Challenges in Geovisualization

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Abstract—The increasing complexity and pervasiveness of geographical information in many walks of life is giving rise to some difficult challenges in the growing field of geovisualization. We take stock of these challenges and argue that mature technologies taken from areas such as databases and computer graphics may offer partial resolution of these challenges.

Index Terms—computer graphics, databases, geovisualization.

1. INTRODUCTION

THE cartographic representation is the traditional method to depict geographical information. This information is represented classically by two-dimensional maps. The visualization of geographical information has become increasingly important due to the escalating need for better and more realistic viewing, more flexible data models, and more diverse data integration, in a wide variety of applications. Geovisualization has become the common term for the visualization of geographical information. It refers not only to the visualization of spatial data but also to the use of new techniques for displaying information that has been extracted following data analysis.

Considerable attention has been devoted to evaluating the existing tools and examining new geovisualization methods. Geographical Information Systems (GIS) are now connected directly to visualization tools. Three groups have predominantly collaborated to develop tools and to investigate new visualization methods: the Association for Computer Machinery's Special Interest Group on Graphics (ACM SIGGRAPH) (www.siggraph.org/~rhyne/carto), the ICA Commission on Visualization and Virtual Environments(www.geovista.psu.edu/sites/icavis) and GeoVRML which is the Virtual Reality Modeling Language for geographical data (www.geovrml.org). Many GIS companies are working on more complete and effective scene representations and a wide variety of visualization systems are already in existence.

Although there has been considerable progress, there remain limitations and some areas need further investigation. Gahegan [5] points out that there are barriers to the development of effective exploratory visualization tools. We believe high performance computer graphics tools and its techniques can contribute greatly to geovisualization and that greater research effort should be devoted to this endeavour.

The effectiveness and use of computer graphics in geovisualization is receiving increased attention. A proposal for virtual environment technology for geovisualization and the need for 3D dynamic displays is described in [10]. The importance of simple color-based highlighting styles is presented in [15], and the importance of 3D computer graphics techniques for geovisualization is also denoted in [3].

In this position paper, we give an overview of recent progress in the area of geovisualization and strongly argue for the need for increased attention to applying techniques from 3D computer graphics to this field.

2. STATE OF THE ART

A variety of different GIS systems or tools exist that support access, data analysis and geovisualization for many activities in many application domains. Recent improvements have largely concentrated on the following issues.

- *Cartographic support*. Many more graphical cartographic features are now available in real systems. Levels of detail may be represented by symbols, colors, annotation and text. Rules can be specified to depict the geometry, natural phenomena, physical objects and relationships among spatial features. Multilayer representations are supported by many systems, and every layer has its meaning and relevance in the real world.
- *Multiple data formats*. A wide variety of data formats can be created through the use of different methods for data acquisition. Terrestrial, aerial and subterranean formats may be used in the same or different systems. Many tools are available to convert among formats or to allow systems to interoperate using different formats. For example, different image formats may be supported and different representations of spatial data such as raster and vector are often allowed.
- *Performance and Scalability*. Several tools have been developed to improve the general quality of visualization and to support system scalability. Particularly when dealing with large data sets, new functions make it

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possible to zoom, to navigate, to fly-by, and sometimes to animate large and complex scenes [9]. Better performance has been achieved using advanced application program interfaces and more careful attention to systems-level issues such as temporal coherence, caching and predictive data prefetching [13].

- *Metadata and Documentation*. Documentation can be supported by more refined tools that record information about the sources of the data, descriptions of individual steps during the data acquisition process and annotations of the general characteristics of the data. The geospatial metadata record includes a catalog of elements describing the characteristics of each data set. Normally this is embodied as a file presented as an XML document that includes all this information and supports every data set [7].
- *Database.* Many vendors and companies that develop GIS's have devoted considerable effort to the use and management of spatial data within a database. Such systems use some spatial database management functions and some provide interfaces to database management products. They are typically based on the relational data model which mainly includes tables with attributes, the description of their instances and some relationships between the geographical objects [19]. There is work that provides integrity constraints derived from the primitives and spatial relationships in spatial databases [1].
- *Increasing use of the third dimension.* A GIS traditionally parameterizes geographical data such as a height-field as a function of two rectangular or angular dimensions. With the increasing diversity and volume of geospatial data, GIS's must now incorporate fully three- or four-dimensional spatiotemporal parameterizations. As mentioned, many systems currently represent a third dimension as an attribute or value that is seen as a function of the other two dimensions. Furthermore, ad hoc solutions are often employed. For example, the visualization of 3D contours and isosurfaces is often flattened into two dimensions for viewing [8]. Several approaches to 3D geovisualization are emerging. One approach, for instance, integrates web-based 2D and 3D technologies for architectural visualization [18]. In another approach 3D modeling is used in geological applications [16, 17].
- *Visualization of texture.* Natural objects have textured surfaces that derive from phenomena such as vegetation or terrain. It is necessary to model surfaces more realistically to enhance human analysis and processing of geospatial data. Some work presents texturing techniques for terrain visualization applications [2], and others have demonstrated how synthetic texture can be generated [12].

3. *Graphical Limitations*

All Geographic Information Systems are mainly geared to a particular application. A quick count reveals about twenty categories for Geographic Information Systems, including soil information systems, urban information systems, and so on. Most of them engage in collecting, analyzing and visualizing data, but they still have considerable limitations for the visualization of spatial information. As mentioned in some recent research work, there is a need to improve the interoperability of three dimensional geovisualization components. Computer graphics rendering libraries and standards evolved independently of geospatial data models. This has resulted in inefficiencies associated with geovisualization. We identify the following key areas of geovisualization that require considerably more work:

1. **Time series animation**. Animation must become a first-class primitive in a geovisualization system as it can depict different forms of temporal variation of spatial data. We can identify the several categories of change: a) measured or simulated evolutionary data changes due to external events such as an earthquake, growth, erosion, or the construction of a new street; b) data changes due to inconsistencies in spatial or temporal data sources arising from combining disparate data sets; c) data changes in the representation due to generalization, enhancement or abstraction. There is some work using computer animation for time series data taken from satellites [11], but traditional tools for geovisualization do not usually incorporate tools to create and manipulate time series animation. For example, the changes of the sea shorelines cannot easily be depicted as a function of tides or seasons.
2. **3D Geovisualization and Extensibility**. Users must be able to create their own features, change scale, rotate objects, etc. The techniques and tools have to be interactive. There is a need for better modeling systems in order to reconstruct data in 3D. Traditionally, spatial data is parameterized two dimensionally but a great deal of data is now three dimensional. Manipulating such data interactively and realistically will naturally require higher-performance hardware and software. However, it will also require more general and powerful geovisualization tools. For

example, the generalization of topological relationships to 3-D for geological purposes is not supported at this point and requires further research.

3. **Combining a database management system with a graphics display system**. The functionality of such a combination is to develop interactive, application-independent data exploration and visualization tools. Such a technology would not rely on special data transformations or formats. Such variations would be accounted for in a data description language. Furthermore, it is widely accepted that commercial geographic information systems are not user-friendly. Just as an appropriate abstraction is needed for data, the user-interaction layer must also be abstracted from the hard-core functionality of any underlying GIS. Although this idea was presented some years ago [6], there has been little progress in this direction. There is a prototype [4 that combines database technology and visualization to support the visualization of ecological data but since the geographical data sets are so complex it is very difficult to develop a general tool with the level of abstraction we are advocating.
4. **Texture mapping.** While (pseudo-)coloring a two-dimensional surface is a fairly well known operation, there has been relatively little research on the more aggressive use of planar two-dimensional or volumetric three-dimensional textures to geovisualization. The former can provide details of the surface structure of an object, allowing easy disambiguation among, for example, varieties of stone, wood, vegetation, etc. On the other hand, a volumetric texture can represent interior structure, such as sedimentary layering, and veining. Volumetric textures can also represent densities of phenomena that have no easily characterized shape, such as mist, smoke, clouds, bodies of water, etc. Texturing provides important visual cues for human observers to analyse and classify, often without prior automatic segmentation.
5. **Distributed Geovisualization**. With the rapid proliferation of data on the Internet, a data set pertaining to the same location can become available from different sources taken at different times. Huge amounts of data of the same location can now come from satellites, aerial images, sensor networks, etc., but that may have been relevant to different applications such as urban planning, geology, health, econometrics and demographics. Such data sets are often stored and managed locally and users often have privileged access only to only one. The integration and concurrent exploration of these data sets can yield considerable insights into the real geospatial structure of a region. However, there are no tools that are capable of automatically extracting and visualizing data located in distributed, disparate databases [14]. We use the term distributed geovisualization to refer to the orchestrated use of tools and data that may be distributed across many applications, workstations and data servers.
6. **Integration of Geovisualization and Geocomputation**. The constantly increasing computational power and rendering speed of commodity workstations is bringing us to the point where geovisualization could occur in tandem with geocomputations such as data integration and analysis. Furthermore, the advent of efficient physical simulations, while still time consuming, afford a further opportunity for interactive visualization. Virtually everything that was once thought of as an off-line process is now a candidate for online, interactive implementation integration. This will allow much more dynamic kinds of data exploration. For example, the analysis of a specific observable phenomenon such as a forest fire or rock slide may be coupled to a simulation interactively to permit a broader exploration of its underlying causes or predictions of its future behaviour. The importance of exploratory data analysis will thus require much more dynamic methods that can help to discover relationships and hidden parts interactively.

4. Tools From Computer Graphics

Although still a very active field of research, the fundamental tools of computer graphics has matured over the past decade into a powerful, stable, high-performance technology. While its main applications have been to film and video, video games, virtual reality, scientific visualization and medical imaging, it also has considerable potential more generally in the area of information visualization. Computer graphics is the science and technology of computer-assisted visual communication, and is responsible for performing a transformation from geometric and physical models to sequences of images. The input primitives for such a process can take on many forms, provided there is a way to transform these primitives into a well understood spatial representation. Furthermore, the underlying algorithms of computer graphics are typically independent of form factor and image resolution, although there exist many customizations to specific display systems and architectures such as large-format display systems, CAVEs, desktop workstations, laptops, handheld devices and embedded systems. The use of more advanced computer graphics techniques appears to be an obvious one for geovisualization, and yet there has been relatively little progress in this area.

We outline a few basic technologies of computer graphics that we feel could be useful in geovisualization.

1. *Color and Shading*. Any object that can be given a color may also be assigned other geometric properties such as a locally-varying surface normal and material properties (water, reflectivity, material composition). With the addition of one or more light sources, this would immediately permit the computation of optically relevant information such as surface reflectance and transmission and shadows.
2. *Geometric modeling, transformation and viewing.* A wide array of modeling tools exist to manipulate geometric representations. Furthermore, graphics systems provide easy workflow to view, clip or slice through models.
3. *Texture mapping*. The introduction of variations in surface coloration through a texture map will allow the realistic rendering of terrains, vegetation and other two-dimensionally parameterized phenomena. Adding three-dimensional textures would allow the computation of illumination in gaseous or fluid environments using multiple scattering.
4. *Bump mapping and displacement mapping*. Textures may also be used to create "bumps" by perturbing local surface normals, and they can also displace the actual geometry according to a height function. This will add more realistic viewing while still maintaining interactivity.
5. *Realistic lighting*. Many computer graphics systems are capable of modeling a wide range of artificial and natural lighting conditions.
6. *Image quality*. Rendering algorithms in graphics are preoccupied with producing high quality images. The use of such technology for text and graphics would automatically lever built-in image quality features such as anti-aliasing and higher quality sampling schemes.
7. *Multiscale representations and levels of detail*. Because computer graphics has a long tradition of needing to work interactively on a wide array of devices, the data representations that are used are characterized at different levels of detail. This affords storage and computation budgets that are amenable to the display environment. Furthermore, level-of-detail algorithms are often employed within the compution of a single image to handle issues such as varying data density across the image. For example, in regions of high perspective magnification such as in the foreground, a greater degree of detail will be needed than in the background, or toward a horizon line.
8. *Animation*. The full power of stop-frame, keyframe, kinematic and dynamic animation techniques would be available to those attempting to perform geovisualization. There is little reason to reinvent the wheel.
9. *Visual Simulation*. A wide array of simulation technologies has been developed that are amenable to interactive viewing. This would provide an attractive workflow for visualization applications in which data analysis, simulation and visualization could occur simultaneously.
10. *Hardware acceleration*. It is important for geovisualization to "surf" the wave of cheap, high-quality graphics acceleration cards that are available virtually as commodity components. Graphics systems are usually able to provide fast, accelerated viewing at interactive rates for screen resolution and then send the same scenes to offline renderers for very-high quality rendering for film or high-definition video.

5. *Concluding Remarks*

The time, we believe, is clearly right for much more dramatic exploitation of computer graphics technology in the display of geospatial information. Computer graphics has largely responded to the challenges of computer animation, entertainment, and scientific visualization. Researchers in GIS have developed their own visualization techniques in isolation that have proven to be somewhat effective but do not go far enough. There is a tremendous potential to adopt the tools and techniques that have been developed over the years in computer graphics to let users explore the full potential of spatial data. This paper has explored some techniques that we feel will be of interest to geovisualization. We have also strongly advocated the need for greater interactivity, for cleaner data abstraction, and for better schemata for data integration.

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