in area and the darker the shading was within the circle. He found that the redundant symbolization resulted in subjects responding more quickly and accurately, which is a somewhat surprising result, given that selective attention studies indicate that size and value are separable dimensions. It may be that people, if asked, can ignore either dimension but do not necessarily do so spontaneously - especially when both dimensions represent the same variable, as they did in Dobson's study. Or as MacEachren has proposed, the apparent redundancy gain may be a function of experimental design (subjects had to search for a specific symbol among other symbols and then interpret it) rather than a pure reflection of classification speed (1995:89).

*"Research on multivariate symbols that is structured so as to identify integral, separable, and configural graphic dimensions would provide cartographers with guidance on how to design maps meant to be read in specific ways."*

None of the studies cited here were planned with the theory of selective attention in mind, but the concept could easily have been incorporated into most of their designs. Research on multivariate symbols that is structured so as to identify integral, separable, and configural graphic dimensions would provide cartographers with guidance on how to design maps meant to be read in specific ways. For example, if a map author wants readers to see how mapped variables co-vary with each other, he or she might devise a symbolization system composed of integral graphic dimensions. Conversely, if the cartographer's goal is to represent two or more thematic variables so that the variables' individual characteristics can be retrieved, then the symbol should consist of separable visual dimensions. If retaining both aspects of the data is desirable (individual values as well as correlations), then configural symbols could be employed.

RESEARCH METHODS

This study was designed to test subjects' abilities to selectively attend to various combinations of graphic variables (e.g., symbol dimensions) that might comprise bivariate point symbols on thematic maps. As the first step in a multi-phase research project, this experiment focuses specifically on point symbolization. Testing took place in an abstract as opposed to cartographic setting. The methodology and analyses used in this experiment were patterned closely after those reported in psychological studies of selective attention (see Carswell and Wickens, 1990, for example). The stimuli, however, unlike most of those tested in psychology, were designed with their potential relevance for cartographic use in mind.

*"This study was designed to test subjects' abilities to selectively attend to various combinations of graphic variables . . . that might comprise bivariate point symbols on thematic*

**Symbol Sets**

Twelve symbol sets were created using those graphic variables most commonly employed in cartographic design (Figure 3). Note that these sets do not include all possible pairings of the graphic variables - only those that seemed most applicable to map design. Furthermore, these sets include two types of pairings: homogeneous (where a graphic variable is paired with itself) and heterogeneous (where two different graphic variables are paired) (Garner 1978; Carswell and Wickens 1990). Since every set was composed of two graphic variables, each of which varied on two levels, four individual symbols comprised each set. In Figure 4, for example, levels 1 and 2 (light and dark shading) of dimension 1 (value) are represented in the upper and lower rows of cells of the graphic. Levels 1 and 2 (small and large) of dimension 2 (size) are in the right and left columns of the cells.

*"Twelve symbol sets were created using those graphic variables most commonly employed in cartographic design."*

**Tasks**

Each symbol set was tested using a battery of speeded classification tasks to assess incidents of separability, integrality, and configurality among the different combinations of graphic variables. The nine tasks that made up the speeded-classification battery are summarized in Figure 2. Baseline tasks provided baseline reaction times for all classifications that could be made by examining only one of the two symbol dimensions. Filtering tasks assessed the ability of subjects to classify symbols by examining one of the two symbol dimensions when the additional dimension varied randomly. Redundancy tasks assessed the ability of subjects to classify symbols when they were defined by redundantly paired dimensions. Condensation tasks required subjects to attend to both dimensions of the symbol to classify it correctly (Carswell and Wickens, 1990).

*"Each symbol set was tested using a battery of speeded classification tasks to assess incidents of separability, integrality, and configurality among the different combinations of graphic variables."*

**Hypotheses**

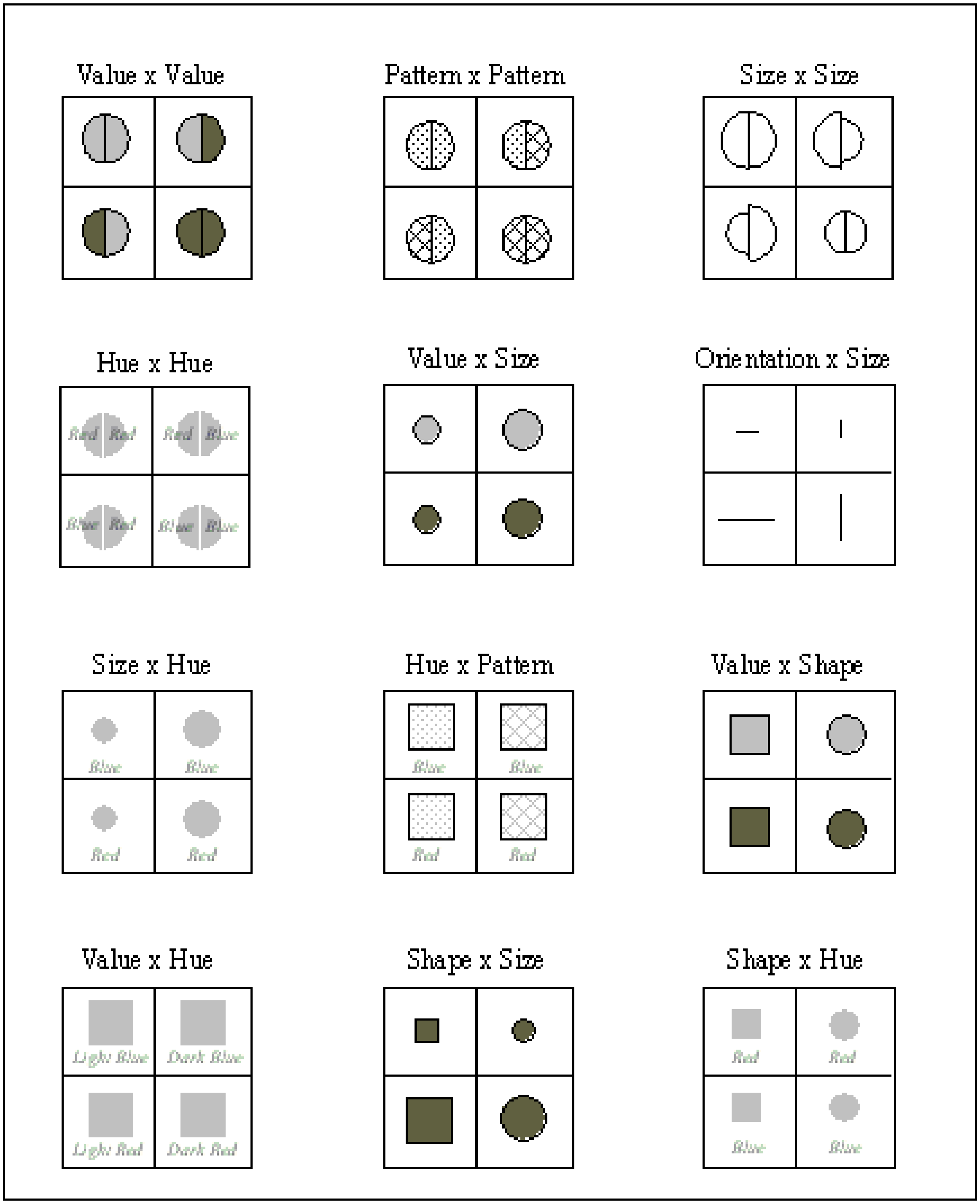


*Figure 3. Symbol Sets*

The primary question asked during this experiment was whether subjects would be able to attend to one dimension of a symbol while ignoring the other. For dimension 1 in Figure 4, then, the question was: Can subjects attend to the shading value of the circle and ignore its size? For dimension 2, a similar question was posed: Can subjects focus their attention on circle size, regardless of the shading value? The battery of speeded-classification tasks was designed to provide data to answer these questions. The following research hypotheses were posed on the basis of results of several psychological studies:

- The graphic combination of size and value should behave as separable dimensions (Handel and Imai, 1972; Gottwald and Garner, 1975; Garner, 1977; Kemler and Smith, 1979; Smith, 1980). For analysis purposes, this means that reaction times for the baseline, filtering, and redundancy tasks will be equivalent; those for the condensation task will show an increase relative to the reaction times for the filtering tasks.

- Graphic combinations that are homogeneous should behave as configural dimensions (Garner, 1978; Carswell and Wickens, 1990). For this to be true, reaction times for the baseline and redundancy tasks must be equivalent. Furthermore, reaction times for filtering tasks must show an increase relative to the baseline tasks, while condensation tasks must show a decrease relative to the reaction times for the filtering tasks.

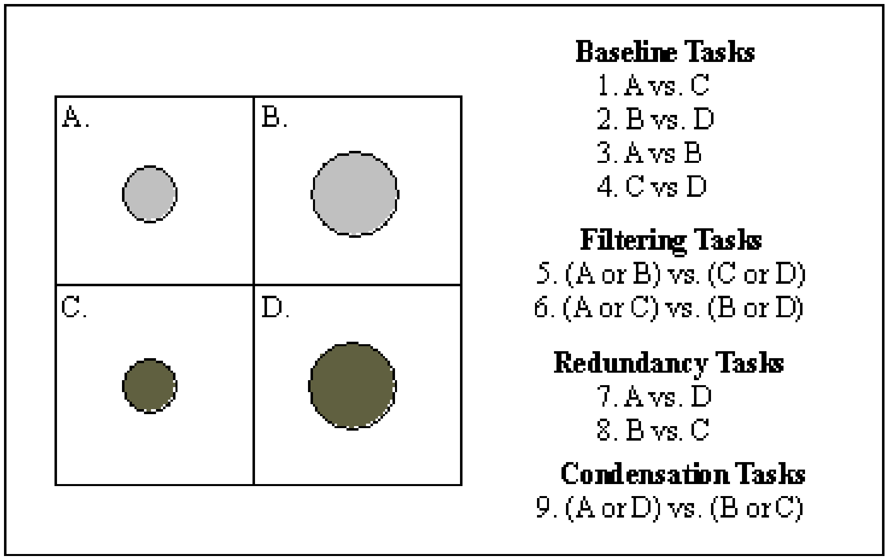


*Figure 4. Speeded-classification tasks used to diagnose separability, integrality, and configurality (after Carswell and Wickens, 1990).*

**Subjects**

Ninety subjects participated in the experiment. Subjects were solicited from the student population at San Diego State University.

*"Each subject performed nine different speeded-classification tasks for four of the twelve symbol sets."*

**Test Procedure**

Each subject performed nine different speeded-classification tasks for four of the twelve symbol sets. Both the presentation and the collection of data were controlled by computer. For each symbol set seen, the subject performed two replications of nine blocks of trials, where each block was associated with one of the nine tasks outlined in Figure 4. The first set of trials for each block was considered a practice trial; therefore, it was not used in the analysis of the data collected. The order of the symbol sets and the order of the blocks for each symbol set were randomized for each subject and each replication.

The procedure for testing was automated by carefully coding the necessary sequence of events using Visual Basic on a Windows/NT operating system. Following the initial instructions of the experimenter, which outlined the central idea and methodology of the experiment to the subject, the computer program was executed. The program presented the subject with a classification rule associated with one of the nine tasks and examples of the four symbols in the symbol set being tested (labeled A, B, C, and D). For example, if the task was one of the filtering tasks, the subject might have been instructed to press the left arrow key if the presented symbol was A or B, and to press the right arrow key if the presented symbol was C or D (Figure 5a). The symbols for the block of trials was then presented on-screen one at a time in a random order (Figure 5b). Each symbol remained on-screen until the subject classified it by pressing one of the two arrow keys. If it was classified incorrectly, the computer responded with a beep to alert the subject. At the end of each block of trials, subjects were given feedback on their performance in two forms: the percentage of classifications they correctly completed and their mean

*"Reaction times and error rates for each symbol set were recorded for analysis."*

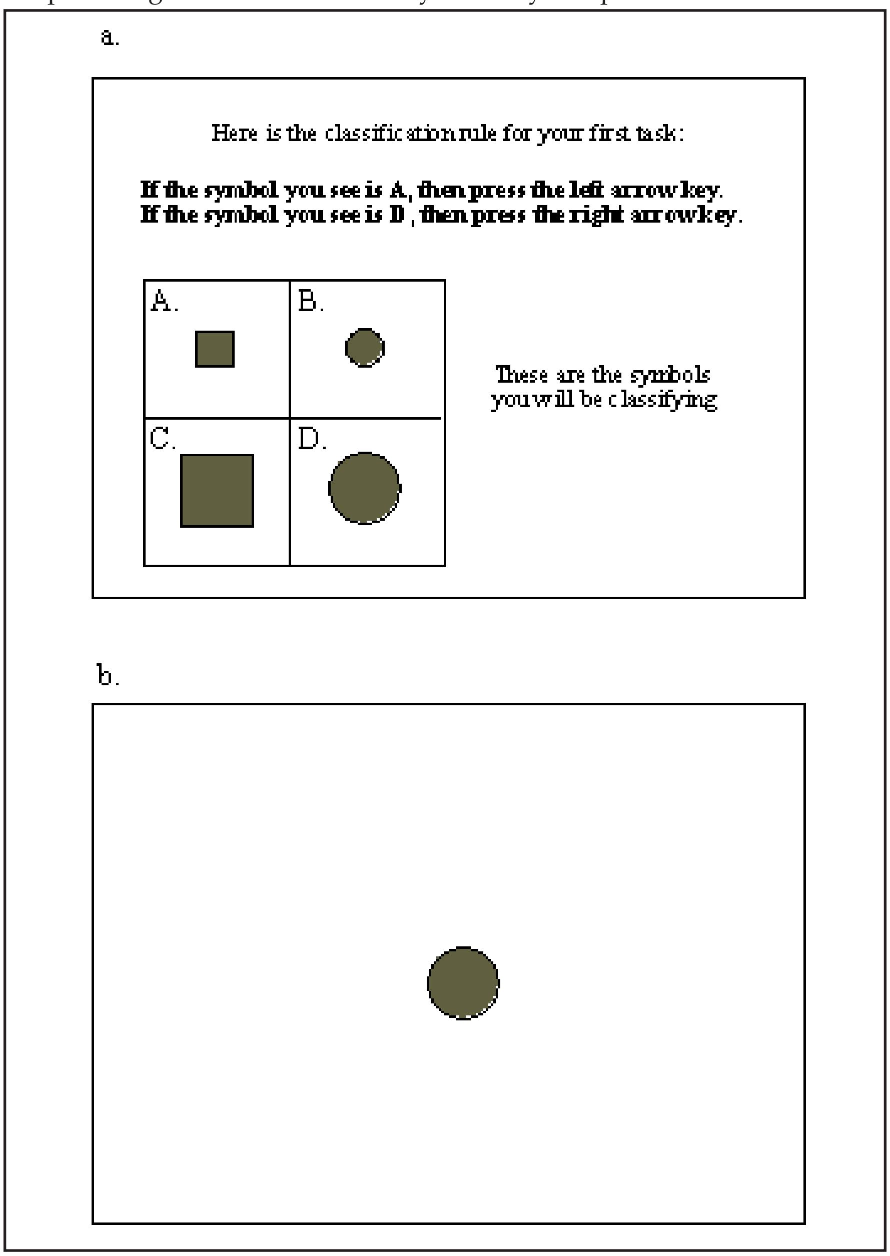


*Figure 5. Experimental Design. (a) shows the presentation of a classification rule and symbol set. (b) shows an actual test screen that required the subject to classify the symbol on the basis of the rule given in (a).*

DATA ANALYSIS

correct response time. When the nine blocks were completed for a given stimulus set, subjects were allowed to take a short break before beginning the test for the next set of symbols. Reaction times and error rates for each symbol set were recorded for analysis.

Two types of analyses were performed on the data collected. First, the data for each symbol set was subjected to an analysis of variance (ANOVA), where the dependent variables were reaction time and percent error. The purpose of these analyses was to evaluate the prevalence of separable, integral, and configural interactions among the combinations of graphic variables comprising each symbol set. Since an ANOVA treats such interactions as discrete (either a symbol set is separable, integral, or configural), these analyses were supplemented with a principal components analysis (PCA), which used a set of summary measures derived from the collected data as input. The inclusion of this analysis allowed the dimensional interactions of the symbols to be assessed along a continuum. This is important, since some combinations of graphic variables may not be strongly configural, integral, or separable, but may have characteristics that place them somewhere in-between these definitions. Principal components analysis plays upon the idea of a continuum of characteristics by locating each symbol set within a multivariate space. The distribution of sets within the space is defined by the summary measures used to create it. Their locations should indicate which sets are more similar to one another on the basis of the defined dimensional interactions and which dimensional interactions best characterize those that are grouped together.

*"Mean reaction time and percent error served as the dependent variables in separate analyses for each symbol set."*

**Analyses of variance**

Reaction time data were first explored using a univariate analysis. Incorrect responses were set to missing data, and extreme values (as defined by Tukey's Hinges (SPSS, 1997)) were deleted. These steps eliminated 14 of 100,224 responses. Since the data were skewed for each symbol set, the geometric means for the remaining data were computed by averaging all subject responses across all categories. Percent error data were also obtained by aggregating all subject responses across all categories.

*"A set of planned comparisons between tasks for the reaction time data were used to assess incidents of separable, integral, and configural interactions for each symbol set."*

Mean reaction time and percent error served as the dependent variables in separate analyses for each symbol set. The independent variable in each case was task (nine levels). The main effect of task was significant for all reaction time analyses ($p < 0.0001$). Corresponding analyses for percent error were not significant. Percent error for all tasks was low (on the order of 3 percent) and produced no significant differences in any of the task comparisons, so these analyses are not reported. A set of planned comparisons between tasks for the reaction time data was used to assess incidents of separable, integral, and configural interactions for each symbol set (Table 1).

Table 2 presents the mean reaction times used to evaluate the effects of filtering tasks on each symbol set. Filtering tasks required subjects to classify symbols on the basis of one dimension while the second dimension varied randomly. For four of the twelve symbol sets (value/value, pattern/pattern, size/size, hue/hue), completion of these tasks took significantly longer than completion of corresponding baseline tasks. This indicates that for these combinations of graphic variables the irrelevant dimension could not be ignored during classification. For symbol sets comprised of orientation/size, value/hue, hue/pattern, and shape/size, analyses suggested subjects could effectively ignore one of the dimensions during filtering tasks, but not the other. Symbols defined by a value/hue combination, for example, exhibited reaction times suggesting that subjects could effectively ignore differences in value when asked to classify symbols on the basis of hue. They apparently could not, however, ignore

*"Significant increases in response times for filtering tasks relative to the mean baseline reaction times suggest that some form of dimensional interaction occurred between the graphic variables comprising those symbols."*

| | A significant difference indicates this type of dimensional interaction: | | |
|---|---|---|---|
| Task Comparison* | **Separable** | **Configural** | **Integral** |
| mean $RT_{(T1, T2)}$ vs. mean $RT_{(T5)}$ | | ✓ | ✓ |
| mean $RT_{(T3, T4)}$ vs. mean $RT_{(T6)}$ | | ✓ | ✓ |
| Faster of mean baseline tasks vs. mean $RT_{(T7)}$ | | | ✓ |
| Faster of mean baseline tasks vs. mean $RT_{(T8)}$ | | | ✓ |
| mean $RT_{(T5, T6)}$ vs. mean $RT_{(T9)}$ | ✓ † | ✓ | ✓ †† |

* T1 = Task 1, T2 = Task 2, etc.
†T9 has significantly longer response times
††T9 has significantly shorter response times

*Table 1. Planned comparisons for ANOVAs*

| | Mean Reaction Time (milliseconds) | | | | | |
|---|---|---|---|---|---|---|
| | *Dimension 1(D1)* | | | *Dimension 2 (D2)* | | |
| **Symbol Set** *(D1 x D2)* | Baseline Tasks | Filtering Tasks | Sig. | Baseline Tasks | Filtering Tasks | Sig. |
| Value x Value | 424 | 478 | **.000** | 412 | 498 | **.000** |
| Pattern x Pattern | 441 | 503 | **.000** | 428 | 523 | **.000** |
| Size x Size | 368 | 469 | **.000** | 399 | 523 | **.000** |
| Hue x Hue | 424 | 478 | **.000** | 412 | 483 | **.000** |
| Value x Size | 455 | 459 | .752 | 388 | 395 | .945 |
| Orientation x Size | 388 | 473 | **.000** | 350 | 361 | .846 |
| Size x Hue | 403 | 420 | .366 | 388 | 388 | 1.000 |
| Hue x Pattern | 420 | 441 | 062 | 416 | 441 | **.002** |
| Value x Shape | 437 | 441 | .970 | 399 | 399 | 1.000 |
| Value x Hue | 407 | 424 | .187 | 424 | 469 | **.000** |
| Shape x Size | 380 | 424 | **.000** | 392 | 407 | .401 |
| Shape x Hue | 392 | 399 | .694 | 384 | 384 | 1.000 |

*Table 2. Analysis of Filtering Interference*

hue when asked to classify symbols of the basis of value. Four sets (value/size, size/hue, value/shape, shape/hue) showed no indication of having any dimensional interactions for this type of task.

Significant increases in response times for filtering tasks relative to the mean baseline reaction times suggest that some form of dimensional interaction occurred between the graphic variables comprising those symbols. To further parse these symbol sets into integral and configural groups, subject performance was examined for redundancy tasks. In these tasks both dimensions of the symbol were varied simultaneously, allowing a correct classification to be made by attending to either dimension or by attending to both dimensions. Table 3 presents the mean reaction times used to evaluate the effects of redundancy tasks on each symbol set. Response

*". . . none of the graphic combinations tested clearly produced an advantage when varied together simultaneously. This suggests that none of these symbol sets can be categorized as strictly integral."*

| **Symbol Set** *(D1 x D2)* | **Mean Reaction Time (milliseconds)** *Dimension 1(D1)* Faster Baseline | Positive Redundancy | Sig. | *Dimension 2 (D2)* Faster Baseline | Negative Redundancy | Sig. |
|---|---|---|---|---|---|---|
| Value x Value | 412 | 407 | .986 | 412 | 403 | .597 |
| Pattern x Pattern | 428 | 416 | .433 | 428 | 420 | .655 |
| Size x Size | 369 | 380 | .536 | 369 | 351 | **.041** |
| Hue x Hue | 412 | 392 | **.003** | 412 | 412 | 1.000 |
| Value x Size | 388 | 384 | .997 | 388 | 424 | **.000** |
| Orientation x Size | 351 | 347 | .982 | 351 | 321 | **.000** |
| Size x Hue | 384 | 369 | .123 | 384 | 392 | .882 |
| Hue x Pattern | 416 | 403 | .467 | 416 | 416 | 1.000 |
| Value x Shape | 395 | 392 | .954 | 395 | 399 | .990 |
| Value x Hue | 407 | 403 | .983 | 407 | 403 | .984 |
| Shape x Size | 380 | 365 | .400 | 380 | 365 | .244 |
| Shape x Hue | 384 | 369 | .203 | 384 | 376 | .953 |

*Table 3. Analysis of Redundancy Gains*

| **Symbol Set** (D1 x D2) | **Mean Reaction Time (milliseconds)** Filtering Tasks | Condensation Task | Sig. (Decrease↓ Increase ↑ ) |
|---|---|---|---|
| Value x Value | 488 | 455 | .000 ↓ |
| Pattern x Pattern | 513 | 469 | .000 ↓ |
| Size x Size | 498 | 433 | .000 ↓ |
| Hue x Hue | 483 | 446 | .000 ↓ |
| Value x Size | 428 | 602 | .000 ↑ |
| Orientation x Size | 416 | 561 | .000 ↑ |
| Size x Hue | 403 | 596 | .000 ↑ |
| Hue x Pattern | 441 | 614 | .000 ↑ |
| Value x Shape | 420 | 620 | .000 ↑ |
| Value x Hue | 446 | 572 | .000 ↑ |
| Shape x Size | 416 | 572 | .000 ↑ |
| Shape x Hue | 392 | 584 | .000 ↑ |

*Table 4. Analysis of Condensation Efficiency*

times for these tasks relative to the faster of the mean baseline reaction times indicate that none of the graphic combinations tested clearly produced an advantage when varied together simultaneously. This suggests that none of these symbol sets can be categorized as strictly integral. Three of the twelve sets (size/size, hue/hue, and orientation/size) showed significant decreases in response times from their baselines for either a positive or negative correlation of dimensions, but not both. The value/size combination showed a significant redundancy effect in the negative correlation of dimensions, but this was a significant increase in response time relative to the baseline, not decrease.

*"... condensation efficiency tasks ... required subjects to attend to changes in both graphic variables in order to make a correct classification decision."*

Response times used to evaluate symbol set performance on condensation efficiency tasks are presented in Table 4. This task required subjects to attend to changes in both graphic variables in order to make a correct classification decision. Symbol sets that show a significant increase in response times for this task, when compared to corresponding filtering tasks, are comprised of variables that do not interact to facilitate classification. This occurrence, when coupled with no significant filtering interference or redundancy gains, suggests the symbol is separable. Those symbol sets that behaved in this manner include size/hue, value/shape, and shape/hue. When symbol sets show a significant decrease in reaction times in conjunction with significant filtering interference but no significant redundancy gains, then the symbol is configural. Those sets that clearly behaved in this manner were value/value and pattern/pattern. The remaining sets did not fall clearly into any one of the three categories.

*"Seven summary measures, first defined in Carswell and Wickens (1990), were used as the basis for this analysis."*

**Principal components analysis**

| Measure | Derivation* |
|---|---|
| Total Discriminability | mean $RT_{(T1,T2)}$ + mean $RT_{(T3,T4)}$ |
| Relative Discriminability | \| mean $RT_{(T1,T2)}$ - mean $RT_{(T3,T4)}$ \| |
| Redundancy Gain | ((Faster of mean baseline tasks/mean $RT_{(T7)}$) + (Faster of mean baseline tasks/mean $RT_{(T8)}$))/2 |
| Redundancy Asymmetry | \| (Faster of mean baseline tasks/mean $RT_{(T7)}$) - (Faster of mean baseline tasks/mean $RT_{(T8)}$) \| |
| Filtering Interference | ((mean $RT_{(T5)}$/mean $RT_{(T1,T2)}$) + (mean $RT_{(T6)}$/mean $RT_{(T3,T4)}$)) |
| Filtering Variability | mean standard deviation of filtering tasks |
| Condensation Efficiency | ((Slower of mean baseline tasks/mean $RT_{(T9)}$) |

* T1 = Task 1, T2 = Task 2, etc.

*Table 5. Summary Measures for the Principal Components Analysis*

Seven summary measures, first defined in Carswell and Wickens (1990), were used as the basis for this analysis (Table 5). These measures provide several characterizations of the dimensional interactions that occurred between the graphic variables comprising each symbol set. Total Discriminability, for example, represents the mean response time required to perform baseline tasks for a symbol set. Longer response times suggest that subjects had more difficulty perceiving perceptual differences within each symbol dimension during classification. Relative Discriminability measures the mean difference in response times for baseline tasks. Larger differences in response times indicate that subjects were able to classify symbols on the basis of one graphic variable more easily than the other. Thus, one would expect that the two dimensions are not equally perceptible. Redundancy Gain measures the ability of redundant variation in both dimensions of a symbol set to improve symbol classification. Larger values of this measure indicate that this property enhanced discrimination between symbols during classification. Redundancy Asymmetry measures the amount of perceptual discrimination that occurs between symbols showing positively correlated dimensions and those showing negatively correlated dimensions. Larger values here suggest that response times for classifying these two types of symbols were more disparate, meaning that redundant variation enhanced discriminative ability in one direction but not the other. Filtering Interference measures how easily irrelevant dimensions can be ignored during classification tasks. Higher values for this measure indicate that irrelevant dimensions cannot easily be ignored. Filtering Variability is a measure of between-subject variability for the filtering tasks. Higher values for this measure indicate increased performance variability for filtering tasks. One possible cause for this may be that some subjects make use of emergent features within a symbol to enhance discriminative ability during classifications, while others do not. Finally, Condensation Efficiency is a measure of how easy it is for subjects to attend to all the dimensional interactions to differentiate symbols. Larger values here suggest that it is more difficult to classify symbols correctly when all dimensional interactions must be considered. These measures were computed for each of the 12 symbol sets and used as input into the principal components analysis. Table 6 presents the component loadings for the first three principal components. These are orthogonally rotated components with eigenvalues of 2.5, 2.0, and 1.7 respectively. Collectively, they account for 88% of the variance among the seven original measures.

*"Component I . . . appears to be describing dimensional perceptibility."*

Component I reveals a cluster of three variables that have high positive loadings: relative discriminability, redundancy asymmetry, and filtering variability. In addition, redundancy gain has a moderately strong negative loading. This component appears to be describing dimensional perceptibility. High values of relative discriminability indicate that the symbol dimensions varied considerably in subjects' abilities to use them for classification. Strong redundancy asymmetry and filtering variability, along with the negative loading of redundancy gains, emphasize that perceptual inconsistency. If the two dimensions are not equally perceptible, for instance, it follows that redundant variation for the purposes of enhancing symbol discrimination will be asymmetrical at best and that filtering out one dimension over the other may be more difficult during the filtering tasks. Those symbol sets that had the highest scores for this component were value/size, size/size, and orientation/length. Those that scored the lowest for this component included shape/hue, shape/size, pattern/pattern, and value/value (Figure 6).

| Summary Measures | Component I | Component II | Component III |
|---|---|---|---|
| Relative Discriminability | .91 | .03 | -.14 |
| Redundancy Asymmetry | .85 | -.10 | -.01 |
| Filtering Variability | .67 | .67 | -.01 |
| Filtering Interference | -.04 | .11 | .98 |
| Condensation Efficiency | -.09 | -.23 | .96 |
| Total Discriminability | -.13 | -.89 | .09 |
| Redundancy Gain | -.45 | .84 | -.02 |

*Table 6. Rotated Component Loadings for the Principal Components Analysis*

*". . . Component II . . . seems to be describing perceptibility within each symbol dimension."*

The strongest positive loadings for Component II were redundancy gain and filtering variability. These are coupled with total discriminability, which loaded negatively for the component. This component seems to be describing perceptibility within each symbol dimension. The bi-polar relationship that exists between redundancy gain and total discriminability suggests an inverse relationship between subjects' abilities to perceive differences within the symbol dimensions comprising the symbol and their ability to use redundant variation of those dimensions to enhance perceptibility during classification. According to this component, those symbol dimensions that have distinct perceptual differences within each dimension (low total discriminability) are the best able to utilize redundant variation (high redundancy gain). They also seem to be associated with strong levels of filtering variability, suggesting that these sets may be associated with the ability to form emergent properties that some subjects my have used to facilitate classification where others did not. Those symbol sets with high scores for this component include orientation/size, shape/hue, and size/size. Those with the lowest scores were value/size, pattern/pattern, hue/pattern, and hue/hue.

*"Component III . . . represents a general configurality component."*

Component III has only two strong loadings and both are positive. High values of filtering interference and condensation efficiency, coupled with a very low positive loading for redundancy gains suggest that this

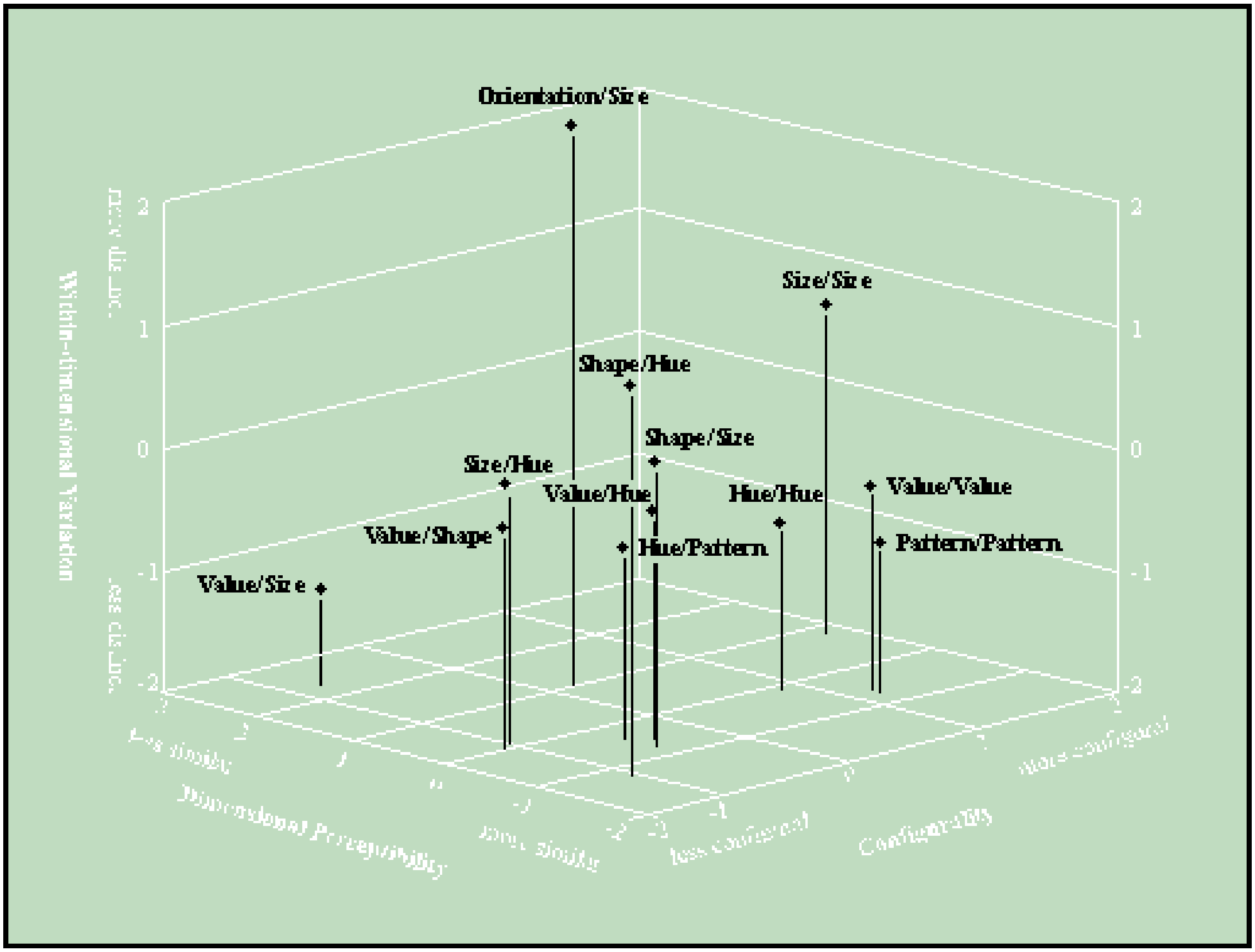


*Figure 6. Principal Components Analysis*

axis of the multivariate space represents a general configurality component. Here symbol sets that are comprised of dimensions that cannot be ignored during classification are also associated with an ability to use all dimensional interactions together to enhance classification ability. Those sets with high scores on this component were hue/hue, pattern/pattern, value/value, and size/size. Value/size, size/hue, shape/hue, and value/hue were the symbol sets with the lowest scores for this component.

## DISCUSSION

The theory of selective attention proposes that there are three distinct interactions that occur when symbols in a visual image, such as a map, are perceptually grouped. In the first case, the dimensions of the symbol in question may be attended to individually of each other, creating separate perceptual groupings for each dimension. At the opposite end of the spectrum, the dimensions of the symbol are completely interdependent, resulting in an integral interaction of symbol dimensions. Here, one cannot perceptually process one dimension without taking the second into consideration as well. The third category, configurality, represents a midpoint between these two extremes. In this instance, the dimensions of a symbol may interact to form a third, emergent property for the symbol. Perceptual grouping may then occur using this emergent property or each parent dimension may be processed separately, depending on the map

*“. . . only two . . . interactions were clearly identified for the symbol sets tested using a speeded-classification task: separability and configurality.”*

user's goals.

In this study, only two of these interactions were clearly identified for the symbol sets tested using a speeded-classification task: separability and configurality. The lack of integral interactions is interesting, but not necessarily disturbing. Although several psychological studies have purported to find integral dimensions in their speeded-classification testing, researchers in that field are now questioning those results (Carswell and Wickens, 1990; Carswell and Wickens, 1988; Casey and Wickens, 1986; Jones and Wickens, 1986). These researchers have found that graphs composed of supposedly integral dimensions do not necessarily enhance the processing of correlated variables, as would be expected. This has led to the proposal that many of these dimensions might actually be more configural than integral, with an emergent feature providing users with a perceptual shortcut for integrating information when required (Barnett and Wickens, 1988; Coury and Purcell, 1988; Sanderson, et al., 1989).

*"Of the twelve symbol sets tested, three are clearly separable . . . size/hue, value/shape, and shape/hue."*

Of the twelve symbol sets tested, three are clearly separable according to the ANOVAs: size/hue, value/shape, and shape/hue. These findings are further supported by the results of the principal components analysis (PCA). Although these graphic combinations are mixed with respect to dimensional perceptibility and within-dimensional variation, they all are clearly grouped at the low end of the configurality axis. The PCA also suggests that value/size is separable, which supports the first hypothesis for this study. Generally, the ANOVA supports this, although it is an imperfect fit. While there is no evidence of filtering interference and condensation efficiency is poor, there is a significant redundancy decrement that does not fit the overall pattern for separability. From a cartographic perspective, this decrement is actually rather interesting. Apparently, when size and value were positively correlated (low value/small size versus high value/large size) subjects were able to key off either dimension to make a correct classification, although the redundant variation did not significantly enhance this ability. When the two variables were negatively correlated, however, this combination actually hindered classification ability. Perhaps subjects couldn't settle on which dimension to use during this classification task since either would suffice, and this switching back and forth caused problems because the two weren't correlated in a cartographically logical manner. It is also possible that low perceptibility within dimensions (component II position) played a role in subjects' abilities to choose which dimension to focus on for the classification.

Also positioned low on the configurality dimension in the PCA were shape/size, value/hue, and hue/pattern. These symbol sets exhibited poor condensation efficiency and no redundancy gains, but each had filtering interference for one of the two dimensions. In the cases of value/hue and hue/pattern, value and pattern could effectively be ignored when classifying on the basis of hue, but hue could not be ignored when classifying on the basis of value or pattern. Such results suggest that some of the graphic variables used in cartography may have more visual weight or pull than others, which shouldn't surprise those who work with or study these variables in a mapping context. It is interesting from the perspective of selective attention, however, because of what it suggests about the design of symbols with multiple graphic dimensions. This interaction of hue with value and pattern suggests that these combinations may not be the best choice if the primary goal is to produce a map where feature attributes can easily be accessed separately from one another. On the other hand, no emergent features seem to be formed from these combinations either. The lack of this type of interaction also makes the symbol a less suitable candidate for map uses that would require the user to consider the inter-relations of the data sets being symbolized. The same might be said of shape/size, where it is possible to ignore size when classifying by shape, but not vice versa.

Positioned high on the configural dimension of the PCA were the homogeneous symbol sets: value/value, pattern/pattern, hue/hue, and size/size. Of these, the ANOVAs clearly support the contention that value/value and pattern/pattern are configural. Hue/hue and size/size also seem to fit best in this category, albeit imperfectly. Both of these combinations show significant redundancy gains for correlated dimensions in one direction but not the other. This asymmetrical performance within the redundancy tasks has been noticed by other researchers (Pomerantz and Pristach, 1989). It is thought to be caused by the use of emergent properties to facilitate classification in one direction of correlation, but not the other. This is regarded as another mark of a configural interaction. These findings support the second hypothesis posed in this study.

*". . . value/value and pattern/pattern are configural. Hue/hue and size/size also seem to fit best in this category, albeit imperfectly."*

The remaining symbol set, orientation/length, fits none of the categories well. It exhibited poor condensation efficiency - a hallmark of separable dimensions, but not when paired with asymmetric filtering interference and redundancy gains. Apparently, one can ignore orientation to classify on the basis of length, but cannot ignore length to classify on the basis of orientation. Furthermore, there appears to be a redundancy gain for negatively correlated dimensions, but not positively correlated ones. Therefore, this symbol seems neither really separable nor completely configural.

The first two components of the PCA do not appear - on the surface, at least - to play crucial roles in determining a symbol set's level of dimensional interaction. Most symbol sets assigned to either the separable or configural dimensions varied greatly in their dimensional perceptibility (component I) and their within-dimensional variability (component II). There are a few specific instances, however, that seem to suggest these variables do play some supporting role in defining dimensional interactions. Those symbol sets that do not fall clearly into any one category of interaction are good examples of this phenomenon. The value/size symbol set, for instance, loads very low on the within-dimensional variability axis of the PCA. If these attributes of the symbol had been more distinct,

| Symbol Set | Dimensional Perceptibility | Within-dimensional Variability |
|---|---|---|
| **Configural Symbols** | | |
| Size x Size | more similar | more distinct |
| Hue x Hue | average | less distinct |
| Value x Value | less similar | average |
| Pattern x Pattern | less similar | less distinct |
| | | |
| **Configural Symbols** | | |
| Value x Size | more similar | less distinct |
| Size x Hue | average | average |
| Hue x Pattern | average | less distinct |
| Value x Shape | average | average |
| Value x Hue | average | average |
| Shape x Size | less similar | average |
| Shape x Hue | less similar | more distinct |

*Table 7. Symbol Set Characteristics*

would subject performance in classification suggest a better fit for separability? Might it have changed the interaction even more dramatically? This is one area that appears to merit further exploration. At the very least, the positions of the symbol sets with respect to these components would still seem to be of interest cartographically. For instance, the most useful symbol combinations would most likely have similar perceptibilities across the dimensions used, while showing distinct within-dimensional variability. With this in mind, one should be able to use the results of this study to determine the symbol sets that match those characteristics for both separable and configural dimensions (Table 7).

## CONCLUSIONS

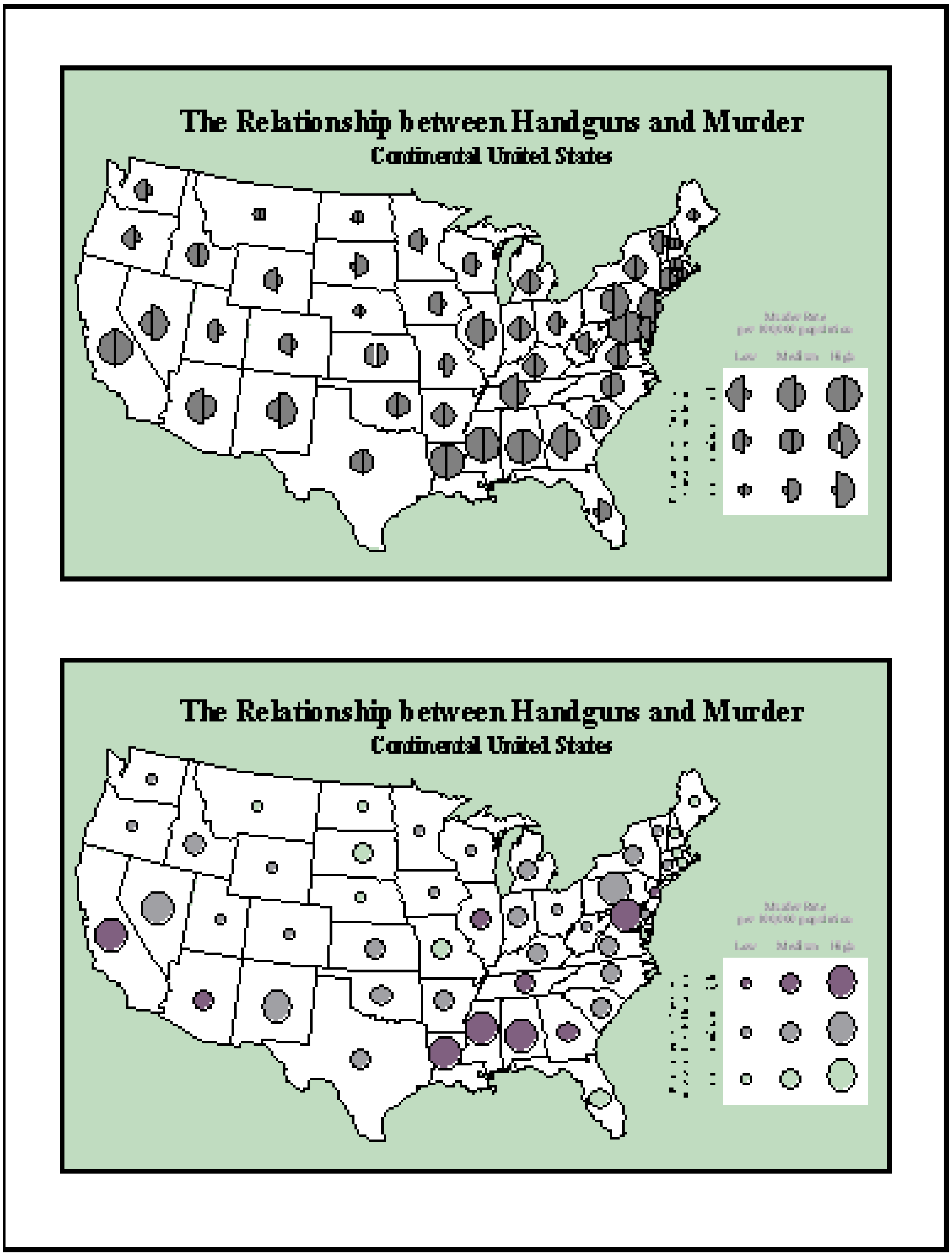


*Figure 7. Two examples of how symbol designs might be used and tested in a map context.*

The results of this research provide an empirical starting point for effectively choosing combinations of graphic variables for bivariate point symbol design. The data collected have confirmed some of the results published in psychological studies and have provided additional categorizations for other combinations of variables considered useful for thematic mapping. The majority of symbol sets tested in this study appear to promote either configural or separable interactions among the graphic variables comprising each set. In addition, different combinations of graphic variables appear to provide varying levels of dimensional discriminability and within-dimensional variability.

*"The majority of symbol sets tested in this study appear to promote either configural or separable interactions among the graphic variables comprising each set."*

Each of these factors would seem to play a role in choosing an effective method of symbolization for a bivariate map. Take, for example, a bivariate symbol needed to map a combination of two quantitative data sets with an emphasis on interpreting the distributional correlations of the data (Figure 7). Here, one might choose to use a symbol that varies size for both distributions, as this symbol set promotes a configural interaction and was also described as being above average in both dimensional perceptibility and within-dimensional variation. On the other hand, if one of the data sets was qualitative and the emphasis was on extracting spatial patterns for individual data sets, then one might choose a size/hue combination. This type of symbol promotes a separable interaction and was described as average in both dimensional perceptibility and within-dimensional variation.

The next step in this project is to confirm these findings within a map environment. This will be done by taking a subset of those symbol sets reported here and evaluating how they function within a map setting. Subjects will be asked to use the symbols to interpret mapped data, and their responses will be used to further evaluate the dimensional interactions of the symbols in question. It is also important to expand the range of graphic combinations tested to include areal, linear, and text symbols to see if the same types of relationships are at work there. A third interesting avenue of research would be to test varying levels of discriminability for combinations of graphic variables. Does the ability to discriminate graphic variables, both within and across dimensions, significantly affect their dimensional interactions?

*"Further examination of selective attention, coupled with the testing of graphic variable combinations in a variety of map and non-map settings, may well lead to the development of more powerful and more understandable bivariate and multivariate maps."*

Further examination of selective attention, coupled with the testing of graphic variable combinations in a variety of map and non-map settings, may well lead to the development of more powerful and more understandable bivariate and multivariate maps. On the basis of this study, the theory of selective attention appears promising as a method of guiding bivariate and multivariate symbol design.

## ACKNOWLEDGMENTS

Comments on the manuscript by the anonymous reviewers are acknowledged with appreciation. A special thanks to Pat Gilmartin for her input in the early stages of this project. This research was funded by a Grant-in-Aid from San Diego State University.

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# Water Quality Mapping for Water Management

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**This paper explores how maps can support water quality management as part of a common project between a water management organization (Service Départementale de L'eau du Conseil Général de Haute-Loire - France) and a research laboratory (Centre de Recherche sur l'Environnement et l'Aménagement - Université de Saint-Etienne - France). Visualization tools are proposed to bring together the different stakeholders in the negotiation process for water management. Two fundamental questions are examined here: (1) how do we communicate the different water quality information to the various stakeholders to improve their awareness of the environment; and (2) how could we evaluate the effectiveness of a cartographic visualization system in the process of negotiation between different stakeholders. Alternative methods are proposed here to present and evaluate water quality information in the form of maps.**

## INTRODUCTION

The process of environmental management has changed in recent years, particularly in the field of water management. In France, two major changes are characteristic of the 1992 Water Law, emphasizing (1) the importance of evaluating "the biological potential of the hydrosystem", and (2) the need for a concerted form of management that involves the various stakeholders. Thus, water management is becoming a more public and democratic process. The discussion/negotiation process prior to decision-making is extended to all individual or collective stakeholders in the watershed. Water quality information concerns all of the stakeholders, but, maps that represent water quality have mostly been designed for and by expert users. Therefore, it is necessary to find ways to communicate information about water quality to a larger audience using the current tools and technologies. The focus here is on two fundamental questions: (1) how to communicate the different water quality information to the various stakeholders and improve the symbology of this information; and (2) can these symbology improvements in cartographic visualization systems produce an increase in stakeholder awareness, and improve the effectiveness of the discussion/negotiation process in participatory planning. The overall purpose of this research is to evaluate water quality mapping methods for non-specialists. To achieve this objective, it is necessary to identify the various needs, determine the stakeholders views on the present environment, and propose cartographic visualizations to improve these views. This research is closely related to the main goals of the Commission on Visualization (International Cartographic Association 1997):

*"Water quality information concerns all of the stakeholders, but, maps that represent water quality have mostly been designed for and by expert users."*

(1) to begin filling the void in understanding how digital geo-information technology interacts with the cognitive and decision-support functions of maps; and
(2) to help cartographers make the transition from being designers of maps to designers of map-based thinking and decision-support tools. A secondary goal is to consider how geo-information technology applied to geographic thinking and decision-support interacts with the social functions of maps and the social context of map use.

This paper is divided into three parts. First we present the importance of water quality in general; the different information intrinsic to water quality, the necessity of water management in a group setting, and existing tools to address this problem. The second section discusses the use of cartographic visualization within this framework, and explores possibilities for improving the representation of water quality by proposing alternative representations and by considering the potential of cartographic visualization. The final discussion presents a method for evaluating the effectiveness of the cartographic visualization in water management issues. The conclusion proposes some directions to extend this field of research.

## WATER QUALITY AND WATER MANAGEMENT

### Water quality and concerted management

The health concerns associated with drinking polluted water make water quality a primary concern. However, environmental criteria are becoming increasingly important in the definition of management policies. In France, the 1992 Water Law protects not only drinking water but also "the biological potential of the hydrosystem." The purpose of this law is to pursue water management without a specific economic objective. It is now the law that all stakeholders must take part in the process of water management. Stakeholders are individuals or groups that are interested in using the water and/or maintaining its quality. Good water quality also reduces the costs of the decontamination of drinking water and increases the quality of the river system for other uses, including recreation. From a socioeconomic point of view, good water quality, especially in rural areas, is a factor in attracting tourists and an important element in the quality of life. Consequently, it promotes the welfare of people that live within an area. According to Hirsch (in Solley et al. 1998), "With increased demands for water for instream uses such as river-based recreation, esthetic enjoyment and fish and wildlife habitat, the overall competition for good quality water will continue to increase." While the quality of water for drinking will continue to be a primary concern, overall issues of water quality, particularly the biological potential of the hydrosystem, will determine water quality management.

*"Stakeholders are individuals or groups that are interested in using the water and/or maintaining its quality."*

Knowing the current state of stream water quality and its evolution is necessary in determining policies for the improvement of quality, uses, and supervision of the testing process (Reseau de Bassin de Donnees sur l'Eau 1997, p. 1). Information on water quality is used by the various stakeholders to make decisions concerning future management. This information, particularly its presentation in the form of maps, is paramount for the management of this resource. Water quality is more than simply quantitative data about the concentration of, for example, nitrates, phosphates, or oxygen. It may also include the human sources of pollution, sectors of recovery (areas where the river is undergoing a natural cleansing process), or possible uses. Water quality is a quantifiable variable and can be scientifically tested. The interpretation of data, however, could lead to a more subjective interpretation. Lastly, the data and its interpretation are of primary importance when groups of people attempt to manage the quality of water.

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Such concerted effort in water quality management provides "those people who depend on the aquatic resources for their health, livelihood or quality of life a meaningful role in the management of resources" (Environmental Protection Agency (E.P.A.) 1996, p. 4). This dialogue has become one of the most important elements in water management. No longer are solutions proposed based on complex models or expert opinion. Rather, it is now a question of presenting information to the stakeholders in a meaningful and comprehendable manner. According to different authors, (Moreno-Sanchez et al. 1996; E.P.A. 1996) environmental conflicts must be negotiated to minimize social conflicts and negative impacts to the environment. But, the stakeholders need information that meets their objectives. The tourist will be interested in water quality for fishing or swimming at various points, whereas the hydrobiologist may want to know the sectors of recovery, or the amount of aquatic life supported by the river.

*". . . environmental conflicts must be negotiated to minimize social conflicts and negative impacts to the environment."*

**Concerted management and visualization tools**

As with any other attempt to manage the environment, the management of water requires a total diagnosis of the problem and the related ecological and humans factors (Montgolfier and Natali 1987). This diagnosis is possible through the analysis of structured data within a Geographic Information System (GIS), but, the use of a GIS for management and decision-making does not meet our needs for several reasons. First, water management is often done by small organizations without sophisticated GIS resources. Second, the validity of the results of future conditions generated by the GIS depends on the sophistication of mathematical models and the quality of the data. This sophisticated form of analysis is again not possible with the smaller GIS systems that are normally available to regional agencies. Third, the use of such models do not take into account the knowledge of the users who need to take part in the process of negotiation. As Carver points out (1998, p. 2), the development of highly specific systems could eliminate certain groups from the decision-making process. The GIS still confers an unwarranted power to the organization that uses it. Goodchild, et al. (1994b, p. 166) point out that to limit the conflicts in decision-making, the mature GIS must be available to all those involved. The use of a GIS is thus essential in water quality management, but more like a spatial database than a powerful analysis tool. However, the use of such systems is meaningless unless the results can be communicated to a larger audience in an effective manner. "Because stakeholders work together, actions are based upon shared information and a common understanding of the roles, priorities, and responsibilities of all involved parties" (E.P.A. 1996, p. 3).

*"The use of a GIS is thus essential in water quality management but, more like a spatial database than a powerful analysis tool."*

Once the data is structured, it is necessary to consider the access by different stakeholders who are often unfamiliar with computing. The information processing systems of public participation offer solutions in this field. Since the end of the 1980's, these tools have been developed with the objective of integrating citizens into a wide-ranging debate that involves both social and technological elements (Jankowski 1998, p. 1). "The chance to participate in the creation of these plans promotes environmental awareness and increases the likelihood of voluntary compliance with environmental legislation and dispositions" (Moreno-Sanchez et al. 1996). A variety of such systems have been proposed including the "Consensus Conference", the "Public Participation GIS" (PPGIS), or the "Spatial Understanding and Decision Support System" (SUDSS) (Jankowski 1998). Other systems that have been proposed include the "Collaborative Spatial Decision Making" (CSDM) (Bennett 1994), the "Interactive Decision Map" (Lotov et al. 1997), and the "Electronic Meeting System" (EMS) (Faber 1995). Three preliminary stages to their successful implementation are essential:

(1) Knowing the various stakeholders and their concerns. Bennett argues that (1994, p. 1): "Before we can design a CSDM system that can support this kind of consensus building we must understand how policy

and management initiatives affect interrelated human, biological and physical processes through time and space." This knowledge should be gained through an inquiry and would enable the second step.

*"When proposing information adapted to the user's needs, the degree of abstraction must be reduced."*

(2) When proposing information adapted to the user's needs, the degree of abstraction must be reduced. For example, what does "fair physicochemical" water quality mean to the average user? New criteria referring to the uses, according to the various parameters of quality, are being studied. For example, the "deterioration method" proposed by the French Water Agencies transforms water quality information into "various possible uses." For this method to be effective, it is essential to reduce times between the analysis of quality and the access to the results by the users. Without proposing models of future states, it is necessary to provide tendencies, according to past results. Finally, water quality contains other important information about the hydrosystem which should be visualized, such as sectors of degradation or recovery. Widening the circle of the water quality data processing and management must be associated with an improvement in the transmission of this information.

(3) Proposing cartographic representations of water quality information that are designed according to the competence and needs of the various users. To know the objectives of various individuals and groups, the tools of analysis and representation must be adapted to the differences in competence of the participants. Armstrong and Densham (1995, p. 57) note: "The support of interactive, group decision-making processes requires the development of new kinds of cartographic displays." To be effective, cartographic visualization must adapt to the user and to the available technology. If not, it risks becoming a gadget and loses its heuristic aspect and its intrinsic functionality for assistance in spatial thinking (Caquard 1998, p. 5).

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In regard to these preliminary stages, the Multimedia-GIS (MM-GIS) seems to be an ideal solution. This tool uses the Geographic Information System (GIS) to georeference, structure and analyze data, and multimedia to create presentations with cross-links to spatial features (Raper and Livingstone 1995). It is also suitable for displaying different cartographic representations to users. "Multimedia applications that present environmental issues in a clear and compelling fashion are desirable in supporting the environmental agency in their education and negotiation functions" (Moreno-Sanchez et al. 1996). Furthermore the MM-GIS can be easily accessible by all the stakeholders through the Internet.

## CARTOGRAPHIC REPRESENTATIONS OF STREAM WATER QUALITY

### Water quality mapping on the Internet

In spite of the general development of maps on the Internet (Peterson 1997, p. 1), examples of water quality maps on the Internet are few. The cost of the data and the sensitivity of this kind of information are still barriers to their availability. Nevertheless, some interesting sites concerning water quality can be found. For example, the "Department of Mathematical Methods for Economic Decision Analysis" of the "Russian Academy of Sciences, Computing Center" <http://www.ccas.ru/mmes/mmeda/resource/program/main.htm> allows the user to visualize the mathematical results of modeling in real time. In this multicriterion application (agricultural output, level of the lake, and water quality), the user chooses which of the three criteria will be emphasized according to what are considered bearable for the others. The final map is a visualization of the result of mathematical modeling. The map itself is not interactive. While the approach is interesting, Openshaw et al. (1994, p. 138) point out: "In

*"In spite of the general development of maps on the Internet, examples of water quality maps on the Internet are few."*

some applications the insights that are gained may be built into computer models and theories, in others there may be no need for any other form of analysis because visualization is itself sufficient."

Two other sites of interest are: "The Natural Resources Monitoring Network - Shepparton Science & Technology Center" <http://www.sheppstc.org.au/water/dynamic/water.asp> in Australia and, the "Irish Environmental Protection Agency's National Freshwater Quality Database" <http://www.compass.ie/epa/system.html>. These sites allow the interactive access to the various water quality data on different areas. The Australian site includes explanatory photographs and textual elements. These two sites are of greater interest to this study because they are designed for more general use. This type of site will see greater applicability as with, "Projet IMAGE" (Ministere de l'Environnement et de la Faune Quebecois) and "Projet de l'Office International de l'Eau français." The Internet must improve access and make it possible to use cartographic visualization. The effectiveness of the message must also be improved by adapting the rules of graphic communication.

*"The Internet must improve access and make it possible to use cartographic visualization. The effectiveness of the message must also be improved by adapting the rules of graphic communication."*

**Proposals for water quality representations**

Water quality is often depicted by representing data with point symbols on maps. Points are easy to represent and are precise in time and space as they correspond to the measurement location of water quality. Nevertheless, this representation is limited because only a small part of space is indicated. Furthermore, points of poor water quality are emphasized because there is usually more information about these points, and they are of more interest to the water quality organizations than points of good water quality. For example, on the tributaries of the Lignon river, the points of very good and good quality drain (i.e., represent) an average watershed of 5.1 km2, whereas those of bad or very bad quality drain an average watershed of 0.4 km2 (Fig. 1). The visual result may be an overestimation of the polluted points as the watershed appears on the map to be more polluted than it is in reality.

This phenomenon can be mitigated by an interpolation of points on the network or by a linear representation since the line represents a larger part of the network. Lines are often used because they are considered easier to understand for the viewer, but there is no empirical support for this. The line representation is simply an extrapolation of the specific point values. Thus, the linear representation must be used with care because the represented information appears more precise than it is. Therefore, the choice in representation between the line and the point is not a neutral decision and may modify the message of the map.

*". . . the choice in representation between the line and the point is not a neutral decision and may modify the message of the map."*

While point and line symbols are frequently used, a third cartographic form of representation, almost never used for water quality mapping, is area. However, this can be an important form of representation because water quality is completely dependent on the impact of the human activities on the whole of the drained watershed area, as well as the capacity of nature to assimilate these impacts (phenomena of deposition, dilution and self-cleansing). Even if these phenomena are complex and difficult to define, normally, when quality improves downstream, the capabilities of nature are higher than the human impact, and vice versa. Extrapolations of the water quality data to the drained watershed can provide this information (Fig. 2). It makes it possible for the user to locate himself spatially in relation to water quality and ask the question: "Does my area contribute to the pollution of the river?" Visually, the advantage is that it produces representations that are simple and very easy to understand. This trans-

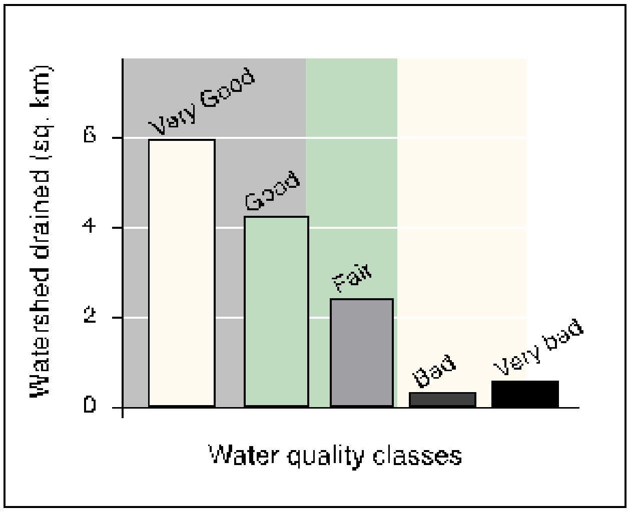


*Figure 1. Differences in area between the watershed drained by the good water quality points and by bad water quality points. On average, a point of very good water quality represents 6 sq. km of the watershed and a very bad one only 0.6 sq. km. The visual result is an overestimation of the polluted points, even if there are only a few of them (Physicochemical quality of the Lignon tributaries / 1992-1997).*

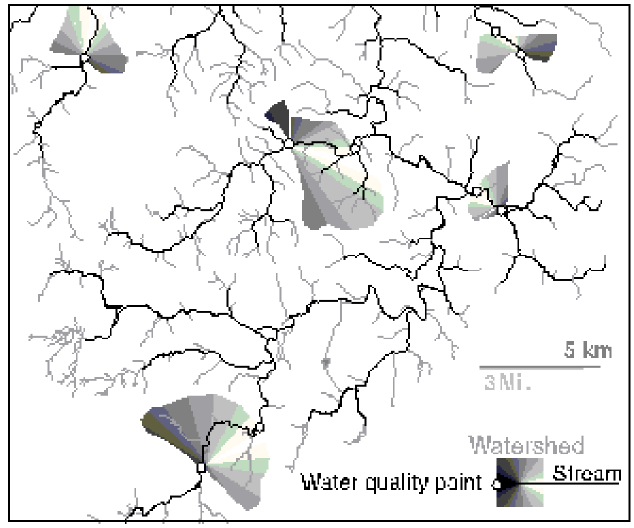


*Figure 2. Watershed and stream sectors where "the capacities of nature are higher than the human impact" (the quality improves downstream).*

formation of a point map to an area map by interpolation corresponds to what Cauvin (1997) calls a "cartographic transformation of state." As Openshaw et al., (1994) point out, loss of precision is the principal limit of this type of transformation. For water quality representation, these limits of precision are two-fold: (1) Spatial precision because a value measured in a point is extrapolated to an area; and (2) Thematic precision, because one deduces other information from water quality such as human impacts and natural phenomena. These thematic transformations must be understood before they can be represented in order to avoid misinterpretation.

Color is generally used to represent the quality of water. It is an excellent selective variable that increases the range of the message (Bertin 1967, p. 91). Although the visual variable of color cannot order (Bertin 1967; Cuff 1973; Gilmartin 1988), colorimetric conventions used for representing water quality seem to be well perceived by map users. In connection with temperature maps, Bemis and Bates (1989, in MacEachren 1995, p. 135) demonstrate that users are able to order colors well, the explanation suggesting that the logic of the order has been learned and is intuitively appealing. This conclusion could apply as well to water quality maps.

*". . . colors cannot be used to represent other features on a map of water quality without interfering with the message."*

In France, the gradation of colors used to represent water quality has been standardized for many years: blue (very good quality), green, yellow, orange and finally red (very bad quality). This gradation is found on the majority of the water quality maps that are available through the Internet. This gradation corresponds to the conclusions of Bertin (1981, p. 221): "For light values, optimum selectivity is obtained by green, yellow, and orange. For dark values, by red, blue, and violet." The counterpart of this convention is that these colors cannot be used to represent other features on a map of water quality without interfering with the message. For example, if the single hydrographic network appears in blue, the reader will tend to interpret a very good water quality. In this case, the blue should be replaced by another color that does not have a water quality connotation, such as a gray, for example.

As Bertin points out, pure colors afford optimum selectivity, and when several variables are combined, selectivity increases. The variation in orientation often affords a selectivity comparable to that of color (Bertin 1981, p. 232). The combination of these two variables will improve the perception. It has also been shown that if the degree of iconicity increases (pictorial representation), the relative abstractness seems to decrease (MacEachren 1995, p. 262). Lastly, according to Forrest and Castener (1985), the perception of color difference is increased by point representation. From the whole of these elements and existing colorimetric conventions, it seems possible to propose other representations for water quality that would improve selectivity while reducing abstraction (Fig. 3). In reference to the representations of uses considered previously, the combination of pictograms, geometrical forms and colors proposed by Forrest and Castener (1985) could be used.

*". . . it seems possible to propose other representations for water quality, improving selectivity while reducing abstraction."*

Size could also be used as another visual variable. To Bertin (1967), size is the only visual variable, and to MacEachren, (1995) it is the variable that is the best adapted to transmit quantitative information. The visual variable of size is completely absent from water quality maps. This absence implicitly means that all the points represented only differ by the quality of the water that is associated with them. Is this realistic? Does a deterioration of the water quality at Sheridan, Wyoming, on the Tongue river really have the same consequences as a water degradation of the Missouri river in Kansas City? The volumes of water are different, as are the uses, the users, and the effect on the economy, ecology and social behavior. It seems logical to integrate these quantitative values into the representation of the water quality. The quantitative information could correspond, for example, to the flow, the surface of the watershed drained by each point, or the bifurcation ratio (Fig. 4). The visual variable of size can also be used to represent differences in perception. For example, it is possible to represent the different values that the various stakeholders give to each water quality point. This representation would allow, for example, the visualization on the same map of water quality and the importance that the various stakeholders place on each point. It would then be easier to draw conclusions about the potential conflicts in water usage.

*"The visual variable of size is completely absent from water quality maps. This absence implicitly means that all the points represented only differ by the quality of the water that is associated with them."*

The last elements to be represented in connection with water quality are changes in space and time. Without this information, it is impossible to properly understand the hydrosystem and to propose future uses. Repre-

*"The last elements to be represented in connection with water quality are changes in space and time."*

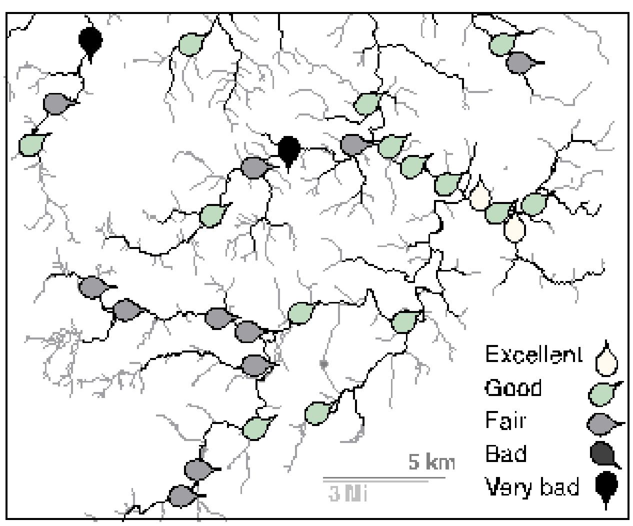


*Figure 3. Association of two visual variables: "color" ("value" in this black and white reproduction) and "orientation with a higher degree of iconicity, to propose another representation of water quality by point.*

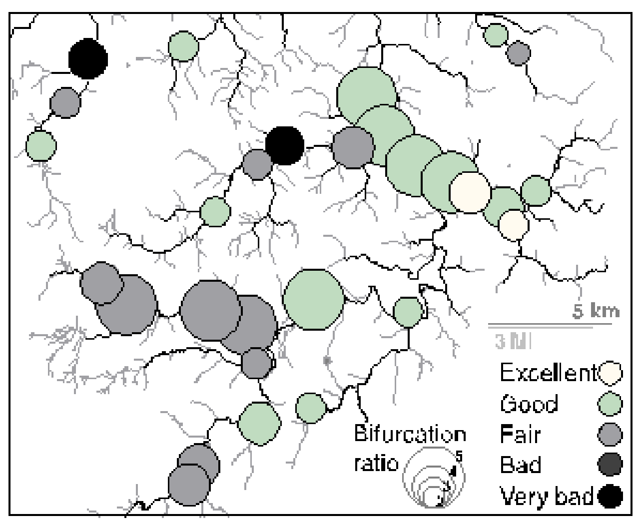


*Figure 4. The visual variable size used to show quantitative values on a water quality map.*

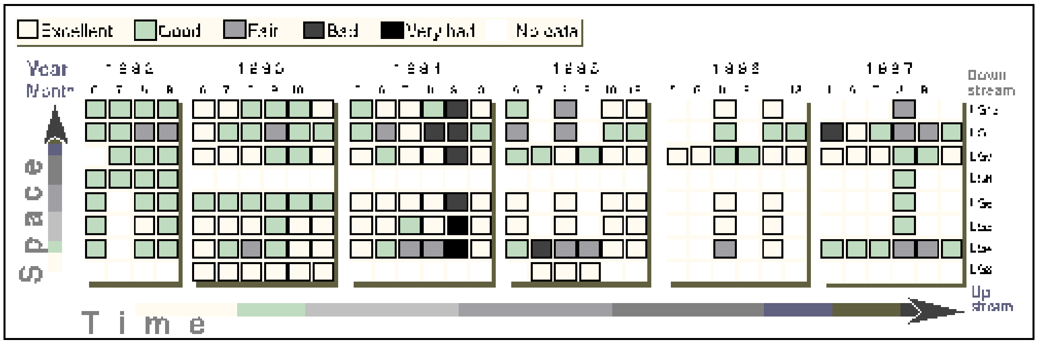


*Figure 5. Schema to represent all of the water quality results of one parameter (physicochemical) on one stream (Lignon river). This representation is an overall picture of a water quality evolution in space (upstream -LG3- (point number 3 on the LiGnon river) to downstream -LG12- (point number 12 on the LiGnon river)) and time (by month between 1992 and 1997).*

sentation in the form of a diagram enables this (Fig. 5). This schematic representation makes it possible to compare different years or different points very quickly. Moreover, it allows the representation of various temporal or spatial steps, or more regular steps over time (i.e., each month) and space (i.e., each mile). This would make it possible to reveal the spatial-temporal aspects in the acquisition of information. For example, why isn't there any information for July of 1996 in the diagram (Fig. 5)? Or, is it necessary to analyze two points that always have the same values?

This kind of representation is limited because it only allows the visualization of one stream at a time. It is thus difficult to compare the various streams from the same watershed. But, the main criticism is summarized by Hearnshaw (1994, p. 195): "Our understanding of data on time, as a variable, is best displayed using time as the display variable." In other words, the use of this static representation to communicate active phenomena can be improved by animation.

*"A considerable amount of work has already been done in the field of cartographic animation*

**Cartographic visualization and water quality**

Animated presentations are ideally suited to represent change over time (Hearnshaw 1994; Peterson 1995). A considerable amount of work has already been done in the field of cartographic animation concerning, for example, the role of the legend (Kraak et al. 1997), the characteristics of temporal visualizations (MacEachren et al. 1994), the visualization of dynamic forms (DiBiase et al. 1991; Peterson 1996), and the various dynamic variables (DiBiase et al. 1992; MacEachren 1995). Applications of animation in cartographic visualization are numerous. For example, the dynamic variables could emphasize: (1) the year or months when the pollution was the greatest; (2) the points where the water quality varies appreciably during the year; (3) the tendencies of water quality change (improvement, degradation or status quo); (4) the rate of change in quality for each point between each analysis; or (5) the existence of causality between water quality and flow. These dynamic variables seem to further the understanding of the operation of the system by the user. Their use to suggest trends must also be considered because as Margolis (1987) points out (in MacEachren 1995, p. 362), decisions are often made by matching present situations against a collection of patterns (or schemata) representing past experience and "knowledge".

*". . . I agree with Kaplan when he compares a theory to a map. For him, theories are remarkable in the questions they do not answer and thereby guide and stimulate intelligent research."*

But, proposing trends doesn't mean proposing solutions. Indeed, I agree with Kaplan (in Weizenbaum 1976, p. 95) when he compares a theory to a map. For him, theories are remarkable in the questions they do not answer and thereby guide and stimulate intelligent research. The heuristic and pedagogic functions of the map are emphasized here, and these functions are probably increased by dynamic visualization. For many authors, changes in the modes of visualization are a fundamental element of dynamic visualization (DiBiase et al. 1991; Turk 1994; Cian et al. 1994; Peterson 1995; MacEachren 1995). Indeed, the multiplicity of representations seems to support comprehension by adjusting the map to user's needs and capacities and are more truthful (i.e., ethical) because they provide a comparative frame of reference (Muehrcke 1990; Monmonier 1991). Therefore, interactivity and multimedia must be used. Interactivity would improve the potential for personal research on the part of the stakeholders, and promote multiple visualizations. Photography, for example, offers other possibilities for geographic communication. It is an uncoded message – a perfect analog of reality (Barthes 1977). The photograph can help answer three types of questions: "Can we see the pollution in a stream?" (macro photography); "Where is the exact point at which water quality was examined?" (landscape photography); and "Where does the pollution come from?" (aerial photograph). The didactic potential of photos must be used even if, as Bertin (1967) points out, the photograph is highly ambiguous because of its polysemia (having many possible meanings). This limit can be mitigated by the use of other media like graphic symbols, text or sound (see Krygier (1994) for a discussion of sound variables). The combination of animation, interactivity and multimedia should enable us to propose an effective tool to communicate water quality. But, how effective will it be in the concerted management of water quality?

*"The combination of animation, interactivity and multimedia should enable us to propose an effective tool to communicate water quality. But, how effective will it be in the concerted management of water quality?"*

EFFECTIVENESS OF CARTOGRAPHIC REPRESENTATION

A number of cartographers have deplored the lack of knowledge about the effectiveness of the various forms of cartographic visualization (Unwin et al. 1994; MacEachren 1995; Rader and Janke 1998). But, how can we effectively evaluate the effectiveness of a strategy of visualization? For a preliminary approach to this question, it would seem appropriate to establish a relative classification of the gain in stakeholder understanding that different representations enable, in reference to an initial representation they already have. In doing so, one must consider that testing visualization techniques on persons who are not actually concerned by the area or the theme represented may not be indicative of the potential visual impact of a given representation. Unlike many cartographic studies, the approach proposed here examines maps in actual use - a "naturalistic" form of research (Petchenik 1983). An inquiry is proposed here to evaluate the effectiveness of maps for water quality management in a concerted map use environment. The inquiry is divided into two parts: (1) a questionnaire submitted to the users before they access the maps, and (2) the same questionnaire afterwards.

**Determining pre-conceived notions of water quality**

One of the principle limits of the effectiveness of Multimedia GIS (MM-GIS) is that the users cannot clearly and completely specify their needs at the beginning of the project (Moreno-Sanchez et al. 1996). "As decision-making becomes increasingly an exercise in public consultation and compromise, decision support requires that all aspects of a project be clearly understood by the public" (Bishop 1994, p. 61). To present the project to the stakeholders and to know the needs of the users are thus two essential steps; but they are not sufficient by themselves. To better plan, design and manage the environment for and with people, their image of the world must be determined (Lynch 1976 in Kitchin 1994, p. 9). These mental conceptions play a large role in our relationship with the environment, our general actions, our behavior and our attitudes about people and places (Tuan 1974 in Peterson 1995, p. 11). Taking the cognitive characteristics of the individual users into account seems to be necessary (Turk 1994).

*"This inquiry must make it possible for users to express their needs and competence . . ."*

To determine the needs and the perception of the users, a questionnaire will be sent to a representative sample of the various stakeholders. This inquiry provides a reference in terms of perception of space, i.e., environmental cognition: the conscience, the impressions, information, the images and beliefs that the individuals have of the environment (Cian et al. 1994). The first part of this inquiry will specifically address the perception of water quality. This inquiry must make it possible for users to express their needs and competence, but it must also enable them to define their mental conceptions about the environment. For that, three sets of questions associated with a reference map will be given (Table 1).

*"The "negociativity" index is a qualitative measure of the relationship between the initial perception of a stakeholder and their "enhanced" perception as a result of cartographic visualization . . . "*

The results will determine the areas of use, types of use, and time of use of various sections of the stream. The purpose is to identify the potential space-time conflicts between stakeholders, while knowing that the potential for conflicts increases with the concentration of the needs in both space and time. However, "objective" solutions may be found for "objective" conflicts, but to what point are these conflicts objective? The potential conflicts associated with perceptions of the causes of degradation by the various stakeholders can be summarized as a "negociativity" index, providing a major element for concerted environmental management. The "negociativity" index is a qualitative measure of the relationship between the initial perception of a stakeholder and their "enhanced" perception as a result of cartographic visualization, enabling us to test the degree of evolution in their perception of the adverse position and the objective phenomena involved in the conflict. Lastly, the level of shift between perceptions of quality and the actual water quality will provide information about the misperception of water quality information and thus enable us to propose representations that are better adapted to addressing this lack of information.

**Determining the effect of water quality visualizations**

*"The impact of cartographic visualizations will be evaluated based on the change in perception caused by the cartographic visualization."*

The second step of this inquiry consists of an assessment of the evolution of perceptions and behavior generated by cartographic communication (Fig. 6). Stakeholders will view cartographic visualizations of water quality data, and these perceptions of the various stakeholders will be compared to those of the first inquiry. These visualizations will help the stakeholders to understand the shifts between their perception and actual water quality measurements. The impact of cartographic visualizations will be evaluated based on the change in perception caused by the cartographic visualization. This will be determined by giving the same questionnaire as during the first inquiry. In this way, the change in perception

| Question | | Purpose |
|---|---|---|
| 1st | Which sections of river do you use? | To understand the various uses and users in time and space. |
| 2nd | In your opinion, what is the water quality of those sections? | To determine pre-conceived notions of water quality. |
| 3rd | In your opinion, what are the causes of pollution? | To find out how individual stakeholders explain causes of water pollution. |
| => Synthesis : definition of a negotiativity index in space and time | | |

*Table 1. Sets of questions will be given to the different stakeholders along with a reference map and an explanation of the purpose for the research.*

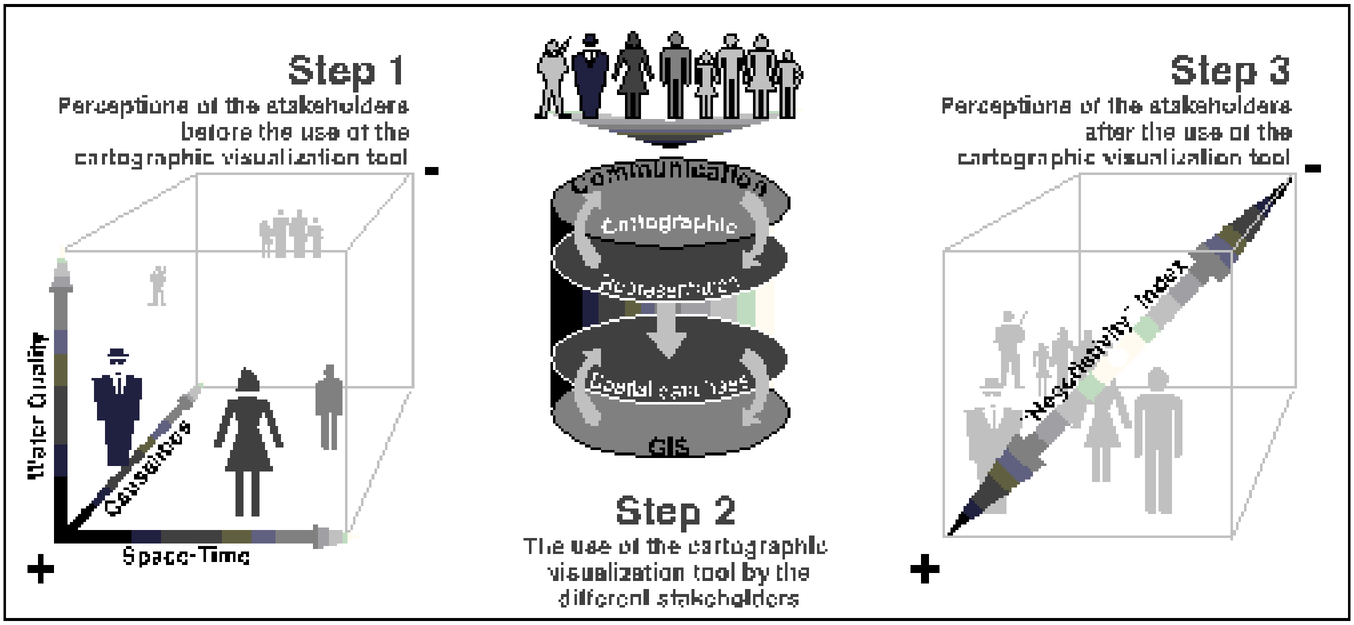


*Figure 6. Assessment of the evolution of perceptions and behavior generated by cartographic communication. Step 1 provides a reference of knowledge and perception of water quality over space and time and causalities of pollution for the various stakeholders. Step 3 provides the same information, but, after using the cartographic visualizations (step 2). The impact of cartographic visualizations will be evaluated by comparing the "negotiativity" index of steps 1 and 3.*

that was generated by this type of communication tool can be quantified. By comparing the results of the two inquiries, an analysis can be made of how geographic visualization can: (1) improve knowledge of the space-time processes influencing water quality; (2) support the access to this information; and (3) help the various stakeholders better understand their impact, the impact of the others and their function within the hydrosystem. The function of this type of tool for concerted management can then be analyzed and new proposals to improve this type of tool can be made.

## CONCLUSION

According to Bishop (1994, p. 64), it is important to continually evaluate each cartographic representation in order to know its legibility according to its use by different people in decision-making. But, as many authors have noted, very little cartographic research has examined maps from this perspective (Unwin et al. 1994; Keller 1995; Torguson 1997; Rader and Janke 1998). This type of research, however, appears necessary for proposing representations adapted to the non-specialist (Kitchin 1994). It will, therefore, be necessary to think about analyzing the effectiveness of various cartographic visualizations in the form of a test, or complementary questions, or even in a "focus group."

The dissemination of water quality information is an interesting field of investigation as well. Indeed, the prohibitory costs of color printing was used in the past as an argument to limit the number of maps that were produced. This argument is meaningless with the potential of the Internet. It will be interesting to study the strategy of water management organizations in order to determine their willingness to make this information freely available.

Finally, the role of the cartographer in this type of project must be considered. Indeed, the multiple views make it possible for the user to find a representation close to their preconceptions and, consequently, ignore others. A detrimental consequence of interaction in mapping would be that each stakeholder finds a particular representation that best defends their interests. In this case, the stakeholders that have the strongest influence will prevail (Carver et al. 1998). It is thus the responsibility of the cartographer to propose robust methods to communicate geographical information correctly. "Cartographic guard rails" must be incorporated according to scientific rules of perception, and to the problems of the users and their perception of space.

How users perceive maps is a necessary question to improve the effectiveness of the cartographic message. But, how cartographic visualizations can improve perceptions of space-time relationships seems to be a fundamental question that needs to be considered for concerted environmental management.

ACKNOWLEDGMENTS

The author gratefully acknowledges the Région Auvergne for financing our research in the Lignon watershed, and the Région Rhône-Alpes for providing a grant to study abroad at the University of Nebraska at Omaha. Special thanks to Michael Peterson for his hospitality during my stay and for substantial help on this manuscript. Thank you to Crane Rodger for his precious help in English.

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# Problems of Cartographic Design in Geographic Information Systems for Transportation

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**Geographic information systems for transportation (GIS-T) seek to integrate the geospatial approach of GIS and the tabular approach of conventional transportation analysis. GIS-T deals with such topics as network analysis, linear reference systems, travel demand modeling, and intelligent transportation systems. Conventional cartographic treatment of route features is reviewed in the context of the mapping challenges introduced by GIS-T. Problems in the visualization of complex linear data are identified and examined as cartographic design issues. Cartographic requirements are specified for mapping route-based data and basic design issues are identified. The representation of complex route-based data layers is posed as an undeveloped specialty of cartographic design. Some of the issues involved in developing such fundamental principles are summarized and potential avenues of research are suggested.**

## INTRODUCTION

Transportation has been a subject of maps for centuries. One can hardly think of a more basic kind of map than a drawing of route directions, whether sketched in the sand with a stick or on a notepad with a pencil. "The ancestry of the road map can be traced to the earliest cartographic efforts..." according to Thrower (1996, 204). Geographic information systems (GIS) are the latest technology to be employed in the service of mapping transportation systems. Recent developments have led to the integration of GIS with the tabular information systems that have long served transportation management and analysis. This hybrid of technologies is sometimes called *GIS for Transportation*, or *GIS-T*. GIS-T was conceptualized and defined by Dueker and Vrana (1992), Vonderohe (1991, 1993) and others both in academia and in professional practice. A defining characteristic of GIS-T is its capacity to perform both transportation and geographic analyses on a common system of networks and routes. Some transportation applications of network analysis are: 1) to understand the behavior of a network (calculate the shortest path from point A to point B); 2) to determine efficient traverses of a network (find the shortest path to visit a selection of places); and 3) and to allocate resources (determine the capacity required of a bus route).

Network analysis is supported by a formal topological structure of links connected at nodes. Modeling transportation systems this way is a useful application of graph theory (Bunge 1966). By reducing the system to a graph, network analysis becomes a purely topological matter with no need for geographic context. GIS-T introduces a geographical representation of the network that locates the transportation system in real space, allowing analysis of the system's geographic as well as its topological characteristics.

Positioning data along the routes within a network is another important function of GIS-T. Transportation organizations need information about features and events that occur on the routes comprising the network, such as the locations of accidents on highways. Positioning features on the links of a network is accomplished by reference to linear distance measures like highway mileposts, rather than by geographic coordinates. In this paper the term *route-based mapping* will be used to identify this function of GIS-T. Route-based mapping is supported by *linear reference systems* that assign to each network link a unique route identity with beginning and ending distance measures. This data model enables GIS-T software to plot tabular data according to its linear reference system location-highway number and milepost, for example. As with network analysis, this function need not occur in geographic space, but can be done on a straight-line diagram of the route. Incorporating the linear reference system data model into GIS-T, however, enables route-based data to be analyzed geographically and presented cartographically.

The purpose of this paper is to examine the cartographic implications of data based on linear reference systems, and to suggest avenues of investigation leading to a better understanding of route-based mapping. GIS-T technology is used by national, regional and local transportation agencies for the management and operation of highway, railroad and transit systems. State departments of transportation, for example, generally use mileage measures to determine positions of features on highways. Each highway route is assigned a unique identifier, and formal starting and ending points. Measuring from the route's starting point, cumulative mileage is used as a linear locator along that route. "Route 66 at milepost 100.5," for example, identifies a unique location: a specific distance down a specific highway (FGDC 1994). Just as a geographic reference system enables location by latitude and longitude, so does a linear reference system (LRS) enable location by route and milepost.

*"Just as a geographic reference system enables location by latitude and longitude, so does a linear reference system (LRS) enable location by route and milepost."*

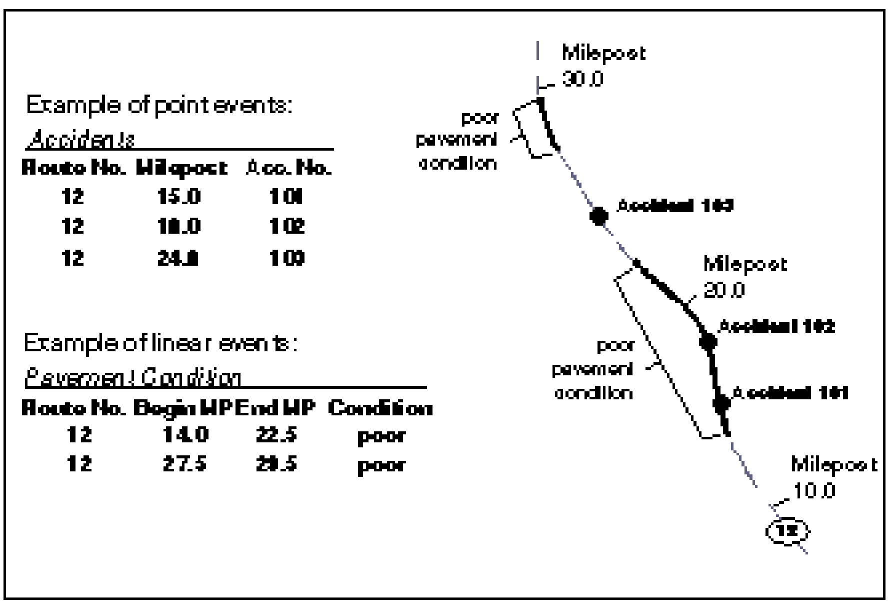



*Figure 1. Tables of data indexed to a linear reference system by* State Route and Milepost *are plotted by the GIS-T process called* dynamic segmentation.

The process of interpolating positions in a linear reference system is called *dynamic segmentation* in the GIS-T literature. Figure 1 shows an example of how route data are plotted on maps through dynamic segmentation. Data representing features and activities that occur on routes are often referred to as *event* data in the GIS-T literature (Dueker and Vrana 1992). This term expresses the concept that objects positioned along routes may be ephemeral or persistent, physical or intangible. Both a culvert and a collision are logically equivalent as *events* on a route. Consider a hy-

This paper presents some of the cartographic problems with mapping route data, suggests map design tactics and identifies issues needing research. The cartographic challenges of linear thematic mapping are not entirely new, but the volume of such activity is expanding rapidly, placing new demands on cartographers. In Muehrcke's (1973, 61) words, "Surges in cartographic activity have followed inventions which allowed cartographers to transcend previously insurmountable obstacles." The characteristics of linear reference systems, and the data based on them, are described here along with the conventional cartographic approaches to representation of linear attributes. The cartographic literature offers little guidance to the map designer seeking tactics or practical ideas for representing elaborate route-based features. Ruggles and Armstrong (1997, 39) tender a theoretical framework incorporating GIS networks into the cartographic paradigm, but theirs is a conceptual overview of the general network mapping problem, touching only briefly on the cartographic behavior of linear reference systems. The "special difficulties" of dynamic segmentation that Ruggles and Armstrong recognize are described here and organized as cases of data representation. The types of route data that need to be represented and the anticipated forms of cartographic expression are used to indicate the kinds of map symbology that must be rendered successfully. Those characteristics of maps that are likely to represent route data successfully are proposed as cartographic design requirements for route-based mapping. Finally, issues of route-based mapping needing cartographic research are identified.

*"Dynamic segmentation allows the mapping of these diverse, complex data sets that heretofore have been impractical to plot manually."*

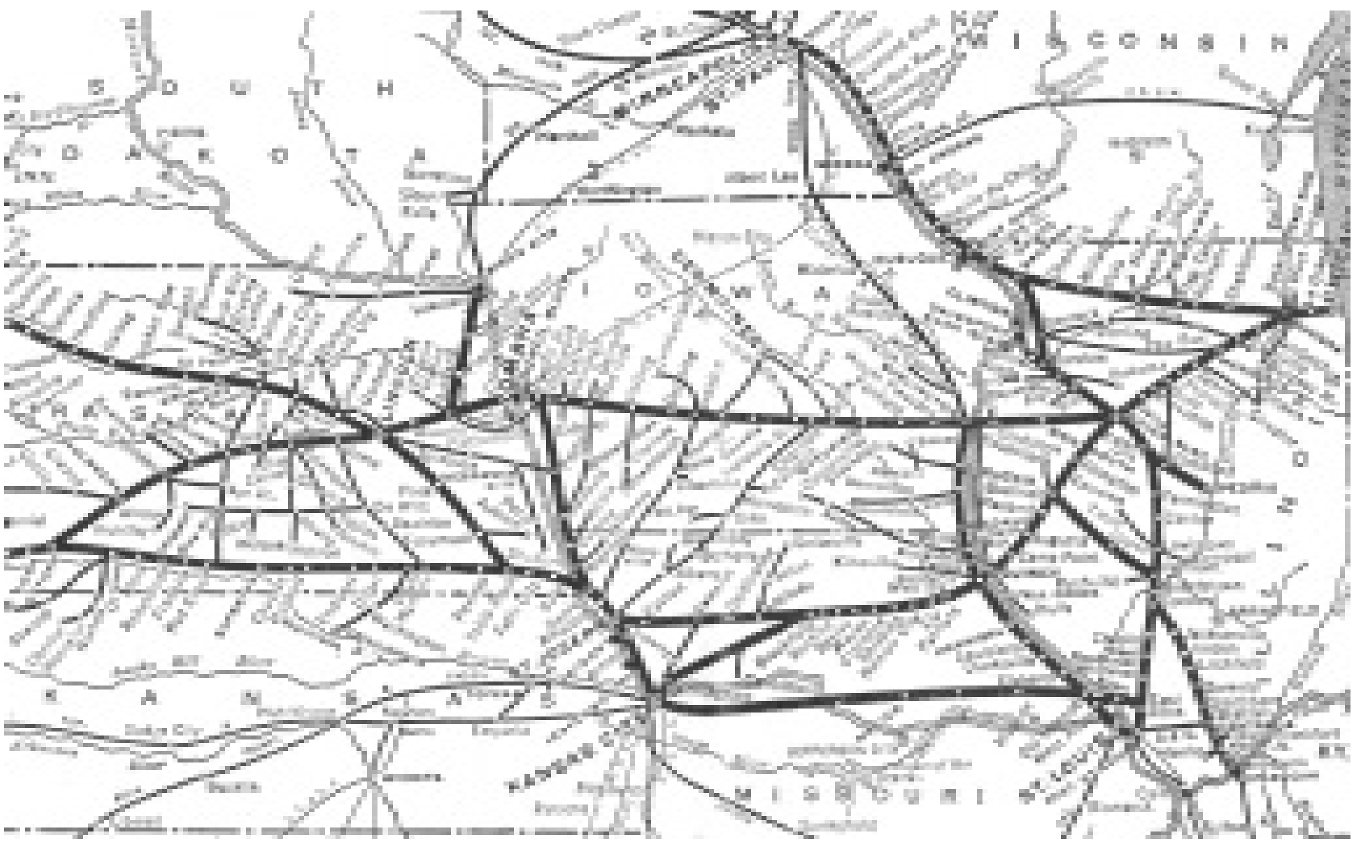
## REVIEW OF THE CARTOGRAPHIC LINE

The cartographic line is used to mimic features of elongated form like rivers and roads, to delimit measurement classifications like contours, to bound areas such as political units, and for artistic effects as in the use of hachures and waves. Of particular interest here is the cartographic line's role in representing transportation networks such as roads and railways. The concept of the cartographic line as a *route* is very old. The Peutinger Table is an oft-cited example of a route map perhaps as old as the 1st century (Goss 1993). Medieval guide maps symbolized routes as a series of events and landmarks astride a corridor (Brown 1950). The transformation of a geographic route into a linear corridor with features along side is obviously not new. Strip-format maps have a long cartographic history as route-following guides (MacEachren 1986).

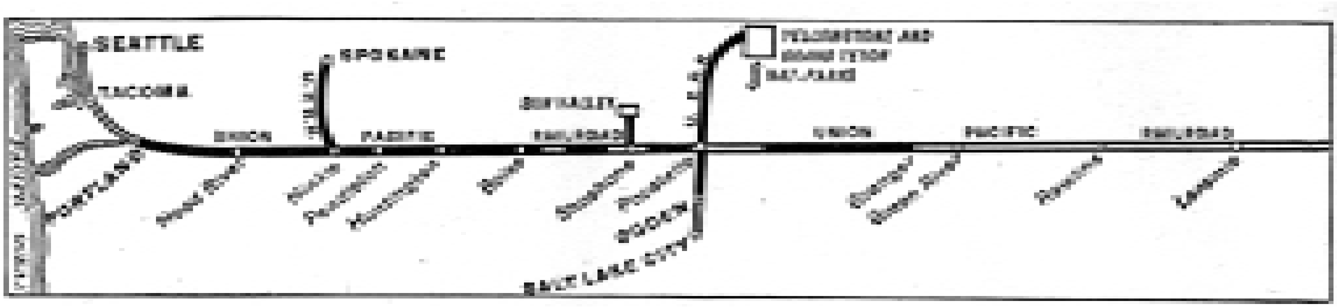
A *route* is a path on which awareness of cardinal, three-dimensional space is unnecessary for successful navigation so long as one follows the correct route in the correct direction. Bunge (1966, 51) conceived of routes as "connections between places" and noted that "Early motorists directed themselves with the aid of descriptive logs or itineraries which told them to proceed so many miles in such a direction from one prominent feature to another." Changes in trajectory are of merely local interest if one's task is to follow the path by landmarks and signs, or in more formal terms, to traverse route segments from one reference point to another. Route logic is that of following directions rather than that of navigating geographically.

The technological developments of the industrial revolution, in particular the railway, advanced the refinement of the route as a geospatial object. In railway system maps, the route is depicted as a compromised spatial and logical transformation. Railroad systems were often mapped with little more than the largest water bodies and political divisions for base map reference (Map 1). Station names and route connections had precedence over geographic space or natural features. These maps approached the schematic character of topological diagrams with their smoothed and straightened lines and cartoon geography. Besides simplifying the syspothetical accident database that stores route number and milepost (the LRS position) for each accident. Because an accident occurs at one and only one route and milepost, accidents are point data—each accident is a discrete event located by route identifier and milepost. The route identifier picks out the specific route in question from all others in the network, and the milepost value indicates distance along that route from its starting point. Dynamic segmentation software interpolates a position for that milepost based on the length of the line representing the route. Milepost 15.0, for example, is plotted halfway along the line between mileposts 10.0 and 20.0. Other kinds of route features are linearly continuous, spanning multiple mileposts. For these features, as with pavement conditions in Fig. 1, two mileposts delimit the range of each event to be mapped. Dynamic segmentation interpolates the positions of these beginning and ending mileposts and creates a segment along the route between them.

Route-based mapping is a rapidly growing form of cartography for transportation organizations. A state transportation department is likely to have thousands of highway features indexed by route and milepost. Some of these are physical infrastructure features like highway ramps, signs, signals, bridges, pavement materials, lane widths, railway crossings and tunnels. Others are ephemera such as traffic volumes, accidents, animal kills, construction zones, and management areas. Dynamic segmentation allows the mapping of these diverse, complex data sets that heretofore have been impractical to plot manually. These vast stores of transportation network features are becoming available for cartographic representation through dynamic segmentation.




*Map 1. Railroad maps are good examples of cartographic design emphasizing network topology at the expense of geographic fidelity. (System Time Table, October, 1961, Burlington Route.* Reprinted with permission of Rand McNally, Inc.*)*




*Map 2. The strip map is a kind of cartogram that represents a route in its elementary conceptual form. (Time Tables, January 11, 1959.* Reprinted with permission of Union Pacific Railroad*).*

tem's complexity for presentation, a promotional purpose of these designs may have been to make the routes appear efficient and direct. Further abstraction made timetable cartograms as much graphic representations of the railroad's schedule as they were transformations of geographic space. The strip map, reduced to a pure route by the removal of geographic constraints, logically complemented the time table's sequence of station names stacked neatly in a column (Map 2).

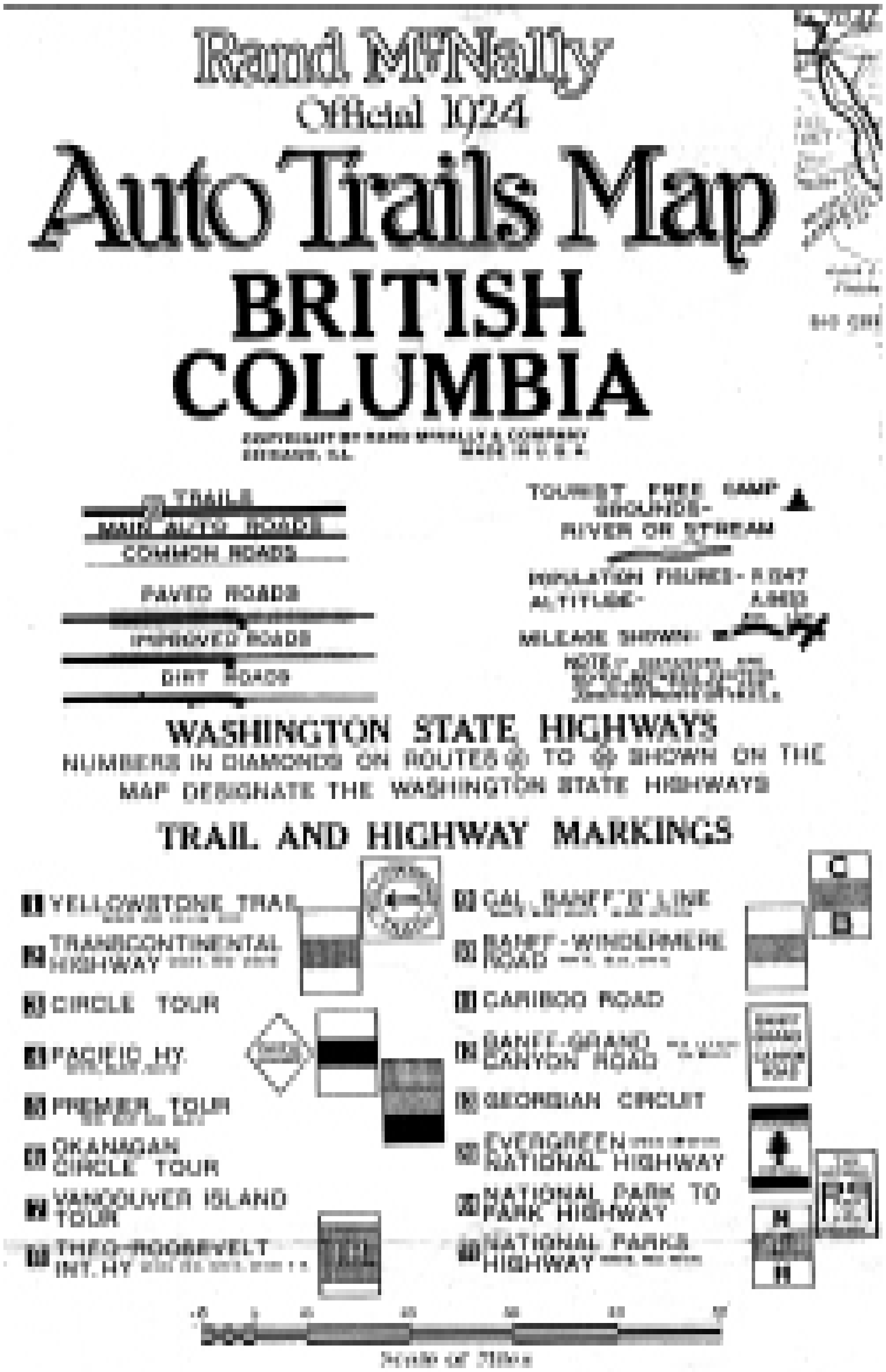
Early highway maps, unlike those for railroads, included much geographic reference detail like hydrography, physiography and political boundaries. Automobile travel often required a more holistic set of navigational skills than travel by rail, air, or vessel. Because the automobile was operated by an individual rather than by specially trained crews, motorists needed tools to do their own way-finding in geographic space. With the ascendance of automotive travel, map publishers took the opportunity to serve a growing map market. In the United States, federal highway funding began in 1916, and national highway numbering in 1926. By the end of the 1920's the road map was a distinct cartographic genre, and publishers had begun elaborating roadway symbols with attributes like surface type, use, highway name, and jurisdiction (Map 3). From that time to the present highway symbolization has been a specific cartographic design problem.

*"By the 1970's most transportation agencies had the well-developed milepost (or kilometer-post) measuring systems that we now call linear reference systems."*

As state highway departments became institutions for funding, building, and maintaining public roads, they adopted systematic operations and management methods, in particular the concept of highways as fixed paths with formally established mileposts. By the 1970's most transportation agencies had the well-developed milepost (or kilometer-post) measuring systems that are now called linear reference systems. Mileposts became the index for locating myriad highway attributes and events: construction projects, surface types, functional classification, signals, signs, bridges, roadside maintenance, and accident sites. A planner or engineer could create a project location map by interpolating the project's beginning and ending mileposts from reference mileposts shown on a base map. In Map 4 we see a construction project location mapped by reference to "stationing," an engineering convention of linear measures in hundreds of feet. This was, in effect, dynamic segmentation performed manually. The stage was set for the integration of tabular and geospatial databases through the transformation of data between linear and geographic reference systems.

**Cartographic Design for Linear Reference Systems**

Linear reference systems are the contemporary manifestation of the age-old route concept. Routes are defined administratively as logically related




*Map 3. Early in the development of road maps, publishers began distinguishing defined routes—named "auto trails," in this case—and symbolizing their characteristics. (Auto Trails of British Columbia, 1924.* Reprinted with permission of Rand McNally, Inc.*)*

subsets of a transportation network. Ownership (state, county, city, or private), level of service (arterial, collector, or local access) and operating practices (bus routes) are examples of factors often considered in devising a route identification system. Measurements for each route in a linear reference system are based on the idea of using an odometer to establish standard distances to reference points along a route's extent. This is in fact how routes are calibrated for linear reference systems. The linear measures start at an officially designated initial point and continue along the encompass all classes of measurement-nominal, ordinal, interval and ratio. For example, accidents may possess attributes about injury classification, number of vehicles involved, time of day, or estimated speed. Any of these might be of interest as a basis for classifying symbology. Continuous events like pavement condition can have equal complexity of attributes: age, type of material, thickness, depth of rutting, or number of lanes, any of which could be classified to represent the pattern of values. Thematic maps for transportation will often need to depict the simultaneous interaction of multiple variables of multiple types of events.

*"As more route-based data become available to GIS, clients will escalate their requests for innovative and analytically complex representations."*

Reviewing the cartographic literature for guidance with these problems reveals a conspicuous void. Most treatments of the cartographic line revolve around linear symbols for entire, discrete lines standing alone, rather than points or segments that are derivative features of lines. Wright (1944) noted the potential of "variable line symbols" but could not recall such use in practice. Ullman's (1957) commodity flow work contained some elegantly effective flow maps, and Monkhouse and Wilkinson (1966) showed an intriguing multivariate flow map of bus frequency by system owner. One theoretical discussion pointed out that variations in thickness, pattern and color could be used to indicate thematic data on lines (Hazlewood 1970). The typical contemporary discussion of linear symbology culminates with flow maps that show ratio data by proportional line thickness (Robinson, *et al* 1995; Dent 1993). Some effective flow map techniques can be unearthed among the older sources (Campbell 1984). Cuff (1982) demonstrated the superimposition of an abstract flow volume arrow over


*Map 4. Open-cased road maps provided the base for manually interpolating the location of information by route and milepost. Here, a construction project is plotted and labeled with "stationing," a kind of linear reference system used by highway engineers. (ca. 1970.* Courtesy of Washington State Department of Transportation*)*

route to the designated end point. The *route log* produced by this process contains linear measures for standard reference points along the route. Junctions, bridges, tunnels and so forth are each assigned their own milepost value. By using these reference points as well as physically posted milepost signs, any feature of interest can be assigned an interpolated or estimated milepost value. Highway departments and railroads have databases full of features indexed this way. Because LRS measures are interval data there can be theoretically an infinite number of discrete points or unique segments along a route.

Most highway departments in the United States employ an LRS to locate features and activities on their highway systems, and much of this information is stored in relational database systems. Some of these data, like accident records or traffic counts, for example, have a high frequency of change. Mapping them by manual interpolation of location, as in Map 4, would be a futile exercise with costs far outweighing benefits. GIS-T, however, offers a technology that automates this process to make the vast stores of route-based data available for cartographic representation. In map production, plotting the data is the easy part. While completing the final design, mapmakers trying to produce a presentable map are likely to find themselves struggling to move and resize symbols and text that were originally expected to be an automatically plotted data layer. As more route-based data become available to GIS, clients will escalate their requests for innovative and analytically complex representations. The cartographer working with dynamic segmentation in the GIS-T environment faces the quandary of having a tremendously powerful new data compilation tool generating graphic design challenges for which there is essentially no body of experience, tradition, or customary reference to consult for insight.

One way to organize this problem is to identify the distinctive elements of route-based mapping that are independent of theme, locale, and the technicalities of LRS implementations. Three characteristics of the route-based mapping problem emerge as central elements influencing cartographic representation: the spatial constraints of lines, the properties of events, and the properties of thematic data in general.

**Spatial constraints of lines—**The most basic cartographic problem of route-based data involves simple spatial conflict of map symbols. Events should be constrained tightly to the narrow corridor on which they occur in order to preserve geographic accuracy and to maintain good graphic association for the map reader. Point events may coincide exactly, or occur closely enough that their symbols overlap. Linear events may coincide exactly, partially or at an intersection. With small data sets or simple network systems these problems are simply part of the traditional map design task. When hundreds or thousands of such cases occur, or when the map is a continuously revised screen display, the problem becomes a crucial design issue.

*"Most treatments of the cartographic line revolve around linear symbols for entire, discrete lines standing alone, rather than points or segments that are derivative features of lines."*

**Properties of events—**Event data have particular characteristics inherited from the route data model:

*linear orientation*— Events may exhibit directionality (forward v. backward) and sidedness (left v. right).

*velocity*— Events that flow exhibit both direction and speed.

*length*— Events may be modeled as either points or lines, depending upon the resolution of the data and scale of representation.

*chronology*— Events may have various durations, sequences and frequencies of occurrence.

**Properties of thematic data—**As thematic data, the attributes of events the geographical rendition of its true route. Fisher (1982) presented four different approaches to flow volumes on a network. The only reference to route-based data may be Keates' (1989) description of the difficulty of maintaining point feature data for road maps. The literature offers some general guidance for linear data, but is apparently barren of any guiding cartographic principles for the depiction of point data on routes. For their part, developers of the GIS-T concept have focused on functional and business requirements (Vonderohe, *et al* 1993; FGDC 1994; Dueker and Butler 1996), and on data structures (Dueker and Vrana 1992; Vonderohe 1995) rather than on cartographic representation.

An effective device for examining the relationship between elements of symbology and classes of data measurement has been to depict examples for each case in a table (Robinson *et al* 1995, Muehrcke 1992). A logical extension of this approach demonstrates some of the issues of route-based mapping. Figure 2 shows how point symbols can vary by size, pattern and color to represent most types of data. Interval and ratio data present some special difficulties, however. It is difficult to envision how a point symbol's pattern might change on a continuous scale to represent interval or ratio data values. Color could be varied in hue or value on a continuous scale but the effectiveness of such point symbols is questionable.

Linear data (Figure 3) present a similar case. Line color and pattern are widely understood as graphic variables for showing nominal and ordinal data, like road classification and surface quality. Line color and pattern are not, however, traditionally considered suitable for interval and ratio data, where line thickness has been the convention.

Figure 4 depicts examples of how coincident and overlapping event data sets might be displayed. Displacement, the setting off of additional symbols parallel to the route, can effectively show the clustering of coincident events when the number of cases is few. This tactic would probably work poorly with more than a few cases. Rather than displace symbols to the side, one could simply let them superimpose where they coincide. Carefully planned symbology might allow readers to recognize the component elements, but again, the question is how far this can be taken. A third approach to coincident events might be to use a symbology

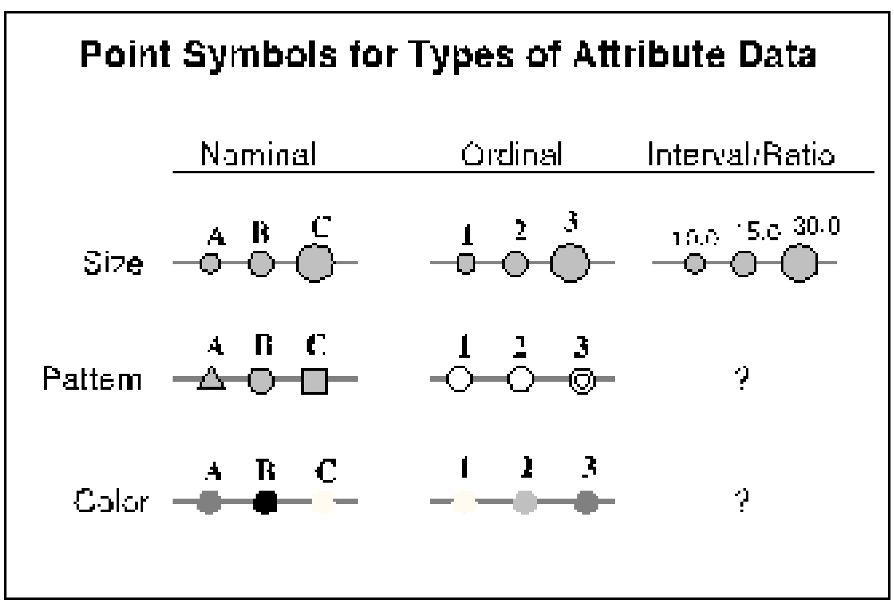



*Figure 2. Point symbols for mapping route-based data.*

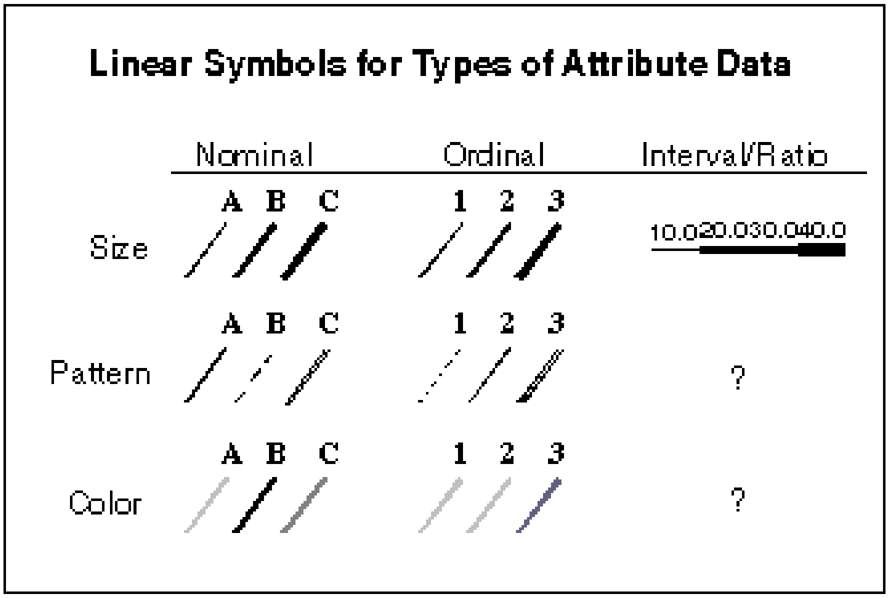



*Figure 3. Linear symbols for mapping route-based data.*

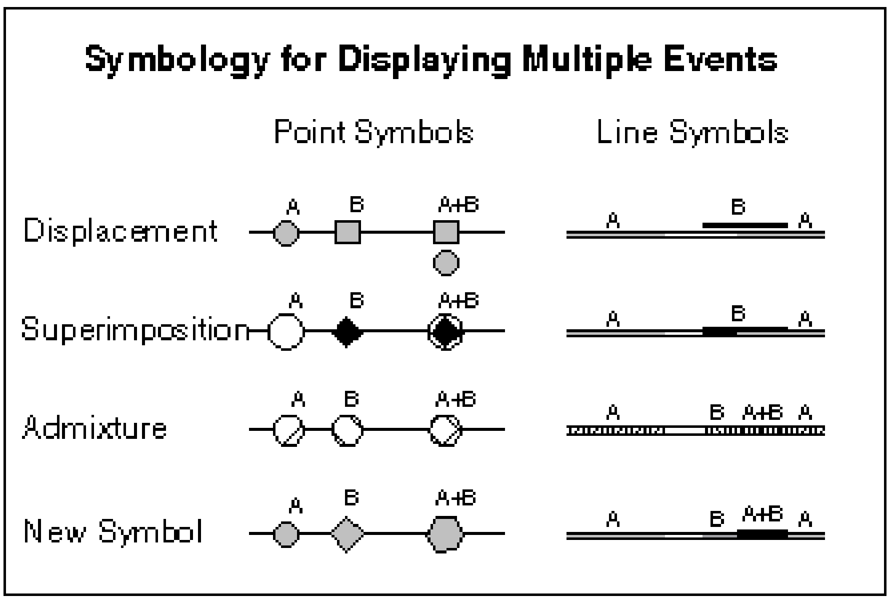



*Figure 4. Some of the symbology options for representing coincident and overlapping instances of route-based data.*

that works in admixture: symbols that when superimposed create a new symbol that the reader can de-compose. This might serve well for cleverly designed patterns, but color is another matter. Can we presume map users would read a purple symbol as the coincidence of blue and red symbols? And how would this supposedly intuitive logic of subtractive colors work on a computer display? A fourth option is to use a distinct new symbol for instances of coincidence and overlap, a solution of limited usefulness. Each case in Figures 2, 3, and 4 could be the starting point for lengthy examination of the many techniques available for cartographic representation.

## CARTOGRAPHIC REQUIREMENTS FOR ROUTE-BASED MAPPING

A specification for route-based mapping begins to emerge when one considers the three characteristics of route-based mapping—spatial conof texture on gray scales (Smith 1987). Bivariate color scales were investigated by Olson (1981) and the interactions of colors on maps have been studied by Brewer (1997).

Another major topic of research has been the choropleth map. Representative examples of work in this area include studies on the selection of class intervals (Olson 1972); the accuracy of choropleth data representations (MacEachren 1985); the ability of map readers to creatively use maps (Carstensen 1986); the performance of computer display maps (Gilmartin and Shelton 1989); and the effectiveness of sequenced displays (Slocum *et al* 1990).

Little of this research applies directly to the design challenges of route-based mapping and such help as it offers comes from inference rather than prescription. This is not to deny that research in psychology and cartography has contributed to our understanding of the capabilities and limitations of map symbols, and there may be experimental work worth revisiting. New perception and cognition studies that build on the foundation of work such as that noted above could contribute much to new knowledge about the visual perception of points and lines that are superimposed on, or offset from, a reference network.

The cartographic requirements of route-based mapping outlined above are general. For each mapping problem there will be a unique combination of elements at work. In particular, there are major differences in the use of, and thus the design of, maps for print versus those for computer display. Given the cartographic requirements identified, the relevant research available to date, and the expected direction of technology, the following five general arenas of research are called for.

*". . . route-based mapping presents more cartographic questions than solutions."*

First, there are the problems of basic symbol interpretation, such as the estimation of the length of lines. If proportional point symbols are used with the expectation that some map readers will attempt to estimate the value represented by a specific symbol, is it not plausible to expect readers of route-based maps to visually estimate the lengths of segments? How accurately do map readers estimate line length in various cartographic settings? Will a bright yellow line be judged as accurately as a black one, and what is the effect of line thickness? The kind of research sought here is exemplified by that of Gill (1988, 1993) who conducted experiments regarding map readers' responses to route symbology. His work offers practical suggestions as well as insight into how route maps are used. Route-based mapping may require a re-examination of symbol perception research. For example, will the findings of past research on symbol size estimation apply when point symbols are superimposed on lines? How well do point symbols superimposed on lines perform under various combinations of hues and values for background, line, and point symbol?

Another area of interest is the set of graphic tools available as desktop publishing software solidifies its presence in mapmaking. Many of these tools should be useful to route-based mapping. Vignettes or halo effects around symbols might be used systematically to portray attributes or characteristics of linear data. Line patterns might be varied in proportion to a data attribute, but is such a symbol effective? Could continuously varying hue be used to represent interval or ratio data on a line? With the ability to manipulate text as a graphic object, could it be cartographically effective to incorporate labeling directly into symbols? Experimenting with ways to vary symbols unconventionally in proportion to attribute values could expand the set of tools available for route-based mapping. The cartogram could also be revisited in the context of route-based data, with the conventional strip map used as a starting point. For certain purposes, a relaxation of geographic space could yield maps showing their straints, event properties, and attribute properties—in light of the kinds of map design problems beginning to be experienced at state transportation departments. Maps of route data are used for: 1) analysis to compare events over time, show different kinds of events together and to visualize the nature of a problem; 2) presentations to boards, commissions, the public; and 3) displays of the operational status of transportation networks. In this environment, maps are published most often as short-run, short-lived plotter output and computer screen displays. Lithography plays a minor role. Both precise data representation and visual clarity are top priorities. Cartographers handling route-based data will face some or all of the following requirements.

*"New perception and cognition studies . . . could contribute much to new knowledge about the visual perception of points and lines that are superimposed on, or offset from, a reference network."*

**Display coincident point and line events—**Cartographers need to display enlightening combinations of data for maps to achieve their potential as tools of revelation. Methods are needed to successfully represent numerous layers of event data. The problems of event coincidence and overlap can involve not only a single set of data, but diverse data sets that need to be shown together.

**Display multiple event attributes—**The complexity of transportation data will frequently require multivariate symbols. Collisions, for example, may have attributes of speed, type of vehicle, and temperature.

**Time—**Much of the data associated with routes is most valuable when analyzed temporally. Transportation networks are dynamic: both physical and operational conditions continually change. Meaningful analysis often depends on the representation of change over time.

**Generalization—**The fluidity of scale available in GIS software will require transformations between event types. A single event might be shown as either a point or a line, depending on data quality, map scale and audience.

**Labeling—**Effective quantitative and technical maps often require thorough labeling of relevant features. Methods are needed for doing this across all scales of display and with all types of media.

**Live maps—**Automated displays of real-time data, such as continually monitored traffic volumes and roadway conditions, require map symbology that will work successfully with little human intervention.

## Topics for research in cartographic design

In its current stage of development, route-based mapping presents more cartographic questions than solutions. Fundamental questions to ask are: What are the goals of route-based mapping? Do these maps work? What does the profession of cartography contribute to this particular kind of data representation?

Psychophysical and cognitive studies have been a central theme of contemporary academic cartography, but surprisingly little research can be found on linear symbology. Perceptual and cognitive research studies of cartography have addressed some of the basic graphic elements used in thematic maps. There has been considerable work done on point and area symbols, and on various characteristics of choropleth maps. Point symbols (the circle, especially) enjoy a forty-year legacy as the subject of research covering such topics as the perception of apparent value (Flannery 1956), the effectiveness of different kinds of point symbols (Flannery 1971, Cox 1976, Heino 1995), and the importance of visual contrast (Griffin 1990).

Color and area patterns have also been prominent subjects of research on the human factors of map reading. Studies have been done on the perception of gray-scale intervals (Williams 1958), shading patterns (Jenks and Knos 1961), un-classed cross-hatching (Peterson 1979), and the effect occur. Such data may be discrete or continuous, permanent or ephemeral, stationary or moving. The mapping of data based on a linear frame of reference poses particular cartographic difficulties that have not been developed thoroughly in the mainstream cartographic literature.

The need for design strategies based on sound principles grows as GIS practitioners embrace the measured route as a base on which features can be mapped. A table of graphic techniques by data type was used as an initial framework for classifying the application of linear graphic variables to route data. This indicated the need for principles of design that address the unique cartographic constraints of route-based symbology such as the effective treatment of symbol conflict, coincidence, interval and ratio data types, and multivariate symbols.

Perceptual and cognitive research is called for to improve our understanding of how well various symbologies work for route data, and how well route-based maps convey knowledge to map readers. These will need to be addressed for both the print and computer screen environments. The depiction of time is of particular concern in the transportation arena, where much of the data represent dynamic phenomena. Cartographic animation and interaction are another arena in which route-based mapping should present unique challenges and possibilities.

*". . . interaction with live maps promises to alter some of our basic approaches to cartographic presentation."*

The problems of route-based mapping outlined in this paper indicate that maps will be increasingly made from *data*, rather than from other maps. Geographic data models are evolving away from their cartographic roots. Most GIS data sets today originated cartographically and analyses based on them are influenced by cartographic idiosyncrasies. This will change, however, as global positioning system (GPS) data and digital ortho-imagery gain use as GIS data sources. Route logs calibrated by GPS data will eventually replace digitized map lines as the "datum" on which linear reference systems are represented. Geospatial data will become scale-independent. Cartographers need to be better equipped than ever to understand, and explain, the cartographic purposes served by the transformations they apply in presenting data on maps. In an era of increasingly complex analytical expectations, using ever more precise and accurate data, cartographers may well be asked to describe explicitly—perhaps quantitatively—the generalizations (introduced errors) applied to the map representations.

SUMMARY AND CONCLUSIONS

An assumption underlying this discussion is the proposition that route-based mapping is to be done, but the availability of a new tool does not necessitate its use. As mapping for linear reference systems develops, cartographers have an opportunity to consider whether it is to be the techniques, or the cartographers, that will be making maps. Cartography involves the transformation of data into representational visual models that communicate, enlighten, persuade and provoke. The knowledge to be gained from route-based mapping depends in part on the ability of cartographers to define the relationship between data models and visual representations of data. If cartography is a transformation process that would inform GIS output with knowledge, then the analysis and explanation of that transformation in the clearest terms possible is an endeavor that cartographers can scarcely fail to pursue.

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thematic features more clearly or pointedly, like the railroad system maps discussed earlier.

Third, many of these publishing software tools can be applied in electronic media as well. Research is needed to indicate how well they serve the needs of route-based mapping for computer displays. The cartographic design problems of screen displays are beginning to receive some attention. Maps in this medium have the dimension of time as a graphic variable that cartographers have begun to explore (Peterson 1997; Karl 1992). Animated maps could help with the effective presentation of complex combinations of linear events by leading the map reader through the data sequentially (Slocum, *et al* 1990). This could be especially effective for the dynamic nature of a great deal of transportation data, for example, the diurnal cycle of traffic volumes and flow directions. Coincident features might blink. Blinking or shimmering point symbols could express one variable, color another, and shape a third. The blink microscope effect might be employed to reveal temporal differences in large, complicated data sets. Dots could run along lines to depict flow direction and speed. Shimmering waves could flow within lines to indicate direction and intensity of a flow. A methodical examination of time as a graphic variable would augment knowledge about symbol cognition to produce guidelines for mapping route-based data. Such studies could add particularly to the effectiveness of live maps of transportation system conditions. Another question for contemporary map design research is the determination of design methods for maps that are to be recognized as the same document in both print and computer display. Such visual equivalency could be important to organizations trying to disseminate authentic information.

*"The problems of route-based mapping outlined in this paper indicate that maps will be increasingly made from* data, *rather than from other maps."*

Fourth, interaction with live maps promises to alter some of our basic approaches to cartographic presentation. Interaction enables the map reader to affect the nature of the display at will. Pop-up annotation is beginning to appear in computer map applications (click on or pause the mouse over a state and its name appears). For mapping route data interactive features could be designed to respond to display scale and to help clarify problems of event coincidence. Lines could collapse into points, and points resolve into lines, at appropriate display scales that the user selects. It should be possible to generalize numerous occurrences into fewer representative events, and to transform a threshold density of points into a linear event. Short network segments and the events occurring on them could receive special treatment at small display scales.

Finally, there is the problem common to both print and computer display of how effective route-based maps can be in communicating quantitative information. How is the character of linear data grasped when a continuous phenomenon is sampled at discrete locations? What does the map reader understand as the difference between point and line symbols along routes? Cartographers have few qualms about generating continuous statistical surfaces from sample points. How should this be done linearly? The concept of linear clusters, aggregations of either discrete points or short segments, may need development. Highway planners use a formula to determine when a cluster of High Accident Locations becomes a High Accident Corridor. Shall cartographers adopt this algorithm *prima facie* or develop their own?

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## reviews

**Envisioning the City: Six Studies in Urban Cartography**.
Edited by David Buisseret. Chicago and London: University of Chicago Press, c1998. xiv, 181pp., ill., maps, bibliographical references and index. US $50.00, UK £39.95 (cloth), ISBN 0-226-07993-7.

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In his introduction, Buisseret notes that town plans, one of the oldest forms of maps, have been neglected in the literature. The aim of these essays is "to develop some themes that could eventually be included in a more complete work . . . ." The themes ". . . concern in one way or another the theory and practice of representation, or the manner in which urban areas have been envisioned." After citing the few significant works on town plans from the past two decades, Buisseret discusses four categories of urban plans: vertical, bird's-eye-view, profile, and model. The plans described by the six authors fit into one of these four categories.

Chapter one, by Nancy Shatzman Steinhardt, is on "Mapping the Chinese City: The Image and the Reality." The author discusses the Chinese tradition of making city plans that differed from reality. The plans projected the vision of city planners who envisioned the city in an idealized form. The principles of Chinese imperial city plans were laid out in the first millennium B.C.; the ideal was a square with a palace complex at the center and three gates in each wall. However, the excavation of cities shows that they did not match their plans. Two other basic plans were also used. Practical needs and the topography of the site often took precedence over the ideal in city planning. The cultural desire to live within walls meant that new walls were built in response to the natural growth of a city rather than in keeping to the ideal plan.

Mapping in early Chinese culture was an imperial activity. The Chinese were sophisticated map-makers and had a literature of map-making. By the fifth century map-making was established in two roles. The first role, for the military, required accuracy and access to it was restricted. The second role, among the cultural elite, used descriptive cartography as an art that was cultivated like painting. In conclusion, the author believes "The reality of the map of a Chinese city lay in the regal system it symbolized . . . ."

In chapter two Naomi Miller writes about "Mapping the City: Ptolemy's Geography in the Renaissance." Her hypothesis is that city maps were a manifestation of an expanding world view as exemplified by the proliferation of Ptolemaic manuscripts during the Renaissance. She examines the ten city maps in the Urbino codex of 1472 and sets this manuscript in the life of the man who commissioned it, and in the context of Renaissance cartography and of developments in Italian and European mapmak-ing. Looking at the maps collectively, she first identifies their common elements: bird's-eye-views, watercolor and ink on vellum, and drawn in orthogonal projection. She then discusses how each city is related to its region: topographical features are emphasized, street networks are absent, architectural elements must be used to get oriented, and religious and civic buildings are shown. Following this overview, the map of each city is analyzed; the cities included are Milan, Venice, Florence, Rome, Constan-tinople, Jerusalem, Damascus, Alexandria, Cairo, and Volterra. Because its style differs from the others, it is likely the view of Volterra was added later, after its capture by Florence. The author believes the addition of city plans to the maps typically found in Ptolemy's Geography reflects the growth in city states and celebrates the great metropolitan areas of the west and the east. These views parallel the texts of the time that are in praise of the city, while the dominance of centrally planned domed buildings show the transition to Renaissance ideas.

Chapter three, by Richard L. Kagan, contrasts "Urbs and Civitas in Sixteenth- and Seventeenth-Century Spain." Using Isaidore of Seville's seventh century definitions of urbs, the city's physical structure, and civitas, the city's social community, the author looks at how these ideas were applied in Spain. The view during that period studied favored people over bricks. Thus cities were ". . . 'mapped' according to criteria that often had little to do with 'description,' . . the aim was to capture the . . . soul of the city . . . ." The author's goal is to make " . . . a comparison between two distinct but sometimes overlapping conventions or modes of urban representation." The first, chorographic, presented a complete visual record of the place. Plans of cities in Spain and the Canary Islands, created by Flemish, Italian, and Portuguese cartographers, are examined. The second, communicentric, presented a metaphor of the city. These plans emphasized locally important monuments, sought to reinforce the spiritual role of Christianity, and ignored the Muslim heritage present in many cities. During this period the plans of other European cities were becoming more accurate. Although the quality of Spanish architectural and engineering training was equal to that in other countries, the towns that needed fortifications and seaports that supported maritime interests. Their scale was large, generally around 1:600. By 1760, the creation of models became a waste of time for engineers who could read contour lines. Collections of models were further devalued when the war of 1870 demonstrated the uselessness of places fortes.

Although some models were destroyed during transport, or for lack of storage space, their historic value and their contribution to the understanding of urban areas and their rural surroundings are now recognized. They attempted to carefully reproduce reality, made the area accessible from all angles in a period before aerial photography was possible, and they depicted sites now lost to further urban development. The author concludes that while models are hard to display in ways that allow their full appreciation, the absence of abstraction makes them the best method for quickly orienting large groups of people.

Gerald Danzer examines the enduring power of visual images in chapter six, "The Plan of Chicago by Daniel H. Burnham and Edward H. Bennett: Cartographic and Historical Perspectives." The author starts from the premise that " A concept of the metropolis as an organic whole was a prerequisite for urbanity, and making maps was one way to address this need for a comprehensive depiction." He discusses the components of urban images, the role of profiles and perspective views as complements to plans, and the purposes of urban views. The Plan of Chicago, the most celebrated plan of the early twentieth century City Beautiful movement, is examined by asking historical questions and by evaluating it cartographically as an atlas. Today the plans's maps and illustrations, rather than its text, are identified as the plan.

The stage for this analysis is set by reviewing Burnham's life experience in Chicago and his accomplishments as an architect. By the time he became a city planner he was one of the country's most notable and influential architects. He had planning experience in major cities like Washington, D.C. and San Francisco and gathered colleagues from these projects to assemble the team that created the Chicago plan. Burnham worked from the vantage point of a penthouse on top of a tall building in the center of the city where his staff gathered all the types of plans and views possible. He was able to draw on his firm's large collection of documents on urban planning in American and European cities. The authors and artists of the plan created a basic vision of what Chicago might be, illustrated the vision in a number of ways, and tried to convince the citizens who knew the city that it could become something else.

Danzer then examines the maps, views, and illustrations in each chapter of the plan and how the use of color, placement and arrangement are a key to understanding the plan. The relationship of the city to Lake Michigan is emphasized while the role of the Chicago River is not. The plan accepted the dominant street pattern based on the township, range, and section lines of the public land survey system, but also aimed to give the city what the grid did not — central places, radiating arteries, expansive views and focal points. The central business district, where the project was conceived, developed, financed, and presented to public is emphasized, and the plan was criticized for that emphasis. In its summary, the creators of the plan outlined the cultural and economic basis for a great city and made the case for public commitment to those goals.

These six essays originated in the lectures on "Profiling the City, " the tenth series of Kenneth Nebenzahl, Jr., Lectures in the History of Cartography, held in November 1991 at the Newberry Library, Chicago. The lecture series, whose quality attracts an international audience, seeks to advance the discipline by identifying a theme worthy of further study and inviting qualified scholars from a variety fields to address an aspect of that theme. These published essays, written by academics from the fields of art, art history, and history, are revised versions of the lectures and are not intended to create the definitive work on urban cartography or to completely survey the field. All the essays in this volume fit the theme of envisioning the city. They do address the subjective elements in urban plans and demonstrate the use of various types of urban plans at different times and places.

The essays vary in length from 16 to 41 pages, the shorter chapters being those that examine cartographic works based on reality (chapters 4 and 5) rather than those that present an idealized view of the city. All the chapters are well illustrated, the number of figures per chapter ranges from 12 to 36. Some of illustrations are difficult to read either due to their manuscript origin or the small scale of the reproduction. The book could be made stronger by the inclusion of a list of figures or an index to cities illustrated. Trying to locate the illustrations of city plans, views, etc. by consulting the index is problematic. The index makes no attempt to identify, for example through the use of boldface, a page that bears an illustration as well as a textual mention. Indexing and cross references are inconsistent. Some cities are indexed under both their original and their modern name, others are not. For example, Pingcheng (original city) does not appear in the index although it is illustrated and appears in the text on page 14. However, Datong, the modern city which Pingcheng is plans of Spanish cities continued to be idealized until the start of the eighteenth century.

In chapter four, on "Military Architecture and Cartography in the Design of the Early Modern City," Martha Pollak examines two seemingly irreconcilable activities, the construction and the destruction of cities. Theorists conceived and planned the ideal city based on principles such as aesthetics and symmetry. For three centuries the radial plan and the orthogonal plan were the two dominant urban designs. The control afforded by this geometry suited sixteenth century dictatorships and seventeenth century absolute monarchies and became the ideal fortresses of seventeenth century military architects. War was important in the creation of early modern states. Conflict resolution through the siege of cities transformed both their appearance and their function. Treatises on military architecture debated the number of sides that offered a city and its fortress the best defense, and military theorists used their personal experience in war and in architecture when creating plans. The fortress, built on the side of the city, not only defended the city but also subdued local unrest and provided shelter to a city's ruler.

The relationship between military architecture and cartography becomes evident in the seventeenth century when the need for representations of fortifications and the relationships between their parts was understood to aid in their evaluation. The creation of plans, elevations, and profiles supported design development, afforded a visual check of fortifications before they were built and aided in their restoration after war damage. The quality of surveying improved because accurate topographic plans were needed to lay siege and to rebuild. The plan, the most abstract and hardest to read, became the most common urban plan. Its scale and vertical view offered knowledge of the entire city, not just the foreground or prominent buildings. Historic urban cartography is tied to military planning because the defense of the city was the source of the seventeenth century cartographic movement that came to influence our perception of the city.

Chapter five, by David Buisseret, studies three dimensional representations of reality in "Modeling Cities in Early Modern Europe." The author first reviews the history of city models that began in sixteenth century Europe. The models were created by those who already made good use of maps and the towns modeled were typically either French, Italian, Bavarian, Spanish or Dutch. Although the English were aware of them, models were not typically done by the English. Their use continued into the nineteenth century, but they were less used after the advent of contour mapping. More recently, models were used during World War II for the D-Day invasion of continental Europe. Today digital imagery and terrain modeling make traditional modeling less important, however, models are still built by students of architecture. Some cities use models to orient tourists and have developed tactile models for the blind.

Buisseret examines in detail selections from among nearly 125 plans-relief. They were constructed over two centuries, from 1660 to 1870, and are the survivors of a famous collection housed in Paris. First mentioned in the 1550s, no models from that period survive. Models were most in vogue from 1663 until about 1760 and were created for cities of strategic importance, for example, frontier

**Visual Explanations: Images and Quantities, Evidence and Narrative**. Edward R. Tufte. Chesire, CT: Graphics Press, P.O. Box 430, Chesire CT 06410, 1997. 156 pp, maps, diagrams, illustrations, index. ISBN: 0 961 3921 2 6. $45.00

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Geographers and cartographers are accustomed to creating, interpreting, and analyzing maps. However, we tend to focus our efforts on the display of spatial information in the form of a two-dimensional representation as a map, often forgetting that maps are but one member of a larger class of graphical formats for the presentation of quantitative information. Although most methods for the display and interpretation of quantitative information are inherently spatial, relatively few scholars within our discipline have investigated the processes whereby individuals sense, assess, interpret and assimilate spatial information in graphical form. Perhaps no one has done more to further our understanding of how humans interpret information spatially than has Edward R. Tufte, a professor who teaches courses in statistical evidence, information design, and interface design at Yale University. In 1983, Tufte published *The Visual Display of Quantitative Information*, followed in 1990 by *Envisioning Information*. Whereas Tufte describes his first book as being about 'pictures of numbers' and the second about 'pictures of nouns', the present volume, *Visual Explanations*, is about 'pictures of verbs'. This triad of books addresses big questions, in some ways filling the void between Huff's *How to Lie with Statistics* and Monmonier's *How to Lie with Maps* by demonstrating, mostly by the correct application of graphical techniques, design mised that there may be a spatial pattern to the residences of individuals affected by a devastating cholera epidemic in London during the early 1850s. By mapping incident cases and the locations of eleven water pumps in the area, Snow identified a pattern of clustering in the neighborhood of one, the Broad Street pump. In a series of events that has assumed the status of myth in the annals of epidemiology, Snow persuaded civil authorities to remove the pump handle, thereby eliminating access to a presumably contaminated water supply. Such is the fabled account found in introductory epidemiology and medical geography texts; Tufte explores the matter further, revealing not only the brilliance, but also the limitations of Snow's pathbreaking exercise in field epidemiology. Snow's famous map does not show trends in cholera incidence over time, nor does it reveal the behavior of the residents of the crowded London neighborhoods involved. While it is true that the epidemic soon abated, this is a natural feature of the temporal sequence of infectious disease outbreaks. Coupled with the fact that many persons fled the city or had already contracted cholera, it is not surprising that the epidemic waned. Would this have happened irrespective of Snow's intervention? We'll never know - but Tufte's point is that there's always more than meets the eye, even when the subject is an example of visual explanation that has achieved the status of an icon.

The second example in this chapter is the space shuttle Challenger disaster on January 28th, 1996. In addition to providing the most comprehensive account of the antecedents and investigation of this disaster, Tufte also presents conclusive graphical evidence to demonstrate that the nature of the O-ring defect was known and could have been avoided. As Tufte concludes from these examples: "there are right ways and wrong ways to show data; there are displays that reveal the truth and displays that do not" (p. 45).

"Explaining magic" is a fascinating chapter in that it deals specifically with the methods whereby magicians, charlatans and other practitioners of sleight-of-hand build disinformation into their routines. Tufte presents this material because the process of creating illusions is "to engage in disinformation design, to corrupt optical information, to deceive the audience" (p. 55).

"The smallest effective difference" deals with the data graphics principle that visual expressions should use "just notable differences, visual elements that make a clear difference but no more" (p. 73). In some cases this means choosing line weights or labels that provide information while not detracting from the graphical image. In other cases color schemes for different map elements can obscure or elucidate quantitative information included in a map.

"Parallelism: repetition and change, comparison and surprise" focuses on strategies of visual parallelism that have their analog in the use of parallel structure in oratory and prose. Tufte introduces this topic with a series of exquisite examples of this graphical design principle in practice. These include parallel images of a sculpture of a horse by Degas, landscape designs by Repton, and Isaac Newton's scientific diagrams. Multiple parallels are also considered in a variety of graphical contexts, as are graphical user interfaces in software applications, a chart depicting aspects of a lengthy stays at a Russian space station, and examples from the field typography and letterforms. Unfortunately, it is easier to err in the use of parallelisms, and Tufte provides several thoughtful examples to depict pitfalls we should strive to avoid. Almost poetically, Tufte concludes this chapter: "And by establishing a structure of rhythms and relationships, parallelism becomes the poetry of visual information" (p. 103). "Multiples in space and time" builds on the previous chapter by illustrating the use of spatial and temporal multiples in a variety of settings.

"Visual confections: juxtapositions from the ocean of the streams of story" pulls the various elements described previously into a four-dimensional array of visual verbs and nouns, depicted over time and at points in time as a 'plane of events'. Examples are provided from the fields of art, architecture, the news media, and museum guides, among others. Tufte defines a visual confection as "an assembly of many visual events, selected . . . from various Streams of Story, then brought together and juxtaposed on the still flatland of paper" (p. 121).

Once again, Tufte has advanced our understanding of the logic of depicting and displaying quantitative evidence. Technically elegant, the book is profusely illustrated and referenced, in a readily readable format that makes its content accessible to its readers. The book might be improved by providing an annotated flow diagram that incorporates all of the data visualization principles explored in the three volumes. But then again, Tufte's major point is that, while there are design principles, these are most obvious when viewed in the breach. Data graphics may be the language of science, but their design remains, to a great extent, an amalgamation of science with art!

As with his previous books, *Visual Explanations* is a masterpiece of technical and artistic detail, both in content and production. Written, designed and published by the author, it personifies the practice of self-exemplification to which so many of us adhere but rarely actualize. Geographers and cartographers who add this book and its principles and research on visual perception, "How Not to Lie with Data Graphics."

The book consists of seven chapters, each with intriguing titles that provide a glimpse of the contents and beckon the reader to look within. "Images and quantities" is concerned with how assessments of quantity are represented in visual expressions. While Tufte devotes much of this chapter to a discussion of a scientific visualization exercise in which a thunderstorm was animated in three dimensions, then redesigned by Tufte to illustrate design principles for 'pictures of verbs', many of the other examples in this chapter are drawn from the field of cartography.

"Visual and statistical thinking" focuses on displays of evidence for making decisions. Tufte uses two effective illustrations, one well-known to medical geographers (Dr. John Snow and the Broad Street pump) and the other a catastrophe that captured the popular imagination (the explosion of the space shuttle Challenger). Snow was an astute clinician who sur-

## *cartographic techniques*

### Creation of Publication Quality Shaded-Relief Maps with ArcView GIS

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#### Introduction

This article describes a project to design a quality map entirely within ArcView GIS. I will briefly outline the purpose and data used, then describe in greater detail the creation of the shaded-relief base map, and conclude with some comments about proofing and printing the map.

#### Designing the Map

In order to produce a quality map, we first had to settle on the purpose of the map and the area it would cover, as well as the format of the final product. We decided to make a map of the Salt Lake City region showing the extent of urbanization and the locations of cities, towns, and major roads in the context of the surrounding terrain. As our final product we planned to publish a quality color map using four-color process printing.

#### Acquiring Data

The next step was gathering the data for the map. For this map we downloaded DEM files from the USGS website, and browsed various publicly available CD-ROM data sets including ESRI sample data. The DEM files are compressed with the GNU "gzip" utility and can be downloaded as compressed or uncompressed files. These files can also be uncompressed with gzip or WinZip, both of which can be acquired from the Internet.

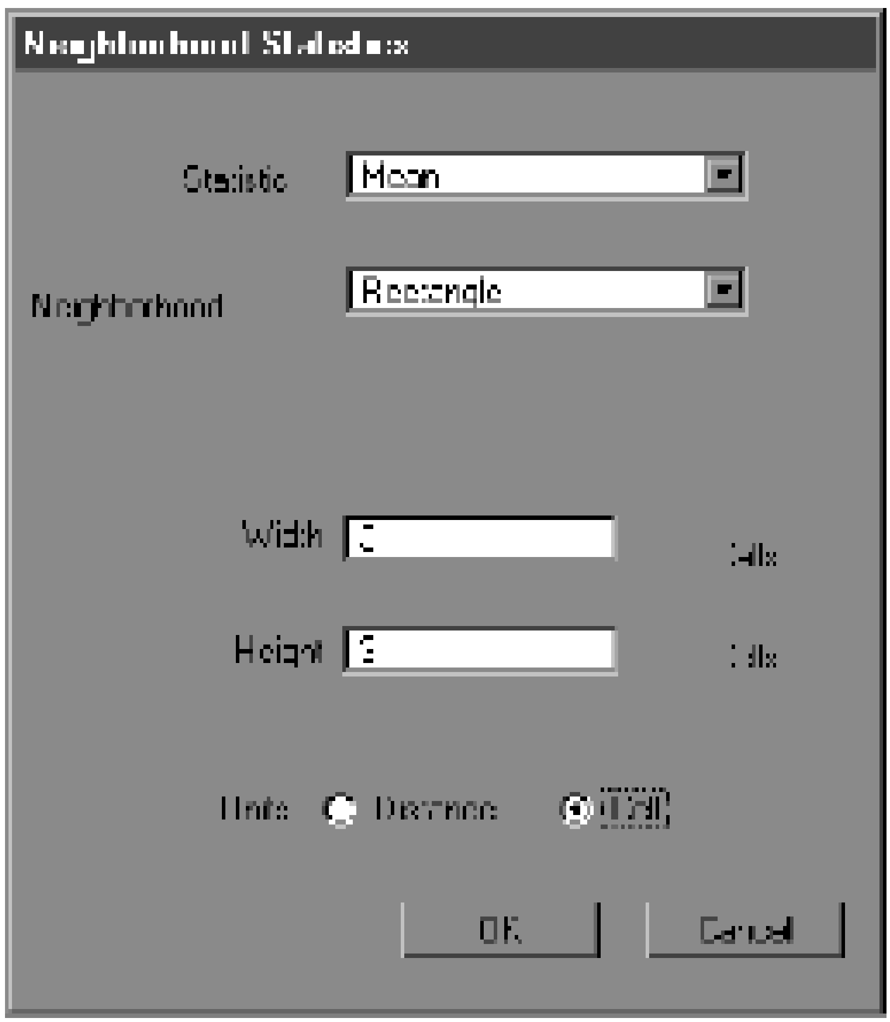


*Figure 1. Neighborhood Statistics dialog from the Analysis menu of Spatial Analyst*

**Adding Vector Data**

The vector data were added to the view as themes, and then symbolized and labeled. There are many options and tools available to the user including spline text, auto-labeling, highway labeling tools, and labels with leader lines. Using map queries the user can create subsets within themes and then label the features within the subsets accordingly. The symbol palette allows the user to adjust colors, symbols, line and fill styles, and fonts for labels and text as well as for most map elements.

Color and symbol choices were designed to enhance the appearance and functionality of the map. For example, we made city labels more prominent by using black text, and mountain labels less prominent by using gray text. These choices establish a hierarchy of information on the map.

**Creating the Hill-Shaded Basemap**

The Spatial Analyst extension has to be loaded when you work with

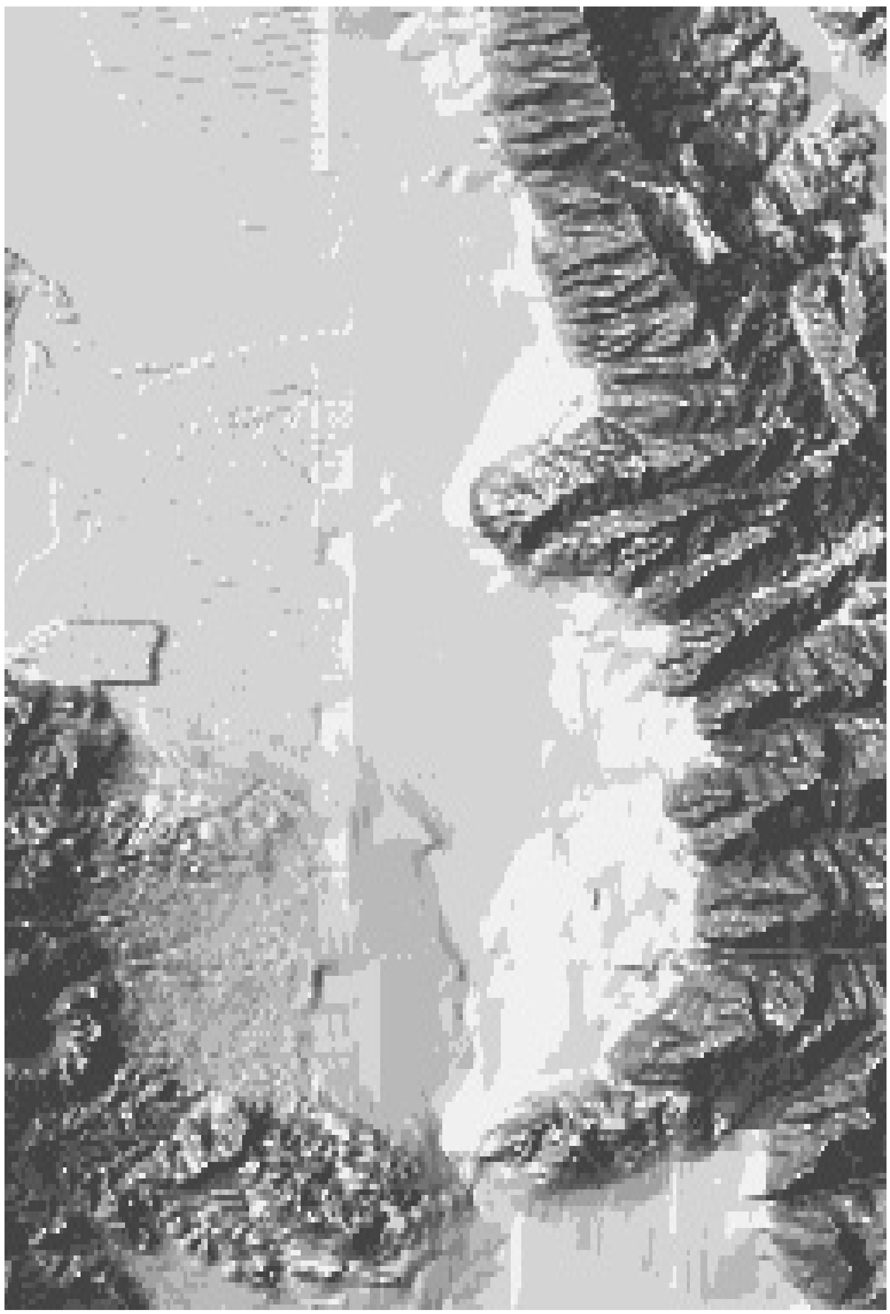

*Figure 2. Combined hill-shaded image (Map calculation 1)*

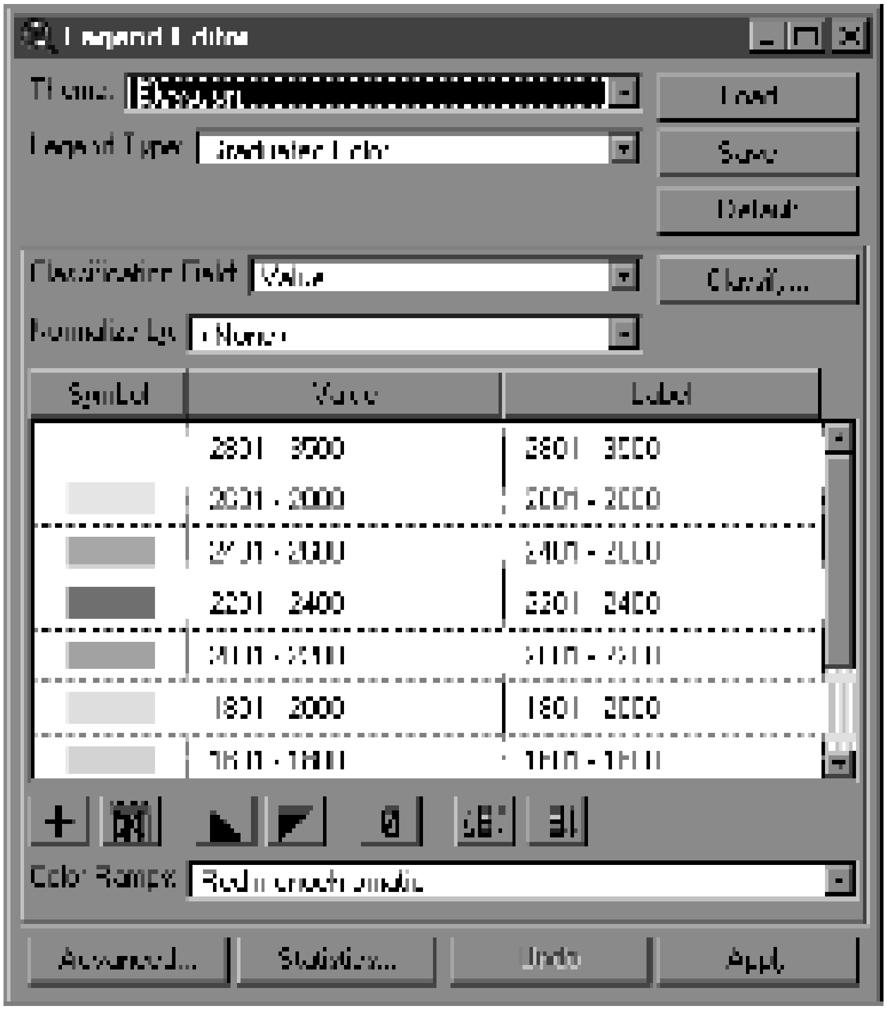


*Figure 3. ArcView's raster theme legend editor*

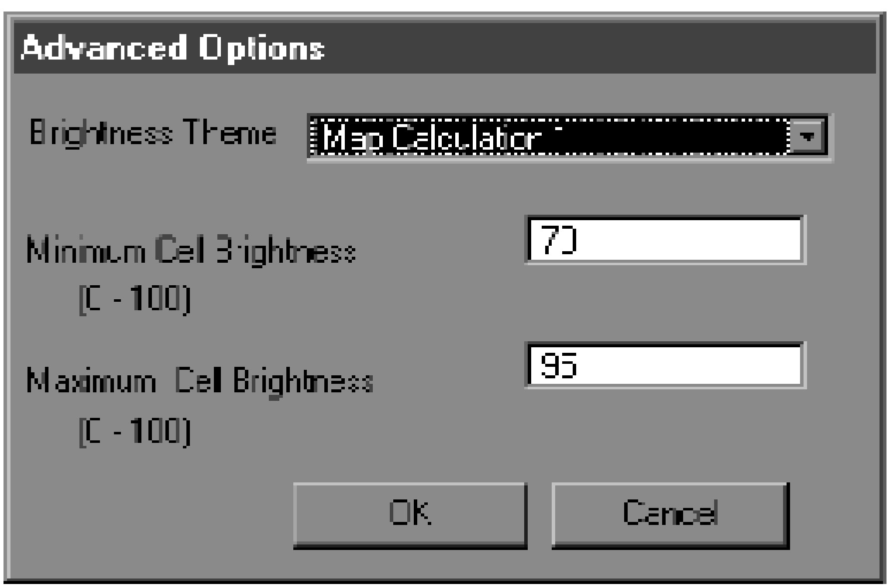


*Figure 4. Advanced options accessed from the legend editor*

grids in ArcView. It is also important to use the data manager under the File menu if you want to copy, rename, or delete grids. This manager will take care of the related files that ArcView uses when handling grids.

To show the DEM files in the same coordinate space as our vector themes, we had to convert the DEM files from arc seconds to decimal degrees. This was done using a sample script called DEMShift that imports and converts the files. This script is available on ESRI's sample scripts website.

Once the DEM files were converted, we created a smoothed version by using neighborhood statistics under the analysis menu and choosing "mean" at the statistics option (fig. 1). This helps smooth out some of the irregularities and other artifacts introduced by DEM data and sampling methods.

Next we created two separate hill-shaded themes with different azimuths from the smoothed DEM by using another sample script called DEMShade. We used azimuths of 315 and 270 and an angle of 60 degrees to produce the hill-shaded themes for the Salt Lake City map. These two themes were then combined by the use of a map calculation to reduce deep shadows and the effect of cast shadows (fig. 2).

We categorized the original DEM theme by elevation to create layers for hypsometric tints. Under the advanced option in the legend editor we set the brightness theme to the map calculation of the two hill-shaded themes (figs. 3 and 4). Minimum and maximum cell brightness levels were set at 70 and 95, respectively, to achieve the desired effect of subdued background colors.

The brightness option requires grid themes for the brightness theme and the current theme. The brightness theme is used to alter the brightness of the colors in the current theme. Any kind of grid data can be used. Using a shaded relief theme adds the appearance of three-dimensional terrain to other kinds of thematic information.

It is important to keep in mind the purpose of the map elements when making color choices in order to enhance the appearance and legibility of the map. In our case the color hill-shaded image is the basemap on top of which all of the vector information is placed.

**Color Proofing**

Once we had created an esthetic and legible map on the layout, we began the iterative process of color proofing. This was necessary because the RGB colors of the computer monitor do not translate directly to the CMYK colors used in printing.

We made preliminary color proofs by printing directly from ArcView to a desktop color printer. As color output from desktop printers can vary considerably due to a number of factors, this was only a first step. Once we felt

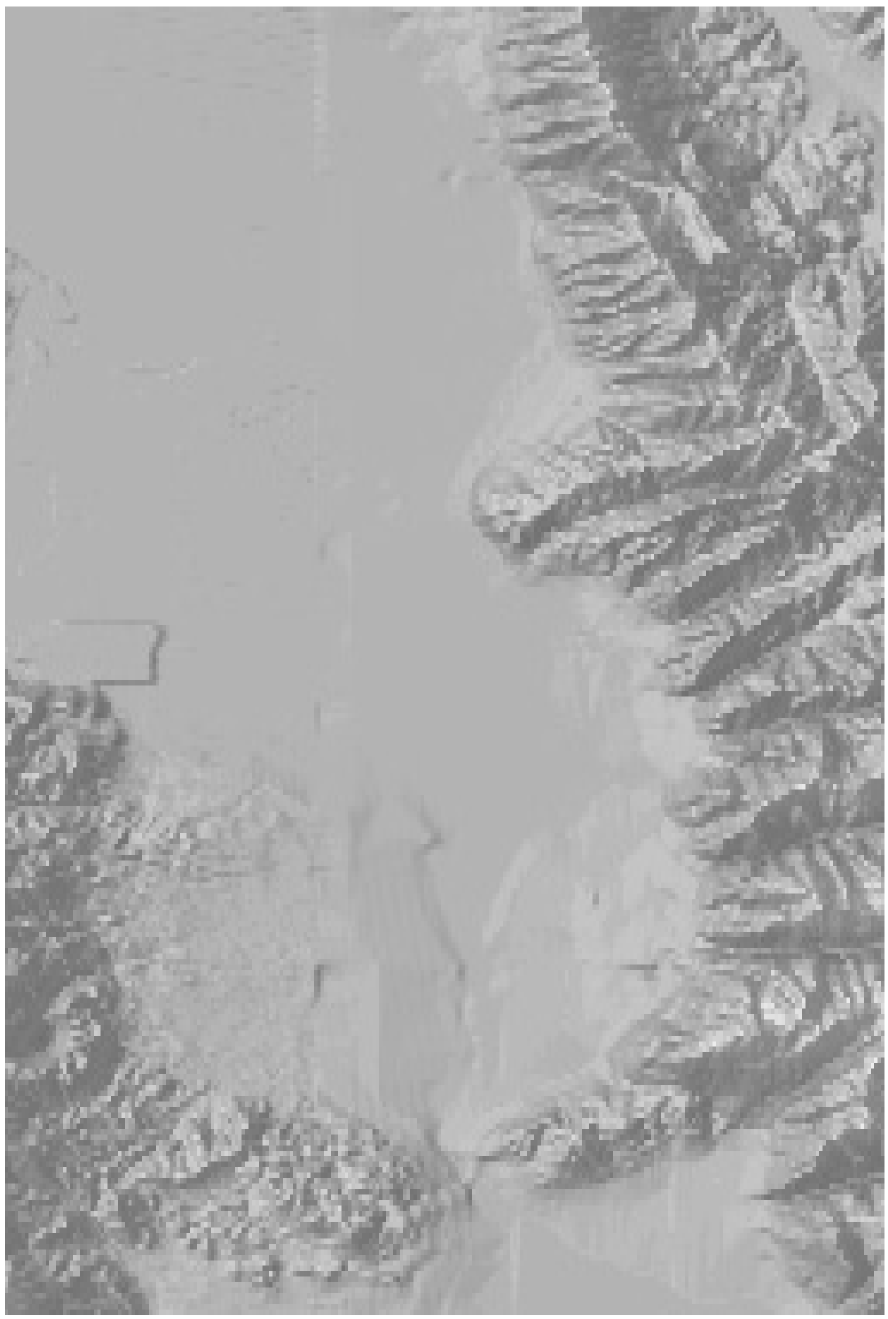

*Figure 5. Elevation theme with hill-shaded image as brightness theme*

reasonably satisfied with the results, we exported the layout to a PostScript (New) file. Our graphics department printed this file to produce a more exact proof.

Imagesetter bureaus, commercial printers, or graphics departments can use color profiles to simulate the inks and papers that will be used to publish the final map. These profiles are used to process PostScript files and produce quality hard-copy color proofs. The proofs are useful as a guide for adjusting colors before negatives are made for printing. It may be necessary to repeat this process to achieve the desired results.

**Printing the Map**

Many factors can influence the appearance of the final printed product including the quality and color of the paper, the inks and color model used, as well as the design of the map. In order to end up with the best printed map, it is helpful to work with the imagesetter and printer throughout the process.

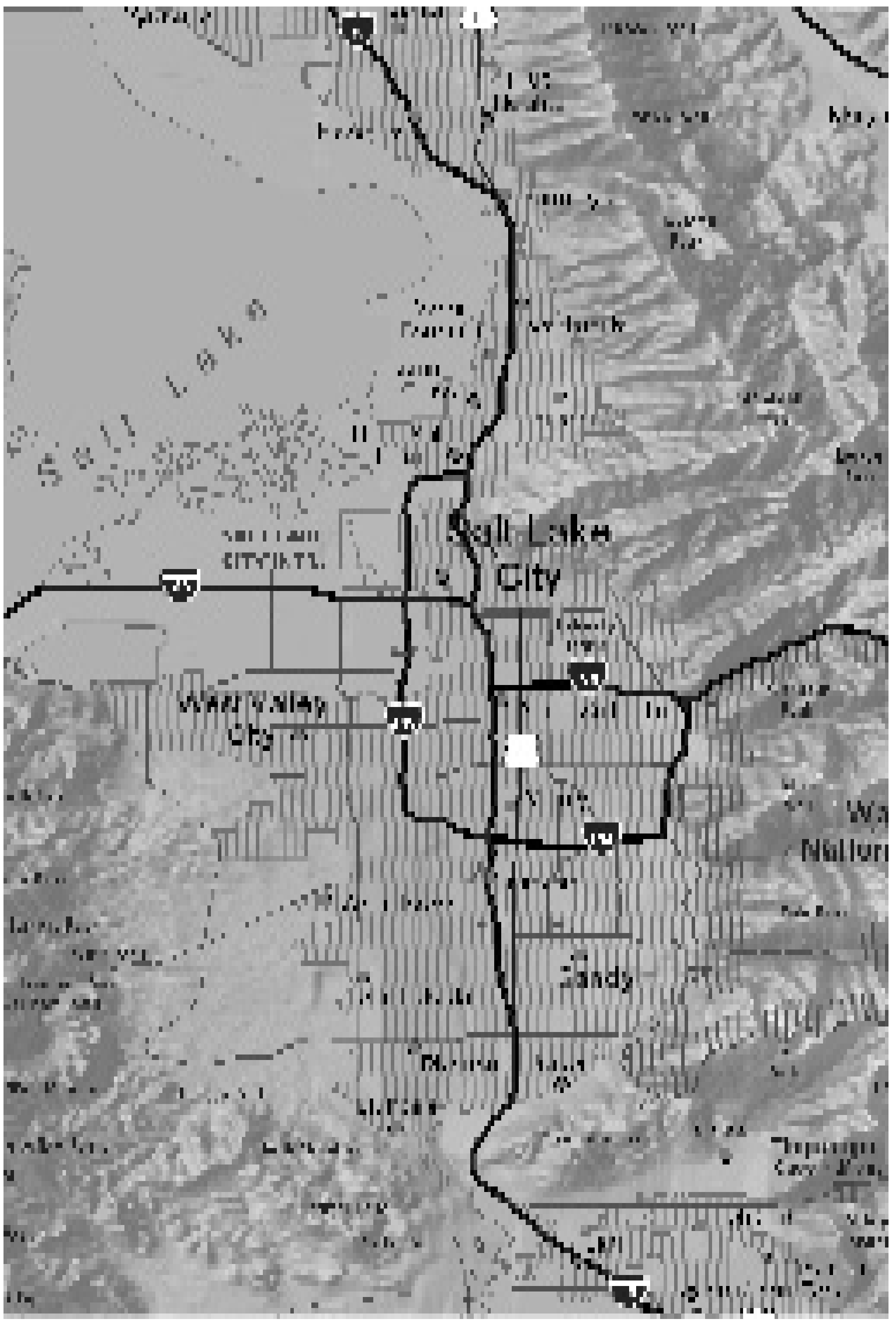


*Figure 6. Section of final map (published map is full color)*

**Further Information**

The USGS home page is located at http://edcwww.cr.usgs.gov

For more information about 1:250,000 scale DEM files see the USGS web site at http://edcftp.cr.usgs.gov/pub/data and navigate to the DEM/270/00README file.

Sample scripts from ESRI are available at http://andes.esri.com/arcscripts/scripts.cfm

The gzip program is available via anonymous FTP at the following sites:

For UNIX: prep.ai.mit.edu:/pub/gnu
For MAC: mac.archive.umich.edu/mac/util/compression/macgziop0.cpt.hqx
For MS-DOS: prep.ai.mit.edu:/pub/gnu/gzip-1.2.4.tar

WinZip can be downloaded from

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The NACIS Program Committee invites you to participate in this meeting by presenting a paper, poster, or exhibit, or planning a session, panel discussion or workshop. Computing facilities at the College of William and Mary will be available for workshops. We look forward to featuring the recent developments in map librarianship & government mapping. All cartographic-related topics are welcome.

*Potential topics include:*

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- *Cartographic visualization*
- *Free-lance and commercial cartography*
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- *Cartography in colonial America*
- *GIS developments*
- *Recreation and tourist map design*
- *Map library issues*

**For Papers:** E-mail your 250-word abstract to the program chair, Tom Patterson, by May 17. Please include your submission within the e-mail message, rather than as an attachment. List names and affiliations of all authors, and include phone and e-mail for the presenting author and specify equipment needs. We encourage student participation.

E-mail abstracts & questions to:
**pattersn@ix.netcom.com**
DUE May 17, 1999
(after the deadline on a space available basis)

**For Exhibits or Posters:** Contact Jeffrey McMichael at jmcmichael@gsu.edu by October 1, 1999 to reserve space and discuss what you plan to display in a poster session.

*from the President*
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vividly. It was my first NACIS meeting and I came with copies of a manuscript corresponding to a presentation about my master's research. I submitted those copies to the Publications Committee chair, Alan MacEachren, and then worked with the new editor, David DiBiase, to prepare the paper for publication. That was the most prescient of conferences in my career; I eventually married that young editor, getting to know him as we worked on preparing my paper for publication in CP, and I am now Alan's colleague on the faculty at Penn State.

CP has grown up too, moving from 24 pages to over 64 under the guidance of three marvelous editors: David DiBiase, Sona Andrews, and now Michael Peterson, as well as a series of guest editors. We've graduated from a bulletin to a journal, to perfect binding, and to a peer-review process of paper submission. CP has retained its multidisciplinary character, gathering news about mapping companies, government agencies, map libraries, academia, and university cartography labs.

We have had the pleasure of a stable and committed 'home office' with Chris Baruth, Susan Peschel, and Sona Andrews keeping things running smoothly: keeping membership organized, negotiating conference hotel contracts, ensuring the treasury is well managed, and keeping us Presidents and Vice Presidents on schedule. This year, the NACIS board happily reappointed Chris to his third four-year commitment as our Executive Officer. We greatly appreciate the American Geographical Society's continued contributions to NACIS through its support of Chris and Susan as they manage our executive office.

This past year, as we have continued to work on improving CP, we have been working on increasing the NACIS membership. This effort has led in numerous directions. We prepared and distributed a brochure to recruit new members and have been reminding our current members to recruit their colleagues. We are currently advertising in ArcUser and ARC News, with a smartly designed 6.5-by-5.5-inch ad by Tom Patterson, and are reaching mapmakers on circulation lists totaling over 300,000. ESRI has been very helpful in assisting promotion of NACIS membership. We have also been working on our web site at www.nacis.org. Jeremy Crampton deserves much thanks for leading our web development work. We are averaging about 100 hits a day, with the most attention to the CP part of the site. The site also includes information on how to join NACIS, lists of university cartography labs and custom cartographers, and conference plans and programs.

We are a healthy and vital organization that creates channels of communication between people from all aspects of mapping. We want to increase our membership to get news out to many more people about mapping from all perspectives. We would be very pleased to hear other creative ideas about ways to increase membership: please contact Tom Patterson, chair of our Membership Committee, at T_Patterson@ccmail.itd.nps.gov
with your suggestions. We always have an eye out for new nominees for the board of directors, for contributions to CP, and for new cartographic web content. So, please participate in NACIS in any way that matches with your interests.

Our 1998 conference in Milwaukee was a success, with high attendance, a jam-packed slate of interesting papers, and an invigorating buzz of discussion and laughter. Please plan to join us at our next conference in Williamsburg in October. The call for papers is out, so please plan your conference participation: abstracts will be emailed to our Vice President, Tom Patterson, who is Program Chair for the conference this year. Preliminary program information will begin to appear on the web site in the summer and will also be mailed to members. I hope to see you there.

*Cindy Brewer*
*President NACIS*
*cbrewer@essc.psu.edu*

**NACIS WEB SITE**
**www.nacis.org**