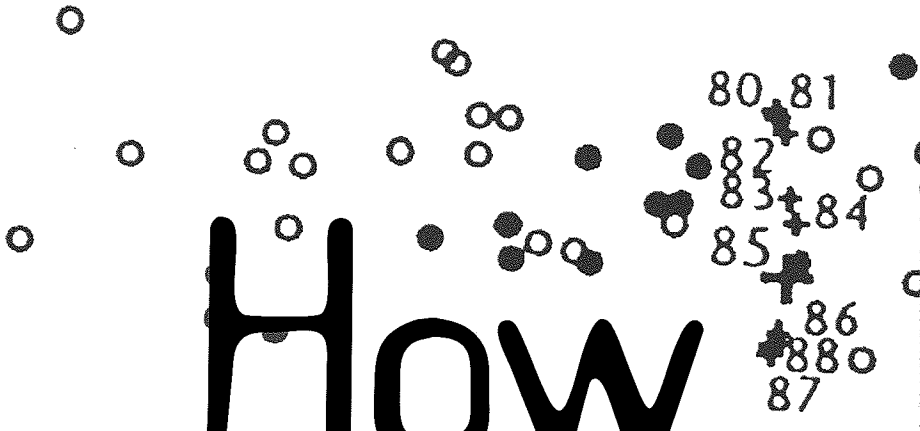

How Maps Work

Representation, Visualization, and Design

Alan M. MacEachren

CHAPTER FIVE

A Primer on Semiotics for Understanding Map Representation

Two dominant semiotic traditions can be identified, one with roots in C. S. Peirce's "semeiotic" and the other in Saussure's "semiology" (associated with North America and Europe, respectively). Peirce (1839–1914) approached semeiotic as a science of signs, taking the perspective of a scientist (with training in chemistry) interested in the "logic of science." He achieved induction into the U.S. National Academy of Sciences in recognition of his contributions to logic. Saussure (1857–1913), in contrast, was trained in France as a linguist. He envisioned the topic of semiology as a science which "studies the life of signs in society" and attempted to link it with the developing field of social psychology, a field that he also saw as focusing on the most important components of language (Hervey, 1982). Saussure's semiology presented language as the analytical paradigm for all other sign systems. The traditions traced to these founding scholars remained, for more than half a century, surprisingly separate. According to Nöth (1990), it was not until 1969 that the term "semiotics" was generally agreed upon as the label for the discipline (when it was selected by the initiators of what eventually became the International Association of Semiotic Studies).[1] Although many "schools" of semiotics (with both theoretical and applied emphases) exist today, their links to either the Peircean or the Saussurean tradition remain evident. The Peircean tradition has provided the most elaborate analysis of the typology of signs and how they "stand-for" their referents, while the Saussurean

tradition has had a decisive influence on the semiotic theory of codes (i.e., the study of sign systems).

The above distinction suggests two fundamental issues of semiotic inquiry relevant to map representation: *the nature of map signs* as relationships between map marks and referents (and associated typologies of signs) and *the nature of map sign systems* as relationships among map signs. Each includes functional components (i.e., related to the mechanism of representation) and lexical components (i.e., related to kinds of meaning and how it is achieved).

THE NATURE OF SIGNS

Among the initial issues that we must address is a precise definition of the topics of discussion: the sign and its components. The terminology of semiotics can be particularly confusing because of the interdisciplinary nature of the field (with terms contributed from linguistics, philosophy, anthropology, logic, psychology, and sociology). To make matters worse, individual scholars are often inconsistent in their own use of terminology. Part of the difficulty seems to be related to issues of dual-category representation (common and scientific), discussed in Chapter 4. Many terms used by semioticians (including the term "symbol") had common meanings before they were usurped for scientific use. Often the common and scientific uses become intermixed, even within the same essay. I preface our semiotic primer, therefore, with a discussion of the terminology to be adopted.[2]

At the broadest level, semiotics considers the relationship between an "expression" and the "concept" to which that expression refers. Not all semiotic theories include reference to the "real" world. In those that do, however, sign is expanded to include the "object of reference." Following Nöth (1990), I adopt the convention of using *sign* to specify this overall relationship: the "entity" encompassing an expression, the concept it stands for, and the object of reference. Thus, a sign (as defined here) is not a "symbol" in the common sense, nor any other kind of mark that carries meaning. Neither is it a physical device used to inform or dictate behavior (as used in the term *traffic sign*).

The "carrier of meaning" will be referred to here as a *sign-vehicle*. While this term is perhaps clumsier than "symbol" or "expression," it does not suffer from the multiple meanings of "symbol" nor the implied links to natural language of "expression." In addition, as will become clear below, the term "symbol" has come to have a very narrow definition in the semiotic literature. A physical traffic "sign" is an example of a sign-vehicle, as is a drawing of a pair of crossed pickaxes on a topographic map.

The "meaning" (or concept) to which the sign-vehicle refers is termed the *interpretant*. This term (borrowed from Peirce) has been selected over the many alternatives (meaning, sense, idea, content, signatum, notion, significatum) because it is unlikely to be confused with an actual object in the real world (as "content' or "signatum" might be) and because it suggests an act of interpretation (making clear that the sign relationship is more than one of simple definition).

Finally, the object of reference to which the sign-vehicle is linked via the sign (in those theories where such an object is included as part of semiotic inquiry) will be labeled the *referent*. This term does not imply that all signs represent physical entities (as Peirce's use of "object" does), nor does it limit consideration to explicit relationships (as Morris's [1946/1971] use of "denotatum" seems to).

Models of the Sign

The two semiotic traditions referred to above (i.e., those traced to Peirce and to Saussure) are linked with two general models of "sign" as a relation. These models are referred to as *dyadic* and *triadic* models, alluding to the number of elements identified in their sign relationship.

For Saussure in 1916 (1959 translation reprinted in Innis, 1985) a sign was the relationship between a sign-vehicle (what he called a *signifier*) and an interpretant (what he called a *signified*). In his linguistic application of the idea, these become a "sound image" and a "concept," respectively (Figure 5.1). This dyadic model for Saussure's "sign" explicitly omits the referent. For Saussure, semiology (i.e., semiotics) operated within the sign system which was, in his view, completely arbitrary (Nöth, 1990). Saussure's theory of the sign, then, had nothing to do with how sign-vehicles refer to real-world entities, only with how they refer to mental concepts. As Nöth (1990, p. 61) notes, "According to Saussure's structuralist view of semantics, meaning is the *value* of a concept within

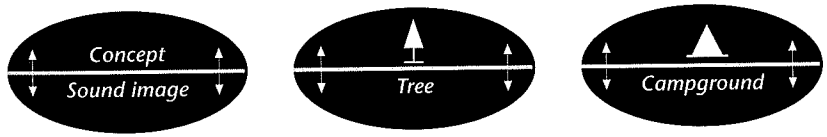

FIGURE 5.1. A depiction of the sign *tree* as proposed by Saussure (1959 translation reprinted in Innis, 1985) and a similar relationship as it might be applied to the sign *campground* as depicted on a map. Note that the referent (or the signified) in the map case could be a mental image of a campground, a propositional representation of a campground, or the word "campground," which in turn could have its own sign relationship with an image or proposition. *Derived from Saussure (1916/1986, p. 99).*

the whole semiological system . . . . These semantic values form a network of structural relations, in which not the semantic concepts as such, but only the differences or oppositions between them are semiotically relevant."

Applying this view to mapping, as at least one recent critique of cartography has done (see Woods and Fels, 1986), we arrive at the conclusion that maps do not refer to the real world, but to concepts about the world. This perspective on map representation seems counterintuitive if considered in relation to a general map schema that has topographic maps as a prototype. Most cartographers would probably argue that the real-world referent is a critical part of the signifying relationship for a topographic map.[3] The idea that map signs do not refer directly back to the real world is most plausible when applied to maps of something like global-climate-model predictions of temperature change due to increased CO_2. Questions of what a map's referents are (and whether there are referents corresponding to all sign-vehicle—interpretant pairs) will be taken up below (in Chapter 7).

In Peirce's theory of signs, the referent (his "object") plays a critical role.[4] The sign, according to Peirce (Innis, 1985, p. 5), "is something which stands to somebody for something in some respect or capacity. It addresses somebody, that is, creates in the mind of that person an equivalent sign, [an interpretant]. . . . The sign [the interpretant] stands for something, its *object*." Elsewhere, Peirce (quoted in Hervey, 1982, p. 27) states that "a sign [sign-vehicle] mediates between the *interpretant* . . . and its object." Hervey uses this statement to propose a graphic model of the sign relation (Figure 5.2). He describes the implications of this interpretation of Peirce's triadic model as follows:

> In this triadic correlation, the role of a sign is to establish a habit or general rule determining both the way the sign is to be "understood" on the occasions of its use, and the kind of perceptible, or at least "imaginable," features of experience to which the sign may be applied. Thus we may take it that the way a sign is to be "understood" implies some kind of mental activity or state, whereas the features to which a sign can be applied presuppose something perceptual or experiential. (Hervey, 1982, p. 28)

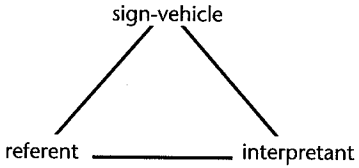

FIGURE 5.2. Hervey's graphic interpretation of Pierce's triadic correlation between object (referent), sign (sign-vehicle), and interpretant. *Derived from Hervey (1982, Fig. 1.6, p. 28).*

Cartographically, this tradic view of signs suggests attention to the way in which map "symbols" are simultaneously linked to actual or possible referents and to concepts about those referents on the part of the map user. From this perspective, map "symbols" might be evaluated on dual grounds: on the basis of the concepts they prompt (or the knowledge schemata they cue) and on the basis of the manner in which they correspond to the real or the imagined world.

Although a triadic interpretation of the theory of signs dominates North American semiotic literature, the relative position of the three elements in the relationship has varied. The primary alternative to Peirce's view of sign-vehicles as the mediator between referent and interpretant was offered by Ogden and Richards (1923). They also seem to have been the first to provide a graphic depiction of the sign relationships in the form that has become known as the "semiotic triangle" (Figure 5.3). The Ogden–Richards triangle depicts an interpretant (which they call the "thought or reference") as mediator between the sign-vehicle (labeled "symbol") and the referent. Their immediate application was to language. Their diagram, then, was meant to suggest that a word (as a sign-vehicle or symbol) has a causal relationship to a thought (interpretant), which in turn refers to a thing (or referent). The "stand-for" relationship between the word and the thing is depicted as less direct than that between interpretant and either sign-vehicle or referent. The word is thus portrayed as linking the thing, primarily through a thought or concept (rather than the concept linking to the thing through the word).

The Ogden–Richards triangle has somewhat different implications for the analysis of cartographic signs than does the initial Peirce triadic model. In the Ogden–Richards approach, emphasis is placed on the nature of interpretants as links between map "symbols" and referents. Attention, for example, might be directed to alternative interpretations of the sign-vehicle–referent relationship. As suggested in Part I, these alternative interpretations can be modeled in terms of knowledge schemata as the mediator between what is seen and what is known. As discussed below, one application of the Ogden–Richards semiotic triangle to visual representation has reinterpreted the connection between sign-vehicle and referent to suggest a connection that can vary in strength (i.e., re-

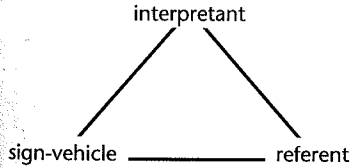

FIGURE 5.3. A depiction of the semiotic triangle with the interpretant (rather than the sign-vehicle) as mediator. *Derived from Ogden and Richards (1923, p.11).*

flecting the degree of similarity between sign-vehicle and referent) (Knowlton, 1966) (Figure 5.4).

Typology of Signs

Signs, whether they are treated as dyadic or triadic relationships, can be categorized on a variety of criteria. Nöth (1990), for example, cites Eco's (1973/1977) proposal of ten criteria.[5] Peirce (Innis, 1985) initially offered three trichotomies of signs, from the point of view of the sign-vehicle, the referent, and the interpretant. From the sign-vehicle perspective, Peirce proposed *qualisign* (a quality that is a sign-vehicle), *sinsign* (a thing or event that is a sign-vehicle), and *legisign* (a law that is a sign-vehicle). From the referent perspective. Peirce proposed *rheme* (a sign of qualitative possibility, it represents "such and such a kind of possible object"—a name is a rheme), *dicent* (a sign that represents in terms of or asserts the actual existence of something), and *argument* (a sign that asserts the truth of something). Perhaps the most important sign categorization criteria in relation to cartographic applications (and certainly the one that has attracted the most attention from both semioticians and cartographers) is the kind of relationship that exists between the sign-vehicle and the referent (i.e., from the point of view of the interpretant). This was the criterion selected by Peirce in devising his well-known typology of *icon*, *index*, and *symbol*.

For Peirce (Innis, 1985, p. 7), the icon is a sign-vehicle that refers "merely by virtue of characters of its own." Through a rather convoluted argument, Peirce ends up deciding that "a possibility alone is an Icon purely by virtue of its quality," thus essentially eliminating the category of icon as a visible sign-vehicle. While no true icons exist (at least ones that can be used on maps), Peirce (Innis, 1985, p. 9) contends that other sign-

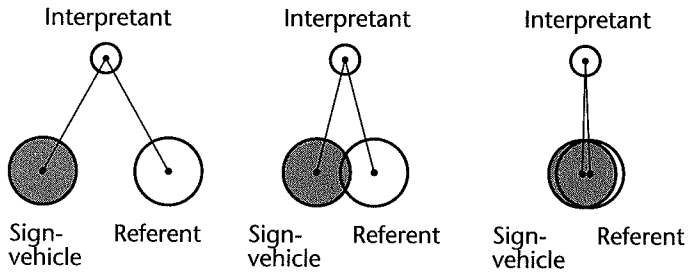

FIGURE 5.4. A depiction of Knowlton's variable strength semiotic triangle. *After Knowlton (1966, Fig. 5, p. 171). Adapted by permission of the Association for Educational Communications and Technology, Copyright 1966, Washington, DC.*

vehicles can be *iconic*, "that is, may represent its object [referent] mainly by its similarity, no matter what its mode of being." The term *hypoicon* is coined to specify these iconic sign-vehicles. Three forms are identified: (1) *images*—those that represent through similar visual qualities (e.g., a drawing of a ranger station on a National Park Service map); (2) *diagrams*—those that represent the relations of parts through analogous relations of parts (e.g., a network diagram that topologically represents stream order for streams in a particular drainage basin); and (3) *metaphors*—those that represent through a parallelism in something else (e.g., the use of up–level–down line orientation to represent increasing–stable–decreasing pollutant indices—as on the map in Figure 3.39). More so than the other hypoicons, metaphorical iconicity is a kind of similarity that generally depends on cultural codes (Lakoff and Johnson, 1980), although the particular line-orientation example cited could be argued to depend upon universal kinesthetic image schemata.

Peirce's definition of an index was as a sign-vehicle that refers to its referent "by virtue of being really affected" by it (Innis, 1985, p. 12). The reference is due "not so much because of any similarity or analogy with it, nor because it is associated with general characters which that object [referent] happens to possess, as because it is in dynamical (including spatial) connection both with the individual object [referent], on the one hand, and with the senses of memory of the person for whom it serves as a sign, on the other hand" (Innis, 1985, p. 12). Examples he cites include a yardstick, a photograph, and a pointing finger.[6] Three distinguishing features of indices are noted: (1) they have no significant resemblance to their referents; (2) they refer to individuals or individual units, collections or continua; and (3) they direct attention by "blind compulsion." With index, Peirce clearly had in mind a sign-vehicle property rather than a kind of sign, and even comments that it would be "difficult, if not impossible," to identify a pure index. Also, Peirce suggests that most sign-vehicles will have some level of indexical quality. Among the most clearly indexical sign-vehicles on maps are the graticule lines or tick marks used to "indicate" latitude and longitude.

Although map graticule provides an example of a map sign-vehicle that might be considered primarily indexical, any map symbol with fixed position has the property of spatial indexicality, regardless of the other sign aspects it may possess. The possibility that a sign can be indexical in relation to location while at the same time signifying some attribute of the place (perhaps iconically) accords with Keates's (1982) dichotomy of locational and substantive information and Schlichtmann's (1985) dichotomy of spatial and nonspatial characteristics. As Schlichtmann points out, this distinction can be separately applied to sign-vehicles and to interpretants (his sign expression and content).

The symbol, in Peirce's typology, represents by virtue of a "law" or "rule" or "convention." The choice of the term "symbol" was perhaps the most unfortunate one made by Peirce. This is because the term is defined in a multitude of ways by other semioticians, some equating it with "sign" and others with its Peircean opposite, the icon.[7]

Various authors have drawn on Peirce's trichotomy of iconic, indexical, and symbolic sign types. Most of these have identified limitations in scope. As a result, several alternative typologies have been advanced that contain more than three sign types. Two will be noted here because they deal with issues relevant to cartographic signs.

Hervey (1982) outlines a typology that he attributes to Martinet (1973) and associates with the branch of semiotics called "functional semiotics." The key differences between this typology and that of Peirce is an apparent limitation of index to "natural indices" (e.g., smoke indicates fire) and the addition (between Peirce's icon and symbol) of a category that has partial similarity (or "motivation"). The functional semiotic typology, then, includes the following types: (1) (natural) index; (2) icon (limited to strong similarity between sign-vehicles and referents—neither of which exist expressly for semiological purposes; a portrait of Queen Elizabeth is one example given); (3) symbol (for which the referent is not arbitrary—it exists—and the sign-vehicle to referent link is partly motivated and partly arbitrary or conventional); and (4) sign (for which both the referent and the sign-vehicle are arbitrary—the example provided is the sign-vehicle "pig" as it refers to the category "species of pig"). Although the addition of a partially motivated (nonconventional) category is an important addition that will be considered in more detail in the next chapter, the use of "sign" to refer to a category of sign and of "symbol" to refer to what Peirce might have termed a hypoicon are problematic.

Sebeok (1976) presents a different kind of variation on the Peircean typology of signs. He begins by stating that he is not attempting to classify signs, but only "aspects of signs." The distinction is an important one because it emphasizes the point (echoed by Eco, 1985b) that signs are seldom of one clearly defined type; instead, they have varying degrees of a range of properties. As noted above, this interpretation of sign typology was implicit in Peirce's approach, but it was ignored by many subsequent authors. These authors then criticized Peirce's categories by citing examples of sign-vehicles that did not fit unambiguously into one category or another. In Sebeok's system, Peirce's original aspects of signs (icon, index, and symbol) are retained with virtually the same meaning as delineated by Peirce. Three additional categories are added. They seem to deal with the intended impact of a sign as much as with the relationship between sign-vehicle and referent. Sebeok's (1976) three additions are: (1) signal—"*When a sign token mechanically or conventionally triggers some reaction on the part of a receiver, it is said to function as a signal*" (p. 121); (2) symptom—"*A symptom is a compulsive, automatic, nonarbitrary sign, such that the signifier is coupled with the signified in the manner of a natural link*" (p. 124); and (3) name—"*A sign which has an extensional class for its designatum is classed a name*" (p. 138). Names have no common property other than a shared label.

Clearly the "name" category is relevant to maps. While I can think of no use of "symptom" as an explicit map sign, it seems that symptoms are related to the use of map schemata for pattern analysis. A map schema that allows a person to recognize a relationship between homeless shelters and wealth of residents, as a *New York Times* map (Ahmad-Taylor and Montesino, 1992) juxtaposing income areas and facility locations allows, may function due to implicit signs that have the "aspect" of a symptom, an apparent natural link. The map can be considered to work to the extent that certain implicit signs (created by attribute–location combinations) are seen as a "symptom" of a particular public policy (protecting the rich from contact with the homeless). In contrast to symptoms, signals seem to be an explicit aspect of signs in a limited range of mapping contexts. An example is the AAA map I picked up to use on a trip to the Association of American Geographers meeting in Atlanta. The yellow highlight drawn by the AAA travel counselor is intended to "signal" me to turn or continue my current direction at various interchanges along the route. The role of dynamic dashboard-mounted maps in wayfinding is increasing and the advent of hand-held personal navigation assistants is predicted (Rhind, 1993). As a consequence, we are likely to see development of a set of dynamic map sign-vehicles intended to act as signals for travel behavior.

Typology of Discourse

Discussion of "signal" brings us neatly to our next topic, Morris's typology of discourse. Signals have a clearly behavioral goal. Morris (1901–1979) had roots in Peircean semiotics but approached all aspects of the field from a behavioral perspective. For Morris (1964, p. 6) the interpretant is defined as "a disposition to react in a certain kind of way because of a sign." Although issues of sign-vehicle to referent relationships were still of interest, an additional avenue of inquiry became dominant—how signs influence (or are intended to influence) behavior. Morris's goal in this effort was to develop a typology of the major kinds of discourse in everyday

life. He set out to accomplish this task by delineating several "modes of signifying" that relate to purposes of sign use. Together these modes and purposes define a matrix of discourse types.

Morris initially proposed five modes of signifying which he reduced to four in his later writing (Hervey, 1982). These five are:

Designative: The sign directs attention to a referent by signifying "observable" properties—properties are "designed." A map example is a choropleth map of population density in which the sign-vehicle (shade or color) designates the density range for that country.

Appraisive: The sign signifies the "consummatory" properties of a referent, it directs attention to preferential treatment of the referent, or it assigns a value judgment. Signs on a highway map such as yellow = scenic route, dashed = unimproved road, etc., constitute appraisive signs.

Prescriptive: The sign signifies how a situation should be reacted to, it directs attention to performing a response (a signal as defined above would, typically be prescriptive). An arrow on a city street map specifying a one-way street can be considered prescriptive.

Indentificative: The sign directs attention to a certain spatial–temporal region (an index will use this mode of signifying). All map signs have indentificative properties in relation to geographic position. Some signs, like simple dots to indicate city location, may be primarily indentificative in mode. Morris dropped the indentificative mode from his later writing.

Formative: The sign signifies in a "logical," "grammatical," or "structural" way. Conjunctions ("and," "or") are considered formators. They perform operations on other signs. On maps, signs can use formative mode to suggest links between places. A double-ended hook symbol (common on tax maps) uses formative mode by indicating an "and" relationship between two parcels of land (Figure 5.5).

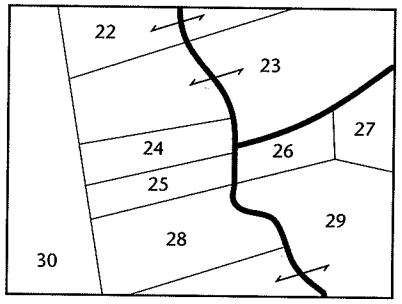

FIGURE 5.5. An example of the formative mode of signifying in which the sign's interpretant (for parcels 22, 23, and 29) is "these two map regions are part of the same land parcel."

Complementary to the modes of signifying, Morris (1946/1971, p. 172) offered four dimensions of use that address the "question of the purpose for which an organism produces the sign which it or other organisms interpret." These dimensions of use include:

Informative: The sign is intended to inform about something.
Valuative: The sign is intended to aid in preferential selection.
Incitive: The sign is intended to incite response-sequences.
Systemic: The sign is intended to organize sign-produced behavior into a determinate whole.

Morris (1964) contends that the modes of signifying and dimensions of sign use have no necessary links. In fact, he provides a matrix indicating all possible combinations and types of discourse to which they might apply (e.g., the designative–informative combination is typified by scientific discourse and the prescriptive–valuative combination is typified by political discourse). He does note, however, that "in general, designative signs are used informatively, appraisive signs are used valuatively, prescriptive signs are used incitively, and formative signs are used systemically" (p. 15). Although we might expect most map signs to match signifying modes and dimensions of sign use in this way, it is those cases that deviate from expectations that provide the most food for thought and that have attracted interest among recent critics of cartographic practice (e.g., Harley, 1989; Wood, 1992). I will come back to this issue in Chapter 7.

Morris's typology of discourse is closely paralleled by Guiraud (1975) who worked from a more Saussurean linguistic base in developing an analysis of "the functions of communication."[8] Since Guiraud contends that the function of signs is to communicate, his analysis can also be considered a typology of discourse. Guiraud's typology includes the following functions: referential, emotive, connotative or injunctive, poetic or aesthetic, phatic, metalinguistic, understanding and feeling, meaning and information, and attention and participation. Even without a detailed account of these functions, it is clear from their labels that correspondence exists with Morris's categories. The main difference seems to be in Morris's separation of modes of signifying from dimensions of sign use. Guiraud's one-dimensional typology does not allow the potential mismatches between how signs signify and how they are used to be identified.

Guiraud's (1975) poetic–aesthetic category has the least clear com-

plement in Morris's typology. Defined as "the relation between the message and itself," this category suggests semiotic analysis of maps as an object of expression in and of themselves. Keates's (1984) views on art in cartography (see Chapter 1) offer a hint of the directions such analysis might take (although Keates does not couch his argument in semiotic terms).

How Signs Signify: Specificity or Levels of Meaning

While an icon–index–symbol typology of signs focuses on the sign-vehicle to referent link and a typology of discourse focuses on how and why signs are used, attention can also be given to the directness/explicitness of the link between sign-vehicle and interpretant. From a logical perspective–typological perspective, Morris (1946/1971) proposed eight categories of sign (or sign-vehicle) distinguished primarily on the basis of consistency or specificity of meaning.[9] Hervey (1982) discounts the possibility of the first category (sign-vehicles that are not part of a sign family), but goes on the summarize the remaining seven. These are defined as:

Singular sign: The interpretant permits only one referent (for a map, an example would be "capital of the United States in 1990").

General sign: The interpretant permits any number of individual referents (a map example might be "river" but could also be "Columbus"—a name-sign for which several referents exist within the United States).

Interpersonal sign: Several interpreters share the same signification (a good map example might be signs dealing with geologic structure for which those trained in geology share a common understanding of the map sign-vehicles, their referents, and their interpretants).

Comsign: Has the same signification for the producing organism and the interpreter (the goal of most communication-model-oriented cartographic research was to develop, discover, or teach comsigns).

Vague sign: Does not allow a determination of whether a particular entity is or is not a referent of the sign (on a map, "forest" without the necessary spatial qualifiers that determine the smallest area that will qualify and the required density of trees is a vague sign).

Unambiguous sign-vehicle: Has one interpretant (this is the goal of most map symbology, but it is only met in those situations where we limit the definition of interpretant to an explicit meaning specified in a legend).

Ambiguous sign-vehicle: Has several interpretants (as discussed in Chapter 7, sign-vehicles on maps are probably ambiguous in this sense more often than cartographers have cared to admit).

Issues of vague signs and ambiguous sign vehicles are also taken up by Guiraud (1975) in relation to what he terms the "codification of signs." According to Guiraud, all signification (the relation between sign-vehicle and interpretant) is codified, or defined by a "code" or convention between individuals for whom the sign serves a communication function.[10] That code may be explicit or implicit. Guiraud's concept of convention, then, is one of degrees. Codification is viewed as "an agreement among the users of a sign [who] recognize the relation between the signifier [sign-vehicle] and the signified [interpretant] and respect it in practice. Such agreement may be more or less inclusive and more or less precise" (Guiraud, 1975, p. 25). Signs, then, can be *monosemic* (i.e., unambiguous) and precise, or *polysemic* (i.e., ambiguous) and imprecise. Similarly, signs can be *explicit* versus *implicit*, *conscious* versus *unconscious*, and *denotational* versus *connotational*.

For natural language, polysemic codes are the rule. With a polysemic code, a single sign-vehicle has multiple referents (e.g., "table" can represent an object to dine on, something that can be done to a decision at a board meeting, or an organized listing of numbers). Scientific languages and signaling systems (e.g., naval signal flags), along with other "logical" codes, are cited by Guiraud (1975) as the only monosemic sign systems. Bertin (1981) contends that cartography is a monosemic system of codes, but many arguments to the contrary can be made. This issue of the extent to which cartography is monosemic or polysemic will be considered in Chapter 7.

According to a number of semioticians, particularly those following in the Saussurean tradition (e.g., Barthes), all codes are polysemic in the sense of having two (or more) "levels" of meaning. The first is the primary, conscious, explicit meaning that can be defined as a sign's "denotation." To this can be added a secondary, implicit and (perhaps) unconscious meaning, the sign's "connotation."[11] Guiraud (1975, p. 28) provides a relatively clear example of the distinction in relation to the sign function of military uniforms: "A uniform denotes rank and function; it connotes the prestige and authority attached to rank and function." He goes on to suggest that "scientific codes, being essentially monosemic, eliminate possibilities of stylistic and connotative variation which abound in poetic codes."

This elimination of possibilities for multiple connotations was clearly the goal of a communication-model-oriented cartography that viewed maps as "scientific," and therefore objective and free from valuative con-

notations. As will be discussed fully in Chapter 7, Harley (1989) contends that cartographers have for too long presented their maps as scientific and free from multiple connotative meanings. Both in semiotics and cartography there has been a growing realization that the separation between science and art is not as clear-cut as science would like to believe and that most signs, scientific or otherwise, carry connotative meaning.

Hjelmslev's theory of connotation serves as a basis for several current semiotic approaches to the denotation-connotation distinction (Nöth, 1990). The key feature of this theory was Hjelmslev's linguistically motivated expression–content dyadic sign model. Signs, in this model (as in Saussure's), were considered to be a relation between an expression and a content. What Hjelmslev added was that signs themselves could serve as either the expression or the content of other signs. He used the label "metalanguage" for signs as content and the label "connotation" for signs as expression. Barthes (1967), building on Hjelmslev, formalized this idea as a graphic model (Figure 5.6).

For Barthes, signs denote via convention (generally accepted relational rules), but connote via *signification*. Signification is, for Barthes (1967), "*a property of objects that do not declare openly their possession of signification.*" In summarizing Barthes's perspective on connotation, Hervey (1982, p. 136) suggests that Barthes' " 'connotation' is appropriately used in cases where a sign acquires a 'higher' level of signification, functioning thereby as a 'secondary' sign that hints at a partially concealed, but all the more conspicuous, not to say insidious, message." For Barthes, there are no "innocent" facts.

In relation to visual images (in advertising), Barthes (1977, p. 37) distinguishes between literal and symbolic (cultural) messages based on knowing what things are versus what they stand for. The "literal image is *denoted* and the symbolic image *connoted*." Barthes contends that the system of connotation "takes over" that of denotation and suggests that we often use language to prevent or limit this "taking-over." Linguistic messages (text on the image) are said to "fix" a "floating chain of signifieds,"

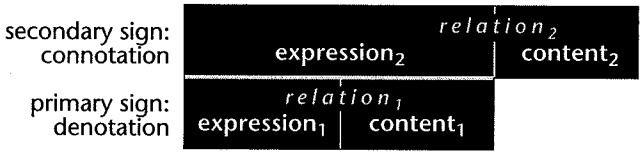

FIGURE 5.6. A depiction of Barthes's model of connotation as a semantic extension of a denotative sign. *Derived from Barthes (1967, p. 90).*

or to "anchor" an otherwise polysemic sign. As an apparent complement to his view that connotations are often hidden in signs so that they exert their influence unconsciously, Barthes (1977, p. 198) suggests that text in images can "remote control [the viewer] toward a meaning chosen in advance." It can prevent connotations from being achieved—precisely its goal on many maps where text is added to define, reduce ambiguity, and generally try to ensure a monosemic system of signifying.

Traditional semantics treats connotative meaning as a secondary meaning that a sign may have in addition to its primary denotative meaning (Nöth, 1990). This idea (apparent in much of Barthes's work cited above) opens up a variety of possibilities for kinds of inference that might be made to achieve this secondary meaning level. Recent deconstructionist ideas suggest that it may actually be impossible to determine which is the denotation and which the connotation, which is the primary meaning and which must be inferred from it. Eco, as early as 1968, seemed to imply as much with his typology of connotations (originally published in Italian, with a German translation; Eco, 1972; cited in Nöth, 1990, p. 102):

1. Connotation of definitional meaning (e.g., Venus = Morning Star).
2. Connotations of the constituent elements (e.g., Lat. *luna* connotes "feminine").
3. Ideological connotation.
4. Emotional connotation.
5. Connotations derived from hyponomy (*tulip* connotes "flower"), hyperonomy (*flower* may connote "tulip") or antonymy (*husband* connotes "wife").
6. Connotations by intersemiotic translation (e.g., a word sign connoting a picture sign).
7. Connotations of rhetorical figures (e.g., metaphors).
8. Rhetorical–stylistic connotations.
9. Global axiological connotations (referring to values).

Regardless of the precision, strength, or multiplicity of levels of the conventional relation or signification between sign-vehicle and interpretant(s), the relation can be one of two types: motivated or unmotivated (i.e., arbitrary). Motivation here is used in roughly the same sense as in Chapter 4; a motivated relationship is one in which there is cognitive economy in recognizing similarity on some criteria. According to Guiraud (1975), motivation is a natural relation that can be either analogical (related to substance) or homological (related to form).[12] Moti-

vated signs are equated to icons as defined above. The important distinctions between Guiraud and most other authors, however, are that motivation or iconicity should be considered a continuum (rather than the discrete categories proposed by Peirce, Sebeok, and others) and that this continuum is a concept that applies to both denotation and connotation. For denotation, Guiraud's concept of a sign motivation continuum is similar to that suggested by Knowlton's variable semiotic triangle cited above.

Typology of Comprehension (or Miscomprehension)

If we are interested in "how maps work," we must consider how signs, at all levels, work. One aspect of this question is whether signs are *comprehended*.

Prieto's theory of semiotic acts (as described in Hervey, 1982) devotes considerable attention to the success and failure of sign "comprehension." The fundamental principle of his theory is that for a sign to function, a person comprehending it must recognize that the perceptible sign-vehicle belongs to a particular class and infer from it that some other indicated entity (the interpretant) belongs to a specific class.[13] Both the sign-vehicle and the interpretant exist in a separate "Universe of Discourse" (defined as the possible sign-vehicle and interpretants). The sign-vehicle (which Prieto calls the "indicator" or "signal" occupies a Universe of Discourse termed a "sematic field" consisting of all the alternatives with which it significantly contrasts. On a U.S. National Park Service map, for example, a pictorial point symbol will have a relatively limited sematic class consisting of the 74 possible symbols in the complete set. The interpretant's Universe of Discourse is termed the "noetic field." For the same Park Service map, the noetic field could vary tremendously in size depending upon how familiar a person was with the features represented on the maps (From some small number of possible interpretants to some indefinitely large number). Comprehension involves comparing these two fields (or Universes of Discourse).

In relation to this general framework, Hervey (1982) provides a concise statement of how Prieto evaluates comprehension.

> Taking cognisance of the fact that the sender intends to convey a message, and perceiving the signal [sign-vehicle] as identifying a particular Sematic field to which it belongs, lead to a state of uncertainty in the receptor. This uncertainty is given specificity by the fact that, on recognizing the appropriate Sematic field, the receptor is, by automatic association, made aware also of the corresponding Noetic field. . . .
>
> Within the Noetic field which the receptor of a signal [sign-vehicle] identifies . . . , the receptor's uncertainty has the precise form of an indecision as to which of a (perhaps indefinite) number of mutually exclusive classes in the Noetic field he could fix on as the class to which the sender's message belongs. Comprehension, therefore, can be seen as the dispelling (in part or totally) of the particular uncertainty in question, ideally by identifying the "narrowest" Noetic class that corresponds to the signal in question. (p. 67)

It should be clear from the above statement that several potential levels of comprehension present themselves, based on both the kind and the level of success in matching sematic and noetic classes. Complete success requires not only correct, but total comprehension. Prieto establishes a typology of sorts to delineate a set of comprehension possibilities. They are as follows:

1. *Complete success*: The interpreter has narrowed the noetic field down to a single class corresponding to the class of the sign-vehicle, and the choice is an exact correspondence (e.g., on a five-class choropleth map of mean income, recognizing the third darkest gray tone as the middle category and successfully matching this to a concept associated with middle income defined by a specified income range.
2. *Partial failure*: Identification of an appropriate superordinate class in the noetic field but failure to be able to narrow the choices down to a single class, thus retaining a level of uncertainty in the sign-vehicle—interpretant match (e.g., on the same choropleth map, recognizing the third darkest category as representing income levels, but being uncertain about which of the three central categories it represents).
3. *Total failure*: The interpreter has narrowed the noetic field down to a single class corresponding to the class of the sign-vehicle, and the choice is wrong (e.g., incorrectly matching the third darkest category with the second highest income level).
4. *Failure due to situational factors*: Specifically situations in which the originator of the sign-vehicle is either not as precise as the situation allows the percipient to be, or in which the originator is quite specific, but there are more interpretants than anticipated (e.g., an interpretation of the middle and next highest category as "middle income" in the context of a news story about "middle income" Americans).

Cartographically, the latter case might just as easily be considered a hypersuccess as a failure because the map percipient might be as likely to infer something useful as to infer the wrong thing.

THE NATURE OF SIGN SYSTEMS

In the context of cartography, a study of signs independent of how they interact with one another (the study of sign systems) would be little more than an intellectual curiosity. The key to productively applying a semiotic approach to map representation is to use that approach to consider how the individual-cognitive aspects of map representation discussed in Part I link to the public function and lexical process to be considered in Chapters 6 and 7. While understanding how signs denote and connote is an important piece in the puzzle, the puzzle is not complete until we consider how signs relate to one another. Issues of "the nature of signs" considered thus far closely parallel those of mental categories discussed in Chapter 4. Those of sign systems (discussed in this section) closely parallel those of map schemata. If maps are to work, mental categories and categories indicated by sign-vehicles need to correspond in some logical way and map schemata must link to the sign systems created by cartographers.

Morris seems to have had the most impact (at least in North America and certainly within cartography) on thinking about this question of sign interrelationships. His *three dimensions of semiosis*, *syntactics*, *semantics*, and *pragmatics*, provide the needed framework for addressing this question. A number of cartographers have tried to adapt these concepts to understanding map representation (Board, 1973; Morrison, 1974; Keates, 1982; Wolodtschenko and Pravda, 1993). Before I consider their efforts (in Chapter 6) a synopsis of Morris's dimensions of semiosis and some other attempts to address issues of semiotic systems is required.

Dimensions of Semiosis

For Morris (1938), semantics studies how sign-vehicles and their referents are related and pragmatics deals with sign-vehicle–interpretant relations. Thus each of these focuses on individual signs (as we did above). The third proposed relationship, syntactics, is probably the most important for cartography, but has also been the most controversial. According to Morris, syntactics is the relation between a given sign-vehicle and other sign-vehicles. There is a critical distinction here (that many cartographers have missed) between Morris's "syntactics" and the linguistic subcategory of "syntax." While syntax puts emphasis on word order and

parsing (i.e., on a linear sequence), syntactics is much broader in scope. Syntactics allows for consideration of any kind of among-sign relationships.[14] Morris (1938, p. 16) makes this point explicitly in his statement that there are " syntactical problems in the fields of perceptual signs, aesthetic signs, the practical use of signs, and general linguistics." He provides an intriguing graphic depiction of his conception of the three dimensions of semiosis applied to the three attributes of a sign (Figure 5.7). Most of what Morris considered to be semantics and pragmatics has been alluded to above, in considering "the nature of signs." Although I will return to these dimensions of semiosis in the next chapters, here I will focus on syntactics.

At least three kinds of sign relationships seem to fall under Morris's umbrella of syntactics (Posner, 1985, in French; cited in Nöth, 1990, p. 51). These include: (1) "the consideration of signs and sign combinations so far as they are subject to syntactical rules" (Morris, 1938, p. 14), (2) "the way in which signs of various classes are combined to form compound signs" (Morris, 1946/1971, p. 367), and (3) "the formal relations of signs to one another" (Morris, 1938, p. 6). Cartographically these perspectives on sign relationships emphasize, respectively, issues such as: (1) development of logic for map legends, (2) rules about combining nominal with ordinal sign-vehicles, and (3) principles for matching graphic variables to differential versus ordinal data.

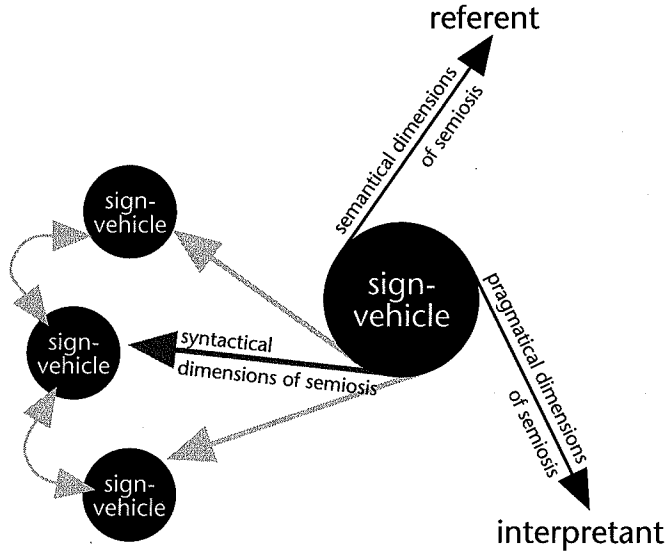

FIGURE 5.7. A depiction of a sign as an entity linking its three components via the relations of syntactics, semantics, and pragmatics. *Derived from Morris (1939/1971, p. 417).*

Robinson and Petchenik (1976) presented a convincing argument that maps have no "syntax." Implicit in their argument was an assumption that linguistic syntax was equivalent to syntactics. Most subsequent cartographers (particularly within North America) accepted the argument against a map syntax and took for granted the equivalence of syntax and syntactics. As a result, North American cartography has largely ignored the concept of syntactics.

Robinson and Petchenik's discounting of syntax as a viable cartographic issue was part of a broader argument against a linguistic approach to cartography. They (rightly) pointed out that individual maps have no predetermined reading sequence, and therefore no "word" order comparable to that considered under the linguistic concept of "syntax." In addition, they asserted that maps have no equivalent to "words" and are not "discursive." To demonstrate the weakness of the mapping-as-language analogy, they pointed to two possible aspects of mapping that might be equated with syntax, both of which were intended to demonstrate that the possible link between mapping and language is tenuous at best. First, they suggested that syntax (for a static map) can only be defined in relation to spatial structure (either horizontally across geographic space or vertically in terms of visual perceptual levels). They went on to concede that there is something weakly analogous to linguistic "syntax" in the structuring of visual levels. One could argue, in fact, that if carefully designed, visual levels could be used to lead a percipient through a series of stages from global patterns to local details. They also conceded that animated maps can have a kind of syntactical structure related to temporal order (but contended that this structure "has nothing to do with the map per se") (Robinson and Petchenik, 1976, p. 56).

As should be clear by now, the point that Robinson and Petchenik (1976) missed is that while most maps do not have syntax in the narrow sense of structured reading order, they do (or should) have a carefully structured syntactics in terms of the interrelationships among signs they are composed of. Most potential applications of syntactics to map representation relate to Morris's broad, nonlinguistic approach. Since 1976, when Robinson and Petchenik developed their argument against map syntax, however, technological changes have resulted in practical tools for the design of animated maps. It is therefore now considerably more important to question their contention that the temporal syntax of animated maps has nothing to do with the map. It is my contention that the temporal syntax of animated maps has everything to do with the map!

When maps play out over time, as a map movie, it may prove useful to borrow some ideas from film analysis to address the many new issues that arise. From a semiotic perspective, the most interesting possibility of film analysis with map animation applications is Metz's (1968/1974)

filmic syntax. Metz developed a model (or typology) of "syntagmatic types" to characterize the temporal–visual manipulation possible in film, but not in other visual media. As Korac (1988) points out, temporal manipulation results in a range of possible syntactic relations from those that mimic real time–space relations (and result in a motivated or iconic sign system) to those that have arbitrary relations with real-world time–space relations (thus resulting in an arbitrary or symbolic sign system). Metz's model is hierarchically organized with a major division into relatively simplistic films consisting of a single coherent sequence (single-shot units) and those more complex films in which there are multiple units (to which the filmmaker exerts varying kinds and degrees of manipulation) (Figure 5.8). The categories depicted can be defined as follows:

Sequence shot: The most "motivated" temporal–visual organization in which filmic and chronological time are *identical* and visual plane has continuity (i.e., full duration from single point of view).

Scene: A highly motivated temporal–visual organization in which filmic and chronological time are identical, but visual continuity is interrupted (i.e., full duration, but from several different viewpoints as typical in a TV portrayal of a sporting event).

Ordinary sequence: Contains both visual and temporal discontinuity,

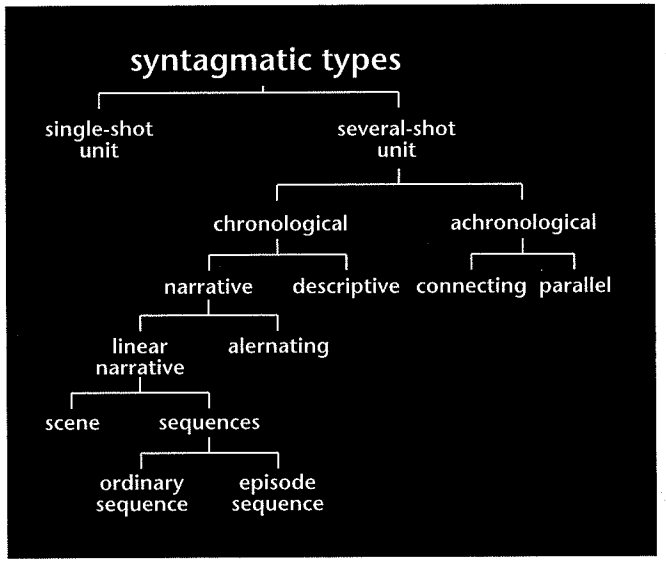

FIGURE 5.8. Metz's semiotic typology of syntagmatic types for film. *Derived from Metz (1968/1974, p. 146) and Korac (1988, Fig. 1, p. 78).*

having changes in duration, gaps in time, and changes in place, but with temporal order maintained.

Episode sequence: Like above, but more extreme. Filmic time is compressed to an extreme degree (e.g., several years in a few minutes created through a sequence of potentially time-compressed shots interposed with large jumps in time).

Alternating syntagm: Events actually taking place at the same time are presented alternately in the film (a variation is alternating flashback and flashforward, producing a psychological rather than a physical sense of simultaneity).

Descriptive syntagm: The use of a time sequence to describe an area (rather than presenting a temporal sequence).

Connecting syntagm: A linear sequence of spatially and temporally different shots depicting objects or events that belong to the same category or class, thereby implying links of ideas due to juxtaposition in film time (e.g., horrors of war signified through a sequence showing bombs dropping, destroyed houses, dead or wounded, etc., regardless of which war is shown). Korac (1988, p. 80) labeled this syntagm "the stuttering filmic equivalent of categorization." This technique uses temporal proximity (a Gestalt property) to suggest grouping due to family resemblance (one aspect of the prototype theory of categorization).

Parallel syntagm: An alternating sequence of shots that depict changes in place but not time, typically places that belong to opposite categories where the temporal juxtaposition of the scenes puts emphasis on contrasts.

The Metz typology has several similarities to the approach to dynamic mapping that some colleagues and I developed (DiBiase et al., 1992). In particular, identification of both temporal and nontemporal uses of time sequence and the attention given to manipulation of time as a sign corresponds to our approach to treating time in a manner analogous to the visual variables of map symbolization (size, shape, orientation, etc.).[15]

Systemology

Morris's tripartite typology of semiosis (into semantics, pragmatics, and syntactics) is not the only cartographically relevant attempt to formalize the study of semiotic systems. Hervey (1982) describes a complementary classification, termed *systemology*, that he defines as a "deductive classification of semiotic systems." Systemology is derived from principles of *axiomatic semiotics*, a variation on *functional semiotics* attributable to Mulder and Hervey (1980). As described in Hervey (1982), both axiomatic and functional semiotics are subfields of (or perspectives on) semiotics that limit their attention to semiological systems and typologies of indices (signs), specifically signs that have an intention to communicate. Differences between the two branches of semiotics are primarily in terms of limits on scope of inquiry, and need not concern us here.

Hervey initially describes why the medium of communication in which signs are used (e.g., sight, sound, etc.) and the pragmatic use of the system (e.g., for the sighted vs. the blind) are not semiotically relevant. He then goes on to contend that *semiotic economy* provides the only important dimension on which to classify semiotic systems.

Semiotic Economy

"Semiotic economy" is defined in relation to two levels of entity in a semiotic system. A distinction is made between the "figurae" and the "signa." This distinction can be interpreted as that between the sign-vehicle and the sign of which it is a part, or perhaps the mark that becomes the sign-vehicle (prior to its becoming part of a sign) and the sign (or sign-vehicle–interpretant relationship). Hervey (1982) uses a simple example to clarify the terms. The example involves the letters *H*, *W*, and C as they often appear on single-knob bathroom shower controls. The letters by themselves are figurae. On the faucet, if the proper sign-vehicle–interpretant connection is made, the result is the signa of: *H* = hot water, *W* = warm water, and C = cold water.

According to Hervey's systemology, figurae occupy the *cenological* (from the Greek indicating "empty" of meaning) level of signification. Signa, on the other hand, occupy the *plerological* (or "full" of meaning) level. Semiotic economy is calculated by determining the ratio of figurae in the cenological level to the signa of the plerological level. For the water faucet example, the semiotic economy of the system is 1:1 because there are exactly the same number of potential figurae as there are signa. Such a system is considered "simple" in contrast to "complex" systems (i.e., those having a one-to-many relationship). A good example of the later is Morse code in which two figurae in varied combinations (a dot and a dash) represent all letters and numbers. Written language, of course, has much greater economy with (in English) only 26 letters able to produce all possible words of the language (native Hawaiian achieves this with only a dozen letters).

Cartographically, if we consider subcomponents of maps separately (e.g., just those symbols forming a system for representing point loca-

tions) we can find examples of both simple and complex semiotic systems. The U.S. National Park Service system of pictorial symbols for depicting feature locations is a simple 1:1 system in which each symbol is a different shape. Semiotic economy is achieved when pairs of graphic variables (e.g., shape and color hue) are used in combinations where one graphic variable acts as a qualifier of the others. One example is the map of Motor Vehicle Manufacturers in the United States for 1986 found in the National Geographic Society's *Historical Atlas of the United States, Centennial Edition*. On this map, seven point symbol shapes are used to represent categories of manufacturers (the four major U.S. firms at the time plus other American, European, and Japanese manufacturers) and three color hues are used to represent type of facility (assembly, parts, headquarters/R&D). The ten figurae can result in 7 × 3 signa, or 21 disparate signs, a semiotic economy of 1:2.1. For maps as a whole, like written language, it becomes clear that we have a system with tremendous semiotic economy. Whether one accepts Bertin's (1967/1983) contention that there are seven graphic variables, or the expanded set of eleven identified in the next chapter, we have a system with a *figurae:signa* ratio of *few:indefinite*. Individual maps, of course, vary in the way they take advantage of the potential economy and we know little if anything at this point about the relationship between semiotic economy of maps and the cognitive aspects of map representation discussed in Part I (i.e., does semiotic economy help or hinder a user's ability to identify visual categories and/or apply appropriate schemata?).

Simultaneity versus Articulation

In addition to the simple–complex dichotomy of semiotic economy, Hervey (1982, p. 193) proposes a second dichotomy, "that between the formation of *simultaneous bundles* and the formation of *articulated constructions*." The two concepts are presented in relation to linear semiotic systems. With simultaneous bundles, for example, the order of combination is irrelevant (e.g., on encountering a pair of highway signs while approaching an intersection, one indicating "Stop" and the other "No left turn," the order in which the signs are encountered has no effect on their meaning). In contrast, when dealing with Morse code with its two units of expression, the order in which dots and dashes (and pauses between them) are encountered provides the basis for meaning. Morse code is one of Hervey's (1982) examples of a prototypic articulated system. Hervey considers articulated systems to be more powerful than those whose sign-vehicle combinations result in simultaneous bundles. Articulated systems can be seen as making use of human pattern recognition abilities (see

Part I). Although articulation is a concept primarily associated with order of presentation or encounter with signs, it has also been applied to nonlinear constructions such as traffic "signs."

For dynamic maps, the concept of articulated versus simultaneous combinations becomes particularly relevant. As demonstrated in DiBiase et al. (1992) and described in the next chapter, if we treat time as a cartographic variable (instead of just something to map), the meaning of a particular set of dynamic signs will be determined, in part, by the order of presentation. A set of cartographic primitives including temporal order as an operator (or figurae, in Hervey's terms) would thus be considered an articulated semiotic system, at least in those cases for which order is explicitly used as a sign-vehicle.

Combinatorial Relations

Hervey (1982) suggests that semiotic systems can be articulated at either the cenological or the plerological level. This combination of two dichotomies results in four possible types of subsystem (Figure 5.9). The highway-sign example above represents a simultaneous–plerological subsystem because combinations are among bundles of "signa" (or signs). Morse code is an articulated–cenological system because in it, figurae (devoid of independent meaning) are combined. Hervey cites arabic numbers as an example of an articulated–plerological subsystem in which the signa (0, 1, 2, . . . , 9) have independent meaning and their combinations are dependent upon how they are arranged (e.g., 123 is not the same as 321). Using a diamond, circle, and triangle on a map to represent hotels, restaurants, and theaters would be an example of a simultaneous–cenological system. The figurae or sign-vehicles have no predetermined meaning and whether you see • ◆ ▽ next to a point on the map or ◆ ▽ •, the meaning is the same (although consistent ordering will probably facilitate more purely perceptual tasks such as visual search). Hervey goes on to contend that some systems exhibit all four subsystems

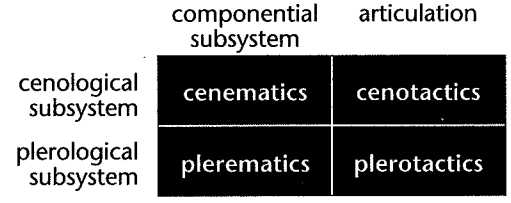

FIGURE 5.9. Hervey's semiological subsystems. *After Hervey (1982, Fig. 7.5, p. 197). Adapted by permission of Routledge, Chapman & Hall.*

at various levels of analysis. Human languages are shown to feature the interlocking of all four, and it seems likely that all could be identified in some dynamic maps.

APPLICATION OF THE SEMIOTIC APPROACH TO MAP REPRESENTATION

This chapter has provided an abbreviated synopsis of selected issues in the field of semiotics. It is my belief that semiotics has tremendous potential as a tool for systematizing our approach to maps as representations and for developing logical systems of, and transformations among, representations. In addition, a semiotic perspective offers a structured way to consider the interaction of the explicit and implicit meanings with which maps are imbued. The remaining two chapters of Part II will make extensive use of this introduction to semiotics as it relates to functional and lexical aspects of map representation. Chapter 6 addresses the structure of cartographic representation as a set of hierarchically interlocking sign systems in which attention can be directed to a range of issues from how individual symbols represent to how entire maps serve as a sign for a particular worldview. Although it is not possible to completely separate Morris's three dimensions of semiosis (semantics, syntactics, and pragmatics), the chapter emphasizes the first two of these, the semantics and syntactics of map representation. Chapter 7 continues from this base to emphasize the multiple levels and kinds of meaning in map sign relationships and the processes by which these multiple meanings arise, thus, the pragmatics of maps.

NOTES

1. The spelling was changed from Peirce's original "semeiotic" and the use of the plural form was officially adopted at this time.

2. For those wishing to pursue a semiotic approach to cartography further, Nöth's (1990) tabulations of terminology should prove useful in comparing ideas by different authors using different terminology. He provides a table listing terms used by 15 scholars who have adopted the dyadic model of "sign" and another table of terms from 10 authors who have adopted the triadic model.

3. Axelson and Jones (1987) and Wood and Fels (1986) point to the ways in which this assumed real-world referent for topographic and other large-scale reference maps can hide and distort other kinds of signifying relationships.

4. Peirce frequently used the term "sign" in both a broad sense of the overall relationship and in a narrower sense corresponding to "sign-vehicle" as defined above, and at times talks about the interpretant as a "sign" in the mind of the interpreter. Quoting from Peirce, therefore, presents interpretation difficulties. To minimize the confusion, I have inserted in brackets [ ] the appropriate interpretation for "sign" in the succeeding passages taken from his work.

5. Nöth's interpretation is based on a 1977 edition of *Zeichen: Einführung in einen Bergriff und seine Geschichte* (Frankfurt: Suhrkamp), which is a translation of a 1973 publication.

6. Peirce also cites a photograph as a kind of image hypoicon. This dual categorization is evidence that Peirce did not consider his typology a mutually exclusive categorization of sign-vehicles, but a categorization of attributes that sign relations could have, individually or in conjunction. It seems, then, that Peirce approached categorization from what later would be identified as a prototypic, rather than a classical, perspective. Although he did not link his approach to category theory (which was developed several decades after Peirce's death), Peirce was quite clear about the difficulties involved in classifying signs (Hartshorne and Weiss, 1931).

7. Saussure's use of symbol fits in the latter category and may be one of several reasons for the lack of interaction between the two traditions.

8. As Guiraud (1975) points out, this typology is derived from Jakobson (1960).

9. He also proposed two categories of relations among signs and one dealing with interpreters of signs (interpreter-family as a group of interpreters for whom a particular sign has the same interpretant). The categories relating signs will be taken up below.

10. Following from Saussure, signs do not exist for Guiraud unless there is an intention to communicate.

11. If we accept Harley's (1989) or Wood and Fels's (1986) critiques of cartography, these secondary connotations are an intimate part of mapping, are one reason for the importance of maps in society, and are anything but unconscious for the cartographers. These issues will be taken up in detail in Chapter 7.

12. Guiraurd's homological motivation seems to be roughly equivalent to Peirce's diagram hypoicon, and his analogical seems equivalent to Peirce's image hypoicon or a combination of image and metaphor hypoicons.

13. Prieto's work is thus far available only in French. The discussion presented here is based on a synopsis of Prieto's theory presented by Hervey (1982). It remains unclear from Hervey's presentation whether Prieto considers the "indicated entity" an interpretant or a referent. Since Prieto seems to have developed his ideas within a Saussurean context, however, it is probably safe to assume a dyadic sign model with the "indicated entity" being an interpretant rather than a referent. See Martinet (1990) for more on Prieto.

14. Throughout this book, the adjective "syntactic" relates to the broader concept of syntactics rather than to syntax.

15. Our approach to dynamic variables for animated maps will be considered in Chapter 6 and the similarities and differences between Metz's typology and our conceptual approach to map animation will be considered in Part III.

References

Ahmad-Taylor, T., and Montesino, D. (1992, December 6). In my backyard? (accompanying map). *New York Times*, p. 54.

Allis, S. (1979, August 5). Underground artistry in New York: When the city changes its subway map, art critics and cartographers crashed head-on. *Washington Post*, p. G3.

Anderson, J. R. (1982). Acquisition of cognitive skill. *Psychological Review, 89*, 369–406.

Andrews, S. K., Otis-Wilborn, A., and Messenheimer-Young, T. (1991). *Beyond Seeing and Hearing: Teaching Geography to Sensory Impaired Children. An Integrated Base Curriculum Approach*. Indiana, PA: NCGE.

Antes, J. R., and Mann, S. W. (1984). Global–local precedence in picture processing. *Psychological Research, 46*, 247–259.

Antonietti, A. (1991). Why does mental visualization facilitate problem-solving? In R. H. Logie and M. Denis (Eds.), *Mental Images in Human Cognition* (pp. 211–227). Amsterdam: Elsevier.

Armstrong, S. L., Gleitman, L. R., and Gleitman, H. (1983). What some concepts might not be. *Cognition, 13*, 263–308.

Arnheim, R. (1974). *Art and Visual Perception*. Berkeley and Los Angeles: University of California Press.

Arnheim, R. (1985). The double-edged mind: Intuition and the intellect. In E. Eisner (Ed.), *Learning and Teaching the Ways of Knowing: Eighty-fifth Yearbook of the National Society for the Study of Education* (pp. 77–96). Chicago: National Society for the Study of Education.

Axelsen, B., and Jones, M. (1987). Are all maps mental maps? *GeoJournal, 14*, 447–464.

Baddeley, A. (1988). Imagery and working memory. In M. Denis, J. Engelkamp, and J. T. E. Richardson (Eds.), *Cognitive and Neuropsychological Approaches to Mental Imagery* (pp. 169–180). Dordrecht: Martinus Nijhoff.

Baddeley, A. D., and Hitch, G. (1974). Working memory. In G. Bower (Ed.), *The*

Psychology of Learning and Motivation, Volume VIII (pp. 47–89). New York: Academic Press.

Balchin, W. G. V. (1988). The media watch in the United Kingdom. In M. Gauthier (Ed.), *Cartographie dans les Médias* (pp. 33–48). Quebec: Presses de l'Université Québec.

Barlow, H. (1990). What does the brain see? How does it understand? In C. B. H. Barlow and M. Weston-Smith (Eds.), *Images and Understanding* (pp. 5–25). Cambridge: Cambridge University Press.

Barsalou, L. W. (1983). Ad hoc categories. *Memory and Cognition, 11*, 211–227.

Barsalou, L. W. (1985). Ideals, central tendency, and frequency of instantiation as determinants of graded structure in categories. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 11*, 629–654.

Barthes, R. (1967). *Elements of Semiology*. London: Cape.

Barthes, R. (1977). *Image—Music—Text*. New York: Hill & Wang.

Bastide, F. (1985, June). Iconographie des textes scientifiques: Principes d'analyse. In B. Latour and J. d. Noblet (Eds.), *Les "Vues" de l'Esprit. Culture Technique, 14* [Special Issue].

Beck, J. (1966). Perceptual grouping produced by changes in orientation and shape. *Science, 154*, 538–540.

Becker, R. A., and Cleveland, W. S. (1987). Brushing scatterplots. *Technometrics, 29*, 127–142.

Bemis, D., and Bates, K. (1989). *Color on Temperature Maps: A Second Look*. Unpublished manuscript, Department of Geography, Pennsylvania State University.

Berlin, B. (1972). Speculations on the growth of ethno-botanical nomenclature. *Language in Society, 1*, 51–86.

Berlin, B., and Kay, P. (1969). *Basic Color Terms: Their Universality and Evolution*. Berkeley and Los Angeles: University of California Press.

Bertin, J. (1981). *Graphics and Graphic Information Processing*. Berlin: Walter de Gruyter. (French edition, 1977)

Bertin, J. (1983). *Semiology of Graphics: Diagrams, Networks, Maps*. Madison: University of Wisconsin Press. (French edition, 1967)

Berton, J. A. J. (1990). Strategies for scientific visualization: Analysis and comparison of current techniques. *Proceedings, Extracting Meaning from Complex Data: Processing, Display, Interaction*, February 14–16, Santa Clara, CA, SPIE—The International Society for Optical Engineering, pp. 110–121.

Beshers, C., and Feiner, S. (1992). Automated design of virtual worlds for visualizing multivariate relations. *Proceedings, Visualization '92*, October 19–23, Boston, IEEE Computer Society Technical Committee on Computer Graphics, pp. 283–290.

Beveridge, M., and Parkins, E. (1987). Visual representation in analogical problem solving. *Memory and Cognition, 15*(3), 230–237.

Beyls, P. (1991). Discovery through interaction: A cognitive approach to computer media in visual arts. *Leonardo, 24*(3), 311–315.

Biederman, I. (1987). Recognition-by-components: A theory of human image understanding. *Psychological Review, 94*(2), 115–147.

Bishop, I. D. (1992). *The Role of Visual Realism in Communicating and Understanding Spatial Change and Process*. Working paper for the AGI Visualization Workshop, July 12–14, Loughborough University of Technology.

Bjorklund, E. M. (1991). Culture as input and output of the cognitive–linguistic processes. In D. M. Mark and A. U. Frank (Eds.), *Cognitive and Linguistic Aspects of Geographic Space* (pp. 65–70). Amsterdam: Kluwer Academic.

Board, C. (1967). Maps as models. In R. J. Chorley and P. Haggett (Eds.), *Models in Geography* (pp. 671–725). London: Methuen.

Board, C. (1973). Cartographic communication and standardization. *International Yearbook of Cartography, 13*, 229–236.

Bowman, W. J. (1968). *Graphic Communication*. New York: Wiley.

Brachman, R. J. (1985). On the epistemological status of semantic networks. In R. Brachman and H. Levesque (Eds.), *Readings in Knowledge Representation* (pp. 191–215). San Mateo, CA: Morgan Kaufmann.

Brewer, C. A. (1989). The development of process-printed Munsell charts for selecting map colors. *American Cartographer, 16*(4), 269–278.

Brewer, C. A. (1991). *The Prediction of Surround-Induced Changes in Map Color Appearance*. Unpublished Ph.D. dissertation, Michigan State University.

Brewer, C. A. (1992). *Color Selection for Geographic Data Analysis and Visualization*. Paper presented at GIS/LIS, November, 12, San Jose, CA.

Brewer, C. A. (1993). *Color Selection for Maps: Interactive Tutorial*. Unpublished hypermedia document, Department of Geography, San Diego State University.

Brewer, C. A. (1994). Color use guidelines for mapping and visualization. In A. M. MacEachren and D. R. F. Taylor (Eds.), *Visualization in Modern Cartography* (pp. 123–147). Oxford, UK: Elsevier.

Brewer, C. A., and Marlow, K. A. (1993). Color representation of aspect *and* slope simultaneously. *Proceedings, Auto-Carto 11*, October 30–November 1, Minneapolis, MN, ASPRS & ACSM, pp. 328–337.

Brown, A., and van Elzakker, C. P. J. M. (1993). The use of colour in the cartographic representation of information quality generated by a GIS. *Proceedings, 16th Conference of the International Cartographic Association*, May 3–9, Cologne, Germany, pp. 707–720.

Brown, M. H., and Hershberger, J. (1992, December). Color and sound in algorithm animation. *Computer*, pp. 52–63.

Brown, R. (1958). How shall a thing be called? *Psychological Review, 65*, 14–21.

Bruce, V., and Green, P. R. (1990). *Visual Perception: Physiology, Psychology, and Ecology* (2nd ed.). Hove, UK: Erlbaum.

Buja, A., McDonald, J. A., Michalak, J., and Stuetzle, W. (1991). Interactive data visualization using focusing and linking. *Proceedings, Visualization '91, IEEE Conference on Visualization*, October 22–25, San Diego, CA, pp. 156–163.

Bunn, J. H. (1981). *The Dimensionality of Signs, Tools, and Models*. Bloomington: Indiana University Press.

Buttenfield, B. (Ed.). (1993). *Mapping Data Quality. Cartographica, 30*(2 & 3) [Special Content Issue].

Buttenfield, B., and Beard, K. (1994). Graphical and geographical components of

data quality. In H. Hearnshaw and D. Unwin (Eds.), *Visualization in Geographical Information Systems* (pp. 150–157). London: Wiley.

Buxton, B. (1990). Using our ears: An introduction to the use of nonspeech audio cues. *Proceedings, Extracting Meaning from Complex Data: Processing, Display, Interaction*, February 14–16, Santa Clara, CA, SPIE—The International Society for Optical Engineering, pp. 124–127.

Caivano, J. L. (1990). Visual texture as a semiotic system. *Semiotica, 80*(3/4), 239–252).

Campbell, J., and Davis, J. (1979). *The Northern Part of the Wakarusa Quadrangle, Kansas Atlas*. Kansas Geological Survey, University of Kansas, Lawrence, KS, and the experimental Cartography Unit, Natural Environmental Research Council, London, UK.

Carr, D. B., Olsen, A. R., and White, D. (1992). Hexagon mosaic maps for display of univariate and bivariate geographical data. *Cartography and Geographic Information Systems, 19*(4), 228–236.

Carswell, C. M., and Wickens, C. D. (1990). The perceptual interaction of graphical attributes: Configurality, stimulus homogeneity, and object integration. *Perception and Psychophysics, 47*, 157–168.

Carswell, C. M., Frankenberger, S., and Bernhard, D. (1991). Graphing in depth: Perspectives on the use of three-dimensional graphs to represent lower-dimensional data. *Behavior and Information Technology, 10*(6), 459–474.

Castner, H. W. (1983). Tactual maps and graphics: Some implications for our study of visual cartographic communication. *Cartographica, 20*(3), 1–16.

Castner, H. W. (1990). *Seeking New Horisons: A Perceptual Approach to Geographic Education*. Montreal: McGill–Queen's University Press.

Castner, H. W., and Eastman, J. R. (1985). Eye-movement parameters and perceived map complexity—II. *American Cartographer, 12*(1), 29–40.

Castner, H. W., and Robinson, A. (1969). *Dot Area Symbols in Cartography: The Influence of Pattern on Their Perception*. Washington, DC: American Congress on Surveying and Mapping.

Cave, K. R., and Wolfe, J. M. (1990). Modeling the role of parallel processing in visual search. *Cognitive Psychology, 22*, 225–271.

Cavenagh, P. (1987). Reconstructing the third dimension: Interactions between color, texture, motion, binocular disparity and shape. *Computer Vision, Graphics and Image Processing, 37*, 171–195.

Cavenagh, P. (1988). Pathways in early vision. In Z. Pylyshyn (Ed.), *Computational Processes in Human Vision* (pp. 239–261). Norwood, NJ: Ablex.

Chang, K.-T., Antes, J., and Lenzen, T. (1985). The effect of experience on reading topographic relief information: Analysis of performance and eye movements. *Cartographic Journal, 22*(2), 88–94.

Chase, W. G., and Simon, H. A. (1973). The mind's eye in chess. In W. Chase (Ed.), *Visual Information Processing* (pp. 215–281). New York: Academic Press.

Cheal, M., and Lyon, D. R. (1992). Attention in visual search: Multiple search classes. *Perception and Psychophysics, 52*(2), 113–138.

Cheng, P. W., and Holyoak, K. J. (1985). Pragmatic reasoning schemas. *Cognitive Psychology, 17*, 391–416.

Cheng, P. W., and Pachella, R. G. (1984). A psychological approach to dimensional separability. *Cognitive Psychology, 16*, 279–304.

Cleveland, W. S. (1991). *A Model for Studying Display Methods of Statistical Graphics*. Unpublished manuscript, AT&T Bell Laboratories.

Cleveland, W. S. (1993). A model for studying display methods of statistical graphics. *Journal of Computational and Graphical Statistics, 2*(4), 323–343.

Cleveland, W. S., and McGill, R. (1984). Graphical perception: Theory, experimentation, and application to the development of graphical methods. *Journal of the American Statistical Association, 79*, 531–554.

Coulson, M. R. C. (1987). In the matter of class intervals for choropleth maps: With particular attention to the work of George F. Jenks. *Studies in Cartography, Monograph 37, Cartographica, 24*(2), 16–39.

Coulson, M. R. C. (1991). Progress in creating tactile maps from geographic information systems (G.I.S.) output. *Proceedings, 15th Conference of the International Cartographic Association*, September 23–October 1, Bournemouth, UK, pp. 167–174.

Cox, C. W. (1976). Anchor effects and the estimation of graduated circles and squares. *American Cartographer, 3*, 65–74.

Crampton, J. (1992a). A cognitive analysis of wayfinding expertise. *Cartographica, 29*(3/4), 46–65.

Crampton, J. (1992b). New directions in the information era—a reply to Taylor (1991). *Cartographic Journal, 29*(2), 145–150.

Crampton, J. (1994). *Alternative Cartographies: New Frontiers of Human Issues*. Unpublished Ph.D. dissertation, Department of Geography, Pennsylvania State University.

Crawford, P. V., and Marks, R. A. (1973). The visual effects of geometric relationships on three-dimensional maps. *Professional Geographer, 25*(3), 233–238.

Cuff, D. J. (1973). Colour on temperature maps. *Cartographic Journal, 10*, 17–21.

Dacey, M. (1970). Linguistic aspects of maps and geographic information. *Ontario Geography, 5*, 71–80.

Darius, J. (1990). Scientific images: Perception and deception. In C. B. H. Barlow and M. Weston-Smith (Eds.), *Images and Understanding* (pp. 333–357). Cambridge: Cambridge University Press.

DeLucia, A. A., and Hiller, D. W. (1982). Natural legend design for thematic maps. *Cartographic Journal, 19*, 46–52.

DeMey, M. (1992). *The Cognitive Paradigm*. Chicago: University of Chicago Press.

Dennett, D. (1990). Thinking with a computer. In C. B. H. Barlow and M. Weston-Smith (Eds.), *Images and Understanding* (pp. 297–309). Cambridge: Cambridge University Press.

Dent, B. D. (1970). *Perceptual Organization and Thematic Map Communication: Some Principles for Effective Map Design with Special Emphasis on the Figure–Ground Relationship*. Worcester, MA: Department of Geography, Clark University.

Dent, B. D. (1972). Visual organization and thematic map communication. *Annals of the Association of American Geographers, 62*(1), 79–93.

Dent, B. D. (1993). *Cartography: Thematic Map Design* (3rd ed.). Dubuque, IA: Wm. C. Brown.

DeValois, R. L., and Jacobs, G. H. (1968). Primate color vision. *Science, 162*, 533–540.

DeYoe, E., Knierem, J., Sagi, S., Julesa, B., and van Essen, D. (1986). Single unit responses to static and dynamic texture patterns in macaque V2 and V1 cortex. *Investigative Ophthalmology and Visual Science, 27*, 18.

DiBiase, D. (1990). Visualization in the earth sciences. *Earth and Mineral Sciences, Bulletin of the College of Earth and Mineral Sciences, Pennsylvania State University, 59*(2), 13–18.

DiBiase, D., Krygier, J., Reeves, C., MacEachren, A. M., and Brenner, A. (1991a). Animated cartographic visualization in earth system science. *Proceedings, 15th Conference of the International Cartographic Association*, Bournemouth, UK, September 23–October 1, pp. 223–232.

DiBiase, D., Krygier, J., Reeves, C., MacEachren, A. M., and Brenner, A. (1991b). *An Elementary Approach to Cartographic Animation*. University Park, PA: Deasy GeoGraphics Laboratory, Department of Geography, Pennsylvania State University [video].

DiBiase, D., MacEachren, A. M., Krygier, J. B., and Reeves, C. (1992). Animation and the role of map design in scientific visualization. *Cartography and Geographic Information Systems, 19*(4), 201–214.

DiBiase, D., Paradis, T., and Sloan, J. L. I. (1994a). Weighted isolines: An alternative method of isoline symbolization. *Professional Geographer, 46*(2), 218–228.

DiBiase, D., Reeves, C., Krygier, J., MacEachren, A. M., von Wyss, M., Sloan, J., et al. (1994b). In A. M. MacEachren and D. R. F. Taylor (Eds.), *Visualization in Modern Cartography* (pp. 287–312). Oxford, UK: Elsevier.

DiBiase, D., Reeves, C., MacEachren, A. M., Krygier, J., von Wyss, M., Sloan, J., et al. (1993). A map interface for exploring multivariate paleoclimate data. *Proceedings, Auto-Carto 11*, Minneapolis, MN, October 30–November 1, ASPRS & ACSM, pp. 43–52.

Dobson, M. W. (1973). Choropleth maps without class intervals? A comment. *Geographical Analysis, 5*, 262–265.

Dobson, M. W. (1979a). The influence of map information on fixation localization. *American Cartographer, 6*, 51–65.

Dobson, M. W. (1979b). Visual information processing during cartographic communication. *Cartographic Journal, 16*, 14–20.

Dobson, M. W. (1983). Visual information processing and cartographic communication: The utility of redundant stimulus dimensions. In D. R. F. Taylor (Ed.), *Graphic Communication and Design in Contemporary Cartography, Volume 2, Progress in Contemporary Cartography* (pp. 149–175). New York: Wiley.

Dobson, M. W. (1985). The future of perceptual cartography. *Cartographica, 22*(2), 27–43.

Dorling, D. (1992a). *Persuading Older Research Workers of the Wonders of Cartograms*. Paper presented at the IBG Annual Conference, January 6, Royal Holloway, London.

Dorling, D. (1992b). Stretching space and splicing time: From cartographic animation to interactive visualization. *Cartography and Geographic Information Systems, 19*(4), 215–227.

Dorling, D. (1992c). Visualizing people in time and space. *Environment and Planning B: Planning and Design, 19*, 613–637.

Dorling, D., and Openshaw, S. (1992). Using computer animation to visualize space–time patterns. *Environment and Planning B: Planning and Design, 19*, 639–650.

Downing, C. J., and Pinker, S. (1985). The spatial structure of visual attention. In M. I. Posner and O. S. M. Martin (Eds.), *Attention and Performance, Volume XI* (pp. 171–188). Hillsdale, NJ: Erlbaum.

Downs, R. M., and Liben, L. S. (1987). Children's understanding of maps. In P. Ellen and C. Thinus-Blanc (Eds.), *Cognitive Processes and Spatial Orientation in Animal and Man, Volume II, Neurophysiology and Development Aspects* (pp. 202–219). Dordrecht: Martinus Nijhoff.

Downs, R. M., Liben, L. S., and Daggs, D. G. (1988). On education and geographers: The role of cognitive development theory in geographic education. *Annals of the Association of American Geographers, 78*, 680–700.

Duncan, J. (1984). Selective attention and the organization of visual information. In M. I. Posner and O. S. M. Marin (Eds.), *Attention and Performance, Volume XI* (pp. 85–106). Hillsdale, NJ: Erlbaum.

Duncan, J., and Humphreys, G. W. (1987). Visual search and stimulus similarity. *Psychological Review, 96*, 433–448.

Eastman, J. R. (1981). The perception of scale change in small-scale map series. *American Cartographer, 8*(1), 5–21.

Eastman, J. R. (1985a). Cognitive models and cartographic design research. *Cartographic Journal, 22*(2), 95–101.

Eastman, J. R. (1985b). Graphic organization and memory structures for map learning. *American Cartographer, 22*, 1–20.

Eastman, J. R. (1986). Opponent process theory and syntax for qualitative relationships in quantitative series. *American Cartographer, 13*(4), 324–333.

Eastman, J. R. (1987). Graphic syntax and expert systems for map design. *Technical Papers, ACSM & ASPRS, 4*, 87–96.

Eastman, J. R., and Castner, H. W. (1983). The meaning of experience in task-specific map reading. In D. R. F. Taylor (Ed.), *Graphic Communication and Design in Contemporary Cartography, Volume 2, Progress in Contemporary Cartography* (pp. 115–148). New York: Wiley.

Eco, U. (1972). *Einführung in die Semiotik*. Munich: Fink.

Eco, U. (1976). *A Theory of Semiotics*. Bloomington: Indiana University Press.

Eco, U. (1977). *Zeichen: Einführung in einen Begriff und seine Geshichte*. Frankfurt: Suhrkamp. (Italian edition, 1973)

Eco, U. (1985a). How culture conditions the colors we see. In M. Blonsky (Ed.), *On Signs* (pp. 157–175). Baltimore: Johns Hopkins University Press.

Eco, U. (1985b). Producing signs. In M. Blonsky (Ed.), *On Signs* (pp. 176–183). Baltimore: Johns Hopkins University Press.

Edney, M. H. (1993). Cartography without progress: Reinterpreting the nature of historical development of mapmaking. *Cartographica, 30*(1), 54–68.

Edwards, G. (1991). Spatial knowledge for image understanding. In D. M. Mark and A. U. Frank (Eds.), *Cognitive and Linguistic Aspects of Geographic Space* (pp. 295–307). Amsterdam: Kluwer Academic.

Ellis, W. (1955). *Sourcebook of Gestalt Psychology*. London: Routledge & Kegan Paul.

Engel, F. (1977). Visual conspicuousness, visual search and fixation tendencies of the eye. *Vision Research, 17*, 95–108.

Eriksen, C. W. (1952). Location of objects in a visual display as a function of the number of dimensions on which the objects differ. *Journal of Experimental Psychology, 44*, 126–132.

Eriksen, C. W., and Murphy, T. D. (1987). Movement of attentional focus across the visual field: A critical look at the evidence. *Perception and Psychophysics, 42*, 299–305.

Eyton, J. R. (1990). Color stereoscopic effect cartography. *Cartographica, 27*(1), 20–29.

Familant, M. E., and Detweiler, M. C. (1993). Iconic reference: Evolving perspectives and an organizing framework. *International Journal of Man–Machine Studies, 39*, 705–728.

Ferreia, J., and Wiggins, L. (1990). The density dial: A visualization tool for thematic mapping. *GeoInfo Systems, 1*, 69–71.

Finke, R. (1980). Levels of equivalence in imagery and perception. *Psychological Review, 87*, 113–132.

Fisher, P. (1993). Visualizing uncertainty in soil maps by animation. *Cartographica, 30*(2 & 3), 20–27.

Fisher, P. (1994). Randomization and sound for the visualization of uncertain spatial information. In D. Unwin and H. Hearnshaw (Eds.), *Visualization in Geographic Information Systems* (pp. 181–185). London: Wiley.

Ford, K. L. (1985). Map reading, divided attention, and limited viewing area (abstract). *Conference Program and Abstracts, 5th Annual Meeting of the North American Cartographic Information Society*, November 10–13, Chicago, p. 10.

Forrest, D., and Castner, H. W. (1985). The design and perception of point symbols for tourist maps. *Cartographic Journal, 22*, 11–19.

Friedhoff, R. M., and Benzon, W. (1989). *Visualization: The Second Computer Revolution*. New York: Harry Abrams.

Frutiger, A. (1989). *Signs and Symbols: Their Design and Meaning*. New York: Van Nostrand Reinhold.

Ganter, J. H., and MacEachren, A. M. (1989). *Cognition and the Design of Scientific Visualization Systems*. Unpublished manuscript, Department of Geography, Pennsylvania State University.

Garling, T., Lindberg, E., and Mantyla, T. (1983). Orientation in buildings: Effects of familiarity, visual access, and orientation aids. *Journal of Applied Psychology, 68*, 177–186.

Garner, W. R. (1976). Interaction of stimulus dimensions in concept and choice processes. *Cognitive Psychology, 8*, 98–123.

Gerber, R. V. (1981). Competence and performance in cartographic language. *Cartographic Journal, 18*(2), 104–111.

Gerber, R., Burden, P., and Stanton, G. (1990). Development of public information symbols for tourism and recreation mapping. *Cartographic Journal, 27*(2), 92–103.

Gershon, N. D. (1992). Visualization of fuzzy data using generalized animation. *Proceedings, Visualization '92*, October 19–23, Boston, IEEE Computer Society Technical Committee on Computer Graphics, pp. 268–273.

Gersmehl, P. J. (1977). Soil taxonomy and mapping. *Annals of the Association of American Geographers, 67*(3), 419–428.

Gersmehl, P. J. (1990, Spring). Choosing tools: Nine metaphors of four-dimensional cartography. *Carographic Perspectives*, No. 5, 3–17.

Gibson, A. E. (1987). A model describing options for parallel color/data structuring. *Technical Papers, ACSM & ASPRS, 4*, 97–106.

Gibson, J. J. (1950). *Perception of the Visual World*. New York: Houghton Mifflin.

Gibson, J. J. (1979). *An Ecological Approach to Visual Perception*. Boston: Houghton Mifflin.

Giere, R. N. (1988). *Explaining Science: A Cognitive Approach*. Chicago: University of Chicago Press.

Gilmartin, P. P. (1978). Evaluation of thematic maps using the semantic differential test. *American Cartographer, 5*, 133–139.

Gilmartin, P. P. (1981). Influence of map content on circle perception. *Annals of the Association of American Geographers, 71*, 253–258.

Gilmartin, P. P. (1988). The design of choropleth shadings for maps on 2- and 4-bit color graphics monitors. *Cartographica, 25*(4), 1–10.

Gilmartin, P. P., and Shelton, E. (1989). Choropleth maps on high resolution CRTs: The effects of number of classes and hue on communication. *Cartographica, 26*(2), 40–52.

Goldberg, J. H., MacEachren, A. M., and Kotval, X. P. (1992). Mental image transformations in terrain map comparison. *Cartographica, 29*(2), 46–59.

Goldhamer, H. (1934). The influence of area, position, and brightness in the visual perception of a reversible configuration. *American Journal of Psychology, 46*(2), 189–206.

Golledge, R. G., Gale, N., Pellegrino, J. W., and Doherty, S. (1992). Spatial knowledge acquisition by children: Route learning and relational distances. *Annals of the Association of American Geographers, 82*(2), 223–244.

Golledge, R. G., and Stimson, R. J. (1987). Spatial cognition. In *Analytical Behavioral Geography* (pp. 52–83). New York: Croom Helm.

Gombrich, E. (1990). Pictorial instructions. In C. B. H. Barlow and M. Weston-Smith (Eds.), *Images and Understanding* (pp. 26–45). Cambridge: Cambridge University Press.

Goodman, N. (1976). *Languages of Art: An Approach to a Theory of Symbols* (2nd ed.). Indianapolis: Hackett.

Gould, P., Kabel, J., Gorr, W., and Golub, A. (1991). AIDS: Predicting the next map. *Interfaces, 21*(3), 80–92.

Gratzer, M. A., and McDowell, R. D. (1971). *Adaptation of an Eye Movement*

Recorder to Aesthetic Environment Mensuration. Storrs, CT: Storrs Agricultural Station, University of Connecticut.

Gregory, R. (1990). How do we interpret images? In C. M. H. Barlow and M. Weston-Smith (Eds.), *Images and Understanding* (pp. 310–330). Cambridge: Cambridge University Press.

Griffin, T. L. C. (1985). Group and individual variations in judgment and their relevance to the scaling of graduated circles. *Cartographica, 22*(1), 21–37.

Grinstein, G., Sieg, J. C. J., Smith, S., and Williams, M. G. (1992). Visualization for knowledge discovery. *International Journal of Intelligent Systems, 7*, 637–648.

Groop, R. E., and Cole, D. (1978). Overlapping graduated circles: Magnitude estimation and method of portrayal. *Canadian Cartographer, 15*, 114–122.

Guiraud, P. (1975). *Semiology*. London: Routledge & Kegan Paul.

Hadamard, J. (1945). *An Essay on the Psychology of Invention in the Mathematical Field*. New York: Dover.

Haining, R. P. (1978). A spatial model for high plains agriculture. *Annals of the Association of American Geographers, 68*, 493–504.

Hall, S. S. (1992). *Mapping the Next Millenium: The Discovery of New Geographies*. New York: Random House.

Handel, S., Imai, S., and Spottswood, P. (1980). Dimensional similarity and configural classification of integral and separable stimuli. *Perception and Psychophysics, 28*, 205–212.

Hannah, M. (1993). *Foucault Deinstitutionalized: Spatial Prerequisites for Modern Social Control*. Unpublished Ph.D. dissertation, Department of Geography, Pennsylvania State University.

Harley, J. B. (1988). Maps, knowledge, and power. In D. Cosgrove and S. Daniels (Eds.), *The Iconography of Landscape: Essays on the Symbolic Representation, Design and Use of Past Environments* (pp. 277–311). Cambridge: Cambridge University Press.

Harley, J. B. (1989). Deconstructing the map. *Cartographica, 26*(2), 1–20.

Harley, J. B. (1990). Cartography, ethics, and social theory. *Cartographica, 27*(2), 1–23.

Harrower, M. (1936). Some factors determining figure–ground articulation. *British Journal of Psychology, 4*, 407–424.

Hartshorne, C., and Weiss, P. (Eds.). (1931). *The Collected Papers of Charles Sanders Peirce, Volumes I and II*. Cambridge, MA: Belknap Press of Harvard University Press.

Harvey, D. (1969). *Explanation in Geography*. London: Edward Arnold.

Harwood, K. (1989). Cognitive perspectives on map displays for helicopter flight. *Proceedings, 33rd Annual Meeting of the Human Factors Society*, October 16–18, Denver, CO, pp. 13–17.

Head, C. G. (1984). The map as natural language: A paradigm for understanding. *Cartographica, 21*(1), 1–31.

Hervey, S. (1982). *Semiotic Perspectives*. London: Allen & Unwin.

Hochberg, J. (1980). Pictorial functions and perceptual structures. In M. A. Hagen (Eds.), *The Perception of Pictures* (pp. 47–93). New York: Academic Press.

Hoffman, D. D., and Richards, W. A. (1984). Parts of recognition. *Cognition, 18*, 65–96.

Hoffman, H. S. (1989). *Vision and the Art of Drawing*. Englewood Cliffs, NJ: Prentice-Hall.

Hoffman, R. R., Detweiler, M., Conway, J. A., and Lipton, K. S. (1993). Some considerations in using color in meteorological displays. *Weather and Forecasting, 8*, 505–518.

Holyoak, K. J., and Nisbett, R. E. (1988). Induction. In R. J. Sternberg and E. E. Smith (Eds.), *The Psychology of Human Thought* (pp. 50–91). Cambridge: Cambridge University Press.

Howard, V. A. (1980). Theory of representation: Three questions. In P. A. Kolers, M. E. Wrolstad, and H. Bouma (Eds.), *Processing of Visible Language, Volume 2* (pp. 501–515). New York: Plenum Press.

Hsu, M.-L. (1979). The cartographer's conceptual process and thematic symbolization. *American Cartographer, 6*, 117–127.

Hubel, D. H. (1988). *Eye, Brain and Vision*. New York: Scientific American Library.

Humphreys, G. W., and Bruce, V. (1989). *Visual Cognition: Computational, Experimental and Neuropsychological Perspectives*. London: Erlbaum.

Humphreys, G. W., and Quinlan, P. T. (1987). Normal and pathological processes in visual object constancy. In G. W. Humphreys and M. J. Riddoch (Eds.), *Visual Object Processing: A Cognitive Neurological Approach* (pp. 43–105). London: Erlbaum.

Hurvich, L. M., and Jameson, D. (1957). Opponent-process theory of color vision. *Psychological Review, 64*(6), 384–404.

Imhof, E. (1982). *Cartographic Relief Presentation*. Berlin: Walter de Gruyter. (German edition, 1965)

Innis, R. E. (Ed.). (1985). *Semiotics: An Introductory Anthology*. Bloomington: Indiana University Press.

Jakobson, R. (1960). Linguistics and poetics. In T. A. Sebeok (Ed.), *Style in Language* (pp. 350–377). Cambridge, MA: MIT Press.

James, W. (1950). *The Principles of Psychology, Volume 1*. New York: Dover. (Original work published 1890)

Japan Cartographers Association. (1980). Examples of methods used for oceanic cartography in Japan. *The Dynamics of Oceanic Cartography, Monograph 25, Cartographica, 17*(2), 157–181.

Jenks, G. F. (1963). Generalization in statistical mapping. *Annals of the Association of American Geographers, 53*(1), 15–26.

Jenks, G. F. (1967). The data model concept in statistical mapping. *International Yearbook of Cartography, 7*, 186–190.

Jenks, G. F. (1973). Visual integration in thematic mapping: Fact or fiction? *International Yearbook of Cartography, 13*, 27–34.

Jenks, G. F. (1975). The evaluation and prediction of visual clustering in maps symbolized with proportional circles. In J. Davis and M. McCullaugh (Eds.), *Display and Analysis of Spatial Data* (pp. 311–327). New York: Wiley.

Jenks, G. F. (1977). *Optimal Data Classification for Choropleth Maps*. Lawrence: Department of Geography, University of Kansas.

Jenks, G. F., and Brown, D. A. (1966). Three-dimensional map construction. *Science, 154*, 857–864.

Jenks, G. F., and Caspall, F. C. (1971). Error on choroplethic maps: Definition, measurement, reduction. *Annals of the Association of American Geographers, 61*, 217–244.

Johnson, G. (1983). *Qualitative Symbology: An Evaluation of the Pictorial Signs of the National Park Service as Cartographic Symbols*. Unpublished master's thesis, Virginia Polytechnic Institute and State University.

Johnson, M. (1987). *The Body in the Mind: The Bodily Basis of Meaning, Imagination, and Reason*. Chicago: University of Chicago Press.

Judson, H. F. (1987). *The Search for Solutions*. Baltimore: Johns Hopkins University Press.

Julesz, B. (1965). Texture and visual perception. *Scientific American, 212*, 38–48.

Julesz, B. (1975). Experiments in the visual perception of texture. *Scientific American, 232*, 34–43.

Julesz, B. (1981). Textons, the elements of texture perception, and their interactions. *Nature, 290*, 91–97.

Kaiser, M. K., and Proffitt, D. R. (1992). Using the stereokinetic effect to convey depth: Computationally efficient depth-from-motion displays. *Human Factors, 34*(5), 571–581.

Kay, P., and McDaniel, C. (1978). The linguistic significance of the meanings of basic color terms. *Language, 54*(3), 610–646.

Keates, J. S. (1982). *Understanding Maps*. New York: Halsted Press.

Keates, J. S. (1984). The cartographic art. *New Insights in Cartographic Communication, Monograph 31, Cartographica, 23*(1), 37–43.

Kienker, P. K., and Sejnowski, T. J. (1986). Separating figure from ground with a parallel network. *Perception, 15*, 197–216.

Kimchi, R. (1988). Selective attention to global and local levels in the comparison of hierarchical patterns. *Perception and Psychophysics, 43*, 189–198.

Kimerling, A. J. (1985). The comparison of equal-value gray scales. *American Cartographer, 12*, 132–142.

Kinchla, R. A., and Wolfe, J. M. (1979). The order of visual processing: "Top-down," "bottom-up" or "middle-out." *Perception and Psychophysics, 25*, 225–231.

Kishto, B. N. (1965). The color stereoscopic effect. *Vision Research, 5*, 313–329.

Klymenko, V., and Weisstein, N. (1986). Spatial frequency differences can determine figure–ground organization. *Journal of Experimental Psychology: Human Perception and Performance, 12*(3), 324–330.

Klymenko, V., and Weisstein, N. (1989). Figure and ground in space and time: 1. Temporal response surfaces of perceptual organization. *Perception, 18*(5), 627–637.

Klymenko, V., Weisstein, N., Topolski, R., and Hsieh, C. (1989). Spatial and temporal frequency in figure–ground organization. *Perception and Psychophysics, 45*, 395–403.

Knowlton, J. Q. (1966). On the definition of "picture." *AV Communication Review, 14*, 157–183.

Koffka, K. (1935). *Principles of Gestalt Psychology*. New York: Harcourt, Brace & Co.

Kohler, W. (1947). *Gestalt Psychology*. New York: Liveright.

Koláčný, A. (1969). Cartographic information—a fundamental concept and term in modern cartography. *Cartographic Journal, 6*, 47–49.

Korac, N. (1988). Functional, cognitive and semiotic factors in the development of audiovisual comprehension. *ECTJ, 36*(2), 67–91.

Kosslyn, S. M. (1980). *Images and Mind*. Cambridge, MA: Harvard University Press.

Kosslyn, S. M. (1981). The medium and the message in mental imagery. *Psychological Review, 88*, 46–66.

Kosslyn, S. M. (1989). Understanding charts and graphs. *Applied Cognitive Psychology, 3*, 185–226.

Kosslyn, S. M., and Koenig, O. (1992). *Wet Mind: The New Cognitive Neuroscience*. New York: Free Press.

Kraak, M.-J. (1988). *Computer-Assisted Cartographical Three-Dimensional Imaging Techniques*. Delft: Delft University Press.

Kraak, M.-J. (1989). Computer-assisted cartographical 3D imaging techniques. In J. Raper (Ed.), *Three-Dimensional Applications in Geographic Information Systems* (pp. 99–113). London: Taylor & Francis.

Kraak, M.-J. (1993). Cartographic terrain modeling in a three-dimensional GIS environment. *Cartography and Geographic Information Systems, 20*(1), 13–18.

Krampen, M. (1965). Signs and symbols in graphic communication. *Design Quarterly, 62*, 1–31.

Kröse, B. (1987). Local structure analyzers as determinants of preattentive pattern discrimination. *Biological Cybernetics, 55*, 289–298.

Krygier, J. (1991). *An elemental approach to animation and sound in information graphics*. Electronically published on the INGRAPHX listserve.

Krygier, J. (1994). Sound and geographic visualization. In A. M. MacEachren and D. R. F. Taylor (Eds.), *Visualization in Modern Cartography* (pp. 149–166). Oxford, UK: Elsevier.

Krygier, J. (forthcoming). *Visualization, Geography, and Derelict Landscapes*. Unpublished Ph.D. dissertation, Pennsylvania State University.

Kubovy, M. (1981). Concurrent pitch segregation and the theory of indispensable attributes. In M. Kubovy and J. Pomerantz (Eds.), *Perceptual Organization* (pp. 55–98). Hillsdale, NJ: Erlbaum.

Kuhn, T. S. (1970). *The Structure of Scientific Revolutions* (2nd ed.). Chicago: University of Chicago Press.

Labov, W. (1973). The boundaries of words and their meanings. In J. Fishman (Ed.), *New Ways of Analyzing Variation in English* (pp. 340–373). Washington, DC: Georgetown University Press.

Lakoff, G. (1987). *Woman, Fire, and Dangerous Things: What Categories Reveal about the Mind*. Chicago: University of Chicago Press.

Lakoff, G., and Johnson, M. (1980). *Metaphors We Live By*. Chicago: University of Chicago Press.

Lamb, M., and Robertson, L. (1988). The processing of hierarchical stimuli: Ef-

fects of retinal locus, locational uncertainty, and stimulus identity. *Perception and Psychophysics, 44*(2), 172–181.
Land, E. H., and McCann, J. J. (1971). Lightness and retinex theory. *Journal of the Optical Society of America, 61*, 1–11.
Larkin, J., McDermott, J., Simon, D. P., and Simon, H. A. (1980). Expert and novice performance in solving physics problems. *Science, 208*, 1335–1342.
Larkin, J. H., and Simon, H. A. (1987). Why a diagram is (sometimes) worth ten thousand words. *Cognitive Science, 11*, 65–99.
Lavin, S. (1986). Mapping continuous geographical distributions using dot-density shading. *American Cartographer, 13*(2), 140–150.
Leach, E. (1964). Anthropological aspects of language: Animal categories and verbal abuse. In E. H. Lenneberg (Ed.), *New Directions in the Study of Language* (pp. 23–64). Cambridge, MA: MIT Press.
Leonard, J. J., and Buttenfield, B. P. (1989). An equal value gray scale for laser printer mapping. *American Cartographer, 16*(2), 97–107.
Levine, M., Jankovic, L., and Palij, M. (1982). Principles of spatial problem solving. *Journal of Experimental Psychology: General, 111*, 157–175.
Lewandowsky, S., and Spence, I. (1989). Discriminating strata in scatterplots. *Journal of the American Statistical Association, 84*(407), 682–688.
Lewis, P. (1992). Introducing a cartographic masterpiece: A review of the U.S. Geological Survey's digital terrain map of the United States, by Gail Thelin and Richard Pike. *Annals of the Association of American Geographers, 82*(2), 289–304.
Liben, L. S., and Downs, R. M. (1989). Understanding maps as symbols: The development of map concepts in children. *Advances in Child Development and Behavior, 22*, 145–201.
Lindauer, M., and Lindauer, J. (1970). Brightness differences and the perception of figure–ground. *Journal of Experimental Psychology, 84*(2), 291–295.
Liu, Y., and Wickens, C. D. (1992). Use of computer graphics and cluster analysis in aiding relational judgment. *Human Factors, 34*(2), 165–178.
Liverman, D. M., and O'Brian, K. L. (1991). Global warming and climate change in Mexico. *Global Environmental Change, 1*(4), 351–364.
Lloyd, R. (1982). A look at images. *Annals of the Association of American Geographers, 72*, 532–548.
Lloyd, R. (1988). Searching for map symbols: The cognitive processes. *American Cartographer, 15*(4), 363–377.
Lloyd, R. (1989). Cognitive maps: Encoding and decoding information. *Annals of the Association of American Geographers, 79*(1), 101–124.
Lloyd, R., and Steinke, T. (1976). The decision-making process for judging the similarity of choropleth maps. *American Cartographer, 3*, 177–184.
Lloyd, R., and Steinke, T. (1985). Comparison of qualitative point symbols: The cognitive process. *American Cartographer, 12*, 156–168.
Lobeck, A. K. (1958). *Block Diagrams* (2nd ed.). Amherst, MA: Emerson–Trussel.
Lockhead, G. R. (1970). Identification and the form of multidimensional discrimination space. *Journal of Experimental Psychology, 85*, 1–10.
Luckiesh, M. (1918). On "retiring" and "advancing" colors. *American Journal of Psychology, 29*, 182–186.

Luria, S. M., Neri, D. F., and Jacobsen, A. R. (1986). The effects of set size on color matching using CRT displays. *Human Factors, 28*(1), 49–61.
Lynch, K. (1960). *The Image of the City*. Cambridge, MA: MIT Press.
Lyutyy, A. A. (1985). On the essence of the language of the map. *Mapping Sciences and Remote Sensing, 23*, 127–139.
MacDougall, E. B. (1992). Exploratory analysis, dynamic statistical visualization, and geographic information systems. *Cartography and Geographic Information Systems, 19*(4), 237–246.
MacEachren, A. M. (1979). *Communication Effectiveness of Choropleth and Isopleth Maps: The Influence of Visual Complexity*. Unpublished Ph.D. dissertation, University of Kansas.
MacEachren, A. M. (1982). The role of complexity and symbolization method in thematic map effectiveness. *Annals of the Association of American Geographers, 72*, 495–513.
MacEachren, A. M. (1989, March). Review of [Yamahira, T., Kasahara, Yutaka, and Tsurutani, Tateyuki (1985). How map designers can represent their ideas in thematic maps. *The Visual Computer, 1*, 174–184.] *Cartographic Perspectives*, No. 11, 5–16.
MacEachren, A. M. (1991a). The role of maps in spatial knowledge acquisition. *Cartographic Journal, 28*, 152–162.
MacEachren, A. M. (1991b). *Visualization Quality and the Representation of Uncertainty*. Orono, ME: National Center for Geographic Information and Analysis.
MacEachren, A. M. (1992a). Application of environmental learning theory to spatial knowledge acquisition from maps. *Annals of the Association of American Geographers, 82*(2), 245–274.
MacEachren, A. M. (1992b, Fall). Visualizing uncertain information. *Cartographic Perspectives*, No. 13, 10–19.
MacEachren, A. M. (1994a). *Some Truth with Maps: A Primer on Design and Symbolization*. Washington, DC: Association of American Geographers.
MacEachren, A. M. (1994b). Viewing time as a cartographic variable. In H. Hearnshaw and D. Unwin (Eds.), *Visualization in GIS* (pp. 115–130). London: Wiley.
MacEachren, A. M. (1994c). Visualization in modern cartography: Setting the agenda. In A. M. MacEachren and D. R. F. Taylor (Eds.), *Visualization in Modern Cartography* (pp. 1–12). Oxford, UK: Elsevier.
MacEachren, A. M. (in collaboration with Buttenfield, B., Campbell, J., DiBiase, D., and Monmonier, M.) (1992). Visualization. In R. Abler, M. Marcus, and J. Olson (Eds.), *Geography's Inner Worlds: Pervasive Themes in Contemporary American Geography* (pp. 99–137). New Brunswick, NJ: Rutgers University Press.
MacEachren, A. M., and DiBiase, D. W. (1991). Animated maps of aggregate data: Conceptual and practical problems. *Cartography and Geographic Information Systems, 18*(4), 221–229.
MacEachren, A. M., and Ganter, J. H. (1990). A pattern identification approach to cartographic visualization. *Cartographica, 27*(2), 64–81.
MacEachren, A. M., Howard, D., von Wyss, M., Askov, D., and Taormino, T. (1993). Visualizing the health of Chesapeake Bay: An uncertain endeavor.

Proceedings, GIS/LIS '93, Minneapolis, MN, November 2–4, ACSM & ASPRS, pp. 449–458.

MacEachren, A. M., and Mistrick, T. A. (1992). The role of brightness differences in figure–ground: Is darker figure? *Cartographic Journal, 29*(2), 91–100.

Mackworth, N. H., and Morandi, A. J. (1967). The gaze selects the information details within pictures. *Perception and Psychophysics, 2*, 547–552.

Maclean, A. L., D'Avello, T. P., and Shetron, S. G. (1993). The use of variability diagrams to improve the interpretation of digital soil maps in a GIS. *Photogrammetric Engineering and Remote Sensing, 59*(2), 223–228.

Makkonen, K., and Sainio, R. (1991). Computer assisted cartographic communication. *Proceedings, 15th Conference of the International Cartographic Association*, September 23–October 1, Bournemouth, UK, pp. 211–222.

Malik, J., and Perona, P. (1990). Preattentive texture discrimination with early vision mechanisms. *Journal of the Optical Society of America, A7*, 923–932.

Margolis, H. (1987). *Patterns, Thinking, and Cognition: A Theory of Judgment*. Chicago: University of Chicago Press.

Mark, D., and Frank, A. (Eds.). (1991). *Cognitive and Linguistic Aspects of Geographic Space, NATO ASI Series D: Behavioral and Social Sciences, Volume 63*. Dordrecht: Kluwer Academic.

Mark, D. M., and Gold, M. D. (1991). Interacting with geographic information: A commentary. *Photogrammetric Engineering and Remote Sensing, 57*(11), 1427–1430.

Marr, D. (1982). *Vision: A Computational Investigation into the Human Representation and Processing of Visual Information*. San Francisco: W. H. Freeman.

Marr, D. (1985). Vision: The philosophy and the approach. In A. M. Aitkenhead and J. M. Slack (Eds.), *Issues in Cognitive Modeling* (pp. 103–126). London: Erlbaum.

Marr, D., and Nishihara, H. K. (1978). Representation and recognition of the spatial organization of three-dimensional shapes. *Proceedings of the Royal Society, 200*, 269–294.

Marshall, R., Kempf, J., and Dyer, S. (1990). Visualization methods and simulation steering for a 3D turbulence model of Lake Erie. *Computer Graphics, 24*(2), 89–97.

Martinet, J. (1973). *Clefs pour la Sémiologie*. Paris: Editions Seghers.

Martinet, J. (1990). The semiotics of Luis Prieto. In T. A. Sebeok and Umiker-Sebeok (Eds.), *The Semiotic Web 1989* (pp. 89–108). Berlin: Mouton de Gruyter.

McCleary, G. F. (1970). Beyond simple psychophysics: Approaches to the understanding of map perception. *Technical Papers*, ACSM, 189–209.

McCleary, G. F. (1975). In pursuit of the map user. *Proceedings, Auto-Carto II*, September 21–25, Washington, DC, U.S. Bureau of the Census & ACSM, pp. 238–250.

McCleary, G. F. (1981). How to design an effective graphics presentation. *Harvard Library of Computer Graphics 1981 Mapping Collection, 17*, 15–64.

McGranaghan, M. (1989). Ordering choropleth map symbols: The effect of background. *American Cartographer, 16*(4), 279–285.

McGranaghan, M., Mark, D., and Gould, M. D. (1987). Automated provision of navigation assistance to drivers. *American Cartographer, 14*(2), 121–138.

McGuigan, F. J. (1957). An investigation of several methods of teaching contour interpretation. *Journal of Applied Psychology, 41*, 53–57.

McGuinness, C., van Wersch, A., and Stringer, P. (1993). User differences in a GIS environment: A protocol study. *Proceedings, 16th Conference of the International Cartographic Association*, May 3–9, Cologne, Germany, pp. 478–485.

McLay, W. J. (1987). *Two-Variable Mapping: A Practical Case for the Soil Map*. Unpublished master's thesis, Pennsylvania State University.

Medyckyj-Scott, D., and Board, C. (1991). Cognitive cartography: A new heart for a lost soul. In J.-C. Muller (Ed.), *Advances in Cartography* (pp. 201–230). London: Elsevier.

Mersey, J. E. (1990). *Colour and Thematic Map Design: The Role of Colour Scheme and Map Complexity in Choropleth Map Communication, Monograph 41, Cartographica, 27*(3).

Metz, C. (1974). *Film Language: A Semiotics of the Cinema*. New York: Oxford University Press. (French edition, 1968)

Metzger, P. (1992). *Perspective without Pain*. Cincinnati: North Light Books.

Meyers, G. (1988). Every picture tells a story: Illustrations in E. O. Wilson's *Sociobiology*. In M. Lynch and S. Woolgar (Eds.), *Representation in Scientific Practice* (pp. 231–265). Cambridge, MA: MIT Press.

Mistrick, T. (1990). *The Effects of Brightness Contrast on Figure–Ground Discrimination for Black and White Maps*. Unpublished master's thesis, Pennsylvania State University.

Moellering, H. (1976). The potential uses of a computer animated film in the analysis of geographical patterns of traffic crashes. *Accident Analysis and Prevention, 8*, 215–227.

Moellering, H. (1980a). The real-time animation of three dimensional maps. *American Cartographer, 7*, 67–75.

Moellering, H. (1980b). Strategies of real-time cartography. *Cartographic Journal, 17*, 12–15.

Moellering, H. (1993). MKS-Aspect™—a new way of rendering cartographic Z surfaces. *Proceedings, 16th Conference of the International Cartographic Association*, May 3–9, Cologne, Germany, pp. 675–681.

Moellering, H., and Kimerling, J. (1990). A new digital slope–aspect display process. *Cartography and Geographic Information Systems, 17*(2), 151–159.

Mollon, J. (1990). The tricks of colour. In C. B. H. Barlow and M. Weston-Smith (Eds.), *Images and Understanding* (pp. 61–78). Cambridge: Cambridge University Press.

Monmonier, M. (1972). Contiguity-biased class-interval selection: A method for simplifying patterns on statistical maps. *Geographical Review, 62*, 203–228.

Monmonier, M. (1989a). Geographic brushing: Enhancing exploratory analysis of the scatterplot matrix. *Geographical Analysis, 21*(1), 81–84.

Monmonier, M. (1989b). Graphic scripts for the sequenced visualization of geographic data. *Proceedings, GIS/LIS '89*, ASPRS & ACSM, pp. 381–389.

Monmonier, M. (1990). Strategies for the visualization of geographic time-series data. *Cartographica, 27*(1), 30–45.
Monmonier, M. (1991a). *How to Lie with Maps*. Chicago: University of Chicago Press.
Monmonier, M. (1991b). On the design and application of biplots in geographic visualization. *Journal of the Pennsylvania Academy of Science, 65*(1), 40–47.
Monmonier, M. (1992). Authoring graphics scripts: Experiences and principles. *Cartography and Geographic Information Systems, 19*(4), 247–260.
Monmonier, M., and Gluck, M. (1994). Focus groups for design improvement in dynamic cartography. *Cartography and Geographic Information Systems, 21*(1), 37–47.
Morita, T. (1991). *The Measurement of Eye Movements for Map Design Evaluation: Legibility of Quantitative Symbols*. Paper presented at the 15th Meeting of the International Cartographic Association, September 23–October 1, Bournemouth, UK.
Morris, C. W. (1938). *Foundations of the Unity of Science: Towards an International Encyclopedia of Unified Science, Volumes 1 and 2*. Chicago: University of Chicago Press.
Morris, C. W. (1971). Esthetics and the theory of signs. In C. W. Morris (Ed.), *Writings on the General Theory of Signs* (pp. 415–433). The Hague: Mouton. (Original paper published 1939)
Morris, C. W. (1971). Signs, language, and behavior. In C. Morris (Ed.), *Writings on the General Theory of Signs* (pp. 73–398). The Hague: Mouton. (Original paper published 1946)
Morris, C. W. (1964). *Signification and Significance*. Cambridge, MA: MIT Press.
Morrison, J. L. (1974). A theoretical framework for cartographic generalization with the emphasis on the process of symbolization. *International Yearbook of Cartography, 14*, 115–127.
Morrison, J. L. (1984). Applied cartographic communication: Map symbolization for atlases. *New Insights in Cartographic Communication, Monograph 31, Cartographica, 21*, 44–84.
Movshon, A. (1990). Visual processing of moving images. In C. B. H. Barlow and M. Weston-Smith (Eds.), *Images and Understanding* (pp. 122–137). Cambridge: Cambridge University Press.
Mowafy, L., Blake, R., and Lappin, J. S. (1990). Detection and discrimination of coherent motion. *Perception and Psychophysics, 48*(6), 583–592.
Muehrcke, P. (1973). Visual pattern comparison in map reading. *Proceedings, Association of American Geographers*, April 14–18, Atlanta, GA, pp. 190–194.
Muehrcke, P. (1974). Beyond abstract map symbols. *Journal of Geography, 73*(8), 35–52.
Muehrcke, P. (1990). Cartography and geographic information systems. *Cartography and Geographic Information Systems, 17*(1), 7–15.
Muehrcke, P., and Muehrcke, J. O. (1974). Maps in literature. *Geographical Review, 64*, 317–338.
Muehrcke, P., and Muehrcke, J. O. (1978). *Map Use: Reading, Analysis, and Interpretation*. Madison, WI: JP Publications.

Mulder, J., and Hervey, S. (1990). *The Strategy of Linguistics*. Edinburgh: Scotish Academic Press.
Muller, J.-C. (1979). Perception of continuously shaded maps. *Annals of the Association of American Geographers, 69*, 240–249.
Murphy, G. L., and Medin, D. L. (1985). The role of theories in conceptual coherence. *Psychological Review, 92*(3), 289–316.
Nakayama, K., and Silverman, G. H. (1986). Serial and parallel processes of visual feature conjunctions. *Nature, 320*, 264–265.
Navon, D. (1977). Forest before trees: The precedence of global features in visual perception. *Cognitive Psychology, 9*, 353–383.
Neisser, U. (1976). *Cognition and Reality: Principles and Implications of Cognitive Psychology*. San Francisco: W. H. Freeman.
Neisser, U. (1987). A sense of where you are: Functions of the spatial module. In *Proceedings of the NATO Advanced Study Institute on Cognitive Processes and Spatial Orientation in Animal and Man, 1985* (pp. 293–311). La-Baume-les-Aix, France: Martinus Nijhoff.
Nöth, W. (1990). *Handbook of Semiotics*. Bloomington: Indiana University Press.
Nothdurft, H.-C. (1992). Feature analysis and the role of similarity in preattentive vision. *Perception and Psychophysics, 52*(4), 355–375.
Nyerges, T. L. (1991a). Geographic information abstractions: Conceptual clarity for geographic modeling. *Environment and Planning A, 23*, 1483–1499.
Nyerges, T. L. (1991b). Representing geographical meaning. In B. P. Buttenfield and R. B. McMaster (Eds.), *Map Generalization: Making Rules for Knowledge Representation* (pp. 59–85). Essex, UK: Longman.
Ogden, C. K., and Richards, I. A. (1923). *The Meaning of Meaning*. New York: Harcourt, Brace & Co.
Olson, J. M. (1972). Class interval system on maps of observed correlation distribution. *Canadian Cartographer, 9*, 122–131.
Olson, J. M. (1976). A coordinated approach to map communication improvement. *American Cartographer, 3*, 151–159.
Olson, J. M. (1979). Cognitive cartographic experimentation. *Canadian Cartographer, 16*, 34–44.
Olson, J. M. (1981). Spectrally encoded two-variable maps. *Annals of the Association of American Geographers, 71*(2), 259–276.
Olson, J. M. (1983). Future research directions in cartographic communication and design. In D. R. F. Taylor (Ed.), *Graphic Communication and Design in Contemporary Cartography, Volume 2, Progress in Contemporary Cartography* (pp. 257–284). New York: Wiley.
Olson, J. M. (1989, February). *Maps for People with Defective Color Vision: Experimental Results*. Paper presented at the Pennsylvania State University Department of Geography Coffee Hour.
Olson, J. M. (1994). Problems and uses of color in cartography: Examples from Michigan State University. In J. Bares (Chair/Ed.), *Color Hardcopy and Graphic Arts III, Proceedings, SPIE—The International Society for Optical Engineering, Volume 2171*, pp. 46–53.
Olson, R. K., and Attneave, F. (1970). What variables produce similarity grouping? *American Journal of Psychology, 83*, 1–21.

Oyama, T. (1960). Figure–ground dominance as a function of sector angle, brightness, hue, and orientation. *Journal of Experimental Psychology, 60*(5), 299–305.

Paivio, A. (1969). Mental imagery in associative learning and memory. *Psychological Review, 76*, 241–263.

Palmer, S. E. (1975). Visual perception and world knowledge: Notes on a model of sensory-cognitive interaction. In D. A. Norman and D. E. Rumelhart (Eds.), *Explorations in Cognition* (pp. 279–307). San Francisco: W. H. Freeman.

Palmer, S. E. (1977). Hierarchical structure in perceptual representation. *Cognitive Psychology, 9*, 441–474.

Papathomas, T. V., and Julesz, B. (1988). The application of depth separation to the display of large data sets. In W. S. Cleveland and M. E. McGill (Eds.), *Dynamic Graphics for Statistics* (pp. 353–377). Belmont, CA: Wadsworth.

Paquet, L., and Merikle, P. (1988). Global precedence in attended and nonattended objects. *Journal of Experimental Psychology: Human Perception and Performance, 14*(1), 89–100.

Patton, J. C., and Crawford, P. V. (1978). The perception of hyposometric colours. *Cartographic Journal, 15*, 115–127.

Peirce, C. S. (1985). Logic as semiotic: The theory of signs. In R. E. Innis (Ed.), *Semiotics: An Introductory Anthology* (pp. 4–23). Bloomington: Indiana University Press.

Penn, A. (1993). Intelligent analysis of urban space patterns: Graphical interfaces to precedent databases for urban design. *Proceedings, Auto-Carto 11*, October 30–November 1, Minneapolis, MN, ASPRS & ACSM, pp. 53–62.

Pentland, A. P. (1985). The focal gradient: Optics ecologically salient (abstract). *Ophthalmology and Visual Science, Supplement, 26*(3), 243.

Perkins, D. N. (1981). *The Mind's Best Work*. Cambridge, MA: Harvard University Press.

Perkins, D. N. (1988). Creativity and the quest for mechanism. In R. J. Sternberg and E. E. Smith (Eds.), *The Psychology of Human Thought* (pp. 309–336). Cambridge: Cambridge University Press.

Petchenik, B. B. (1975). Cognition in cartography. *Proceedings, Auto-Carto II*, September 21–25, Washington, DC, U.S. Bureau of the Census & ACSM, pp. 183–193.

Peterson, M. A., and Gibson, B. S. (1991). The initial identification of figure–ground relationships: Contributions from shape recognition processes. *Journal of Experimental Psychology: Human Learning and Memory, 29*(3), 199–202.

Peterson, M. A., Harvey, E. M., and Weidenbacher, H. J. (1991). Shape recognition contributions to figure–ground reversal: Which route counts? *Journal of Experimental Psychology: Human Perception and Performance, 17*(4), 1075–1089.

Peterson, M. J., and Graham, S. E. (1974). Visual detection and visual imagery. *Journal of Experimental Psychology, 103*(3), 509–514.

Peterson, M. P. (1979). An evaluation of unclassed crossed-line choropleth mapping. *American Cartographer, 6*(1), 21–37.

Peterson, M. P. (1985). Evaluating a map's image. *American Cartographer, 12*, 41–55.

Peterson, M. P. (1987). The mental image in cartographic communication. *Cartographic Journal, 24*(1), 35–41.

Peuquet, D. J. (1988). Representations of geographic space: Toward a conceptual synthesis. *Annals of the Association of American Geographers, 78*(3), 373–394.

Peuquet, D. J. (1994). It's about time: A conceptual framework for the representation of temporal dynamics in geographic information systems. *Annals of the Association of American Geographers, 84*(3), 441–461.

Phillips, R. J. (1984). Experimental method in cartographic communication: Research on relief maps. *New Insights in Cartographic Communication, Monograph 31, Cartographica, 21*(4), 120–128.

Phillips, R. J., and Noyes, L. (1977). Searching for names in two city street maps. *Applied Ergonomics, 8*(2), 73–77.

Phillips, R. J., Noyes, L., and Audley, R. J. (1978). Searching for names on maps. *Cartographic Journal, 15*, 72–77.

Phillips, W. A. (1974). On the distinction between sensory storage and short-term visual memory. *Perception and Psychophysics, 16*, 283–290.

Phillips, W. A. (1983). Short-term visual memory. *Philosophical Transactions of the Royal Society of London, B302*, 295–309.

Pike, R. J., and Thelin, G. P. (1989). Shaded relief map of U.S. topography from digital elevations. *Eos, 70*(38), cover, 843, 853.

Pinker, S. (1984). Visual cognition: An introduction. *Cognition, 18*, 1–63.

Pinker, S. (1990). A theory of graph comprehension. In R. Friedle (Ed.), *Artificial Intelligence and the Future of Testing* (pp. 73–126). Norwood, NJ: Ablex.

Pittman, K. (1992). A laboratory for the visualization of virtual environments. *Landscape and Urban Planning, 21*, 327–331.

Plumb, G. A. (1988). Displaying GIS data sets using cartographic classification techniques. *Proceedings, GIS/LIS '88: Assessing the World, Volume 1*, November 30–December 2, San Antonio, TX, pp. 340–349.

Pomerantz, J. R. (1985). Perceptual organization in information processing. In A. M. Aitkenhead and J. M. Slack (Eds.), *Issues in Cognitive Modelling*. London: Erlbaum.

Pomerantz, J. R., and Garner, W. R. (1973). Stimulus configuration in selective attention tasks. *Perception and Psychophysics, 14*, 565–569.

Pomerantz, J. R., and Schwaitzberg, S. D. (1975). Grouping by proximity: Selective attention measures. *Perception and Psychophysics, 18*, 335–361.

Pomerantz, S. (1983). Global and local precedence: Selective attention in form and motion perception. *Journal of Experimental Psychology: General, 112*(4), 516–540.

Posner, M. I. (1980). Orienting attention. *Quarterly Journal of Experimental Psychology, 32*, 3–25.

Pylyshyn, Z. W. (1981). The imagery debate: Analogue media versus tacit knowledge. *Psychological Review, 88*, 16–45.

Quinlan, P. T., and Humphreys, G. W. (1987). Visual search for targets defined by combinations of color, shape, and size: An examination of the task con-

straints on feature and conjunction searches. *Perception and Psychophysics, 41*(5), 455–472.

Rabenhorst, D. A., Farrell, E. J., Jameson, D. H., Linton, T. D., and Mandelman, J. A. (1990). Complementary visualization and sonification of multi-dimensional data. *Proceedings, Extracting Meaning from Complex Data: Processing, Display, Interaction,* February 14–16, Santa Clara, CA, SPIE—The International Society for Optical Engineering, pp. 147–153.

Rader, C. P. (1989). *A Functional Model of Color in Cartographic Design*. Unpublished master's thesis, University of Washington.

Raichle, M. (1991). Plate 3.1: Computerized PET images showing the changes in local blood flow in the brain, associated with local changes in neuronal activity, that occur during different states of information processing. In C. M. Pechura and J. B. Martin (Eds.), *Mapping the Brain and Its Functions: Integrating Enabling Technologies into Neuroscience Research*. Washington, DC: National Academy Press.

Ramachandran, V. S., and Anstis, S. M. (1986). The perception of apparent motion. *Scientific American, 254*(6), 102–109.

Raper, J. (Ed.). (1989). *Three-Dimensional Applications in Geographic Information Systems*. London: Taylor & Francis.

Ratajski, L. (1971). The methodical basis of the standardization of signs on economic maps. *International Yearbook of Cartography, 11,* 137–159.

Ratner, C. (1989). A sociohistorical critique of naturalistic theories of color perception. *Journal of Mind and Behavior, 10,* 361–372.

Rheingans, P. (1992). Color, change, and control of quantitative data display. *Proceedings, Visualization '92,* October 19–23, Boston, IEEE Computer Society Technical Committee on Computer Graphics, pp. 252–259.

Rheingans, P., and Tebbs, B. (1990). A tool for dynamic explorations of color mappings. *Computer Graphics, 24*(2), 145–146.

Rhind, D. (1993). Mapping for the new millenium. *Proceedings, 16th Conference of the International Cartographic Association,* May 3–9, Cologne, Germany, pp. 3–14.

Rice, K. (1990). Disoriented prism maps: A recognition experiment (abstract). *Cartographic Perspectives, 4,* 32.

Robinson, A. H. (1952). *The Look of Maps*. Madison: University of Wisconsin Press.

Robinson, A. H. (1953). *Elements of Cartography*. New York: Wiley.

Robinson, A. H. (1960). Symbolization and processing map data. In *Elements of Cartography* (2nd ed, pp. 136–145). New York: Wiley.

Robinson, A. H. (1967). Psychological aspects of color in cartography. *International Yearbook of Cartography, 7,* 50–61.

Robinson, A. H. (1973). An international standard symbolism for thematic maps: Approaches and problems. *International Yearbook of Cartography, 13,* 19–26.

Robinson, A. H., and Petchenik, B. B. (1976). *The Nature of Maps*. Chicago: University of Chicago Press.

Robinson, A. H., Sale, R. D., Morrison, J. L., and Muehrcke, P. C. (1984). *Elements of Cartography* (5th ed.). New York: Wiley.

Rogers, J. E., and Groop, R. E. (1981). Regional portrayal with multi-pattern color dot maps. *Cartographica, 18*(4), 51–64.

Rollins, M. (1989). *Mental Imagery: On the Limits of Cognitive Science*. New Haven: Yale University Press.

Rosch, E. (1973). Natural categories. *Cognitive Psychology, 4,* 328–350.

Rosch, E. (1975a). Cognitive reference points. *Cognitive Psychology, 7,* 532–547.

Rosch, E. (1975b). Cognitive representations of semantic concepts. *Journal of Experimental Psychology: General, 104*(3), 192–233.

Rosch, E. (1977). Human categorization. In N. Warren (Ed.), *Studies in Cross-Cultural Psychology* (pp. 27–48). London: Academic Press.

Rosch, E. (1978). Principles of categorization. In E. Rosch and B. B. Lloyd (Eds.), *Cognition and Categorization* (pp. 27–48). Hillsdale, NJ: Erlbaum.

Rosch, E., and Lloyd, B. B. (Eds.). (1975). *Cognition and Categorization*. Hillsdale, NJ: Erlbaum.

Rosch, E., Mervis, C., Gray, W., Johnson, D., and Boyes-Braem, P. (1976). Basic objects in natural categories. *Cognitive Psychology, 8,* 382–439.

Roth, I., and Frisby, J. P. (1986). *Perception and Representation: A Cognitive Approach*. Philadelphia: Open University Press.

Rowles, R. A. (1978). Perception of perspective block diagrams. *American Cartographer, 5,* 331–344.

Rumelhart, D. E., and Norman, D. A. (1985). Representation of knowledge. In A. M. Aitkenhead and J. M. Slack (Eds.), *Issues in Cognitive Modeling* (pp. 15–62). London: Erlbaum.

Rumelhart, D. E., and Ortony, A. (1977). The representation of knowledge in memory. In R. C. Anderson, R. J. Spiro, and W. E. Montague (Eds.), *Schooling and the Acquisition of Knowledge* (pp. 99–135). Hillsdale, NJ: Erlbaum.

Rundstrom, R. (1993). The role of ethics, mapping, and the meaning of place in relations between Indians and whites in the United States. *Introducing Cultural and Social Cartography, Monograph 44, Cartographica, 30*(1), 21–28.

Saint-Martin, F. (1989). From visible to visual language: Artificial intelligence and visual semiology. *Semiotica, 77*(1/3), 303–316.

Salichtchev, K. A. (1983). Cartographic communication: A theoretical survey. In D. R. F. Taylor (Ed.), *Graphic Communication and Design in Contemporary Cartography, Volume 2, Progress in Contemporary Cartography* (pp. 11–36). New York: Wiley.

Saushkin, Y. G., and Il'yina, L. N. (1985). Conversations in the language of maps. *Soviet Geography, 26,* 1–10.

Saussure, F. de. (1986). *Cours de Linguistique Générale, 25th ed.* (C. Bally and A. Sechehaye, Eds.). Paris: Payot. (Original work published 1916)

Schank, R. C., and Abelson, R. P. (1977). *Scripts, Plans, Goals and Understanding: An Inquiry into Human Knowledge Structures*. Hillsdale, NJ: Erlbaum.

Schlichtmann, H. (1979). Codes in map communication. *Canadian Cartographer, 16,* 81–97.

Schlichtmann, H. (1984). Discussion of C. Grant Head, "The map as natural language: A paradigm for understanding." *Cartographica, 21,* 33–36.

Schlichtmann, H. (1985). Characteristic traits of the semiotic system "map symposium." *Cartographic Journal, 22*, 23–30.

Schlichtmann, H. (1991). Plan information and its retrieval in map interpretation: The view from semiotics. In D. M. Mark and A. U. Frank (Eds.), *Cognitive and Linguistic Aspects of Geographic Space* (pp. 263–284). Amsterdam: Kluwer Academic.

Schneider, W., and Shiffrin, R. M. (1977). Controlled and automatic human information processing: 1. Detection, search, and attention. *Psychological Review, 84*, 1–66.

Schustack, M. W. (1988). Thinking about causality. In R. J. Sternberg and E. E. Smith (Eds.), *The Psychology of Human Thought* (pp. 92–115). Cambridge: Cambridge University Press.

Schweizer, D. M., and Goodchild, M. F. (1992). Data quality and choropleth maps: An experiment with the use of color. *Proceedings, GIS/LIS '92*, November 10–12, San Jose, CA, ACSM & ASPRS, pp. 686–699.

Sebeok, T. A. (1976). Problems in the classification of signs. In T. Sebeok (Ed.), *Contributions to the Doctrine of Signs, Volume 5, Studies in Semiotics* (pp. 71–143). Bloomington: Indiana University Press.

Shannon, C., and Weaver, W. (1949). *The Mathematical Theory of Communication*. Urbana: University of Illinois Press.

Shapley, R., Caelli, T., Grossberg, S., Morgan, M., and Rentschler, I. (1990). Computational theories of visual perception. In L. Spillmann and J. S. Werner (Eds.), *Visual Perception: The Neurophysiological Foundations* (pp. 417–447). New York: Academic Press.

Shepard, R. N. (1978). The mental image. *American Psychologist, 33*, 125–137.

Shepard, R. N., and Cooper, L. (1982). *Mental Images and Their Transformations*. Cambridge, MA: MIT Press.

Shortridge, B. G. (1979). Map reader discrimination of lettering size. *American Cartographer, 6*, 13–20.

Shortridge, B. G. (1982). Stimulus processing models from psychology: Can we use them in cartography? *American Cartographer, 9*, 155–167.

Shortridge, B. G., and Welch, R. B. (1980). Are we asking the right questions? Comments on instructions in cartographic psychophysical studies. *American Cartographer, 7*, 19–23.

Shortridge, B. G., and Welch, R. B. (1982). The effect of stimulus redundancy on the discrimination of town size on maps. *American Cartographer, 9*, 69–80.

Simcox, W. A. (1983). *A Perceptual Analysis of Graphic Information Processing*. Unpublished Ph.D. dissertation, Tufts University, Medford, MA.

Singh, G., and Chignell, M. H. (1992). Components of the visual computer: A review of relevant technologies. *Visual Computer, 9*, 115–142.

Slocum, T. A. (1983). Predicting visual clusters on graduated circle maps. *American Cartographer, 10*, 59–72.

Slocum, T. A., and McMaster, R. B. (1986). Gray tone versus line plotter area symbols: A matching experiment. *American Cartographer, 13*(2), 151–164.

Slocum, T. A., Roberson, S. H., and Egbert, S. L. (1990). Traditional versus sequenced choropleth maps: An experimental investigation. *Cartographica, 27*(1), 67–88.

Smith, E. E., and Medin, D. L. (1981). *Categories and Conceps*. Cambridge, MA: Harvard University Press.

Smith, S., Grinstein, G., and Pickett, R. (1991). Global geometric, sound, and color controls for iconographic displays of scientific data. *Proceedings, Extracting Meaning from Complex Data: Processing, Display, Interaction II*, February 26–28, Santa Clara, CA, SPIE—The International Society for Optical Engineering, pp. 192–206.

Speeth, S. D. (1961). Seismometer sounds. *Journal of the Acoustical Society of America, 33*, 909–916.

Spiess, E. (1978). *Some Graphic Means to Establish Visual Levels in Map Design*. Paper presented at the 9th International Conference on Cartography, July 26–August 2, College Park.

Spiess, E. (1988). Map compilation. In R. W. Anson (Ed.), *Basic Cartography for Students and Technicians, Volume 2* (pp. 35–69). London: International Cartographic Association.

Steinke, T. R. (1987). Eye movement studies in cartography and related fields. *Studies in Cartography, Monograph 37, Cartographica, 24*(2), 40–73.

Steinke, T. R., and Lloyd, R. E. (1983a). Images of maps: A rotation experiment. *Professional Geographer, 35*(4), 455–461.

Steinke, T. R., and Lloyd, R. E. (1983b). Judging the similarity of choropleth map images. *Cartographica, 20*, 35–42.

Suchan, T. (1991). *Useful Categories: A Cognitive Approach to Land Use Categorization Systems*. Unpublished master's thesis, University of Washington.

Szegö, J. (1987). *Human Cartography: Mapping the World of Man*. Stockholm: Swedish Council for Building Research.

Tanaka, K. (1932). The orthographical relief method of representing hill features on a topographical map. *Geographical Journal, 79*, 213–219.

Tatham, A. F. (1991). The design of tactile maps: Theoretical and practical considerations. *Proceedings, 15th Conference of the International Cartographic Association*, September 23–October 1, Bournemouth, UK, pp. 157–166.

Tatham, A. F., and Dodds, A. G. (Eds.). (1988). *Proceedings of the Second International Symposium on Maps and Graphics for Visually Handicapped People*. London: University of Nottingham.

Taylor, D. R. F. (1991). Geographic information systems: The microcomputer and modern cartography. In D. R. F. Taylor (Ed.), *Geographic Information Systems: The Microcomputer and Modern Cartography* (pp. 1–20). Oxford, UK: Elsevier.

Thomas, E. L., and Lansdown, E. L. (1963). Visual search patterns of radiologists in training. *Radiology, 81*, 288–292.

Tobler, W. R. (1981). Depicting federal fiscal transfers. *Professional Geographer, 33*(4), 419–422.

Travis, D. S. (1990). Applying visual psychophysics to user interface design. *Behaviour and Information Technology, 9*(5), 425–438.

Treinish, L. (1993). Visualization techniques for correlative data analysis in the earth and space sciences. In R. A. Earnshaw and D. Watson (Eds.), *Animation and Scientific Visualization: Tools and Applications* (pp. 193–204). New York: Academic Press.

Treisman, A. (1988). Features and objects: The fourteenth Bartlett Memorial Lecture. *Quarterly Journal of Experimental Psychology, 40A*, 201–237.

Treisman, A., Cavenagh, P., Fischer, B., Ramachandran, V. S., and von der Heydt, R. (1990). Form, perception, and attention. In L. Spillmann and J. S. Werner (Eds.), *Visual Perception: The Neurophysiological Foundations* (pp. 273–316). New York: Academic Press.

Treisman, M. (1985). The magical number seven and some other features of category scaling: Properties of a model for absolute judgement. *Journal of Mathematical Psychology, 29*, 175–230.

Tsal, Y., and Kolbert, L. (1985). Disambiguating ambiguous figures by selective attention. *Quarterly Journal of Experimental Psychology, 37A*, 25–37.

Tsal, Y., and Lavie, N. (1988). Attending to color and shape: The special role of location in selective visual processing. *Perception and Psychophysics, 44*, 15–21.

Tufte, E. (1983). *The Visual Display of Quantitative Information*. Cheshire, CT: Graphics Press.

Tufte, E. (1990). *Envisioning Information*. Cheshire, CT: Graphics Press.

Tukey, J. W. (1977). *Exploratory Data Analysis*. Reading, MA: Addison-Wesley.

Tversky, B., and Hemenway, K. (1984). Objects, parts, and categories. *Journal of Experimental Psychology: General, 113*(2), 169–191.

Tyner, J. A. (1974). *Persuasive Cartography*. Unpublished Ph.D. dissertation, University of California at Los Angeles.

Ucar, D. (1993). A semiological approach to typology of the map signs. *Proceedings, 16th Conference of the International Cartographic Association*, May 3–9, Cologne, Germany, pp. 768–781.

Ullman, S. (1984). Visual routines. *Cognition, 18*, 97–159.

U.S. Environmental Protection Agency. (1990). *Region 6 Comparative Risk Project, Appendix A: Ecological Report*. EPA Region 6 Office of Planning and Analysis, Dallas, TX.

Usery, L. (1993). Category theory and the structure of features in geographic information systems. *Cartography and Geographic Information Systems, 20*(1), 5–12.

Uttal, W. R. (1988). *On Seeing Forms*. Hillsdale, NJ: Erlbaum.

van der Wel, F. J. M. (1993). Visualization of quality information as an indispensable part of optimal information extraction from a GIS. *Proceedings, 16th Conference of the International Cartographic Association*, May 3–9, Cologne, Germany, pp. 881–897.

Vasconcellos, R. (1992). Knowing the Amazon through tactual graphics. *Proceedings, 15th Conference of the International Cartographic Association*, September 23–October 1, Bournemouth, UK, pp. 206–210.

Vasilev, I., Freundschuh, S., Mark, D. M., Theisen, G. D., and McAvoy, J. (1990). What is a map? *Cartographic Journal, 27*(2), 119–123.

Vernon, M. D. (1962). *The Psychology of Perception*. Baltimore: Penguin Books.

Wade, N. J., and Swanston, M. (1991). *Visual Perception*. New York: Routledge.

Wanger, L. R., Ferwerda, J. A., and Greenburg, D. P. (1992, May). Perceiving spatial relationships in computer-generated images. *IEEE Computer Graphics and Applications*, pp. 44–55.

Watt, R. J. (1988). *Visual Processing: Computational, Psychological and Cognitive Research*. London: Erlbaum.

Wever, E. (1927). Figure and ground in the visual perception of form. *American Journal of Psychology, 38*, 194–226.

Wiedel, J. (Ed.). (1983). *Proceedings of the First International Symposium on Maps and Graphics for the Visually Handicapped*, International Cartographic Association.

Williams, L. G. (1967). The effects of target specification on objects fixated during visual search. *Acta Psychologica, 27*, 355–360.

Wilson, H. R., Levi, D., Maffei, L., Rovamo, J., and DeValois, R. (1990). The perception of form. In L. Spillmann and J. S. Werner (Eds.), *Visual Perception: The Neurophysiological Foundations* (pp. 231–272). New York: Academic Press.

Wolodtschenko, A., and Pravda, J. (1993). Cartosemiotics—ideas and inducements. *Proceedings, 16th Conference of the International Cartographic Association*, May 3–9, Cologne, Germany, pp. 1235–1237.

Wong, E., and Weisstein, N. (1983). Sharp targets are detected better against a figure, and blurred targets are detected better against a ground. *Journal of Experimental Psychology: Human Learning and Memory, 9*, 194–202.

Wong, E., and Weisstein, N. (1984). Flicker induces depth: Spatial and temporal factors in the perceptual segregation of flickering and nonflickering regions in depth. *Perception and Psychophysics, 35*, 229–236.

Wood, C. H. (1976). Brightness gradients operant in the cartographic context of figure–ground relationship. *Proceedings, American Congress on Surveying and Mapping*, pp. 5–34.

Wood, D. (1977). Now and then: Comparisons of ordinary American's symbol conventions with those of past cartographers. *Prologue, 9*, 151–161.

Wood, D. (1978). *Cultured Symbols: Thoughts on the Cultural Context of Cartographic Symbols*. Unpublished manuscript, Department of Landscape Architecture, University of North Carolina at Chapel Hill.

Wood, D. (1992). *The Power of Maps*. New York: Guilford Press.

Wood, D., and Fels, J. (1986). Designs on signs: Myth and meaning in maps. *Cartographica, 23*(3), 54–103.

Wood, M. (1968). Visual perception and map design. *Cartographic Journal, 5*, 54–64.

Wood, M. (1972). Human factors in cartographic communication. *Cartographic Journal, 9*, 123–132.

Woods Hole Oceanographic Institute. (1982). *Georges Bank* (map). Cambridge, MA: MIT Press.

Woodsworth, R. S. (1938). *Experimental Psychology*. New York: Holt.

Woodward, D. (1985). Reality, symbolism, time, and space in medieval world maps. *Annals of the Association of American Geographers, 75*(4), 510–521.

Wright, J. K. (1942). Map makers are human: Comments on the subjective in maps. *Geographical Review, 32*(4), 527–544.

Wright, J. K. (1944). The terminology of certain map symbols. *Geographical Review, 34*, 653–654.

Yamahira, T., Kasahara, Y., and Tsurutani, T. (1985). How map designers can represent their ideas in thematic maps. *Visual Computing, 1*, 174–184.

Yapa, L. S. (1992). Why do they map GNP per capita? In S. K. Majumdar, G. S. Forbes, E. W. Miller, and R. F. Schmalz (Eds.), *Natural and Technological Disasters: Causes, Effects and Preventative Measures* (pp. 494–510). Easton: Pennsylvania Academy of Science.

Zadeh, L. (1965). Fuzzy sets. *Information and Control, 8*, 338–353.

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