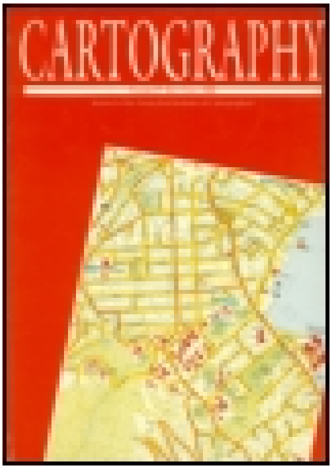

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Cartographic Visualization: Analytical and Communication Tools

Bin Jiang [a]
[a] Institute of Geographic Sciences Free University of Berlin , Arno-Holz-Str. 12, D-12165, Berlin, Germany Phone: +49 30 838 3892 Fax: +49 30 838 3892 E-mail:
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Cartographic Visualization: Analytical and Communication Tools

Bin Jiang

Visualization is attracting more and more attention in a variety of disciplines including the domains of geographic informtion systems and cartography, since the US National Science Foundation workshop held on the Visualization in Scientific Computing initiative. The focus of this paper is on cartographic visualization as analytical and communication tools. To achieve this aim, the paper begins with an introduction concerning visualization research pursuits. This is followed by the definition and scope of cartographic visualization, then the features of cartographic visualization involving animation, interactive exploration and hypermedia are elaborated. Three technical levels of visualization i.e. hardware/software, visualization tools and applications, are also presented.

Bin Jiang
Institute of Geographic Sciences
Free University of Berlin
Arno-Holz-Str. 12, D-12165 Berlin, Germany
Tel: +49 30 838 3892, Fax: +49 30 838 6739
Email: bjiang@geog.fu-berlin.de

INTRODUCTION

Visualization has been attracting more and more attention in a variety of disciplines including geographic information systems (GIS) and cartography. In October 1986, the US National Science Foundation (NSF) sponsored a panel meeting summoning a group of well-known scientists, software engineers, artists, and hardware and software vendors, to discuss the technical development and research strategy of Visualization in Scientific Computing (ViSC). The panel consensus was that top priority should be placed on the development of visual computing tools and visual interface tools. In the subsequent report, visualization was defined as (McCormick *et al.*, 1987):

> *. . . a method of computing. It transforms the symbolic into the geometric, enabling researchers to observe their simulations and computations. Visualization offers a method for seeing the unseen . . . Visualization embraces both image understanding and image synthesis. That is, visualization is a tool both for interpreting image data fed into a computer, and for generating images from complex multidimensional data sets. It studies those mechanisms in humans and computers which allow them in concert to perceive, use and communicate visual information.*

Since then, scientific visualization as a new discipline has received attention in a variety of academic journals and proceedings. Visualization is used in a series of traditional and emerging disciplines including chemistry, medicine, informatics and virtual reality.

Visualization is not a new concept to cartographers, since a map is a visualized product, i.e. a graphic representation of abstracted reality. Firstly, mapping can be seen as using visual variables to abstract, generalize and represent reality. And secondly, map users perceive maps through visual thinking. Earlier definitions can be found in cartographic literature, e.g. *a peculiar geographic skill demanding a synoptic view of the distribution(s) portrayed on the map(s)* (Board, 1978).

Visualization has a new aspect since its emergence has been accompanied by the rapid development of modern computer technology, particularly that of computer graphics and image processing technology. Maps are no longer only paper maps; nowadays they are often found in a digital mapping environment. This has had a great impact on cartography. Cartographers no longer adhere to the traditional idea that cartography is concerned only with maps, and that data representation can only be done by way of a map. Instead, cartographic visualization tools include such features as animation, interactive exploration and hypermedia structure, so that in addition to representation they are also concerned with analysis.

It is estimated that over half of the brain's neurons are associated with vision. Studies of the industrial revolution by a historian of science at New York University (White, 1989), emphasize the significance of image manipulation. White notes that almost all the great industrial inventors thought in images, and he emphasizes the importance of exploded drawings for technical innovation. A notable early visualizer in science was James Clark Maxwell, one of the founders of thermodynamics. Maxwell built 3D clay models to help understand the behaviour of the function of two variables, in the same manner that visualization systems are used today (Wood and Brodlie, 1994).

Visualization has received wide attention in studies of GIS and modern cartography. In 1992, the US journal *Cartography* and *GIS* published a special issue on the subject. In the same year, the Canadian journal *Cartographica* produced a special issue on the visualization of data quality. Recently, books entitled *Visualization in Geographic Information Systems* (Hearnshaw and Unwin, 1994) and *Visualization in Modern Cartography* (MacEachren and Taylor, 1994) have demonstrated the latest research results.

This paper is intended to consider cartographic visualization as analytical and communication tools. The scope of cartographic visualization is described focusing on analysis and communication, together with visual variables and exploratory acts. It is followed by the distinction between cartographic representation and visualization. The paper argues that not only cartographic representation, but upgraded visualization tools, are urgently required in current GIS systems. Finally, the paper concludes with a few remarks.

CARTOGRAPHIC VISUALIZATION

Cartographic visualization, or geographic visualization, is mainly concerned with the visual representation of spatial or geographic data. Cartographers make much of the importance of psychological aspects of cartographic visualization, defining the subject as . . . *first and foremost, an act of cognition. It is a human ability to develop mental representations that allow us to identify patterns and create to impose order* (MacEachren et al., 1992). In the same paper, geographic visualization was defined as . . . *the use of concrete visual representations - whether on paper or through computer displays or other media— to make spatial contexts and problems visible, so as to engage the most powerful human information-processing abilities, those associated with vision.*

Cartographic visualization has roots in traditional cartography and was stimulated by the advent of new technology. Maps, remotely sensed images, and multimedia representations are cartographic visualization tools. Maps were important visualization tools well before the advent of spatial statistics or computer graphics, even before geography was a recognized academic discipline. For instance, cartographic portrayal of cholera data allowed identification of a link between cholera incidence and a specific water pump (MacEachren, 1992). Remotely sensed images can also be viewed as a visualization tool, able to provide synoptic views of the earth. A remotely sensed image is for the geoscientist what the telescope is for the astronomer.

Recently emerging multimedia representations provide good possibilities for the visualization of geographic information from multiple perspectives including sound, video, images, and animation. The important thing is that it provides a mechanism for cross-referencing, hyperstructure, and for integrating a variety of media together to form a scientific hypothesis.

In addition to data representation, cartographic visualization also serves analytical functions. In the pre-computer era manual systems were used in data exploration by means of such facilities as transparent plastic map sheets, light tables and pencils. This kind of spatial analysis is time-consuming. Advanced digital technology, however, offers sophisticated exploratory facilities such as CRT monitors, keyboards and mice. Furthermore, graphic user interfaces provide sophisticated and convenient tools for data exploration.

Visualization is regarded as an extension of spatial analysis, particularly when a GIS is configurated as a spatial decision support system. There is a trend to combine visualization and spatial analysis thereby allowing them to benefit each other. Spatial analysis, on the one hand, is directed at exploratory spatial analysis which needs support from visualization. On the other hand, visualization provides powerful tools to set up and present analysis procedures and to present the information itself.

Increasing numbers of new terms are emerging to define the intersection between spatial analysis and visualization. Following Tukey's exploratory data analysis (EDA) (Tukey, 1977), many similar terms such as exploratory geographical analysis (EGA) (Openshaw, 1990) and visual data analysis (VDA) (Tang, 1992) are being used in this field. These terms explicitly link visualization and spatial analysis. It is emphasized that visualization is part of the analysis, rather than a post-analysis activity (Warner, 1990). The same view is held by physicists such as Wolff (1988) who claimed that . . . *visualization should not be viewed as the end result of a process of scientific analysis, but rather as the process itself.*

THE SCOPE OF CARTOGRAPHIC VISUALIZATION

Cartographic visualization means slightly different things to different researchers. In this section, two components of cartographic visualization are emphasized, *presentation* and *exploration.* In principle, presentation is mainly concerned with known information, while exploration is related to the discovery of unknown information. The former has been widely recognized as the basic task of traditional cartography, in which Bertin's visual variables have been recognized as the theoretical framework (Bertin, 1983).

From the analytical viewpoint, visualization can be regarded as an analytical tool. Recent research in GIS (e.g., Batty and Xie, 1994; Xia and Fotheringham, 1993) has demonstrated that visualization can play an important role in understanding not only huge volumes of data, but analytical processes as well. *Exploratory acts* provide tools for exploration in animated cartographic environments.

Visual variables and presentation as a communication tool

Bertin's system of visual variables (Figure 1) has been recognized as the first systematic, detailed and comprehensive analysis of the elements of graphics (Bertin, 1983). This system could constitute a graphic language for visual perception.

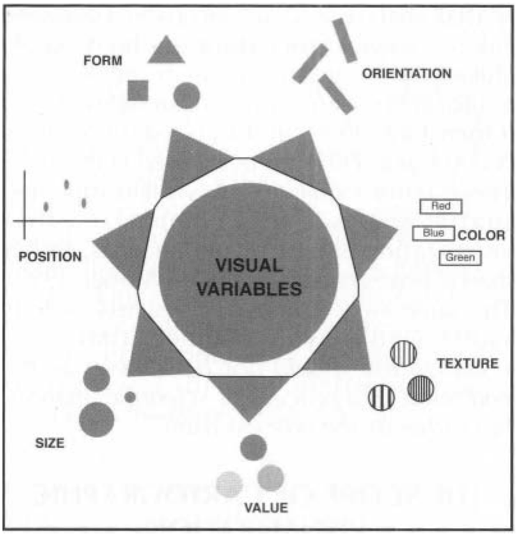

Figure 1. *Bertin's system of visual variables (Bos, 1984)*

The seven visual variables described by Bertin are as follows:

- Position. x and y coordinates to indicate the location of spatial objects.
- Form. This is the graphic characteristic provided by the form of a graphic mark. A shape may be regular as for a circle and triangle, or irregular like the pictographic rendering of a tree or bridge.
- Orientation. This refers to the directional arrangement of an enlongated individual mark or the parallel lines of marks as they are positioned with respect to some frame of reference.
- Colour. In the context of the visual variables, colour refers to hue. But colour has three primitives: hue, saturation, and lightness. It has been recently divided into individual variables.
- Texture. This refers to the size and spacing of component marks that make up a pattern. Different textures are obtained from photographic enlargement compared to reduction of patterns
- Value. This refers to the relative lightness of a mark, whether within black or of any other hue.
- Size. Marks vary in size when they have different apparent geometric dimensions—length, height, area. Usually the larger a sign, the more important it is perceived to be.

According to the specific visual variables used, the perception of symbols creates a spontaneous response from the user; such a perceptual response connected to a visual variable is referred to as the *perception property* of visual variables. In this context, we speak of *associative* perception, *selective* perception, *ordered* perception, and *quantitative* perception. Bos (1984) provided a summary of the relationship between visual variables and perception properties (Table 1).

Recently, extension of the basic system has been made for the requirement of visualizing uncertainty and temporal information. For instance, MacEachren (1994) provided an extension of Bertin's visual variables from seven to ten; Colour was divided into three colour variables involving hue, lightness and saturation (Brown and Van Elzakker, 1993). With the advent of multimedia techniques,

	Association	Selective	Ordered	Quantitative
Position	+	-	-	-
Form	+	-	-	-
Orientation	+	o	-	-
Color	+	++	-	-
Texture	o	+	o	-
Value	-	+	++	-
Size	-	+	+	+

Table 1. *Perception properties of the visual variables (Bos, 1984)*
(++ = very good; + = good; o = moderate; - = poor)

non-visual variables have been put forward (Krygier, 1994). It seems reasonable to discern new sensory variables from the perspectives of uncertainty visualization, temporal data visualization, and exploration visualization.

Communication is always related to information. Information is understood as data being transmitted from one person or group to another, either orally, in writing, or by means of various technical devices. Geographic information is the geo-referenced information which involves graphic, attribute and time information. The process of information transmission is referred to as communication. This transmission process in the broad sense includes exchange of information between man and computer, or vice versa.

The book, *Graphic Communication and Design in Contemporary Cartography* (Taylor, 1983), provides a comprehensive insight into communication and design. A map represents a communication system between map-makers and map-users. In maps, a considerable amount of cartographic information is depicted, and it is this emphasis on communication that signalled the emergence of cartography as an independent discipline.

Conventional maps only provide static graphic representation, and as a result this type of map is non-interactive. Interpretation of a map depends on the cartographic knowledge and expertise of the user. But advanced digital technology opens up many ways of representing information, thus enhancing the effectiveness of information transfer. In addition, communication of non-visual information is possible in a multimedia environment. More importantly, hypermedia provides mechanisms for cross-referencing.

Three decades of cartographic communication research have had some impact on visualization. However, the early cartographic work on this topic may not be of great help, since the new electronic products are different from conventional maps and perception of electronic images by the human brain is not the same as that of traditional products (Taylor, 1994).

It is argued that an over-emphasis on computer and related technologies to the exclusion of both cognition and communication is not helpful to cartography as a discipline (Taylor, 1983). Relatively little cartographic research has been carried out in this area, but its obvious importance may lead to a revitalization of research and applications in the field of cartographic communication.

Exploratory acts and exploration as an analytical tool

Compared to the pre-computer era, advanced computer environments offer flexible platforms for the purpose of analytical processing. It has been proved that not all parts of a screen display are given equal attention. Sometimes, in order to focus on some area, highlighting could be used to attract attention in the course of exploration. It is with the *point-and-click* interface that the click is used to trigger pop-up explanations in interpreting visualization, or to offer other presentations (so-called perspective). A set of exploratory acts has been defined to stimulate visual thinking in the process of exploration (Figure 2). Akin to Bertin's system of visual variables, it provides an advantage in the early stages of research by filtering massive amounts of data quickly and efficiently, and serves to confirm some proposed hypothesis. The exploratory acts are described as follows:

- Blink. Blink refers to the act of blinking at a certain frequency. It attracts attention when it is applied to some object on the screen. In fuzzy data exploration, the areas with certainties over 50% in which we are likely to be interested, could blink to attract attention. Since not all parts of a screen display can be given equal attention (Hearnshaw, 1993), the blink is useful in attracting attention to parts which might be neglected.
- Highlight. Highlighting shows up selected areas or object categories of a picture or photograph by making them lighter. Like the blink, it is another method of attracting attention. In the same fashion, fade is the opposite of highlight.

- Zoom in/out. This changes the size of an object, i.e. zoom-in magnifies while zoom out shrinks. Zoom-in helps to find / recognize a more detailed internal structure, while zoom-out helps to gain an overview of complete patterns.
- Pan. To pan is to change the position of an image relative to the monitor screen through the scroll bars attached to windows. There are four basic directions: left, right, up and down.
- Drag. Dragging means picking up an intended object and putting it in another position for further exploration. For instance, putting object groups into two juxtaposed sublayers facilitates comparisons to assess co-occurrence or correlation. By dragging, one may for example, note the similarity in shape of the African and South American coastlines—a key step in Wegener's development of the theory of continental drift (MacEachren and Ganter, 1990).
- Click. Click, including single-click and double-click, is the basic cursor act. Other exploratory acts often start with the primary click. In addition, some node information behind certain hotspots can be popped-up after clicking.

Just as the visual variables are used for static graphic representation in conventional maps (Bertin, 1983), exploratory acts can be viewed as exploratory variables in the animated cartographic environment. That is to say, unlike visual variables, exploratory acts are used in animated exploration instead of static representation.

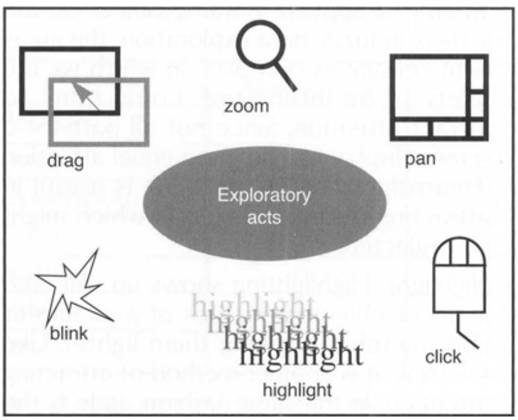

Figure 2. *Exploratory acts for exploration*

It is in a digital environment that animated visualization and a series of non-visual representations are possible. Not limited to communication, the analytical function of visualization has been emphasized here. Usually it is termed *exploration,* which is synonymous with analysis.

Visual thinking can be viewed as an objective of visualization. As DiBiase (1990) noted, visualization tools may play different roles at different stages of scientific research. He identifies four stages: exploration, confirmation, synthesis, and presentation. The first two largely represent visual thinking. At the exploratory stage, often the analysts are not sure of the questions to pursue. Primary patterns and relationships could be created in one stage, which need to be confirmed in the next stage: confirmation. After these two stages, the role of visualization shifts from visual thinking in the private realm to visual communication in the public realm. As the third step, synthesis is designed to help the analysts step back from the specific data in order to put the problem into a larger theoretical context. Finally, all the analysis results will be presented for communication. Actually, the last two steps serve the purpose of communication as did traditional cartography.

Figure 3 illustrates two parts of visualization that have been investigated in this paper for cartographic visualization, exploration and representation.

When visualization is discussed, terms such as communication often occur with the

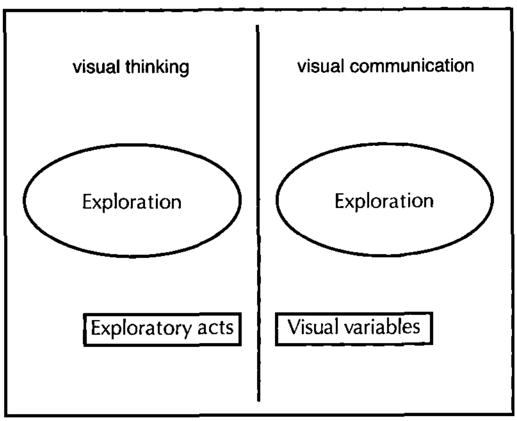

Figure 3. *Two tasks of visualization*

modifier visual, e.g. visual communication and visual exploration. Other sensory modes including hearing, smelling and touching could also be considered when multimedia GIS comes of age.

FEATURES OF CARTOGRAPHIC VISUALIZATION

Geo-scientists have long understood the value of cartographic representation to render functional relationships of quantitative data. Graphic devices such as contour plots, structural diagrams or ball-and-stick models, have been familiar tools. Moreover, computer-driven plotters and CRT's have been used to display these traditional forms of scientific graphics since the early 1960s. However, none of these can be regarded as offering real cartographic visualization, although they have contributed to it.

Traditional media such as paper, plastic or polyester film used to be the carrier of information in cartographic representation. Separation of data storage and data display in a digital environment leads to the fundamental distinction between cartographic representation and cartographic visualization. Although some existing cartographic representation methods are applied to visualization, cartographic visualization is not synonymous with cartographic representation. The distinction can be shown through the following aspects:

- Animated map versus static map
- Interactive exploration versus representation of the results
- Multiple perspective versus single optimum map

Animated map versus static map

The basic cartographic elements presented by Szego (1987) are as follows:

- the setting
- the actors
- the play

The play represents motion of actors in a certain setting. Szego has further elaborated on the three basic types of movements distinguishable in the geographic setting as:

- the unique movement
- the channel-bound movement
- the spatially-defined movement

Obviously, geographic phenomena are often moving rather than static, and traditional maps are just the snapshot of one horizontal section in the axes of time. The movement with which traditional maps are concerned is mainly a kind of spatial movement which can be viewed as:

$$(x,y,z)\rightarrow(x+\Delta_1, y+\Delta_2, z+\Delta_3) \quad (1)$$

where Δ_i denotes the distance of movement in space, for instance, using arrow symbols to represent the transportation of cargo, or the immigration of population.

Spatial data have three components, i.e. spatial, attribute and temporal, which results in three basic query types: *where, what,* and *when.* Dealing with time is what temporal GIS (TGIS) is concerned with, and efficient visualization of temporal information should be provided. It is with the following form that temporal information can be viewed:

$$(x,y,z,t)\rightarrow(x+\Delta_1, y+\Delta_2, z+\Delta_3, y+\Delta_t) \quad (2)$$

Animated maps will have a more prominent position in future GISs.

The emergence of TGIS has increased the demand for maps displaying the temporal component. Time has been added to the list of visual variables for temporal information. Much effort has been put into seeking dynamic variables for mapping the demands of: duration, order, and rate of change (DiBiase *et al.* 1992). Three additional variables have been suggested by MacEachren (1994): display date, frequency and synchronization. A new kind of map, called a *temporal map,* has been discussed by Kraak and MacEachren (1994). Animated information representation as a new branch of cartography is receiving more and more attention (Ormeling, 1995).

Interactive exploration versus presentation of results

The purpose of cartographic representation is to communicate to the user the information that the map maker has encoded in the map. What is transmitted through the map is the cartographerís point of view regarding the data. In other words, cartographic represention involves the presentation of results.

As stated above, from the analytical point of view exploration is one of the features of cartographic visualization, which has an impact on spatial data analysis. In this case, the purpose of visualization is to help the analyst to gain insight and a better understanding about the data being investigated. What the analyst faces is an unknown situation, and he/she has no clear ideas about what may exist in the data. Exploration to uncover unknown structures and patterns distinguish visualization from cartographic representation.

Conventional, non digital maps are inconvenient to be used as analytical tools. Conventional representation finalises the results after information collection and processing. With the separation of data storage and data display in a digital environment, unlike the paper-based map, one can retrieve data more flexibly, and a map display on screen can be modified easily. Interactve exploration is becoming an important component of cartographic visualization.

Visualization serves the exploration function and benefits from the following technological tools. Firstly, there is the flexible *point-and-click* graphical user interface, particularly the graphic elements such as multiple document interface and icon. Secondly, there is the development of multimedia and hypermedia technologies, which provide not only multiple forms of presentation, but also the hyperstructure mechanism for cross-referencing.

If a device such as scatterplot brushing is utilized, the exploration potential becomes virtually limitless, because variable relationships can be examined both with reference to the passage of time as well as within any particular time frame (Campbell and Egbert, 1990).

Multiple perspectives versus single optimum map

Traditionally, cartographers have produced single maps to represent spatial data. This is often due to the limited space available for maps. It has been common practice to focus on only one aspect of a spatial pattern, for which only one map is necessary. The users of GIS, however, express wide-ranging needs. Advanced interactive computer graphics technologies offer a more flexible approach to visualize spatial information from multiple perspectives based on the same data.

The principles of hypertext, extended into other multimedia such as graphics, video and sound, provide one mechanism for browsing through different types of information. In this context, multimedia and hyperstructure can greatly facilitate visualization. The former provides multiple perspectives on a dataset, while the latter offers the cross-referencing mechanism (Jiang et al., 1995).

Visualization, which typically refers to a synthesis of computer graphics, image processing and optical storage, is not a single technology, product or market, but is a collection of technologies (Table 2).

Task	Products	Techniques	Viewing media	Storage media
- DBMS	- tables	- cartography	- CRT / monitor	- film
- analysis	- diagrams	- image-processing	- paper	- paper
- design	- maps	- spatial data analysis	- photo - tape	
- mapping	- images	- 3D modelling	- screen	- disk
- object modelling		- animation		- CD-(i) (ROM)
- presentation		- business graphics		- optical disk
		- CAD(M)		

Table 2. *Overview of the elements of visualization (Velden and Lingen, 1990)*

THREE TECHNICAL LEVELS OF CARTOGRAPHIC VISUALIZATION

Visualization research pursuits in GIS may be formulated at three levels (Figure 4). The fundamental part is basic hardware/ software, which supports other levels. This has been publicised in the report of the NSF workshop held on the ViSC initiative. The investigation includes short and long-term technical needs (McCormick et al., 1987). The second level which involves important extensions, i.e. animation, interactive exploration and hypermedia, consists of cartographic visualization tools based on the basic hardware/software. The third one includes specific cartographic visualization approaches which fulfil the demands of various domains using appropriate tools.

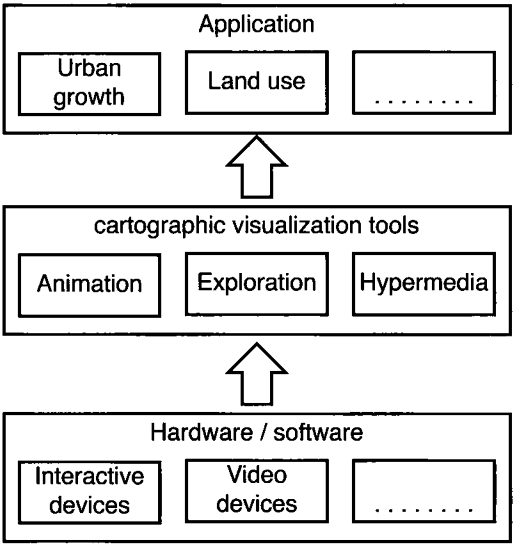

Figure 4. *Three technical levels of cartographic visualization*

It has been estimated that over half the human neurons are devoted to processing and understanding visual input. Therefore, to optimize the ability to cope with voluminous sets of numerical data, one must make maximum use of this important human visual apparatus. Moreover, one must give the scientist control over those data-driven pictures: animation and exploration must be used together. That is the goal of *visualization* (Levine, 1988). One more extension of the cartographic *visualization* tools based on hypermedia was added (MacEachren *et al.,* 1992).

Hardware /software devices

The most critical level of visualization involves the hardware/software devices. Basic hardware includes interactive devices such as keyboard, mouse, tablet etc., and video devices, namely, recorder, digital camera and hypermedia. Computer languages and graphical libraries are the main elements of software. The rapidly developing computer industry provides faster processing hardware and more sophisticated computer graphics, including animation.

Visualization tools

A number of computer manufacturers have developed powerful visualization systems, such as AVS and Iris Explorer, and these are now in use worldwide. A related review has been made by Slocum (1994). Exploration, animation and hypermedia together make possible the three functions of visualization tools. It is possible to integrate these functions, as shown in some sporadic but successful studies such as SPIDER (Haslett *et al.,* 1990) and the SCOLT multimedia project (Raper *et al.,* 1992). But cartographic visualization is still in its infancy, and the prototypes need to be improved.

Applications

This level may include all application areas of GIS. For instance, the environmental system is a dynamic system which generates a great amount of data. Apart from their spatial representation, it is also required to interpret and explore the data with innovative visualization tools. A set of examples has been presented by Koussoulakou (1994). In this domain, two main issues which deserve attention are temporal visualizing and visualization of uncertainty information.

CONCLUSIONS

Much effort in seeking effective visualizations should be devoted to research on perception and cognition, as indicated by Taylor (1983) in the pre-computer era. The human visual system is still a black box in which many mechanisms are not clear, but it is widely recognized that knowledge and cultural background affect the way we see things. In the pre-computer era research into effective spatial information presentation, particularly maps, had been on-going for many years. Many principles and guidelines developed at that time are still relevant today. However, this knowledge can not be applied to the computer environment without empirical investigation. Particularly in the context of current GIS, the data to be visualized has become more and more complex, especially for temporal and uncertainty information. All these considerations are turning traditional cartography into a *new* cartography.

As far as the definition of cartographic visualization is concerned, there are two points to be considered from this paper. The first is that visualization is the mental process for obtaining spatial information, with the aim of finding patterns using visual thinking. The second is that visualization can also be a sophisticated tool, used by domain specialists for individual scientific research. Such approaches to visualization should have the distinguished features of *animation, exploration,* and *multimedia.* Further research is required in developing the relevant visualization tools.

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