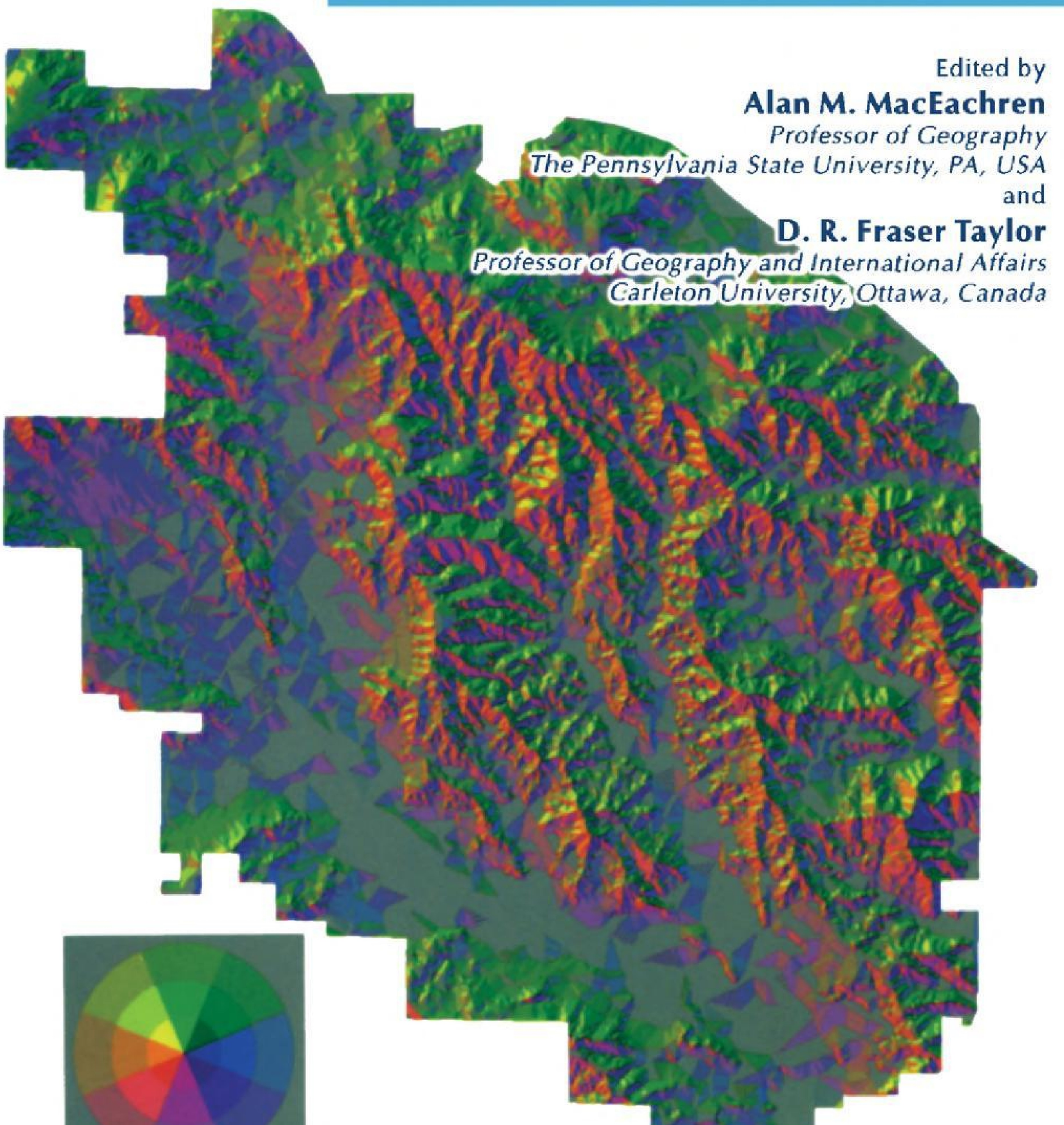
MODERN CARTOGRAPHY VOLUME TWO

visualization in modern cartography



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Front Cover

Cynthia Brewer's aspect/slope color scheme allows terrain visualizaton through relief shading while simultaneously categorizing the surface into explicit aspect and slope classes. Aspect categories are mapped with hues, slope categories with saturation, and near-flat slopes with gray for all aspects. Lightness sequences are built into both the aspect and slope color progressions to approximate relief shading. The map was developed from a database of digitized topography of Hungry Valley State Vehicular Recreation Area (north of Los Angeles, California) provided by the Steven and Mary Birch Foundation Center for Earth Systems Analysis Research in the Department of Geography at San Diego State University. The aspect/slope scheme is an elaboration of Moellering and Kimerling's MKS-ASPECT scheme and is described in Brewer and Marlow's AutoCarto 11 proceedings paper referenced in Chapter 7.

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Introducing Geographic Visualization (GVIS)

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CHAPTER 1

Visualization in Modern Cartography: Setting the Agenda

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Introduction

The title of this book, *Visualization in Modern Cartography,* demands some explanation. What cartographers mean by visualization and how we respond to visualization developments outside cartography are critical to what cartography can become as it moves to the 21st century. Cartography is at a crossroads, balancing precariously between links with geography and links with other "mapping sciences", between past traditions and the "threat" of geographical information systems (GIS) to replace cartography as we know it, between the demands to be proficient technologists who can build mapping systems and competing demands to draw upon our cognitive expertise to evaluate whether the system we build will work....and I could go on.

David Rhind, the Director of the Ordnance Survey in the UK, signaled the demise of the paper map in his Cologne International Cartographic Association (ICA) address (Rhind 1993); a profound event for the discipline if (or should I now say "when") it comes to fruition. Over the past five or six years, we have witnessed a dramatic ascension of visualization as an acceptable method of scientific practice. This development has been mirrored by an explosive advance in multimedia technology that promises to deliver interactive visual/audio products to the public. Map-making firms are already involved in the production of animated maps for CD-ROM encyclopedias. In January 1994 I read in the local newspaper that

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Blockbuster Video (the largest video rental company in the US) is beginning to rent CD-ROMs as well as videos, and a recent newspaper had two articles on US efforts to built an "information highway" based on fiber optic cables. At least one spatial information provider is marketing a travel information product that runs on personal digital assistants (PDAs) such as the Apple Newton; if your PDA has a fax modem, it will even fax your reservation to a selected restaurant.

In this rapidly evolving scientific/business climate, it seems essential to consider the implications of maps as dynamic interactive spatial information tools (in contrast with their more traditional role as static storage devices for spatial data). This move to interactivity is a key theme that threads through the chapters that follow. While interactivity is not the central issue in every chapter, each chapter considers issues that arise when interactive access to spatial information (often by non-cartographers) is possible.

As noted in the opening paragraph, to produce a book about visualization in modern cartography requires some attention to just what is meant when we use the term "visualization". The section that follows presents my own (continually evolving) thoughts on this question. An earlier draft was circulated to all authors for comments (in August 1993). I invited responses and suggested that those who either agreed or disagreed with the perspective might use my essay as an anchor (or target) for their own views. I received several insightful replies (some of which are recounted in the endnotes to this chapter).

(Cartography)³

Visualization through mapping has long been treated as a fundamental geographic method. This point of view is illustrated by Philbrick (Philbrick 1953: 11) who submitted that "....not only is a picture worth a thousand words but the interpretation of phenomena geographically depends upon *visualization* by means of maps" (my emphasis). Philbrick's perspective suggests that cartographic visualization deals with maps as geographic research or spatial analysis tools. DiBiase's more recent research-sequence characterization of cartographic visualization matches this view (DiBiase 1990); see also (MacEachren and collaborators 1992) (Fig. 1.1).

Borrowing from the literature of both scientific visualization and exploratory data analysis (EDA), DiBiase (1990) proposed a framework for thinking about geographic visualization (GVIS) in the context of scientific research (with particular attention to earth science applications).[1] His framework emphasizes the role of maps in a research sequence. It defines map-based scientific visualization as including all aspects of map use in science, from initial data exploration and hypothesis formulation through to the final presentation of results. Emphasis is on re-establishing links between cartography and geography (as well as the earth sciences in general) and on the role of maps at the exploratory end of the research process. A key distinction made is that between maps to foster *private visual thinking* early in the research process and those to facilitate *public visual* *communication* of research results. Following this approach, visualization is not a new aspect of cartography, but a renewed way of looking at one application of cartography (as a research tool) that balances attention between visual communication (where cartographers have put much of their energy during the past two or three decades) and visual thinking (to which geographic cartographers of the first half of the century devoted considerable attention).

John Ganter and I (MacEachren and Ganter 1990, Fig. 7: 79) also incorporated a public–private distinction in our discussion of how "cartographic" visualization tools might be applied. To this distinction we added one between visualization tools intended to facilitate scientific research and those geared toward architectural and engineering applications (e.g. design of a building, highway, industrial park, or golf course). As DiBiase did, we linked the private use of visualization tools to exploring options and developing an approach to a problem. Our presentation and DiBiase's both suggest that representation options are reduced in number (ultimately to a single view) as the public end of the visualization tool use continuum is approached.

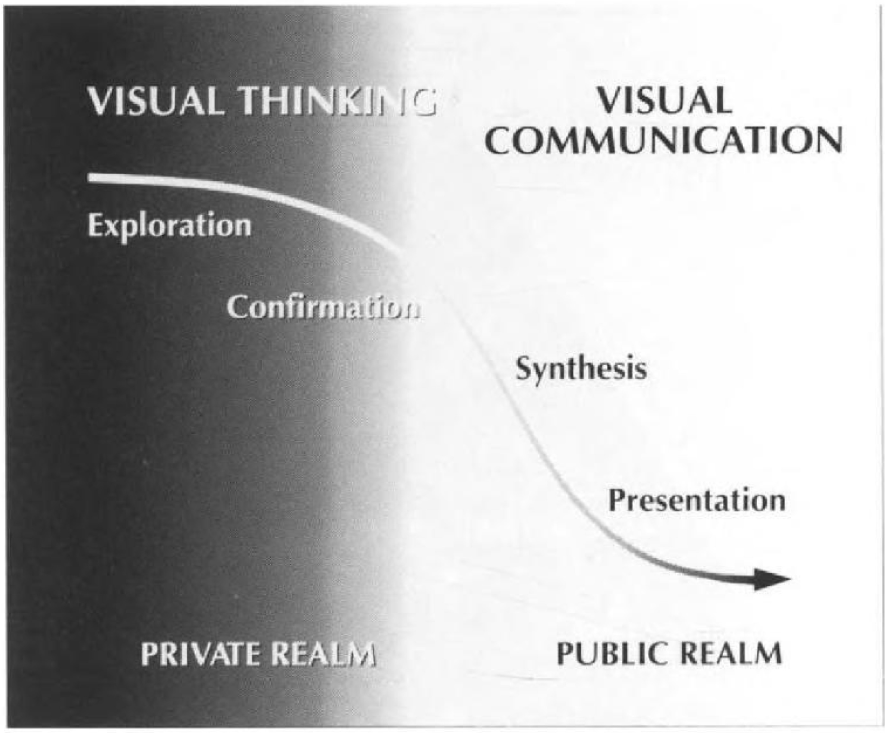

FIG. 1.1. DiBiase's depiction of visualization as a tool of scientific research. The curve depicts the research sequence through which different kinds of graphic depictions play a role. At the exploratory end of the sequence, maps and other graphics act as reasoning tools (i.e. facilitators of visual thinking). At the presentation end of the sequence, the visual representations serve primarily a communication function to a wider audience. Reproduced with permission from DiBiase (1990), *Earth and Mineral Sciences, Bulletin of the College of Earth and Mineral Sciences*, The Pennsylvania State University.

A complementary perspective on visualization as it relates to cartography has been offered by Taylor (1991) who focuses, not on how visualization tools are used or who uses them, but on the place of visualization within various cartographic research approaches of the past few decades. Taylor portrays visualization as occupying center stage, as the meeting ground of research on cartographic cognition, communication, and formalism (with "formalism" being used to suggest the strict adherence to rule structures required when computer technologies are applied) (Fig. 1.2). He calls visualization "a field of computer graphics" that attempts to address both "analytical" and "communication" issues of visual representation. By implication, then, visualization (for cartography) becomes the application of computer mapping to analytical and communication issues of map representation. Taylor stresses, however, that attention to computer formalism has dominated the discipline at the expense of cognitive and communication issues. He contends that research in all three areas is required to support successful cartographic visualization.[2]

A primary difference between Taylor's perspective on visualization and that offered by DiBiase (1990) or the one Ganter and I originally proposed (MacEachren and Ganter 1990) is in the emphasis placed on technology supporting visualization versus uses of visualization. Taylor links visualization directly to computer graphic technology but does not restrict visualization tool use to particular kinds of

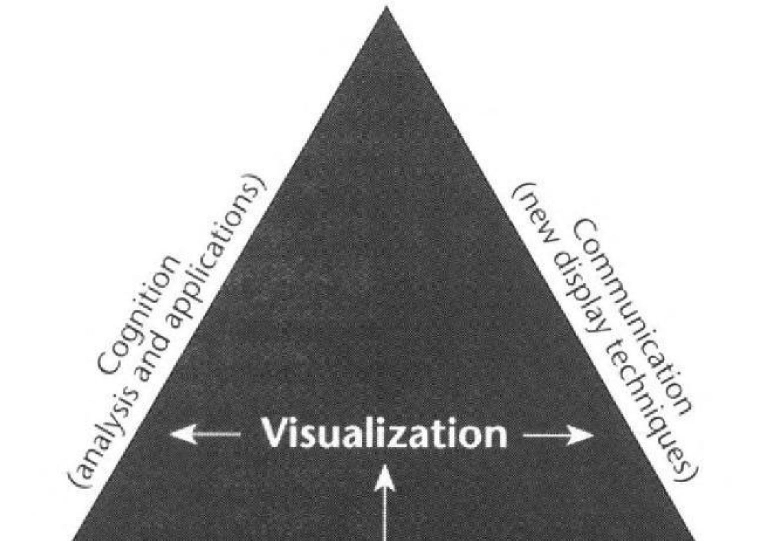

FIG. 1.2. Taylor's representation of visualization as the amalgamation of approaches to cartography associated with cognition, communication, and the formalism of computer technologies. Reproduced with permission from Taylor (1991) *Geographic Information Systems: The Microcomputer and Modern Cartography*, Pergamon Press.

application (i.e. scientific research). Both DiBiase and MacEachren and Ganter de-emphasize the technology producing the visualizations and concentrate on the kinds of uses to which they are put. All authors, however, seem to agree that visualization includes both an analysis/visual thinking component and a communication/presentation component and suggest (or at least imply) that communication is a subcomponent of visualization.

One problem with the views on visualization considered thus far is the appropriation of communication under the umbrella of visualization. If visualization includes both visual thinking and visual communication we might pose the question of what it does not include (and some have done so). Is "cartographic visualization" simply a new name for cartography? Saying that visualization involves computer graphics does not help much. It simply equates visualization with computer cartography. While Taylor drew attention to the links between visualization and computer graphics, Monmonier and I took this one step farther to place the emphasis on changes in computer technology that have made real-time interaction possible. We suggest not only a technological difference in tools for representation, but a "fundamental" difference in the nature of how analysts interact with those representations:

> The computer facilitates direct depiction of movement and change, multiple views of the same data, user interaction with maps, realism (through three-dimensional stereo views and other techniques), false realism (through fractal generation of landscapes), and the mixing of maps with other graphics, text, and sound. Geographic visualization using our growing array of computer technology allows visual thinking/map interaction to proceed in real time with cartographic displays presented as quickly as an analyst can think of the need for them. (MacEachren and Monmonier 1992)

The increased potential for human–map interaction that has become possible with current computer tools seems to be a critical component of GVIS as it contrasts with other kinds of map use. Friedhoff and Benzon (1989) make a similar point for scientific visualization in general.

As part of my efforts to organize a visualization working group under the auspices of the Map and Spatial Data Use Commission of the ICA, I found that the variety of ways in which visualization was defined by cartographers made discussion of the goals for a working group difficult, if not impossible. In response to the divergence of views, I developed a graphic characterization of visualization to be offered as an initial organizing concept for the visualization working group. The generally positive reaction to this characterization by a number of colleagues at the ICA meeting led to its use as a framework for linking contributions in this book. The characterization is based on treating cartography (or at least map use) as a cube — thus the $(Cartography)^3$ heading for this chapter section (Fig. 1.3).[3]

To make sense of how "scientific" visualization links with cartography, I start with the view that "visualization", like "communication" is not just about making maps, but about using them as well. As a communication approach has been dominant in cartography (particularly English language cartography) for at least two decades, it seemed that any attempt to delineate the territory of visualization (facilitated by maps) would have to consider how it relates to communication

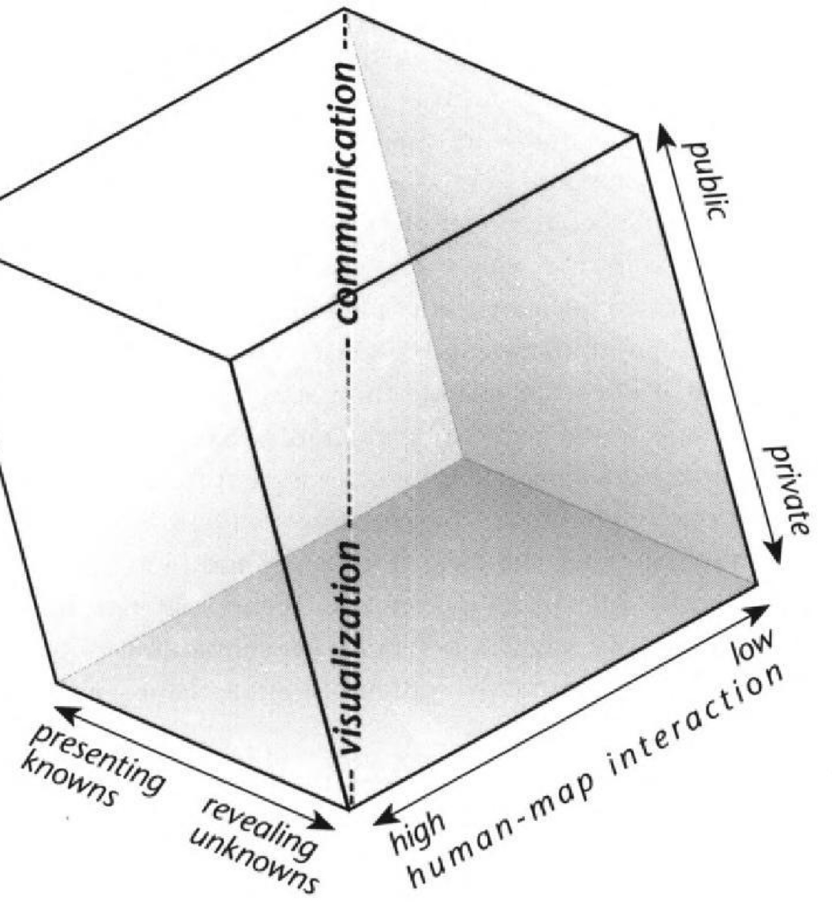

FIG. 1.3. (Cartography)^3 — a representation of the "space" of map use and the relative emphasis on visualization and communication at various locations within this space. This representation deals, not with kinds of maps, but with kinds of map use. Thus a particular category of map (e.g. a topographic map) might occupy any position within the space, depending upon what a user does with the map for what purpose.

(via maps). DiBiase's view places communication within the realm of visualization (as one of four components of visualization tool use). Similarly, Taylor's perspective presents visualization as the integration of three cartographic research streams. Both perspectives, in essence, imply that "visualization" equals "cartography" (with communication a subcomponent of the whole), a view leading to the conclusion that visualization offers nothing new. This conclusion, in turn, creates the potential for the *visualization revolution* in science to pass us by, while we sit on the sidelines thinking that cartography has done it all before.

The approach presented here *defines visualization in terms of map use* (rather than in terms of map-making or research approaches to cartography). The fundamental idea is that map use can be conceptualized as a three-dimensional space. This space is defined by three continua: (1) from map use that is private (where an individual generates a map for his or her own needs) to public (where previously prepared maps are made available to a wide audience); (2) map use that is directed toward revealing unknowns (where the user may begin with only the general goal of looking for something "interesting") versus presenting knowns (where the user is attempting to access particular spatial information); and (3) map use that has high human–map interaction (where the user can manipulate the map(s) in substantive ways — such as effecting a change in a particular map being viewed, quickly switching among many available maps, superimposing maps, merging maps) versus low interaction (where the user has limited ability to change the presentation) (Fig. 1.4).

There are no clear boundaries in this use space. There are, however, identifiable extremes. The space has the private, revealing unknowns, and high interaction ends of the continua meeting in one corner and the public, representing knowns, and low interaction ends meeting at the other corner. GVIS (as defined here) is exemplified by map use in the former corner and cartographic communication is exemplified by the latter. In my opinion, it is not interaction, private map use, or a search for unknowns that (individually) distinguish visualization from other areas of cartography, it is their combination.

I want to be clear here on what I am not saying. I do *not* suggest that research on cartographic communication is irrelevant – many maps are designed to communicate particular messages. Similarly, I do *not* suggest that the dividing line between visualization and communication is sharp (in fact, I think it is becoming fuzzier all the time). Communication is a component of all map use, even when visualization is the main object. Correspondingly, even the most mundane communication-oriented map can serve as a prompt to mental visualization. I view my definitions, then, as a convenience that allows us to emphasize the difference

	high interaction		low interaction	
	revealing unknowns	presenting knowns	revealing unknowns	presenting knowns
private	use of Ferreia and Wiggin's (1990) 'density dial' to manipulate class break points on a choropleth map in an effort to identify and enhance the spatial patterns.	use of a hypermedia interface to access a map collection – see Andrews and Tilton (1993) for discussion of a system designed to access the American Geographical Society Collection.	use of a 'closed' graphic narrative generated in response to a 'user profile' to take a 'guided tour' through a set of data (see Monmonier chapter).	use of a plat map to retrieve information concerning size of lot, rights-of-way, etc. for a piece of property
public	use of SimCity to allow students to assess the implications of public policies -or- use of MOSAIC via the Internet to give groups of scientists shared access to interactive simluations	use, by a TV meteorologist, of sketched annotations to a weather map (e.g., flow lines, position and direction of the jet stream, etc.) while explaining a storm situation.	use of Pike and Thelin's (1991) digital terrain map of the U.S. to explore geomorphic features and anomalies at varied scale.	use of you-are-here maps by the general public to figure out where they are in a shopping mall and how to get to particular stores.

FIG. 1.4. Exemplars of the eight extremes of map use space defined by the cube of Fig. 1.3. Each exemplar corresponds to a corner of the cube.

in goals (and design principles) for maps whose *primary* function is to facilitate transfer of knowledge from a few people to many people, versus maps whose *primary* use is to help individuals (or small groups of individuals) to think spatially. With respect to human–map interaction, no map use can take place without some level of interaction (although at times this interaction might be confined to visually scanning the map). In addition, higher levels of interaction do not require computers (e.g. you can draw lines of maximum gradient on a topographic map as an aid to mentally visualizing the runoff pattern of a drainage basin). "Interactive" computer tools, however, expand the possibilities for "interaction" with maps and thus the possibilities to facilitate visual thinking, perhaps in qualitative as well as quantitative ways.

Whether the terms visualization and communication (and the continua used to define them) are ultimately adopted by the discipline as I present them here is not important.[4] What counts is that cartographers become aware of the profound differences in goals (with the corresponding differences in approach to map design and evaluation of designs) that the distinction implies.

I share DiBiase's view that a key part of a visualization perspective on cartography is an increased attention to the role of maps in private data exploration – thus to the role of maps in research. Krygier (1994) contends that this maps-in-research emphasis is creating a fertile environment for a renewal of a "geographic" cartography in which cartographers are as concerned with the multiple roles of maps in geographic research as they are with how well people understand individual maps or map symbols. This shift in emphasis should draw cartographers closer to their geographic colleagues, after several decades of drifting apart. Krygier's view is echoed by Taylor (1993).

I have gradually come to the conclusion that visualization has implications for cartography that go beyond renewed attention to visual thinking and collaboration with our geographic colleagues for whom visualization tools can be developed. These developments in themselves are significant, and I do not want to diminish their importance. Beyond these, however, I think that GVIS can be to cartography what GIS has been to geography – a reinvigoration of an old, often taken for granted discipline whose relevance is increasingly recognized outside the discipline because it can help tackle important interdisciplinary issues.

Structure of the Book

Depending on your perspective, visualization is either a subset of communication, the opposite pole of a continuum (the other end of which is communication), or a superset that (if the qualifier "cartographic" is added) just becomes a more cumbersome equivalent to "cartography". As indicated in the above, I support the middle position. My emphasis is on visualization as a kind of map use. This is, however, only one of several contextual issues that should be considered as we explore the topic of visualization in modern cartography.

To give a more complete picture of the implications of visualization for modern cartography, my introductory comments are followed by a section (*The Context for GVIS Development*) that relates GVIS to our cartographic roots and to developments in the broader arena of spatial knowledge representation. Wood puts visualization in an historical cartographic context by presenting an argument that "visualization", if defined as the interactive use of maps to facilitate visual thinking, has gone on for as long as we have made maps. In this essay, he introduces the notion that an understanding of cognition (particularly of imagery) is essential as a basis for exploring questions of visualization in cartography. Peterson follows with specific cognitive issues relevant to visualization. He considers development of the cognitive perspective within psychology and application of that perspective by cartography. From this base he explores the links between "mental visualization" and dynamic visualization tools designed to facilitate visual thinking. Artimo concludes the section by placing visualization development in a technological context that includes GIS and what she defines as cartographic information systems (CIS).

If we are to use and design map-based visualization systems, there are a variety of factors that we must consider from perspectives not previously required by a more static cartography. The next section of the book: *Issues for Tool Design: Technology, Symbolization, and Human–Tool Interaction*, emphasizes three such factors. For each, two chapters address complementary topics.

Cartwright provides an overview of multimedia hardware and software as they relate to dynamic interaction with geographical information. He gives particular attention to the role of multimedia tools in the creation of spatial decision-support systems. Slocum and coworkers follow with an assessment of eight software environments that can be used to develop exploratory scientific visualization applications. Their chapter combines insight on the capabilities of several visualization development tools with an approach to selecting or designing visualization software (suited to geographic/cartographic applications) that is general enough to outlast the "half-life" of the specific software considered.

In relation to symbolization, two key issues were identified for consideration: color and sound. Computer-based GVIS environments today all use color. If analysts (or students) are to generate maps on the fly in response to database queries, there will be no time (even if the user had the expertise) to carefully consider the design of each map displayed. Interactive visualization requires much more precise specification of cartographic rules than has been required by traditional designers. Brewer provides a careful analysis of the issues involved when linking color schemes to data categories and proposes a set of guidelines that can allow visualization system designers (as well as designers of individual communication-oriented maps) to put the principles developed into practice. A second symbolization issue that few cartographers have considered is the sonic representation of data. Paper maps do not come with sound effects, but the hardware and software of visualization and multimedia environments makes sound a display tool that cannot be ignored. Krygier provides a brief review of the relevant "sonification" literature, describes a set of sonic variables analogous to Bertin's graphic variables, then offers several examples of how they might be used on maps.

The section concludes with a pair of chapters devoted to issues of user interaction with visualization environments. Lindholm and Sarjakoski provide an approach to the design of user interfaces that borrows from the computer science literature, but adapts principles to the unique demands imposed by geographically referenced information. McGuinness provides an introduction to expert–novice issues that cartographers must begin to face as we design visualization tools for narrowly targeted user groups. She also offers a synopsis of an experimental study that demonstrates some of the likely expert–novice differences in information access demands, and how to empirically assess them.

After setting the context and presenting some critical issues to consider in all visualization system design, we move on, in Section 3 (*Linking the Tool to the Use: Prototypes and Applications*), to emphasize specific GVIS tools and their applications. Prototype systems are described and guidance is provided on designing visualization tools targeted to applications in environmental assessment, education, and planning.

The section begins with Monmonier's discussion of graphic narratives as a base from which to build visualization tools that facilitate environmental risk assessment. Asche and Herrmann follow with an account of issues in developing prototype GVIS applications on a Macintosh platform using commercial multimedia authoring tools. They discuss applications in both planning and education. In contrast with Asche and Herrmann's use of commercial authoring tools, Koussoulakou describes a prototype system developed using lower level programming/graphics languages. The system is designed to facilitate transportation planning associated with air pollution amelioration in Athens, Greece. Where Koussoulakou emphasizes two-dimensional display and animation, Kraak's chapter focuses on three-dimensional depictions and direct interaction, again with an environmental application emphasis. The final two chapters of Section 3 share an emphasis on symbolization issues. In both, the focus is the development of symbolization to meet particular visualization application needs. DiBiase and his colleagues provide an overview of literature from several disciplines dealing with the problem of multivariate data representation. They go on to describe a prototype visualization system that allows analysts to look for relationships among climate variables (both actual and model derived). Van der Wel *et al.* then provide a review of recent efforts to visualize data quality and present some solutions to data quality visualization in the context of a transportation development plan.

Finally, my collaborator on this project, Fraser Taylor, offers some perspectives on the future of visualization in modern cartography. These perspectives include attention to the place of visualization in cartographic theory and practice.

My characterization of cartographic visualization as a kind of map use that emphasizes the private, high interaction, exploratory corner of map use space influenced the choice of chapters outlined above. Each chapter, however, stands on its own merits (and some actively counter my definition of visualization). However visualization is ultimately defined within cartography, the contributions included here chart a new territory that cartographers should find exciting to explore.

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Endnotes

[1] The terms "cartographic" visualization and "geographic" visualization are both used to refer to spatial visualization in which maps are a primary tool. Although my initial publication on visualization as it relates to cartography (MacEachren and Ganter 1990) used the term "cartographic" visualization, I now favor the use of GVIS. The latter term implies a broader range of possible activities than the former. Cartographic visualization seems to exclude visualization in which remotely sensed images, photographs, diagrams, graphs, etc. are used together with maps to illuminate geographic questions. Visualization in modern cartography implies an integration of spatial display tools that the term GVIS seems to encompass.

[2] In a recent statement on visualization, Taylor (1993) has moved beyond the characterization of visualization as a field of computer graphics. In this paper, he emphasizes a revitalized approach to the cognitive level of spatial thinking that is fostered by attention to visualization. In particular, he stresses the potential for visualization to draw cartography and geography back together.

[3] The graphic model presented was formulated during the 16th ICA Meeting in Cologne, May 1993. It was influenced by participants in the initial meeting of the visualization working group (at which panelists Janos Szegö, Menno-Jan Kraak, Mike Wood, Mike Peterson, and Daniel Dorling discussed various aspects of visualization and its role in cartography). The seeds of the idea were sown in my initial collaboration with John Ganter and our discussions

with David DiBiase (in 1989–90). The idea began to germinate at a Workshop on Visualization in GIS organized by David Unwin and Hilary Hearnshaw at Loughborough University in July 1992. At that workshop, Ian Bishop, Anthony Gatrell, Jason Dykes, Mitchell Langford, Daniel Dorling, and I sketched out a draft section on "Advances in visualizing spatial data" for a book titled *Visualization in GIS* (Hearnshaw and Unwin 1994). Components of the scheme presented here can also be found in the chapter on visualization that I produced (with the collaboration of Barbara Buttenfield, James Campbell, David DiBiase, and Mark Monmonier) for Abler, Marcus, and Olson (eds.) *Geography's Inner Worlds* and the introductory essay (written with Mark Monmonier) for the special geographic visualization issue of *Cartography and Geographic Information Systems*. The insights offered by all of these colleagues had a substantial impact on my approach to visualization – but, of course, only I can be held accountable for the arguments offered here.

[3] Among the responses to my (cartography)^3 ideas were several critiques of various aspects of the model. Terry Slocum, for example, pointed out that the three-dimensional depiction of the model implies that there are only three axes to map use space (but that there are probably more) and that the cube also implies orthogonality among the continua (when this may not be the case). Mike Wood and Mike Peterson both objected to excluding the communication corner of the model from the purview of visualization; Wood because such a restriction does not match common usage in computer science (where all computer-generated displays have come to be called "visualizations") and Peterson because he contends that all maps can prompt mental visualization (which I agree with) and that all acquisition of knowledge from a map is fundamentally an act of communication (which I do not agree with). Beyond the critiques from other authors, six students in my graduate seminar on GVIS also provided a range of constructive criticism. In particular, they helped clarify the distinction between interaction with maps and the interactivity of computer software, and prompted development of the matrix of map use examplars presented in Fig. 1.4. Together, the various critiques tempted me to back off from my contentions and adopt the terms "visual thinking" and "presentation" as the labels for ends of the key diagonal. On reflection, however, I decided to retain my original terms, comment on the objections, and await responses. There were, of course, positive reactions to the (cartography)^3 idea, or I would have discarded it. Among them, Cindy Brewer provided a useful sketch of the three-dimensional map use space that helped to refine my own rather crude preliminary drawings. She also offered suggestions on the kinds of map use that occupy the corners of the model. Menno-Jan Kraak went so far as to suggest that I locate each chapter as a dot in its appropriate three-dimensional model position. I seriously considered this, but decided that I would never achieve consensus on the relative position of various chapters – I leave it to the reader to determine which chapter is the prototypic example of geographic visualization.