Computers are involved in many stages of an archaeologist's work, from field recording and data storage, to the analysis and presentation of information. This is not to suggest that all archaeologists use such technology, and that those who do use the computer for all processes from recording to presentation. Much of the software which is used in archaeology is not specifically written for the task to which it is applied, but is deemed applicable to the problems which archaeology presents. One consequence of this situation is that the applications of some specific computer methods are limited to those areas of archaeology which fit the criteria for pre-existing software.

This paper deals with the problems of the analysis of antiquarian records (specifically dealing with the example of the records relating to the neolithic henge monument of Avebury) and the specification of software required to facilitate analysis. Such a solution involves the use of a computer for storage, analysis and presentation. The appeal of the computer is that it can mediate between these activities.

We do not attempt in this paper either to cover the results of re-analysis of a site like Avebury, or to describe in detail the tools which either exist or need to be created; rather, we outline some of the existing tools and their uses, and prescribe in broad terms what the next generation of archaeologists will need. Although the majority of field archaeologists do not use antiquarian records, there will be an increasing need for tools which allow for analytical comparison of different interpretations of archaeological sites.

THE COMPUTER AGE

The antiquarian record consists of textual and visual records. The computer-based analysis will need to address the problems presented by the visual evidence; the computer tool to aid analysis will consist of the three aspects already mentioned: storage, analysis and user interface. It is useful to consider other archaeological applications which deal with these three areas in order to provide a context for the concepts to be introduced below.

The use of computer databases for storage of archaeological data is widespread, ranging from small PC-based relational systems for
on-site storage to large depositories such as the national database of the Royal Commission on Historical Monuments. Such large systems provide for easier access than archive collections, although the potential does not necessarily imply utilization (cf. Hart and Leech, 1989). Figures 1 and 2 show two uses of a relational database; the example is a set of pottery records. Figure 1 gives numerical results, total weights of pottery by fabric, while Figure 2 provides spatial data in numeric form, the weight of pottery in grid squares of the site map. Even in such a ‘mainstream’ example, the traditional database only gives partial help in getting to grips with the data.

```
>select fabric,rim,total=sum(weight)
>from pot
>group by fabric,rim
```

<table>
<thead>
<tr>
<th>fabric</th>
<th>rim</th>
<th>total</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-0</td>
<td></td>
<td>71</td>
</tr>
<tr>
<td>10-1</td>
<td></td>
<td>413</td>
</tr>
<tr>
<td>10-1</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>10-1</td>
<td>5</td>
<td>48</td>
</tr>
<tr>
<td>10-1</td>
<td>5.5</td>
<td>10</td>
</tr>
<tr>
<td>10-1</td>
<td>7.2</td>
<td>50</td>
</tr>
<tr>
<td>10-11</td>
<td></td>
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<td></td>
<td>140</td>
</tr>
<tr>
<td>10-2</td>
<td></td>
<td>278</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

**FIGURE 1: QUERYING A RELATIONAL DATABASE FOR SUMMARY INFORMATION**

There are systems designed to deal effectively with the storage and retrieval of historical texts, and these may be relevant to the analysis of works of antiquarian authors which embody vague and ambiguous information, making their inclusion into conventional data-processing tools based on rigid data schemata impracticable. The HiTeX system (Oliveira et al., 1991), for instance, provides a suitable organization for documents and access via a knowledge base derived
from the information; but the very existence of academic projects like HiTEx reveals a crucial problem in the application of computers in the historical sciences: the inability of commercial software to deal with unstable, ambiguous information. One of the directions research has taken, the development of hypertext (Rahtz et al., 1992 outlines some ideas about hypertext in archaeology), is of great help with the exploration of unstructured textual databases, and even in the relationship between formal databases and structured text (preferably involving the SGML standard for structured text (Goldfarb, 1990); cf. Smith 1992 for a discussion of SGML and archaeological databases in relation to the classical Perseus project at Harvard). Stutt and Shennan (1992) have pointed in the direction of a combination of hypertext and formal reasoning about archaeological inference at a high level of interpretation. But hypertext does not yet provide an integrated environment for analysing documentary sources in conjunction with picture data.

If pictures are the primary data source, these are even less suited to the structured, or even the textual, database. While many database programs allow the storage of images of some kind (and have been widely used in archaeology), no commercial system allows for search-
ing pictures (cf. Goodson 1989 for a discussion of specialist systems for dealing with pottery profiles). The analysis of information through visualization of archaeological datasets, on the other hand, is an area which is receiving considerable attention. In the simplest case, Figure 2 can be better expressed by visual display in Figure 3, while topographic survey data and electro-magnetic survey data can be displayed in a wide variety of ways. Some of the issues are considered in detail by Fletcher and Spicer (1992, 1988; Spicer, 1988); Figure 4 is a representation of survey data from a simulated prehistoric barrow. Their type of surface modelling was designed with archaeologists’ requirements in mind, and they used the system to investigate survey methods to discover which produced the most fruitful results in visual form. It is often the case that new methods of investigation into evidence require new methods of data collection to fulfil their potential. In the case of the antiquarian records, the reverse is true: the software must be designed to fulfil the potential of the records.

FIGURE 3: TWO-DIMENSIONAL DISPLAY OF POTTERY DISTRIBUTION
FIGURE 4: VISUALIZATION OF TOPOGRAPHIC SURVEY DATA
Clonehenge, presented here, is an imaginary site, generated from the ‘henge’ function published in Fletcher and Spicer, 1989. Supplied by Dick Spicer.

Geographic Information Systems (GIS) are a currently popular method of visual analysis (Lock and Harris, 1992 give the most up-to-date and comprehensive survey of the field). GIS allow for the spatial analysis of data with respect to relevant archaeological, topographic and environmental evidence, facilitating easier comparisons and new correlations of evidence. A simple example is given by Figures 5 and 6: Figure 5 shows the distribution of a type of object across an archaeological site, while Figure 6 shows the same data as a ‘distance surface’ whereby all points across the site are classified by their distance from a mongongo nut. The overlay of a plan of huts and hearths stresses the conclusions about activity areas. The ideas behind this kind of analysis are old, but the means of performing the analysis at low cost is a new phenomenon.

Visualizations for presentation purposes are becoming common, although the expensive computer hardware required for much of the work limits the number of projects undertaken. The use of solid modelling software (developed for engineering purposes) to create three-dimensional reconstructions of archaeological remains can produce attractive results. The major application of this technique to date
is for public display, although some researchers have a more distinct analytical purpose (Reilly, 1992 gives a recent summary of the field). The Grafland project uses solid modelling for analysis (described in Reilly, 1992). The aim is to create a set of archaeological deposit records in three dimensions, and then to display these deposits in three dimensions. This would allow for repeated examinations using different methods of enquiry. The visualization method again requires the development of new recording methods, and at present is confined to the use of simulated data.

PUZZLING EVIDENCE

The vast range of data presented in *Avebury reconsidered* (Ucko et al., 1991)\(^1\) prompts us to consider the design of new computer-based tools

\(^1\) ‘I find the book too crammed with tantalizing information, and would really like better access to the data’ Dick Spicer, *pers. comm.*
for the visual analysis of the antiquarian plans of Avebury. The large quantity of evidence of a similar nature which exists for other sites, such as Stonehenge, suggests that although our tools are being developed with Avebury to the fore they would also be applicable to a wide variety of archaeological sites. The development of the tools for the analysis of Avebury serves as a test case for the validity of such methods and of the evidence available.

A brief tour of the evidence presented in *Avebury reconsidered* will outline the nature of the problem to be tackled in this specific case and will give some idea of the general forms of data available for analysis. *Avebury reconsidered* concentrates on the main stone setting around the village of Avebury. The authors undertook comparative visual analysis using transparencies of the plans. The book revolves around the record made by three antiquarian authors, Walter Charleton, John Aubrey and William Stukeley. The content and format of the antiqua-
rian plans vary in drawings by the same author (cf. Figures 8 and 9), and between authors. There is also a disparity (to modern eyes) between descriptive plans and interpretative plans, some consisting of a mixture of the two. Stukeley was by far the most productive of the antiquarian authors, producing a series of eleven plans (e.g. Figure 7) of the site, many different in content and format, and also a series of different pictures of the site which contain detailed information about stone shapes. These plans come from a variety of contexts, some to aid in discussion of the site at a meeting of the Royal Society in 1663, others as part of seventeenth-century publications about the antiquities of Britain. The modern book also contains information about the context of the creation of each of the plans, and written accounts of the site by various authors from a similar period. The most extensive excavations of the Avebury henge and the ‘avenue’ stone rows were carried out by Keiller in the 1930s, and were later presented in Smith’s 1956 report. The Royal Commission for Historic Monuments has recently undertaken survey work for the production of a new plan to replace Gray’s plan created during the Keiller excavations. There is currently an embargo on excavation at the site, and so the most recent fieldwork has utilized non-destructive investigation techniques, specifically magnetometry and resistivity surveys.

This account of the available evidence gives some idea of the

FIGURE 7: PLAN OF AVEBURY BY WILLIAM STUKELEY
(Ucko et al., 1991, plate 33)
quantity of what is available, but more importantly it shows the wide range of formats in which available data exist. What we need are computer-based tools which will allow the entire data set to be combined into a compatible and flexible format.

REMAINS IN THE LIGHT

The aim of *Avebury reconsidered* was to establish a ‘truth’ about the state of Avebury in the seventeenth century, by comparing all the known
records and finding the path of least resistance through the mass of data. To illustrate the sort of mediation between different types of information that is required, let us consider a specific example taken from *Avebury reconsidered*. Aubrey carried out a plane table survey of the Avebury henge in 1663, the results of which are shown in Figure 9. The plan appears to contain discrepancies, possibly a product of the survey technique employed. The hypothesis is that the survey was carried out in four quadrants defined by the intersection between the henge and the roads, and then the four sections were joined together to make the plan. To test this we can use a series of comparisons of each of the quadrants with corresponding ones from modern plans created from electromagnetic survey data and excavation results, and try to match features (e.g. stones, entrances). Hence we may be able to orientate the quadrants and test their 'accuracy' as quadrants. Then we might realign the quadrants according to our new discoveries, and thus reposition stones for which there is no other evidence.

A visual analysis tool must provide an accessible environment in which all appropriate data will be available. It must fulfil three requirements:

1. to provide visualizations of the antiquarian plans, modern plans, and survey data;

![FIGURE 9: DETAIL OF AUBREY'S PLANE TABLE SURVEY](Ucko et al., 1991, plate 7)
2. to provide facilities to manipulate the components of the visualization;
3. to allow the construction of interpretative visualizations based on the existing evidence.

The necessary operations include movement of objects (by direct interaction or according to a desired transformation) and some object-matching capability (mainly by position). The generation of 'insight' is the main aim of these tools, and experimentation in object representation is needed to find the most useful forms.

If we are to construct interpretative visualizations we will require some sort of visual argument to support our conclusions. In the example given above, the analysis of each quadrant must consist of a series of object matches (e.g. stone matching resistivity anomaly), each of which must be recorded and explained as a step towards proving the larger hypothesis. The tool will provide operations to save successive steps of visual comparison and allow the addition of text to explain the exact actions carried out between saved steps. The visual history will be presented as a tree structure with the initial piece of data (e.g. an antiquarian plan) as the root, and the resulting branches of the inquiry spreading from this until we have the final interpretation as the leaves.

Since the tool will serve both to form and to test hypotheses, many of the operations required for testing are as yet unknown; a tool must be designed so as to allow for easy addition of such operations. The analysis envisaged is comparative, and to a large degree is a visual process.

TAKING A WALK THROUGH THE PEACEFUL MEADOWS

The screen is a window through which one sees a virtual world. The challenge is to make that world look real, act real, sound real, feel real. (Sutherland 1965)

In order to facilitate the comparison of the wide variety of data formats, tools must provide a flexible environment in which all pictorial and textual data can be combined. It is desirable to take this degree of flexibility to its operational extreme in order to reduce the degree to which the actual environment affects the analysis. Such an environment must also conform to the The Chapel Hill Criterion (CHiC) (Brooks 1988), that is to say:

Our systems must be:
• so simple full professors can use them, and
• so fruitful that they will.

The user interface for a two-dimensional analysis can be realized through one of the widely used window-style environments, such as is found in Windows, the Macintosh, and the X-Window system. There
is, however, a considerable challenge in developing a user interface for a three-dimensional graphics display which will be as intuitive as many people find the current systems.

The evidence provided by some of the antiquarian plans and pictures (specifically those of Stukeley) contains material which can only be studied using comparisons in three-dimensional space. Evidence of the shape of the stones, which is potentially very useful in matching recorded stones with existing ones, can only be achieved with the third dimension in the visualization. 3-D models will also be very useful in simulating obstacles which may have caused problems during the surveying work of the antiquarian scholars. During the period of their work at Avebury, for instance, the area within the bank and ditch was cluttered with fences, buildings and other domestic obstacles: the written accounts contain details of the difficulty of access to some areas. A hypothesis suggested in *Avebury reconsidered* is that this difficulty may have been the cause of some of the errors in at least Aubrey's fieldwork. The best way to test such a hypothesis is to simulate conditions at the time of survey, using a three-dimensional model of the site.

Three-dimensional reconstruction of historical buildings has already been undertaken by archaeologists (Wood *et al.*, 1992; Lavender *et al.*, 1990) using solid-modelling software. Although such software is not ideally suited to the construction of irregular shapes, such as standing stones, the greater problem is the 'two-dimensional interface', a passive interaction consisting simply of viewing the screen. For instance, the code in Figure 10 draws a flat surface with six posts sticking up out of it, but the user's interaction is limited to typing in this code and then viewing the high-quality model displayed on the

```
post = cylinder(0.1,0,0.6,0) colour(4);
draw ( post at (0.1,0.1,0.1) union
      post at (0.2,0.1,0.4) union
      post at (0.3,0.1,0.5) union
      post at (0.4,0.1,0.25) union
      post at (0.35,0.1,0.0) union
      post at (0.7,0.1,0.7) union
      plane(0,1,0) at (0,0.1,0) colour(2)
    ) xrc(-10).
```

**FIGURE 10: PROGRAM CODE IN WINSOM SOLID-MODELLING SOFTWARE**

This example of WINSOM code (Burrige *et al.*, 1989) draws a surface with posts sticking up.
screen. With the increasing power of computer processors the ‘edit / compile / run / view’ cycle is now becoming so fast that it is less visible to the user, and interactive solid model editors are now viable commercial products. But the vast majority of such systems (including the visualization tools like Uniras and the sophisticated design systems like Autocad) suffer from a lack of integration with other data sources (text, video, knowledge bases), and navigation around a three-dimensional model is not well handled by normal keyboard or mouse devices.

We require 3-D interaction as well as 3-D modelling, best achieved (as suggested by Brooks 1988; see also Sturman et al., 1989) by the techniques of virtual reality. This requires the use of special equipment for both input and output, in the form (for instance) of a glove containing sensors which react to hand movements, and of a headset containing screens which provide all of the input to the user’s eyes. Virtual reality allows the user to interact from within the model space, making interaction and navigation easier and more intuitive. In a ‘Virtual Avebury’ we could have the current site with buildings removed and actually perceive the site as a whole rather than according to the sections dictated by the intersection of the roads.

The technology and application of virtual reality is available but still very much in its infancy. It must be considered as the most effective method of interaction with a computer model. Such a model of Avebury would be of great assistance in the analysis of the antiquarian plans and of considerable potential as a tool for communication and education. The latter development is some way away but it is hoped we can achieve the desired quality of interaction and insight.

We have hardware technologies to suit archaeology. Current optical disc systems permit the storage of approximately 100,000 pictures on a laser videodisc, and about 600 megabytes of data (equivalent to about 5 metres of library bookshelf space) on a CD-ROM. Publication of large multimedia information resources could have a tremendous impact on many different aspects of archaeology. Raw data allows the researcher to study locations not only in great detail without having to be constantly on site, but also in a global way such as was not possible before.

Structured data also provides a rich resource for teaching and learning. Educators can use visual material for presentation purposes and it is possible to define directed paths through hypertext structures to create instructional material. Thus, learners will be able to follow guided instruction paths, or to branch off into a database (utilizing hypertext links) to carry out their own investigations. This will create an environment in which it is possible to learn by problem-solving,
using as raw material the evidence that archaeologists have found on a site. Similarly, simulation software can be created by educators based on the raw material in a database (such as the SyGraf system, described in Wheatley 1991). The use of videodisc technology to provide visitor information to museums, art galleries and other public information centres is becoming quite widespread and very popular (though not always to a very high analytical level; Makkuni 1992 discusses a more thoughtful approach).

Current academic work is crippled by readership which is so small as to make normal publication unviable, making adequate reproduction of photographic and colour graphics material impossible (cf. Biek 1988); there is a mass of pure data fighting for space with semi-interpreted catalogues and linear narrative interpretation, and the potential of hypertext is particularly clear. Work on third generation hypertext (for instance at Southampton: Rahtz et al., 1990; Fountain et al., 1990) has concentrated on separating a ‘hypertext-compatible’ generically marked-up text from the hypertext front-end, and we believe that this must be an important direction to take. We have official or de facto standards for permanent storage of information (SGML markup for text, PostScript for graphics, and SQL-compatible databases for structured data), and we may confidently proceed with some parts of archaeological analysis and presentation.

But this must be only a beginning. Archaeology has always relied heavily on visual comparison and understanding of space. The revolutionary ‘Avebury Walk’ audio-visual presentations of 1988 (to the British Association for the Advancement of Science) and 1989 (to the Council for British Archaeology) demonstrated the wide variety of ways in which people from different backgrounds could react to the views and spaces of a well-known monument and its environment (Ucko and Phillips, 1990). These experiments showed how limited were existing ways of ‘publishing’ the monument. We need new ways to approach the records of the past, whether these be records of early antiquarians or our own field records of last week. The ‘archaeology of archaeological records’ becomes a greater and greater problem every day, and we must equip ourselves with the tools to approach it. Environments for visual comparison, and virtual reality explorations, are needs of the archaeologist, not idle suggestions for the future.
ABOUT THE AUTHORS

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