# Geospatial Information Visualization User Interface Issues

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# Geospatial Information Visualization User Interface Issues

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**ABSTRACT:** User interfaces for geospatial information are the tools by which users interact with and explore that information. The provision of appropriate interface tools for exploiting the potential of contemporary geospatial visualization products is essential if they are to be used efficiently and effectively. This paper addresses issues and challenges in interface development and usage that are identified as paramount within the geospatial visualization community.

**KEYWORDS:** Interface, interactivity, navigation, collaboration, metaphors, usability

## Introduction

*"What makes a technology interactive? Is radio interactive? Television? What about books, lectures, conference sessions? Is interactive multimedia really interactive? A TECHNOLOGY is not in itself interactive— it is the INTERFACE we design for it that is interactive." (Wills 1996, p. 187)*

Technological changes involving both cartography and computer graphics have made modern cartographic representation different in both quantitative and qualitative ways. Quantitatively, a wider range of different cartographic products can be made faster and less expensively, and, qualitatively, interaction with visual displays in almost real-time is now possible. This has moved the emphasis from static to dynamic map use (Taylor 1994) and thus introduced new requirements for the design of representation artifacts and interfaces to those artifacts. Using representations requires the availability of interfaces that work, and ones that work with different "representation machines" and with different users. The challenge is to provide flexible access to increasingly powerful geospatial (and related) representation software.

Complementary papers in this volume detail new forms of geospatial representation and address cognitive/usability issues in geovisualization (from both a cognitive theory and usability engineering perspective). This paper focuses on the future research needs for human–computer interaction between human users and one or more cartographic/geospatial representations. It explores the recent technological developments and perceived needs of geospatial information users and develops an international, interdisciplinary research agenda directed to designing innovative user interfaces for spatial representation.

The starting point for the research agenda presented here was a set of initial 'Interface Design'" priorities identified by members of the ICA Commission on Visualization and Virtual Environments: a typology of visualization operations; controls for operations; facilitating information access in complex hyperlinked information archives; intelligent 'GeoAgents'; and collaborative visualizations (MacEachren 2000). Starting from these suggestions, the authors of this paper, reorganized, refocused, and extended the original outline, as will become clear below.

The next section of the paper discusses three general themes and issues related to interfaces and explores the possible questions within each that require investigation. The themes are: interfaces and representations of geography, navigation, and universal access. Sections that follow outline the state of the art on which we can build and identify specific research challenges. A summary of the primary research challenges is provided, and brief conclusions are made.

# Themes and Issues

The interface design process is essential to developing interaction tools and techniques for using geospatial visualization tools effectively. Here, we outline the themes and issues that provide a context for subsequent discussion of research challenges. First, the general concepts of interfaces and their use for interacting with representations of geography are addressed. Second, we explore navigation, access and manipulation, which together constitute an important theme with respect to the design of interaction. This theme includes the design of metaphors and access routines, manipulation tools and techniques as well as navigation. Third, the importance of universal (particularly international) access is discussed, with international Internet standards efforts seen as a key factor here. And, finally, the practical implementation of interfaces using new technologies is addressed. Our approach to geovisualization interface themes and issues emphasizes design and, thus, is complemented by perspectives on cognitive/usability issues discussed by Slocum et al. elsewhere in this issue.

## Interfaces and Representations of Geography

*What are the differences between "normal" visualization interfaces and geospatial visualization interfaces?* There is a large literature on the design of interfaces for general applications (for example, Shneiderman 1999). However, we contend that interfaces for geospatial representations, be they inherently spatial, or "spatialized" representations of non-geographic phenomena, introduce a unique set of themes and issues worthy of research.

One facet of interaction and navigation with representations of geography (shared with architectural representation and distinguishing both from most other forms of information representation) is that the phenomenon being represented is also the one being used for navigation. Therefore, both the interface and the representational structure of (hyper)media are central to the development of more effective and efficient means of transferring knowledge. Representations of geography differ from those of architecture due to their emphasis on scales that cannot be experienced directly and on depicting the non-visible (e.g., mortality rates or temperature). It is this combination of scale, range of things represented, and the use of space to represent space that sets representation of geography apart.

An early prototype to adopt an innovative, natural, interface for working with geospatial data was "The Geographer's Desktop" (Egenhofer and Richards 1993). It developed the notion that users would find it intuitive to use a virtual light table on which they could "drag" map overlays and then view the composite image. The use of Macintosh icon "dragging" to assemble the desktop enabled users to bypass keyboard commands and get direct access to the spatial overlays on-screen. A number of tools were proposed for user manipulation and interrogation of the desktop maps, as well as methods for the user interface to be personalised. Initial testing by Egenhofer and Richards (1993) received positive feedback from users. Though an innovative approach to the use of geospatial information was demonstrated by The Geographer's Desktop, it was not further developed as an interface metaphor. Reasons why such innovations have neither been adopted nor developed need to be investigated.

Geographically based visual methods have been used to access diverse non-spatial information such as documents and news stories (Chalmers 1993; Skupin and Buttenfield 1996), and non-spatial visual interfaces have been employed to give access to spatial data. Interface designers have continually strived to develop interfaces that enable users to exploit the displayed results of interrogations of information resources. In addition to interface functionality, design aesthetics must be considered, because aesthetics may help to enhance initial take-up and acceptance of a product. Innovative interfaces like that developed by Egenhofer and Richard (op. cit.) may have had a greater interest from potential consumers/users if developed into a more complete and aesthetically pleasing product. However, transforming a research prototype into a viable product is a difficult task, one that may require greater cooperation between universities and the private section.

One contemporary interface to geospatial data that has aesthetic appeal is provided by *Understanding USA*, published by Ted Conference Incorporated. Whilst the paper version of this atlas does not provide an easily interpretable piece of graphics, the complementary (and free) Web-delivered “mirror” allows users to explore the graphics using VRML (Wunnan 2000). The interfaces, both graphical and textual, are innovative and functional, providing the means to interpret the massive quantity of data displays that depict information collected during the last US census. Figure 1 illustrates one of the graphical interfaces within *Understanding USA*. Whilst it can be said that products like this do have aesthetic appeal, their usability still needs to be investigated.

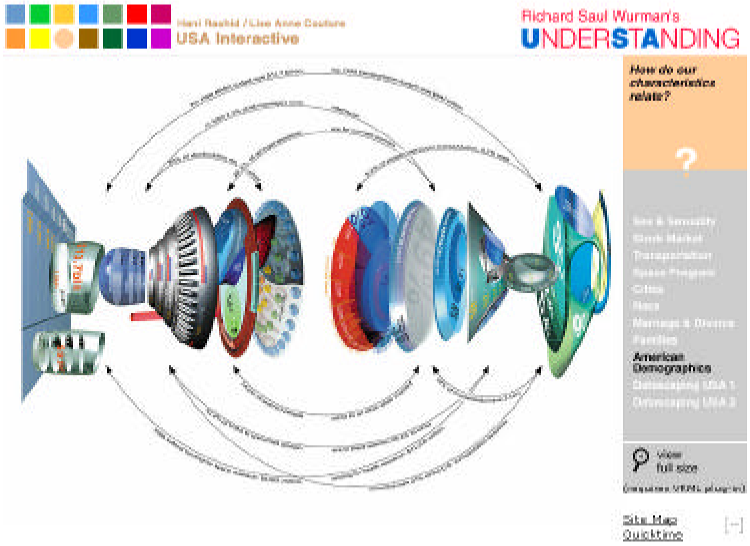


Figure 1. Understanding USA – American Demographics. VRML 3D graphics. (Source: Wunnan, 2000a, http://www.understandingusa.com/chaptercc=10&cs=222.html)

Beyond aesthetics there is a need for more natural interfaces to geospatial information environments, to make these often complex environments accessible to more people. Natural interfaces have a long history in cartography (e.g., DeLucia and Hiller 1982). More recently, Lowe (1996) proposed that new technologies such as speech input, intelligent software assistants, and virtual reality may help create natural environments accessible to even the most unskilled computer users. Some exploratory work has been conducted to ascertain how these natural interactive environments might enhance geospatial information displayed with New Media.[1] For example, Sharma et al. (2000) have described speech and natural gestures as interfaces to large screen maps. If interfaces are designed with the aesthetics of the display and natural interaction as a priority, then more acceptable, and more usable products should result.

According to van Niekerk (1996, p. C3), there are two groups of people: the 20 percent who are good at abstract mental models and the 80 percent who are not. He noted that:

> *“...if you show people a picture of an information space and show them where they are, it makes it so much easier for them to navigate.”*

From the perspective of geographical visualization, interaction design for navigation implies that the user is able to both navigate the visualization itself and navigate the synthetic geography that it represents. Navigation can refer to navigation between “map” representations; navigation within “map” representations (e.g., pan, zoom, scale, generalization); navigation between and within datasets; navigation between spatial objects and related temporal and thematic attributes and related information; and navigation between spatial objects and metadata.

Navigating/browsing a geospatial representation (whether it be a map, a 3D virtual environment or whatever) requires the user to be able to do some standard things. These include changing the scale, map projection, level of generalization and field of view; pan, move, browse across the “map” extent/content; access attributes relating to spatial objects including related information; and manipulate the design representation parameters (such as color, texture, and speed). Interface tools to support these tasks should be designed so that they correspond to cognitive usability principles.

A number of research programs have been undertaken related to user interfaces that may be relevant when refining user interface research strategies that are specific to geospatial information visualizations. These include work on browsing large images (Plaisant et al 1995); dynamic queries (Shneiderman 1994); data exploration (Plaisant 1993); interactive labeling (Fekete and Plaisant 1999); and linking multiple visualizations for analysis—particularly the "snap together" project (North and Shneiderman 2000; Fredrikson et al. 1999).

In relation to geospatial information navigation and browsing, specifically, Kraak and van Driel (1997) propose and implement several New Media methods for "hypermap navigation" that emphasize a distinction among thematic, temporal, and spatial links. Plaisant (personal correspondence, 2000) has identified important elements in navigating/browsing a spatial representation successfully. Among them are: the provision of an overview interaction "map" with a fully synchronized field of view that would enable navigation and "placefinding" (where the user would either know or be able to locate their "place" in the visualization), the use of fisheye techniques, and the application of advanced labeling algorithms.

Beyond support for browsing and data access, Robertson (1994) contends that geospatial visualization tools must provide better support for interacting with data models and hypotheses (particularly in the context of environmental resource applications). He suggests that not only can interaction enable expertise, but it can also be used to build expertise. To be effective, interaction needs to be integrated within standard working tools that support decision-making related to geospatial data (thus with GIS and spatial analysis).

## Universal Access

The term "universal usability" has been used to describe a system that is designed to support the empowerment of "everyday" experts, citizens, and both casual and intensive users of contemporary information technology. The challenge of universal usability has become a focus of considerable attention (see Shneiderman 1999 and the World Wide Web Consortium's accessibility initiative W3C 2000). Among the roadblocks to universal usability are technical and social factors dealing with access to technology (Pickles 1995; Hearst 1996) and human factors such as language differences and user disabilities (Nielsen 2000).

In relation to disabilities, when paper maps were the sole tool for visualizing geospatial information there were many efforts by the geospatial community to provide tactile or tactual maps for the vision-impaired (Roberts 1983; Golledge 1991) so as to not exclude certain members of the community. Similarly, research has produced guidelines for use of color on maps (and other displays) that minimizes interpretation problems for those with color vision impairment (Olson and Brewer 1997). The same needs to be done for contemporary visualization products. Access to geospatial information, and the interfaces that provide the "gateways" to this information, need to be designed in sympathy to all users, so as to ensure equity of access and use.

Whilst geovisualization products for experts might need support for customization, public access geovisualization tools may be more effective if some standardization is imposed. Developing public access geovisualization will require an integrated approach that includes attention to global standards, such as those developed for the Web, and to usability assessment that fuses human–computer interaction methods, computer-supported cooperative work and related domains with the cartographic tradition of cognitive (including perceptual) research focused on understanding map use and improving map design.

For Web-delivered products, the World Wide Web Consortium (W3C) recommends minimum standards for interfaces so as to ensure universal access. The W3C is working on improving access to the Web for all users by developing new ways for users to interact with the Web so that telephones or hand- and eye-free devices can be used (W3C User Interface Domain 2000). For geovisualization, a fundamental challenge will be to make the results of dynamic visualization accessible through the new Web devices being developed and to users who may not have the training to interpret complex visual displays or perhaps have impaired vision.

## Practical Implementation of Interfaces Using New Technologies

Choosing an appropriate interface, and one that can be implemented practically, using available visualization devices, requires that many factors be addressed. Just as there are many methods for representing geospatial information itself there is also a plethora of realization devices for providing the interface to geospatial visualizations. The development of both the realization method and the interaction procedures needs to be undertaken in a user-focused, task-centered, cognitive manner. Research is needed to facilitate standards for interface design and assessment that are geovisualization specific but are "built" on the findings from the wider user–interface community. Methodologies need to be established for developing tools and techniques and procedures need to be put into place for evaluating them. Practical implementations require standardization and proven implementation guidelines to ensure the provision of practical interface design and production tools that can be introduced into usable systems.

## State of the Art

Here, we focus on current technologies and usage research related to geovisualization, as a basis for delineation of research challenges in the next section. Particular attention is given to: distributed interfaces, new interface devices, the prospects for delivering geospatial information using multi-sensory interfaces, 3D and Virtual Environment interfaces, interfaces for collaboration, textual interfaces, navigation, and "GeoAgents."

### Distributed Interfaces

New Media uses communication resources to link computers locally through intranets or internationally through the Internet. The combination of geospatial information representation devices and the Internet offers fascinating possibilities (Peng 1997; Cartwright 1999b). The Internet has changed the conditions of data access, data transmission, and access to geospatial visualization and analysis tools, and it enhances the functions of geospatial information in many parts of society, such as administration or business. For example, the proliferation of general Web-delivered mapping resources from MapQuest and Falk enable visually represented geospatial information to be made available "on-demand," enabling geospatial information to be part of an "at-hand" resource.

Using the Internet for the distribution of maps has many implications for map appearance and conditions of user access. Many Web-based mapping and visualization tools allow users to control design of their own displays. This provides important flexibility for experts to explore data. However, as previously stated, communication systems such as the Web have popularized contemporary visualization systems, and users with no prior training in geovisualization (or in any other geospatial information tools) require systems that offer proven access methods and procedures—systems that generate good default displays in relation to data characteristics and context of use.

A second issue is the limitations that technology imposes on display quality (due to both image transmission speed and screen resolution). These limitations have led to a "drill-down" design, i.e., one item of information for one view with details accessible by "drilling down" instead of all information provided on one view. Drill-down methods are, of course, quite popular in information visualization and the work of Jern (1997) and Roth et al. (1997) are typical of the research already conducted. Drill-down methods were developed to handle the large amounts of data now available. To ensure that drill-down methods are effective when applied to geospatial information visualization, appropriate interface systems are required to assist the technique.

There are a number of other issues that relate to distributed interfaces. These include methods for combining datasets, different projections, at different scales and how to cope with different levels of generalization. These areas are being addressed by the Open GIS Consortium (2000) in their quest to develop interoperability standards. Dynamic generation techniques present issues such as automated text placement and how to effectively combine the components of dynamically generated products so that a "seamless" visualization results. Some work has already been done in this area by Ovait (1995) and Ocait et al. (1996), an by developers of both *The Northern Territory Bird Atlas* (2000) and the *Australian Coastal Atlas* (2000).

## New Interface Devices

The Internet has enabled the re-packaging of maps into service-based *applications* that provide the user with both interactivity and customisation not previously possible with paper based mediums. However, the fact that online mapping services are now technically feasible does not mean that they will be adopted, nor do the current interfaces guarantee successful use or (geospatial information) resource exploitation. In fact, one of the greatest barriers to date has been that most online services are delivered to PC browsers that are inherently desk-bound. One of the simplest and most compelling features of a paper map is the fact that it is truly mobile and assists the user "in the field" where it is highly valued.

Recent advances in mobile technology have enabled purpose-built Internet browsers to be integrated within mobile devices (Mitchell 2000). Wireless Application Protocol (WAP), and other similar standards, have effectively removed a substantial barrier to multimedia mapping. This allows mapping and guidance services to be delivered to users in the field, through mobile telephones (Hypergeo 2001), by the use of in-car navigation displays (Larish 1994), and other devices. A remaining barrier to adoption, however, is the lack of understanding about how to design effective interfaces to such mobile mapping devices.

Mobile devices assist decision-makers in business and field-related activities, where "here-and-now" information is not just expected, but demanded. Decisions that depend upon immediate access to geospatial information now make different demands on providers of services, and "just" making the information available may not be enough. As the popularity of these devices facilitates moving geographical visualization into the mainstream of information provision there is a need to ensure that the representations provided include adequate and functional interface routines. To have an impact beyond specialized niches, wireless mapping must become available on generic, inexpensive devices that have color displays with greater resolution than is currently the case. For initial ideas toward such interfaces for hand-held geospatial displays, see Cartwright et al. (1998), and for related work on hand-held devices generally, see Kahn et al. (2000); Kramer et al. (2000); and Minsky (2000).

### Multi-sensory Interfaces

The asymmetry in sensory bandwidth between the computer–environment interface and the human–computer interface is most clearly seen in systems in which multi-sensor data are converted to entirely graphical form for visual interpretation. In contrast, a multi-sensory environment would support the use of several human senses (sight, hearing, touch, smell, and taste) in the information interchange between computer system and human analyst. Shepherd (1994) was among the first to propose a multi-sensory geospatial research agenda that includes the investigation of the major sensory modalities suitable for encoding geospatial information and the most appropriate means of designing multi-sensory representations for different users, different tasks, and different usage conditions. This is illustrated in figure 2.

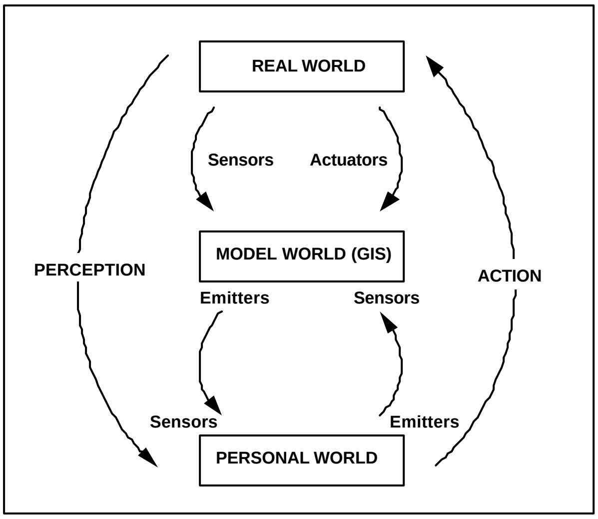


Figure 2. Information pathways and GIS. (after Shepherd, 1994, p. 358.)

A number of recent research projects have begun to investigate multi-sensory interfaces. Oviatt (1996), Oviatt et al. (1997) and Blaser et al. (2000) have explored the integration of sketching with speech and Sharma et al. (1999) investigated integration of natural free hand gestures and speech. For those with vision impairments, the use of sound (hearing) as an interface for navigating Web maps has been explored (Brown et al. 1999).

Plaisant (personal correspondence, 2000) noted that voice should have a strong benefit only in special cases where the user is “hand busy.” She also noted that natural language interfaces are not necessarily the most effective interfaces due to the potential for interpretation errors, the need for confirmation dialog, and the ambiguity of the natural language. Research is needed to extend information related to the use of these interfaces beyond just the ease of use of the system. It needs to address the time taken to complete tasks (compared to completing the tasks using “traditional” interfaces), error rates, the time needed to train users, and the general “non-advantages” of using aural interfaces.

## Virtual Environments

The development of virtual environments (also called virtual worlds, geovirtual environments, virtual landscapes, virtual reality) for representing and interacting with geospatial information is an active area of research. The essence of the approach is in the development of a spatial metaphor for the representation of information, interaction with information, and navigation through geo-information space. Virtual Environments (VE) is expected to be an effective interface for geospatial information because humans have day-to-day experience of navigating within three-dimensional space. The realism of both representation and navigation devices (see, for example, Dykes et al. 1999) is expected to minimize the “cognitive effort” required to explore and interact with data.

Virtual environments fail as interfaces, however, when viewers become lost within the immersive space. This can be for a number of reasons. These include the mapping of the 6 degrees of freedom required for true three-dimensaional navigation onto the two degrees of freedom provided by conventional mouse input devices; navigation over distances and speeds unfamiliar in the viewer’s experience; and lack of visual detail in the representation of space. Also, research into appropriate navigation metaphors suggests that many “realistic” modes of movement (such as walking, driving, flying) are inappropriate when exploring data with scale ranges extending over many orders of magnitude (Fuhrmann and Kuhn 1999).

A number of approaches have been taken to address such problems. Several authors (Moore et al.1999; Darken and Cevik 1999a, 1999b; and Fuhrmann and MacEachren, 2000) suggest that both three-dimensional and conventional two-dimensional map views should be shown simultaneously, providing both synoptic and immersive viewpoints. A superficial landscape is frequently used as a contextual backdrop to the space being represented. Rendering techniques such as *mipmapping* and progressive mesh triangulation (see, for example, Hoppe 1997; Koh and Chen 1999) allow extra levels of detail to be added to and removed from a representation depending on the apparent distance from the viewer.

New Media can afford access to information via virtual universities, classrooms, libraries, and virtual cities. The Institute of New Media and the Bank Academy in Frankfurt, Germany, have collaborated to produce an avatar-enhanced project—*SkyLink*—, which provides a model of Frankfurt that includes skyscrapers containing the major banks (Hasebrook 1999). Skylink (Figure 3 is a “Hypertecture-Project” and consists of *Dynanet*, *Skystation*, *Skylink* (Franken 2000a, 2000b) and *Skywalk*. The authors of the package contend that the ‘hypertecture’ provides an alternative to the desktop metaphor as a way to access information and tools, due to its immersive properties. The avatar allows users to ‘float’ around the scene and view different information elements like cash flows between the banks. This model is being enhanced with VRML and MUDs (Multi-User Dungeons) for educational use.

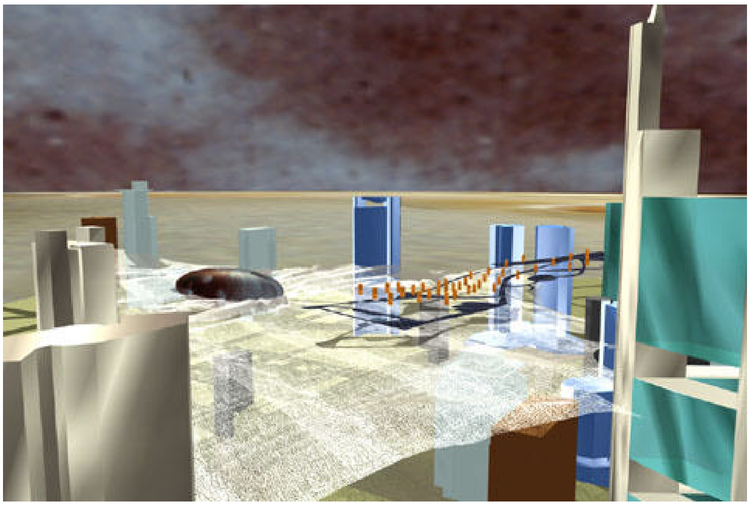

Figure 3. SkyLink. (Source: Wygoda 1996) http://www.inm.de/info/inm_info/planundbau_0696.html)

## Interfaces for Collaboration

The use of the Web for collaboration has been of interest to many researchers. Collaborative processes have focused upon diverse areas that range from problem solving to education (Watters and Wu 1999). Collaboration involves re-thinking interfaces in order to promote and facilitate joint work. Considerable attention has been given to non-geospatial aspects of collaborative interfaces (see, for example, Kahn et al. 2000). Here, we highlight three ongoing projects in which collaboration is a focus and geospatial–environmental information is a component.

First are two ideas generated at the professional design workshops conducted at the 1996 *Doors of Perception 3* conference (Netherlands Design Institute 1996) that are particularly applicable to the geo-spatial sciences. They are:

- *EcoNet* (mapping global resources), an infrastructure intended to enable "network-based under-standing through collaboration" among scientists, policy makers, industrialists, media, local gov-ernment, and practitioners located anywhere, but focusing on local problems (*op cit.*, p. 2); and
- *Memory Wall*, a social graffiti system containing the oral history of a community, made available on interconnected (no connection method was elaborated upon) "screen-like walls" located around that community (*op cit.*, p. 2).

Second, in the Italian-sponsored program *Parole* (Parole 2000), *Gruppo A12* has collected words that document change in environments since 1994. The interface uses only text (see Figure 4) and it is a "place" where authors collaborate on non-linear writings.

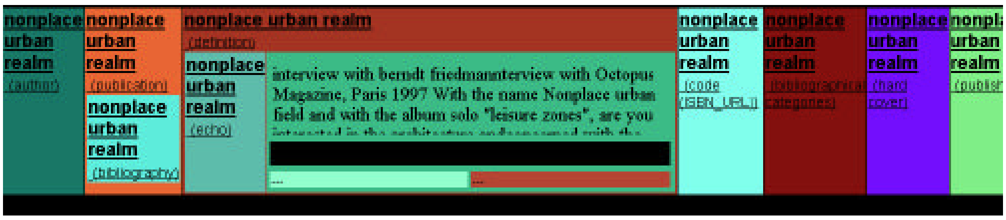


Fig. 4. Parole – an 'Electronic Meetingplace' for collaborative writing. (Source, Parole, 2000, http://king.dom.de/parole/work/index.php3?words_id=14)

Third, the U.S. Digital Earth initiative focuses specifically on geospatial information and has resulted in the development of a number of collaborative interfaces (*Digital Earth Initiative* 2000a and 2000b). As proposed in 1998, the Digital Earth interface is "a multi-resolution, three-dimensional representation of the planet into which vast quantities of data can be embedded" (Crockett 1998). Work on the concept so far includes an Inter-Agency Working Group effort to develop a Digital Earth reference model which would firm up requirements for hardware and software infrastructure, user interfaces, interoperability, technology, and content (Crockett 1998), as well as give attention to elements such as user scenarios (Kahn et al. 2000). A number of Digital Earth prototypes have been built, and many of these were developed under the “umbrella” of the Open GIS Consortium Web Mapping Testbed (Open GIS Consortium 2000). One innovative product is NASA Goddard's Digital Earth Workbench (Figure 5).

Figure 5. NASA Goddard's Digital Earth Workbench. (Source: NASA, 2000 http://holodeck.gsfc.nasa.gov/digitalearth/)

Rijken (1996) identified four levels of complexity related to collaboration: (a) the person (traditional human–computer interaction); (b) the group (computer-supported collaborative work); (c) the community (the design of enterprise systems for large organizations); and (d) the world (the design of information ecologies). New digital mapping systems are required to work at all of these levels. Achieving success may require a completely new information provision paradigm. Many approaches do exist for facilitating more efficient access to geospatial information and the Digital Earth concept is provided here as an example of an interface concept that was developed to enable both personal and collaborative impressions of data to be represented.

## Using Text as a Query Tool

The most effective interface to geovisualization tools is not necessarily graphical. For some applications, formal languages for building and interacting with visual applications can be more efficient and flexible that graphical methods.

A number of scripting languages exist (e.g., user-level languages such as Tcl/Tk, ArcView’s Avenue, Macromedia Lingo, and system designer scripting like Perl, CGI or Python (2000). The latter is a high-level interpreted language used for prototyping or as an extension language for C applications, where high-level commands are used to connect existing software tools that would otherwise only allow for independent operation. Users with expert knowledge and scripting skills can quickly develop geographic interfaces to spatial and non-spatial data, run processes, and perform visualization in an extremely flexible and interactive manner (Dykes 1996; Brunsdon and Charlton 1996). Text is typed into a console to specify the graphical representation, its behavior and its relationship with any GUI that exists. The graphical environment is realized, and possibly modified, with new instructions. This type of “rapid prototyping” interaction provides an opportunity to formalize dynamic cartography for visualization.

Wilkinson takes a different approach to these concepts in his *Grammar of Graphics* (1999). Here, he asserts that a presentation graphic can be defined as a realization of a mathematical graph, which in turn can be defined as a subset of a crossing of sets. These ideas are incorporated in the object-oriented graph building toolkit nViZn.

## 3.7 Navigation

Monmonier (1994) contends that the two most important metaphors for dynamic cartography are *Navigation* to locate facts, images and other relevant information; and *Narration*, the introduction to new data sets through a "guided tour" (using narratives of useful/interesting information).

How the user moves into and through a visualization and the success of these movements through information spaces (i.e., the success of finding particular and pertinent information) are paramount when evaluating the success of interfaces and interface metaphor applications. A number of different navigation strategies have been applied to geospatial information visualization, such as the provision of a familiar "space". An example of this is the "gallery" used in the Domesday videodisc (Goddard and Armstrong 1986); or Encarta's guide; zoom and pan controls in the Mapquest Web pages; and the location maps in the Dorling Kindersley Publishing (1995) *World Reference Atlas*. Appropriate navigation interfaces are important components of the suite of tools required to exploit geospatial visualization tools.

## GeoAgents

Can geovisualization products offer too much information? The Web enables access to vast stores of information, much of it with geospatial referencing, thus Web-based geovisualization has the potential to overwhelm users with a huge volume of unorganized information. The key question here is how can we provide the "information filters" that avoid this overload and allow users to work with a myriad of information.

Building functionality into a computer using "interface agents" has become an active topic of research in human–computer interface design. The idea is to build computer surrogates that possess a body of knowledge both about something and about the user in relation to that something (Negroponte 1995). Users can have their own personal "trips" in personal computing—guided by an agent (or Geoagent) (Nevile 1993). Developers of multimedia systems have investigated the use of agents to move through the virtual space of information systems, relating huge sets of information in short spans of time. The concept of "agent-based software" or "valet software" has been investigated by Apple, Magic Cap and the MIT Media Lab., among others (Cooper 1994). Agents have also been used for collaboration in virtual environments (Noll et al. 1999).

Education has embraced agents as a means of facilitating educational programs online. A typical example can be found in the Virtual University ("The U"), developed and created as a prototype in Active Worlds (Activeworlds.com 2000), a Web site dedicated to developing the concept of different, virtual worlds. The U has a virtual campus (see Figure 6), virtual lecture theatres, and agents to provide assistance (Contact Consortium, 2000).

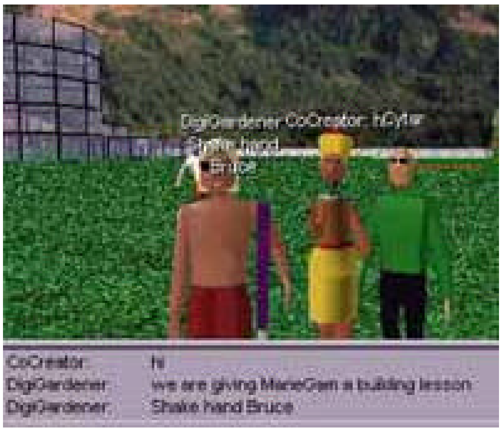


Figure 6. 'Students' (avatars) meeting on the Campus at the Sophia-Antipolis Prototype VRU
Source: Contact Consortium, 2000, http://www.ccon.org/theu/history.html

To support geospatial information access, the concept of "The Guide" and "The Sage" metaphors, proposed by Cartwright (1999a) might be implemented through agent-based technology. To support geovisualization, specifically, GeoAgents need to be aware of their location in space, know the amount of generalization that has occurred before their "area of operation" was defined and be responsive to zooms, pans, and other movements around and within the visualization. They need to be "spatially aware" and "cartographically informed" (about the "rules" that can sometimes be imposed to guide the design and visualization of geospatial information).

Whilst the use of GeoAgents offers the potential to build innovative interfaces there are some dangers associated with their usage. Users can become frustrated by loss of control and understanding of what the system is actually doing; this can result in a lack of confidence in results. A better approach to follow may be to suggest and explain, rather than take charge (Plaisant, personal communication, 2000).

GeoAgents, atlas metaphors, interface navigation strategies, collaborative interface environments, specific interfaces for distributed geospatial information, multi-sensory interfaces, and interfaces that "work" with new and developing devices are some of the "state of the art" issues that relate directly to interfaces, and their effective use, for geospatial representation. The next section of this paper looks at research challenges for interface design and development that relate to how we make information available to our users.

# Research Challenges

For the geospatial sciences, contemporary geovisualization tools offer the ability to create novel representations of geospatial phenomena, perhaps changing the geospatial data access paradigm. These products must be designed, tested, evaluated and refined, if they are to be accepted as a real alternative to "conventional" representations (including those representations now being produced and delivered electronically).

## Potential of Visualization tools to prompt creative thinking

Do computers and access to many mediums allow people to think differently? Papert (1993) contends that they do. Do interactivity and visualization tools give users the ability to think and to solve problems in ways dramatically different from traditional "generalist"/mathematical ways of thinking? Do they promote "bricolage" described by Claude Lévi-Strauss as a "use what you've got'," "improvise," "make-do" way of problem solving? In the context of geovisualization, these questions suggest a set of specific challenges:

- Do interactivity and geovisualization tools give users the ability to think and to solve problems in different ways?
- How do we determine this? Through cognitive studies?
- How would we apply this knowledge to interface design?
- How would this knowledge change geovisualization?
- What is creative thinking with regard to geovisualization?
- Of what relevance are other theories (eg., bricolage) to geovisualisation and how can they be applied?

By investigating these issues it should be possible to obtain a better understanding of how users are actually using new media. The answers will enable us to design better metaphors and tools for effectively using geographical visualization tools.

## Metaphors for Geovisualization

The effective use of an appropriate metaphor requires designers to ensure that both the user and the producer properly understand how to use that metaphor. Both the user and the producer of the metaphor contribute to the 'best practice' of metaphor use. That is, the 'expert' in content production needs to master the ways in which the metaphor should be best applied to the actual problem-solving exercise and the user has also to master the proper and most efficient use of the metaphor to be able to put the package to its best use (Nevile, personal correspondence, 1996). This could result in a more appropriate activity (for that particular task) than merely providing one metaphor for all tasks, no matter how appropriate a particular generic metaphor might be. The specific challenges identified in relation to geovisualization metaphor development and applications are:

- Understanding the relationship between metaphors and interface functionality;
- Understanding the cognitive processes associated with user interaction with geographical information;
- Understanding the ways metaphors might be merged effectively to support complex multi-scale, multi-variate, multidisciplinary geo-information access and analysis needs;
- Developing guidelines for the application of metaphors and associated knowledge (for practical implementation);
- Determining the best metaphors for different environments of use (Web, mobile), for different tasks, and for different users;
- Determining necessary differences between geospatial and other metaphors, if any; and
- Identifying metaphors appropriate to multi-sensory and collaborative interfaces.

## Interfaces to Accord with the Digital Earth Initiative

As noted previously, in a keynote paper given at the 1999 ICA conference in Ottawa, Canada, Goodchild (1999) proposed a landscape metaphor as being the most appropriate way of interacting with Digital Earth. The question, however, is whether the Digital Earth metaphor is appropriate for general implementation, and, should this one metaphor be applied to all visualization access initiatives? The most important challenge thus is to:

- Determine the effectiveness of the Digital Earth metaphor.

## 3D and VE Interfaces

Virtual world interfaces may provide an intuitive "window" into complex data representations. Does the use of virtual world interfaces to visualize facts such as currency flows in a finance network (as depicted in Figure 3) provide clearer depictions of virtual networks or virtual worlds? Geospatial representation packages have addressed this type of interface with applications in the mapping of Cyberspace (Dodge 1999; 2000) and other non-(conventional) geographies like the 'geography' of finance or information resources. We need to investigate how to best use three-dimensional and Virtual World interfaces to access complex geoinformation, such as that about (virtual) commodity dynamics. Specific challenges include:

- How effective are VE interfaces for the general/expert user?
- What are the most appropriate metaphors/interaction tools for these environments?
- What kind of geographic and non-geographic problems are most effectively explored using the virtual environment metaphor'?
- What kinds of controls make sense for interaction with abstract geospatial representations in GeoVE (e.g., a multidimensional space-time-attribute volume)?
- How do we provide users with access from within a GeoVE to geospatial databases that underlie the visual representations?

## Formal Languages as Interfaces

In order to encode visualization, languages that specifically address geo-graphics are required, for example Wilkinson's Grammar of Graphics (Wilkinson 1999). This in turn requires formalization and encoding of cartographic and visualization functionality and the formalization of interface operations on data and on visual representations. Interactive graphics, observer-related map behaviors (Shepherd 1995), requirements for exploratory data analysis (Unwin 1999), and developing forms of cartographic representation must also be considered and incorporated if they improve the geospatial information visualization tool. Work being undertaken on visual programming environments could also be applied to geospatial information representation.

Efforts being undertaken to formalize a theory of interactive graphics (see, for example, Wilhelm 1998) could be incorporated into a language for dynamic cartography. Extensible languages and software libraries provide the potential for extending the graphical scripting approach with reusable code that performs standard graphical and statistical procedures. The ultimate flexibility in scripting would be provided by high-level languages containing existing software components from which the user can "drop down" to an appropriate level of program specifics. The Java programming language can support this model, and geo-libraries already exist (see, for example, MacGill and Turton 1998). Java may also provide opportunities for incorporating multimedia data objects into a formal language to specify dynamic cartography (through Java 3D API, Java Media Framework API). Work in this area could lead to the kind of synthesis between compiled code, GUI and command line interaction that Unwin (2000) has championed. Certainly, extensible languages provide the opportunity to formalize and extend cartographic functionality by producing high-level cartographic languages that explicitly follow cartographic convention and procedure. Research challenges include:

- To develop visual programming environments for geovisualization;
- To develop a formal language for dynamic cartography;
- To investigate the applicability of visual programming approaches for formulating queries linked to geovisualization or building visual geospatial representations; and
- To determine the geovisualization problem contexts and range of users for which visual programming environments are most appropriate.

## Designing Usable Geo-interfaces

In recent years, the importance of usability has been recognized by researchers in a range of academic disciplines (Nielsen 1993). In particular, Web usability has come to the fore as an important area of research (Buckingham Shum and McKnight 1997; Nielsen 2000; Randall 1998). Some of the efforts to develop and apply usability engineering methods for design and evaluation of computer interfaces have been directed to interfaces for spatial information representation. Research in this area has looked at interfaces for GIS users, including public participation GIS (Elvins and Jain 1998); collaborative geospatial decision making (Nyerges et al. 1998); virtual environments (Gabbard and Hix 1997; Hix et al. 1999); digital spatial libraries (Buttenfield 1999) and spatial concepts for the representation of information (Buttenfield 1999; Fabrikant 2000).

In order to design effective interfaces for spatial information representation, it is necessary to understand how users interact with the interface tools and environments we develop. This requires the testing of metaphors and interfaces with "real-world" users undertaking "real-world" tasks in "real-world" situations (Hackos and Redish 1998; Nielsen 1993; Nielsen and Norman 2000; Rubin 1994). As detailed in the paper by Slocum et al. (this issue), an integrated cognitive science–usability engineering approach is likely to be productive here. However, developing this approach to match the unique characteristics of geovisualization environments and their application is, itself, a challenging research problem. A particularly difficult part of this problem is to:

- Develop a typology of geospatial interface tasks that can be used to structure both tool design and formal testing.

Most geovisualization environments developed thus far have been designed for expert users with relatively narrow application needs (for example, climatologists studying global change). However, never before has the general population had at its fingertips such a diverse range of spatial information and this trend will continue (Baker 1999). Thus, one challenge facing researchers is to:

- Extend our approach for the design of usable geovisualization interfaces to meet the needs of the general population or non-expert users.

This trend toward ubiquitous use of geovisualization makes it imperative that we are able to:

- Overcome the current lack of knowledge relating to both interface usability and the manner in which the general population interacts with flexible and dynamic interfaces.

The more general challenge facing researchers is to ensure that all interfaces developed are both usable and useful, with the developmental focus being on user-centered design and usability engineering

(Brown et al. 1999). In the past, many development projects have focused more on the application of new technology and the investigation of technical issues in applying that technology to geospatial information. Currently, although research into the usability of interfaces for spatial information visualization is increasing, a far greater effort is required. As Hix et al. (1999, p.1) state with respect to virtual environments, "Although usability engineering is a newly emerging facet of VE [virtual environment] development, user-centered design and usability evaluation in VEs as a practice still lags behind what is needed." This statement applies equally to research into the development of a wide range of interfaces for geospatial information access and visualization.

## Summary

Section four of this paper introduced a number of research challenges. The identification of these challenges was a result of virtual and in-person discussion by the authors and a large number of colleagues who have participated in Commission workshops and/or who have shared ideas in other ways. Here, we delineate what, based on these deliberation, we consider to be the six core user interface research problems facing geovisualization.

*1. In what ways should geospatial interfaces be different from other interfaces?*

With New Media and their use in visualizing geospatial phenomena it is asserted by the authors that we need a completely different approach to mapping and maps (if that is in fact what we call products from this geo-spatial information/knowledge provider) and to the provision of interfaces and "access nodes" into that information. One of the key research issues for the provision of interfaces for representing geospatial information concerns the sensory realism that is necessary.

*2. How do we adapt or create interfaces to interact with geovisualization using new and emerging devices? And, how do we measure interface effectiveness?*

The ever changing world of communication and visualization devices offers continual challenges for developers to produce packages that serve two "masters." Firstly, the needs of existing systems require maintenance and improvement to facilitate the best use of established systems. And, secondly, evolving technologies demand attention if appropriate systems are to be made available in a timely fashion. A central issue here is how to establish one systematic program that addresses the design of interfaces that are both applicable to existing systems, and their continually introduced newer versions, and are able to be quickly modified and adapted when new systems are introduced.

*3. What are the most appropriate interaction methods for different applications and users? And, what kind of geospatial problems can be answered by different metaphors of interaction?*

Users of dynamic geovisualization environments exert control over display design that was once left to cartographers (as discussed above). As users become the designers of the map, interfaces must change. A dilemma that must be addressed is that, while maps have become more manipulatable and changeable, non-expert users expect the same appearance on different platforms if the same manipulations have been applied and similar styles of manipulation from one geovisualization application to another. Although it is now possible to create highly interactive maps, the "design" and manipulation of which are left to users, no theory of interactive geovisualization design has yet been developed, no general guidelines exist, and we have very limited knowledge of the impact of interactivity on how people think or make decisions with interactive environments. There is a similar lack of knowledge in the wider visualization community, thus a coordinated, multidisciplinary effort is called for. These general issues are expanded upon in the following linked problems.

*4. How do users with different expertise actually interact with interface tools?*

Usability testing is needed to discover how users—expert and novice—interact with the tools developed by the geospatial representation community and interfaces should be developed using the principles of usability engineering.

*5. What are the fundamental components of interfaces that have an impact on collaboration and interaction between geovisualization users and how do these interface components relate to categories of collaboration?*

Linking visualization and collaboration together presents different problems than those associated with one user/one computer interaction. To understand and facilitate collaboration using geospatial information visualization tools requires that we learn what users actually do when using tools, as well as how they might collaborate electronically outside the geospatial visualization realm.

*6. How can we encode different interaction / interface styles? How do we transform between styles? And, is there a typology of georepresentation operations?*

There are a number of cognitive issues arising from user navigation and interaction (data exploration or mining) through a distributed/online mapping interface, including efficiency and success. These include individual differences, interface facilitation of success, and cognitive wayfinding strategies. Individual users develop their own particular “style” of using geovisualization packages. Once they are familiar with a product they can use an interface in ways that a designer did not envisage. If packages “learn” particular user traits, then perhaps user “bookmarks” or “user/usage metadata” can be written back into a package that will enable an appropriate interface for particular users when they re-visit the package. If a typology of georepresentation operations could be identified it could be used as a 'framework' upon which to build customized interfaces from stored user metadata.

## Conclusion

The challenges and core problems delineated above represent a subset of those discussed and developed during the various ICA Visualization and Virtual Environments Commission meetings. The questions outlined in this paper are those identified as the most pressing current issues. To take full advantage of the wealth of geospatial information becoming available to science and society, it is imperative that the issues about how best to work with geovisualization tools be addressed. This needs to be done with due consideration to expert and novice users, how they use geospatial visualization tools, and how they might effectively utilize these tools in collaborative projects.

> *As the bandwidth of networks increases, the capacity to publish multimedia conference proceedings, and university handbooks, will become the norm. … The technologies are there, but do we yet understand the techniques for guaranteeing the interactor a truly interactive experience? (Wills 1996, p. 199).*

Might we still ask this question a number of years hence?

Geovisualization, enables the exploration of information from multiple perspectives and thus through multiple complementary representations. Making them work (individually and together) is a difficult task. Sometimes we undertake the design and production of visualizations, and the associated access/interaction components somewhat remotely from the user. The mapping industry has always strived to create products by adapting available technology. This strategy proved to be useful and has iteratively changed the way in which maps were produced, delivered or consumed. As Müller (1989) noted some time ago, we will still need to fully research the possibilities of “intelligent” front-ends.

> *“Perception is no longer anchored by the vanishing point in representation. It drifts in a landscape with no horizon. The affective interface is about a certain tension between physical and digital matter and space. It is about a two-sided membrane which forms their common boundary and which is increasingly permeable to the senses, permitting a flow of information that carries expression, intelligence, and personality in both directions, and more significantly perhaps, into the interstices between the two spaces that the membrane defines”.* (Falk 2000, p. 29)

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Footnote:

[1] *New Media* includes a range of new delivery and display platforms; among them are the World Wide Web, interactive digital television, WAP technologies, interactive hyperlinked mapping services, and enhanced mapping packages that are "linked" to large databases—national or global. For discussion of *New Media* research, see http://www.skipper.gseis.ucla.edu/faculty/llievrou/html/HNMhome.html.