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GRAPHICAL, VISUAL, AND IMMERSIVE INTERACTION WITH GEOGRAPHIC DATA

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ABSTRACT

The creation of human-computer interfaces is, by necessity, becoming an increasingly sophisticated endeavour. This is caused by the desire to have the computer user less and less burdened with questions about the computer and its software, and more about the user's application. Graphical user interfaces have thus become standard in any work with digital maps and geographic data.

In this paper we will discuss the advance from graphical to visual and immersive user interfaces. Visual interfacing is applied in the context of multimedia data, and immersive interfaces create a virtual reality for the user. We suggest that Geographic Information Systems will become more like hypermedia systems and more three-dimensional in nature, particularly in the context of urban settings. Interaction with such truly three-dimensional worlds will be best by means of stereoscopic presentations; the magnitude of the databases may furthermore suggest that the user be given the ability to "roam through" the data. Visualisation will improve to become photorealistic rather than a symbolised representation of points, lines and shaded regions, as is the case in the tradition of symbolised line maps. And the conventional view of terrain from a map-perspective will be augmented to include views "from the ground". This will indeed be a "scale-free" representation of geographic data.

INTRODUCTION

We propose that urban Geographic Information Systems (GIS) be set up and used in a fully three-dimensional manner. Current GIS typically present only two-dimensional data, where the third dimension is kept as an attribute of otherwise two-dimensional database entries (Bill & Fritsch, 1991).

We further suggest that urban GIS support photographic images as a fully integrated part of the database. Many desirable pieces of knowledge do not lend themselves very well to abstract presentation in a vector-based GIS, but communicate very well via photographic imagery. Also, it may well be that such imagery is less expensive to create than the highly abstracted data types commonly found in a GIS (Sarjakoski & Lammi, 1991).

This combination of three-dimensional data types and integrated imagery creates a need for innovative interaction between human and computer. The need therefore exists to abandon current two-dimensional graphical interface standards, such as X Windows, and substitute an ability to deal with imagery and geographic data in a three-dimensional manner. This also

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goes beyond the current multimedia approach to interfacing which remains an interface in the two-dimensional domain.

We will review the current status of human-computer interfaces and discuss the status of GIS with regard to images. We will then examine the usefulness of current hypermedia work to image-based GIS. And we will conclude with a discussion of three-dimensional data and images in an urban environment, thereby pleading the case for the use of stereoscopic viewing and of emerging virtual reality technology.

USER INTERFACES AND HUMAN-COMPUTER INTERACTION

Graphical User Interfaces

Graphical User Interfaces (GUIs) have become the standard method of presenting data to and soliciting input from the user. The all-pervasive "desktop metaphor" presents the computer's display as a "desktop" on which overlapping sheets of "paper" lie. Each such sheet is represented as a window, in which a particular task proceeds. A single user is able to control multiple tasks via such windows.

Within a window, user interaction is typically not via textual commands, but via icons a user can click on. Command menus are often provided slung beneath a menu bar at the top of the window, the menu items sometimes having associated keyboard "accelerators". Direct manipulation techniques allow the user to grab graphical objects in an application window and interact (move, delete, query) with them directly.

Both (Shneiderman, 1992) and (Tognazzini, 1992) are excellent general sources of information about user interface issues and techniques.

Multimedia and Hypermedia

Multimedia and hypermedia systems take the GUI a step further. Multimedia systems integrate various types of media: text, images, drawings, sound, video, etc. into one system. Typical examples might be desktop publishing applications, or multimedia encyclopedias on CD-ROM. (Blattner & Dannenberg, 1992) present an overview of the state-of-the-art in multimedia interfaces.

Hypermedia introduces the concept of non-linear linking. Documents may contain computer-navigable links (references) to other documents, which may be followed according to the reader's interest. Documents can be seen as nodes in a graph, the links being edges between nodes. Some hypermedia systems superimpose a hierarchical structure upon the basic node-link model, whereby nodes are clustered into collections and subcollections. Others provide search facilities to help locate documents of interest.

The advantage of hypermedia lies in its more intuitive model of information access: a reader can browse through an information base by following links to related information. Nielsen's book(Nielsen, 1990) is an excellent introductory text about hypermedia.

Three-Dimensional Interfaces

Gradually, computer hardware supporting three-dimensional graphics is becoming more commonplace. With it, truly three-dimensional interfaces are also emerging. Perhaps the best-known example is the Information Visualiser (Robertson et al., 1993) work at Xerox PARC. A user can "walk" around in a room, examining the contents of the room at his/her leisure.

Clicking on a door causes the door to swing open, and the user is pulled through into another room (like following a hypermedia link). The rooms are populated with artefacts representing various kinds of information, for example a three-dimensional cone tree showing the hierarchical structure of a company or the directory structure of a file system.

Another example is the work at Graz University of Technology, where three-dimensional nodes are being integrated into a fully-fledged hypermedia system (Andrews, 1993). A 3D polygonal model can be explored by a viewer, and links followed to or from any other kind of hypermedia document (text, image, film, etc.). The two most common types of 3D model here are models of *objects* which one examines, and models of *scenes* which one explores. Figure 1 shows an example model of a scene, one of the authors' office, being explored.

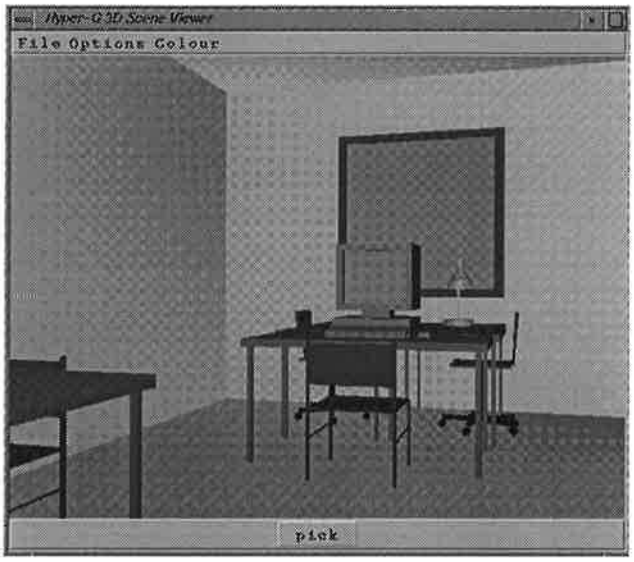

Figure 1: Example of 3D Hypermedia Scene

Such three-dimensional interfaces can be termed "through the window" interfaces: the user interacts with a computer-generated 3D world displayed on the computer screen, as if looking through a window.

Immersive Techniques

The attention-grabbing alternative is the immersive approach known as *Virtual Reality* or VR (Pimentel & Teixeira, 1992), in which the user enters a virtual world wearing data garments to map the senses directly to the digital environment. A helmet provides a stereoscopic image (through separate displays for the left and right eyes) and accompanying binaural sound (through built-in stereo headphones). A dataglove projects an image of the user's hand into the virtual world: objects in the computer-generated reality can be manipulated, or hand-gestures can be used to navigate: for example, by pointing in the direction one wants to fly.

Until recently, such virtual realities were somewhat thin illusions, mainly because the graphics hardware used was incapable of displaying more than simple shaded polygons at interactive speeds. However, a new generation of graphics hardware is now able to display texture-mapped surfaces at interactive speeds, allowing the creation of very convincing visual environments.

For VR to become acceptable in GIS applications, it will need to create photorealistic perspective images consisting of perhaps 500 by 500 colour pixels in *real time* (i.e. at a rate of around 25 such stereo pairs per second). As a result, the user will perceive a three-dimensional scene and be able to move dynamically in it. For example, every move of the head will cause, within 40ms ($1/25^{th}$ of a second), the corresponding stereo images to be generated and the user's view to be updated. The necessary computing power will need to be available to accomplish such photorealism in real time.

However, there exists an intermediate solution that simulates immersive interaction with data by offering a three-dimensional view through stereoscopic perspectives, but at a rate of image generation that is much slower than real time. Conceptually, the data are not being investigated through real-time feedback loops and data garments, but through an interactively prepared script. Script preparation may be supported by highly simplified cartoon-like data presentation and may therefore be accomplished in real time. Photorealism is then computed off-line and the result presented stereoscopically. In this approximated virtual reality, interaction is via highly simplified data; photorealism is employed in an open rather than a closed loop.

THE GIS AS A TWO-DIMENSIONAL DATABASE

Current Geographic Information Systems are mostly based on data consisting of line, point, and symbol elements that are abstractions of features of the real world of interest to geographers, economists, urban planners, etc. Coastlines, rivers, borders, city borders, roads, railroads, city centers, and mountain peaks are examples of typical small-scale, atlas-type data. The exact layout and location of streets, buildings and parks, street names and house numbers, the position of traffic lights, one-way streets, speed limits and other traffic restrictions, and many more (e.g. urban utilities) are typical for large-scale, GIS-type data used in urban management systems.

These geometric base elements are usually combined with grid and location based data. Aerial photography, satellite images, and records of human construction activity are the most common sources of GIS data, which is then either extracted manually or automatically by image processing tools.

The visualisation of GIS data usually employs very abstract concepts: data are displayed using geometric elements (lines, polygons, and symbols), which help in the analysis of features and present abstract views of these (like thematic maps in traditional cartography). Missing from a GIS are high quality (beautiful) maps in the tradition of high quality physical maps in cartographic publishing: These maps are also abstractions, but they provide a good balance of abstraction and realism that has developed over centuries. In fact, in many cases GIS may have replaced the use of traditional cartographic maps. Where maps are still applicable, cartographers refer to the transition from the "scale-free" data in a GIS to a cartographic representation as "cartographic modeling".

GEOGRAPHIC INFORMATION AND HYPERMEDIA SYSTEMS

The most fundamental feature of GIS is represented by the "I" in the name: interactive Information retrieval and analysis using the computer. It is well known that traditional cartography and photogrammetry at first adopted the computer as a tool for machine supported drafting to create the same traditional cartographic products. It was the GIS's interactive information retrieval that rendered digital map drafting systems obsolete; they mutated into the contemporary GIS. This emphasis on digital data, interactive information retrieval, spatial and pictorial data etc. lead to the observation that GIS may, in fact, be considered a special case of more general hypermedia information systems.

In this sense, map and location data in GIS style can form the backbone of a hypermedia system where, for example, icons symbolising data entries are automatically positioned on the map and form the sources of links to corresponding data items. To gain user acceptance such a system has to *look good* and has to provide the analysis features of a GIS. The most successful approach so far uses traditional maps (scanned images) and hides the GIS under it. A typical example of a system of this kind is the Vienna City Map developed in Graz at IMMIS: It offers high quality maps, route optimisation, database integration and two-dimensional queries.

Of course, some of this type of data use represents a distinct difference from a GIS: the maps are digitised in their iconic form as digital images, thereby ignoring the descriptive and topological elements of geographic information. Mere digital map data storage and intelligent retrieval applications have been reported for traffic management, real estate documentation and in military settings, but are not typical of GIS.

The most widely applied Geographic Information Systems at the moment are ESRI's ARC/INFO (Redlands, California), the system by GeoVision (Denver, Colorado), Intergraph's TIGER (Huntsville, Alabama), and in Europe, Siemens/Nixdorf's SICAD (Munich, Germany). We observe in these widely distributed systems that they excel in the manner in which geographic data can be stored and organised, how the user may be supported in queries, and how data can be cast into hardcopy visualisations of both the GIS-data and derived query and analysis results. However, their focus is on data and data visualisations, not on advanced human-computer interfacing issues. This is where hypermedia systems present a separate class of tools.

IMAGES AND GEOGRAPHIC INFORMATION

The highly abstracted geometric elements (lines, polygons, symbols) commonly found in a GIS convey certain kinds of information very well, but are lacking for other kinds. Integrating support for photographic images into a GIS opens up a whole new horizon. Initially, such capabilities are being added to GIS products in the form of so-called *ortho-rectified* aerial photographs and satellite images (Ehlers et al., 1989; Derenyi & Pollock, 1990; Fritsch, 1991; Yang, 1991).

Ortho-rectification refers to the geometric warping of photographs so that the result is in the coordinate system of the geographic data, i.e. the photographs are transformed from camera coordinates into the world coordinates of the GIS. However, the role of such images is merely as a "backdrop", enabling the user to concurrently view both symbolised GIS data and photographic images of the terrain. Should the GIS be vector-based, then the combined visualisation is accomplished through a vector-to-raster conversion of the GIS-vectors to the raster of the photographs. If the GIS is raster-oriented (as is the case for example in the public domain software GRASS) then the photographs can be integrated as a layer of information in the GIS. The data themselves do not "interact". (Kienegger, 1992) discusses a photo-based GIS where pixel data are not just a visual backdrop, but serve in automated data analysis, just as another layer would in the conventional GIS. An example of such interaction is the automated assignment of a texture parameter to a polygonal area in the GIS, using the photograph as the source of the texture. So while high quality map images can be used as an underlay for the standard GIS grid, icons linking to photographic imagery can be overlaid as well, for example photographs of street fronts in an urban setting. This has become an accessory to GIS products for real estate applications.

Hypermedia systems are borrowing typical GIS features, such as using a map as a central navigation aid, and vice versa. While GIS are slowly being enhanced to incorporate images, hypermedia systems were originally conceived with images in mind. IMMIS has produced a number of hypermedia systems that integrate high quality maps and pictures. The base maps are produced in cooperation with the Viennese map and book publisher Hölzel.

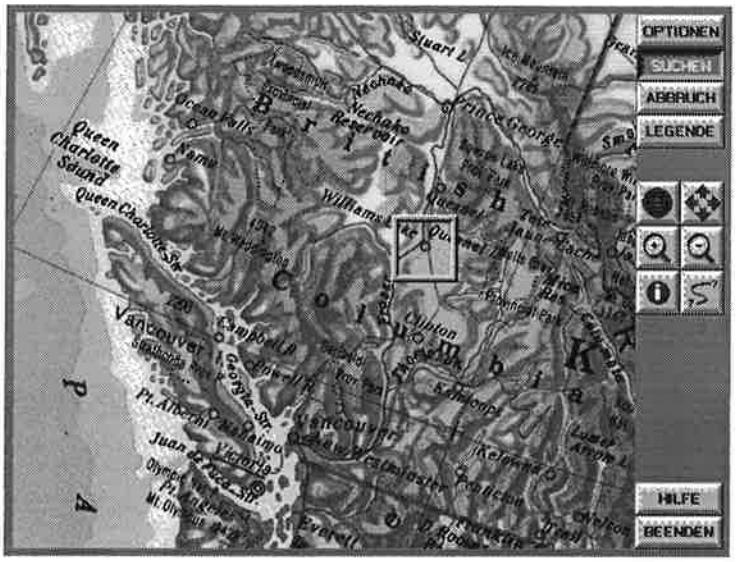

Figure 2: ELWAT, Electronic World Atlas

ELWAT, an electronic world atlas on CD-ROM includes high quality physical maps of the whole world in several magnifications. An index allows 100,000 place names to be located, around 3000 pictures present a pictorial overview of the world, and about 8000 articles from a German encyclopedia (Meyer/Brockhaus) describe cities and landscapes (see Figure 2).

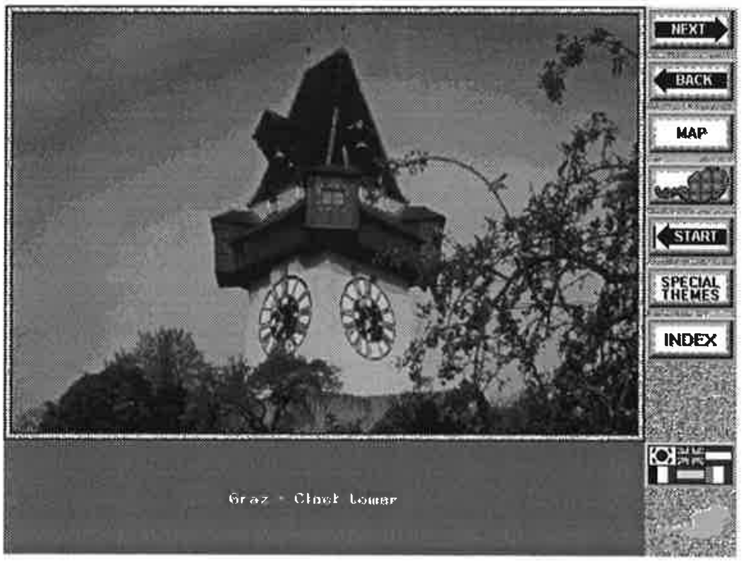

Figure 3: AMAPA, Electronic Presentation of Austria

AMAPA is the electronic presentation of Austria on display at the World Expo 1992 in

Seville, Spain, and Expo 1993 in Seoul, South Korea. It features a map of Austria with icons embodying links to pictures, textual information and digital films (see Figure 3).

TOWARD A 3D GIS

Current standard GUI technology is two-dimensional. This is entirely sufficient for work involving numbers and text, but may quickly become inadequate for graphical data if such data addresses more than two dimensions, as it typically will: while the world which we observe from an airplane may appear two-dimensional, the world in which we move is three-dimensional, and we are very well-equipped to experience and operate in such a three-dimensional universe.

Computers and GUIs are not normally equipped to cope with the three-dimensional world. Worse: many physical phenomena can only be described with more than three dimensions. Examples include air mass, water temperature, noise, pressure, and many other environmental factors expressed as a function of 3D space.

Development of GIS and industrial Computer-Aided Design (CAD) systems has evolved largely separately. While industrial CAD systems are naturally three-dimensional, GIS have evolved as 2-dimensional systems. At the scales commonly used with geographic data, it is entirely understandable that the third dimension is treated merely as an attribute of two-dimensional objects. We suggest that as the scale of a problem domain moves into ground-based issues and increases to the details of buildings and their individual parts, the GIS will become a CAD-like fully three-dimensional tool.

We believe that in this scenario feature coordinates will be 3D, and object points will be connected to define 3D facets. These facets will be assembled into 3D objects which can be viewed from various perspectives (above, from the side, from below etc.). "Objects" are placed geometrically on top of the so-called "bald Earth", a concept that is of relevance as one moves from 2D GIS to fully 3D concepts.

To experience 3D information, and to interact most effectively, such data should be presented in stereoscopic form. As one assesses certain issues through a 3D GIS, it may become important to provide data visualisations not only in 3D via stereopsis, but also in photorealistic form. Photorealism implies, however, that information exists about each object facet's surface texture and light reflective properties. We come to see the outlines of a 3D GIS specification, as summarised in Table 1.

- object coordinates in XYZ
- objects made up of facets
- "bald earth" populated with 3D objects
- surface texture and reflective properties
- stereopsis
- photorealistic visualisations

Table 1: Some Features of a 3D GIS

Inspired by 3D CAD and 3D computer interface developments of recent years, the 3D GIS is but an engineering effort away from implementation. In so-called industrial photogrammetry applications, mapping technology has begun to move from 2D (sometimes also denoted as $2\frac{1}{2}$D due to the third dimension as an attribute of 2D objects) to fully three-dimensional data systems. Three-dimensional user interfaces have begun to become available for computer workstations – the challenge is to apply this new technology to the realm of GIS.

EXPERIENCING AN URBAN ENVIRONMENT IN 3D

Imagine for a second being the size of an ant and walking around a traditional cardboard scale model of a neighbourhood of Vienna. Walking around a virtual model, existing solely within a computer, of the same neighbourhood by means of immersive VR technology is a similar experience.

The quality of the illusion depends directly on the effort expended in building the virtual model. A simple polygonal model appears like a scale model built of plain cardboard – the house fronts and roofs have simple uniform colours. Applying texture maps to the polygons greatly enhances the realism of the model – like glueing scale photographs of the actual house fronts and roofs to the cardboard faces.

A tourist could don the necessary garments and take a (virtual) walk down Kärntnerstraße, the main shopping street in Vienna. Reaching out to touch an information plaque on a house wall might start an audio clip describing the building's history. An urban planner might use a particular hand gesture to turn the pavement semi-transparent, revealing the underlying layout of gas or water mains. The architectural model of a new building project could be imported from a CAD system and viewed in the context of its surroundings.

ISSUES OF IMPLEMENTATION

How would one go about implementing such a three-dimensional GIS? There are two main issues: that of building the underlying system and that of data preparation.

The underlying system necessitates an information storage and retrieval component, and a run-time user interface component. Depending on the underlying GIS implementation, traditional information storage and retrieval techniques already used in 2D GIS may not be capable of dealing with intrinsically three-dimensional data. In this case, the 3D GIS structure may be better derived from current CAD technology. The user interface component will also be dramatically different in character from current ones. Powerful 3D graphics hardware and new user interface techniques such as stereopsis and immersive VR will be necessary to fulfil the potential of 3D GIS and offer users new insights into spatial data.

As regards data preparation, techniques from the field of photogrammetry will serve to construct a 3D model from photographs of an original object. In the context of urban GIS, photographs taken of the building fronts along a street (terrestrial photographs) will be used to automatically generate a 3D model of the street. These photographs will be combined with aerial imagery to provide a coordinate framework for the entire urban environment. As an urban model of buildings and streets comes into existence by means of photogrammetry, one may also consider the addition, in 3D, of underground and overhead data, of the insides of buildings, the quality and colour of surfaces, and the conventional thematic or attribute information in a GIS, such as cadastral data, ownership, date of construction, etc.

The photographs for photogrammetric measurements mentioned above exist in digital form and therefore can be the source of texture maps to be applied to the model. State-of-the-art graphics hardware can display relatively complex texture-mapped models in real-time, thus opening the way for the vision of photorealistic 3D GIS we champion here.

Currently, the necessary hardware is available for upwards of US $100,000, off-the-shelf 3D real-time database modeling software for around US $50,000. Virtual reality hardware, software, and associated immersive user interface techniques are only just emerging from research labs into the wider market. However, as with all new components, prices are expected to plummet and performance rise as the technology takes hold. In a few years, affordable solutions will become available for university departments and small to medium sized companies, hence opening the way for the widespread introduction of 3D immersive GIS.

We suggest a first move towards an integrated multi-media, three-dimensional urban geographic information system, consisting of a number of developmental steps:

- an existing CAD system is augmented by urban data requirements;
- 3D urban geographic data are collected into such a system from digital photogrammetric sources, and are augmented by conventional urban thematic and locational data;
- facets (surfaces) are annotated with photo-extracted textures and reflective properties;
- a stereoscopic user interface is developed for interactive viewing, processing and editing of urban geographic data;
- an interactive tool is developed to create a script for 3D photorealistic and kinematic visualisation, and to lay the groundwork for true Virtual Reality visualisations of, and interactions with, urban geographic data.

These steps should be tried out on a particular city neighbourhood and include data about the inside of buildings and creative modes of visualisation and interaction. Concepts of hypermedia, digital photogrammetry, 3D computer graphics, and immersive user interfaces will combine into entirely novel ways of urban data management.

CONCLUDING REMARKS

We have illustrated the analogy between Geographic Information Systems and hypermedia systems. This supports our view that these technologies will merge in the future so that geographic information is but a special case of general types of information, both spatial and thematic, with which to interact. We have furthermore made the point that data interaction will not only be fully three-dimensional, but will also become immersive, once the tools of virtual reality have become sufficiently widespread that costs and capabilities fulfill the promise of instant 3D photorealism at kinematic rates of 25 picture pairs per second.

Cartography has gone a long way to arrive at today's compromise between abstraction and realism. Today's and tomorrow's technology can change this dramatically: We will be able to produce maps that can change at the blink of an eye from a very abstract presentation of demographic and economic data to a two-dimensional traditional map, and then at the wave of a hand to a sophisticated simulated reality completely immersing the viewer.

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