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Maurizio Forte
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Archaeology, GIS and desktop virtual reality: the ARCTOS project

Virtual Environments (also called Virtual Reality or Cyberspace) are regarded as a significant step forward in Man-Machine Communication. Following non-interactive, command-driven and graphical-interactive systems, Virtual Environments now allow an easy-to-understand presentation and more intuitive interaction with data. The computer's internal world, consisting of data and processes, represents various aspects of a natural environment or even an artificial world outside of any human experience.

In this paper we want to show that an interactive approach in 3-D scientific visualization of archaeological data is an important cognitive information system, in particular using GIS with virtual reality systems.

1 Introduction

Scientific Visualization is related to the use of computer graphics in the analysis of scientific phenomena (McCormick *et al.* 1987; Smarr 1991). Some problems, such as complex three-dimensional structures common in the fields of medical imaging, environmental science, and molecular modelling, are studied best by computer graphics tools which help the researcher to understand the structure of the phenomena by drawing pictures. Moreover, interactive computer graphics, which allow real time control over how the graphics are generated, through the use of a computer further enhances the researcher's ability to explore a phenomenon. When the phenomenon under study is three-dimensional, the display is projected onto the two-dimensional display screen and the two-dimensional mouse movements are mapped into three-dimensional control. The mouse typically controls both the viewpoint of the projection and the position of the object in view.

Virtual environments provide a fully three-dimensional interface for both the display and control of interactive computer graphics. A stereoscopic head-tracked display with a wide field of view (fig. 1) presents a compelling illusion of a three-dimensional world generated by computer graphics. The researcher feels immersed in this world full of computer generated objects which appear and behave as if they were real. The display device tracks the user's head and controls the point of view of the computer generated scene. Using an instrumented glove, the researcher can reach out and directly manipulate the virtual objects' position and orientation in three dimensions. Using these techniques, virtual environments attempt to create an illusion so compellingly realistic that one interacts with it as naturally as if it were real. Virtual environments provide a natural, intuitive Man-Machine Interaction. Using virtual environment control techniques, the researcher can rapidly change what and where data is displayed, allowing the exploration of complex data environments. Normally, immersion is achieved either by wearing a head mounted display (HMD), using a binocular omni-orientation monitor (BOOM), or by moving within a room with — probably several — large screen projections, as for example in the CAVE system (Cruz *et al.* 1993).

2 VR interfaces and cooperative work

The effective use of VR involves design opportunities that include intuitive exploration environments with directly controlled visualization tools such as interactive colour-mapped cutting planes. Use of the new interaction and display capabilities effectively poses challenges whereas VR performance requirements pose constraints. All computation and rendering must take place within at most 0.1 second to support both the illusion of immersion and direct user control. Computation, rendering, and data management processes should be asynchronous, so that long delays in one will not affect others.

Some application areas for VR-based visualization environments, such as fluid flows or astronomical data, require relatively simple computation and rendering, but others, such as real time archaeological landscape navigation together with photorealistic reconstructions of buildings and objects, require more ambitious systems not yet available including shared, distributed, multi-user VR-based environments.

Cooperative interpretation and analyses of data (CSWC - computer supported cooperative work) will enable dispersed groups to access the same datasets and to perform better, producing more efficient and creative work than would group members working alone.

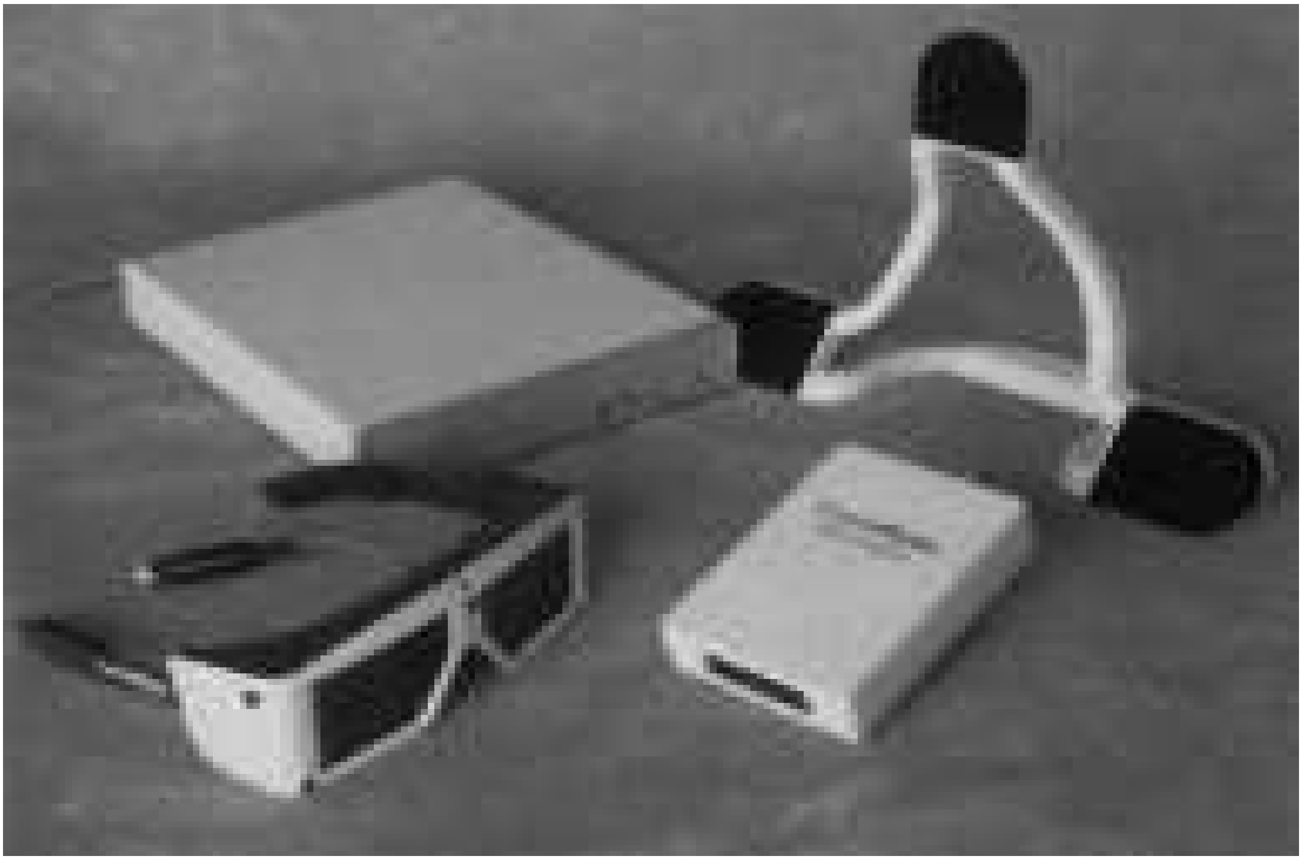

Figure 1. Crystal Eyes System.

We need to merge visualization, imaging and visual computing. Research topics for this area will include distributed viewers for iconic and graphic data and interactive scientific visualization on public networks.

3 Visual Output Devices

There are many different kinds of output systems for presenting virtual worlds visually. In selecting an output device, the desired image resolution and image quality must be considered, as well as the degree of immersion which is to be achieved, i.e. the illusion of presence in a virtual world. In general virtual technology utilises stereoscopic displays for improved depth perception, and a wide angle field of view for immersion.

Typical systems are:

- traditional desktop monitor,
- large projection screen (sometimes several simultaneously),
- head bound systems (e.g., helmets or glasses).

This list is sorted roughly according to an increasing degree of immersion. Nowadays, many graphics workstations offer ways of displaying stereoscopic images. Mostly, this is achieved by means of shutter systems in time multiplex mode. These systems typically have a frequency of 120 Hz and switch between perspective images for the left and right eye. A shutter mechanism (e.g., a pair of glasses with LCDs) is used to deliver each image to the appropriate eye, resulting in 60 Hz images for each eye. Such systems allow stereoscopic viewing of high resolution true colour images, but due to the limited field of view, immersion is not achieved. Latest research aims at autostereoscopic viewing without glasses.

Large screen projection can extend the field of view, thus increasing the perception of immersion. By combining several images or by special techniques, convincing panoramic views can be achieved.

In VE systems, large screen projections often present stereoscopic images. Head tracking allows to 'walk around' scene objects, which further increases the

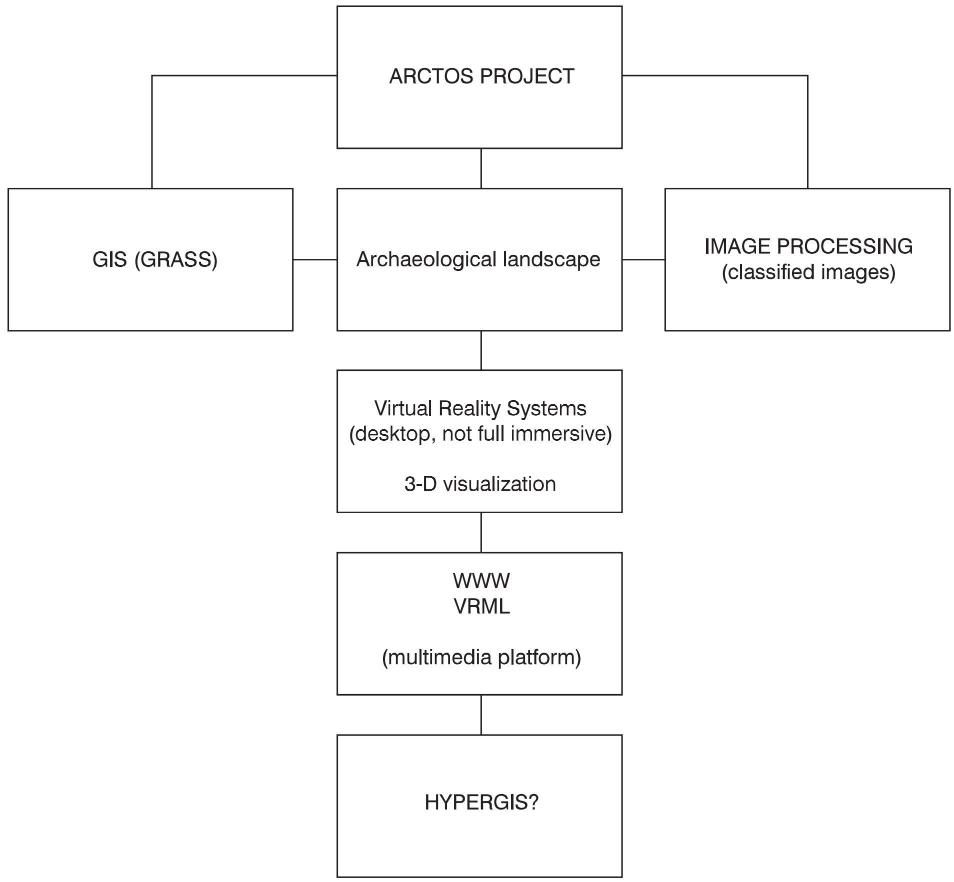

Figure 2. ARCTOS Project development.

impression of immersion. Stereoscopic large screen projection can be achieved by means of a shuttering technique or by means of a time parallel system (i.e., simultaneous display of perspective image for the left and right eye, with image separation by means of polarized light).

The highest degree of immersion is achieved by head bound systems. We distinguish systems which rest directly on the head (helmet and glasses) from systems which, due to their weight, are fixed to a mechanic system and are merely held in front of the head. Both systems use a separate screen for each eye in order to achieve a stereoscopic image. In both cases, the output systems are attached to the head and follow its movements. Liquid crystal displays (LCD), cathode-ray tubes (CRT), and glass fibre optics are used. Special optics allow to achieve a field of view of approximately 100 degrees.

The performance of a graphics workstation is limited in the maximum number of polygons which can be processed in real time. Complex world models (which are of prime interest) exceed this limit easily. A set of rendering techniques allow the user to handle and conquer complex worlds, where level-of-detail techniques prove to be the most promising and successful. Level of detail means the generation of several variations of the objects of differing complexity. Selection criteria determine the current level of detail to be rendered and displayed. Distance, view angle and movement criteria can be applied. When changing the viewpoint it may be necessary to switch from one level of detail immediately to another.

The generation of multiple levels-of-detail of objects can be controlled either to match a given quality (shape, appearance) or a given quantity (number of points, faces).

4 The ARCTOS Project

The ARCTOS project (fig. 2, Visualization and Virtual Reality methodologies for a cognitive system on an archaeological Sicilian pattern) was carried out by CINECA (Interuniversity Consortium for Supercomputing Applications) and the Scuola Normale Superiore (Pisa, Laboratory of Ancient Topography) with the support of IBM SEMEA, for the study of the archaeological site of

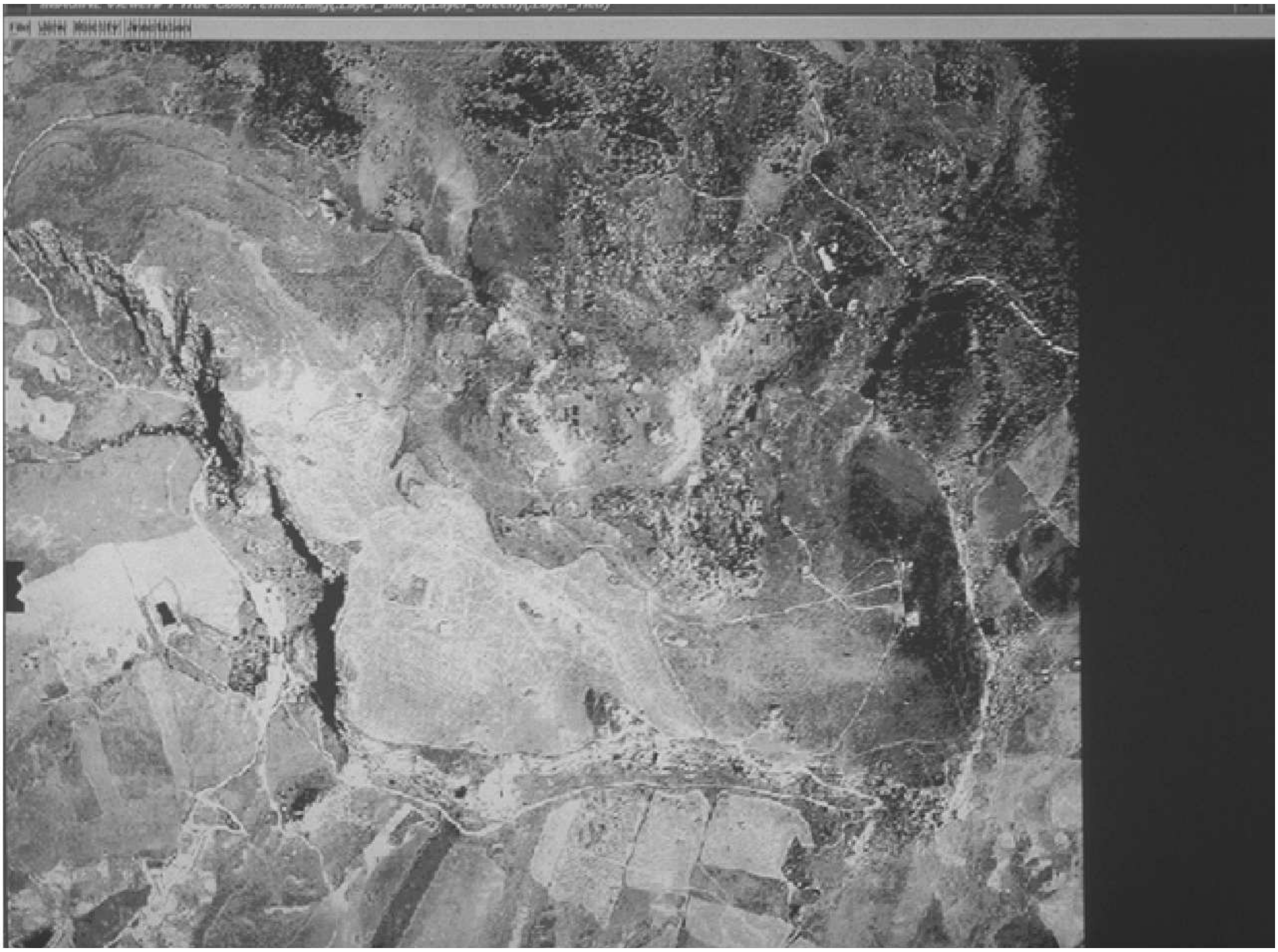

Figure 3. Rectified aerial photograph.

Rocca di Entella (Palermo). This is a very important, geomorphologically separate, multistratified area (*c*. 60 ha) dating from the Neolithic to the medieval period. In the last years 13 distinct archaeological areas have been investigated, for each chronological phase the structural areas show different features concerning buildings, materials, functions and uses.

Having to analyse such complex information layers, the research trend was to process 2-D and 3-D data so as to visualise the scientific content; it was particularly important to allow the users to move in real time into virtual spaces, such as archaeological landscapes (Forte 1993c). We believe that the interactive 3-D perception is fundamental to our cognitive system because it allows us to understand all the features of the archaeological landscape (Forte 1993a), and the relationships both inter-site and intra-site.

In visual perception, several cues (e.g., light and shade, perspective, stereo vision, etc.) are identified which provide the observer with spatial relationships within an image. Moreover, an important feature for deriving information from data is the interaction within the scene. Interactive visualization which supports, for instance, the manipulation of objects or of the camera, requires a high image generation rate in order to offer an immediate interaction feedback.

Consequently, interactivity and real time play an important role in visualization. Interaction and real time visualization are closely related issues, because interactive visualization systems will be accepted only if the system response time for user actions is minimised. There is always a trade-off between the complexity of data sets, the rendering speed on specific computers, and the interaction techniques provided to the user. In visualization, various types and amounts of data have to be considered (Cremaschi *et al.* 1994); with the availability of high-performance graphics workstations, data can be visualised

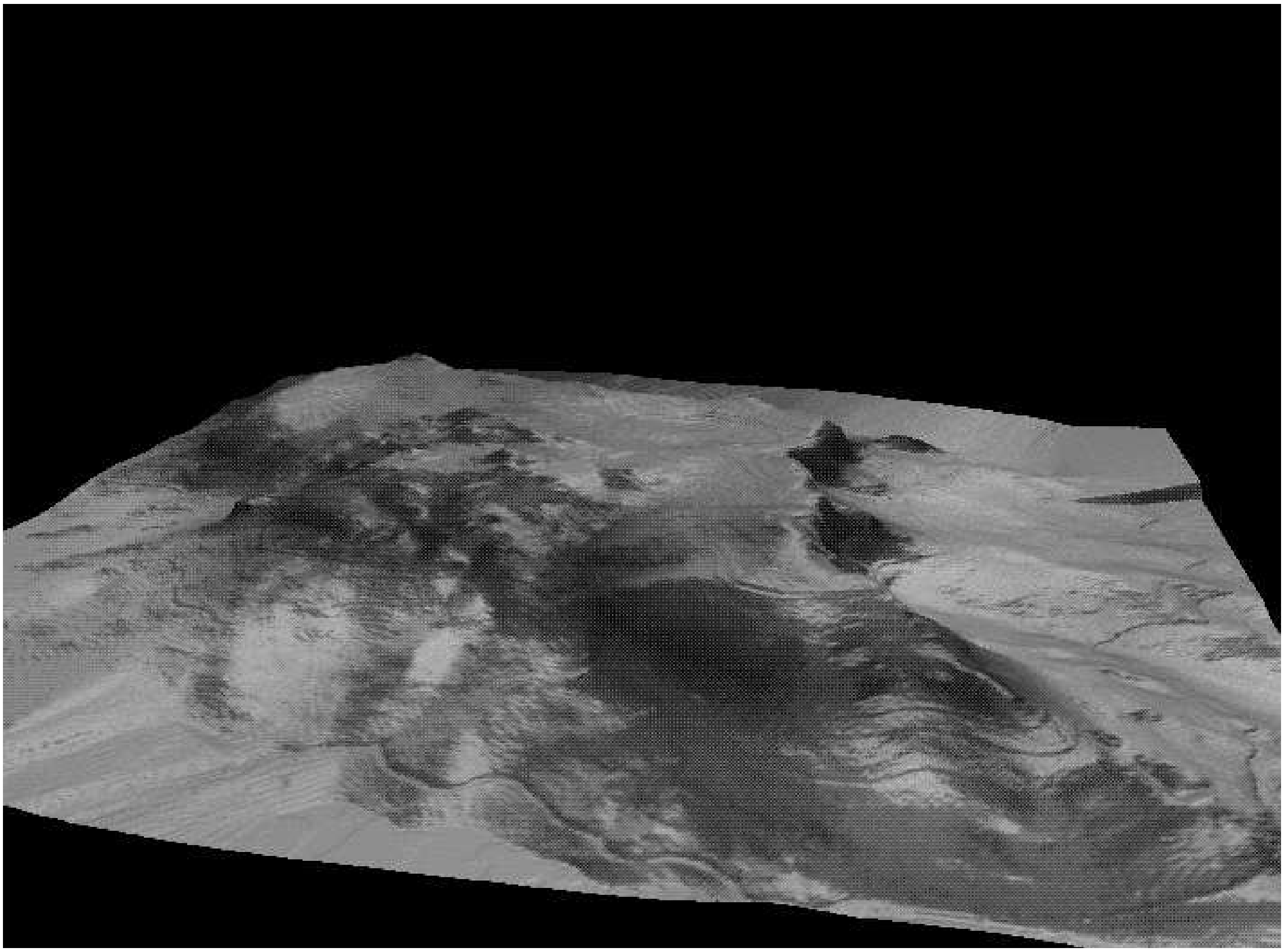

Figure 4. (Digital Terrain Model) in 3-D interpolated by cartographic contour levels (GRASS): dark colours correspond to the highest areas.

three-dimensionally (or even more than 3-D). However, the graphics output remains two-dimensional and therefore when complex data sets are visualised on a 2-D screen a loss of information occurs.

The final aim of the ARCTOS project is to reconstruct a 3-D virtual archaeological park, including geomorphological features and archaeological sites, distinguished in different information layers, such as:

- 2-D and 3-D geographical data (D.T.M., contour levels),
- 2-D vectorial data (cartography, sites topography, etc.),
- raster data (aerial photographs),
- databases.

In the case of Rocca di Entella a landscape model (including known archaeological sites) has been reconstructed using D.T.M. (digital terrain modelling) (fig. 4) and digital images of the area (aerial photographs, fig. 3). This kind of application includes the following steps:

Input data:

- Aerial photographs of the landscape (two colour aerial photographs, dating back to the summer of 1981 and on scale 1:10.000, fig. 3);
- excavation photographs (fig. 8);
- graphic documentation (vectorial);
- cartographic documentation (maps on 1:2000 scale).

Output data:

- digital cartography (acquired by digitizer);
- vectorial data visualization (fig. 7);
- 3-D model generation (D.T.M., fig. 4);
- texture mapping (fig. 5);

Figure 5. Texture mapping of the aerial photograph on the D.T.M. (GRASS).

– digital image processing and classification (figs 6, 7);
– interactive 3-D model animation (desktop Virtual Reality, figs 7, 9).

5 Image processing and digital classification

In order to classify and interpret (Forte 1993b; Forte/ Guidazolli 1992) the aerial photograph of Entella, GRASS and ERDAS software have been used. Before 3-D reconstruction and visualization, it was important to have digital information of the image in order to identify unknown archaeological areas (predictive information, fig. 7). Furthermore, it was necessary to compare the digital classification of the aerial photograph with the pertinent D.T.M. (figs 4-6): any micro-difference of the 3-D model can reveal significant archaeological and geomorphological information.

The whole image processing was carried out as follows:

– Image rectification (fig. 3). A GRASS viewer allows one to rectify interactively the image point by point, checking the level of deformation; it is possible, for example, to select georeferenced or known points on a map, and then to overlay them on the image.
– Image processing, i.e.
  1. histogram and digital statistics visualization;
  2. histogram equalisation (fig. 6);
  3. image restoration, in order to remove agrarian tracks from the image;
  4. contrast enhancement (high pass filter);
  5. edge detection: filtering (3 × 3 kernels) and edge detection to enhance tracks and chromatic discontinuities (figs 6, 7);

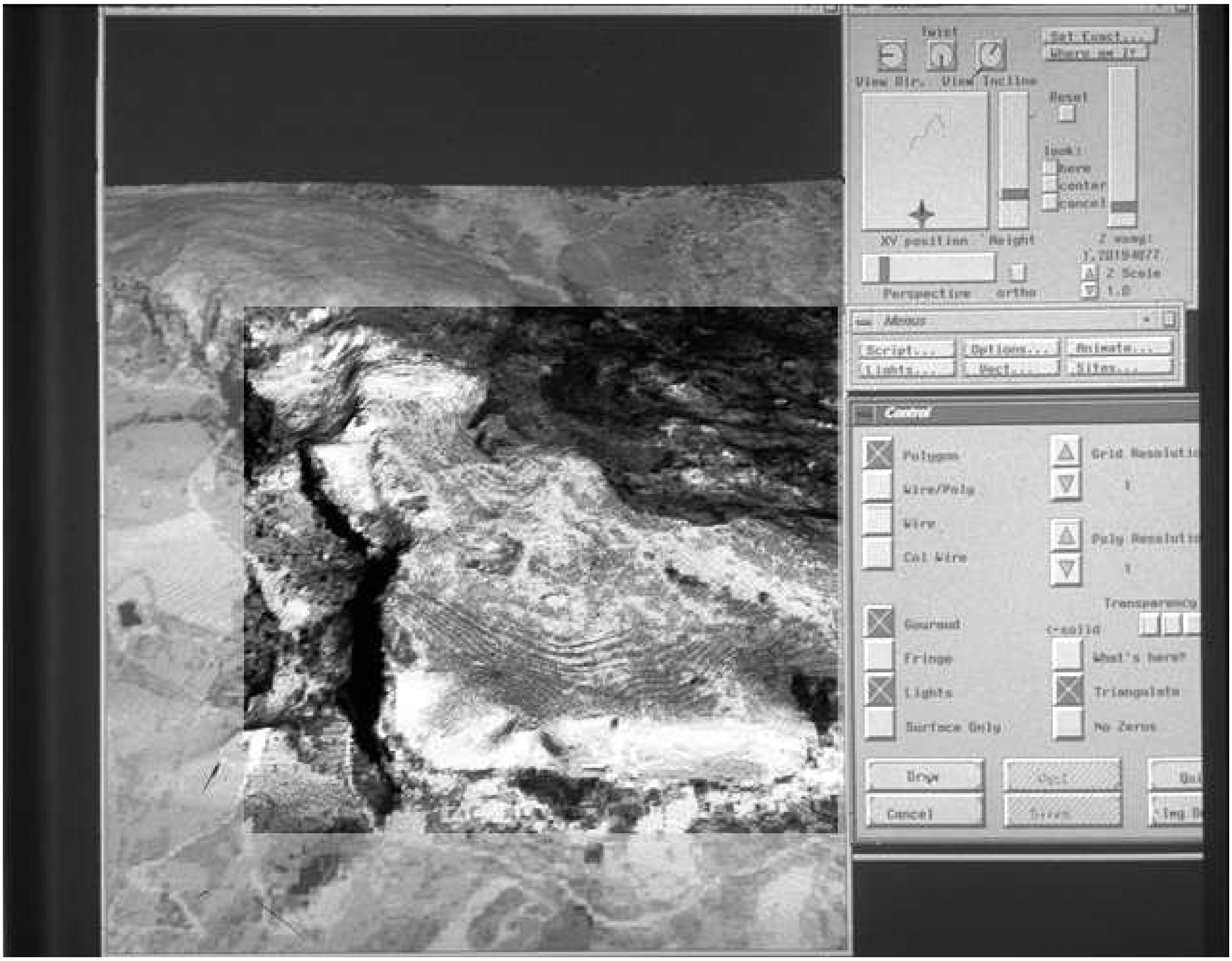

Figure 6. 3-D Digital classification of the aerial photograph: histogram equalisation and density slicing (ERDAS + GRASS).

6. vegetation index calculation;
7. principal components analysis;
8. density slicing (fig. 6);
9. pseudo-colour processing.

– Digital classification (fig. 7). On the basis of the digital processing results a new image has been obtained, with different classification colour layers (not visible in the figures in this paper).

The digital classification allows one to suggest important interpretations of the information content of the image; in fact on the basis of these results it has been possible to identify other unexplored archaeological areas. If we observe figure 7 we note that archaeological areas have been identified (indicated by arrows, because of colour absence) on the centre of the rock, where archaeological excavations were not carried out. Moreover the orthogonal or linear tracks identifiable in this area could be interpreted as Hellenistic buildings not explored yet .

5.1 ERDAS SOFTWARE

ERDAS is one of the most important software tools for an 'intelligent' digital image classification and interpretation. ERDAS delivers a full-scale production environment designed to incorporate all input data into a geographic data base that can be viewed, analysed, queried and output. This output may take the form of statistics, reports, tables, graphics or cartographic-quality maps; these powerful visualization capabilities are available in a GIS and image processing system.

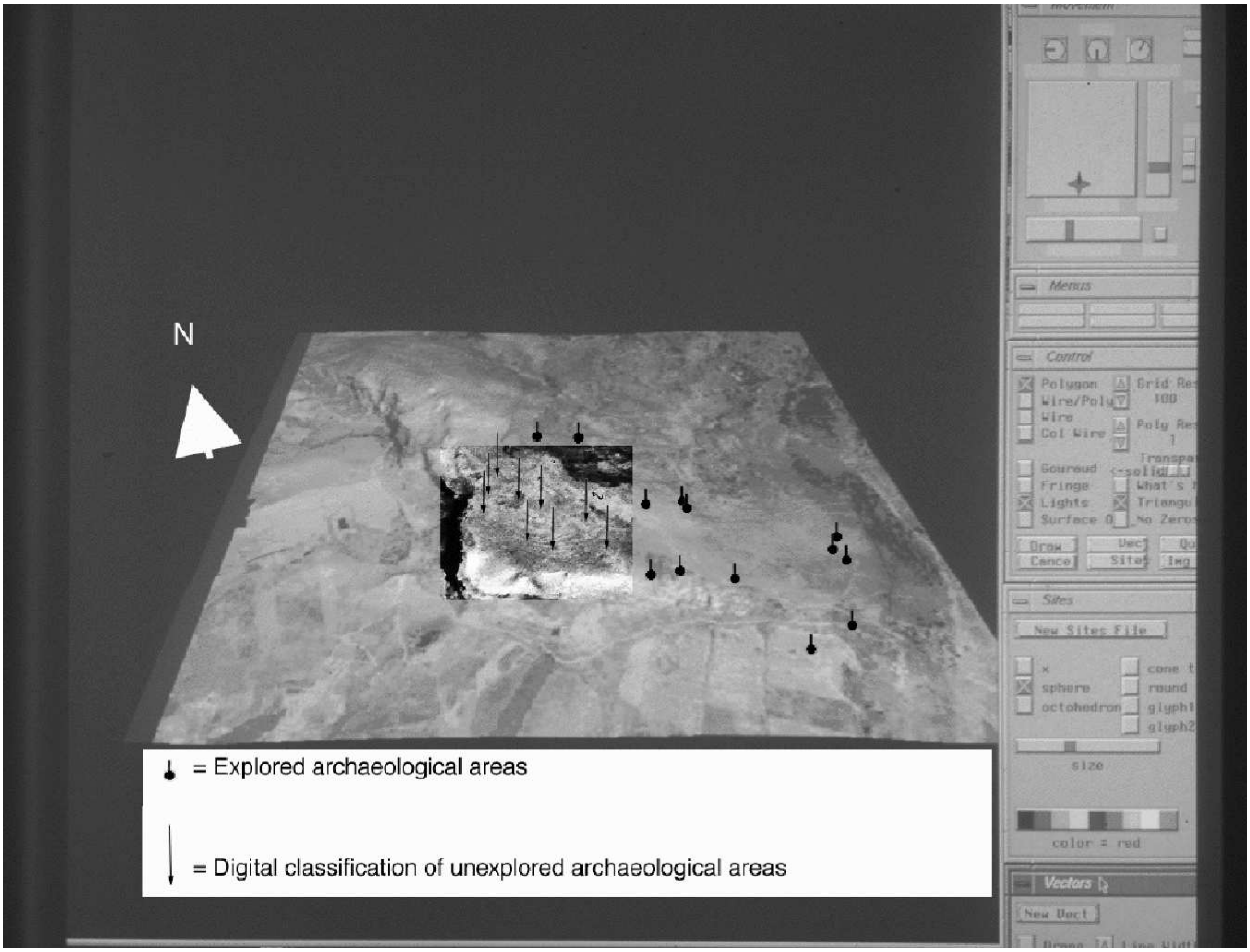

Figure 7. 3-D Digital classification: known archaeological areas (vectorial data) and unexplored archaeological areas (digital predictive information, ERDAS + GRASS).

The principal components of the software are the following:

Component	Capabilities.
Viewer	Displays queries and annotates single or multiple layers in the image viewer. An unlimited number of viewers can be opened simultaneously, and viewers can be dynamically linked.
Image interpreter	Performs complex analyses such as contrast stretch, colour selection, convolution filtering and principal components quickly and easily.
Rectification	Georeferences images to maps or images to images by interactively locating ground control points, computing a transformation matrix, and creating an output layer.
Spatial modeler	Performs spatial and statistical GIS modelling and image algebra functions on all data layers with an easy-to-use graphical editor. More complex models can be written using the Spatial Modeler Language.
Map Composer	Creates maps and presentation graphics using single or multiple images, and annotates text, borders, scale bars, legends and more.
Radar	Sophisticated processing tools for data handling, speckle noise removal and image enhancements.
File Manager	Views image statistics, projection information and map information.

Figure 8. Rocca di Entella (Palermo): a Hellenistic building (4th century BC).

EML Interface tools	Customises the ERDAS IMAGINE Interface by modifying existing or designing new dialogue boxes, control panels and icons to suit a particular application.
Developer's I/OToolkit	By using this specially designed subset of the C Programmers' Toolkit, developers can link their hardware to ERDAS IMAGINE.

6 GIS and 3-D visualization

Once we processed the digital aerial photograph, it was possible to integrate all these raster data with the D.T.M. and the other vectorial data (contour levels, cartography), and finally the texture mapping of the image was processed on the 3-D model (fig. 5). So as to obtain the best 3-D visualization and data management at that point, GRASS GIS was used, because in a single system all kinds of data (raster, vectorial, geographical) could be processed and described.

Interpolating the vectorial data (contour levels), a 3-D model was generated in the SG3d GRASS viewer (fig. 4), including wire frame model, and textured-shaded model (texture mapping with lights for rendering).

The SG3d viewer is intended as a tool for visualizing a data surface in three dimensions using GRASS on Silicon Graphics IRIS computers. Hardware requirements are a Z-buffer and 24 bit graphic emulator, such as that on the IRIS Indigo. SG3d requires a raster file to use as 'elevation' and another raster file to use for surface colour (or three files for Red, Green and Blue colour components). Although a true elevation data file used as elevation will produce the most realistic surfaces, users are encouraged to be creative in selecting other types of data to be represented by the vertical dimension. Most continuous (as opposed to discrete) data types will result in a coherent visualization. Since a wire grid can be drawn very quickly, such a grid is used to provide real time viewer positioning capabilities. Similarly, a lighting model provides real time feedback as the user adjusts lighting.

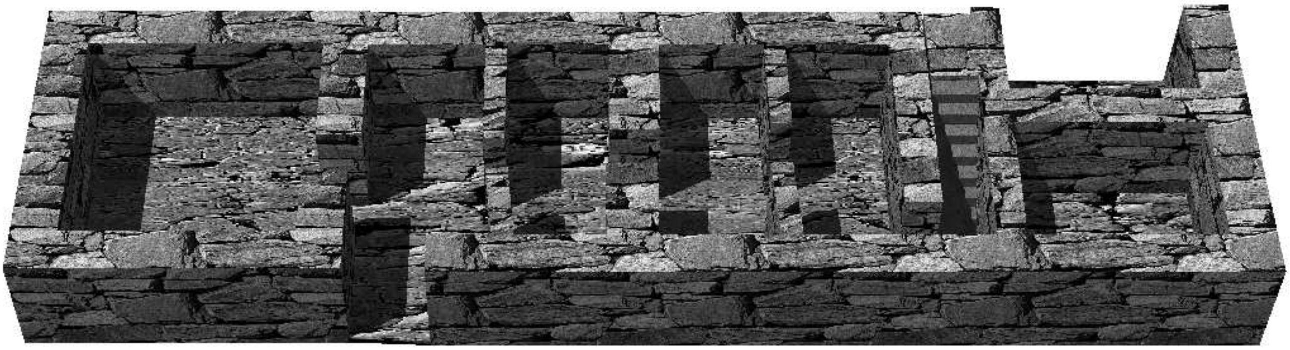

Figure 9. Rocca di Entella (Palermo): computer graphic reconstruction of a Hellenistic building.

Grid and polygon resolution control allows the user to further refine drawing speed and detail as needed. Continuous scaling of elevation values (from 1.0ee-7 to 1.0ee+7) provides the capability to use various data types for the vertical dimension.

In the last release, SG3d allows interactive lighting specifications (fig. 5), vector draping data querying (see What's here?), easier viewer positioning, an option to save current settings in a GRASS database (3-D view) file, animation capabilities, scale objects, labelling, an option to display lat-long data wrapped around a sphere, the capability to save images in IRIS rgb format files, and a few less dramatic changes such as background colour options and an animate display type option that allows the user to view a fully rendered image while adjusting viewer positioning. The navigation interface is a *Movement Panel* that checks the user-position in the 3-D model and the Z-scale of the surface. Then a *Control Panel* selects the kind of texture-surface on the model: it is possible to modify resolution of the grid and of the polygons, visualizing colour, wire or Gouraud surfaces, with a shading of surface, and all elevation data. It is also possible to visualize layers and vectorial information concerning cartography and archaeological sites with the Control Panel.

7 3-D Visualization and virtual navigation

Virtual Reality and scientific visualization experiments in archaeology, such as GIS, can concern different fields of application (Forte 1993b, 1995), mainly: inter-site and intra-site analysis, architectural reconstructions or interactive navigations in archaeological landscapes; the modelling level depends on quality and quantity of data (Forte 1993c, 1995).

Full processing and simulation are especially useful to discover and enhance the geomorphological and archaeological features of the landscape in connection with its evolution and the ancient settlements. Our aim was to visualize interactively the archaeological landscape of Rocca di Entella using all the principal types of GIS data.

During the CAA95 Conference a computer graphic video was shown concerning a virtual navigation in the archaeological landscape of Rocca di Entella (Palermo); it summarised, using different information techniques, the archaeological landscape of Rocca di Entella (Palermo). Techniques used were:

– three-dimensional D.T.M.
– vectorial data
– texture mapping of the aerial photograph (fig. 5)
– texture mapping of the aerial photograph classified by ERDAS (predictive information on the archaeological sites).

While in the video navigation was recorded frame by frame (25 frames per second), in desktop virtual reality applications we have used specific navigation devices in real time. For obtaining a 3-D stereoscopic vision, the VR Crystal Eyes system (fig. 1) and monitors with 120 Hz frequency were used. The VR system provides intuitive look-around capability, similar to a hologram, by tracking the location of the user's eyewear and changing the viewpoint with head movement. The system consists of Crystal Eyes eyewear, an ultrasound head tracking device with six degrees of freedom and rapid response. This kind of VR system is desktop, i.e. non immersive; for our application interactivity and high resolution of the images are very important, and these are not attainable with full immersion VR systems such as head-mounted displays (HMD).

On the other hand the VR Crystal Eyes system, interfaced with a GIS (GRASS), makes an intelligent scientific visualization possible, selecting all the data useful for research, and showing a complex virtual space to explore in an interactive way.

Take a Virtual Walk through Lightscape Models!

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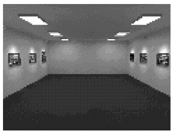
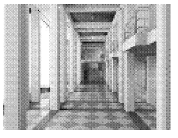
The following models were generated with the Lightscape Visualization System and converted into VRML files.

Click on an image to take a virtual walk through the model. Please note that you will require a VRML viewer such as WebSpace to view these models.



The Lightscape Image Gallery *(links to hidden models!)*
© Copyright 1995 Lightscape Technologies, Inc.
2.5 MB



Hall model
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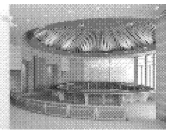

Jerusalem City Hall model
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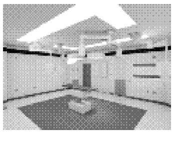

Operating Room model
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Figure 10. Virtual Reality Markup Language: walking through 3-D information models.

Finally the EXPLORER software (SGI) package was used for two methods of 3-D exploration: *walking* or *flying*; we can select different views and directions for either method.

7.1 Virtual Reality interactive presentation

Presentation domains for humans are related to the human senses (sight, hearing, smell, touch and taste). The presentation can be rated by the following criteria (fig. 1):

– quality of representation: each application requires specific mapping techniques to filter and turn the numerical data into perceptible information. Often applied techniques in visualization are function plots, histograms, or 3-D models.
– quantity of representation: dynamic presentations help to understand time-dependent proceedings in nature or engineering. Time is a distinguishing data parameter which in visualization can be applied as a single static picture or an animation.
– degree of immersion: adequate output devices couple humans tightly to the system. With novel innovative devices like head mounted display or 3-D audio the degree of immersion is high when compared to standard

monitor screen applications in computer graphics. Presentation of data is accomplished in several steps: mapping of numerical data into rendering objects, rendering of objects into easily transmittable information and output of this information.

8 Conclusions and future directions

The ARCTOS Project is an experimental approach towards interactive 3-D visualization concerning the archaeological landscape (fig. 2). The choice of recording data from the Rocca di Entella site allows us to analyse a very complex information set but in a defined geomorphological space with multistratified archaeological layers.

For this we have used GIS integrated with Virtual Reality applications so as to increment cognitive information of data, stimulating the physical perception into the 3-D virtual world. In fact the scientific information content of data depends specifically on the standard of presentation; if the researcher/user can interact with visualization models, he can acquire a better quality and quantity of information in real time.

In interactive visualization we have experimented with the Crystal Eyes VR System, an ultrasound head tracking device with six degrees of freedom, connected with an INDIGO Extreme 2 Silicon Graphics workstation, which is a very effective desktop virtual reality system because it operates at a very high graphic resolution. The user perceives a full stereoscopic vision and can navigate through 3-D spaces and objects without other devices such as 3-D mice or HMD systems.

On the basis of these results we should like to create a virtual archaeological park, a multimedia platform in which to install hypertextual links associated to two-dimensional and three-dimensional information. At the end of this processing we hope to put our 3-D models on Internet - WWW in VRML (Virtual Reality Markup Language) so as to ensure their accessibility.

At the 3rd International Conference on World-Wide-Web, *Technology, instruments and applications* (Darmstadt, 10-14 April 1995), a new graphic language was presented, the VRML (Virtual Reality Markup Language) that, for the 3-D computer graphics, represents a parallel to HTML, now used to store the images. VRML is a descriptive language of 3-D objects (fig. 10), in ASCII code, derived from Open Inventor (Silicon Graphics) with the tag 'LINK'. HTML and VRML are complementary: from textual navigation it is possible to pass into three-dimensional spaces and vice versa. WebSpace is the VRML implementation by Silicon Grahics (URL is http://www.sgi.com/Products/Web-FORCE/WebSpacej3). When following a link, connected with a VRML space, the browser opens WebSpace into a 3-D navigation, until a link is found, in the 3-D space (fig. 10), associated with another multimedia document. WebSpace on an INDIGO workstation is very easy to use: objects can be rotated, moved and observed in all the views (fig. 10).

This powerful graphic language opens new and extraordinary possibilities for processing multimedia and GIS data in 3-D spaces: all the data, including databases, can be observed and analysed by hyperspace links: can we talk of hyperGIS (fig. 2)?

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