35
INSITE: an interactive visualisation system for archaeological sites

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35.1 Introduction

A great deal of evidence of ritual performance exists for the society found on the Maltese islands between the fourth and third millennium BC (Bonnano *et al.* 1990; Stoddart *et al.* 1993). However, the interpretation of these activities, even using the archaeological evidence of elaborate ritual architecture, specific ritual furniture and artefacts, is difficult without a complete and flexible three dimensional reconstruction of their context.

Recent developments in computer graphics have made it possible to 'construct'' virtual environments on a computer and view photo-realistic images of these scenes (Pattanaik 1993). It is possible, therefore, to recreate an archaeological site on a computer and provide the viewer with an accurate representation of the actual remains. Furthermore, geometric modelling techniques enable extrapolations from existing evidence to reconstruct the site as it may have appeared to the original inhabitants (Reilly & Shennan 1989).

Although static images are useful for providing impressions of a site, far greater insight can be provided by making it possible for the user to navigate through this three dimensional representation. This experience will be enhanced by the photo-realism of the computer model including accurate illumination and the presence of environmental factors such as candle smoke, dust or fog. It is essential that such a navigation system is inter active, responding immediately to the operator's directions (Airey *et al.* 1990).

Previous research of these photo-realistic image synthesis techniques on sequential computers has demonstrated that the computational effort required to achieve this visualisation precludes the critical interactive nature of the envisaged system (Pattanaik 1993). However, the application of advanced parallel processing methods should allow the design goals to be accomplished in real-time (Chalmers *et al.* 1993a; Jansen & Chalmers 1993).

35.2 Archaeological Perspective

Three dimensional visualisation techniques are generally associated with idealised touristic representations. There are certainly advantages for tourism in creating unique visualisations of archaeological sites since they reduce pressure on archaeological monuments. On the other hand, it is also true that a single reconstruction imposes a single 'true' vision of the past on the viewer. This can produce an impression of misleading accuracy as has been correctly pointed out by other authors (for example, Miller & Richards, this volume)

The new techniques introduced by INSITE increase the optical realism of the images and thus magnify the risk of the observer accepting the reconstruction as the necessary appearance of past reality. In these circumstances it is necessary to emphasise that it is planned to employ INSITE as a research tool to establish the architectural framework in which activities took place and then to set varied hypothetical scenarios which require archaeological interpretation.

The visualisation method used by INSITE works best in circumstances of enclosed architectural space where light sources can be effectively controlled. Early prehistoric examples include natural cave systems adapted for ritual use. The palaeolithic cave systems of the Franco-Cantabrian area would be good candidates for this type of visualisation with the availability of good survey data and a detailed study of artificial light sources. A particularly interesting study could be made of the later cave system of Porto Badisco in Puglia (Graziosi 1980) where cave deposits have successively changed the internal space of the cave.

These structures are all below ground and largely natural in their configuration. The Maltese islands are the location for the earliest free standing public buildings constructed from stone in the world. As such, they offer a refreshing and unusual context for visualisation which has generally concentrated on the classical and medieval world. These 'temple' structures are providing the material for the elaboration of INSITE which can subsequently be extended to other monuments of different period, culture and spatial location.

35.2.1 The Maltese monuments

In fourth millennium BC, two classes of monuments were constructed which provide contrasting contexts for visualisation: *burial hypogea* and *temples*. The burial hypogea were constructed underground. In the case of Hal Saflieni this involved the excavation from the soft globigerina bedrock of nearly seventy chambers on eleven vertical levels. Unfortunately, this monument survives as an architectural shell with little information on the ritual use of space. The Brochtorff Circle is the second known subterranean monument where natural caves were modified over at least a millennium for human burial.

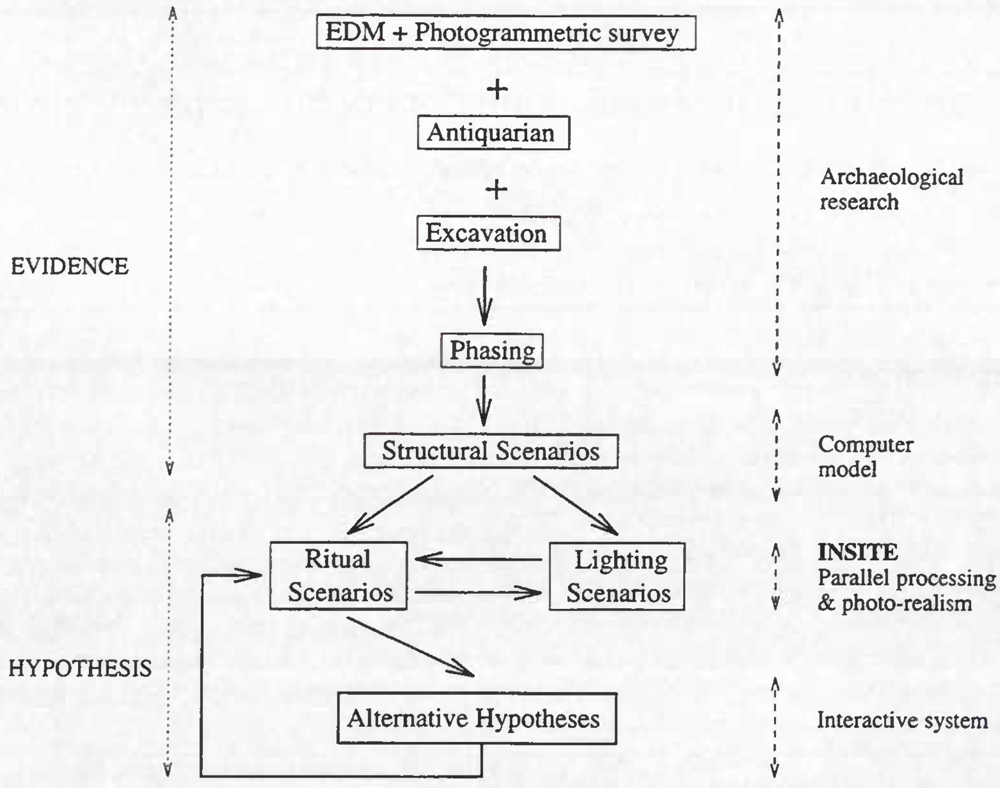

Figure 35.1: Elements required to visualise archaeological sites.

The current excavations will allow a much more dynamic reconstruction of the successive forms of the monument.

The temples were constructed above ground. They are substantial constructions, which in the case of Ggantija still stand to a height of some 6m and measure nearly 30m^2 internally. The internal organisation of space is apparently much more simple than the hypogea consisting in the case of Ggantija of two sets of five compartments. In some cases, as is the case at Ggantija, only a well preserved shell is preserved. In others, for example Tarxien, it is possible to add a considerable range of contextual information from more effectively conducted excavations.

These monuments provide essential contrasts. Hal Saflieni is composed of a series of interlinked compartments with interrupted visual contact between different areas. The only light source was artificial. The temples generally have one highly emphasised line of sight with subsidiary viewsheds at right angles. Different reconstructions of the upper part of the monument would lead to different possible sources of light.

35.2.2 Visualisation of the Maltese monuments

Earlier reconstruction of the internal space of the Maltese monuments has been topological or two dimensional (Bonnano *et al.* 1990; Stoddart *et al.* 1993). In particular, various hypotheses for the placing of the ritual specialists and other participants have been posed which are difficult to assess in two dimensions. The addition of various scenarios of realistic three dimensional reconstruction will greatly aid the setting of hypotheses for the reconstruction of the ritual organisation of these monuments.

The first stage is to provide the architectural framework for the modelling. This involves accurate EDM and photogrammetric survey. This has now been completed for Ggantija and Brochtorff Circle, although the excavation of the latter still continues. In the case of these two monuments there are accurate watercolours of the monuments by the nineteenth century artist Brochtorff which can be stretched to fit the EDM and photogrammetric survey. At the Brochtorff Circle, excavation allows phasing of the architectural framework, however, the expertise of a standing buildings expert will be required to determine the architectural phases of Ggantija. These procedures will provide a set of structural scenarios into which different hypotheses of ritual and the interlinked question of lighting can be set. The interaction of the various elements for the visualisation of archaeological sites is shown in Figure 35.1.

35.3 Computer Science Perspective

Precomputed video and multi-media walkthroughs or static images present a *fait accompli* representation of a site. In order to investigate hypotheses concerning site utilisation and formation on the computer, the user needs to be able to alter scene parameters and view the results. The value of these results will be greatly enhanced if they are of photo-realistic quality and they are produced immediately.

35.3.1 Interactive Photo-Realistic Visualisation

In all image synthesis techniques, the fundamental step is computing the amount and nature of the light from the three dimensional environment which reaches the eye from any given direction. This computation is carried out by simulating the behaviour of the light in the environment, and thus the greater the correlation between the simulation and the physical world, the greater the realism that can be achieved. However, in the physical world, the lighting, reflection and scattering effects are very complicated, and although the behaviour of light as a form of radiant energy has been extensively studied and mathematically modelled (Howell 1968), the prime problem that still must be addressed is solving the simulation based on these mathematical models in reasonable times.

Medium participation is an important aspect that must also be considered when reconstructing archaeological sites. Mediums that can have an effect on an environment's lighting include light emitters such as flames, light absorbers such as soot clouds, or light scatterers such as dust or smoke.

The particle tracing model traces the path of photons as they are emitted from the surface of the light sources and uses the reflected particle flux given by a large number of these particles per unit time as a measure of the illumination of points in the environment (Pattanaik 1993). This model accurately simulates the physical propagation of light within the environment, and can be used for complex scenes including the interaction of the medium within the environment. A solution based on every photon is obviously computationally intractable, but Monte Carlo methods can be used to simulate this particle model to obtain an estimate of the global illumination. The accuracy of the solution will improve as the number of particles traced is increased, that is, the more particles used, the 'more realistic' the result. Naturally, the computation time associated with the particle tracing method depends on this number of particles. Experience, based on a sequential implementation of the particle tracing method, has shown that even for relatively simple environments the number of particles that have to be considered in the simulation can be of the order of a few hundred thousand. On the single processor machine this can amount to many minutes and even hours of computing time.

The paths of the particles through the environment may be traced independently and then the resultant fluxes combined to produce the global illumination. It is this independent path tracing that suggests that the particle tracing method is suitable for implementing in parallel. However, the particle tracing method also exhibits certain characteristics which complicates its solution on multiprocessor systems. These characteristics include: very large data requirements; variations in computational complexity associated with the data; and, the need for global communication. So, if anything approaching an interactive visualisation of Hal Saflieni, Brochtorff Circle and the Ggantija Temple (and other archaeological sites) is to be achieved on a large multiprocessor system, then a number of fundamental parallel processing issues must still be addressed.

35.3.2 Parallel Processing

The inherent characteristics of the particle tracing method will necessitate a large amount of global communication between the independent processors of the multiprocessor system in order to successfully co-operate during the solution of the problem. These communication overheads must be minimised if parallel processing is to be successful in reducing computational times. This will require careful attention to the system architecture of the multiprocessor system (Chalmers *et al.* 1993a). The areas that need to be investigated include: data management; task management; and, communication protocols. The strategies developed to solve the particle tracing method interactively on a large multiprocessor system will, of course, be equally applicable to a large class of problems with similar characteristics.

35.3.2.1 Data Management

The very large data requirements to model archaeological sites accurately may contain far more data objects than may be accommodated locally at each processor in a multiprocessor system. It is necessary, therefore, for the processors to fetch data from remote parts of the system during the course of their computation. The latency in acquiring a data item which is not available locally can be significant. Techniques such as prefetching, profiling and caching, must be introduced in order to reduce this delay time (Chalmers *et al.* 1993b).

35.3.2.2 Task Management

Task management attempts to keep all processors busy so that overall system performance is not too severely compromised. Task management is thus necessary to ensure the amount of work is evenly distributed amongst the processors and the processors do not become idle when the data management strategies have failed to provide the necessary data on time. This latter case may entail the processor saving the current state of a task and commencing a new task whenever a requested data item is not available locally, or to have not one, but many tasks being executed on each processor. Now, although one task may be suspended awaiting a remote data item, the other tasks may still be able to continue. Current work suggests that although multi-tasking does indeed improve system performance, correctly determining the number of tasks which need to be present at each processor at any time is important, because too many tasks may have an adverse effect on message densities within the system, while too few may not be sufficient to overcome the data fetch delays (Chalmers *et al.* 1993b).

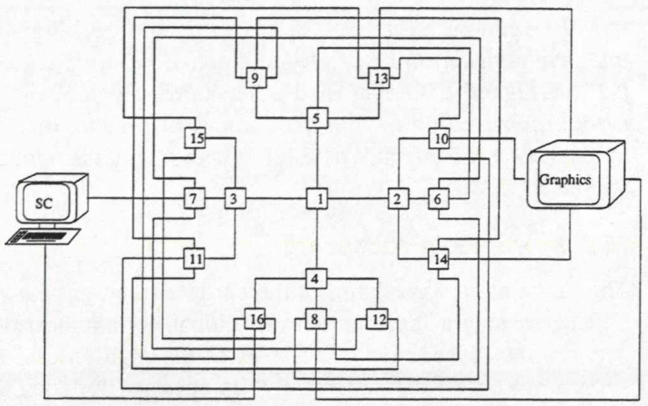

Figure 35.2: 16-processor AMP for visualisation.

35.3.2.3 Communication Protocols

Communication overheads may also be reduced by efficient communication protocols. The solution of problems, such as the particle tracing method, which require global communication between all processors benefit from a communication scheme which reduces the distances messages have to travel between processors which are not directly connected. As the number of processors in the multiprocessor systems are increased to achieve the desired interactive nature of the system, communication overheads have an increasing impact on overall system performance and may limit the scalability of the system unless effectively tackled. Minimum path configurations have been shown to be successful in this respect (Chalmers 1991). Figure 35.2 shows the 16-processor minimum path (AMP) configuration used to reduce the communication overheads of the parallel implementation of the particle tracing method. The nodes in Figure 35.2 represent individual processing elements of the parallel system. Each processing element consists of a single processor running the particle tracing code and the system software processes which provide the necessary communication and data and task management facilities. T800 transputers were chosen as they integrate the CPU, floating point unit, memory interface and four communication links on a single chip thus providing a flexible architecture for building large multiprocessor systems (Homewood *et al.* 1987). The system controller (labelled SC in Figure 35.2) provides the input/output facilities, while the computed images are rendered on the high resolution graphics display.

35.4 Conclusion

A computer visualisation system can enable archaeologists to investigate hypotheses concerning ritual performances, site utilisation, structure, contents and development of the area. Such a system must be flexible, allowing archaeologists to alter the scene parameters and view the results immediately. To fully appreciate the modelled environment, the computer images should be of photo-realistic quality and include media such as smoke and dust.

INSITE combines archaeology and computer science expertise to achieve the three dimensional computer reconstruction and interactive photo-realistic visualisation of archaeological sites. To demonstrate the efficacy of the approach, the project is exploiting recent archaeological evidence and detailed photogrammetric survey data to reconstruct and visualise prehistoric sites in Malta. The system will shortly be expanded to include archaeological and heritage sites from other countries.

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