MacEachren, A., Bishop, U., Dykes, J., Dorling D. and Gatrell, A. (1994) Introduction to advances in visualizing spatial data, in D. Unwin and H. Hearnshaw (eds), Visualization and GIS, London: Belhaven Press, 51-59.

# 7 Introduction to advances in visualizing spatial data

A. MacEachren, I. Bishop, J. Dykes, D. Dorling & A. Gatrell

## ... Visualization techniques for spatial data

There are many approaches to visualizing spatial data. There is variety in the intended purpose, proposed audience, level of interactivity and degree of intimacy with the data themselves. The chapters in this section illustrate this variety together with some of the ways modern visualization ideas are helping to solve some very old cartographic problems. Clearly the work represented here is not the sum total of advances in visualization of spatial data, nor is it intended to be, but we hope that it will give readers a reasonable overview as well as pointers to some of the work that has not been included.

In order to understand how the chapters fit within the broad framework of visualization approaches it is appropriate to set the context and provide some definitions. Our basic organisational tool in this introduction is a simple typology of visualization techniques for spatial data based on distinctions drawn according to four dimensions of variability. The first distinction to be made is in *purpose*. DiBiase (1990) proposed the model of how visualization tools are used by science shown in Figure 7.1. This was derived from Tukey's sequence of exploratory, confirmatory and presentational statistics, and suggests that visualization tools are used by science for a range from data exploration and confirmation (prompts for visual thinking) to the synthesis and presentation of ideas (vehicles for communication). We will refer to the ends of this continuum as communication and ideation and these form end-points on the first dimension of our typology.

Scientific visualization has been developed primarily to help scientists extract ideas from masses of multidimensional data. As the chapters in Section A have argued, the emphasis on ideation is at the exploratory end of this purpose continuum. Such visual data exploration techniques have not yet been heavily used in GIS but are being applied elsewhere in, for example, seismology, climatology and meteorology (see DiBiase, 1990, for an overview). In contrast to the general emphasis in scientific visualization on exploratory analysis and ideation, much of the work linking visualization to GIS done by the landscape architects is directed towards communication in which designers use visualiza-

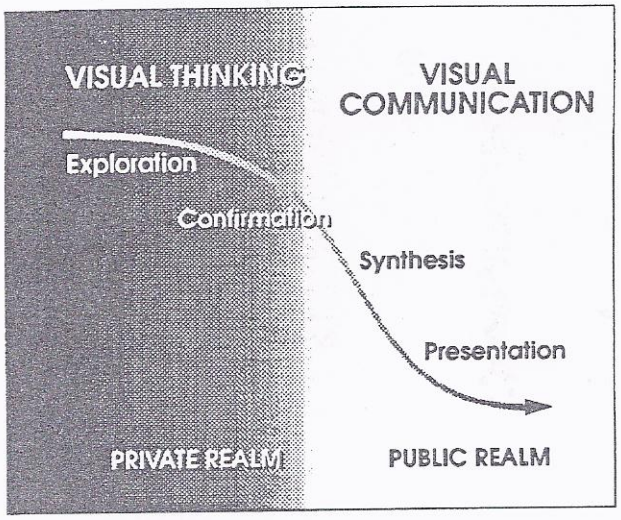


**Figure 7.1** DiBiase's model of the range of uses to which maps can be put in geographical inquiry

tion tools to present plans to clients or decision-makers. Running approximately parallel to this distinction in purpose is one in audience. As suggested above, the principal consumer of visualization tools supporting ideation is the scientist/data analyst. The audience for communicative visualization is the non-expert public. In the latter case the audience may be large numbers whereas in the former it is frequently a single individual.

A second dimension in our multidimensional visualization application space is the *degree of interactivity available* to the audience shown in Figure 7.2. While an archive of static images or movie clips can be appropriate for communication to the public, the scientist interested in posing 'what if?' scenarios will generally demand an interactive capability to get the most insight from the data. As technology allows, interactive GIS based visualization will be taken increasingly into the public arena in order to permit, for example, a public meeting to debate the

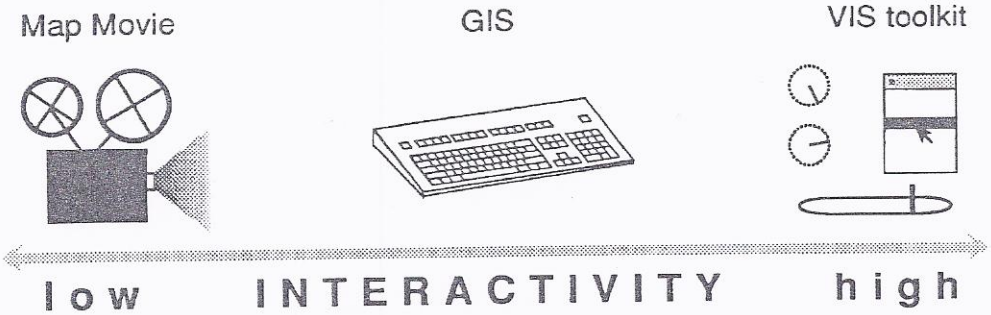


**Figure 7.2** The range of interactivity available with various visualization tools

consequences of alternative resource management strategies. The need for interaction in presentational visualization tools will, therefore, increase.

A third axis in this non-orthogonal set of dimensions is the *degree of abstraction* in the visualization. As Figure 7.3 shows, this can range from the highly symbolic to the highly detailed and realistic. Abstract representations may be largely unfamiliar to someone not trained in visualization tools use, while less abstract representations can provide a view that is both familiar and accessible

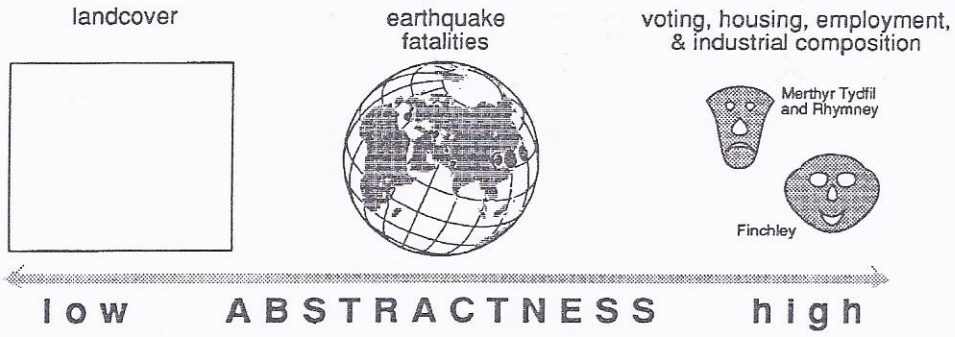


**Figure 7.3** The abstractness range of visualization tools

to workers in other disciplines or to the general public. This continuum, therefore, to some degree parallels the audience axis. Depictions at the realistic end of the continuum facilitate representations of the physical world (whether landscape or human anatomy) and identification by the viewer of what occurs at particular locations. Depictions at the other, abstract, end facilitate the contemplation of abstract concepts and may even use space to depict things other than space such as a multidimensional scaling solution showing the position of GIS in geography's disciplinary 'space'.

Finally, spatial visualization is distinguishable according to the *aspect of the phenomenon to information process* about which is it concerned. One end of this range involves concern about how well the data representation available in a GIS matches the phenomenon for which it provides a model and/or how to restructure and combine information available in a GIS to produce an appropriate model of the spatial information to be visualized. The chapters in this section by Gatrell, Bracken and Dorling emphasise these issues. Included at this level are considerations of data about data (metadata) dealing with accuracy, classification and so on. Complementary to this focus on how data represent phenomena is a concern about how displays represent data. Issues of symbolisation choice and generation are relevant here. In this section Bishop explores the use of techniques for the photo-realistic presentation of spatial data, Dorling discusses the use of Chernoff faces as multidimensional symbols on a schematic cartogram base, and MacEachren and Openshaw, Waugh and Cross focus on the graphic building blocks or variables that become available when we move from a static to a dynamic visualization environment.

## ...WHERE ADVANCES ARE BEING MADE

Figure 7.4 attempts to show where the work described in this section falls in relation to three of the dimensions identified above. With suitable visualization tools we could map each contribution into the complete multidimensional space but as yet this would be hard to convey to the reader on the printed page. Instead each axis is shown independently, with the span of each author's activity shown by an arrow whose head indicates the direction in which they anticipate their work will move as technology allows. Four trends emerge from these figures which are worthy of discussion.

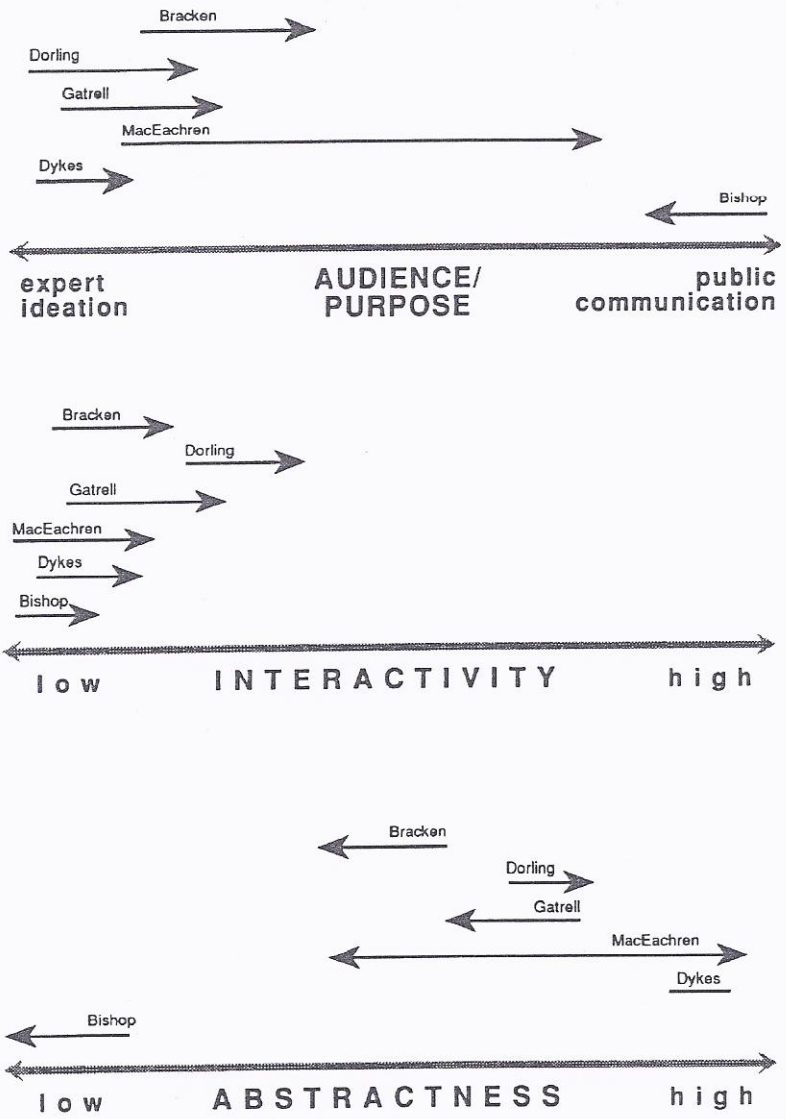


**Figure 7.4** Emphasis of chapters in Section B in terms of purpose/audience, interactivity and abstractness of display

### *Audience*

Most of the applications described match the overall trend in scientific visualization to emphasise tools for use by experts in scientific exploration. With his emphasis on presentational tools accessible to non-experts in a public policy context, Bishop is the main exception. There is general agreement that, for visualization to benefit non-scientific applications of GIS, it will be necessary to direct more attention to visualization materials suited to a wider audience. In this regard, we are seeking to improve our understanding of rendering such that it becomes familiar and accessible to the public. This may also involve some degree of public education to introduce the new symbolism of abstract visualization. The typical GIS emphasis on applied over basic research and public presentation over individual scientists manipulating a dataset offers our greatest challenge in adapting principles of scientific visualization for use with GIS.

Although not apparent from these contributions, the midpoint of the continuum between private exploratory analysis and public presentation has not been ignored by those interested in geographic visualization tools. One of the most significant contributions is Monmonier's (1992) Atlas Touring project. In this, Monmonier has developed a hypermedia environment that guides users through a network of information using a combination of maps, graphics and text. The system is based on his concept of graphic scripts as structured 'narratives' for presenting spatial information. One of Monmonier's goals, with implications across the whole exploratory to presentational continuum, is to automate the production of graphic phrases (subsections of overall graphic scripts) that act to focus a user's attention on 'interesting' views selected by the system.

### *Abstraction*

Most of the contributions to this section emphasise highly abstract representations of spatial phenomena. Several contributors, however, are seeking to reduce the abstract nature of the rendered product as a step toward widening audiences. At the same time, others point out that the advantages of abstracting reality, as demonstrated by centuries of cartographic success, will remain important in the context of expert analysis as a means of coping with increasingly complex and voluminous datasets. At a level of abstraction beyond that emphasised by the contributors to this section, significant advances have been made by Cleveland and his colleagues (Cleveland and McGill, 1988) in Exploratory Data Analysis (EDA). EDA researchers have made innovative use of tools developed by others for realistic rendering, such as stereo views, shading and other depth cues, as a means for depicting complex data relationships in abstract data spaces. In the context of land cover analysis from remotely sensed images, Hodgson and Plews (1989) adapted these techniques to design of an n-dimensional extension of the commonly used co-spectral plot. Cleveland and others have also given considerable attention to design of sophisticated interactive data manipulation tools. Monmonier (1989) has adapted one of their techniques ('scatterplot' brushing) for application in a spatial data analysis ('geographic' brushing) and DiBiase et al. (1992) have extended the method to

a temporal context. In addition to Bishop's contribution, there is also a variety of other efforts underway to take advantage of realistic rendering tools in GIS visualizations. Among the most notable is Moellering's (1989) use of stereo display technology that allows an image on a single monitor to appear three-dimensional, and the application of three-dimensional rendering and image filtering techniques to visualization of plant growth and pest models by Orland et al. (1992).

### *Interactivity*

All contributors to this section see a need for increasing the interactivity of visualization tools linked to GIS. Achieving this depends, however, on hardware and software developments in the GIS environment particularly the derivation of appropriate data models and displays for dynamic analysis. Although all the developments presented here have implications for real-time interaction with spatial data embedded in a GIS, only limited forms of interaction have yet been explored. The interactive exploration of GIS datasets will be as critical to visualization in GIS as it has been for ViSC in general. If appropriate data models and display forms are not developed, however, this interaction is as likely to mislead as to provide insight.

Although in this section we chose to emphasise the phenomenon-to-data model and data model-to-display stages of visualization environments, there have been several researchers who have addressed the issue of interactivity in spatial data analysis. Monmonier's (1989) geographic brushing mentioned above was among the first examples but perhaps the most explicitly GIS oriented application of interactive visualization tools is MacDougall's (1992) *Polygon Explorer*. This prototype software is specifically directed at statistical visualization of polygon data, which MacDougall argues is the most common data structure used in GIS. *Polygon Explorer* links statistical graphics of a variety of types to a polygon database and allows the analyst interactively to probe and query in both spatial and aspatial ways by pointing to locations on maps or graphs. Tools for identification of outliers and for regional grouping by cluster analysis are also included.

Interactive visualization of spatial data, if it is to go beyond the experimental stage of the *Polygon Explorer*, will require highly efficient data storage and extraction. This graphic and attribute data management function is best performed by GIS. Most of the applications described in this section have involved the use of GIS somewhere in preparation of their visual displays but in no case has this been a seamless operation. Each researcher has had to write transfer programs and tie their operations to the GIS with 'boot laces and sticky-tape'. Functional interactivity will require something better than this. Not only will GIS vendors have to incorporate additional visualization options in their tool kit, they will also need to speed up data extraction, processing and screen-draw operations, taking advantage of such developments as object oriented data management and the specialised graphics processors offered by visualization oriented workstations. It is unlikely that we will see sophisticated visualization tools incorporated directly in GIS software in the near future. What we must work towards is smoother links between GIS and visualization systems, some-

thing that will require vendors to become more sensitive to the role of visual display as more than a final output and that will require visualization system vendors to develop ways in which their tools can be linked directly to the complex space–time data structures required in GIS.

### *The promise of developing technology*

A variety of emerging computer technologies have the potential to contribute to the visualization of spatial data. Interactive stereographic displays are now available and should prove valuable to the individual scientist seeking insight into three-dimensional data. Movies for communication can also be projected in stereo for wider audiences. In both movies and at workstations, sound will become more than the overlay of narration to accompany visualization events. As an information presentation variable, sound is being actively pursued by a number of researchers. In addition, multimedia tools increase the possibility to link visual displays, sonic feedback, graphics and text in ways that give users of GIS-visualization environments multiple perspectives on problems. Beyond multimedia, virtual reality systems may offer additional possibilities for extending visualization toward realism. Currently, virtual reality developments involving head mounted displays and body gloves are cumbersome, of low graphic quality and expensive. While the idea of walking/driving/skiing through a simulated landscape is clearly attractive, it is less clear whether or not the ability to take a virtual stroll through an abstract 3D graphic such as Dorling's (1992) three-dimensional space–time cartograms is of any real advantage.

## ... Introduction to order of papers

Having provided our typology of techniques, and stipulated that the axes on which we locate our work are neither mutually independent nor ranked in terms of significance, it is evident that defining a vector through four dimensional, non-orthogonal, research space by which the following chapters might have been ordered was a complex task. Several groupings occur within the section, and it is stressed that for maximum gain the section should be read as a whole. According to their interests and perspectives, individual readers may find the continua illustrated in Figure 7.4 of use in ordering their reading of the section. Although several orders seemed suitable, the section has been ordered roughly by the degree of correspondence between the visual product discussed in each chapter and reality.

At the realistic end of this continuum, Ian Bishop advocates the use of visual familiarity as a tool for effectively communicating spatial process. He argues that realistic scenes can be used at either end of the audience continuum to convey multiple scenarios to a non-expert audience, or to facilitate the analysis of model success to the scientist. There follow two papers dealing with the zone-based enumeration data common in much geographic work. These provide examples of ways in which the traditional choropleth map may be superseded if additional locational data are integrated with the area-valued data. Tony Gatrell outlines the restrictions of this data type and shows how zone

centroids can be used to estimate a spatially continuous density surface. Through this transformation the visual product bears a closer resemblance to the surface from which the data are collected than does the traditional choropleth map. A similar transformation is illustrated by Ian Bracken who focuses on using zone-based data to create a raster model using a weighted decay function as an approximation to a spatially continuous surface of population density. The results are visually appealing, but, just as important, the data structure produced is compatible with the majority of GIS.

Less familiar, more abstract representations are discussed in the next two chapters. These also deal with zone-based enumerated data, but focus on the visualization of topological, rather than metric, relationships. A set of transformations are discussed by Dan Dorling, who puts the case for using cartometric space as a necessary part of analysing the spatial nature of social structure. He proposes severing the strong traditional link between land area and mapped area in favour of a particular (non-spatial) social variable as the spatial metric. A variety of techniques can be applied to the resulting spatial arrangement, including the surface generators described above. Jason Dykes continues the theme of analysing relationships in non-geometric space showing how he uses visual representations of these relationships to improve more traditional displays.

Whereas Chapters 8 to 12 focus on ways of improving traditional representations, those by Alan MacEachren and by Stan Openshaw, David Waugh and Anna Cross outline the variables available to the visualizer when maps are animated. Whether viewed as a movie or by interactive browsing, the ability to order in sequence and step through a set of scenes adds to the communicative or investigative cartographic bandwidth. The methods described can be applied to any of the preceding techniques, for example a time series of socioeconomic rasters or bulging population surfaces illustrating social change, Dorling's swinging vote cartograms and Dykes' co-occurrence volumes with fly-by and dynamic iso-surface variation, or real time update from base-map modification (re-expression). It seems appropriate to conclude this introduction by this indication of the wide variety of combinations of spatial and temporal cartographic variables that are becoming available to visualizers as technology improves.

## ... References

Cleveland W S, McGill M E (1988) *Dynamic Graphics for Statistics*, Wadsworth & Brooks/Cole Advanced Books & Software, Belmont, Calif.

DiBiase D (1990) Visualization in the earth sciences. *Earth and Mineral Sciences* Bulletin of the College of Earth and Mineral Sciences, The Pennsylvania State University 59(2): 13–18. Requests for a copy of this paper should be sent via e-mail to: dibiase@essc.psu.edu

DiBiase D, MacEachren A, Krygier J, Reeves C (1992) Animation and the role of Map design in Scientific visualization. *Cartography and GIS* 19(4): 201–214

Dorling D (1992) Stretching space and splicing time: from cartographic animation to interactive visualization. *Cartography and GIS* 19(4): 215–227

Hodgson M E, Plews R W (1989) N-dimensional display of cluster means in

feature space. *Photogrammetric Engineering and Remote Sensing* 55(5): 613–619

MacDougall E B (1992) Exploratory analysis, dynamic statistical visualization, and geographic information systems. *Cartography and GIS* 19(4): 237–246

MacEachren A M, Buttenfield B, Campbell J, DiBiase D, Monmonier M (1992) Visualization. In: Abler R, Marcus M, Olson J (eds) *Geography's Inner Worlds*, Rutgers University Press, New Brunswick, NJ pp. 99–137

Moellering H (1989) A practical and efficient approach to the stereoscopic display and manipulation of cartographic objects. *Auto-Carto 9, Proceedings, Ninth International Symposium on Computer-Assisted Cartography*, Baltimore, Maryland, pp. 1–4

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

Monmonier M (1992) Authoring graphic scripts: experiences and principles *Cartography and GIS* 19(4): 247–260

Orland B, Onstad D, Obermark J, LaFontaine J (1992) Visualization of plant growth and pest models. *Technical Papers*, ASPRS/ACSM/RT 92, 5, Resource Technology, 246–253