Cognitive Map-Design Research in the Twentieth Century: Theoretical and Empirical Approaches

Daniel R. Montello

ABSTRACT: Cognitive map-design research has the goal of understanding human cognition in order to improve the design and use of maps. As a systematic sub-discipline of cartography, cognitive map-design research is a phenomenon of the twentieth century, specifically the latter half. Robinson's *The Look of Maps*, published in 1952, played a seminal role in the genesis of cognitive map-design research in several countries, but it had interesting precursors. Empirical work that followed from *The Look of Maps* included psychophysical studies of graduated circles and studies of eye movements during map reading. Theoretical work that followed included a variety of cognitive theories but especially the development of the communication model as a comprehensive framework for scientific cartography. I chart the changing fortunes of cognitive map-design research after *The Look of Maps* and offer explanations for these changes. I also consider the legacy of cognitive map-design research—ways in which it has or has not mattered. I conclude with a list of questions suggested, but not decisively answered, by this exploratory essay.

KEYWORDS: History of cartography, cartographic research, map perception, map cognition, communication model, Arthur Robinson

"Make me no maps, sir, my head is a map, a map of the whole world"
[Henry Fielding 1730, *Rape upon Rape*, act 2, scene 5]

Introduction

Cartographers have long realized that maps do not present the world directly and transparently. Maps *re*-present the world by providing versions of truth for human minds to apprehend. In turn, minds represent the world too, internally as "cognitive maps." Over the centuries, many cartographers have undoubtedly recognized that maps contribute to our inner mental worlds. Some cartographers of old may even have understood their task as that of designing maps to provide input to mental worlds—maps as cognitive devices. In a sense, map design can be thought of as mind design; the way a map is designed will influence the views of the world it stimulates or inhibits.

The recognition that map design is about the design of human cognition might be termed intuitive map psychology. Although some cartographers must have appreciated this intuition before the twentieth century, it was not a formal part of the discipline of cartography, whether seen as art, craft, or engineering (Robinson and Petchenik 1976). As chronicled in this essay, the intuition of maps as cognitive devices became a standard part of cartographic training in the twentieth century. Furthermore, for the first time in history, twentieth-century cartographers came to understand that intuitions about map cognition could be developed more systematically by applying the theories and methods of science, particularly that of psychology. Conversely, some psychologists (and other behavioral scientists) attempted to understand cognition by employing the favorite graphical device of the geographer: the map. Taken together, these efforts made up the new study of cognitive cartography.

Cognitive cartography encompasses the application of cognitive theories and methods to understanding maps and mapping and the application of maps to understanding cognition. The study of cognition is the study of knowledge structures and processes in sentient beings—humans, other animals, machines (e.g., Wilson and Keil 1999). Cognition includes perception, learning, memory,

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thinking, reasoning and problem-solving, and communication.[1]

It is useful to conceptualize cognitive cartography as consisting of three areas of research. The first area, and the focus of this essay, is map-design research. This is research, primarily by academic cartographers, that has as its goal the understanding of maps, mapping, and map use in order to improve them (make them more efficient, effective, rewarding). In this essay, I focus on cognitive aspects of map-design research, which is a significant part of the enterprise of cognitive cartography.[2] As discussed below in greater detail, not all map-design research has had this cognitive focus.

Besides map-design research there is additional research in cognitive cartography that has not been motivated by the desire to improve maps and their use (see Olson 1979). A second area of cognitive cartography is map-psychology research. This research, conducted primarily but not exclusively by academic psychologists, has as its goal the understanding of human perception and cognition (e.g., Lloyd and Steinke 1984; Tversky 1981). Such research uses maps as stimuli but is not necessarily concerned, even ultimately, with improving map design. Finally, a third area within cognitive cartography is map-education research. This research has been conducted by researchers in cartography, geography, education, and psychology who have had a special interest in improving education with maps and about maps (see Rushdoony 1968).

This essay focuses on the history of cognitive map-design research. Map-design research includes much of what has variously been called "perceptual cartography," "the human factors of maps," "evaluation research," "usability research," "communication research," or "experimental cartography" (Board 1978; Board and Buchanan 1974; Castner 1983; Hopkin and Taylor 1979; Olson 1979).

Of the three areas of cognitive cartography, map-design research has played by far the greatest role in the history of twentieth-century cartography. Its breadth, reflected in the theoretical models reviewed in this paper, makes it the most general of the three. However, like just about any organizational framework, the distinction among the three research areas is not precise. In particular, map-design researchers have attempted comprehensive theories of map production and use that include concerns not only of a variety of sub-disciplines within psychology and education, but of geography, art, engineering, earth sciences, social sciences, mathematics, politics, and more. Nonetheless, support for distinguishing the three areas is provided by the historical fact that research in the three areas of cognitive cartography has been carried out in different disciplines with largely different methodological and conceptual training, different motivations, and different publication and conference outlets. The three areas have had relatively little influence on each other, less than it appears they could have. I return to this theme at the end of the essay.

The terms theoretical and empirical in the title signal my focus on scientific cartography. Empirical has its standard scientific meaning here: an epistemology in which ideas about the world are generated and verified through systematic observation and measurement (Committee on the Conduct of Science 1995). The systematicity of empiricism is critical here. Systematic observation is standardized, controlled, recorded, repeatable, and publicly verifiable. It is to be distinguished from the informal and unsystematic observations each of us makes every day that form an important basis for our commonsense beliefs. Importantly, systematic empiricism is also to be distinguished from the traditional "craft" approach of cartographers, who have developed trial-and-error conventions over the centuries about how to design maps (Robinson 1952). And it should also be distinguished from informal "experiments" cartographers have often carried out to "test" the effectiveness of a new map design by looking at it themselves, or showing it around to people in the hallway (e.g., Davis 1911). Of course, not all empirical work in cartography involves cognitive theories or human subjects (e.g., Monmonier 1980).

None of this is meant to imply that only scientific empiricism leads to truth, nor that it necessarily does lead to truth. And it certainly does not mean that a scientific approach will necessarily result in better maps than a traditional crafts approach. But when empirical research is combined with the rational use of predictive and explanatory ideas, or theories, a sufficiently distinct mode of human inquiry emerges known as science (Committee on the Conduct of Science 1995). As will become evident in this essay, the distinction between theory and empiricism in fact provides a valuable organization to the history of cognitive cartographic research of the map-design variety (Castner 1983; Petchenik 1983; Robinson and Petchenik 1976).

[1] A finer distinction, discussed in this paper, is sometimes drawn between low-level perception and high-level cognition.

[2] Henceforth, unless explicitly stated otherwise, I imply this focus when I refer to map-design research.

I turn now to the story of map-design research, starting with the seminal publication of Robinson's The Look of Maps in 1952. But before that, a few comments are in order about the sources of material for this essay. Published and unpublished literature was the source of most of the ideas presented. Much of that literature is included in the reference section, especially when it contributed to a particular point in a specific way. There is, however, a larger body of literature that has influenced my understanding of map-design research and played a nontrivial role in the history of cognitive cartography generally; I do not list all of these references here because of space limitations, and because of the nature of this essay as a history rather than a scientific review. In addition, I have interviewed, both formally and informally, several people involved in cartographic research in the twentieth century. They are listed in Appendix A, though I avoid crediting them with specific statements in order to preserve confidentiality.

The Story of *The Look of Maps*

In 1952, the University of Wisconsin Press published a slim book titled *The Look of Maps*: *An Examination of Cartographic Design*. The book was written by the new professor of cartography at Wisconsin, Arthur H. Robinson. It was based on his dissertation in the Geography Department at Ohio State University, completed in 1948 under the title *Foundations of Cartographic Methodology*. The book would later come to be widely recognized as seminal in cartography, especially the area of map-design research (though the book was mapless). Robinson would have a large impact on academic cartography in the twentieth century, as large as anyone (McMaster and McMaster 2002, and this volume). He mentored future leaders in cartography, devised methods and questions for map-design research, motivated people to think about map design systematically, and inspired an attitude about what maps are and what they could be. Additionally, the National Geographic Society in the U.S. used for several years the influential Robinson projection, which he designed.

The Look of Maps put forth the proposition that the function of maps is to communicate to people. This function depends on the visual appearance of maps, and this appearance, in turn, depends on explicit and implicit design decisions made by mapmakers. So to understand and improve map function, cartographers need to understand the effects of design decisions on the minds of map users. "The work that makes the data intelligible to the reader … is the essential cartographic technique" (Robinson 1952, pp. 3-4). These links had rarely been recognized by cartographers, Robinson claimed; a state of affairs that needed to change. Furthermore, he proposed that the best way to understand map communication was the way other mysteries of our world had best been understood—through rational thought and systematic study. This provided an early blueprint for cartography as science.

The Look of Maps: Precursors and Influences

We can identify several influences on Robinson and academic cartography that help explain the genesis of *The Look of Maps* and map-design research in general. Four events or movements of the nineteenth century set the context. First is the emergence of scientific thinking as the dominant intellectual way of understanding the natural world, including humans (Knight 1986). This would set the stage for cartographers and geographers to strive later to develop a model of their disciplines as sciences. The rise of science included the emergence of new scientific disciplines, including psychology. Scientific psychology emerged as a separate discipline in the nineteenth century (Heidbreder 1933). The year 1879 is conventionally identified as its start, the year Wilhelm Wundt opened his psychology lab in Leipzig, Germany. Along with Ernst Weber and Gustav Fechner, among others, Wundt was a pioneer in the study of *psychophysics*, which would become a major approach to empirical map-design research.

A second nineteenth-century movement that influenced map-design research in the twentieth century was the development of thematic mapping (Robinson 1982; Taylor 1983; Tufte 1983). Thematic maps focus on presenting the spatial distribution of data for one or a few variables; these variables may not even be perceptible in the landscape (e.g., mortality rates). In contrast, reference maps attempt to show many perceptible features of the landscape with as much locational accuracy as appropriate (Muehrcke and Muehrcke 1998). While reference maps have been around for thousands of years, thematic maps are a relatively recent invention, first appearing in the seventeenth century but not developing as a recognized separate form until the nineteenth. The development of thematic mapping is important to the story of this essay because most empirical map-design research has been done on thematic mapping symbols (Board 1981; Castner 1983). This has been true in part because the more limited and specific goals

of thematic maps, as compared to reference maps, made them easier to manipulate in experiments. It is clearer what a viewer is supposed to take away from a thematic map, assuming, as many researchers did, that maps work by delivering specific "take-home" messages. (More on this later.)

A third nineteenth-century influence was the widespread effort, particularly in European military contexts, to develop effective methods for portraying relief on maps (Taylor 1985). This was significant because it led to explicit discussions of the way map design influenced whether maps did or did not work as communication devices. For example, the British military, which explored a variety of graphic methods for depicting slopes and relative heights, was guided by the conviction that a good method would create an effective appearance of relief to the eye of the observer, known as coup d'oeil militaire (Jones 1974).

Finally, a fourth nineteenth-century influence on twentieth-century map-design research was neither scientific nor cartographic. It was art and art theory. Photography and the Impressionist Movement, in particular, were nineteenth-century developments in art that served as catalysts for new ways of thinking about images in terms of their visual appearance, in addition to their content or emotionality (Arnason 1998). *The Look of Maps* echoes this insight by its notion that maps function, for better or worse, via their visual appearance.

Turning to the twentieth century, we can identify several influences on Robinson's thinking that were more direct. To start, it is interesting to note that his ideas apparently did not come directly from academic geography or cartography. His doctoral committee at Ohio State, including his advisor Guy-Harold Smith, approved of his dissertation but did not suggest it.[3] Robinson himself believed his ideas were quite novel in academic circles, at least in geography and cartography. The lack of influence by academic geography and cartography, and thus the novelty of Robinson's ideas, is further suggested by the lack of receptivity it first encountered in academic circles. By all accounts, the work his first students at Wisconsin carried out in the 1950s was met with more than a little skepticism by other faculty in the department. More than one map-design researcher since then has encountered such skepticism from other academic geographers and cartographers.

But the ideas in *The Look of Maps* did not appear fully formed in Robinson's mind out of nowhere. At least five twentieth-century influences and precursors for *The Look of Maps* can be identified: Robinson's military experiences during World War II, a small number of prior books and articles by other academic cartographers and geographers, map-education research, non-cartographic psychological research, and Robinson's own artistic leanings.

Robinson's experiences making maps for the military were particularly formative. Richard Hartshorne, who later hired Robinson at Wisconsin, first heard of him from Roderick Peattie at Ohio State. Hartshorne was then in charge of the Geography Division of what was to become the Office of Strategic Services (OSS). He needed someone who could "make maps," and Peattie suggested Robinson, who was about to start a dissertation on the history of mapping the Mississippi Valley. So the impending war interrupted and delayed Robinson's plans, and eventually altered them drastically. He ended up in Washington, D.C., in late 1941, and soon became head of the newly formed Map Division of the OSS, where from 1942 to 1945 he oversaw the production of several thousand of maps.

The maps Robinson helped make for the OSS were mostly thematic, showing cultural and economic characteristics of inhabitants. Faced with the constant demand to make map-design decisions, Robinson realized his decisions would affect the impressions his maps made. He also realized he had no solid guidance on how this would occur. Elsewhere in the military, research was being conducted on the human factors of maps, charts, and other imagery, but this research was largely unknown to Robinson. The research would continue after the war (Crook 1949; Crook et al. 1954; Kishler et al. 1951; Miller 1951; Murray 1953; literature surveys in Hopkin and Taylor 1979; Taylor 1973). In any case, Robinson would later meld concern for the needs of military mapping with an appreciation for the artistic eye, which had, in fact, been presaged by the nineteenth-century discussions of relief representation in the British military mentioned above (Jones 1974); landscape artists played an important teaching role at British military colleges.

Although *The Look of Maps* was innovative in its call for systematic research, it was not the first academic call to understand maps as designed objects, nor was it even the first call to apply psychological research to improving maps. Most important in

[3] Even so, Smith's work on thematic mapping (e.g., 1928) was undoubtedly influential and suggests the advisor was receptive to Robinson's plan.

this respect were the writings of the German cartographer Max Eckert (later Eckert-Greifendorff), whom Robinson cited and discussed in *The Look of Maps* as the only person to examine exhaustively the bases of cartographic "method." In a 1908 paper, Eckert explained that "map logic" is one of the most important topics for scientific cartography; by map logic, he meant the principles for creating maps and for cartographic perception. He thus recognized the subjectivity involved in map communication. These ideas were further developed in his two-volume magnum opus titled *Die Kartenwissenschaft: Forschungen und Grundlagen zu einer Kartographie als Wissenschaft* (*The Science of Cartography [or of Maps]: Research and Foundations for a Cartography as Science*), published in Berlin in 1921 and 1925. Here, Eckert set the agenda for a science of cartography:

> Scientific cartography is related to applied cartography … such as art history is to fine arts … Even though artists may more or less instinctively follow the rules of perspective … the painting … cannot be considered a science. It is the subtle teasing out and determining of aesthetic, psychological and physiological laws … that make it a science (1921/1925, p. 5).

Eckert advocated the application of psychological research to cartography, although he did not report any such studies with maps, nor did he offer a detailed plan for how psychology should be applied to maps.

In addition to the important work of Eckert, a few other pieces by academic cartographers and geographers influenced Robinson. *The Look of Maps* discussed Karl Peucker's work on color and relief representation (discussed in Eckert 1921/1925). In 1941, the journal *Social Research* published an influential article by Hans Speier on propaganda mapping, intriguingly titled "Magic geography." Robinson noted the onset of explicit propaganda mapping as an early recognition that visual relationships in maps mattered. The following year, *The Geographical Review* published "Map Makers Are Human: Comments on the Subjective in Maps" by John K. Wright (1942). Wright explained that maps were necessarily a reflection of both objective reality and the subjective world of the cartographer. He noted that only in discussions of maps as art did this subjectivity get an explicit hearing.

A third source of inspiration for *The Look of Maps* was the cognitive cartographic area of map-education research. This is the first of the three approaches in cognitive cartography that actually applied systematic research techniques. In particular, Gulliver (1908) discussed the issue of map orientation, especially how it influences the learning of geography by children; in this article, he included conclusions from his experiments done at several schools.[4] Robinson cited this work in *The Look of Maps*. A report by the National Society for the Study of Education (1933) on "The Teaching of Geography" included a sizable list of questions about the psychological effects of maps (see also Miller 1931). Robinson cited this report and claimed it was the first statement of a "functional" approach to cartography in the United States.

Non-cartographic perceptual research influenced Robinson in important ways too (as it had Eckert). Robinson did not take psychology courses as a student, though he would later collaborate with a psychologist at Wisconsin in teaching his seminar on map psychophysics. As mentioned above, German psychologists developed the approach of psychophysics. In *The Look of Maps*, Robinson cited research by both Weber and Fechner, along with more specific experimental and marketing psychology from the early twentieth century on the perception of lettering, color, and graphical structure. Research on the perception of statistical graphing symbols, such as circle diagrams and bar charts (Croxton and Stryker 1927), would influence Robinson and his student James J. Flannery in their later work on graduated circles).

Finally, art influenced map-design research not just in the general way described above, but in a very specific way: Robinson himself had definite artistic leanings. He had done a lot of work in the Art Department at Miami University (of Ohio) during his undergraduate days, and when he decided to attend graduate school, he chose between art and geography. Because he lacked sufficient credits in art, geography was his choice. During his war days at the OSS, Robinson hired two artists to look over each map, in an effort to improve its appearance. At least one of these men, Robert Coffin, was in Fine Arts at Ohio State and would later confer on Robinson's doctoral work.[5] Robinson was a particular fan of the art theorist and historian Rudolf Arnheim, who wrote explicitly about the psychology of art, starting with his 1928 dissertation (see Arnheim 1954).

The impact of artistic thinking on Robinson's book is more than a little ironic. In a couple of places in *The Look of Maps*, he implies that artistic thinking is often the cause of design failure, as

[4] Unfortunately, the scientific standards of the time did not compel him to include sufficient detail for us to evaluate his studies.

[5] He would also marry Robinson's sister, who was a professor of art.

when he writes about cartography and architecture: "Functional inadequacies have been concealed beneath the guise of artistry, a standard form of refuge among many intellectual pursuits" (p. 13). We should probably interpret all of this to mean that the insight that maps are designed objects is an artistic insight (Board 1981 discusses poster art in this regard); the insight that map design and its effects can be systematically studied is a scientific insight. Both are found in *The Look of Maps*.

Before turning to the empirical and theoretical work that followed from *The Look of Maps*, two influences on map-design research that were largely contemporaneous deserve note. In a sense, these two movements help us place map-design research in a broader intellectual context. The first is the so-called "quantitative revolution" in geography; Board (1981) and Castner (1983) discuss this influence. The apparent regard that some corners of the discipline of geography had for empirical analysis and systematic theory (of a nomothetic flavor) spread to cartography; map-design research fit comfortably into a scientific approach, at least for a time. The second contextual influence for map-design research at about this time was the meeting of geography and psychology during the 1960s, in the guise of behavioral geography (Cox and Golledge 1969) and environmental psychology (Proshansky et al. 1970).

Cognitive Map-Design Research after *The Look of Maps*

Empirical Approaches

In *The Look of Maps*, Robinson called for cartographic researchers to systematically observe and measure—collect data on—how people look at and interpret maps. This call led first to the application of psychophysical methods to map-design research. Psychophysics is a sub-discipline of experimental psychology that describes the relationship of variation in a physical stimulus dimension (such as the amount of energy emitted by a light source or the concentration of sugar in a solution) to variation in a person's psychological responses to that stimulus, such as perceived brightness or sweetness (Gescheider 1985). The logic of this approach to map-design research was straightforward and, at least at first, sensible. Cartographers frequently use, for example, the area of a symbol such as a circle to stand for the value of a quantity at a mapped location. In order to decode such symbols, map viewers must perceive the area of the symbol and then relate this to the corresponding value of the variable being mapped. For the map viewer, it is perceived or apparent size that allows interpretation of the map symbol, not actual size. If perceived circular area differs much from actual area, and if it does so in a sufficiently consistent way across time and viewers, then it makes sense to determine the relationship of actual area to perceived area and use it to design circle symbols.

In fact, most of the earliest empirical map-design research was on the psychophysics of such graduated circles.[6] Based on suggestions by Robinson, his advisor at Wisconsin, Flannery completed his dissertation titled "The Graduated Circle: A Description, Analysis, and Evaluation of a Quantitative Map Symbol" in 1956. The topic was thought to be unusual for a geographer at the time; in his acknowledgements, Flannery thanks his department for encouraging "the investigation of a topic which is marginal to the field" (p. i). Based primarily on magnitude-estimation tests given to over 1,000 subjects (students at various colleges), Flannery derived a formula to describe the psychophysical function for the area of graduated circles. Taking the median of the results from several parts of the data, he offered the following formula as his best estimate of the relationship of apparent circular area (Y_c) to the logarithm of actual area (X), raised by an exponent and multiplied by a scaling constant:

$$Y_c = 0.98365X^{.8747}$$

Flannery and Robinson had read enough experimental psychology to question the use of Fechner's logarithmic function to model psychophysical data; they opted instead for the then emerging power-function model. This was somewhat prescient on their part, as it was at a time when S. S. Stevens had just begun to popularize the *Power Law* (the standard reference being Stevens 1957), which would later become widely accepted in psychophysics. In fact, Flannery did not cite any literature by Stevens or any other psychophysicist—he and Robinson apparently derived the idea of a power function themselves, by observing the straightening of their graphs when they were subjected to logarithmic transformations.

It is not always recognized, however, that Flannery was not quite the first to do psychophysical work on map symbols (Castner 1983). In his dis-

[6] Tobler (1957) provided a surprising exception in his M.A. thesis, an empirical evaluation of hypsometric tinting.

sertation, Flannery cited a paper given by Robert Williams at the annual meeting of the Association of American Geographers in 1954, titled "Visual Interpretation of Map Symbols" (Williams (1954) abstract in the *Annals of AAG*). This work was published by Williams in 1956 and then appeared as his dissertation at Harvard in 1957, under the supervision of Erwin Raisz (Williams 1957). Williams's work was more diverse than Flannery's in that it included squares, triangles, and stars as well as circles; it also included an early study of graytone scale perception and observations on the perception of volumetric symbols. Flannery's result, specifically the value of his power function for circular area, did not match that reported by Williams. In a final short section of his dissertation, Flannery commented on Williams' findings. Flannery was uncertain what the difference in the exponents meant, but he thought that it must at least have been due to the variety of stimuli Williams used that he, Flannery, had not. This variation in findings provides a fitting segue to the following decades of map-symbol psychophysics.

During the next twenty-five years, many additional studies were done on the psychophysics of graduated circles and other proportional-area symbols (Castner 1983; Chang 1977; Crawford 1973; Ekman et al. 1961; Flannery 1971; Gilmartin 1980; Meihoefer 1973). In addition to ratio and magnitude scaling techniques (Gescheider 1985), such as those used by Flannery and Williams to determine the form of the *Power Law*, other psychophysical techniques such as the "just noticeable difference" method were used.[7]

Other tasks and techniques not derived from psychophysics were also applied to the study of map perception, including tasks wherein the speed and accuracy of searching for particular targets or answering particular questions were recorded (Dobson 1983). Along with psychophysical scaling, these methods were used to study the perception of a variety of symbol and map designs (Potash 1977), including region areas on conformal projections (Mackay 1958), dot-area symbols (Castner 1964), graytone scales (Crawford 1971; Kimerling 1975), type fonts and lettering (Bartz 1970; Shortridge 1979), and color (Brewer 1992; Cuff 1973; Olson 1981). The most significant map-design research on reference maps, as opposed to thematic maps, was carried out on topographic maps, including those symbolized with isolines (contours), hachures, and shaded relief (Eley 1987; Griffin and Lock 1979; Hsu and Robinson 1970; Phillips 1984; Phillips et al. 1975; Potash et al. 1978; Shurtleff and Geiselman 1986).

One of the more significant empirical approaches to map psychology involved recording the eye movements of subjects as they viewed maps.[8] The logic of recording eye movements is this: People look at places on the map to which they wish to attend; visual attention is the selective focusing of information processing on some parts of the visual field rather than others (Findlay et al. 1995). So if you know where someone is looking on a map you know where they are attending on that map—where they are attempting to pick up information visually. More precisely, to "look at" means to "foveate"—to move one's eyes so the central area of the retina, the fovea, receives input from a place in the visual field. The fovea has the greatest concentration of visual receptor cells (particularly cones), and those cells have the densest connections to post-retinal layers of the visual system, so that places in the visual field that are foveated are visually perceived with greatest resolution. If one somehow records the time-registered locations of foveations, continuously or very frequently, one will have a record of the temporal and spatial patterns of eye movements—a "scan path" when diagrammed. An implication not always recognized is that you will also have a record of places to which people were not attending.

Systematic eye-movement recording was conducted in psychology and various specialized fields of textual and graphical communication, such as art and advertising, during the first half of the twentieth century (citations in Steinke 1987). Several researchers outside cartography conducted studies throughout the 1950s and 1960s.[9] A watershed event was the Symposium on the Influence of the Map User on Map Design, held in 1970 at Queen's University in Kingston, Ontario, and organized by McGrath and Castner (see Castner and McGrath 1971). The meeting included talks on a variety of cognitive cartographic topics, including eye-movement research. Leon Williams, a psychologist, reported some results from his non-cartographic eye-movement studies, and papers

[7] The j.n.d. is the smallest change in stimulus intensity that can be noticed by a human subject. Castner [1964] referred to the "least practical difference" as the smallest perceptible difference that can be reliably produced by the map-production process—a difference that is frequently larger than the j.n.d.

[8] An historical review may be found in Steinke (1987).

[9] Yarbus (1967) provided an influential review and additional studies.

by Merriam and Castner cited and discussed eye-movement studies and their possible implications for cartography.

George F. Jenks, cartography professor at the University of Kansas, attended the 1970 meeting at Queen's University. Jenks would eventually be recognized as a leader in map-design research in the United States, particularly in its empirical manifestations, probably second only to Robinson in influence. At a seminar Jenks held at Kansas during the early 1970s, he and his students drew region boundaries on a dot map showing hog production in North Carolina. The class spent a great deal of time discussing variation in their regionalizations, including possible explanations for it.[10]

Armed with the interest in eye-movement techniques he had picked up at the Queen's meeting, Jenks and his students conducted seminal recordings of the scan paths of viewers studying the dot map. (Figure 1 provides an example.) Although it is safe to conclude that this eye-movement study did not particularly illuminate causes for the different regionalizations of his students, it did demonstrate the feasibility (albeit with difficulty) of conducting eye-movement research in cartography. In this way it provided a stimulus for a host of subsequent research using the technique, by several of his students (Dobson 1975; 1977; Steinke 1979) and others, notably Castner and his colleagues (Castner and Eastman 1984; 1985), Chang and his colleagues (Chang et al. 1985), DeLucia (1974), and Phillips and Noyes (1977).

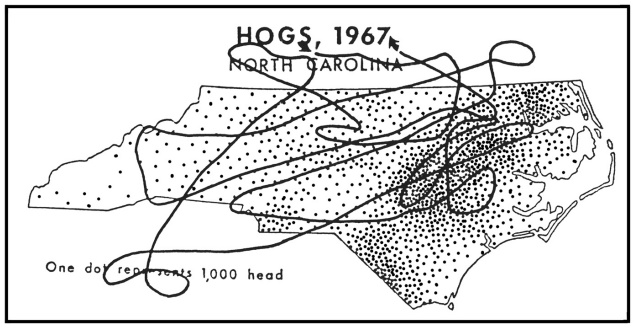

Figure 1. Hog map of North Carolina with overlaid scan path recorded from the eye movements of a person studying the map (Jenks 1973).

Cognitive Map-Design Theories

The Look of Maps and its predecessors offered a way to think about cartography as a discipline that attempts to pass along the cartographer's conception of the world to the mind of the map reader via the symbolic medium of the map. This was a seed for the communication model, a broad and comprehensive theoretical framework for describing and explaining cartography. It became the major theoretical focus of academic cartography in many countries during the 1960s and 1970s. From the perspective of this essay, the communication model provides a theoretical framework within which to justify empirical map-design research (though it probably was not created for that reason, according to Board (1981)).

In its simplest form, the communication model portrays maps as "channels" that transmit information from a source (the world) to a recipient (map reader) (Figure 2). Additional complexity may be added, such as an encoding process from the source to the map, a decoding process from the map to the recipient, and the possibility of "noise" in the transmission. Over the course of just a few years in the 1960s and 1970s, several graphic elaborations of the communication model were offered, bringing out details of particular components, and resulting in some rather complex diagrams of boxes and arrows. Figure 3 illustrates perhaps the most important example, by Koláčný (1969).

Excellent reviews of the origin and development of the communication model are found in Robinson and Petchenik (1976), Freitag (1980), Board (1981), Taylor (1983), and Castner (1990); many influential papers are reprinted (in English translation when needed) in a 1977 *Cartographica* monograph edited by Leonard Guelke. As early as 1964, John Keates introduced the idea of maps as communication devices at a meeting in London, explicitly linking cartography with information theory (Board 1981). The psychologist and semiotician Abraham Moles made similar connections in a 1964 French-language article, though to an audience of non-cartographic readers. Board himself presented a sophisticated conception of cartographic communication using a flowchart analogy for the process of map production and use (Board 1967). Perhaps the most influential paper on the communication model was presented in 1968 at an international conference by the Czech cartographer Koláčný (1969). He argued that map production and use should be understood as a single process of communicating cartographic information. Koláčný's prominence was recognized by his appointment as chair of the Working Group on Cartographic Information set up by the

[10] McCleary (1975) reports similar work on dot-map regionalizations and makes interesting speculations about the meaning of the individual differences.

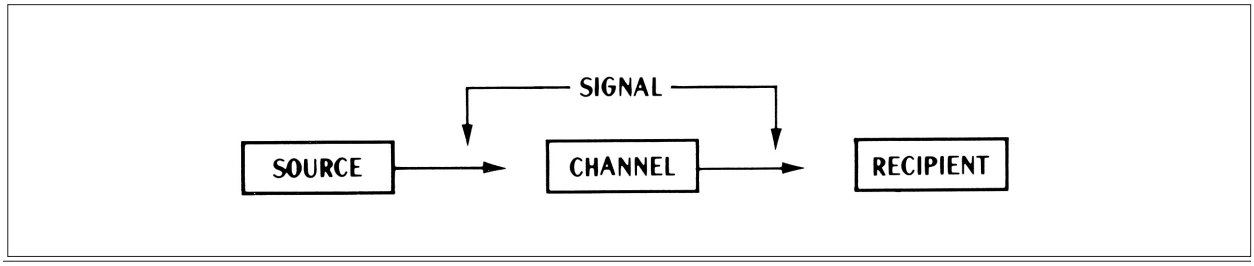

Figure 2. Simple framework for communication model (Robinson and Petchenik 1976).

International Cartographic Association (ICA) in 1968.

The early 1970s saw the communication model rise to its historical zenith as a theoretical conceptualization of the cartographic process, becoming the dominant conceptualization of scientific cartography. Ratajski (1973—in Polish in 1970) introduced the notion of "cartology" as the science of place information transmitted by maps. In Germany, Freitag (1971) and Hake (1973) presented models of the cartographic process that incorporated the idea of map communication as symbolic, thereby pointing to the role of semiotics (the study of signs and symbols) and linguistics in cartographic communication. Spurred by the rising popularity of the communication model, the ICA enhanced the status of its Working Group on Cartographic Information by establishing a full-fledged Commission on Communication in 1972. Lech Ratajski had taken over as chair by this time, in part because of travel limitations placed on Koláčný by the Czech government; Ratajski summarized his view of the Commission's discussions of the communication model in a 1978 paper.

The communication model led some authors to discuss cognitive aspects of cartography (see especially Koláčný's 1969 famous diagram). But it must be noted that the communication model is only partially a cognitive model; some would probably claim the model is not even necessarily about cognition at all, if that is understood as the knowledge states and processes of sentient organisms. A major inspiration for the communication model was, instead, the general engineering model of communication and information theory (Medyckj-Scott and Board 1991), developed and popularized at Bell Laboratories by Shannon and Weaver, among others, which was widely discussed in scientific circles of the time. In its more developed forms, the cartographic communication model would incorporate other theories that are not inherently cognitive but formal, such as those of structural linguistics.

An important example of a map-design theory that is not cognitive in the above sense is the semiotic theory of the French cartographer Jacques Bertin (1967). Bertin's semiotics (or "semiology") showed cartographers how to make design choices based on ideas about consonance between data characteristics and map symbol characteristics. This was a groundbreaking attempt to analyze the elements of map graphics—to develop a "language" of cartography (Freitag 1980). Although Bertin's work is an admirable application of intuitive psychology to the design of maps so they will communicate effectively to humans, at best it is only marginally a cognitive theory. It presents no empirical data—though later research by others has evaluated some of it—and it is not based on theories of human cognition (though he does acknowledge the advice of a psychologist, Abraham Moles, in the preface to the second, 1973 edition, in French). In fact, though his reasoning was keen, Bertin generally did not reference any scientific literature.

Authors who did focus explicitly and systematically on cognitive aspects of the cartographic process did so by essentially "unpacking" some of the boxes and arrows of less cognitive models. Cognitive aspects of communication are to be found in the mind of the mapmaker and, especially, the mind of the map reader. An early statement about the role of cognition was made by A. F. Aslanikashvili (1968), who defined cartography as the science of cognition that uses the methods and techniques of maps and map-making (Board 1981). In 1976, Robinson and Petchenik published *The Nature of Maps*, a thin book (like Robinson's 1952 volume) that consisted of a detailed and sophisticated exposition of theories and concepts relevant to the map as a communication device: theories including cognitive mapping and Piaget's theory of knowledge development, as well as information theory, linguistics, and semiotics.

At about the same time, Morrison (1976) presented an analysis of the communication model that focused on cognition. Both publications elaborated the simple communication model by defining the encoding process as the cartographer's cognitive system and the decoding process as the

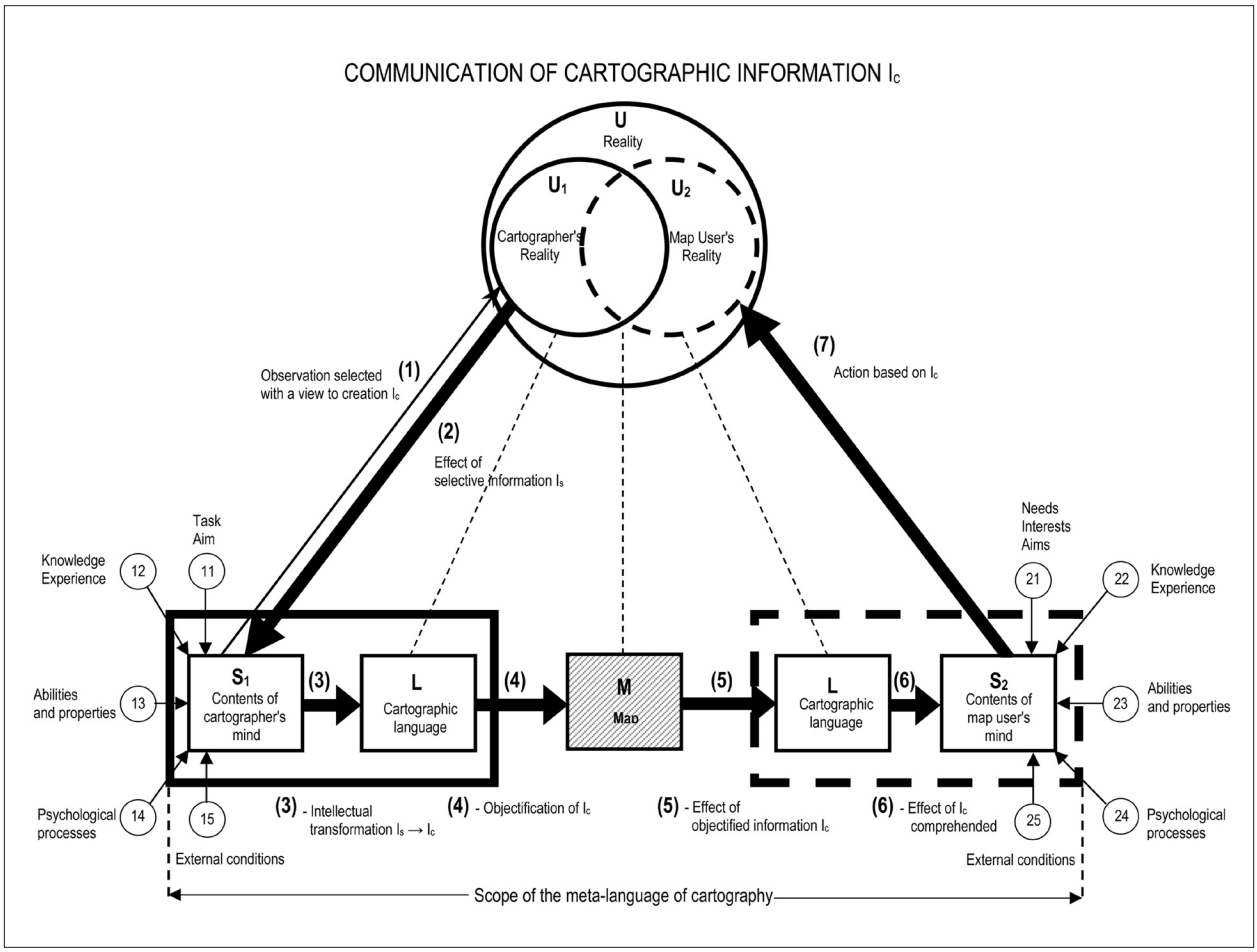

Figure 3. Complex framework for communication model, redrawn from Koláčný (1969).

recipient's cognitive system. This helped make explicit some important aspects of cartographic communication, namely, that the cartographer and/or the user could have incorrect conceptions and that users already had extensive beliefs before viewing any map. Because of this, knowledge could be inferred from maps that was not intended by the cartographer; conversely, some information the cartographer intended might never be apprehended by the map reader. In other words, the communication model became more accurate by recognizing that maps function not only because they "contain" meaning put there by the cartographer, which was transmitted to the mind of the map reader, but also because map users have preexisting knowledge that is necessarily involved in the comprehension of the map (Guelke 1976; Petchenik 1975). To exaggerate only a little, maps do not communicate knowledge; they stimulate and suggest it.

Before leaving this discussion of theory, it must be noted that a variety of cognitive theories have been applied by map-design researchers to the problem of understanding the cognition of mapping and map use. These theories are certainly more specific than the broad framework of the communication model but do include some influential ideas with fairly broad implications. Examples include: Gestalt theories of perceptual organization, Jean Piaget's constructivist theories, J.J. Gibson's direct theories of perception, Harry Helson's adaptation-level theory, and information-processing theories of cognition (e.g., Castner 1983; MacEachren 1995; Medyckj-Scott and Board 1991; Robinson and Petchenik 1976).

Major Contributions Outside North America

In this section, I discuss additional contributions to the international story of cognitive map-design research. Most of my discussion thus far has focused on researchers from the United States and Canada, all of whom were likely influenced directly by Robinson's *The Look of Maps*. This book

influenced work in other countries too, including non-English language work. In some cases, however, cognitive map-design research in other countries emerged somewhat independently of the influence of *The Look of Maps*, or at least made contributions deserving of separate consideration even if strongly influenced by *The Look of Maps*. Because several researchers from outside North America have already been discussed (notably Eckert and Freitag from Germany, Koláčný from Czechoslovakia, Ratajski from Poland, Salichtchev and Aslanikashvili from the U.S.S.R., Board from the U.K.), this section highlights a few additional contributions of special significance.

German-Language Work: Eckert's Legacy

As reviewed above, Freitag (1971) and Hake (1973) contributed to the international discussion of the communication model in the early 1970s. Their work represented a continuation in Germany (and Austria) of the important tradition begun by Eckert in the early 1900s. Following this tradition, cognitive map-design research, both empirical and theoretical, flourished in German cartography. As early as 1962, Heinz Schmidt-Falkenberg included a discussion of perception theory as part of what he considered the "basics of a theory of cartography." Imhof (1965) called for attention to human vision and the experience of map readers as bases for designing maps. A recent leader of map-design research has been Koch (e.g., 1981). In 1993, he published a review of experimental cartography, summarizing past results and offering future directions (Koch 1993). His department at Dresden offers the only degree in cartography in Germany. At the University of Berlin, Bollmann completed a dissertation under Freitag (Bollmann 1981) in which he empirically evaluated some of Bertin's ideas about cartographic signs. He later went on to start the Experimental Cartography Unit at the University of Trier. In Austria, Vanecek (e.g., 1980) and Arnberger (e.g., 1982) have published a variety of papers on map perception. This literature, and much more that could be cited, indicate the magnitude and richness of German-language literature on cognitive map-design research.

Britain

A noteworthy contribution to the history of map-design research from the United Kingdom is the work of David P. Bickmore and the Experimental Cartography Unit, or ECU. (Rhind [1988] provides a history of the ECU.) Created and sustained by Bickmore, the ECU was concerned with automation and computer-assisted cartography, and is an important part of the history of GIS. Negative experiences in producing *The Atlas of Britain* convinced Bickmore (around 1958 or 1959) that cartography needed the computer to increase efficiency, update information, and "facilitate experimentation with many alternative graphic depictions of the data in map form" (Rhind 1988, p. 279).

Acting on this insight, Bickmore convinced the Natural Environment Research Council of Britain to fund a research unit in automated cartography, the ECU, which became operational in 1967-68 at the Royal College of Arts in London. The main work of the ECU was the computer-assisted production of high-quality maps, typically in collaboration with government agencies such the British Ordnance Survey. But in his earliest writings, Bickmore pointed out that we knew little about what was effective graphic design for maps, and instead based our designs on cartographic convention. This inspired several years of psychological (and other) studies at the ECU on topics such as the perception of pseudo-maps and photographic image maps. Bickmore was a practical person, "uncomfortable with academically speculative projects which did not have demonstrable payoffs over quite short periods" (Rhind 1988, p. 281). So the map-design research of the ECU, which peaked in the early 1970s and tailed off in the 1980s, consisted of very focused empirical studies aimed at solving design questions for specific maps to be produced. No particular general theory emerged from this work.

A variety of additional cognitive map-design work has been carried out in Britain since the early 1970s. Board's theoretical contributions to the communication model (discussed above) have been notable. Board and Buchanan (1974) list many of the empirical human-subject studies of cartographic communication done in the U.K. as of 1974. Starting in the early 1970s and continuing to the present, the psychologist R. M. Taylor and his colleagues, working at the Royal Air Force Institute of Aviation Medicine, have contributed a great deal to this literature. They have written at least 50 published and unpublished research papers, technical reports, and literature surveys on the human factors of maps and charts, including a great deal of work in the context of military aviation (Board and Taylor 1977; Hopkin and Taylor 1979; Taylor 1973, 1974, 1984, 1985; Taylor and Hopkin 1973).

Soviet Work—Communist Cartography

The stamp of communist doctrine had wide impacts on all academic and scientific disciplines in the Soviet Union during the twentieth century. Cartography was no exception. In a 1957 review, the leading Soviet cartographer K. A. Salichtchev credits Lenin as writing that a cartographic science should be developed that would allow the proletariat to understand their country's resources (natural and human) and the actions of their government. In other words, maps had to be comprehendible by everyone—an ironic principle in view of the intentional censorship and map distortion later practiced by Soviets (Postnikov 2002, and this volume). Krempolskii (1959) and Boginskii et al. (1979) repeated this idea that cartographers need to think about readily perceived map symbols, fonts, and colors. This was essentially a call for maps as communication devices, echoing the communication model. As early as the 1950s, according to Salichtchev (1970), some Soviet cartographers understood that map use and the map user were part of the subject matter of cartography. However, no evidence is provided in any of this literature that the concern for communication led to explicit use of psychological theories or empirical studies of map cognition. As reviewed above, Salichtchev (as well as Aslanikashvili) had been involved in international discussions of the communication model and map semiotics. In this regard, however, Salichtchev was often noted most for his view that the communication model provided a poor basis for cartography as a science (e.g., 1970). In the 1970s, Lyutyy continued work on the "map language" (Komedchikov 2000) as a semiotic theory of map design, but again this did not involve empirical research or explicit cognitive theorizing.

The Rise and Fall of Cognitive Map-Design Research

Cognitive map-design research had its heyday in the 1970s. Evidence of this is provided by Gilmartin (1992), who reported a content analysis of research published in major English-language cartographic journals from 1964 to 1989. She used the term "user-oriented" for research articles on communication, perception, and cognition. The period from about 1975 to 1982 had the most user-oriented articles, peaking in 1978 and 1979 at over 30 percent of all articles in those journals—the largest single category. Before the late 1970s, historical topics were predominant; the 1980s witnessed the growth of automated cartography as a topic. Major American universities where this work occurred during the period from the 1960s to the early 1980s included the University of Wisconsin, the University of Kansas, the University of Washington, Clark University, and the Pennsylvania State University.

Numbers aside, the reputation of cognitive map-design research was noticeably damaged in the 1980s, when both empirical and theoretical work became increasingly suspect. As the primary conceptualization of scientific cartography, the communication model had always had its dissenters. Salichtchev, as mentioned above, had criticized the communication model as focusing excessively on the map itself rather than its geographic content. In addition, early versions of the communication model mistakenly assumed that the mapmaker, and the map, had a specific message to pass along—a successful map being one for which all viewers got the message.[11] Such versions of the communication model were thought to ignore the importance of prior knowledge in using maps (MacEachren 1995). Clearly, quite a few cartographers have felt disdain for the "boxes-and-arrows" diagrams that didn't tell them how to make better maps. Others (Freitag 1980) attributed the communication model's limited application to improved map design to the lack of a consensus model of map communication, undoubtedly still the case at a detailed level.

Empirical research, including psychophysical work on the Power Law and eye-movement studies, was thought to lack ready application to the production of maps. For a time, study after study, thesis after thesis, examined some nuance of the perception of graduated circles. Graduated circles were "poked and prodded from every angle, the white rat of cartographic research" (Kimerling 1989). And it did not add up to conclusions obviously useful to mapmakers; rather, to many, it became an exercise in the beating of pack animals that were already deceased. Similarly, many cartographers had recognized the potential value of eye-movement studies but came to believe that it told the mapmaker nothing he or she did not already know. Conclusions such as "subjects look more at areas of the map that contain relevant information" or "different map designs produce different eye-scan paths" were not earthshaking revelations.

Barbara Petchenik's (1983) searing critique was especially telling because she had been reared in the map-design tradition (as Robinson's student)

[11] This assumption may reflect narrow attention to thematic rather than reference maps, but it is largely incorrect either way.

and was working in production cartography (at R. R. Donnelley) as map editor for the World Book Encyclopedia. She pointed out that map-design research was not helpful because it was based on faulty assumptions about the way people use maps (such as that they always have a single, definite question to answer when they look at a map) and because of fundamental differences in the goals of designers and researchers. (The first think synthetically, the second analytically.)

Petchenik noted that the results of empirical studies seemed inconsistent and context-dependent; changing the nature of the map task or the precise design of the test materials often led to variability in the results (Cox 1976; Chang 1980). Other problems included the existence of individual differences—map users are different, and to a certain extent (sometimes great), they look at and think about maps differently. There are potentially a large variety of innate and experiential factors that cause these differences. Flannery himself recognized the individual variation in his data but managed to offer a single exponent to describe the relationship of actual to apparent circular area by using the median values of estimates. Of what use is a single correction factor for the sizes of graduated circles when that factor is based on an average over several people, several symbols, and several tasks? Much of the empirical work labored to make progress because it was atheoretical, to some extent flailing about without direction. For example, simply recording foveal fixations ignores the important role of peripheral vision in alerting attention where to focus.

A frequent criticism of psychophysics was that it kept researchers from considering the active thinking mind of the map user, supposedly because it was part of the paradigm of behaviorism in psychology (Petchenik 1975; Salichtchev 1983). Whatever the failings of either paradigm, it is inaccurate to apply a critique of behaviorism to psychophysical map-design research. Neither psychophysics nor any other approach in the history of cognitive cartography has ever relied much on behaviorism as a theoretical framework; psychophysics in psychology predates behaviorism by at least a couple decades, and its use in cartographic research grew as behaviorism declined in psychology. However, commentators have validly criticized approaches such as psychophysics for focusing too much on low-level map tasks such as feature detection and size perception. During the late 1970s and 1980s a number of authors (including Petchenik (1975), Olson (1984), and Gilmartin (1981)) called for research on higher-level cognitive tasks, such as reasoning and inference-making, which required a more holistic consideration of relations on maps, not just of isolated symbols. It should be remembered, though, that while a focus on the perception of isolated symbols certainly characterizes psychophysical studies, this apparent myopia does not warrant their complete dismissal insofar as such low-level tasks are an essential precondition for seeing anything on a map.

Aside from these intellectually substantive reasons for the decline of cognitive research in cartography, the advent of the computer in cartography contributed to its decline for pragmatic reasons. Several cartographers with whom I spoke believe that the "digital revolution" (that is, automated cartography and GIS) dampened, if not destroyed, interest in cognitive cartographic research. One reason is simply that GIS gave graduate students something to pursue that was seen to be easier and more tractable. High-quality behavioral research requires training of a kind not readily available in geography departments; a lack of such training led to poorer research, which in turn led to some of the deserved discrediting of map-design research. Moreover, map-design research is difficult and time-consuming. Eye-movement studies (Castner 1983), in particular, require expensive and technically complicated equipment and produce huge amounts of data whose signal is buried in considerable noise and irrelevant components. And there are many options as to how to analyze these data (fixation locations and durations, scan lengths, number of direction changes, etc.)—options that require theory for their understanding.

Given the modest increase in knowledge that apparently resulted from the average map-design study, many researchers in-the-making may have decided to do a GIS project instead. Certainly, many of them understood that GIS training would open up more job opportunities. These opportunities, and the intellectual and practical limitations and difficulties of cognitive map-design research, led to a waning enthusiasm for empirical studies in the early 1980s. Although a few studies taking this approach continued to appear throughout the 1980s there is no question that its popularity declined, particularly in the United States.

Cognitive Map-Design Research Rises Again: 1990-2000

As discussed above, it is widely believed that GIS helped to decrease enthusiasm for and interest in cognitive cartography; it probably decreased enthusiasm for cartography in general. However, several cartographers I spoke to recognize that the

computer might eventually foster a resurgence of interest in map-design research, once a sufficient number of technical problems are solved. In fact, a few cartographers recognize that resurgence in map-design research is under way already. Evidence supports this view.

The most comprehensive review of map-design research ever written appeared in 1995 under the title *How Maps Work*. Written by Alan MacEachren, the book covers in detail cognitive (including perceptual) and semiotic research on the design and interpretation of maps and other "geo-visualizations." The reference list, which includes many studies done after 1990, highlights ongoing work at Penn State's GeoVISTA Center. Among other signs of intellectual progress in map-design research, MacEachren's book reflects awareness of some of the earlier mistakes of the approach. For example, its conceptualization of communication is fully informed that maps do not "contain" and "transmit" their messages to users, but stimulate ideas and inferences by interacting with the prior beliefs of those users.

A report by Pickle and Herrmann (1995) includes a series of papers on recent map-design research. The style of these papers not only suggests an appreciation for human-subjects evaluation as a standard tool in the cartographic toolbox but also reflects historical maturation in this approach beyond earlier research. Commissioned by the National Center for Health Statistics, a U.S. government agency, the research in this publication focuses on the design of thematic maps.

Additional evidence for the resurgence of cognitive map-design research is provided by the publication of *Cartographic Design: Theoretical and Practical Perspectives* in 1996. Edited by Wood and Keller, the book is based on the Symposium on Cartographic Design and Research, held at the University of Ottawa in August 1994. The meeting was inspired by a recognition that the digital revolution had led to a neglect of map design and map-design research; it was explicitly intended as an update to the meeting held at Queen's University in 1970. Most of the chapters in this book are concerned with cognitive theory and data (e.g., Nelson and Gilmartin 1996).

In addition to these books, articles continue to appear in major journals.[12] All of these 1990s publications suggest that cognitive map-design research maintains its status as an important, if not dominant, component of cartography as a scientific discipline. They also indicate that much current research has made the transition from the lower-level perceptual approaches to the higher-level cognitive approaches called for by Petchenik and others; evidence is provided by the addition of higher-level cognitive methods such as protocol analysis and collaborative decision-making to the researcher's toolbox (e.g., Slocum et al. 2001).

An examination of doctoral degrees awarded recently provides further evidence for the resurgence of interest in cognitive map-design research. I have found at least twenty dissertations completed in the general topic area of cognitive cartography in the U.S. during the 1990s, and several more at European and Japanese universities. Several of these can readily be characterized as map-design research (e.g., Cammack 1995; Egbert 1994; Wood 1992). These numbers compare favorably to the two dozen or so completed in the 1970s and 1980s, especially when one takes into account that cartography has probably decreased in importance in Ph.D. programs in geography. Michigan State and South Carolina emerged as major American contributors to cognitive map-design research in the 1990s.

Various reasons might explain the rising popularity of cognitive research in cartography. Certainly methodological advances, such as the movement away from simple psychophysical techniques, are one reason; newer methods provide the means to tackle a broader set of questions. The rise of interdisciplinary approaches on campuses and in research disciplines (e.g., the activities of the NCGIA and of COSIT, described below) has provided more support for cartography students to seek training in non-traditional skills, such as human-subjects methodology. A cynic might wonder if a lack of awareness of past problems with map-design research provides some explanation too ("Those who forget the past . . .").

But the advent of GIS may, ironically, provide the major explanation for trends in cognitive cartographic research. The computer can definitely facilitate map-design research (Brewer and McMaster 1999). For one, it can help in the preparation of stimuli; a major difficulty in the past was the substantial effort required to prepare controlled variations of a single stimulus map. The computer can also administer data-collection procedures, including the randomization of stimulus presentations, and can automatically record responses. Even eye-movement studies, notoriously difficult and expensive, have become easier to conduct (though not exactly easy or inexpensive); they are, in fact, widely carried out in other cognitive-science and human-factors research

[12] Two of at least fifty English-language examples that could be cited are Lloyd (1997) and Slocum and Egbert (1993).

(d'Ydewalle and van Rensbergen 1993; Findlay et al. 1995). Data analysis usually takes only minutes with any of several widely available software packages, especially since it can be guided by a wealth of available theory about how to analyze the data. Cartographers themselves, in fact, continue to explore the application of eye-movement methods to understanding and improving map design (Brodersen et al. 2002).

More than these pragmatic issues, the computer continues to be used to look at (listen to, touch, etc.) geo-referenced data in new ways: animations, sonifications, tactilizations, and virtual and augmented realities. There is great interest in using these new techniques to depict data quality or "uncertainty" (Buttenfield 1993; Evans 1997; MacEachren 1994), recognized as an important issue at least as long ago as 1942 by Wright. Furthermore, computerized geo-information is becoming ubiquitous: in cars, on desktop computers, in cellphones, in public sites from airports to shopping centers. These ongoing developments have clearly inspired new interest in research to predict and explain the effectiveness of geo-visualizations as communication tools, understood broadly to include knowledge discovery as well as confirmation (Aretz 1991; Hirtle and Sorrows 1998; MacEachren 1995; McGranaghan et al. 1987). Such applications will require rapid communication of information to lay consumers as well as cartographic and geographic experts.

Further evidence of a renewed interest in cognitive issues being inspired by GIS is provided by a variety of activities during the 1990s as part of the emergence of "geographic information science." Several of the meetings organized by the (U.S.) National Center for Geographic Analysis and Information (http://www.ncgia.ucsb.edu/) have been explicitly interdisciplinary and focused on language, reasoning, and the cognition of geographic information. The (U.S.) University Consortium for Geographic Information Science (http://www.ucgis.org/) includes, as one of its research priorities, "Cognition of Geographic Information." The International Conference on Spatial Information Theory (COSIT), a leading conference for theory in GIScience, focuses on combining geographical, cognitive, and computational approaches to spatial information. Usability studies (cartographic human factors) are promoted by the Commission on Visualization and Virtual Environments of the International Cartographic Association in an article by Slocum et al. (2001), appearing in a special issue of the journal *Cartography and Geographic Information Science*. In all of these cases, cartographic communication, perhaps termed "visualization" or "interface design," is a central concern.

The Legacy of Cognitive Map-Design Research

To ask about the legacy of cognitive map-design research is to ask how it has mattered to cartography, whether academic, commercial, or otherwise. There are several ways one can answer the question of how cognitive map-design research has mattered. Such research has clearly influenced the activities of academic cartographers a great deal. Faculty and students have spent time thinking about it and doing it. Conferences have occurred, articles and books have been published, money has been spent, research subjects have answered countless questions. Many courses in cartography include discussions of the communication model and map-design research. It is still the case that the communication model, including its cognitive aspects, provides one of the major frameworks for understanding cartography as a science.

To some people, a more interesting question is the extent to which map-design research has mattered to the production of maps, both by agencies and private companies in the business of making maps, and by mapmakers without professional training (e.g., many media cartographers). The answer here is "it has not mattered much." This is recognized by every cartographer I have spoken to; it was a key discussion point in Petchenik's (1983) critique. For example, in spite of the way Flannery packaged his conclusions about graduated circles in terms of a readily applicable mathematical correction, it appears that no map production unit except the U.S. Census has made maps with perceptually scaled circles. This is in spite of the fact that as long ago as 1963, McCleary empirically demonstrated the effectiveness of perceptual scaling; unfortunately, his manuscript was not published. Similarly, according to one of my informants, Taylor's copious research on aviation maps did not persuade pilots or military mapmakers to change their map designs, even though the research was conducted in highly realistic contexts.

But this is not to say that map-design research had no impact on map production. Rhind (1988) claims that the work of Bickmore's ECU in Britain during the early 1970s included the design of "innovative and provocative maps based on empirical psychophysical tests" (p. 286), though,

admittedly, Rhind believes the influence of this work was short-lived. Petchenik herself was in production cartography at Donnelley, where she conducted a great deal of empirical work as part of her job. Research on color is an especially important example of the application of map-design research. Brewer has done notable work on color for the U.S. Census and the Environmental Systems Research Institute, makers of the widely used Arc/Info GIS (see note 47 by Frye in Brewer and McMaster 1999). The color scheme developed and tested by Olson and Brewer (1997) for the color-vision impaired has been used by the U.S. Center for Disease Control in their Atlas of United States Mortality. According to one informant, the results of cognitive map-design research have strongly influenced the design of school atlases in German-speaking countries. Recently, ESRI modified its popular GIS software ArcInfo to let mapmakers rescale their area symbols to accommodate perceptual effects.

In some ways, the critique that map-design research has had little effect on map production is not entirely fair. Empirical map-design studies have been done for less than fifty years, and so many of the mistakes and false starts of these pioneers are to be expected. And though definitions of "basic" science, including completely reputable hard sciences such as physics, typically note that research on fundamental explanatory questions "may one day be applied to help humanity," they are rarely attacked within academia for being useless to immediate practical application.[13] It may say something about the way some cartographers understand science, or the way they understand cartographic research exclusively as applied science, that they would consider such an immediate lack of application a damning statement about map-design research. Such an observation applies to critics of map-design research, but it also applies to those proponents of map-design research who claimed, a bit naively, that their research would show mapmakers the right way to make maps.[14] While cognitive research has taught us some things about making better maps, and undoubtedly will teach us more, it is never going to replace completely the wisdom and aesthetic sensibility of a good designer. Research can augment informed intuition in several ways, however. In particular, systematic theory and empirical methods can not only provide tests of the conventional wisdom, some of which is likely wrong, but also suggest effective ways to use new visualization tools whose application goes beyond the existing wisdom.

Furthermore, academic cartography in general has not connected well with production cartography. Even if map-design research had been carried out at the highest levels of quality, it would still have had a difficult time influencing production. An attitude of resistance to change by map producers undoubtedly slowed the adoption of map-design results. The best mapmakers rely on conventions, often based on decades or centuries of trial-and-error development, that would not easily be improved by scientific research. The inertia of tradition, especially in large bureaucracies, would tend to prevent it in any case. Map producers are busy and do not have much time or training (or perhaps the inclination) to digest academic research. The costs of remaking maps works against the adoption of new designs, and economics further prevents many map producers from trying new things that may alienate their markets. Finally, the amateur "cartographers" who make widely disseminated maps (e.g., in many media outlets), and who have a communication influence far beyond their foundation of training, are not likely to make use of map-design research when they do not make use of basic cartographic principles in the first place.

There is yet another answer to the question of how cognitive map-design research has mattered—a more abstract answer, but real and significant nonetheless. Map-design research shifted attention to an idea about maps and cartography that is fundamentally correct: map design should be considered in terms of its effectiveness for helping people understand the world. Robinson himself sees as an example of this notion the widespread recognition that the Mercator projection is inappropriate for most general-purpose uses. Furthermore, the efforts of map-design researchers led to the development of a detailed analysis and vocabulary for describing the varied tasks of map users and producers; the simple notion of "reading" a map has been greatly expanded in appreciation of the fact that there is no single universal way that maps are "read" (Castner 1983). In sum, map-design research has created a new way of thinking and talking about maps and mapping that continues to affect the entire discipline of cartography. "Thirty years of psychophysical and cognitive research . . . have changed the way cartographers approach map design" (Jenks 1987, p.

[13] Freitag (1980) made this point about critiques of communication theory in cartography.

[14] The excessive precision of Flannery's correction exponent for graduated circles is an example.

112). Several cartographers recognize the demise of the notion that any old way of mapping is fine as long as it is based on the cartographer's intuition. The needs and capacities of the user have become recognized as central. This is undeniably a significant legacy of map-design research for the cartography of the twentieth century.

Conclusions

Cognitive map-design research has been almost entirely a development of the twentieth century. The insight that maps influence people's minds and that the mapmaker is thus a mind maker are insights that some cartographers undoubtedly had centuries ago. But the application of a scientific approach, involving testable theories and systematic empiricism, is a recent development. The publication in 1952 of Robinson's *The Look of Maps* is widely credited as a seminal event in these developments. Although there were clearly movements in this direction prior to 1952, notably Eckert's *Die Kartenwissenschaft*, map-design research only emerged as a significant movement after 1952.

In the latter half of the twentieth century map-design research, particularly its cognitive aspects, contributed greatly to the development of cartography as a scientific discipline. In part, this is because questions about how people see and interpret maps are clearly scientific questions, unlike many other cartographic issues that are more obviously craft, historical, or mathematical in nature. Furthermore, the role of cognitive map-design research in cartography as a scientific discipline was helped by the fact that there already existed the developed science of psychology to help show cartographers how to approach cognitive map-design questions. Because of the events described in this essay, cartography may now be considered part of the cognitive sciences (as suggested by Lloyd in note 45 of Brewer and McMaster 1999).

I conclude with several interesting questions about the history of cognitive map-design research. Suggested by my research for this essay, these questions deserve further attention:

1. In this essay, I proposed a distinction between map-design, map-psychology, and map-education research. I claimed the three have had much less mutual interaction than logic would suggest, especially from the perspective of some of the grand theoretical frameworks offered by map-design researchers (e.g., *The Nature of Maps*). This question of the degree of interaction among the three areas deserves attention. Trowbridge (1913), who published a seminal paper in the psychological study of human spatial cognition, was familiar with the 1908 paper by Gulliver, a geographer. Why hasn't subsequent interaction been greater? Would increasing it provide benefit to cartographers, whose main concern is maps and map use? Would it benefit behavioral and cognitive scientists whose main concern is not maps? As reviewed above, some of the interdisciplinary meetings of the 1990s point to an increase in this interaction. A few papers are being published that better integrate cognitive cartographic work across disciplines (Lloyd 2000).
2. A second question is that of the mutual influence of map-design research published in different languages. To what degree was the apparent influence of *The Look of Maps* restricted to English-speaking researchers? How important has the lack of translations, particularly into English, been to the relative inattention some work has received? Taylor (1983) discusses this, citing Bertin's work as an undeniable example in cartography.
3. The widely held characterization that cognitive map-design research lost favor during the 1980s is somewhat problematic. Some cartographic researchers in North America and Britain continued to work in this area throughout the 1980s and 1990s, Gilmartin's (1992) content analysis notwithstanding. Since at least the early 1970s there has not been a year without one or more cognitive articles in English-language cartographic journals. Restricting one's analysis to English-language journals, as Gilmartin did, is problematic. The references I cite in this essay, as well as a much larger list I have collected, suggest that the popularity of cognitive map-design research has not waned at all in Germany during this time.
4. To what degree, and how, will map-design research affect map production and education in the twenty-first century? How will map-design research be conducted so that is does produce more practically useful results? Increasing the availability of cartographic training in the research methods of the behavioral sciences is one possibility. Given the increasing role of computerized geographic information systems in everyday life, especially apparent in systems for navigation and tourism, the need to produce widely and easily comprehensible cartographic displays will only increase. As a complement to research that aims to make

maps easier to use, perhaps future research will also focus on developing educational programs to make map users more competent (Castner 1983, 1990; Olson 1975).

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