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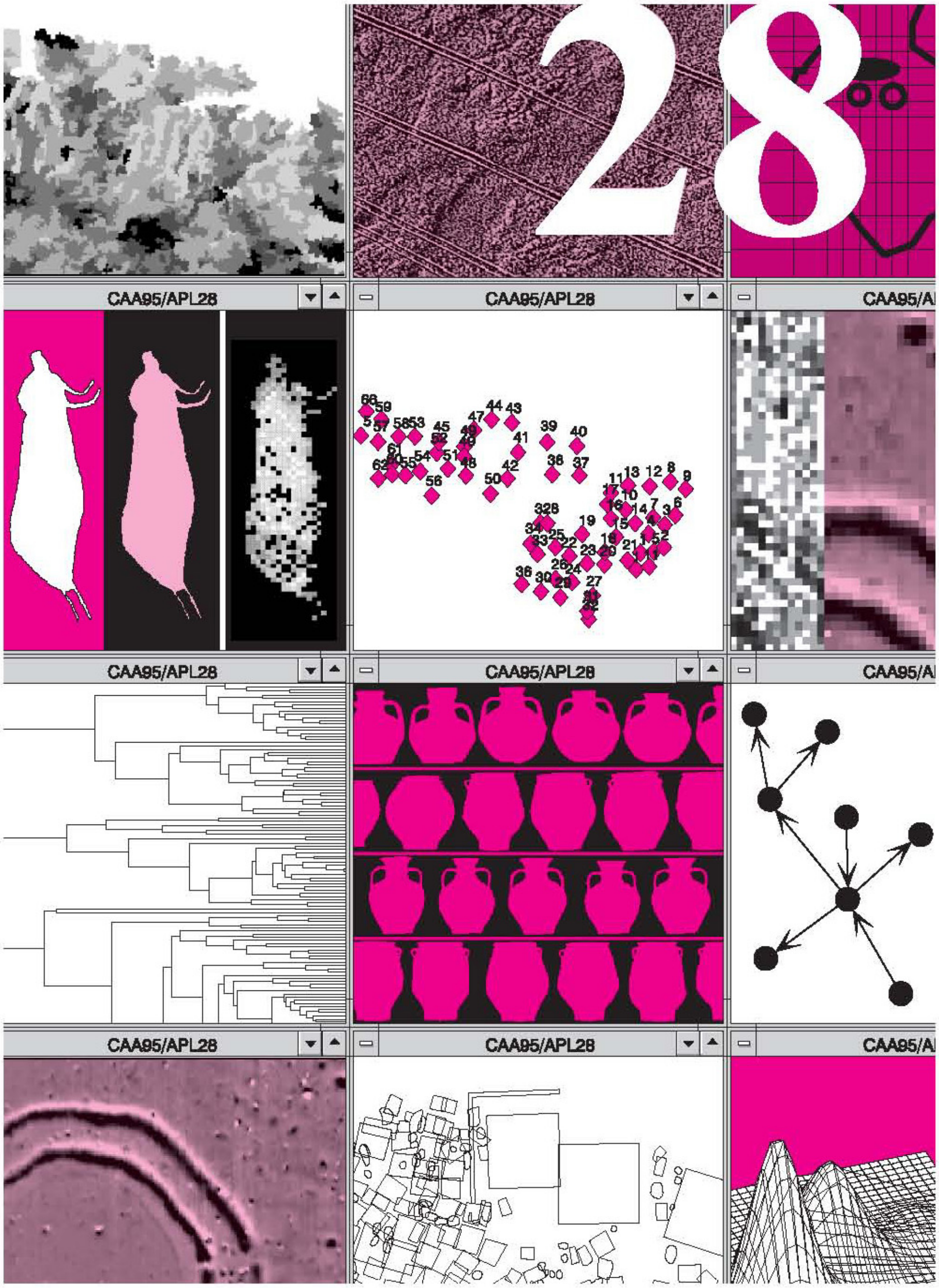

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preface

CAA95, the 23rd annual Computer Applications in Archaeology conference, was held at the University of Leiden from 31st March - 2nd April 1995, and was hosted by the Faculty of Pre- and Protohistory.

The conference was organised jointly by the R.O.B. (State Service for Archaeological Investigations) in Amersfoort, the RAAP Foundation of the University of Amsterdam and the Faculty of Pre- and Protohistory of the University of Leiden.

One hundred and ninety nine people attended the 1995 conference, 44 of which were students. Apart from archaeologists connected with universities and museums, many participants came from local, regional and national government bodies concerned with the management of our cultural heritage.

The geographical distribution of the participants was: United Kingdom 59, the Netherlands 53, France/Spain/Italy/Greece 22, Germany/Switzerland/Austria 20, Norway/Sweden/Denmark 16, Poland/Romania/Slovenia/Hungary/Czech Republic 13, USA/Canada 11, and the Argentine/Japan/Australia 5.

At the conference, a total of 93 papers and 6 posters were presented, while there were 20 demonstrations of systems and applications. The papers were given in four parallel sessions and were grouped into eight different themes, with the following number of contributions: Analysing Ritual 6, Archaeometry 7, Classification 12, Cultural Resource Management 12, Databases 12, Free Range Subjects 13, Geographic Information Systems 19, and Multi Media 12.

For the 1995 proceedings we have regrouped the subjects under six main themes: Database Management, Archaeometry, Statistics and Classification, Geographic Information Systems, Visualisation, and Education and Publication. Reviewing the proceedings of conferences over the last twenty years, one sees that particular fields of research seem to be 'fashionable' at certain times. What does 1995 show us?

Database Management

In the first ten years, most papers presented at CAA conferences fell into two categories, data capture/management and analytical techniques. Database management remains a dominant topic in archaeology, 20-30% of the papers in the last ten proceedings dealt with this subject. With 18% this subject is still well represented this year. Improvements in both hardware and software allow larger and more complex databases. We now have relational databases on sites, combining excavation, curation and site management data, and databases containing nationwide information on archaeological sites and monuments. There are also museum databases, integrating site files, museum catalogues and bibliographic files.

Archaeometry

Until now archaeometry has not been treated as a separate subject in CAA proceedings. It was grouped with, for instance, 'applications of quantitative methods' or 'statistics — methods & techniques'. For our overview we have grouped archaeometry with 'statistics and classification'. We have therefore no history to compare with but the trends described under 'statistics and classification' apply.

Statistics and Classification
Statistical applications have always been very popular at CAA conferences. Ranging from between 20% (1990) to almost 80% (1980) of the contributions have been on this subject. There has been some decline in popularity in recent years because statistical methods are less popular with 'real world' archaeologists than twenty years ago. Statistical approaches were very much part of 'new archaeology', now called processual archaeology, and post-processualists seem to feel less at ease with this subject. But there are signs that in the near future the pendulum will swing again in the other direction. The application of 'hard science' in archaeology is on its way back. The main reason for this is that much of the funding of scientific archaeological research is by way of 'hard science' projects linked to the environment. We are not sure whether statistical applications in archaeology are part of 'hard science' but they will certainly benefit from this development. In the present proceedings 33% of the articles are devoted to this subject, a fairly low percentage that continues the trend of the last five years. We should, however, expect an increase in future years.

Geographic Information Systems
After a hesitant start with one article in 1986, none in 1987, and two in 1988, GIS has become popular in the CAA proceedings. The proceedings of the conference in Aarhus in 1992 contained already 11 articles on the subject and today GIS is widely used among archaeologists. We suggest, however, that it should not be treated as a separate subject. It is a combination of a (spatial) database management system with a (most of the time rudimentary) statistical package and it creates, often beautiful, pictures. Most of the problems people have with using GIS in a useful manner, stem from the fact that they consider it as something completely new and different. It is not. An often used definition of GIS is that it is a computer assisted system for the capture, storage, retrieval, analysis and display of spatial data. We could do all these things before. All components, database management, graphic applications and statistical analysis were there. New is the integration and the pretty pictures. The picture is, however, not the answer but only the question. A computer can not (yet) replace human thought and analysis. To get at the right question requires study of the tool. In the present volume 23% of the articles are on GIS, the highest score so far!

Visualisation
The number of articles in the CAA proceedings on this theme has varied a lot over the last ten years, from about 5% in 1983 to almost 30% in 1993. In the 1995 proceedings it scores 13%. The main topics in this field are visualisation and the use of CAD, and multi-media seems to be the new buzz word here.

Education and Publication
This has always been a regular topic, usually scoring about 13%. Also in this volume the percentage is 13. Though often enlightning, we have noted that so far the subject of Education has not shown any article explaining why the education in statistical techniques creates so many problems for archaeologists. It does not seem to matter whether you use difficult or simple textbooks, most archaeology students and archaeologists have problems with statistics. Fletcher and Lock speak in this respect of an 'instant mental paralysis in many otherwise competent archaeologists'. We are looking forward to the day when Education in quantitative analysis will solve this problem.

So these proceedings do not really show many changes in the interest of 'computer' archaeologists, but follows the past trend. CAA times are not yet 'a-changin'.

Acknowledgments
The realisation of the conference was made possible by the hospitality and support of the University of Leiden and financial support from the Department of Education, Culture and Science, the Royal Netherlands Academy of Arts and Sciences, and the Leiden University Fund.

Computers for the demonstrations were generously made available by JCN Computer Systems BV and CRI Institute for telecommunication and computer services (University of Leiden), while apparatus for the ARCHIS demonstration was provided by SUN Microsystems Nederland BV.

The State Museum of Antiquities offered the use of the Taffeh hall for a reception on the first evening of the conference which was financially supported by the Committee for the celebration of the 420th anniversary of Leiden University and by Taylor & Francis of London.

We are greatly indebted to Roel Brandt, Monique van den Dries, Jenny Hes, Marianne Wanders, Philippine Waisvisz, Milco Wansleeben, Paul Zoetbrood and the many students who helped before and during the conference.

For the realisation of this book we would like to thank Prof. Dr L.P. Louwe Kooijmans and Prof. Dr C.C. Bakels for their invitation to publish these proceedings in the Analecta Praehistorica Leidensia series, Marianne Wanders for the text editing, Peter Heavens for the computer graphics, Henk de Lorm for the layout and cover design, and of course the reviewers Roel Brandt, Eelco Rensink, Iepie Roorda, Mark Spanjer, Pieter van de Velde, Philip Verhagen, Albertus Voorrips, Milco Wansleeben, Ronald Wiemer, and Paul Zoetbrood for their useful criticism and commentary. We are very grateful to the Foundation for Anthropology and Prehistory for their financial support in the publication costs of this volume.

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Data Management

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IDEA – the Integrated Database for Excavation Analysis

1 Introduction

Archaeology has many diverse appearances. It can degrade to a mechanical manipulation of artefacts with seemingly no theoretical foundation, or it can escalate into wild theoretical digressions with virtually no reference to the archaeological record. One reason for this variability in archaeology is the almost paradoxical epistemological conditions of the discipline: on the one hand the subject matter of contemporary, physical objects, and on the other hand the aim to create a mental construction called the past (Madsen 1994: 31).

In the study of artefacts, during archaeological survey, and last but not least during archaeological excavation, the theories of the researcher are confronted with observations of the real world, and it is through this process that new knowledge is created. This is the reason why archaeological excavations *do not* constitute a mechanical unearthing and subsequent recording of objective facts, an opinion not uncommonly stated in archaeology.

Because of the destructive nature of archaeological excavations, attention is frequently focused on the recording of this activity. It has been customary in recent years to stress the subjective nature of excavation records, an attitude we fully share. However, in their eagerness to point out the biased nature of archaeological doings the critics tend to forget the status of excavation records in archaeology. Although coloured and filtered, these recordings are statements of observations of the real world: one may deliberately select and unwillingly overlook, but one cannot (by the code of the discipline) record something not seen. This is the reason why records from archaeological excavations are to be treated as historical documents and why it makes sense to establish a structured archive of recordings from archaeological excavations.

Still, a major problem in archaeology is to master the inherent complexity, diversity, and quantity of archaeological data. No wonder computer based recording systems for archaeological excavations have been and are continuously being created all over the world. Far the major part of these are either fairly simple flat file systems or hierarchically organised systems (Arroyo-Bishop/Zarzosa 1992; Rains 1995). Flat files and hierarchies, however, are too simple structures to provide a general basis for the description of archaeological reality in all its complexity. As a rule more or less well adjusted *ad hoc* solutions to particular situations become the result (Madsen 1993).

In the late eighties we began to discuss the potentials of relational data modelling applied to archaeological excavation recording, and at the CAA in Southampton in 1990 we presented a paper on the structure of information from archaeological excavations viewed in a relational framework. For various reasons the paper was only published two years later in another context (Andresen/Madsen 1992). Initial attempts to acquire money for realising our IDEA were not successful either (Madsen 1994: 27), but in late 1993, we finally succeeded. A three year project funded by the Danish National Research Foundation for the Humanities was established (Madsen/Andresen 1993).

The purpose of the project is to create a general system for recording, analysis and presentation of information from archaeological excavations. The system is intended to serve as an archive of recordings from all types of archaeological excavations, and it shall be able to automate the production of the archival report as a paper-copy. In a next phase of development, not covered by the current funding, the system should develop into an analytical tool for the processing of excavation information.

The core of the system is implemented in a Relational Data Base Management System (RDBMS), naturally. We have chosen Microsoft Access for this purpose because it combines sophistication as a RDBMS with a low cost availability within today's standard PC environment. The advantages are amongst others: low learning curves for the users, high potential for integration with other application software, and upgrading security. Furthermore, the National Museum of Denmark has also chosen Microsoft Access as their development tool for their interface to the Danish central SMR. Using identical development tools should help us to overcome some of the technical obstacles in attempts to integrate data from the excavation archive with SMR-recordings — at least on a national scale.

2 The conceptual model

The basic conceptual model for the system has already been presented and discussed in some detail (Andresen/Madsen 1992, 1994). We will not repeat the discussion here, but only summarise the structure and basic entities of the model.

Fundamental to our model is the acknowledgement of three universal entities into which we can categorize all excavation information. These entities we termed Layers, Objects and Constructs (fig. 1).

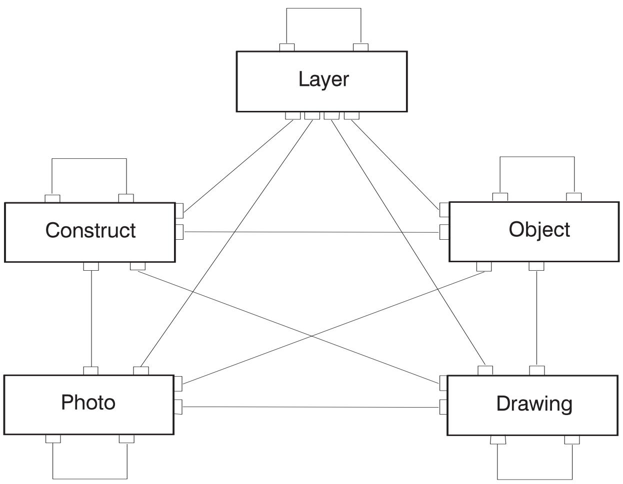

Figure 1. The core of IDEA: five basic entities – Layer, Object, Construct, Drawing and Photo – linked with many-to-many relationships between entities as well as internally between records of the same entity.

A Layer is an entity of deposition separated from its surroundings by its physical and chemical properties. In this sense a layer can be seen as a geological entity, even if often it owns its existence to human activities. Other names for a layer often seen are fill or context (Carver 1985).

Essentially an Object is a subpart of a layer, segregated from this by the actions of the archaeologist. Any part of a layer that an archaeologist sticks a label on, bags, and brings home from the excavation automatically becomes an object, or perhaps as it should be named more correctly, a find or component (Carver 1985).

The Construct is a slightly more controversial entity. In our definition it is any interpretation category that an archaeologist may impose on Layers or Objects, alone or in any combination.[1] In its simplest form an instance of the Construct entity could be something like ‘pit’, ‘post-hole’, etc. At the more complex level it could be ‘activity area’, ‘village’, ‘chronological phase’ etc. Traditionally this is what would be classified as cuts, features, structures and beyond (Carver 1985).

In addition to these three universal entities we also defined two documentary entities — Drawings and Photos. These two auxiliary entities are fully interlinked with the archaeological entities. One may question, if it is possible to draw or indeed take photographs of interpretations/Constructs. On the other hand it is customary in archaeological recording systems to refer to interpretation units in the documentary sources, so we have chosen to endorse this practice and allow links between Constructs on the one hand and Drawings and Photos on the other.

This conceptual model may at first glance seem fairly simple, but due to the many-to-many relationships between all five entities and internally within each entity, it is a fairly complex model to implement. Further, there are a number of additional concepts and features that modifies and qualifies the model, adding further complications to the implementation.

One such moderator is the concept of project. In order to be able to handle more than one excavation in the same database, and indeed to be able to handle excavations differently with respect to structure of recordings and classifications of content, we have defined the project as the primary separator of information. Everything within a project is by definition fully comparable. Information from different projects is only compatible and comparable to the extent that the projects share equivalent definitions and classifications of structure and content.

An important, but also a potentially very difficult qualifier to handle is the concept of event. On a fairly simple level it is the ability to record the who and when of a drawing being created by a number of draughtsmen over a period of time at a number of different ‘drawing events’, or the ability to record information according to a number of different excavation campaigns. On a much more complex level it could be the possibility of recording ‘the history’ of interpretations of a site. That is, instead of overwriting an interpretative Construct, a substitution takes place with the former Construct being kept as a historical, currently obsolete, piece of information concerning the interpretation. Historical information like this should be hidden, but not forgotten. That is, it should be possible to recall former interpretations on demand.

A full handling of events is truly complicated, and we have decided to take up only the simplest part of the problem relating to different recording events during excavations. Thus, at the moment we are not going to try to solve the problem of event recording in connection with the interpretation of an excavation.

Another very important qualification to the system is the possibility for users to customise the structure of recordings as well as differentiate classifications of their content. In a system where all entities are interlinked, the number of

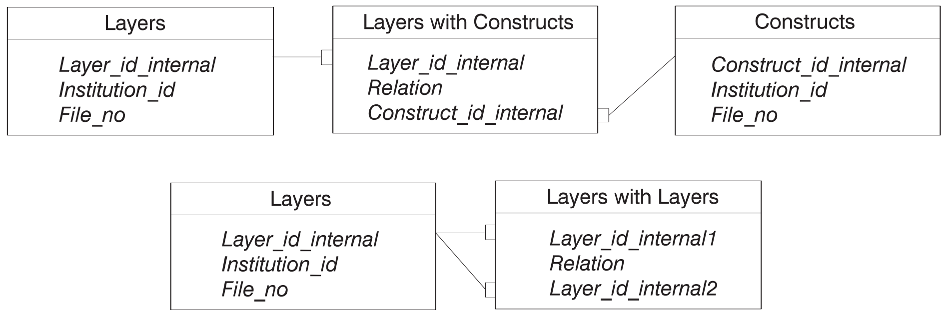

Figure 2. Implementation of many-to-many relationships using link tables. The upper part shows linking between entities, and the lower part linking within entities.

ways to structure the information (by choosing different channels through the web) is high. What particular structure should be used in relation to an excavation is not a programmer's decision. It must be a user decision. The same applies to the classification of items of information, for instance the artefacts. A Stone Age and an Iron Age excavation certainly cannot use the same classification and description system for artefacts. It is the user who should decide the classification system to be used, and the user must be able to tailor the system to fit his or her needs.

3 Implementation of the model

Even though each instance of the database is able to hold data from several excavations — and thus might be maintained by a central authority — the decentralised structure of Danish archaeology (and archaeology in most other countries) demands a decentralised solution. This is one of the reasons why our system is organised into two separate parts: the core data structure in one module and the user-interface in another. This division has several advantages during the phase of software-development. For the end user, one advantage is that by telecommunication channels it will be possible to interface different geographically dispersed data sets. At the same time new versions of the user-interface can be implemented without any side effects on the data part. Indeed, there is the possibility to create multiple user-interfaces to the same set of data, should this be needed.

Another consequence of this architecture is the possibility to separate archaeological from administrative information on the project level. Administrative information dependent on country and institution can be included as tables in the user-interface part. They cannot be separated from their entry forms anyway. Likewise, the structure and layout of reports are also country and institution dependent and thus should be kept entirely in the user-interface module as well.

A disadvantage of this two-level architecture is that uploading of data from one instance of the database to another has to be monitored by a module of specially written code. This we foresee will cause some head-scratching to write. The technical problem is that each entity instance in each instance of the database is given a unique sequential number (key) by the RDMBS. Thus entity instances are very likely to share the same identifiers throughout the various instances of the database. Because these numbers are used as pointers (foreign keys) in the link tables, it is obvious that uploading has to occur as a sequence of multiple, nested transactions in order to maintain integrity of the uploaded database.

The backbone of the implementation consists of five tables corresponding to the five basic entities of our conceptual model. Each of these contain basic information, which subsequently can be tied together using link tables. The link tables are of two kinds (fig. 2). One type consists of link tables interconnecting the five entity tables. There are ten of these, each having the primary keys of each of the two tables they connect as foreign keys, and in addition a field called ‘Relation’ to hold the type of relation between the two basic tables. Together the three fields of the link table constitute its primary key, and hence a unique entry. The other type of link table is that which connects an entity table to itself. Logically there are five of these, although we have not implemented Photos linked with Photos as we cannot imagine who would use it. This kind of link table is constructed like the former except that both foreign keys refer back to the same primary key in one single table.[2]

The field ‘Relation’ in link tables between entities is customarily filled in with a ‘is linked to’ string, but it is currently not used for any purpose, as we have seen no way in which we could make use of different types of relations. Should the need arise, however, the system is prepared for multiple relation types.

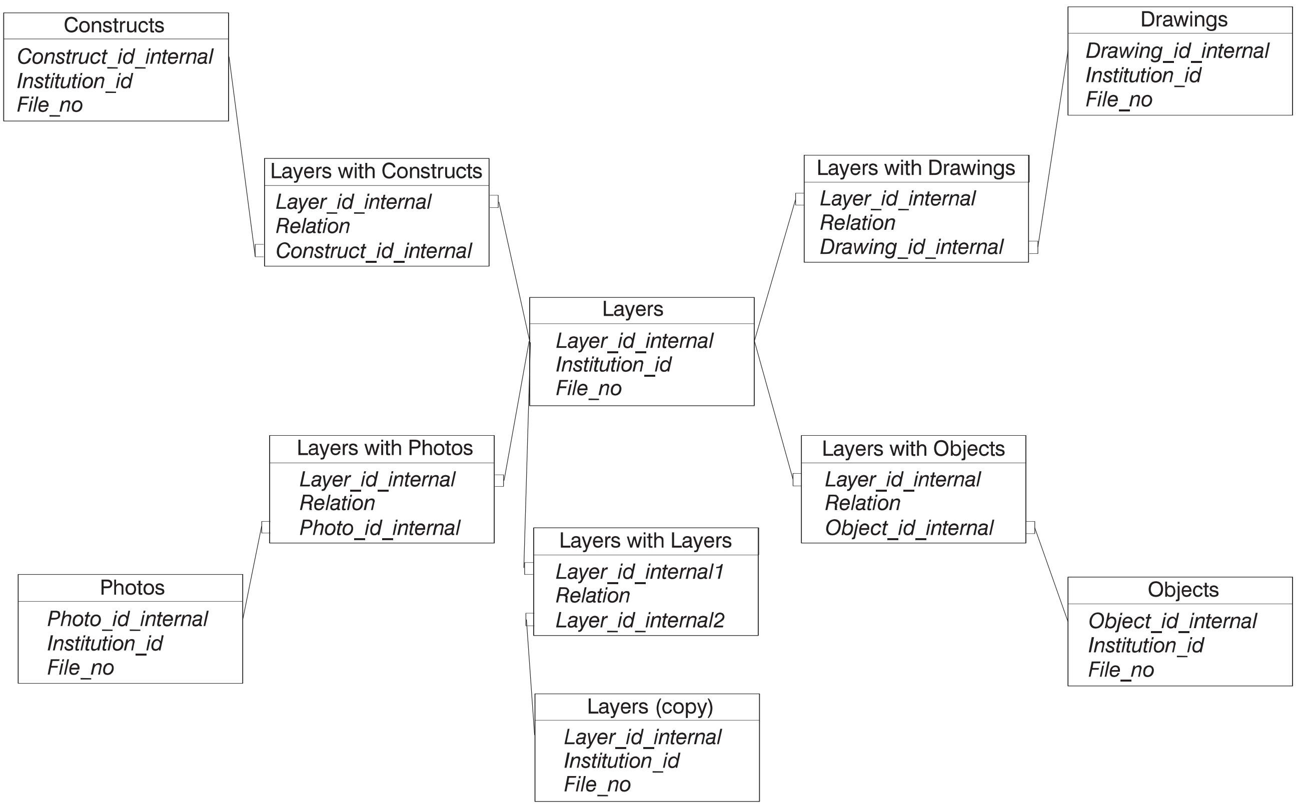

Figure 3. The core of IDEA as seen from one entity (Layers). No other entity is more than one link table away.

In link tables connecting entity tables internally, however, the field holding the relation type in the link table is very useful. Thus in the example shown in figure 2, where Layers are linked to Layers, the field can hold various types of stratigraphic relationships. Had the example been Objects linked with Objects, the relations could have been various types of information on refitting the objects in question.

The implementation of the conceptual model (fig. 1) leads to what looks like a spaghetti junction construction. However, when viewed from any particular entity the structure appears fairly simple. Any entity table is only one link table away, and we have what may be described as a five armed octopus (if that is not too much of a contradiction) (fig. 3). Four of the arms lead through link tables to the four other entities, while the fifth arm leads through a link table to the entity itself.

In figure 3 we view the structure of the system as seen from the Layers table, but a view from any of the other entity tables would look exactly the same. Any of our five basic entities is thus linked directly to the others as well as to itself. It is our claim that in using this structure we can map most if not all data models for archaeological excavations.

One pre-condition in our implementation of the conceptual model, is that any instance of an analytical or documentary entity has to be uniquely identified. Thus if we want to store information about a specific sherd from a bag find, then this sherd has to be identified separately. Because the user-supplied identification does not enter a key-field in the underlying table, the sherd identified need not be renumbered, that is double-numbering of user-supplied identification is allowed! The key-field for any record in the tables is assigned by the RDBMS automatically as a positive long integer unknown and hidden to the user.

In cases of double numbering the problem for the user of course remains as ever: the difficulty to separate instances with identical identification. The obvious solution is, as it has always been, to number every instance uniquely.

Provided that information has been loaded into the basic entity tables, setting links between the entries in these tables is a fairly simple matter. We have chosen to implement the linking through a form where we can pick any number of items available from the entity you wish to link to, and connect them to the current record of the current entity table. Linking thus always takes its starting point from a specific entity instance, say a layer in the Layer entry form. If we wish to link objects to this layer we call up the linking form by pressing a button at the base of the Layers entry form. This provides us with a form containing two list boxes (fig. 4). The one on the right contains all those finds, if any, already linked to the layer, while the other box contains all recorded finds not linked to the layer. Setting links, or removing already established links is simply a matter of using the arrows between the two list boxes, or by just double clicking the item we want to move.

Figure 4 shows the form used to set links between entries in different entities. As mentioned we do not need to work with different relation types in this case, but if we move to the internal relations (say Layers with Layers) we need to be able to set the type of relation as well. This we do in a form much resembling the one in figure 4, but with the addition of a combo box, where we can choose the type of relation we wish to view and set.

The implementation of the 'project' concept is rather simple. We have created two tables, *Institution* and *File*. An institution may be an archaeological unit, a university, a museum etc. Each institution may house many excavation-projects, each uniquely numbered in the *File*-table. The key-fields of the two tables are included in the five primary tables of the core database and in some auxiliary tables which hold other relevant information.

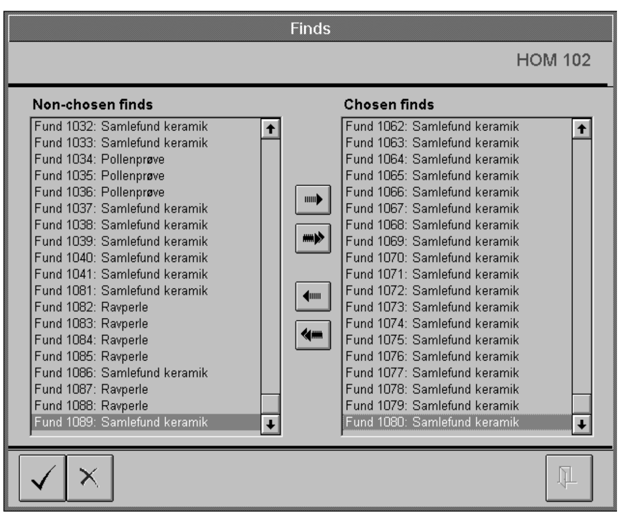

Figure 4. The form used to set relationships between the current record (could in this case be a construct, layer, drawing or photo) and any number of available objects. The list box marked Chosen finds contains those finds already linked to the current record, while those listed in the Non-chosen list box are those finds still available for linking.

Further subdivisions within a project may be implemented utilising numbering conventions in the user-supplied identifiers. I.e. area codes and calendar year could be used as suffixes to the identifier of the entity instances. Therefore we can foresee a future demand for a customisation module to take care of project subdivisions and numbering conventions.

4 Customising the system

4.1 Implementing a datamodel

At the bottom of each of the entity entry forms (fig. 5) a number of buttons with arrows across opens up link forms to other entities of the type shown in figure 4. However, if we allow users to link as they please we seriously risk that the entries entered will cause inconsistency in the database. Very different structuring of the information can result from unconstrained linking of entity instances.

One way of controlling input is to disallow users to input data to a particular entity, say Objects, unless it is controlled by another entity, say Layer. That is, the only way you will be able to enter Object data is through an input form activated by the Objects button on the Layer entity form. In this case you will not get a link form in response to a press of the button, but an input form setting a pre-defined link as part of the data entry process. At the

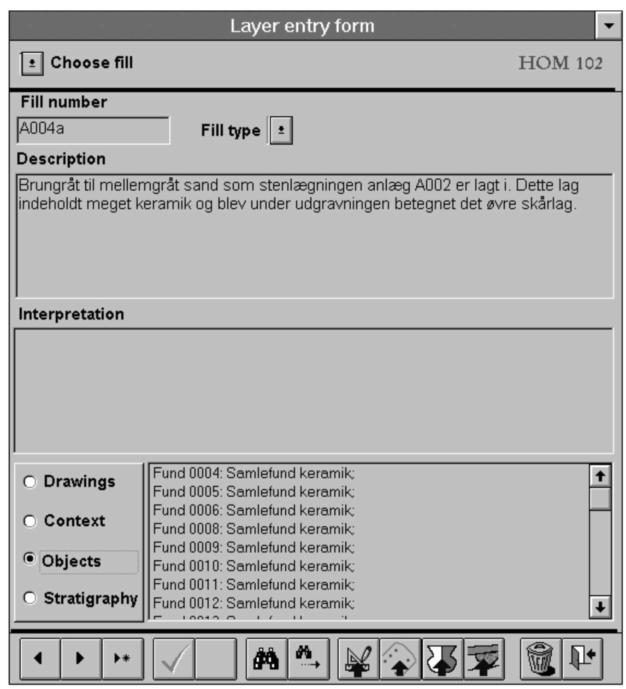

Figure 5. A standard entry form for a basic entity in IDEA (here the entity Layer). Buttons with arrows across call up either link forms of the type shown in figure 4, or other data entry forms with a forced link to the current record.

same time all other buttons leading to a linking of Object information can be disabled, making linking of Objects to Layers the only option available.

Thus by controlling what buttons are available, where and when, and what they will call up, structure can be provided to the recording of excavation information. Different views on the structure of excavation information — that is different data models — can be mapped onto the system by varying the availability of input forms, and not least through the sequence in which these must occur, as well as what possibilities of linking to other entities are available.

Figures 6 and 7 show two examples of data models for excavations. In figure 6 a three-level model is shown. The Construct is seen as the basic entity categorising all observations at the excavation level. That is the excavator has to interpret his observations in the field in terms of structures and features as he proceeds. The Constructs which may well be nested in internal hierarchies are characterised by containing one or more layers or fills, and each layer may contain one or more objects. The principal constraint of this model is that an Object has to be a part of a Layer, which has to be a part of a Construct. Photos and Drawings are seen as independent documentation evidence that may be freely linked to any of the three main entities.

Figure 7 shows a two-level model based on Layers and Objects. A model of this nature, where the Construct entity has been excluded, is widely used in excavations from the old Stone Age, where a geological frame of reference rather than one of man-made structures is prevalent. However, even here the Construct entity is needed. As stated in the paragraph on the conceptual model the Construct covers more than we immediately observe during the excavation. During the post excavation phase or even during the excavation itself we may add interpretations in terms of categorisation of information that goes beyond 'evident structures'. Potentially at any point we can record what has been termed 'latent structures'. Thus in old Stone Age excavations analytical entities like 'living floors' or 'activity areas' are frequently isolated as if they were observable. As a consequence we have to supply forms that allow the entering into the Construct table of latent or inferred structures and the free linking of these regardless of how the model is otherwise structured.

A specific data model should be applied to any excavation to avoid ambiguity in recordings. However, there are reasons why it should be possible to bypass the data model and let experienced operators go into a mode of unconstrained data entry. First of all, if data entry is to occur in a post excavation situation from written lists, it provides far the fastest way of data entry. Secondly, if mistakes occur for one or other reason, it may provide the fastest way to clear things up. In unconstrained data entry mode the operator has to be very much aware of the model (s)he is dealing with, and use those links only that will give the intended structure.

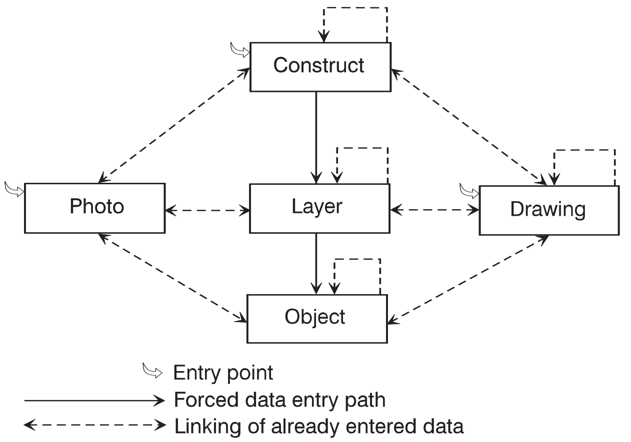

Figure 6. A three-level model for the recording of an excavation with constraints demanding that any object must be part of a layer, which must be part of a construct. 'Entry point' indicates where data input can be initiated.

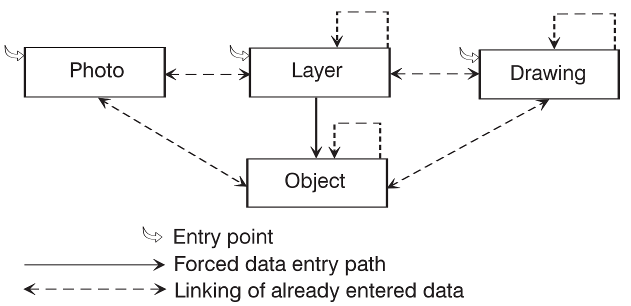

Figure 7. A two-level model, where the Construct entity has been excluded, and where any object must be part of a layer. "Entry point" indicates where data input can be initiated.

As demonstrated, it is fully possible to map different data models onto the underlying table structure. However, it is not sufficient for us to have a system where we as programmers can set up different views of the database. It is important that it is the user who can customise the system dynamically.

To make user customisation possible we have created a data model definition module, where it is possible to define how the connections between tables should be presented in terms of optional linking or forced data entry flows. Basically, the customisation is implemented through a full square matrix, where the five basic tables are cross related with each other (fig. 8). A number of possible values for each cell is defined by us, and can be selected by the user in drop down boxes for each cell. A data model may then be defined by setting a combination of the values in the matrix. The choices in each cell include link, no link and (forced) path in the off-diagonal cells and a combination of entry/no entry and link/no link values on the diagonal.

The user can define and select a model. However, we cannot allow this to happen at any time. It is important that there is consistency in recordings throughout any particular excavation. Thus, when initially a project is defined, the user must select the model to be used, and from that moment it is a binding choice for that particular project, not to be changed. Anything else would be an invitation to chaos.

4.2 Definition of internal relations of entities

The capability to handle relationships internally between instances of entities makes the system extremely powerful and versatile. It enables users to build up data structures dynamically, and thus removes one of the major weaknesses of most digital excavation recording systems sofar — the predetermined data structures hard coded into the system by the programmer. Thus for the Constructs entity it would in most traditional systems be necessary to operate with a pre-defined hierarchy of features, structures, groups etc. and to stick with these. In our system, however, it is possible to assemble data structures of Constructs dynamically into higher levels of interpretation units to any level and any complexity.

In order to make the use of the internal relations as flexible as possible the users can define the relations they need (fig. 9). Four types of information have to be supplied in the definition form. The domain (i.e. whether the relation is valid for Objects, Layers, Constructs or Drawings), what the relation should be named, the name of the inverse relation, and what abstract data type the specific relation is an instance of. If the relation is symmetric, (i.e. ‘same as’) one enters the relation name in the inverse relation field as well. In figure 9 an example of defining a parts breakdown is shown: the domain is Constructs, the relation is ‘is part of’, the inverse is ‘contain’, and the type of structure is ‘hierarchy’.

Following the definition of the relationship the user may use it to relate an instance of a Construct to another instance of a Construct. Thus a specific ‘post-hole’ may be assigned to a specific ‘house’ as being ‘is part of’ that house. Seen from the viewpoint of the house, a ‘contain’ link to the post-hole will automatically be entered by the system in the same transaction.

The type of structure is selected from a number of types we have defined. Currently we have isolated a set of six

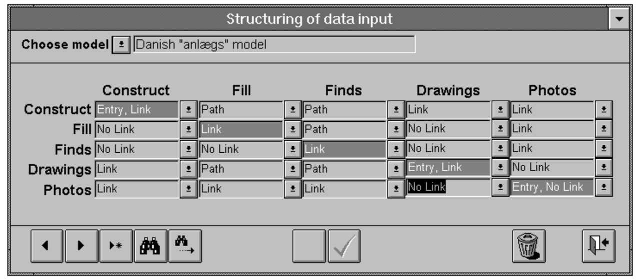

Figure 8. Form used to define a data model. Each cell has a drop down box providing a number of pre-set alternatives.

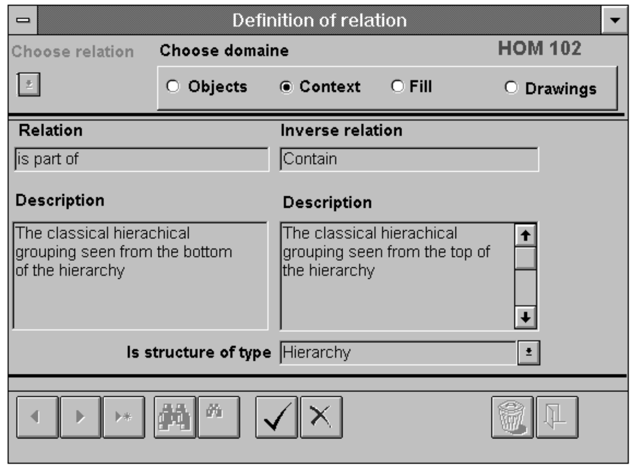

Figure 9. Form used to define internal relationships in entities.

types: Set, Series, Hierarchy, Web, Directed web without loops, and Directed web with loops.

A ‘Set’ represents an unordered collection of items. The relationship ‘same as’ is a typical representative of this type. A ‘Web’ is an unordered collection of items, too. But in contrast to the ‘Set’, the edges between the items are significant. The relationship ‘fits together with’ (i.e. used for refitting of sherds) is a typical representative of the ‘Web’ type. The type ‘Directed web with loops’ is used if a relationship has an inverse, and if it is possible to return to a specific element when a path through the structure is followed. Currently, we have not come across representatives of this type but we will not exclude their existence, i.e. in complex webs of interpretation.

A ‘Series’ is an ordered collection of items. The relationship ‘is younger than’ is a typical representative of this type. A more complex structure is the ‘Hierarchy’ mentioned above. It is a recursive structure with only one top-node and only one edge pointing to any other node. One may distinguish several variations of ‘Hierarchies’, but we have found no reason to do so at the moment. A more general structure is the ‘Directed web without loops' used, for instance, in stratigraphical relationships. In this structure a node may be pointed at by one or more edges.

Each type represents a characteristic organisation of data (fig. 10), which can be used in the system in different ways. Thus knowing that the structure being defined in figure 9 is of the type 'Hierarchy' we can set up a checking mechanism on data input which prohibit logic failures. I.e. if 'post-hole A' is part of 'house B' then an attempt to record 'post-hole A' as being a part of 'house C' would result in an error, because the entry would violate the constraints of the structure defined.

Another area where the type information can be used is in connection with the presentation of data to the user. As can be seen from figure 10 each type has inherent graphical characteristics that may be utilised in presentation screens (Ryan 1995). Thus we do not need to know the actual content of the recordings, only their type in order to do a proper presentation. Another perspective is that we will be able to combine and display several relationships, as for instance when combining 'same as' and 'lies above'/'lies below' relationships for stratigraphy.

4.3 Setting up classification and description systems for entities

A further and very important point of user customisation is the possibility to classify and describe the content of the individual records of the entities Constructs, Layers and Objects.

It is of course easy enough to implement a user defined classification, unique within each individual project. However, the critical issue is the varying number of variables relating to each class defined, and their values. We are not yet through with the implementation of this, but we have made some successful proto-typing exercises. The first step is to set up a structure to hold the user defined classification and description system. As shown in figure 11 this can be done in three tables, Object Type, Description Variables and Values of Description Variables linked in that order to each other with one-to-many relationships. This will allow any type to have an unspecified number of variables and any variable to have an unspecified number of potential values.

To use this system in our database we will need at least two tables. The Object table is identical to the one already existing in the database, including a field for the basic classification of the Objects. The other table, linked to the Objects table in a one-to-many relationship, holds the description of the object in terms of the particular variables relevant to the type of the object and the values they exhibit.[3] The two table solution may not, however, be flexible enough. If an object has to be classified as type x as well as type y, we need to add an extra table holding the classification exclusively. That is, we will need a table holding the artefact as an object (the one we already have), a table holding one or more classifications of the artefact, and a table holding the descriptions. These three tables are linked of course in one-to-many relationships in the order mentioned.

A possible way to implement the variable description in relation to a classified object is through a pop-up form

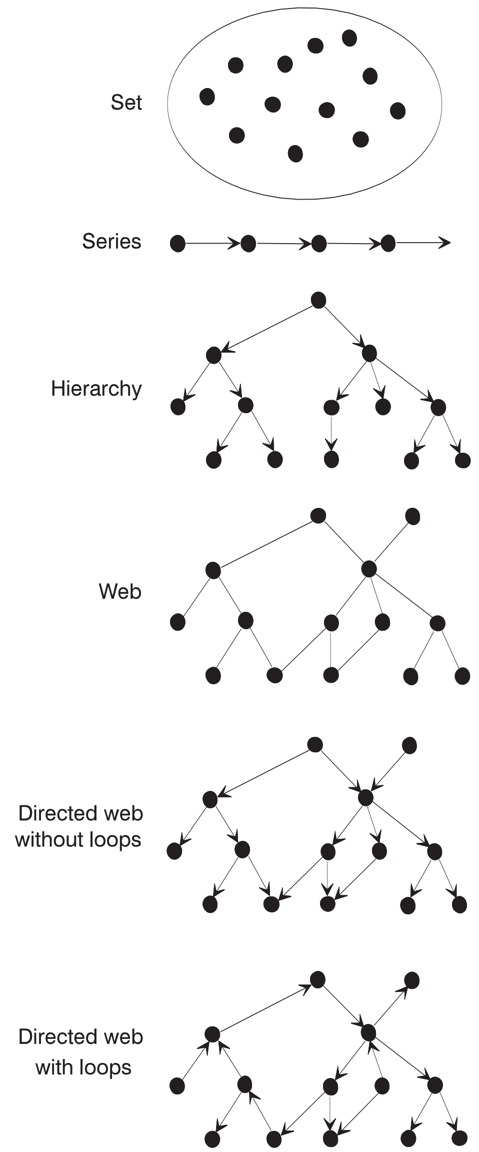

Figure 10. A graphical presentation of the characteristics of six data structures recognised in IDEA.

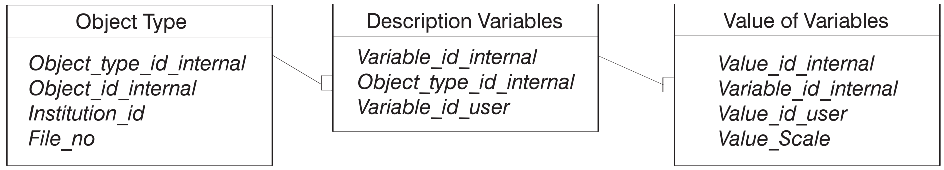

Figure 11. A table configuration for a general object classification system.

(fig. 12). The form works in tight correspondence with the classification tables. The choice of a type for an object, decides which variables will be available in the drop down list of the pop-up form for the variable field, and subsequently the choice of a variable will decide what values are available in the drop down list of the value field. Pressing the buttons of the drop down fields in the wrong order will merely result in a lack of available choices.

4.4 Setting the Language

An obvious area of customisation is the language presented to the user on the screen. Whereas our documentation of the system is held in a language akin to English (Danelish), the user interface has to be native to the area where it is presented. We have solved this problem by storing all labels, messages, etc. in a special language table, where each language has its own column, and each string to be presented to the user has its own row. Initially we enter all strings in this table in Danish and English, the two languages currently supported. Adding a new language is simply a matter of translating the strings in the table and writing the translation in a new column. Selecting a language is a simple choice among the currently available languages in a combo box in the customisation form. The language will change instantly. The currently selected language will be saved to an ini-file, and thus be remembered from session to session until a new language is selected.

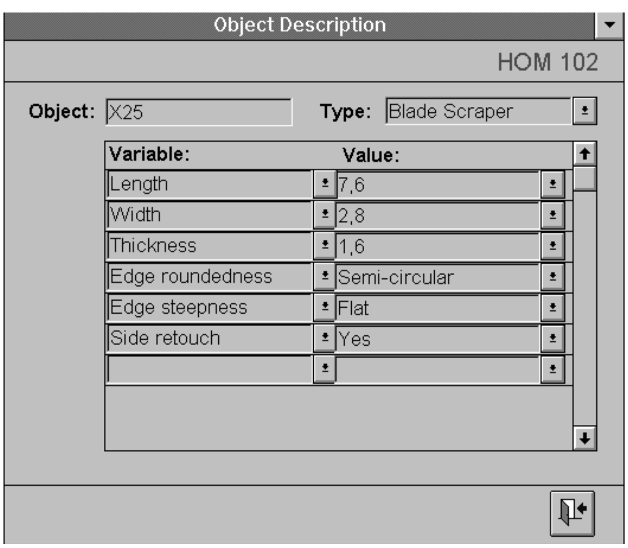

Figure 12. A form for entering a classification and a formal description of an object. Variables available in the drop down boxes will vary according to type chosen, and values will vary according to variables chosen (at the time of writing the classification system has not yet been implemented in IDEA).

5 Programming with a minimum of code

Since the beginning of the project we have placed a lot of effort in making the system as easy and cheap to maintain as possible. We have tried to keep the amount of written code to an absolute minimum, as software development projects producing thousands and thousands of lines of code tend to drown in their own complexity. The result is all too often progressively rising costs in maintenance at best and total failure at worst.

5.1 Event programming of forms

The answer of the software industry to the code boom problem, is Object-Oriented Programming (OOP) (Booch 1991). One of the key features of OOP is that objects are self-contained modules, which respond to events. In the case of Microsoft Access, the various objects of the form (i.e. the controls or the form itself) offer the programmer the possibility to write code defining the functionality of an object responding to a particular event. The code itself is not written in an object-oriented language but instead in a Basic dialect. This Basic dialect is able to interact with the so-called DataAccessObjects library.

Using this functionality, the five basic entry forms include only approx. 250 lines of code each, including error-messages. Most of the buttons at the bottom of the forms are enabled and disabled by one global module which contains approx. 150 lines of code. The two forms for setting the internal and external relationships contain approx. 300 lines of code each. Altogether the amount of code is negligible.

5.2 Creating complex reports with no code at all

One of the areas, where Access really proves its 'fourth generation status' is through its report generator. At first it does not look much. At a second glance you realise that it is very much akin to the forms generator, and indeed has inherited most of its properties from this (Access is indeed object oriented behind the curtains). Finally you realise that a number of features has been added, compared to the forms definitions, making the report generator a truly flexible tool by itself.

One of its stronger features is that reports can be embedded and fully synchronised within reports three levels deep (the same applies to forms). The result is that you can set up a highly complex hierarchical structure involving a number of entities without writing as much as one line of code. In fact for all practical purposes we can handle our rather complex data structure in one code-less construction. Thus without a line of code we can build a list of features from the construct table, where for each feature the layers are listed, and for each layer of the feature, the objects with their descriptions are listed.

In Denmark there is an authorised format for so-called Level II data for the archives (see Carver 1985, fig. 4 for this concept — with reference to the Frere report). This format involves a fair amount of hierarchically organised lists, where especially the lower levels of the hierarchy are cross-referenced to other lists. We have succeeded in implementing this format in the system, and it only takes a press of a button to write out the complete report. Codes are used in two areas only. One is for the creation of an index to the report. The other is to tie parallel parts of the report together in a sequence (in fact we could have avoided this had a fourth level of embedding been available).

6 Future development of the IDEA

What we have achieved sofar is a flexible system for recording traditional textual information from excavations. This is the result of the first year of the project. There is, however, a very long way to go before the IDEA becomes reality.

Next, we have to add full support for the recording of three-dimensional data, not just in terms of a point in space for an Object, a Layer or a Construct, but also in terms of two-dimensional polygons positioned in a three-dimensional space. We have no ambition of achieving a full three-dimensional presentation, since the archaeological recordings in the field in plan and section are — and will always be — ambiguous with respect to a full 3-D representation.

We have characterised the system as an integrated database for excavation analysis, and for very good reasons. Our primary objective is to create a system which is analytical in its approach to excavation recordings rather than just descriptive. In order to obtain this we will implement analytical methods into the system. These are planned to be of two kinds. One set will be implemented around a GIS-type of interface. Another set will be based on a graph browser type of representation of data. The idea is that we will allow for different types of views on the same set of data, and that any interrogation in one representation is reflected dynamically in others (Ryan 1995).

Providing a system with the ability to handle spatial data, requirements for constraints in the spatial location of entity instances will be created. If for instance a find is assigned to a layer, it is natural that the system should check for consistency in their spatial relationships, that is whether the find location is within the boundaries of the layer. Furthermore it will become necessary to include a quantifier in the various link tables to store information like 'post-hole A' 'is x meters from' 'post-hole B'.
The analytical perspective is that the quantifier may serve as a distance operator in descriptions of complex and heterogeneous archaeological objects (Dallas 1992; Dickens 1977).

One set of problems we probably cannot solve within the three year limit of the current project, is the question of user-defined queries and reports. One may foresee the demand for a 'Wizard' (essentially another specialised database) which sets up screen presentations and reports according to the defined model for the project. Furthermore one can foresee a demand for facilities to query multiple projects with different data models, classifications and relationships.

7 Conclusion

In our opening form we have used the Globe as a symbol. By conviction we seek global rather than narrow *ad hoc* solutions to problems. We believe quite simply that by addressing problems in their total complexity we will come up with solutions which in the long run are worth far more than the quick *ad hoc* solutions.

Our project is to run another two years (at the date of CAA95), and we have no guarantee that we will be given money to continue thereafter. It is not however to be an academic project, where the results disappear with the money. We are determined that the destiny of the system is to be used and to be further developed. To ensure this we are very open to cooperation with anybody who can *seriously* contribute to the development of the system.
We have already initiated co-operation with different people on various aspects of the system, and it is indeed our hope to be able to widen this co-operation.

notes

1 We coined the word construct because it sounded as a good and meaningful term for the concept. At that time we did not know (shame on us) that Gardin (1980) had used the same word with a very similar meaning.

2 This solution is due to Paul Zoetbrood, generously offered during a very memorable evening at the CAA88 in Birmingham.

3 The idea for this implementation was abducted from a set of tables presented by Lene Rold (1990: 14)

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The Other Computer Interface

1 Introduction

This paper discusses some of the conceptual problems that arise during the implementation of a Relational DataBase Management System (RDBMS). Specifically it focuses on the problems encountered during the implementation and use of the ORACLE RDBMS in a commercial archaeological unit; the Museum of London Archaeological Service (MoLAS) during a one year inter-specialist research project into the Roman London's Eastern Cemeteries (RLEC). The project involved 10 team members with various specialisms, and resulted in the creation of 67 tables, and 17 validation forms. On completion, some 40,000 rows of data have been recorded.

Yet it is not the structure of the RLEC database, the means by which it was interrogated, nor the various techniques developed to help elucidate patterns within the cemetery data sets that is of interest here. Rather it is the interface between the user and the *concept* of relational storage and manipulation that is considered, and how problems in that conception manifest themselves in poorly structured requests, that do not exploit the functionality of the RDBMS. More importantly, such conceptual problems can lead to disillusionment, as the advantage of the new system remains un-apparent, and old conceptual battle-lines between specialist data sets are simply re-drawn in the syntax of a newer technology.

2 Justification

The paper is then about problems, worse still it is about problems with an apparently mundane computing application. The benefits of RDBMSs, seem to be implicitly understood by a CAA audience, as indicated by its casual reference in the manner of a detail within the proceedings; i.e. 'attribute information is stored in an RDBMS while the graphical data is ....' Indeed, this paper also assumes some of that awareness, by not providing an introductory description of RDBMS architecture and mathematical set theory, or data modelling and normalisation.

However, this familiarity is both a bonus and a burden, with the latter becoming apparent during the implementation process when one is both engineer and evangelist. While bringing the good news of dynamic systems to a user group largely disenfranchised in the rounded interdisciplinary business of archaeological interpretation by inadequate IT, it is easy to forget how ignorant one was before one's own conversion. Users, who for years have dealt with cumbersome data systems offering rudimentary relational capabilities via cryptic procedural syntax, (e.g. most archaeologists at MoLAS) have a theory laden perception of data management which can remain unaffected by the word of Codd (Codd 1970) and the promises of their own computing section. The confounding effect of that perception must not be under-estimated, and is best addressed in an educative dialogue between designer and user. The broad promises of evangelists, must be demonstrated by practical little miracles among the familiar objects of archaeologist's lives.

3 Old Systems And Resident Experts

The conceptual legacies of previous systems, need to be understood and addressed. User-groups who have experienced a gradual implementation of data systems, carried out by various 'resident experts', at various points in time often enjoy an especially rich inheritance of this type. Within archaeology such patterns of implementation are perhaps more common than we would like to admit. The typically idiosyncratic style of systems devised in this manner is understandable, given that the resident expert is generally motivated to design systems to ease her work in her field. Equally the brief of such individuals, if there were one, is unlikely to have been to design for inter-specialist data compatibility, and all that that entails; *i.e.* agreeing referential standards, unique numbering schemes, accepted key-word lists etc. Less excusable, is for such individuals to remain the resident expert, and for the solution they devised not to be shared. The *resident-expert-and-the-bus* problem, (i.e. what would we do if X got ran over by one tomorrow?) is well known, but more subtle, is the question of levels of education and the existence of strategic motivation.

The 'expert' on his or her initiative has provided a solution for an archaeological need that has been inadequately defined. The brief is not for instance, to simply design a system that can record details of animal bones recovered from an excavation and a set of reports that will enable non-(Computing) specialists to print this data out. Rather it is to do these things, and to enhance further analysis through the use of the system, by *explaining* some of its functionality, and the potential it offers. This is not an argument to train further resident experts, for it is unnecessary for users to be able to design relational databases, it is simply to open their eyes and minds to the possibilities. To paraphrase the words of an anonymous sage, the biggest single need for a successful relational database implementation is not for improved recall speed, more rigorous input forms, congenial interfaces or prolonged memory, but for better questions and better use of answers.

The strategic question, is simply that a strategy must be made. A unit must have a policy regarding the utilisation of appropriate IT in general, and the adoption of rationalised systems to store and manipulate the data recovered from an excavation in particular. For archaeological units this is neither as obvious nor as glib a point as it may seem. In such situations the possibility to implement new systems in the manner of the standard System Development Life Cycle (SDLC) with all the steps that process implies (Hussain/Hussain 1991: 215) does not exist. The required time, staff and resources are often unavailable, to allow the necessarily exhaustive process of organising wide blanket development and education to take place. Rather, systems are developed in the manner of prototypes.

> ‘A prototype is a tentative system, a model based on the interaction between analysts and users,.. *(it)* works best for systems that are highly interactive, (have significant human-machine dialogue), and is particularly useful when end users have difficulty specifying their information needs. Typical ad hoc decision support systems meets these requirements. Prototyping is also useful when problems to be solved are unstructured.’ (My italics)
>
> Hussain/Hussain 1991: 222.

A prototype system has the advantages of speed of development, and thus cost, it enhances end-user participation in systems development, practically acts as a conversation piece, and often generates a more accurate determination of user requirements. The fact that in archaeological units such prototypes often evolve into the information systems themselves, and therefore that the strict developmental process defined as ‘protoyping’ is a misnomer, is not a problem in itself. Rather it simply continues the eclectic tradition by which archaeological theory and method has often developed. Yet such gradual modular development can easily mutate to resemble the idiosyncratic efforts of the past resident-expert-specialist, as each user group is focused on in turn. For small archaeological units, the need for firm strategies to be drawn up and monitored is of the utmost importance, for the very reason that the realisation of those strategies will be a modular, incremental and probably project based process, and one unsuitable to the more rigorous developmental checks that a properly resourced SDLC approach would allow. Organisational as well as interpretative problems will arise if such protoyping is conducted outside a firm policy of implementation, sanctioned by management with the aim of providing a single integrated and rationalised relational system that delivers a communal benefit.

> ‘... the general lesson to be drawn from the relevant management literature is that technological change is likely to influence archaeological organisations and their structures, and the roles of archaeological professionals, very widely.’
>
> Cooper/Dinn 1995: 89.

4 Identifying Changing Needs

Properly implemented and supported, the RDBMS is then an agent of profound change in the conduct of single or multi-site/thematic archaeological enquiries carried out in commercial units for whom such technology is now truly accessible. Misjudging just how profound that change is, will at the very least render the technology impotent in the minds of many.

4.1 Shifting tasks

An appreciation of the degree of this change, is not aided by the classical route of systems analysis, and the stages it involves. Identifying users tasks for instance, allows the designer to characterise the overall purpose of an organisation by considering the components of which it is made. Fundamental questioning of the type What is the task, why is it necessary, what data is required for it, is the task duplicated elsewhere and so forth brings to light poor reasoning of the type *‘because we’ve always done it’*, *‘because I was told to’* or the infamous; *‘I don’t really know.’* The designer understands the individual’s role as a component of a larger structure and builds systems to support and ease the data-based tasks those individuals perform. An architectural response is provided for understood business needs, yet how does such an approach fare when the architecture itself is changing the nature, purpose or value of the tasks it is attempting to classify?

For example a finds researcher will identify the pottery from a context, compile lists of the types present and assign a *terminus post-quem* to the assemblage. This list will be passed to the site supervisor who will use it to phase the relative sequence of site development that has been deduced on the basis of structural data. With relationally disciplined tables of find and site data, the task of that finds researcher can and should change. Functionally, the structure makes the conventional 'passing' of data between finds researcher and site supervisor as a single act obsolete. Rather, this occurs at the point and in the manner of the user's choosing, The nature of the intercourse between the two groups also changes as *any* data set they produce is able to use the relational structure in which they exist. For example with access to stratigraphic information, the finds researcher is able to identify residual or intrusive assemblages augmenting their list of tasks and adding value to their role in the whole interpretative process.

The design of systems to support decision making, must begin by understanding the current state of information processing, to identify its weaknesses and strengths. Knowledge of these past modes of organisation however, must not be allowed to inhibit the generation of fresh and innovative solutions and aids to that decision making process. This argument is enforced in the context of archaeological decision making for here necessarily *structured* systems must be designed to record, manipulate and simply cope with large yet notoriously incomplete data sets that are then used to inform us about an *unstructured* phenomena; the past. Our databases have to balance the need for structure and thus intelligibility of data, against the cyclical hermeneutic character of archaeological enquiry that gives that data meaning. Initiatives voiced for an objective post-processual recording methodology, (Hodder 1994) threaten an unworkable imbalance by overfavouring the latter.

4.2 Interfaces And Understanding

An equally adept means of diverting attention from the profundity of what one is doing when implementing a relational system, is to place too much emphasis on graphical user interfaces and more generally the means by which the system is operated and accessed. Clearly such devices are intrinsic components of a successful implementation. They provide the crucial defence against the accusations of systems disenfranchising the archaeologists as interpreter, by enabling them to interrogate their data without recourse to specialised knowledge.

For RDBMS the Structured Query Language (SQL) requires knowledge of simple fourth generation non-procedural English-like languages. WIMPS based data browsers however, can spare the user even that hardship, as queries are built up from pull down menus of acceptable terms, parameters added and results posted to the screen. The issue here, is that much of the system's potential as an analytical device is dependent on users *conceiving* appropriate questions for the new architecture, which may then be phrased through such congenial object based environments. This point is returned to below.

In summary the conceptual problems that need to be addressed if archaeologists are to realise the potential benefit to their analysis that an RDBMS offers, are subtle, prone to growth without the confines of a strategic plan, and are not dealt with simply by the provision of a cordial interface. Not discussed here, yet equally relevant to the perception of new systems, is the more chaotic world of human emotion and how this is best handled. In this world, such powerful analytical tools which enhance the power of the individual to conduct multi-variable analysis, may also appear to threaten specialist authority, weaken job-security and effect career development. If one is prototyping systems for various user groups, which one shall be chosen first, how will the others feel?; apprehension and scepticism can mingle freely with enthusiasm. (See Cooper/Dinn 1995 for further discussion of this topic).

5 Some Specific Problems

In the course of the RLEC project introduced earlier, there were three distinct conceptual problems encountered. These were characteristic of users in transition between the older systems described in paragraph four, and the Oracle system they were confronted with. They are now considered.

5.1 Inter Specialist Boundaries

In common with most archaeological units, MoLAS has various basic specialist divisions, environmental, finds and field. These divisions also have sub-divisions, e.g. animal bone analysis, human bone analysis, pottery, building material etc. The divisions correspond to various areas of expertise, and in the initial stages of a project, specialists work in relative isolation, identifying what has been excavated. The extension of these divisions into the interpretative phase, either as an active decision or as a result of inappropriate information technology, will inevitably deny the generation of more holistic interpretations.

Relational database systems enable various archaeological data to be inter-related so that ceramic information may for instance, be related to the stratigraphy to indicate the degree of residually or deposit disturbance within a site. This much is clear, yet it is a bland statement to simply point out the possibility of myriad data relations, and ignore the environment in which such potential is released.

The evolution of recording systems at MoLAS, is a history of balancing the need to record excavations as accurately as possible, (the archaeological incentive) yet as quickly as possible, (the commercial imperative). Non-hierarchical site recording, using various pro-forma context sheets, carried out by archaeologists who are responsible for defining, planning and recording their own contexts, were all in direct response to the requirements of the complex urban rescue environment (Spence 1993). At the interpretative stage, the structural site details would be analysed to provide a frame from which other data sets — once they were available — would be hung, in order to contextualise the structural account. Thus dating information would enable the relative sequence of structural development to be phased.

There are two points here. Firstly that rationalised recording systems are essential if excavations are to be efficiently completed, and secondly the way in which data sets have been related in the past is not *solely* dictated by the adequacies of the information system employed. Thus the use of new systems must be considered within the necessary confines of the interpretative environment. This is not to say that such systems should simply make current practices more efficient, on the contrary there are inevitable consequences for working practices when new systems are implemented. Rather the practical adequacy of each improvement, change and addition to existing empirical techniques must be thoroughly considered relative to the real world in which (in this case) London's commercial archaeology is carried out. A realist stance based on the notion of practical adequacy, (Sayer 1992) is most appropriate to the environment in which MoLAS works, and provides the first line of defence against the use of novel systems and applications on a 'because we could' basis (Huggett/Cooper 1991: 40).

However, in order to provide the right conditions for systems offering improved data relatability to yield innovative solutions, the nature of specialist boundaries, and specifically the means by which 'relatability' will be effected, must be considered. There are two main factors; the architectural and the human.

The purpose of RDB architecture, is to enable relatability between data sets. Therefore table design that enables this functionality through the mechanism of referential integrity is a prerequisite. If properly designed, the relatability of data sets in computing terms is not a problem.

For researchers to adapt to the technology in conceptual terms requires some re-assessment of the forms in which the findings of one specialist group are communicated to another. It is important to point out, that one is interested here in the transmission of database information; an activity that occurs in parallel with the discussions, arguments and debates that occur between the specialists themselves. In the RLEC project, two examples of such reassessment can be given.

Human osteological information on sex and age was determined from some 14 different bone traits, both metric and non-metric. All of these traits are valuable to the specialist, with a final statement of overall age and sex being the culmination of those observations abetted by a greater or lesser degree of intuition. It is this aggregate decision that is of interest to the team, thus fields for overall age and sex were added to the appropriate osteological tables, enabling other users direct access to appropriate data.

The 2512 small finds recovered from the sites, of themselves, yielded much valuable information to the specialist and some to the rest of the team. But their contribution to the team, was enhanced when finds were grouped into functional categories, (luxury items, items of personal adornment etc.) that were stored as numeric codes in the object index tables. An interpretative, hierarchical judgement was made that built on the specialists work, (i.e. the initial identification of the object) but which enabled that specialist data to relate to the other data sets in a new and possibly more comprehensible way.

5.2 The Spreadsheet Mentality

A more practical problem, the 'spreadsheet mentality' as it was christened, is characterised by a desire to see all data of interest in a single large table, and by the belief that in order to compare one's data with someone else's, an extra column has to be added to the table and the appropriate data imported. It indicates a belief that data has to be in the same place to be relatable, which is a conceptual legacy traceable to older storage devices, the typical format of familiar reports and published data tables. It is a problem because it indicates that the comparison of traits is perceived as a structural problem and data structures are things that are not easily altered, ergo the potential for any data set to freely interact with any other has not been realised ergo the relational functionality is not used, result: disenchanted users. In this situation, the designer must emphasise two key points; the breaking down of specialist barriers and the importance of retrieval technique.

Excavation is a subjective exercise, and the data it generates is inevitably dependent on the recording procedures employed, and the individual who implements them on site. Yet a good relational structure dictates subsequent interpretation of that theory dependent data as little as possible by storing it in its most disaggregated state, and providing the means by which an aggregated state (of which there will be many) may be reached. One consequence of this is that inter-specialist boundaries are not only unenforced, they cease to be relevant, as the information from the excavation is expressed in terms of common relatable units. Such boundaries are concepts that the database need only be aware of for administrative purposes, a function ably catered for by a systematic table naming conventions. The RDBMS then, by its very nature is not disposed to enforcing incompatibility.

The spreadsheet mentality can also be addressed by emphasising the technique by which data is retrieved from the RDBMS. The user may query the database, and at that point, and in the manner of their choosing, tables are related. Thus querying becomes a more dynamic and slightly different process. Instead of solely analysing a table of data printed by a standard report, users are compelled to expend some time analysing the very form of the table itself. If one is already thinking more systematically about what one really needs from the database, then it is easier to progress to the next stage where the analytical functionality of a system like Oracle is realised.

5.3 The Pile Of Paper Mentality

This is characterised by general requests for large runs of data with little or no filtering criteria, or grouping. One reason for this is the belief that the computer is hiding information and that a visual check is necessary, another is that analysis is perceived as something that occurs outside the computer. A third is the wholly conceptual one, of data simply needing to be seen in all its exhaustive detail for the researcher to 'get her head around it'. (It could reasonably be argued that this is partly a product of the first two).

The problem is similar to that discussed in the previous paragraph, i.e. the ability of the database to search, verify and summarise data is not realised. Yet it differs, in that it sends a clear signal that the message *access is analysis* has not yet been assimilated (an assimilation that does not take place solely by *providing access*, i.e. an easy to use GUI interface). The volume of data to which access is now possible, and the diminishing resources available to analyse that data, means that it is becoming impractical to approach such resources without some research objective in mind, however insignificant it may be. At a time when project budgets are demanding the most efficient working practices to enable some funds to still be available for the actual analysis of the carefully rescued data, the need to replace mechanisms such as high-lighter pens, hand calculators and visual scans with the targeted search criteria, statistical functions and group operators of the RDBMS itself, is clear.

6 Conclusion

The problems discussed are neither difficult to address, nor are their effects hard to identify; they are however, easy to ignore. If users are to benefit from RDBMS technology in the core area of their profession — the quality and thoroughness of archaeological interpretation — such conceptual problems must be overcome. A poor implementation is that which ignores its own consequences, and for commercial archaeology in the 1990's a proper understanding of the positive benefits that new systems provide, must be recognised for the crucial component of a successful implementation it is. The quality of archaeological interpretation from those working in the commercial sector depends on it.

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Conceptual Data Modelling for Prehistoric Excavation Documentation

1 Introduction

Archaeological method and practice often deals with information that is tentative, liable to change and fuzzy. Data gathered in the field are usually fragmented posing the need to associate between pieces of relevant context. Drawing archaeological knowledge, which is by nature uncertain, from tentative and incomplete information and fragmented data is a formidable task which in itself would justify archaeology being a science (Richards/Ryan 1985; Ross *et al*. 1991).

Traditionally data is kept on paper (including photos and sketches), is organised in a single manner and all non-trivial processing takes place in the archaeologists head. This practice gives rise to problems in sorting and cross-referencing data with related information content. Informatics, or electronic data processing, promised, among others, to facilitate recording and association of excavation data by providing the means to organise and manipulate archaeological information efficiently. This promise has only partially been fulfilled. One reason is that some pieces of computer technology have until very recently been missing (integrating maps, images, text and attribute information in a single system). Another very important reason is the incorrect development of archaeological information systems (lack of methodology, indifference to issues of conceptual data modelling).

Conceptual data modelling of an application is the process of formally describing its static and dynamic properties for purposes of understanding the application's requirements and communication between the application developers and the system's users. This description of the application's properties is done independently of implementation issues and is carried out by use of a certain *conceptual data model*. The outcome of the conceptual data modelling of an application is called a *conceptual schema* and is an abstraction of reality as it is perceived by the intended users of the system, namely the archaeologists.

Computer users express their requirements in natural language — which includes diagrams, images, maps and processes — while computers execute machine code. Applications bridge this gap by executing programs that satisfy users' needs. The transition from user requirements to machine executable code is done by use of intermediate representations which facilitate the implementation of the desired system. One of these representations is produced at the stage of conceptual data modelling (Batini *et al*. 1992; Navathe 1992). Conceptual data modelling aims at the realistic representation of the information content of the application under research, therefore it should not be performed without the co-operation of its users, who are responsible for describing requirements and explaining the meaning of data. The conceptual schema that is produced is understandable to users, so mistakes can be detected at this very early stage. Moreover, the application converges towards the expected result. Furthermore, the designers' choices can be tested and the process of implementation is thus facilitated. Owing to the fact that the conceptual modelling process is independent of implementation details, the conceptual schema produced during the conceptual modelling process can still be used even if the software used at the stage of implementation changes. Lastly, maintenance and transformation of the system (e.g. in the case that application requirements change or are enhanced) are facilitated, because the existence of the conceptual schema of the application eases understanding of its structure and functions.

The *information system* for a specific project (e.g. an excavation documentation system) is a collection of activities that regulate the sharing and distribution of information and the storage of data that are relevant to the project. Information systems' development is a process which follows a series of steps, called the life-cycle of an information system. This life-cycle usually contains the following main stages: requirements analysis, design, implementation and maintenance. An application development methodology is a structured set of procedures, concepts, methods, models and tools covering the whole life-cycle of the system. For data-intensive applications the area of computing technology that leads from problem specification to system implementation is *database design*. Database design is a complex process and can be broken down into conceptual, logical and physical design. The purpose of conceptual database design is to organise data for effective processing by use of a model that is expressively rich and user understandable in order to facilitate implementation. There are several conceptual models that are used in conceptual design. One of them, namely the Entity-Relationship (E-R) model, has emerged as the leading formal structure for conceptual data representation, becoming an established standard. The E-R model is based on only a few modelling concepts and has a very effective and understandable graphic representation. The E-R model is described in detail in section 4 below.

This approach is not sufficient to cope with the special needs of archaeological applications since they deal with information which has three basic dimensions: the *spatial* dimension, which refers to the position of archaeological entities in space (for example the place where certain artefacts were found), the *a-spatial* or *descriptive* dimension (attributes that describe the form of archaeological information, for example the possible uses of artefacts), and also a *temporal* dimension, which refers to objects' location in time. The need for handling sufficient archaeological information as a whole demands a conceptual model enriched with spatio-temporal constructs. Moreover, prehistoric excavations have requirements that are not so evident in other types of excavations. These requirements stem from the fact that there is a vast number of scattered prehistoric excavation data that need to be correlated carefully in order to draw useful conclusions. Since interpretation is the most important task in a prehistoric excavation, the excavation documentation system should be able to provide the means of organising and manipulating archaeological data without eliminating individual observations and interpretative conclusions.

Archaeological information systems have only been developed in recent years (Allen *et al.* 1990; Lock/Stančič 1995), so there is little that can be said about previous work on the subject. While a lot has been accomplished towards the development of predictive modelling for site locations, little work has been done towards conceptual data modelling for excavation information systems. As a result, the excavation documentation systems that have already been developed are inadequate for manipulation of archaeological information and can usually not easily be adapted to satisfy the needs of other archaeological excavations or to handle changes in archaeologists' views and requirements.

The rest of the paper is organised as follows: Section 2 points out the special requirements posed by excavation documentation systems and presents a justification of why a special modelling approach is needed. Section 3 is a description of a prehistoric excavation scenery as viewed by a computer scientist. The archaeological information is analysed and presented, the primary objects are described and the relationships among them are identified. The main contribution of the paper is presented in section 4, which formally describes the conceptual model that is proposed and used and also explains the approach that was adopted by the authors. Section 5 contains a summary, an assessment of the paper as well as ideas on future research on the subject.

2 Why a specific modelling approach for archaeological applications?

Archaeological information can benefit from a special conceptual modelling approach on the following grounds:

Archaeological information is located in space. As mentioned above, an important aspect of archaeological information is its spatial dimension, the *position* of archaeological phenomena in space as well as their *shape*. The position of an archaeological object is a special attribute in the sense that any change on it affects other objects' positions. This does not usually happen in the case of properties like 'material' or 'use'. For example, a change in the position of a stratum may affect the position of the neighbouring strata. Additionally, the *shape* of an archaeological entity may relate to the shapes of other archaeological entities; consider a set of excavation units with specific shapes 'comprising' a stratum. The conceptual schema must be able to represent such cases.

Archaeological data need also to be 'located' in time. One of the most important features of archaeological data is their time dimension. An excavation documentation system should be able to record information about the dates when the archaeological data were discovered and the dates of their cultural affiliation and, also, to perform temporal queries. Temporal information about the archaeological entities can then be used to view the chronological history of particular phenomena, e.g. the construction phases of a wall. Interpretation itself poses the need for versioning. Consider the case of an artefact. At time A the archaeologist in charge thought that this was an arrow head, whereas at time B the same archaeologist decided that it was the blade of a knife.

Need to handle partially defined objects. Archaeological information about certain finds may sometimes be incomplete or uncertain due to constraints posed by factors such as short time due to lack of funds or construction projects in the area, and destruction of finds by later impositions which can make interpretation rather difficult.

Need to draw useful conclusions from data that do not follow patterns or follow patterns unknown at database design time. Archaeological data are characterised by a variety of form and lack of iteration. That is, archaeological method and practice involve objects that are usually unique and which an archaeologist attempts to classify. In most cases classification poses the need for unique descriptions. Classifying information that does not follow specific

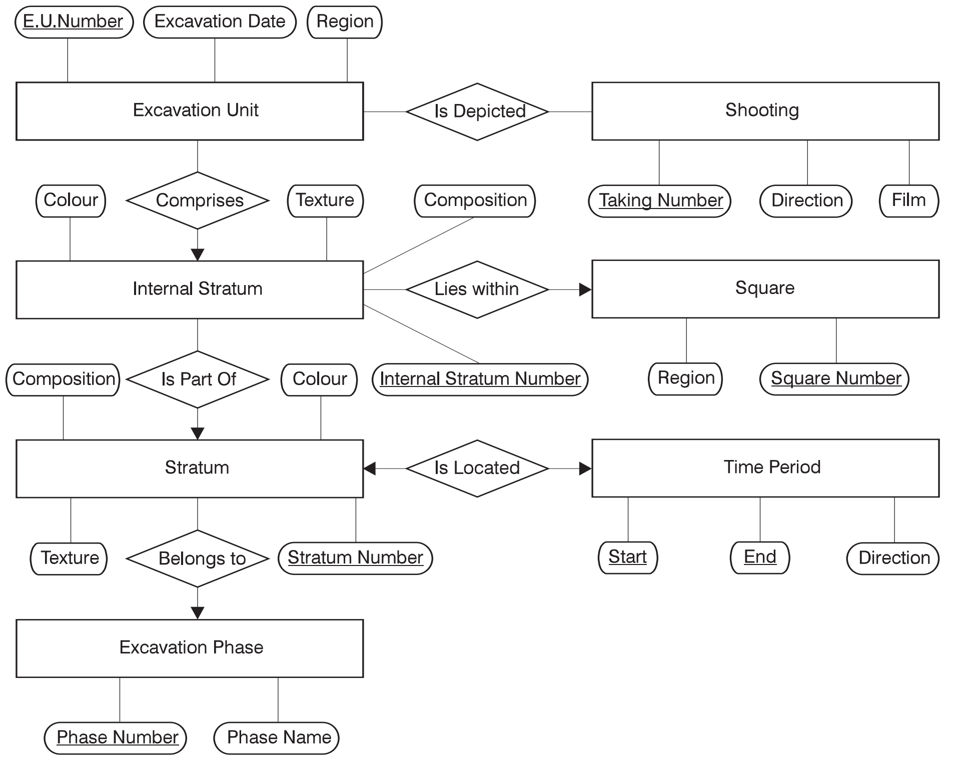

Figure 1. The Conceptual Schema.

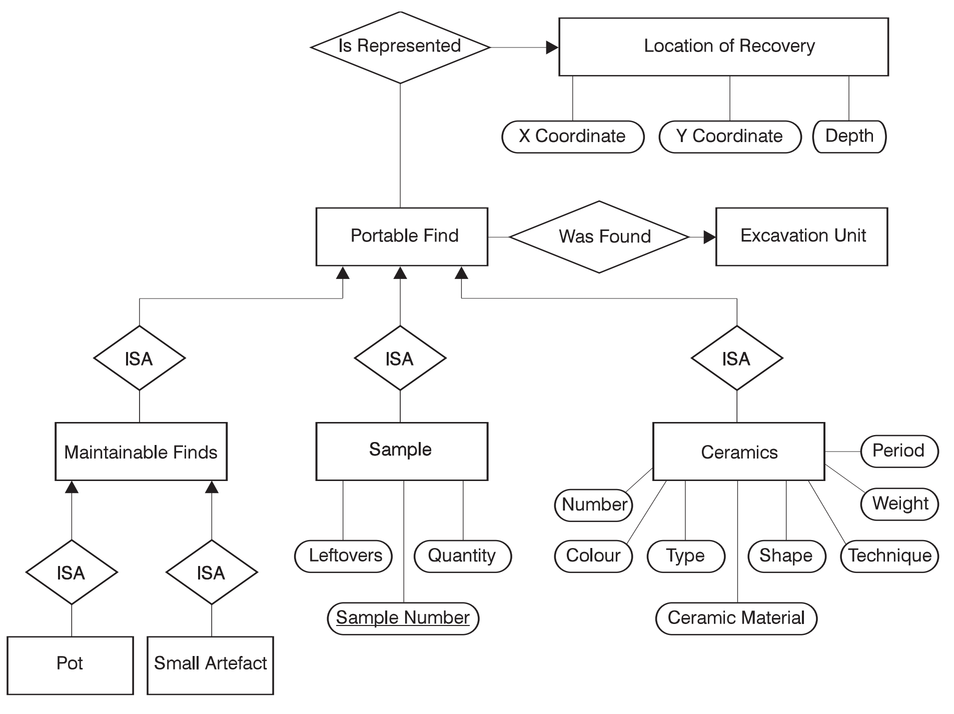

Figure 2. Portable finds.

patterns is a very special kind of decision making, on which interpretation is based. Drawing interpretation in an archaeological project where information does not follow specific patterns from attributes that are not repeated requires a special 'description' attribute in the archaeological database.

3 A layman's description of a prehistoric archaeological excavation

When compared to other kinds of archaeological excavations (e.g. classical or Roman), prehistoric excavations appear to have certain peculiarities that make the excavation practice and interpretation more difficult. Firstly, there is a vast number of prehistoric sites and finds which makes those that are under research only a small sample of the whole. Therefore, a prehistoric excavation cannot be representative of the context of others. An important aspect of a prehistoric excavation is that the information of interest is scattered. Therefore, it is very difficult to associate related pieces (for example finds, walls or hearths) as well as to visualise the excavation scenery as a whole. Moreover, prehistoric finds either have been destroyed by later impositions or are likely to be destroyed during the excavation itself, since excavating is by nature a destructive process. Many destructions are due to the errors and the inexperience of the archaeologists in charge. Therefore, the primary objective of a prehistoric excavation is the reproduction of a prehistoric scenery as well as the association between the elements of the archaeological information. This should be the objective of the excavation documentation system too.

Another important issue in archaeological excavation is *interpretation*. Interpretation is a decision-making process that depends very much on the cultural and scientific background of the archaeologist in charge. In prehistoric excavations, interpretation is very much limited by the findings.

Observation and experiment are very important parts of a prehistoric excavation method and practice. For example, it is possible to construct tools with the methods and techniques which are believed to have been used by prehistoric people. Then, these tools are tested upon use and are compared to finds. Prehistoric excavation itself can be thought of as an experiment, which unfortunately cannot be iterated. Therefore, errors in a prehistoric excavation may be very crucial to the conservation of finds.

Below follows a description of a prehistoric excavation scenery (Andreou/Kotsakis 1991; Andreou *et al.* 1995; Kotsakis *et al.* 1995). This paper presents a specific archaeological method for prehistoric excavations. However, the conceptual data modelling approach that is presented can be easily adapted to suit the needs of other prehistoric excavations.

The excavation site is divided into *squares* (or cuts). The square is the reference point for all archaeological activity that falls within its boundaries. Each find, each excavation unit and each stratum is identified within a certain square. Each square measures 4 × 4 m. The squares are separated from each other by lanes of earth that are not excavated and are called *witnesses*. Each witness is 1 m large. The witnesses are useful in order to study the stratigraphy of the ground in each square.

Most excavation methods use the *stratum* as the basic excavation entity that is located in time. The methods that are used for chronology can be either empirical or absolute (e.g. dendrochronology, chronology with C14). Determining the boundaries between consecutive strata is a very important archaeological decision which relies heavily on the experience of the archaeologist. Stratigraphy usually follows the rule of *overlaying*, which states that strata that are located closer to the surface are associated with more recent time periods than those that are deeper. However, this is not always the case. There are times when strata located in places with different elevations belong to the same chronological period. Since the square is the basic unit that controls the excavation process, strata are usually numbered with regard to the square in which they were identified. Aim of an excavation documentation application is to provide a unified stratigraphy and numbering for the whole of the excavation site. This numbering can take place after the end of the excavation. One must note that it is possible that strata belonging to different cuts are classified as contemporary in the final stratigraphy of the excavation site. Strata are characterised mainly by the colour, the composition and the texture of the soil that they contain.

Strata are usually divided into pieces of undetermined shape and size named *excavation units*. An excavation unit cannot go beyond the boundaries of a stratum and defines a constrained space where finds are distributed. Its fundamental use is to describe the progress of the excavation process.

Chronological period is the main historical product of a prehistoric excavation and provides a reference point for determining chronology for archaeological finds. Since chronological evaluation methods are applied directly to the stratum, the chronology of a certain period is determined by the strata that comprise it. Each period refers to a certain stage in a prehistoric settlement's life. For example, a fire that destroyed the settlement triggers the end of a period and the beginning of another, even if the new settlement is characterised by the same cultural and technological features as the previous one.

Until recently, excavation activities have been recorded on paper on a daily basis. The information that is kept refers to the square, the stratum and the current excavation unit; it describes the activities performed each day. It also contains the positions of artefacts. A large part of these paper manuscripts are in natural language and may also contain sketches, photographs, etc. However, there are some code expressions, for example those that refer to the colour of the ground. The use of code expressions aims at avoiding vagueness in descriptions and at facilitating interpretation. For example, ground samples with the same colour, which is expressed either by use of a code expression or by use of a standard colour set can be easily classified as belonging to the same stratum.

Prehistoric finds may be spatially fixed or not. Finds that are spatially fixed cannot be moved easily, such as walls or floors, hearths, post-holes and pits. All spatially fixed finds have a name or number that uniquely identifies them for the whole of the excavation site. For walls and floors it is interesting to note the material used to construct them (e.g. mud-bricks) and the depth of their foundations. Hearths, post-holes and pits are characterised by the number of their external phases, that is the number of times they were reconstructed or repaired. The phases of hearths, post-holes and pits are different from the phases of the prehistoric settlement.

Finds that are not spatially fixed may be pots, ground samples, seeds, shells and small artefacts that are usually classified with regard to the material used to construct them (stone, metal, bone or clay). Small artefacts, independent of classification, are described by information concerning their dimensions and shape, the material used to construct them, their colour, their type and possible use and are depicted in photographs and sketches. Some artefacts may require additional information recording, for instance concerning their decoration (type of decoration, technique and motif).

4 Modelling archaeological information

4.1 The Entity-Relationship Model

The *Entity-Relationship* model (E-R) described below is a conceptual data model that is entity-centred since its main objective is to represent entities (the primary objects, their attributes and the relationships in which they participate). The E-R model is a standard conceptual model which offers a very simple but abstractive means for structuring information. Due to its simplicity, it is widely used for the conceptual modelling of applications with very large information spaces. Certain variations and extensions of the model have occasionally been produced and used in order to satisfy the needs of certain applications.

Below follows a description of the fundamental constructs of the model. Each concept is further described by examples from the prehistoric excavation paradigm presented above. Examples are essential to aid understanding of concepts and to differentiate between similar concepts.

4.1.1 Entities

An entity is a thing or object of significance, whether real or imagined, about which information needs to be known or held. An entity represents a type or class of things — not an instance. For example, an entity named Stratum corresponds to the set of strata of a prehistoric excavation. This implies that each stratum identified in the field, for example stratum No 2, is an instance of the entity Stratum. Each entity must be uniquely identifiable. That is, each occurrence (instance) of an entity must be separate and distinctly identifiable from all other instances of that type of entity. In a conceptual schema entities are depicted by rectangles.

4.1.2 Attributes

An attribute is any description of an entity. Attributes serve to identify, qualify, classify, quantify or express the state of an entity. In a conceptual schema attributes are represented diagrammatically by circles which are linked to entities by undirected edges. The entity Stratum, discussed before, may have an attribute called Composition, which refers to the composition of the soil that each stratum in the excavation site contains. A combination of attributes usually serves to uniquely identify an entity. These attributes are then called the *key* for that entity. For example, the stratum number serves to uniquely identify a stratum (the assumption is made that the final stratigraphy of the excavation site consists of strata that are identified by different numbers), therefore an attribute named Stratum Number is the key for the entity Stratum. Attributes that are part of the key for an entity have their names underlined in the conceptual schema.

4.1.3 Relationships

A relationship is a significant association between entities. A relationship definition is one that represents a type of association between entities, to which all instances of relationships must conform. A relationship is represented by a diamond linked to their constituent entities by edges. As an example, consider the relationship which associates the portable artefacts with the excavation units in which they were found. Relationships have a functionality, which may be one of the following:

4.1.3.1 One-to-one

An example of a one-to-one relationship is the association between strata and chronological periods. Each stratum refers to one and only one chronological period. Furthermore, each chronological period is associated to one and only one stratum. (It is assumed that contemporaneous strata are merged in the final stratigraphy.) A one-to-one relationship is represented in the conceptual schema by directed edges that point to the entities forming the relationship.

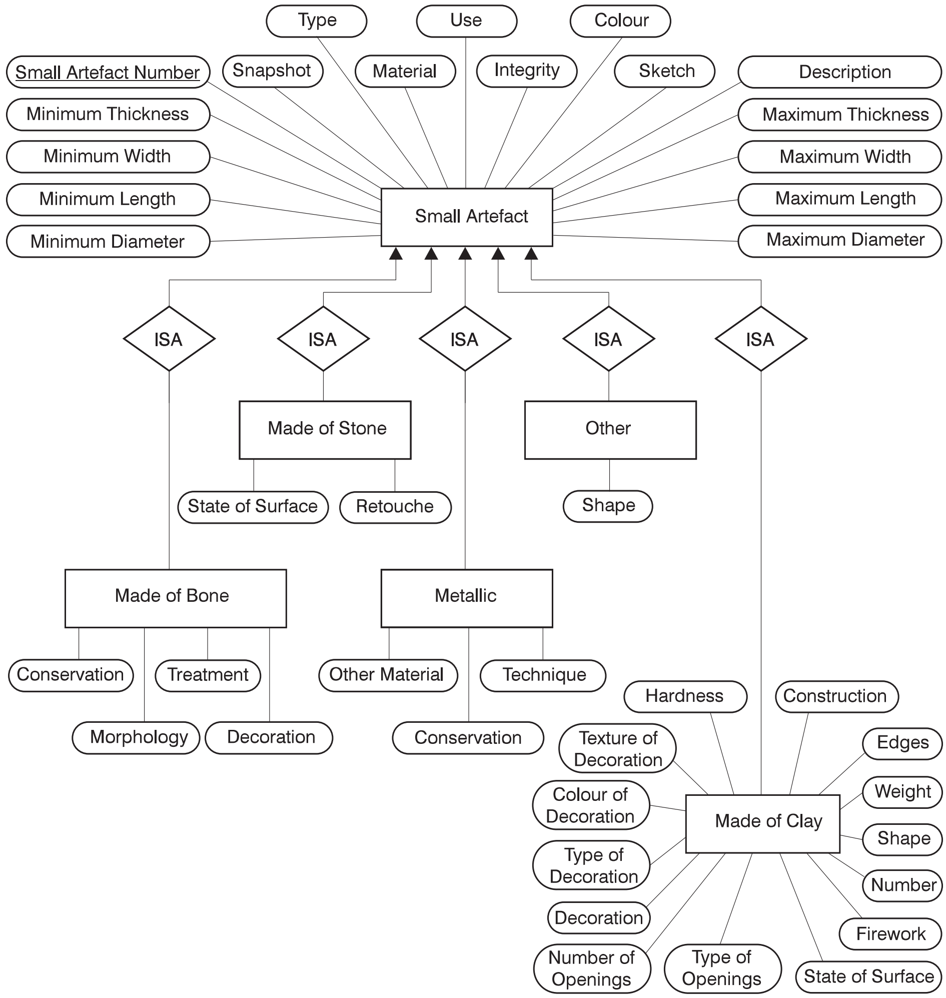

Figure 3. Small Artefacts.

4.1.3.2 Many-to-one

An example of a many-to-one relationship is the association between strata and excavation units. Each excavation unit belongs to one and only one stratum, whereas each stratum may consist of more than one excavation unit. A many-to-one relationship is represented in the conceptual schema by a directed edge that points to the entity which lies in the 'one' part of the relationship and undirected edges pointing to the rest of the entities participating in the relationship.

4.1.3.3 Many-to-many

An example of a many-to-many relationship is the association between spatially fixed finds and strata that surround them. Each spatially fixed find, a wall for instance, may be surrounded by more than one strata, whereas each stratum may surround more than one wall. A many-to-many relationship is represented in the conceptual schema by undirected edges pointing to the entities that participate in the relationship.

4.1.4 Isa Relationships

As we have seen, the Entity-Relationship modelling technique represents the world in terms of Entity Sets (e.g. Artefacts, Sites, Archaeologists) and Relationships among Entity Sets (e.g. 'found at' can be a relationship between Artefacts and Sites). 'Isa' is a special relationship indicating that one Entity Set is a ('Isa') subset of another. For example Archaeologists Isa Persons or Vases Isa Artefacts. The importance of this relationship is that the subset 'inherits' the properties of the superset. For example since Vases Isa Artefacts and Artefacts has the relationship 'found at' with Sites, then Vases also has the relationship 'found at' with Sites and we do not need to explicitly state this; thus when programs will be written we do not need to write a special program to interrogate where a vase was found; the general program written for all artefacts will suffice. On the other hand, if Vases have an additional property, say 'type of clay' but not all artefacts have this property, we do not need to store a field 'type of clay' for all artefacts (and have it with value 'NON APPLICABLE' for all but vases): subsets (Vases in this example) can have additional properties to the ones they inherit from their supersets (Artefacts in this example).

Put another way, Isa relationships serve to declare special cases of entities. These entities implicitly inherit all the attributes and relationships of the entity at the higher level, but they can have attributes and relationships in their own right. For example, consider the case of the entity named Small Artefact. Since a metallic artefact is a special case of a small artefact, there is an Isa relationship between the entities Metallic Artefact and Small Artefact. This means that each occurrence of the entity Metallic Artefact (that is, each metallic artefact) is distinguishable by its identification number (as all small artefacts are) and is described by attributes like Type, Use or Colour. However, a small metallic artefact is further described by attributes of its own, such as Technique, Other Material and Preservation Status. The same holds for small artefacts made of stone, clay or bone.

4.1.5. Is-part-of and Is-member-of relationships

Is-part-of and Is-member-of relationships are special cases of the Isa relationship often present in some of the extensions of the E-R model. The is-part-of relationship refers to entities that form part of another entity and therefore share some of its properties, whereas the is-member-of relationship refers to an entity that is a member of a set of entities sharing common properties.

4.2 Modelling archaeological information for prehistoric excavations

Below follows a presentation of a conceptual schema for the prehistoric excavation presented above. In order to explain choices that were made during the conceptual modelling process, we present briefly the main entities and relationships they participate in. The basic entities of the conceptual schema are the following:

4.2.1. Excavation Unit[1]

Excavation units are described by their number (unique to the whole of the excavation site), the date they were excavated (it is assumed that an excavation unit corresponds to activities of one day) and the region where this excavation activity took place.

4.2.2. Square

Squares are identified by their number which is unique to the whole of the excavation site.

4.2.3. Stratum

The entity Stratum corresponds to strata that belong to the final stratification of the excavation site which is determined at the end of the excavation process. Since prehistoric excavations are usually performed in squares, during the excavation process information is kept for strata that belong to the certain square that is being excavated. Strata that are determined this way may be part of a stratum that expands to more than one square. At the end of the excavation, strata are classified and correlated and thus the stratification of the excavation site is determined. To satisfy the need for storing information about strata during the excavation the conceptual schema contains an entity named Excavation Stratum, which corresponds to the strata that are identified during the excavation of a certain square. Information stored about excavation strata can then be used to help the decision-making process of determining stratification by facilitating the association of strata from different squares that share the same properties. Strata as well as excavation strata are described by their numbers as well as other properties, such as the colour, texture and composition of the soil they contain.

4.2.4. Phase

A phase is identified by its name (or number) and its description.

4.2.5. Portable Find

Portable finds may be small artefacts, samples, pots or ceramics. Small artefacts are classified into one of the following categories: of bone, of clay, of stone, Metallic and Other.

4.2.6. Spatially fixed find

Spatially fixed finds may be walls or floors, hearths, pits or post-holes. All spatially fixed finds are uniquely identified by their name, for example Room A. Like in the case of strata, spatially fixed finds are recorded during the excavation of squares. Therefore, it is possible that parts of houses belong to different squares. Since post-excavation work requires that spatially fixed finds are viewed as a whole, the entity Part of Spatially fixed Find is used in the conceptual schema to suit the need for on-site recording of spatially fixed finds.

The basic relationships are:

1. An excavation unit *comprises* an excavation stratum. This is a many-to-one relationship, since more than one excavation unit comprises an internal stratum and each excavation unit may belong to only one stratum.

2. An excavation stratum *lies within* a square. A many-to-one relationship since each excavation stratum lies within one square exactly whereas each square contains more than one excavation stratum.

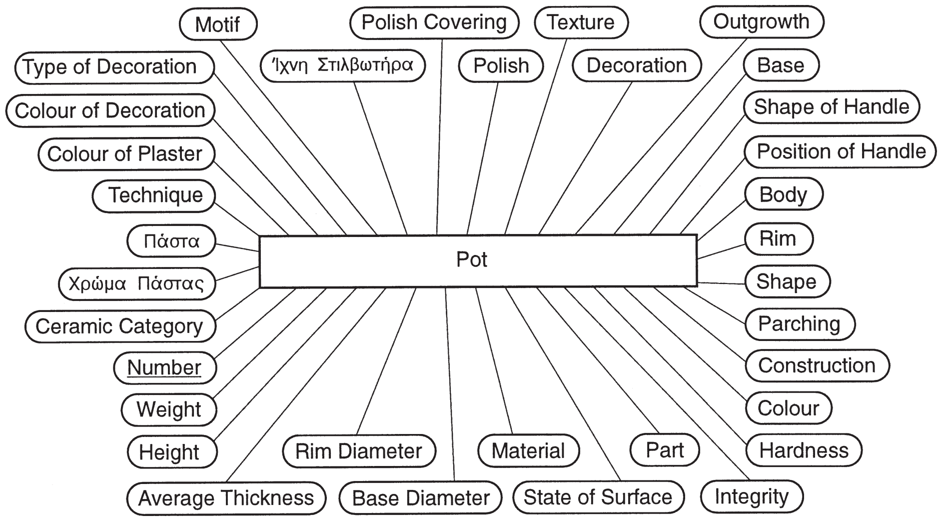

Figure 4. Pots.

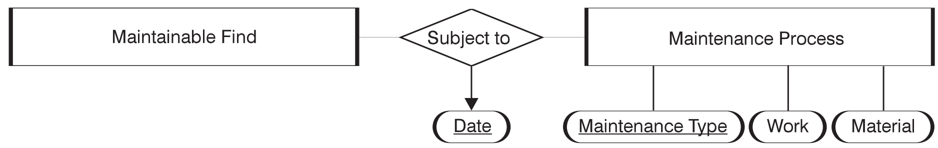

Figure 5. Maintenance of prehistoric finds.

3. An excavation stratum *is part of* a stratum. A many-to-one relationship since each stratum corresponds to more than one excavation stratum and each excavation stratum is part of exactly one stratum.

4. A stratum is *'located'* in a time period. This relationship is one-to-one. Each stratum is located to belong to exactly one time period and each time period corresponds to the chronology of exactly one stratum. It is assumed that strata that belong to the same time period are unified.

5. A stratum *belongs to* a phase. This relationship is many-to-one. Each stratum belongs to exactly one phase and each phase may contain more than one stratum.

6. An excavation unit *is depicted in* a shooting. This is a many-to-one relationship. Each excavation unit is depicted in more than one shooting, whereas each shooting depicts exactly one excavation unit.

7. A portable find *was found in* an excavation unit. This is a many-to-one relationship. Each portable find was found in exactly one excavation unit, whereas each excavation unit could contain more than one portable find.

8. Maintainable finds, samples and ceramics *are* (*Isa relationship*) portable finds.

9. Small artefacts and pots *are* (*Isa relationship*) maintainable finds.

10. Artefacts made of clay, stone, bone or metal *are* (*Isa relationship*) small artefacts.

11. Buildings, hearths, post-holes and pits *are* (*Isa relationship*) spatially fixed finds.

12. Walls (and floors) *are part of* buildings. A many-to-one relationship since each wall belongs to exactly one building and each building comprises more than one wall.

13. A spatially fixed find *is surrounded by* an excavation stratum. This is a many-to-many relationship. Each spatially fixed find may be surrounded by one or more excavation strata, whereas each excavation stratum may surround more than one spatially fixed find.

14. A spatially fixed find *is located in time* by a stratum. This is a many-to-one relationship. Each spatially fixed find is referenced in time by exactly one stratum, whereas each stratum may be used to chronologically reference more than one spatially fixed find.

15. A maintainable find *is subject to* a maintenance process. This is a many-to-many-to-one relationship. Given a specific date, a maintainable find may have been subject to one or more maintenance procedures. The other way round, given a specific date the same maintenance procedure may have been performed on one or more maintainable finds. What is more, there is only one day where a maintainable find has been subject to a specific maintenance procedure.

16. A portable find *is represented by* a point, the location where it was found. This is the graphical representation needed to map archaeological entities on the map of the excavation site. This relationship is many-to-one.

17. A spatially fixed find *is represented by* a set of solids. A one-to-many relationship. Solids are used to represent 3-dimensional entities in the excavation site and correspond both to the position of entities and to their shape.

18. An excavation unit *is represented by* a solid. A one-to-one relationship.

19. A square *is represented by* a solid. A one-to-one relationship.

20. A stratum *is represented by* one or more solids. A one-to-many relationship.

4.3 The Conceptual Schema of the archaeological database

This subsection presents the conceptual design of a database for a prehistoric excavation based on the previous description. The conceptual design, or schema, is presented in a diagrammatic form, known as E-R diagrams, using four symbols: rectangles denote entities; diamonds denote relationships between related entities; attribute names are encircled in oval shapes; underlined attributes are keys, i.e. unique identifiers, of the corresponding entities. Figure 1 is the E-R diagram of the overall excavation relating strata, excavation phases and excavation units. Figures 2, 3, 4, and 5 are the detailed diagrams of the four main types of archaeological finds: spatially fixed ones, portables, small artefacts and pots. Figure 6 is the design of that part of the database which deals with the maintenance of the finds, while figure 7 relates strata and excavation units to space, denoting that it is a 3-dimensional representation we are interested in.

5 Conclusions

Until recently, excavation documentation systems have not been much more than fast archiving systems. What is more, they often have not been correctly and efficiently designed. This paper presents the 'right' way to start developing an excavation documentation system by providing a modelling approach suitable to cope with the needs posed by the majority of information systems (Hadzilacos/Stoumbou 1994; Hadzilacos/Tryfona 1995). This approach is able up to a limit to deal with a substantial amount of the requirements posed by prehistoric excavations. However, as mentioned above, prehistoric excavations do require special treatment as they present many peculiarities.

In the direction of providing a conceptual model suitable to deal with the special requirements often placed in the case of prehistoric excavation documentation systems, it would be interesting to search among the existing extensions of the E-R model in order to be able to chose the more suitable one for modelling prehistoric excavation information or even design a new extension that would provide the means to efficiently model data from prehistoric excavations.

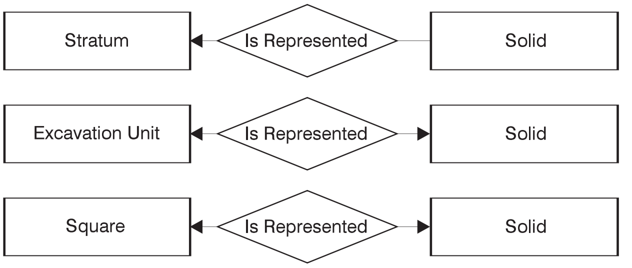

Figure 6. Position of excavation units, strata and squares.

Acknowledgements

We would like to thank Professor George Hourmouziades who provided the initial stimulus for this work. Professors K. Kotsakis and S. Andreou reviewed presentations of early versions of this work and made fruitful comments; they provided us with relevant material from the prehistoric excavation at Toumba, Thessaloniki. We would like to stress that although the conceptual modelling approach presented in this paper reflects their views on the subject of prehistoric excavation documentation, the authors have full responsibility for any mistakes on understanding the archaeological methodology.

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note

1 The excavation unit is an entity that is conceived by the archaeologist in charge of the excavation. Some archaeologists do not use excavation units in practice, while others that agree to the use of excavation units give different definitions to the term 'excavation unit'. The conceptual schema presented here can be easily adapted to cover such cases.

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Handling Excavation Maps in SYSAND

1 Introduction

SYSAND is a system to help archaeologists in processing and interpreting excavation data. It has been designed for the excavations of the Gallo-Roman town of Anderitum (now Javols in Lozère, France), but it could be easily adapted to handle data of other sites.

SYSAND records stratification unit (US) cards, checks consistency of physical relationships, and constructs and draws Harris matrices. The archaeologist can visit information related to each unit by navigating in the matrix representation (Maggiolo-Schettini *et al.* 1995a, Maggiolo-Schettini *et al.* 1995b).

To access pictorial and graphical information related to stratification units, SYSAND has been extended with the module SIGMA. In particular, SIGMA inputs maps digitized by means of a scanner. Maps (drawn during the excavation) are given to the scanner in portions. SIGMA reconstructs and stores each map in a stack related to a given year of excavation. The archaeologist has a complete view of the entire site, on a reduced scale, as resulting from the last excavation or from the excavation of a certain year. He can move in on such view, can move to the view related to another year, or can superimpose maps of the same part of excavation but related to different years.

The archaeologist has also at his disposal tools to modify maps by inserting or eliminating elements. For example, he may want to insert hypothetical elements or leave on the map only particular elements, such as walls, and, so store 'particular views' of excavated areas. Moreover, the archaeologist can associate to a line on a map the drawing of a section passing through that line, create links between the card of a stratification unit and maps containing that unit, and, vice versa, and create a link from a point on the map and the card of the related unit. Maps can also be consulted from the cadastral map of the area.

The described system runs on a portable Macintosh Powerbook. Both SYSAND and SIGMA are hypertexts realised in a HyperCard environment. Cadastral maps and sections which require a resolution higher than that of maps are manipulated by using the application Photoshop of SIGMA.

The requirement of being able to run the system on a portable computer at the excavation site, together with economic limitations, made us opt for the HyperCard environment rather than other systems such as GIS, that are much more powerful but also require much more powerful machines and incur higher costs.

Two years experience at the Anderitum excavations have shown that the system is efficient and easy to use, also by inexperienced persons.

2 SIGMA

SIGMA (Sistema Ipertestuale per la Gestione di Mappe Archeologiche, that is Hypertextual System for Handling Archaelogical Maps) extends SYSAND with facilities to input and manipulate pictures from the excavation, such as maps and sections (drawn on the site) and photos. SIGMA is implemented in HyperTalk (the programming language of HyperCard), and HyperCard allows to establish links between images and textual information. A consequence of the choice of HyperCard is that images can be handled in two ways: on cards (basic elements of HyperCard for storing text and images) and on external windows. Images on cards may be only bitmap, may have a maximum resolution of 72 dpi, or may be manipulated automatically and manually with HyperCard tools. Images on external windows may be either bitmap or of vectorial type, have no resolution limits, and may be zoomed-in and zoomed-out, but can be modified only with specific graphical applications. We have therefore chosen to have excavation maps on cards, as they do not need a high resolution but may have to be manipulated frequently, whereas sections, photos or cadastral maps of the site are on external windows, as they need a greater resolution but no frequent manipulation.

To input excavation maps, the procedure consists of the following phases:

1. Manual decomposition of each given map into portions suitable for scanning. Maps, drawn by archaeologists, measure 50 × 50 cm (representing 10 × 10 m squares of the excavation). Each map is subdivided into six 16,6 × 25 cm portions.

2. Manual scanning of each portion. Each map is digitized with a resolution of 72 dpi and then saved on disk.

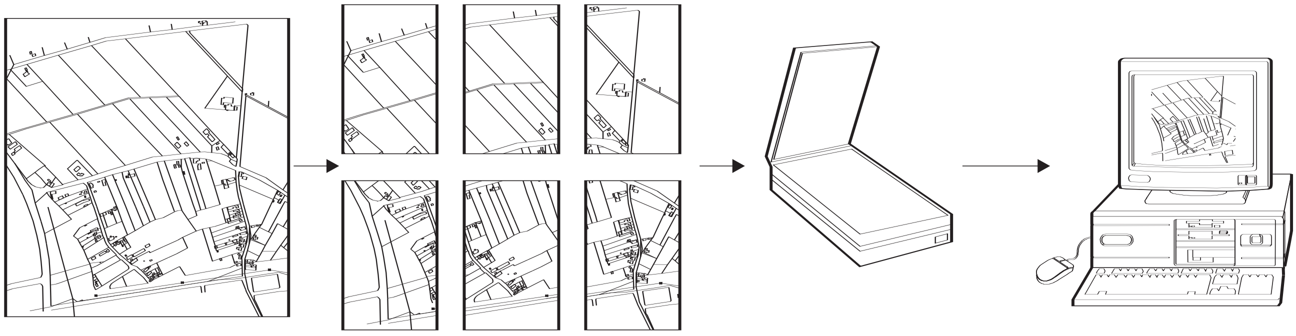

Figure 1. Phases of input procedure.

3. Automatic reconstruction of the original map with a 50% reduction. Such a map is stored in a sequential stack with information needed to view it in its real position in the planimetry.

The entire procedure is illustrated in figure 1.

Experiments suggest that 5 minutes are required to accomplish the first two phases. The third phase takes about 2 minutes (for a precise evaluation see Agresti/ Saccoccio 1994).

With sections, photos and cadastral maps, phase 1 differs from the one described for excavation maps because sizes are variable, while in phase 2 a resolution of 300 dpi is chosen. Phase 3 is not automatic, the sections, photos and cadastral maps are reconstructed by the user, piece by piece, by means of a graphical application, such as Photoshop or Canvas.

3 Visualising and navigating in the excavation planimetry

Characteristic of hypertext is the possibility of linking pieces of information according to an ideal arrangement, possibly independent of how they are stored in reality. For excavation maps, the ideal arrangement is the planimetry of the site. One may therefore want to be able to move horizontally on the planimetry in a particular direction. As one has a planimetry for every excavation year, one may also want to move vertically from a map of a certain year to the corresponding map of another year.

Each excavation map has an associated map number. A map number is a sequence of integers: the last integer representing the position of the map in a 10 × 10 map array, the last but one representing the position of this array in an array whose elements are arrays like the one considered, and so on.

From the map number the system can compute numbers of adjacent maps (in four directions) in the planimetry, and let the user view these maps (the user has a palette at his disposal to accomplish this).

Apart from the described horizontal navigation in the planimetry, a vertical navigation along excavation years is also offered. It may well be possible that the planimetry of a given excavation year is incomplete, for instance, the map for one particular square of one particular year may be missing. But as there are maps available of that square from different excavation years, the planimetry is automatically completed by inserting a map from a different year.

Single maps of the planimetry can be accessed in three ways (fig. 2):

1. going through the stack of map cards;
2. starting from the cadastral map;
3. through an ‘interface’, namely a reduced view of the most recently created planimetry.

Let us first describe the stack of map cards. Each card contains a reduced view of a single map, together with information such as among others the square number which identifies the map, the list of US numbers contained in the map itself, and a flag which is set on if there are drawings of sections of the represented square. From the map card one can access the related map, and may do a number of search operations; for instance, one can view, in a sequence, all maps containing a given stratification unit.

Secondly the cadastral map. It is a square, measuring 1 × 1 m, which offers a global view of the area comprising the excavation site. The archaeologist can inspect this cadastral map by exploring it continuously. By means of a single click he gets the number of the map of the selected location, by means of a double click he can visualise this map.

And finally, the ‘interface’ is a stack of cards, each containing a reduced view of fifty maps of the excavation (corresponding to 50 × 100 m in the real world). It is also possible to access one single map from the ‘interface’. One can also go back and forth between the ‘interface’ and maps.

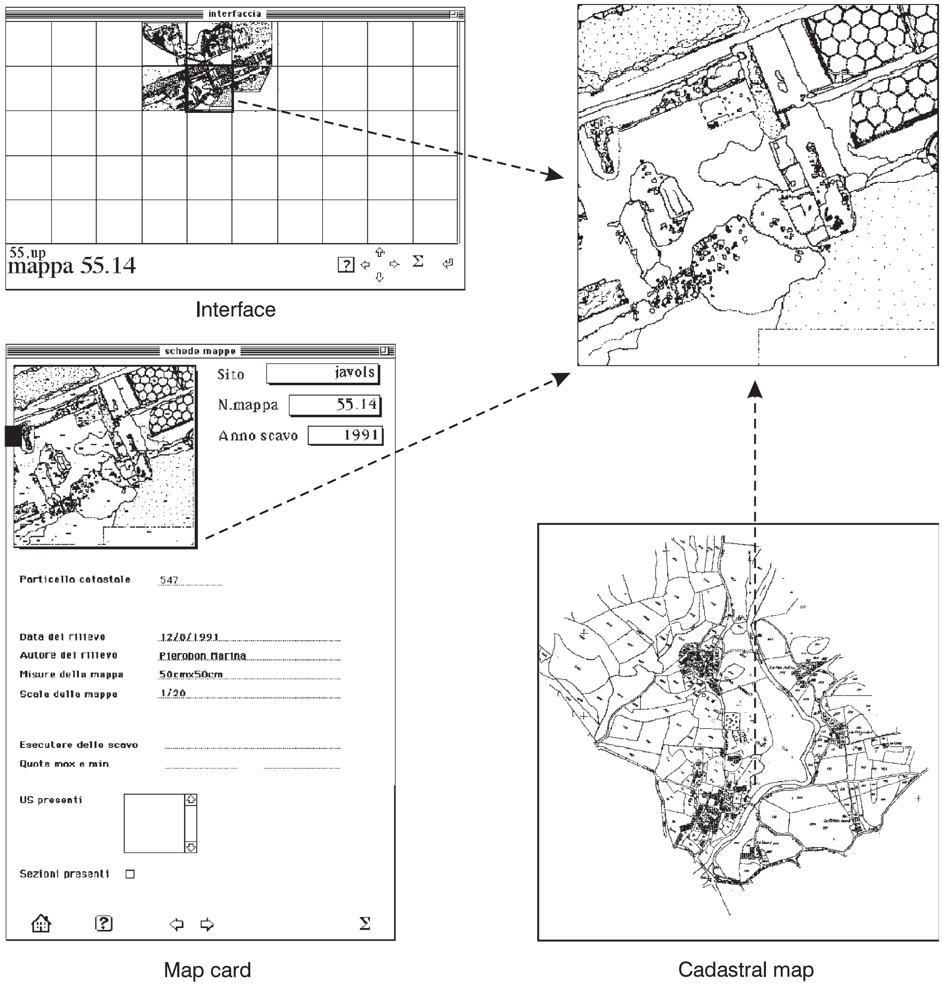

Figure 2. Ways of accessing planimetry.

The main difference between accessing maps through the cadastral map and accessing them via the 'interface', is that, in the latter case, one can also access non existing maps obtained by joining parts of the real maps. We call these 'intermediate maps' and we shall give more details about them later. Maps of the interface will also be automatically updated when a new map is added so that one always gets a view of the most recent map of an area, unless a particular excavation year is specified.

4 Tools for consulting and interpreting excavation maps

In the horizontal navigation in the planimetry one normally moves discretely with one map step. Thanks to the intermediate maps mentioned earlier, one can view a map consisting of pieces of scanned maps. Note that this map is obtained by patching maps belonging to different years if maps of the same year are not found. The user should be warned that consulting intermediate maps is rather costly.

As an aid to archaeologists, the possibility is provided of superimposing either the altimeter curves or a grid on the maps. The archaeologist may also want to superimpose maps of different years for two purposes: joining parts that are complementary (thus giving an updated view of the entire area) and showing the temporal evolution of the excavation.

To a map the archaeologist can associate drawings of sections. A sign on the map indicates the existence of a section; by a single click on this sign the direction of the section is represented on the map, by a double click the section itself is shown.

The archaeologist may also want to zoom out maps in order to have a more comprehensive view. This is not possible if maps are stored in HyperCard cards, as in our

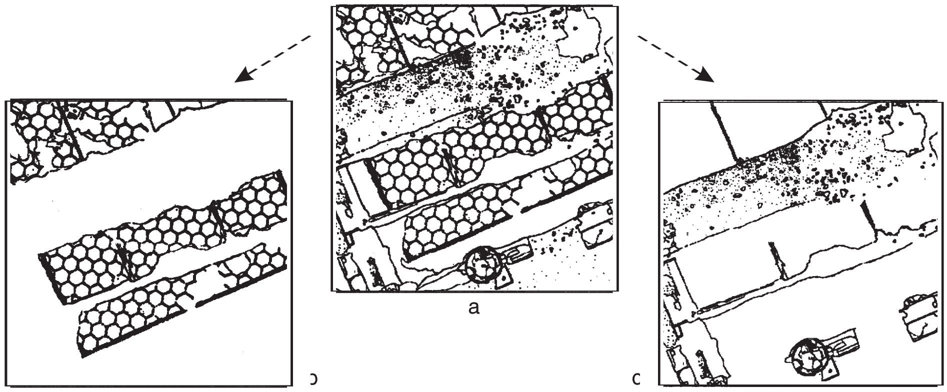

Figure 3. (a) A general view,
(b) A view with only mosaic,
(c) A view with only walls.

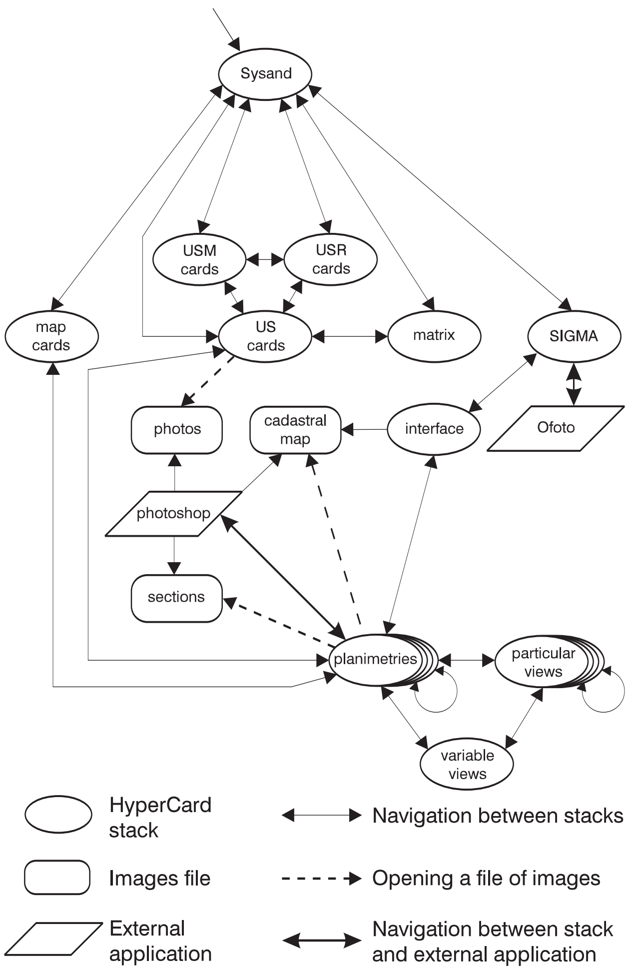

Figure 4. Scheme of links.

case, but it can be simulated. The archaeologist may wish to view m times n maps together, with m being an integer up to 10 and n an integer up to 5. This requires the creation of a card in which the desired maps, suitably reduced, are patched together. Once created, these cards, called 'variable view', can be stored for future consultation.

As an aid to interpretation, it may be useful to add information to or remove information from a given map. For instance, one may want to leave on a map only information representing walls, or one may want to complete a map with hypothetical elements. This is achieved by supplying the archaeologist with tools for modifying a map, that, once modified, can be stored as a 'particular view'. A planimetry of these particular views can be created and navigated upon (fig. 3). All facilities for such a navigation are also supplied.

5 Moving around in SYSAND

In previous sections we have described the modules of the system. By modules we mean stacks of programs, such as SYSAND and SIGMA, stacks of US cards, USM cards (cards that detail information of the US cards when the stratigraphic units are walls), USR cards (cards that detail information of the US cards when the stratigraphic units are pavements of tiles, mosaic, etc. or plasters, frescoes, mosaics, etc.), map cards, map 'interface', planimetries, particular views, variable views, files of images such as pictures, sections, and cadastral maps, and, finally, external applications such as Ofoto and Photoshop.

We have already mentioned a number of links created between cards in a stack (such as those that allow the visualisation of excavation maps as a planimetry) or between stacks, like those between planimetries.

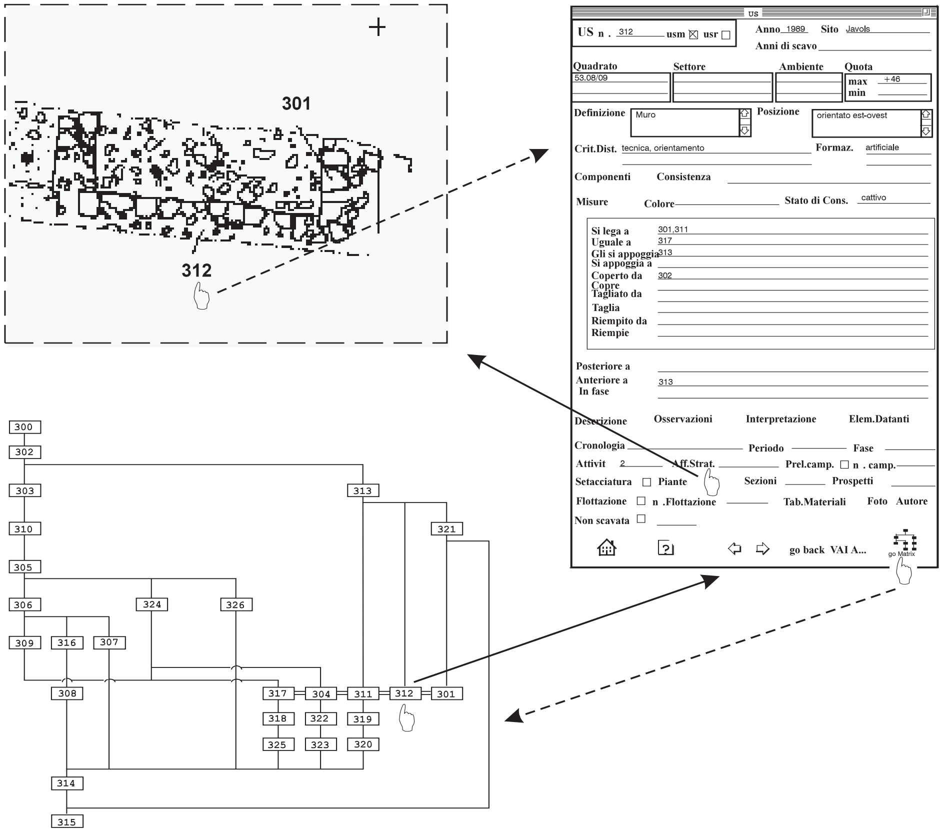

Figure 5. Navigating among US card, matrix and map.

We will now describe other links, both static ones, which are established by the programmer, and dynamic ones, which are created by the user.

Such links appear in the picture in figure 4. Circles denote HyperCard stacks (e.g., SYSAND, US cards), squares denote images files (e.g., photos, sections), and rhomboids are external applications (e.g., Ofoto). Double arrows between two modules indicate that one can navigate between the two; we distinguish navigation between stacks of HyperCard, represented by a double thin arrow, and between navigation between a stack of HyperCard and an external application, represented by a boldface double arrow. Simple dotted arrows represent the possibility of opening a file of images from an external application or from a stack (e.g. a cadastral map either from a planimetry or from Photoshop). Note that this case differs from that of navigation between, for instance, a planimetry and ‘interface’, where the stack of a planimetry is left to go into the interface stack. When opening the cadastral map from a planimetry, the stack of the planimetry is not left, the cadastral map is only consulted and can be used to navigate between the cards of the planimetry.

The usual way to access the system is from SYSAND. One can also enter US, USR, USM stacks and either consult them or introduce new cards. In this case one may reconstruct the new stratigraphy. The already computed stratigraphy may be viewed either starting from SYSAND or from any US (USR, USM) card. From SYSAND one may also consult map cards (that are created by SIGMA when maps are inserted into the system).

With SIGMA one can digitise a new map, calling Ofoto, reconstruct the map from the digitized portions, and consult planimetries via ‘interface’.

One has the possibility of opening a US card from the related node of the matrix, and, from the US card, consult maps, photos and cards of materials found in that US (to be done) (fig. 5, the path indicated by dotted links). Links between US cards and maps are established by the archaeologist, who has a suitable tool to sensitise an area on the map to which the US number is associated, so that by clicking on this area the relative card is opened. One can, therefore, also go from a map to a US card and from this card to the matrix (fig. 5, the path indicated by solid links).

6 Future work

At present, our work is concentrated on integrating into SYSAND a relational data base system of material found on the excavation site.

For each stratification unit a card gives a general description of Common pottery, Fine pottery, Small objects, Miscellaneous material, all associated with the unit. To each such card, detail cards will be associated with a precise description of each piece. The archaeologist should be able to query the data base, to ask for statistics and to create thematic maps.

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An Integrated Information System for Archaeological Evidence

This paper reports on an ongoing programme to provide a tailor-made database facility including linkage to stratigraphic analysis and automated procedures for the visualisation of principle classes of artefacts.

1 Introduction

The Xaghra Brochtorff Circle site in Malta was excavated for seven seasons (1987-1994) resulting in the recovery of many artifacts including thousands of human bones (Evans 1971; Malone 1986; Malone *et al*. 1988; Stoddart *et al*. 1993). The archaeologists now face the daunting task of characterising, quantifying and analysing these finds. A system is under development at the University of Bristol to computerise this procedure, and provide an integrated framework for visualising and analysing the multitude of archaeological evidence from this important site.

The foundation for the system is a detailed database of the information. Constructed on top of this database is an interface to allow archaeologists to use established tools such as a Harris Matrix package, as well as new facilities which have been developed to enable the location of the bones and artifacts to be viewed in a three-dimensional volume. The Harris Matrix program establishes the relationship between different contexts in an archaeological site as a two-dimensional hierarchy (Harris 1989). As there are more than 1500 contexts within the Brochtorff Circle, such a computerised hierarchy is essential to gain an easy understanding of the contexts. The three-dimensional volume visualisation of the bones may be used to determine spatial relationships between the contents of a spit, distinctive bones from an area, or the orientation of the bones within the site.

2 The System

Data gathered at a site currently is recorded on paper forms. (The growing availability of inexpensive portable computers could enable this data to be directly entered into the computer.) To minimise errors, the data entry interface resembles the paper version as closely as possible. The individual records have a unique identifier, so once entered, they can be selected, amended or deleted. Some records which in previous years had already been entered into an alternative database format can be added to the system using the file conversion interface so the database is complete. The Harris Matrix Analysis Program and the Graphical Display of Bones use these stored records.

2.1 User interface

The User Interface is a series of windows. Movement between the windows is either by pressing the highlighted key, clicking on the button using the mouse or by moving to the choice using the Tab key and pressing Return. Figure 1 shows the screen used for capturing all the necessary information concerning the bone finds.

The design of the data entry screens was based on the paper forms filled in at the site to aid the transfer of the data. The form is split into four parts, each containing its own fields. When data entry for a field is completed, pressing tab moves the cursor to the next field. The final field in each window is a button allowing the user to move to the next part of the form. The order of tab movement is based on the number identification used on the paper forms. Creating a new form or exiting from the data entry screens will save the data to a file. Individual forms can be retrieved by typing in the context number, the unique identifier for each form. This also serves as an error detector so that no form can have the same context number.

There are four entities in the database: Common, Stratigraphic, Interpretation and Small Finds. The Context Number field is the primary key of the Common entity and the foreign key for all the other entities, so that the four parts of the one form can be retrieved together. The system provides, via the Stratigraphic entity, an automated interface between the database and a widely available Harris matrix program.

2.2 Harris Matrix Analysis

A Harris Matrix Diagram is a simple way in which relationships between stratigraphic sections can be viewed on a single diagram, as shown in figure 2. It describes the stratigraphic sequence of the site as found during excavation, no matter how complex the individual sequences may be and helps to clarify the relative chronology. The Bonn Harris Matrix Analysis Program

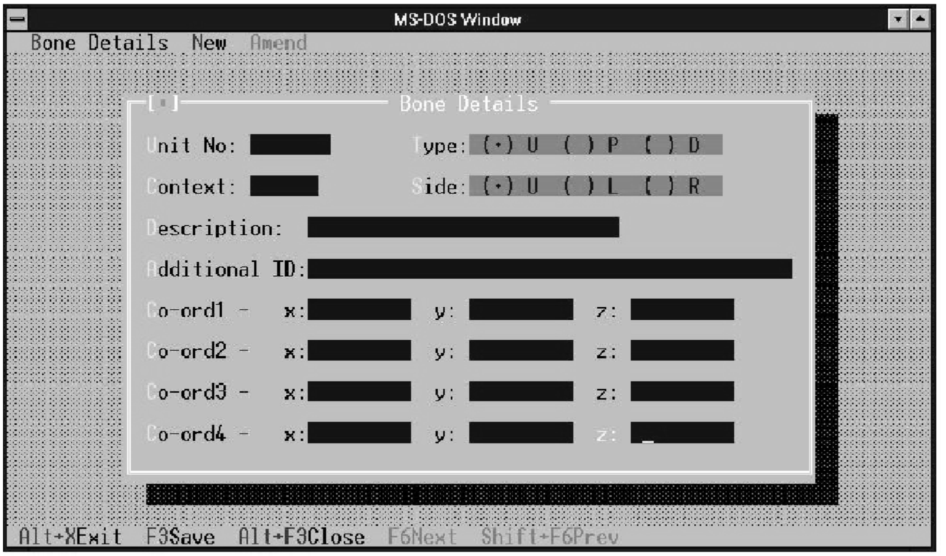

Figure 1. Bone information capture screen.

provides a computer-aided method of stratigraphic analysis (Harris 1989).

The Harris Matrix Program provides a file converter called Harconv. This converts an ASCII file for use by the Harris Matrix program. On choosing this option, the program generates the ASCII file, passes it to Harconv and runs the Harris Matrix program. On start up the Harris Matrix program asks the user for the data set to be used. By entering the name of the file created from file conversion the user will be able to carry out analysis on the data.

3 Visualising the Bones

A substantial number of human bones have been recovered from the site in Malta. There is thus an enormous amount of data that needs to be incorporated within the system. The bone visualisation facilities within the system can be split into three main areas: recording the information about each bone, obtaining analysis details from the user and displaying the results graphically.

There is an individual record within the database for a single bone, identified by a unique bone number. This number is assigned by the archaeologist during data preparation. The details recorded for each bone include:

– Four sets of (x, y, z) coordinates to specify the three dimensional location of the bone with respect to a reference point; and,
– the bone type, side, proximal/distal, additional identification, context, age and method used, sex and method used, measurements, pathology, conservation, related units and any remarks.

In setting up the database the archaeologist is required to enter such details for every bone recovered from the site. Hence a data entry screen with all such fields is presented to the user to enable each bone record to be created. Additional options to assist this process are display, amend and delete. The creation of the full database of bones is expected to be carried out prior to any analysis, as incomplete data may affect the results produced, which in turn could lead to an incorrect assessment of such results. This will, however, be a lengthy process due to the large amount of data.

3.1 Obtaining Analysis Details

The main body of the system consists of a series of pull-down menus that the user is able to manipulate to enter all the details required for the analysis. The options available for entering data are:

– rotation: enter degree and axis
– scaling: enter ‘factor’ and ‘focus’
– sectioning: enter axis and coordinate value to define partitioning line
– grid squares: indicate whether to add or remove
– bone details: enter new bone type
– bone details: enter bounding coordinates (x_1, y_1, z_1) and (x_2, y_2, z_2) for a particular area

These latter two forms of data entry result in the search for and retrieval of all matching bones from the bones database. The first of the two finds all bones of the specified type, setting up a new temporary data structure in main memory recording bone unit number and the four sets of coordinates for each match. The latter sets up a similar structure for all bones recovered from the specified area. The user is able to enter a maximum of ten types to be used in the analysis at any one time, but only one area can be specified. In addition to entering such data, the user is also able to display and delete bone types, and display the full records (i.e. all relevant details stored in the database of bones) of those bones which satisfy the specifications entered.

A final option offered is to display the site, either the whole site with the bone types specified, or the specified area of the site with all bones recovered from that area. The results of these options are outlined in the following section.

3.2 Displaying the Results

The three-dimensional visualisation facility of the system uses computer graphics techniques to manipulate the large database of bone finds. The initial display on screen depends on the choices made by the user as outlined in the previous section. Whatever the choice, however, the user is presented with a representation of either the whole or part of the site, containing all relevant bones. At present, the 'whole' site is not actually the whole of the site in Malta, but a specific area of it, namely that enclosed within 98E to 102E, 108N to 114N, and 135.4 m up to 137 m vertically. Thus the representation of the whole site on screen is a cuboid with dimensions 4 × 6 × 1.6 m. Similarly, when only part of the site is displayed, a cuboid of the relevant dimensions is constructed on screen. Such cuboids are labelled with the relevant world coordinates in order to aid analysis and avoid confusion.

The bones within the representation of the whole site are the 4 sets of coordinates from the bones database linked by coloured lines, where each colour represents a different type. A key is displayed on screen to relate these colours to the actual type descriptions. When a particular area is displayed, the bones are again the 4 sets of coordinates linked by lines, but this time no colours are used as there are likely to be too many types displayed on screen to enable a colour coding scheme to be used effectively. Hence, if an area is chosen from which many bones have been recovered, the display is simply a mass of lines on the screen. The only way this display can be improved is to introduce a more sophisticated method of graphical display, such as scanning the bones in or producing a set of accurate illustrations for all possible bones. Then the display would consist of detailed representations of all bones recovered from an area, each of which could be identified by the archaeologist from the shape alone, with perhaps an accompanying list to detail all bones displayed.

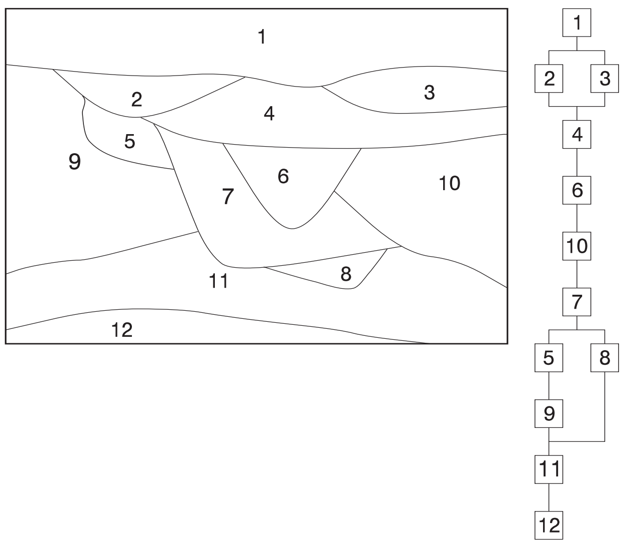

Figure 2. Sample Harris Matrix Analysis.

One of the problems encountered in producing even such simple graphical displays on the screen was the representation of a three-dimensional image in a two dimensional environment. Perspective projection was used in the solution of this problem, as this converts world coordinates into screen points in such a way as to enable the user to perceive depth in a two-dimensional image, namely by displaying distant lines as shorter than lines of the same length that are closer. Perspective projection is achieved by firstly choosing a view reference point (VRP) which is the point from which the site is viewed, and the distance (d) of the object plane away from the viewpoint. These were determined during the design stage of the project to produce images that would represent those seen from an observer located centrally, standing a couple of metres away from the site. Then, for each of the world coordinates (both of the site and the bones) the screen point is calculated by the following algorithm:

- translate the point so the VRP becomes the origin (i.e. subtract VRP from world coordinate);
- set two-dimensional coordinate x to world coordinate x multiplied by d and divided by world coordinate z;
- set two-dimensional coordinate y to world coordinate y multiplied by d and divided by world coordinate z;
- reposition and scale to produce image of required size in required area on screen.

Hidden surfaces also had to be considered in the display of the site and bones: those on the site are displayed as dotted lines on the screen, to prevent any confusion; the bones are sorted before display into order of depth, from those furthest away to those closest, thus any that are hidden will not be seen unless the site is rotated.

In addition to the initial display of the site and bones on screen, facilities to rotate, scale and section the site are available to the user. These use the data entered by the user as in the previous section, and enable the user to view any section of the site from any angle, to any degree of magnification.

The rotation facility enables the user to rotate the site (and all bone types displayed within it) about any axis (x, y or z) by the required degree (1 - 359). The standard rotation equations below were incorporated into the system to produce the rotation effect:

About the x-axis (θ degrees):
$x' = x$
$y' = y\cos(\theta) - z\sin(\theta)$
$z' = y\sin(a) + z\cos(a)$

About the y-axis (θ degrees):
$x' = x\cos(\theta) + z\sin(\theta)$
$y' = y$
$z' = z\cos(\theta) - x\sin(\theta)$

About the z-axis (θ degrees):
$x' = x\cos(\theta) - y\sin(\theta)$
$y' = x\sin(\theta) + y\cos(\theta)$
$z' = z$

The centre of the site was chosen as the most logical coordinate to fix as the point about which to rotate the site. When carrying out the rotation, it is necessary to rotate the world coordinates of the site (including bone types) to produce new world coordinates, which are then converted to points on the screen by perspective projection and scaling.

The scaling facility enables the user to 'zoom in' to the site representation at a particular point to the required magnification. These two pieces of information, referred to as the 'focus' and the 'factor' respectively, are specified by the user as required. The effect is achieved in implementation by:

1. taking the focus to be the origin, thus translating all world coordinates appropriately;
2. scaling all the coordinates by the factor;
3. translating all coordinates so that focus returns to its original position; and finally,
4. converting the world coordinates to screen points as outlined earlier.

A 'zoom out' facility is also provided to the user to reverse any enlargement of the display. This is achieved in implementation by the same procedure as 'zoom in' but with the focus being replaced by its reciprocal.

Finally, the sectioning facility enables the user to divide the site into two separate cuboids by specifying a line to act as the partition (i.e. x = a, y = b, or z = c). Both cuboids are displayed on the screen at the same time, with each occupying half the area used to display the full site.
The rotation and scaling facilities are applicable to both representations, though the user is required to specify which cuboid. This is achieved by using the same procedures as outlined earlier, but with two different sets of world coordinates. Clipping is also required for any bones that may cross the boundary line used to partition the site.

4 Future Developments

The system developed so far has proved to be a useful prototype for analysing bone finds from Malta. There are several areas of the system that will be developed in the future to enhance the existing facilities. For example, the visualisation of the site could include some of the natural and cultural features, such as the surrounding rock, and the central stone bowl discovered at the site. These features would aid the archaeologists, as they would be able to incorporate them within their analysis of the site. The graphics display of the bones could also be improved to provide a more detailed and accurate illustration of bones recovered. The Archaeology Department would also like to see some statistical displays as part of the system – e.g. all femurs, skulls, etc. found within a certain area plotted on a histogram.

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The National Documentation Project of Norway – the Archaeological sub-project

1 Introduction

The National Documentation Project of Norway is a cooperative project between the Faculties of Art in the Norwegian universities, and is now in its fourth year. The main purpose of the project is to convert information from paper based archives to electronically readable media in order to make the archives more accessible. The project has been working with what can be called the 'collection departments', like the Department of Lexicography, the Department of Folk Music and the university museums with Archaeological and Numismatic collections. The aim is to create a national database for language and culture, where it will be possible to do multidisciplinary studies, combining material from all Norwegian universities.

2 Project organization

The project has its base at the University of Oslo. It uses hand-picked, previously unemployed persons to convert the information (Ore 1995: 278). The workforce is organized in a number of small groups in southern Norway, and four larger groups in northern Norway. The different groups are assigned to different part projects. The people converting the archaeological data do not necessarily have any previous experience with archaeology, but through supervision they are given sufficient education to be able to perform the required text analyses and encoding.

The aim is to create a system that integrates information from several disciplines. Because of this, it is not sufficient to create computerized versions of today's archives. One of the most important aspects when building such a data model, is to have a fruitful dialogue between programmers and professionals in the different disciplines. There is of course no one solution as to how this system should be made, but it is vital that the system is not dramatically different from what is in use today. The cooperating institutes need systems that they feel comfortable with, so that the computerized versions will be of use and will be used by all staff members.

3 Using the data

The resultant information will eventually be more readily accessible to researchers, students, people working with Cultural Resource Management and the general public. Information from the different sections of the project will be combined, so that studies concentrating on a certain area will retrieve information from all the different sources. These sources, (fig. 1) Archaeology, Runes, Old Norse, Modern Norwegian, Dialects, Syntax/semantics, Place names, Folklore and Folk Music will all be connected through the variables Time, Location and Word. This will be accessible for enquiries from Government Planning Agencies, Norwegian Archaeological Authorities, the National Archives, people interested in local history, the Norwegian Mapping Authority, and the Norwegian Language Council. It will be useful in connection with dictionary production, as a writing assisting tool and for primary education.

Combining these sources with an incremental database structure, the system makes it possible to look at an area in a time perspective (fig. 2). Textual information is combined with drawings, photos, maps and sounds to create a Geographical Information System which will eventually include all of Norway. It will be possible to make queries about language development, place names and archaeological sites and finds. The potential inherent in the combination of different sources is especially useful to synthesizing disciplines like archaeology and history.

4 The archaeological sections of the Documentation Project

Norway has five archaeological museums. They are situated in Oslo, Bergen, Trondheim, Tromsø and Stavanger, and with the exception of the latter, all are university museums. Norway does not have a central museum, although the museum in Oslo tends to take a leading role, being situated in the capital. All five museums started as private collections and gradually developed into regional museums. Each museum has a collection of items from its own district. However, previously the geographical division between the museums was not so rigid, resulting in the different museums having artefacts from other museum districts. This means that it is necessary to combine information from all museums to get as complete a picture as possible of the known artefacts.

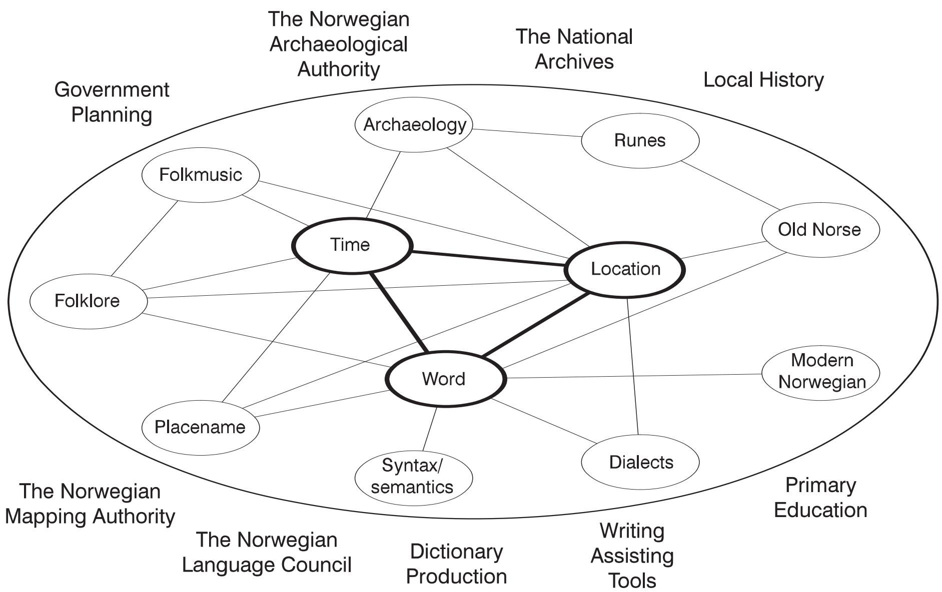

Figure 1. The university information system with its data types, their connections and possible use. (After Ore 1995: 278).

Comprehensive archaeological surveying has been conducted by the Land Use Mapping Agency based at the archaeological museums since 1963 (Larsen 1990: 48). Through this, large parts of the country have already been surveyed. All the resultant information from Oslo university museum, Oldsaksamlingen's district is now stored on computer in a 'free text' database called SIFT (Boaz/ Uleberg 1993: 178-179).

The archaeological sections of the Documentation Project are presently limited to the universities in Oslo, Bergen and Tromsø. Work in Bergen started with converting information on sites, and is continuing with the artefact catalogues. Tromsø has just started, beginning with the artefact catalogues. At the Oslo university museum, the Oldsaksamlingen, the work within the Documentation Project started with conversion of information related to archaeological sites. Since 1993, it has also focused on the artefact catalogues. The artefact catalogues have been converted to machine readable format, and Standard General Markup Language (SGML) is used as a tool to make them more readily accessible.

5 Ongoing Projects

In addition to the work with the existing archives, the Documentation Project cooperates with ongoing rescue excavation projects. At the moment we are actively collaborating with three projects. One of which has mainly Stone Age excavations, one with Bronze Age/Iron Age excavations, and one is an excavation in a Medieaval town.

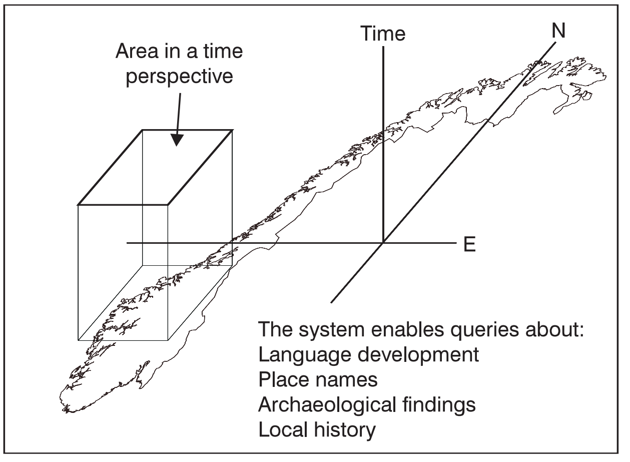

Figure 2. The system makes it possible to look at an area in a time perspective. (After Ore 1995: 281).

Materials from the Stone Age excavations offered the possibility to develop a Geographical Information System to be used on a small scale – to study the artefact spread within one site.

The Bronze/Iron Age excavations gave us a possibility to develop systems to increase the accuracy and efficiency when exposing large areas, and the Medieval town gave the entanglements of a multilayer site. The methods developed, allows the excavator to have a constant overview over the different structures that are found, both by viewing them on screen, and by printing out distribution plots.

Perhaps the most important aspect is that the data capturing devices that are in use during the excavation make it possible to use the information immediately during the excavation and not just in the final stages of analysis. In addition, the preparation of the final reports can be conducted much more efficiently when the complete data are readily at hand at the end of the field season.

6 The database model

The conceptual model of the database is object oriented, and consists of a number of different relational bases. The concept of an event is a crucial element in the model. An event has been defined as 'something that takes place in time and space, perhaps on account of 'someone' or 'something'' (Rold 1993: 215). There are basically two types of events: internal and external. In this context, all internal events takes place at the museum, external ones out in the field. Internal events include cataloguing, conservation work, etc. Examples of external events are surveying, describing and excavating sites.

The event allows us to make the system incremental, adding a historical depth to the database. It is not a relational database with only the updated information. Every time an action is undertaken, there will be information added to the base. All events will create documents such as artefact catalogues, excavation reports, plan- and profile drawings, photographs, surveying reports and test results. The documents will be in the form of free text, hypertext, bitmap files, scanned documents and pictures. All events will be connected to either an artefact, a site or both. The event makes it possible to retain the information from the original cataloguing as well as incorporating the information from magazine revisions and researcher's special studies on selected artefacts.

All original names are kept when transferring the original artefact descriptions. This means that there will be outdated names on artefacts as well as on places. Lengthy discussions commonly surround the terminology of artefacts. We have avoided this discussion, and will later add standardized artefact names on a higher level, using a meta-language to select for all objects of a particular type, originally given different names in the catalogue. The meta-language will interpret the data without changing the original data (Rold 1993: 218). This will solve problems in cases where old and new terms define the same artefact classes. However, in cases where there is only partial overlap, where one old type now is defined as several new ones, the database will not give precise answers to a query. This situation will gradually be resolved in the future as researchers reclassify these artefacts, and their results are added to the base.

Standard General Markup Language (SGML) is used as a tool to make the converted texts more readily accessible. The SGML is based on formatting a text through adding tags showing the type of information following the tag. In the archaeological artefact catalogues, there are tags for location, material type, artefact type, decoration, dating, and so on. This makes it easier and faster to search in a text, and it also creates a link between a relational database and the free text. In this way, the SGML is a means for structuring a text. One might say that while a database is putting text into tables, SGML is putting a table on a text. The text structure is outlined in a Data Type Description (DTD).

Since a number of different people have written the catalogues at the museum, there are at least as many text structures. A very tight SGML system will give ample opportunity to check that the text is consistent with the DTD, but it will not be possible to incorporate all texts. A system that covers all possible types of text structures, will have become so loose that it is not a structure any more. The final DTD must be somewhere in between these two possibilities.

7 Geographical information

The relation between an artefact and a place needs special consideration in two ways. First, we have to know the present-day equivalent of the old place name, since the original catalogue texts are always used. A problem arises because boundaries between administrative units have changed, and in many cases objects do not have an exact provenance. Because of this, every place name must be associated with a chronological date, indicating what geographical area is covered by that place name.

Secondly, we must decide what to do with artefacts without an exact provenance — perhaps only the parish, county or even just the country is known. One solution is to let the artefact's position be a point somewhere within an area corresponding with the most accurate provenance data. When looking for artefacts from a smaller area, like a group of farms, there is a possibility that artefacts only related to a larger area, like the county, could actually come from that smaller area. Therefore, one must also be able to search for artefacts with a possible provenance within a specified area. This means, that an artefact that cannot be attributed with certainty, should have a geographical location as a point included in a surface area. When users search for artefacts from a certain geographical area, they should obviously retrieve all artefacts where the area of the artefact coincides with or is contained within the search area. In addition, they should also retrieve the artefacts where the search area is contained within the artefact area, as well as the artefacts whose area intersects with the search area.

8 Conclusion

The National Documentation Project creates a system where databases from different institutions can communicate through the Internet, forming a national database for language and culture. A user will be able to access a client section which will be designed according to the users' needs and use privileges. The databases can be aware of each other, send queries according to a predefined protocol, and interpret the resulting data according to the predefined data models.

The system will allow individual users to create their own interfaces. One such interface can be created in connection with the preparation of an exhibition. Information from different archives related to the exhibited items can be put together in an application running in the exhibition rooms.

There are three major assets of the National Documentation Project of Norway. Firstly, it is an effective system for converting large amounts of data in a relatively short time. Secondly, it promotes a dialogue which is vitally important between system developers and professionals from different disciplines. This ensures the development of effective systems that are sufficiently familiar to be used by all staff members.

A third and final aspect is the increased availability of vast amounts of data. This opens up possibilities, not only for researchers and students, but also for teachers and for the interested public. Most people want to know their local history and what is found at or near their homes. The day is soon at hand when an interested member of the public can turn to the computer in their library to obtain access to information concerning them.

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Statistical view of the Archaeological Sites Database

1 Introduction

When CIMEC — Information Centre for Culture and Heritage — initiated a database for sites and monuments in 1992, using existing lists in order to gather, within a short time, a core of information regarding our immovable heritage, the attempt raised a chorus of 'don't do it', accompanied by arguments such as: 'not enough information', 'wrong information', 'wait until a site form will be designed', 'there are other institutions more capable of creating a national record'.

We nevertheless proceeded. We had ten years experience with the National Database of movable heritage — over 700,000 records — and seriously needed to have references for the field 'place of discovery'. The Ministry of Culture agreed to finance our project. In the last three years, while various commissions debated over a site card — with no final conclusions yet — while the organisations and people responsible for the monuments changed several times and the law for the protection of cultural heritage is still being debated — we recorded the existing information regarding the sites and monuments proposed for protection, using a core data standard. Thus, with modest resources and much perseverance, we have sofar gathered over 16,600 records which are proving to be a valuable source of information. And a reason for the Ministry of Culture to decide this year to finance the expansion of the initial project at CIMEC. It would seem therefore that we were right to proceed, instead of to wait.

2 The source of information: from paper list to computer record

The Romanian Archaeological Sites and Monuments Database has 3,900 records of sites and 12,700 records of monuments proposed for protection. The main source of information — a national list compiled manually in 1991 by the Historical Assemblies, Monuments and Sites Direction (DMASI) — still remains to be checked and updated and no new list has been forthcomimg for the last four years.

The formal distinction between a 'site' and a 'monument' was based on the position — under or above ground level, on the chronological period — 'monuments' are mostly late medieval and modern, while 'sites' are prehistoric to early medieval, and on its condition — ruined versus roofed over. We maintained this formal grouping of the list, as is traditional in Romania. There is also a special chapter for buildings with a memorial value — very confusing in fact, as there are many buildings with both an architectural and a memorial value.

Because the list we used to record the information from was often ambiguous, both in content and in form, as well as difficult to read, we had to analyse, check with other sources and interpret the information.

Descriptive information regarding location, period and finds was separated into multiple fields but the data content still requires improvement. We also tried to normalise the terminology by compiling terminology lists for periods, cultures and site types. The present information in the database therefore closely follows that in the list, while being much more structured and thus suitable for analysis.

The list of protected sites and monuments was based on proposals sent in by county museums. The list is richer for those counties where archaeological excavations have a longer tradition and were a significant number of archaeologists are involved in the area (around the university centres, such as Cluj and Iaşi, for instance, or in Dobroudja). We had no information regarding archaeological sites in Bucharest and consequently, our statistical data will not include Bucharest. Although there will certainly be archaeological areas underrepresented, the selection is a sample of present knowledge in the field. Only a systematic survey will bring more light in the future. Part of the recorded sites are not excavated and there is no guarantee that the periods and the site types indicated for them are correct.

Nevertheless, for the first time, we have a core of data for analysis. We have tried to look at the distribution of sites by period, archaeological culture, site type and location. Our software is Paradox 4.0 (Borland) on PC.

3 Statistical view of the database

Statistical analysis is very exciting for the researcher. As soon a number of records have been gathered, the temptation to try various ways of sorting, counting and grouping is overwhelming. First, you get hundreds of data from thousands of records. Very interesting, but still

Table 1. The distribution of sites by location.

region		%	number of sites
Moldavia	(eastern part of the country, 19.4% of the territory)	16	654
Dobroudja	(southeastern part, 6.5%)	14	550
Walachia	(southern part, excluding Bucharest city, 19.8%)	19	755
Oltenia	(southern part, 12.3%)	8	334
Banat	(southwestern part, 7.2%)	6	225
Transylvania	(central part, 23.9%)	32	1,278
Crişana & Maramureş	(northwestern and northern parts, 10.9%)	5	193

difficult to follow or to graph them. Then, you realize that you have to group the information in larger classes in order to make some sense out of it:

– administrative divisions (40 counties), in historical regions (8);
– site types, in categories (for instance, various types of settlements grouped as 'settlement');
– various periods and archaeological cultures, in larger chronological divisions.

During this preliminary processing, you must take care not to alter the basic information through artificial grouping. Yet, you realize that if you want to identify dominant features or trends by periods or geographical areas that you should ignore low frequency data (site types mentioned only once in a period and county, for instance) and establish a limit beyond which you consider the data for comparison.

As much as you find the figures obtained fascinating, they are boring for a reader, the more so if he or she hardly knows the geography or the history of the territory. I therefore want to present fewer figures and more what they said to me.

3.1 General view

The database contains 3,900 site locations. Among them, 63% are declared single-level sites while 37% are complex, multilevel sites. Among the two thirds of sites identified by only one period or site type, future research will certainly reveal more complex situations.

The entity 'site' is defined by place, site type and period. For 3,900 locations, we entered over 4,500 records of site types, 6,000 records for periods and 4,800 records for archaeological cultures. For each record we have entered location (county, town/village, place, location details), single or complex site, site type, name, period, culture, date, finds, and references.

3.2 The distribution of sites by location

The distribution of the sites by location is shown in table 1 and figure 1. Central and southeast Romania — that

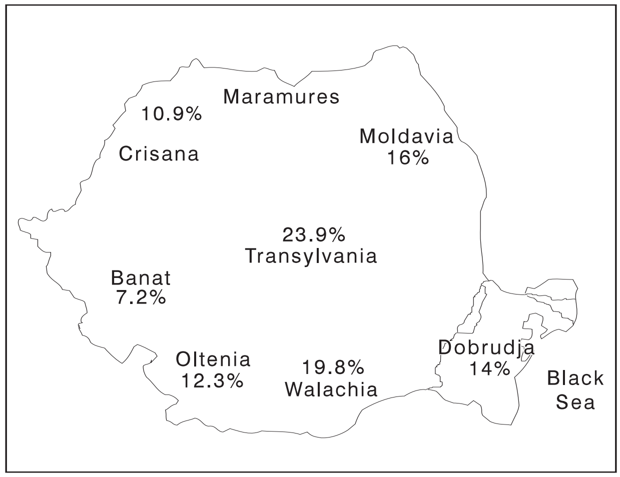

Figure 1. Distribution of sites by region.

is, Transylvania and Dobroudja — have the highest site density related to their surface. The density of the sites in those areas indicates a long tradition of habitation due to geographical and environmental conditions.

The counties with the largest number of sites (over 100) are, in descending order: Cluj (325), Constanţa (288), Tulcea (262), Dâmboviţa (217), Bistriţa-Năsăud (190), Iaşi (184), Sălaj (168), Caraş-Severin (128), Buzău (124), Prahova (120), Mureş (114).

The high number of sites for a single period in a county can show the dominant archaeological feature of that area. For the Roman Period, the greatest number of sites is in the area of the former Province of Dacia (Cluj county – 124 Roman sites on a surface of 6,650 square km; Bistriţa-Năsăud – 92 Roman sites etc.) and in the former province of Moesia Inferior and Scythia Minor (Tulcea county – 121 Roman sites and Constanţa county, 118 sites for the same period). For the Medieval Period, the area around the former capital of Moldavia, Iaşi, has the highest number of protected medieval sites – 94. For the Bronze Age, Dâmboviţa county has 83 sites.

Table 2. The distribution of sites by period.

period	until	%	number of sites
Prehistoric Period including Palaeolithic Neolithic, Bronze Age, Hallstatt	the 5th c. B.C.	40	2,546
Palaeolithic	6 millennium BC	1	69
Neolithic	2nd millennium BC	12	766
Bronze Age	12th century BC	14	869
Hallstatt	6 - 5th century BC	12	767
Greek	7th c. BC-1 c. AD, Dobroudja	1	40
La Tène	4th c. BC-1 c. AD	13	1,312
Roman Period	1st-late 3rd/ 4th c. AD	21	1,312
Early Byzantine and Migrations period	4th-12th c.	9	572
Medieval	13th-late 18th c.	16	1,053
Various periods	uncertain	1	63

With the exception of the Neolithic Period and the end of the La Tène (2nd-1st centuries BC), during all the periods the greatest density of human remains were found in the hill areas, on both sides of the Carpathians Mountains.

3.3 The distribution of sites by period

The distribution of the sites by period is given in table 2 and figure 2. Of the prehistoric archaeological culture, in descending order of frequency, more than half are Geto-Dacian sites (53%), followed by the great Neolithic cultures of Cucuteni (14%), Gumelniţa (5%) and Starčevo-Criş (3%), which represent together 21% of the sites with a known culture. The Bronze Age culture has 19%: Monteoru (5%), Noua (5%), Suciu de Sus (5%), Tei (4%).

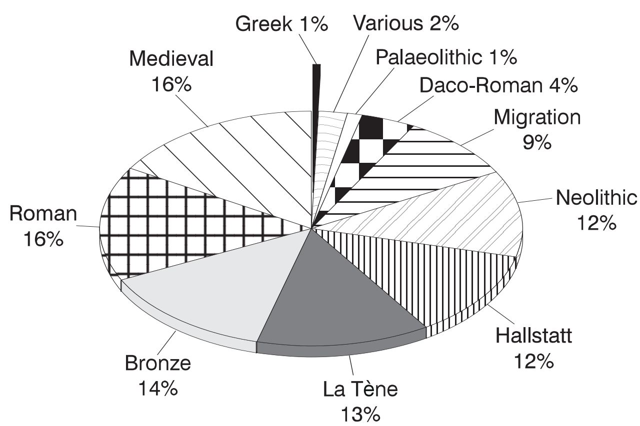

Figure 2. Distribution of sites by period.

3.4 Sites by period and by region

The *Palaeolithic* is best represented in Northern Moldavia: (Iaşi 9 sites and Botoşani 2), the Southwest (Hunedoara 7 and Timis 5) and the South Carpathian Hill Region (Vâlcea 5, Argeş 4, Gorj 3).
The *Neolithic Period* — more evenly spread: (Cluj 70, Iaşi 69, Vrancea 35, Botoşani 32, Buzău 32, Giurgiu 31).
The *Bronze Age*: (Dâmboviţa 103, Cluj 60, Maramureş 53, Buzău 52, Sălaj 46, Vrancea 36, Vâlcea 34).
Hallstatt: (Bistriţa-Năsăud 51, Iaşi 42, Cluj 31, Buzău 30, Vâlcea 26).
La Tène: (Iaşi 98, Tulcea 57, Călăraşi 46, Bistriţa-Năsăud 42, Vâlcea 41).
The Roman Period: (Cluj 124, Tulcea 141, Constanţa 132, Bistriţa-Năsăud 92, Sălaj 67, Caraş-Severin 58, Mureş, Sibiu, Vâlcea).
The *Medieval Period*: (Iaşi 154, Dambovita 53, Constanţa 49, Tulcea 66).

The high number of archaeological sites in an area is in part a sign of demographic growth for a certain period but also a consequence of the continuous movement of the population over a territory, a phenomenon encountered from Prehistoric times until the Early Middle Ages. Some of the sites are temporary settlements.

3.5 Sites by site type

The settlements represent about two thirds of the number of sites (60%), followed by cemeteries (15%) (fig. 3). The number of settlements could be inflated due also to the fact that any uncertain site is often classified as ‘settlement’. Also the fortifications which appeared as early as the Neolithic Period, and became significant in the Bronze Age, built as they were on high peaks and with complicated defence systems, led archaeologists to classify them as a ‘fortress’ rather than as a ‘settlement’ or fortified settlement. The sites designated as fortresses cover 8% of the sites. We also found over 90 records for barrow areas, period not indicated.

Table 3. Site types by period. In brackets number of sites.

	periods					
	Neolithic	Bronze Age	Hallstatt	La Tène	Roman	Medieval
settlements	84% (530)	83% (724)	71% (334)	74% (650)	50% (528)	59% (620)
occupation layers	6% (39)					
Tell	4%					
fortifications	2% (26)	3% (24)	8% (33)	12% (109)	24% (254)	16% (164)
cemeteries	2% (15)	8% (68)	11% (52)	8% (73)	8% (90)	11% (120)
mines				1% (1)	1% (3)	
salt mines	1% (2)					
vestiges	10% (6)					
isolated burials		<1% (3)				
isolated structures				1% (1)	% (88)	8% (84)
undetermined		6% (54)	10% (49)	5% (40)	9% (99)	6% (69)

3.6 Sites by site type and by location

I wanted to look at the distribution of the main site types by county, taking into consideration only the counties with more than ten sites of the same type. The settlements Iaşi, Dâmboviţa, Bistriţa-Năsăud, Buzău, Giurgiu, Prahova, Tulcea, and Vâlcea have the highest number of locations, in hill areas and along river valleys. Areas undergoing frequent movements of populations have also a large number of barrows, cemeteries, and isolated burials: Buzău, Cluj, Tulcea, Constanţa, Prahova, and Caras-Severin. In the border areas — along the Danube —, in Tulcea and Constanţa, along the Carpathian Mountains, on the Transylvanian side — Harghita and Covasna, and at the Northern border of Dacia — Cluj and Bistriţa-Năsăud, the number of fortifications is the highest.

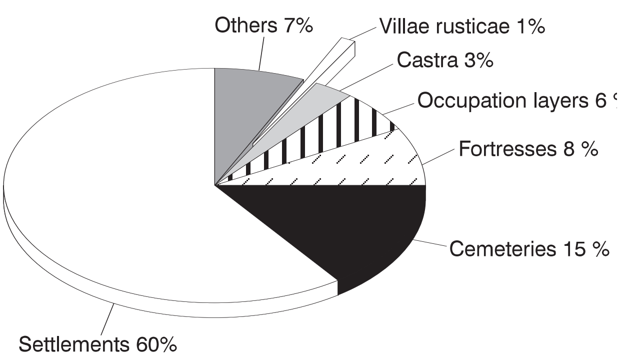

Figure 3. Distribution of sites by categories.

3.7 Sites by site type and by period

Site types by period show more or less the same characteristics, with a greater variety of site types for the Roman and Medieval Periods, when the social structure and economic activity became more complex (table 3).

4 Conclusions

A statistical analysis of the distribution of sites can reveal the degree to which the protection list properly reflects the field reality, and is not a subjective personal selection.

It clearly indicates the need for a systematic survey, with modern investigation methods, for the proper recording of the sites to be protected. Until then, we can try to find further answers to our questions through statistics.

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A Strategic Appraisal of Information Systems for Archaeology and Architecture in England – Past, Present and Future

1 Introduction

The growth of the available literature on sites and monuments records in central and local government in England has been notable, especially in publications arising from CAA. These contributions have mainly been submitted from the perspective of one of the three major interested parties, in local government, the county sites and monuments records (SMRs) and in central government, English Heritage (EH), as the national body concerned with conservation management, and the Royal Commission on the Historical Monuments of England (RCHME) as the national body of survey, record and dissemination. While these papers have made valuable inputs to the development of information systems, and have made reference to the links between systems, a published strategic overview of their inter-relationships, both in theory and in practice, has been lacking.

In a European and international context, the heritage record systems in England can appear confusing. This paper attempts to address the current synergy between these local and national bodies. It examines advancement in the context of the current initiative of the government's organ of heritage policy, the Department of National Heritage, to coordinate certain aspects of the operation of national heritage records, particularly in relation to records of statutory protected buildings. The paper also makes reference to progress made in developing national, European and international coordination of data standards. Our discussion will be measured against the likely future potential of the technology and the future requirements for providing access to information including the needs of conservation management.

In a provocative paper delivered to the CAA conference in 1994, Booth argued that archaeology had 'missed out' on the information age (Booth 1995b). He suggested that, despite the extensive use of information technology in a wide number of application areas within the heritage community — museums, cultural resource management, excavation and survey — this has not extended to the major media of dissemination. He concluded that this lack of dissemination through digital techniques risks making archaeology and, by implication, the built heritage, more marginal than it presently is in the public consciousness, reducing the potential for public participation in the heritage, because of a general failure to embrace electronic means of presenting information, whether as text, images or sound.

Although Booth's argument was not exclusively directed towards monument records systems, these were included in some detail as part of his review. It is therefore a pertinent component of his paper and one to which we shall return. To commence, we present a model of the information relationships between the various heritage bodies and related functions in England at the levels of policy, data and function. We then look in detail at the historical inter-relationships of these systems, and finally assess progress towards an idealised model and the extent to which these heritage information systems have transcended Booth's thesis. The paper also presents a new and comprehensive bibliography of the available literature on monuments records in England.

2 Information Frameworks in England

Figure 1 provides a model of the current policy frameworks within which the three principal heritage information systems operate. This functional model reflects the policy roles of the Department of the Environment (DoE) and the Department of National Heritage (DNH) and the executive functions of EH and RCHME. The DoE is responsible for setting planning policy for both central and local government and does not itself create heritage information. It does, however, manage records at a regional level. The DNH is responsible for heritage policy. This is subsequently executed by English Heritage (EH) for conservation management, and by the RCHME through its role in surveying, recording and disseminating information. Within local government, conservation and record functions for archaeology operate mainly at the county level and for the built heritage, primarily at a more local, district level. The current review of local government in England (1994-1995) is set to create further urban, and some rural unitary (single tier) authorities, augmenting the urban unitary authorities set up in the local government review of 1985/1986. To some extent, this will erode the current two tier

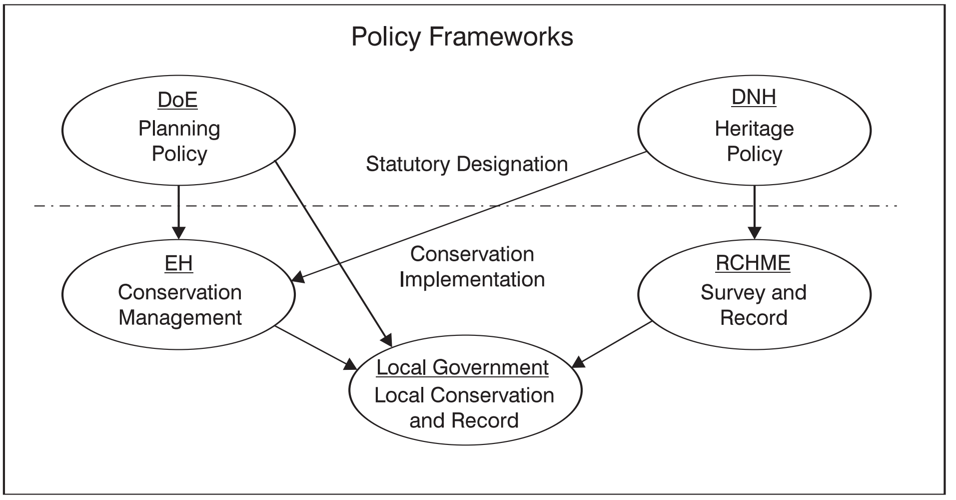

Figure 1. Policy Frameworks.

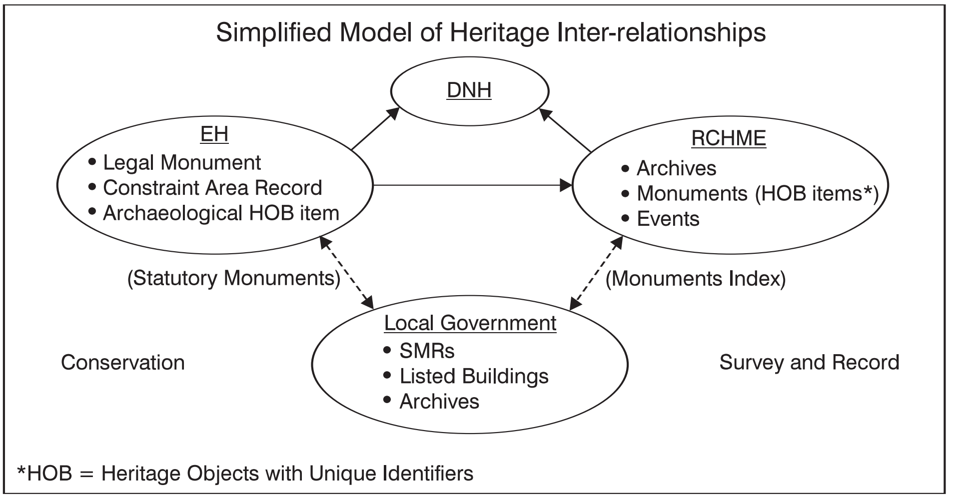

Figure 2. Simplified model of heritage inter-relationships.

system of local government comprised of counties and districts.

Figure 2 illustrates in summary form the principal data relationships between the information systems of the main holders of heritage information. EH information systems are oriented towards the automation of the conservation processes, including statutory protection and casework and RCHME systems towards the automation of recording, curation and dissemination processes. In local government are the county SMRs, complemented by records of historic buildings, largely held at district level for management purposes. In central government, EH is the government's adviser on designation for statutory protection, and RCHME the national body of survey, record and dissemination. These three records systems share several common interests in recording information on the historic environment and also have interests related to the functions of the host body.

The EH records system (mainly comprising statutory and management records) and the RCHME National Monuments Record MONARCH database (which includes both statutory and non-statutory records and associated data and archive for dissemination) have in common the concept of a 'heritage object', providing a close intellectual link between them. The National Monuments Record (NMR) of the RCHME and local SMRs are less formally connected, but a model (unpublished) agreement forged in September

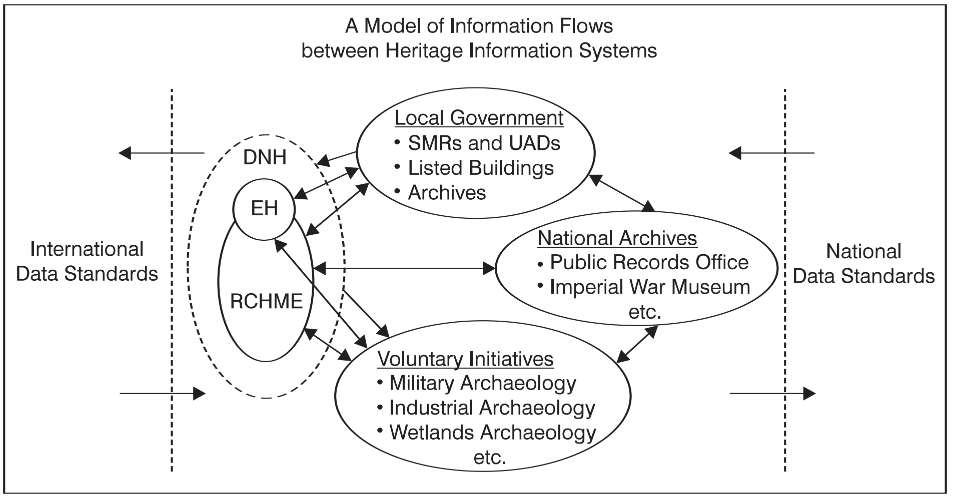

Figure 3. A model of information flows between heritage information systems.

1994 provides for the exchange of information between the two bodies at the level of a core index. This provides for information on the location, period, site type, form, condition and a basic reference for the site or monument. At a national level, it will provide the means to concord information on a thematic basis, and identify gaps in both local and national records. At a local level, it will ensure that all information on sites is registered as a constraint within the local planning process by SMRs.

A model of the information flows between the principal heritage information bodies is given in figure 3. At a national level, the combined records of RCHME (including its SMRs index), EH and DNH comprise the national heritage data set. Within local government, other, sometimes more detailed records are held primarily for the implementation of local management. Both interface with archives held locally (through County Archive Services) and nationally (for example, through the Public Record Office). Partly outside of this framework of public administration, there are also a growing number of 'voluntary' initiatives creating substantial databases concentrating on a theme, period or region. Many of these have received support in kind or through grant aid from the DNH, EH and RCHME. Each of these bodies contributes, in some respect, to the development of data standards, though contributions to international standards initiatives have tended to come almost exclusively from central government.

The next four sections of the paper look in more detail at the development of systems in local government, and RCHME and at the operation and impact of the Department of National Heritage at the policy level.

3 Sites and Monuments Records in local government

The English system of SMRs held in local government are unusual in a European context, where the norm is for unitary national records (see for example Hansen 1993). The situation has recently been further complicated by the development of SMRs at a district level, and by the creation of Urban Archaeological Databases, centred on the 30 or so most important historic urban centres in the country (EH 1992b).

While local government SMRs have benefited from a considerable degree of central government funding, they have maintained a singular independence, expressed both at the level of their national body, the Association of County Archaeological Officers (ACAO) and through the individual constitutional status of their host bodies.

Local government SMRs are a discretionary function of local government. The first were established as manual systems in the late 1960s (Benson 1974). The development of local sites and monuments records in the last 21 years has been an impressive phenomenon, in parallel with the growth of the RCHME National Monuments Record (see below). In 1973, when ACAO was first set up, there were just 5 members, and only one county had considered a programme of computerisation of its SMR records. The nearest equivalent to a national archaeological record at that time was the index records and maps held by the Archaeology Division of the Ordnance Survey, Britain's National Mapping Agency, which was then an entirely manual system. All SMRs in England have to some extent been founded on this card index, which was transferred to the RCHME in 1983.

Despite these modest origins, the importance and potential of local SMR record systems was recognised from an early date. In 1974, a working party on archaeological records was set up by the Council for British Archaeology, at the request of RCHME, which published a joint report in 1975 (CBA 1975). While this did not lead to the adoption of the common standards which many had hoped for, it did make the important distinction between the compilation of 'intensive' and 'non-intensive' records at national and local levels, and this has been influential in the development of records ever since.

The Survey of Surveys, undertaken by the RCHME in 1978 (RCHME 1978) urged the establishment of compatibility and standardisation of local records, a theme to which we shall return. It noted the extent of non-conformity, but recommended that 'County-based sites and monuments records should be the major, detailed archive for their areas'.

The significant investment in the development of computerised SMRs in the mid 1980s by EH, in part to assist its Monuments Protection Programme, built rapidly on these earlier foundations and helped to create the information base and architecture of 'cultural resource management' in English local government as we know it today.

In 1989, the RCHME was given the task of coordinating local SMRs, a responsibility confirmed in its new Royal Warrant of 1992. It has assisted developments through the production of joint data standards (RCHME 1993b), a review of SMRs (RCHME 1993a), and the development of the MONARCH for SMRs product, which is currently being piloted in four sites, and is likely to be used by at least a quarter of the SMRs in England.

4 English Heritage – the national conservation body

4.1 Background

English Heritage (EH) is sponsored by the governments Department of National Heritage (DNH) to undertake statutory responsibility for preserving England's architectural and archaeological heritage and for encouraging the enjoyment of the historic environment. It advises the government on statutory protection such as the scheduling of monuments and the listing of buildings and gives grants towards conservation generally. It manages and markets nearly 400 historic properties in the care of the state, including world-famous sites such as Stonehenge, parts of Hadrian's Wall and the Iron Bridge at Coalbrookdale. Many of the records it creates for operational purposes also form part of the permanent public national archive curated within the NMR of the RCHME.

EH was established in 1986 and most of the functions assumed at that date had been undertaken previously by the Department of the Environment. There has been a long tradition of heritage computing within the Department and EH, including applications for scientific analysis (for example see Jones *et al*. 1980) and archaeological excavation and other investigations (Hinchcliffe/Jefferies 1985; Jefferies 1977), but this paper concentrates on information systems which support monument records. The key areas are the scheduling of monuments and listing of buildings with their associated processes and spatial and graphic requirements.

4.2 Scheduling of Monuments

The history of the DoE/EH record of scheduled monuments is described in Booth 1988a. Computerisation began in 1980, using a suite of programmes originally developed for recording excavations and known subsequently as 'Version 1 Software'. By 1984, facilities for on-line data entry, editing and interrogation were required and Southdata's Superfile package was selected. From 1986, EH began to plan an enhanced programme of scheduling known as the Monuments Protection Programme (Darvill *et al*. 1987). It became evident that the record would no longer be a relatively static Inventory of monuments and that a new system would be required to manage the data and to automate much of the scheduling process (involving among other things the writing of around 50 letters for each of the monuments scheduled), and to provide a dynamic system for the management of monuments. The system, known as the Record of Scheduled Monuments (RSM) was designed during 1986-1989 and implemented for the automation of the scheduling process in 1991 (Clubb 1991a, 1991b; Clubb/Startin 1995).

Also in preparation for MPP, EH implemented in 1987 a computer mapping system providing for the management of 6,000 'raster' images of Ordnance Survey maps of England and the vectorised outlines or constraint areas of monuments (Clubb 1988). This system has fulfilled every expectation, but is now (1995) looking old-fashioned in its functionality and is reaching the end of its useful life.

4.3 Listing of historic buildings

The computerisation of listed buildings has a different history. Problems in securing funding for the computerisation of listed buildings records (Clubb 1995) led to the introduction of a partial interim solution to support the listing process within EH (Clubb/White 1990). Following a review of the cycles of activity and flows of data relating to the listing process, a Clipper compiled version of dBASE was established for the processing of listed buildings recommendations to DNH since 1990, but this holds merely a small proportion of the total number of buildings listed. The mapped representation of listed buildings at a national level has remained as a manual system.

4.4 Strategic developments

The first strategic review of information systems within EH took place in 1991-1992 (for details see Clubb/Startin 1995) and confirmed at a corporate level some of the concepts developed in the RSM, particularly the relationships between the monument and building records and their associated procedures and case-work and the requirement for flows of information from and to other bodies, including DNH, RCHME and local SMRs. It is understood that subsequent strategic analysis at EH has focused on the requirements for spatial and geographic information and on detailed data modelling and definitions.

A major achievement of EH activity on monument records has been the development of the complex model which embraces archaeological items, monuments as legally defined and areas of land (constraint areas) which do not necessarily have a one to one relationship (fig. 2 above). These have different attributes associated with them and different management implications.

5 Royal Commission on the Historical Monuments of England – the national body of Survey, Record and Dissemination

RCHME is also sponsored by DNH and was established in 1908 to investigate and report on the historical monuments of England (prior to 1992, it was sponsored by DoE). Its record and archive functions have expanded in recent years with the assumption of responsibility for the National Buildings Record (1963), the archaeological records section of the Ordnance Survey (1983) and the national library of air photographs (1984), all now managed and disseminated within the unified National Monuments Record (NMR). The NMR also provides an access point for certain records created by EH in the course of its operations. The first major computer implementation was the archaeological record from 1984, as the permanent national public database for buildings and monuments (Aberg/Leech 1992; Beagrie 1993; Grant 1985; Hart/Leech 1989; Lang 1995).

A strategic review of requirements was carried out in 1990 and this recommended the development of a unified data-base to replace the original archaeological data-base and a number of other archaeological and architectural data-bases, again using Oracle. The new system (MONARCH) was developed in 1991-1992 and implemented in 1993 (Beagrie 1993). However, its major contribution to the development of monument records is undoubtedly the analysis and implementation of the complex model which relates monument records, activities/event records, archive and bibliographic recording and the roles of individuals and institutions (fig. 2 above). Two other significant advances are the development of a sophisticated thesaurus module and a general enquiry mechanism which provides powerful retrieval facilities to individuals with little or no programming experience. Recent strategic analysis within RCHME has focused on the requirements for spatial and geographic systems, in parallel with similar EH initiatives.

In 1989, government gave RCHME a lead role for the coordination of local SMRs in England (RCHME 1990b). In 1993 RCHME published a review of local SMRs (RCHME 1993a) which seeks to establish a new partnership between local records and the national record.

It is worth considering here the degree of co-operation achieved by RCHME and EH to date. As stated above, both organisations recognise the concept of the ‘heritage object’, an entity which may have a one-to-many or a many-to-one relationship with physical space (such as constraint areas or land parcels) which is at the heart of their information systems. Both also agree on the concept of ‘core’ data, a sub-set of the record system defining type, location, status and source authority (‘references’) for monuments as the basis for compatibility of information at national and international levels (see section 8 below; Clubb/White 1990; Bold 1993b; Grant 1990b). They have cooperated in data standards (Booth 1988b; RCHME 1993b). EH and RCHME have produced joint publications on thesaurus terms for monument and building type (RCHME; EH 1989, 1992, 1995). There has been co-operation on relationships with local SMRs (RCHME 1993a). The decision by EH to adopt Oracle software for the RSM implemented in 1990-1991 was influenced directly by its use in RCHME and the potential for sharing expertise between staff and the requirement for flows of information between DNH, EH, RCHME and local SMRs. Most recently, there has been cooperation in the context of the DNH’s proposal for a heritage management database.

6 The Department of National Heritage and the Heritage Management Database

6.1 Background

The main role of the Department of National Heritage is to help foster the ideas, creativity and skills which help generate new heritage work and which care for the inheritance of England’s past. Its role is thus essentially one of policy rather than direct involvement with operational issues.

Many of the functions of DNH resided with the Department of the Environment prior to 1993. The DoE as sponsoring body for EH and RCHME and, indeed, with an interest in local SMRs through its oversight of the planning process, did not intervene significantly in heritage records matters. One exception was that it supported EH in 1988 on the choice of Oracle for the RSM system on the grounds of compatibility with RCHME. However, the DoE were reluctant to take a proactive role between 1986 and 1993 in encouraging the computerisation of the statutory lists of historic buildings which were still a major omission from the national record (see above; Clubb 1995). Ten major studies (and several lesser studies) were produced between 1986 and 1993, but funding for the work remained elusive until 1994, given the costs of retrospective computerisation (around £ 2 million), until the present Heritage Management Database initiative was launched.

6.2 The Heritage Management Database

The various studies and initiatives carried out by RCHME and EH attempted to deal with the requirements of other bodies, including SMRs, as well as their own needs. A significant new development coincided with the transfer of heritage sponsorship responsibilities from the DoE to the new Department in 1993. In particular, the new Department showed greater interest in coordinating certain aspects of the information strategies of its sponsored heritage bodies. The situation had changed following a report in 1992 by the Audit Office which commented on the lack of computerisation of the lists of the 500,000 or so listed historic buildings in England (National Audit Office 1992). The new Department of National Heritage decided to act on an earlier internal Information Systems Planning Framework report within the Heritage Division, then still part of the Department of the Environment, which recommended that a feasibility study was needed to determine the requirement for a National Heritage Management Database. In 1993, the Department of National Heritage commissioned consultants Ernst & Young to carry out a feasibility study into the National Heritage Management Database (Ernst & Young 1993).

The substantive project began in Autumn 1994 including the generation of indexes by RCHME to the agreed data standard. The development of the data standard for listed buildings is based on existing initiatives. The list is due to be fully computerised by 1996, with well-developed links to the RCHME MONARCH system. There is an appreciation of the requirement to link the listed building record with other data, both images of the buildings and spatial/geographical information, although these are not currently funded.

6.3 The impact of the Heritage Database on RCHME and English Heritage

The project is intended to reflect the operational roles of RCHME (recording, curation and dissemination) and EH (conservation management). As stated last year (Clubb 1995), two main issues continue to be of interest; the proposal for two main computer platforms, and the tripartite management arrangements between DNH, EH and RCHME which will govern how the proposals work out in detail, given the medium to long term problems to be solved in coordinating the information systems strategies of organisations which may have different priorities and different cycles for budgeting and planning. The Ernst & Young proposal for the computing platforms is set out in summary form in Clubb and Startin (1995). One computing platform hosted by EH is planned to support the new heritage management database and maintain the records of statutory constraints such as listed buildings and scheduled monuments. This platform is linked closely to the DNH and EH systems which support the process of listing and scheduling on the one hand and their case management systems on the other.

In parallel with the new platform is the RCHME National Monuments Record (MONARCH) system, already in place, which, under the proposals of the study, is set to contain an updated copy of the publicly-accessible sections of the heritage database (in effect, a record of statutory constraints) as a sub-set of the total national record to be disseminated. Links to the local authority sites and monuments records are provided through the ‘extended’ National Monuments Record (see also RCHME 1993a).

The listed buildings project represents a significant development in monument records at national level. Not only has there been a more proactive policy role on the part of the sponsoring government department, but the potential, if funding permits, that a similar approach might be adopted for future developments such as spatial/geographic systems and imaging/multi-media services means that the information system strategies of the three bodies would need to be finely tuned to each other for the foreseeable future, at least in respect of records of monuments/buildings with statutory protection and their dissemination. This would have both advantages and potential problems at an operational level.

7 Data standards and European/international cooperation

7.1 International data standards

While DNH, EH and RCHME have all taken an interest in data standards and co-operation at European and international levels, as have the equivalent bodies for the rest of the UK, RCHME has taken a lead role in these areas in England as the national body of survey and record. Data standards begin at national level and the role of RCHME in conjunction with EH and local SMRs has been described above. At European and international levels co-operation has been initiated on the basis of both architectural and archaeological documentation. The concept of a European core data standard for the documentation of the architectural heritage was first discussed at the Council of Europe Round Table in London in 1990, organised under the architectural documentation programme of the Cultural Heritage Committee in cooperation with RCHME (Council of Europe 1990a) and developed further at a European colloquy organised by the Council of Europe and the French Directeur du Patrimoine in Nantes in 1992 (Council of Europe 1993). Proposals for the core data index are set out in Bold 1993b and approval of the representatives of the participating governments of the Council of Europe is anticipated very shortly.

The major international development on core data standards for archaeological sites has been carried out under the auspices of the International Documentation Committee (CIDOC) of the International Council of Museums (ICOM). The Archaeological Sites Working Group is chaired by Roger Leech of RCHME and is well advanced in preparing a standard due to be made available in draft at the triennial ICOM meeting at Stavanger, Norway, in June/July 1995. This standard is intended to be compatible with the European core data index for architectural documentation. It is being developed as a European initiative under the auspices of the Council of Europe for discussion at an international conference on archaeological heritage documentation to be held at Oxford in September, 1995. Both architectural and archaeological standards are compatible with the core standards recommended for use in the UK and employed by DNH, EH and RCHME.

Finally, within the context of terminology control, several multi-lingual thesaurus projects have been initiated. For architectural records, the International Terminology Working Group, sponsored by the Getty Art and Architecture Thesaurus (AAT), includes the AAT, the L'Inventaire Général, the Royal Institute of British Architects and the RCHME, and liaises with the Council of Europe. For archaeology, a pilot project under the auspices of the Council of Europe is working towards a multi-lingual glossary of monuments for the European Bronze Age (Council of Europe 1995).

7.2 Local government data standards in England

Notwithstanding the significant level of agreement at national and international levels, traditionally, local SMRs have not concerned themselves greatly with data standards. A modicum of communality has been achieved through the promotion of standards by the Department of the Environment and EH (DoE 1981), and more recently, through the jointly developed Data Standard for the extended national archaeological record between the ACAO and RCHME (1993b), although the latter is too recent to have yet made a major impact. Commonly agreed local authority standards for the recording of standing structures are, if anything, even less well established, although RCHME has provided guidance for buildings recording conventions (RCHME 1990c, 1991).

Although the original support provided by the Department of the Environment and EH for SMR development was coupled with suggested data fields, adherence to this structure was not mandatory, and was viewed as being of secondary importance compared with the political imperative to establish a local SMR network. Recording instructions, where developed, were not coordinated. Hence, between local recording bodies, many of the problems of consistency and compatibility, highlighted in previous reviews, remain (e.g. Chadburn 1989; Lang 1992; RCHME 1993c). Indeed, in some instances, local SMRs have preferred to make a fresh start on their record, using data from the RCHME National Monuments Record as the basis of their system as the most cost-effective option for achieving consistency in data compilation.

Standards work has not been prominently exploited by local government SMRs, though valuable contributions have been made both through the efforts of individual sites, and through input to national fora (for example, the ACAO and RCHME Data Standards Working Party, which led to the publication of the Data Standard for the Extended National Archaeological Record (RCHME 1993b)).

To the extent that local authority SMR staff are often fully committed to case work as opposed to records maintenance, the growth of developer funded archaeology in the last five years has meant that SMRs have become a victim of their own success. The increasing demands of development control-related duties threaten, in many Counties, to undermine the continued development of the very record providing the basis for planning decisions. The RCHME's SMR Review (RCHME 1993a) highlighted the staff shortages and growing recording backlogs in many SMRs. These shortcomings are exacerbated by the shortage of available funding to adhere to published standards, and to migrate from some of the older database management systems, which are now coming to the end of their useful lives.

Data modelling has been less prominent in the development of local government SMRs, but significant progress is being made in some counties in the development of spatial information systems. Some of these are currently in advance of developments in either of the two national bodies, predominantly, though not exclusively, because of difficulties in negotiating an affordable national mapbase.

8 An idealised model of information relationships

Following on from the above assessment of existing national and local systems in England, it is possible to describe an idealised model of information relationships

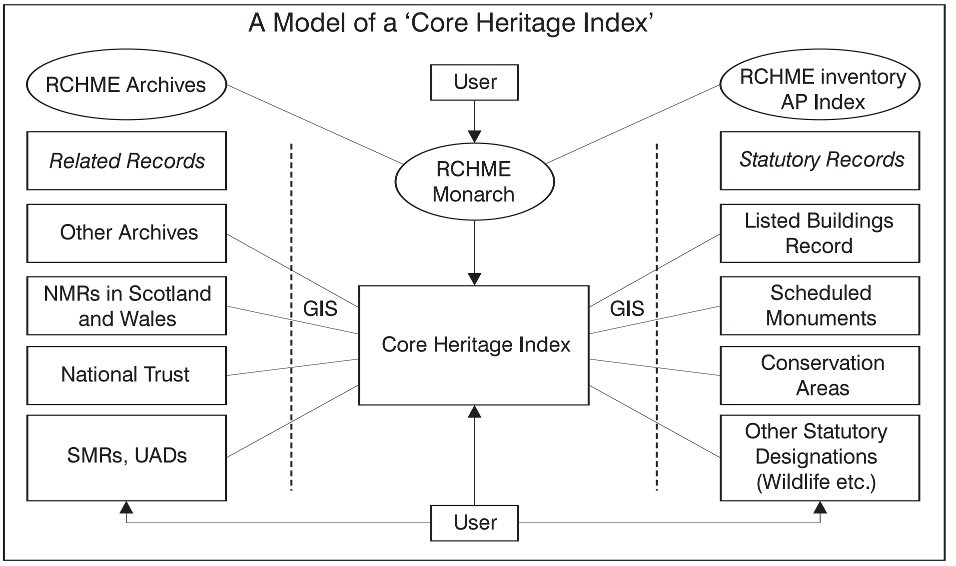

Figure 4. A model of a 'core heritage index'.

between these systems. The physical mechanisms behind this model are beyond the scope of this paper (whether through a physical network or through use of a smart meta-data set), but in either case, the underlying principles may be applied. The system we have in mind would be accessible through a national publicly accessible spatial index, which could interrogate a core heritage record common to all of the three information systems we have previously described (fig. 4).

It is suggested that the RCHME is the logical body for the management of such an index given its national role in survey, record and dissemination, its lead role for SMRs and its substantial data bases and archives which add significant value to the index concept. RCHME's archive and inventory, both retrievable through its MONARCH information system, provides a substantial base in combination with statutory records of archaeology, architecture and ecology and related non-statutory records held by other bodies for a powerful spatial database of the historic environment.

We would envisage that further information held in addition to the core index could be made available for public dissemination via the custodian body as the intensive disseminator of that information, or supplied on a more restricted basis to other custodians of information within the network (for example, where confidential management implications apply). The model would assume there will be at least some elements of a physical (or meta-physical) network between participating bodies enabling data sharing and dissemination, and that satisfactory agreements would exist covering ownership, copyright, security and standards issues. While not wishing to diminish the difficulties attendant on turning this model into reality, it may be suggested that the foundations for its deployment are in large part in place.

9 Conclusions

In the first section of this paper, we referred to Booth's hypothesis (1995b) that archaeology had missed out on the information age. In the light of the above, in relation to heritage information systems, this thesis seems to us to be one requiring further qualification.

We have attempted to demonstrate in this paper that significant steps *have* been taken towards establishing compatible information systems within archaeology and architecture. There has been progress in the development of data standards, controlled vocabulary and reference data both at national and international levels. In England, developments in geographical and spatial information systems, imaging and multi-media have often been more feasible at a local rather than a national level. Nonetheless, the data standards and models already established provide a springboard for future national development. We would therefore contend that significant progress is being made towards a coordinated approach, leading to a coherent information network embracing not merely our national interests, but with the rapid potential to expand to our European colleagues, and indeed to operate within a truly international framework.

Information systems for the historic environment in England have been developed originally without a central model guiding their deployment. In RCHME and EH, significant progress has now been made on data modelling. Robust systems now exist in the EH RSM, governing the relationship between archaeological items, constraints and legislative processes and in the RCHME MONARCH system, governing the relationship between events, monuments and archives. Support for the processes of scheduling of ancient monuments, listing of buildings and monument recording is generally well developed and effective, underpinned by the key concepts of the 'heritage object', 'core data', data standards initiatives and the integrated archaeological and architectural thesaurus. Archival recording is perhaps less well established, but through the development of the archive module of the RCHME MONARCH system during 1995-1996 significant progress may be expected over the next year. Issues of funding, however, still dampen progress with spatial and multi-media projects associated with these models at a national level.

These, then, are some necessarily tentative thoughts on the inter-relationships of the principal archaeological and architectural information systems in England, and their current relationship to complementary systems abroad. We would welcome seeing more papers from our colleagues in other countries setting out the relationships between their respective heritage information partners. The more explicit documentation of the inter-relationships of heritage information systems in Europe may help us move perceptibly closer towards truly integrated systems.

Notwithstanding this, Booths's assertion concerning the compatibility and retrievability of data does raise significant concerns, which must be addressed through much greater investment in developing communal and compatible interfaces to information systems, or rigorous meta-data routines. Ultimately, these should enable our systems to communicate with one another, in effect, in a common language. This would seem to be a pre-requisite for the widespread digital dissemination of monument record information. There is, thus, some truth in Booth's suggestion that heritage data is still not disseminated effectively in England to the wider heritage community and beyond. Issues of protecting monuments against metal detector abuse and buildings against architectural thefts still require resolution in terms of the free supply of information (for example, see ACAO 1991, 1992; Council of Europe 1990b; Stine/Stine 1990). However, the essential models for the effective management and dissemination of heritage data are now in place. The European heritage and traditions are shared and valued by millions throughout the world, and can only gain strength and vitality through fostering an accessible, commonly understood medium of interchange.

Acknowledgements
This paper is based on existing published literature but, of course, the analysis remains our responsibility. The ideas will undoubtedly require further development and refinement in the light of further analysis of the strategic and business requirements of the local, national and international heritage community and the public. We are grateful to many colleagues in EH, RCHME and local government, and in central government in Europe and the United States for stimulating a debate over a period of some years which has made this paper possible.

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Learning from the achievements of Information Systems – the role of the Post-Implementation Review in medium to large scale systems

1 Introduction

In the last decade, a number of papers on information systems supporting heritage records in English local and central government have been published. Several of these have stressed the considerable financial value accruing to these information systems, which may often be disguised by the relatively modest initial investment in the basic technology to sustain them. The purpose of all information systems, whether large or small, is to support the business of their parent organisation, and the process of managing these projects seeks to ensure their cost-effective and timely delivery to meet the business objectives. Regular reviews during the life cycle of the information system are an essential process to ensure these objectives are achieved.

For central government in England, Clubb (1989) has already described the Investment Appraisal process, which may govern a decision to initiate a new information system. In this paper, the authors seek to describe the logical conclusion to an implementation — the Post-Implementation Review (PIR). It is an important phase in the life cycle of all IT projects, although it is often overlooked, or paid scant attention. This paper places the PIR in the context of the systems development process, sets out potential areas of risk to projects and considers four English cases studies, of which the authors of the paper have first-hand experience:

– the English Heritage Record of Scheduled Monuments (RSM),
– the Royal Commission on Historical Monuments of England (RCHME) National Monuments Record, MONARCH,
– the Greater London Council/English Heritage Greater London Sites and Monuments Record,
– the West Midlands Sites and Monuments Record.

The implementation of all new computing systems requires, to some degree, a process of learning. Heritage computing will only progress if we are all willing to share the knowledge derived from this process, both good and otherwise. We are grateful that colleagues in the organisations mentioned in this paper have been willing to share their experiences in this way.

2 The system development process and areas of risk to the success of information systems projects

Large information systems projects usually require to be managed through a series of discrete stages, sometimes called the system development process or project life cycle. A typical project life cycle will follow some or all of the following stages illustrated in figure 1 (not necessarily in the order shown, since certain processes may run concurrently).

The PIR occupies a critical role in the system development process in reviewing the system as implemented against the original assumptions and preparing the way for future developments. Before embarking on a major system, it is worth examining in advance some of the areas of potential risks. These should be anticipated in the Investment Appraisal (Clubb 1989) which should include both an appraisal of risk and the testing of the sensitivity of the investment to changes in the fundamental assumptions inherent in a project.

2.1 Areas of risk:

All information systems are susceptible to a number of areas of risk. These may include some or all of the following:
– lack of clearly defined objectives and benefits,
– lack of user commitment or system 'ownership',
– failure to improve data/procedures *before* developing new systems,
– lack of formal project management/development methodologies,
– lack of clearly defined project rules,
– failure to define acceptance criteria and testing protocols
– failure to estimate adequate resource, including training and documentation,
– failure to assess hardware/software capacity,
– failure to establish formal disaster recovery plans and security standards,
– lack of legal/contractual advice on relationships with suppliers,
– lack of documentation.

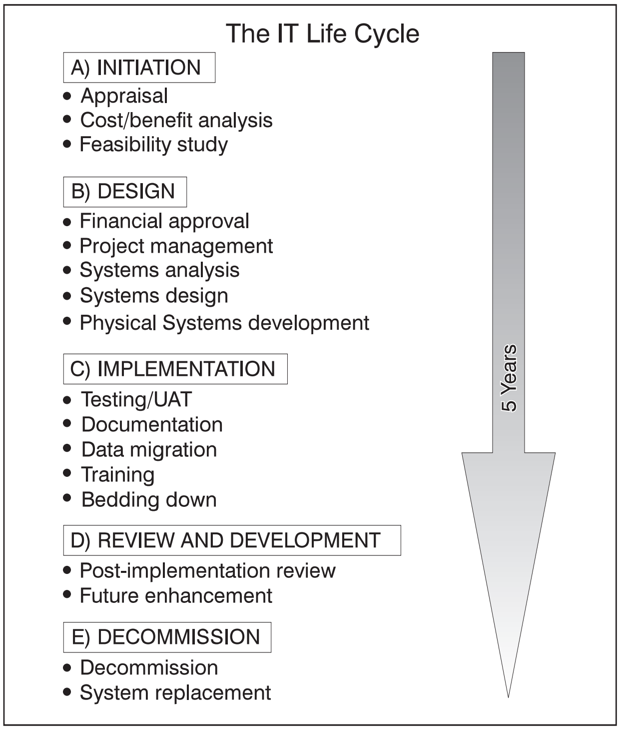

Figure 1. The IT life cycle.

Those responsible for managing an information project should ideally have the necessary experience to anticipate risks and act to minimise them.

2.2 The Role of the Post-Implementation Review

In the system development cycle, the PIR performs a critical role in assessing the achievements of a system against the original expectations which justified the decision to invest in its development. If an organisation does not conduct reviews, then it is likely that its information systems will not be properly managed. Money will be wasted because it is likely that:

- information systems will not be fully aligned with the business objectives of the organisation,
- the organisation which has funded the initiative will have no means of knowing whether its investment is providing value for money,
- benefits management will not be effective and the benefits predicted in the business cases will not be realised,
- the costs and risks to the enterprise will not be minimised,
- generic lessons, of use to future implementations within the organisation and to others will not be assimilated.

The PIR is normally initiated when the new system is fully implemented and when the users are fully conversant with its features and facilities. The timing of the review needs careful judgement. For micro-systems, normally, about three months after implementation is appropriate. For larger scale systems, the review would normally be conducted between six and twelve months after implementation. If the review takes place too soon, then it may attach undue importance to what are no more than short-term technical issues and this may lead to erroneous conclusions. The focus of the review should, in the main, be on the medium to long term and the degree to which the system supports the business activity. It is particularly important that the timing of the review adequately covers any cyclical features, such as quarterly, bi-annual or annual tasks which the system is expected to perform.

In summary then, the primary purpose of the review is to determine whether:

- events have proved the validity of the planning assumptions,
- the claimed savings and/or benefits have been achieved.

The scope of a PIR will be governed by the size and the complexity of the project to which it relates. For simple micro-systems, this may be a very brief document, but this in no way lessens the desirability of holding the review. For larger systems, PIRs can often be extensive documents, and consideration should be given to the adoption of a formal review methodology such as MEVIOS (Method for Evaluating the Impact of Office Systems, CCTA 1989).

Information for the PIR can be gathered from:

- interview or the circulation of questionnaires to those operating and using the system,
- examining system documentation such as project minutes, user and training documentation, testing protocols, system maintenance logs and computer resource accounting packages,
- observations on the business and IT operations,
- feedback from external clients of the system, where appropriate.

The PIR may be undertaken as an in-house review, or by an external consultant. As one of its final actions, the IT project board overseeing the project should have set up the terms of reference for the review. The key issue is to ensure that the process is undertaken as objectively as possible. This usually means that the report should be prepared by someone not directly involved with the project, either as developer or user.

A formal methodology for risk assessment, such as CRAMM (Computer Risk Analysis and Management

Models, CCTA 1988) and general security issues should be undertaken periodically after any significant new change to a system.

Against this background, the authors would like to examine four case studies, two drawn from central government records systems, the Record of Scheduled Monuments, operated by English Heritage, and the National Monuments Record application (MONARCH) run by the RCHME, and two at a local level, the Greater London Sites and Monuments Record (SMR), now managed by English Heritage, and the West Midlands SMR, run by the West Midlands Joint Data Team, a jointly sponsored body established to service strategic information systems requirements by the seven metropolitan district councils of the West Midlands County.

All four systems are substantially successful, but they all provide lessons for their host organisation, as well as for others.

3 English Heritage – Record of Scheduled Monuments

3.1 Objectives of the system

The objectives and implementation of the English Heritage RSM are well documented elsewhere (Clubb 1991a, 1991b; Clubb/Startin 1995). The system curates the national database of scheduled monuments and automates the complex processes involved in the identification, legal protection and management of the most important archaeological sites in England.

3.2 Implementation history

A cost-benefit analysis carried out in 1988 concluded that the costs of the system of £ 605,380 over a 7 year period would represent savings over a range of alternative ways of meeting the requirement. The investment appraisal associated with the decision to develop the system is discussed in Clubb 1989 and included an element of both risk analysis and sensitivity testing. The system was developed during 1990-1991 using the Oracle relational database.

3.3 Post-implementation review

The PIR was carried out by external consultants and completed in April 1992. The system was undoubtedly a success in terms of automating the procedures of scheduling monuments. The PIR identified strengths in the project implementation as follows:

– significant financial savings achieved,
– systems liked by staff,
– system analysis, design and programming handled well,
– reliable application software,
– meets original design specification, administrative activities and data storage requirements,
– choice of Oracle software will facilitate links with RCHME systems and sharing of expertise between English Heritage and RCHME.

3.4 Conclusion

The PIR also concluded that some lessons could be drawn from the project. Although system analysis, design and programming had been handled well, it was noted that system testing, user acceptance and data take-on experienced delays. It was also noted that without the dedication and sheer tenacity of key members of staff, several aspects of the project would have been unlikely to have been successfully implemented. It recommended that the English Heritage information technology system development standards provided a good basic framework, but required strengthening. It also commented on the need for formal project management methodologies. Other recommendations identified the need for regular planning exercises on hardware capacity and for English Heritage to review the balance between local information technology support and the need for a large central support and maintenance team.

4 Royal Commission on Historical Monuments (RCHME) – National Monuments Record (MONARCH) system

4.1 Objectives of the system

The objectives of the MONARCH system are discussed elsewhere (Beagrie 1993). It sought to unify a number of existing computer databases within the RCHME, provide a single point of entry to RCHME information systems for external users and staff and to offer a number of other benefits of convenience, speed and scope of coverage. The system presents a new model of the relationships between monuments and their associated archives and events.

4.2 Implementation history

The first major computer implementation in RCHME was the National Archaeological Record (NAR) from 1984 (Aberg/Leech 1992; Beagrie 1993; Grant 1985; Hart/Leech 1989; Lang 1995). A strategic review of future requirements was carried out in 1990 and this recommended the development of a unified database to replace the original NAR database and a number of other archaeological and buildings databases. The key elements of the new system were Monument Recording, Activities/Event Recording, Archive and Bibliographic Recording and persons/organisation. This system was developed in 1991-1992 and implemented in 1993.

4.3 Post-implementation review

The PIR was carried out by a senior member of RCHME staff who was independent of the MONARCH system development process and reported in December, 1994. The system undoubtedly broke new ground in analysing the relationship between monuments and their sources. The PIR identified strengths in the project implementation as follows:

- underlying philosophy and architecture excellent,
- opened internal communication and discussion of harmony of working procedures,
- considerable range and complexity of retrieval mechanism,
- successfully handles large quantities of complex data,
- links, associations and cross-references a major development in concept and functionality.

4.4 Conclusion

The PIR also concluded that some lessons could be drawn from the project. The decision to proceed with the system was based on the corporate benefits of a unified database which should have been underpinned by a formal cost-benefit analysis. This would make it much easier to assess the strengths and weaknesses of the new system against the original assumptions. Most of the other issues raised relate to the need to develop project management methodologies and to ensure proper training and involvement of staff. The PIR also examined the timing of the introduction of a new system. Sometimes a project may act as a catalyst for corporate improvements in existing working arrangements and procedures. It is debatable whether a more effective approach is to review existing working practices and procedures *before* system development is undertaken. These are issues on which an organisation must exercise judgement in devising an implementation plan.

5. Greater London Council/English Heritage – The Greater London Sites and Monuments Record

5.1 Objectives of the system

Details of the original objectives and implementation of the Greater London SMR have been published (Clubb/ James 1985; Jones 1989). The objectives are similar to those of the West Midlands SMR (discussed below), although there was a greater emphasis on historic buildings as well as archaeological sites and monuments. This reflected the original sponsor of the SMR, the Historic Buildings Division of the Greater London Council (GLC), which worked in close association with the museums and archaeological services for London in developing the project.

5.2 Implementation history

The Greater London SMR was first developed in the period 1984-1986 on an ADABAS database on the GLC mainframe. On the abolition of the GLC in 1986, the project was transferred to the London Region of English Heritage with a privatised computer bureau service provided by Hoskins plc. The costs of the bureau service were considerable, nearly £ 100,000 pa and following a consultants' report in November 1987 it was decided to re-develop the computer system using Oracle as an in-house facility. This was estimated to cost £ 200,000, but the lower running costs subsequently were expected to ensure that there were significant financial advantages in the proposal, as well as benefits in the migration from ADABAS to the Oracle relational database. The transfer took place in 1991-1992.

5.3 Post-implementation review

The PIR was carried out by external consultants and completed in March 1993. The project is undoubtedly a success in providing a better, less expensive system. The PIR identified significant strengths in the project implementation. These are summarised below:

- project delivered on time and on budget,
- successful migration from old to new system,
- system testing was effective,
- improved functionality,
- good change control procedures,
- significant financial savings achieved (about £ 37,880 pa).

5.4 Conclusion

The PIR also considered that some lessons could be drawn from the project. Although it should be regarded as successful in terms of the original objectives, the success was due to the natural ability of those concerned and relied heavily on the abilities of those individuals. The consultants concluded that any degree of risk to the project could have been minimised by the use of a structured project management methodology and with associated project management tools. They also recommended that project managers should be trained in project management. Of some interest is the suggestion that the envisaged benefits from the system should not just have centred on the benefits of an outside bureau versus an in-house operation but should have revisited the SMR from first principles and considered the total cost of the system against the benefits rather than just the savings.

6 West Midlands SMR

6.1 Objectives of the system

Details of the organisational objectives and implementation of the West Midlands SMR have been published (Lang

1989; Lang/Stead 1992). In essence, these were to establish a computerised inventory of archaeological and architectural sites and monuments to provide for more effective management and planning control of this resource, though the details of how the system would support these functions were not established prior to implementation.

6.2 Implementation history

The West Midlands SMR was developed as a stand-alone computerised system from 1987 onwards on a PC using Superfile database management system software. It closely followed the standard of DoE Advisory Note 32 (DoE 1981). In common with many SMRs, the initial capital set-up costs were very low, amounting to around £ 4,000. However, by the end of the four year strategic plan for its development, investment in the system, including data entry costs, amounted to some £ 75,000. In 1989, on transfer to the West Midlands Joint Data Team, an organisation of around 40 information professionals providing information processing and analytical services for the 7 West Midlands District Councils, it was decided to develop a new system to improve data handling, development control, and cartographic manipulation. Although resources for the SMR were scarce, by combining this initiative with other requirements within the Data Team, it was possible to justify the investment. Following an extensive evaluation, a solution using a relational database and GIS software (INGRES and Genamap) was selected and prototype systems were constructed.

6.3 Post-implementation review

In common with the majority of SMR systems established in local government, no formal process of review was required either by the host authority or by English Heritage, as the initial grant aiding body (although monitoring of data entry rates was conducted throughout the period of grant aid, see below). The strengths of the systems development may be summarised as follows:

- development costs were shared with other functions within the organisation,
- the operational requirement was clearly established and the procurement was carefully controlled,
- there was close integration of database and spatial GIS elements of the system,
- it met its principal requirement -development control-both through the SMR and in support of archaeological development control functions elsewhere,
- the analysis for the system broke new ground through defining generic groupings of related monument types,
- the system provided both tangible and intangible benefits through enhanced functionality.

6.4 Conclusion

There were also some areas where the review indicated improvements could have been made. The main areas of weakness were in underestimating resource requirements for the development. In common with most local government SMRs, the conflicting pressures of development control-related work, and maintenance of the existing system, meant that development work could not be reliably programmed and progress was slower than anticipated. This could have been avoided through including external technical consultancy in the development of the system, though, given the constraints of local government funding, it is not certain whether this could have been better resourced. Finally, the project was (perhaps inevitably in such a small team) closely identified with a single member of staff. The subsequent departure of that member of staff has caused considerable delays to the full implementation of the system as originally envisaged.

7 Conclusions

Post-implementation reviews are an essential mechanism for minimising risk in IT systems, and should be seen as an integral and indispensable part of the overall review process within the life cycle of an information system. The examples quoted above provide solid examples of the benefits derived from a formal review, and also point to some of the dangers in failing to measure system performance against the original expectations of the system, as opposed to the performance of individuals as processors of data. They also stress the need for formal methodologies and the potential risk of depending on a small number of individuals.

In central government, PIRs are an expected part of all significant IT projects, and for major initiatives, these are normally conducted by external consultants. Post-implementation reviews are also accepted practice in local government computing, but do not tend to be applied as a formal requirement in quite the same way. In the case of local authority SMRs, very few have been subject to a formal review process, with, in many cases, adverse consequences.

The original justification for computerised local SMRs was made largely by the Department of the Environment (and later by English Heritage) at a central government level. English Heritage took responsibility during the 1980s for the extensive ‘pump-priming’ of local government SMR systems, having a considerable influence over the choice of software systems used in over half of the 46 County SMRs. While local government officers took up the development of these systems with considerable enthusiasm, the responsibility for ensuring the effective initial implementation of these systems through the review process must rest with central government.

The initial supervision of local SMR implementations was made almost entirely by the Department of the Environment Ancient Monuments Inspectorate (English Heritage after 1986), which consisted of archaeological professionals who were not necessarily ‘computer literate’. Their concern rested largely with the achievement of data entry rates as a key performance indicator, rather than with the quality of the system developed, the integrity of records being entered or the testing of assumptions about the ability of these systems to answer questions in the furtherance of central and local government objectives. These were regarded as local matters, although as early as 1984, one member of the Inspectorate was lamenting that there had been no formal analysis of the operational requirement and functionality for SMRs (Inspectorate of Ancient Monuments 1984).

In local government as a whole, SMRs are generally considered to be peripheral IT systems. It may be argued that the case for making these more robust would be enhanced through the adoption of formal review methodologies. Following the establishment of a lead coordinating role for local authority SMRs, RCHME is helping to support audits of sites and monuments records considering taking the PC version of the MONARCH database. Although these are not intended as PIRs, much of the information provided through the audit could be used, with minimal further translation, to form the basis for a PIR, and are being used to make the case for further IT development.

In general, the required investment in technical development and maintenance of local SMR systems has been substantially underestimated, with only a minority having defined the resources for formal development. Nonetheless, the majority of local SMRs report that their systems *do* successfully support their internal functions qualitatively, but their ability to provide statistics for national programmes has often been found to be more limited.

The lack of formal management methodologies in IT planning for local SMRs means that further investment is now required to maximise the benefits from these systems, including the establishment of efficient protocols for digital data exchange with the RCHME National Monuments Record and other relevant bodies. This is not simply a question of providing resources to support data preparation and input (though both should be covered in IT planning). It is equally a question of the need to review and to measure performance against original objectives. These are areas where the RCHME, as the lead co-ordinating body for SMRs, should, perhaps, develop a more proactive role in the future, in the light of experience of PIRs of their own systems.

Our companion paper in this volume (Clubb/Lang ‘A Strategic Appraisal of Information Systems’) includes an extensive bibliography, with relevant additional literature to that specifically cited in the text. The paper seeks to achieve a strategic appraisal of monuments records in England and PIRs have a critical role to play in helping to refine this process.

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Excavations and Archives: Alternative Aspects of Cultural Resource Management

1 Introduction

In this paper I would like to explore how some issues of cultural resource management are beginning to affect the collection of information about excavations and the management of archaeological archives in England. I would like to focus on four main issues:

1. The rapidly increasing volume of archaeological documentary and finds archives and the need for long-term curation and storage.
2. Access to information on excavations and archives for cultural resource managers.
3. The analysis of trends in archaeological fieldwork and its contribution to our interpretation and management of the past.
4. The contribution of national computerised databases and analytical tools to these areas, using examples from the MONARCH database of the Royal Commission on the Historical Monuments of England.

I am conscious that I will be talking solely about England and that the volume of archaeological fieldwork and the organisational structures of archaeology vary greatly across Europe but the issues raised should also be of interest to colleagues outside England.

2 The Development of the RCHME's Database Information on Archaeological Events and Archives

There has been an increasing trend in recent years in England to re-examine archaeological databases and to begin to distinguish between information on sources and primary investigation and secondary interpretation. This has proved to be particularly important in urban areas with complex and fragmentary deposits and this distinction has been fundamental in the development of Urban Archaeological Databases in England. This distinction has also been fundamental to MONARCH.

I now wish to explain to you the background to how the RCHME began to collect discrete database information on archives and excavations and related archaeological issues.

In England there has been a diverse and thriving network of individuals and local, regional and national bodies, undertaking archaeological work, several hundred museums and other institutions in which this material has been deposited, and almost as many newsletters, journals and monographs in which this work could be published.

Growing concern in the 1970s over the very large backlog of publication in England, the safekeeping of documentary archives and finds, and the need to improve awareness and access to them has led the RCHME to actively compile information on archaeological excavations and archives as one of its core activities.

3 The Management of Archaeological Archives in England

There have been a number of fundamental shifts in British Archaeology in recent years with funding being increasingly derived from developers rather than government and an increasing emphasis on small-scale evaluations and use of the planning system rather than large excavation projects.

A recent article in British Archaeological News shows that the rapid increase in excavations and volume of archive being deposited in museums is now an issue in England, particularly in major urban centres such as London (Council for British Archaeology 1994).

The existence of a national database with discrete and retrievable information on excavations and archives can provide quantification and analysis of such issues, which extend beyond any one locality or region. To illustrate this, I would like to look at information held on archaeological collections in museums in England by the RCHME, and present some national quantification of the resource derived from information on excavations and archives held in MONARCH.

We have only recently completed the updating and expansion of our information on archaeological events. However, I think the value of a national dataset on archaeological interventions is already apparent (fig. 1). The scale of the increase in excavation in England since the early 1800s, and by implication, its impact on museum collections, can now be seen from the data we have

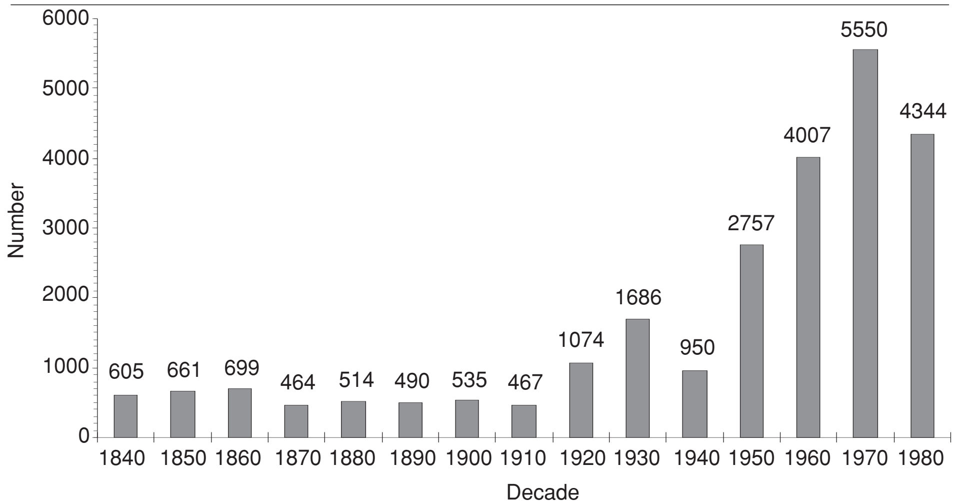

Figure 1. Number of Excavations undertaken in England by Decade.

collected. Figure 1 shows the number of excavations which have taken place in England in each decade since 1840.

From the outset we have aimed for comprehensive national coverage and have recorded excavations of any date, on sites of all archaeological periods, including sites from the industrial revolution, and excavations which have recorded negative as well as positive results. We have collected information on excavations undertaken by early antiquarians in the nineteenth century, through to the growth in excavations between the two world wars and the major surge in excavations from the 1960s onwards. As you can see, there were over 5,500 excavations in England in the 1970s alone.

This information has recently been updated to include all excavations up to 1992/1993 and we have added information on evaluations and watching briefs, and finally surveys funded by English Heritage or its predecessors since 1960.

As of March 1995 we have recorded:

– 28,777 excavations,
– 7,482 evaluations and watching briefs,
– we have located the documentary archives for 53% and the finds for 54% of the total excavations recorded.

For a session on the future of archaeological archives at the Institute of Field Archaeologists conference in England in April 1994, MONARCH was used to provide a broad quantification of the scale of the likely archive and publication problems facing the profession (fig. 2).

The period 1940-1980 was selected to cover the archives being tackled in post-excavation backlogs. 1980 was chosen as a cut off date as information on the late 1980s was still being entered onto MONARCH when these figures were compiled.

Over 13,000 excavations were recorded for the period 1940-1980. Final reports had been published for 37%, while for 11% there was no known publication at all. Substantial post-excavation and publication programmes are in progress which will reduce these backlogs, but much will remain unpublished: this emphasises the growing importance of the archives as repositories of original data. The cost of publication and the consequent trend towards summary publication reports supported by a publicly accessible archive will also emphasise the importance of the archive.

Documentary archives and finds had been located for 65% of the excavations over this period. Of the documentary archives located, 51% were in museums, 17% with individuals, and 32% in other locations (principally units and local societies). For the finds located, 72% were in museums, 9% with individuals, and 19% in other locations.

I should emphasise that these statistics should be regarded as best estimates as they cover 2/3rds of the archives for excavations undertaken between 1940-1980; the remaining 1/3rd, for which we have no information on the archive, may not follow an identical pattern.

These figures provide some insight into the growth of archaeological collections, the potential transfers to repositories in the next decade and pressures on resources, which may arise in England. Without central collection and computerisation of information on excavations and archives such an analysis would have been impossible.

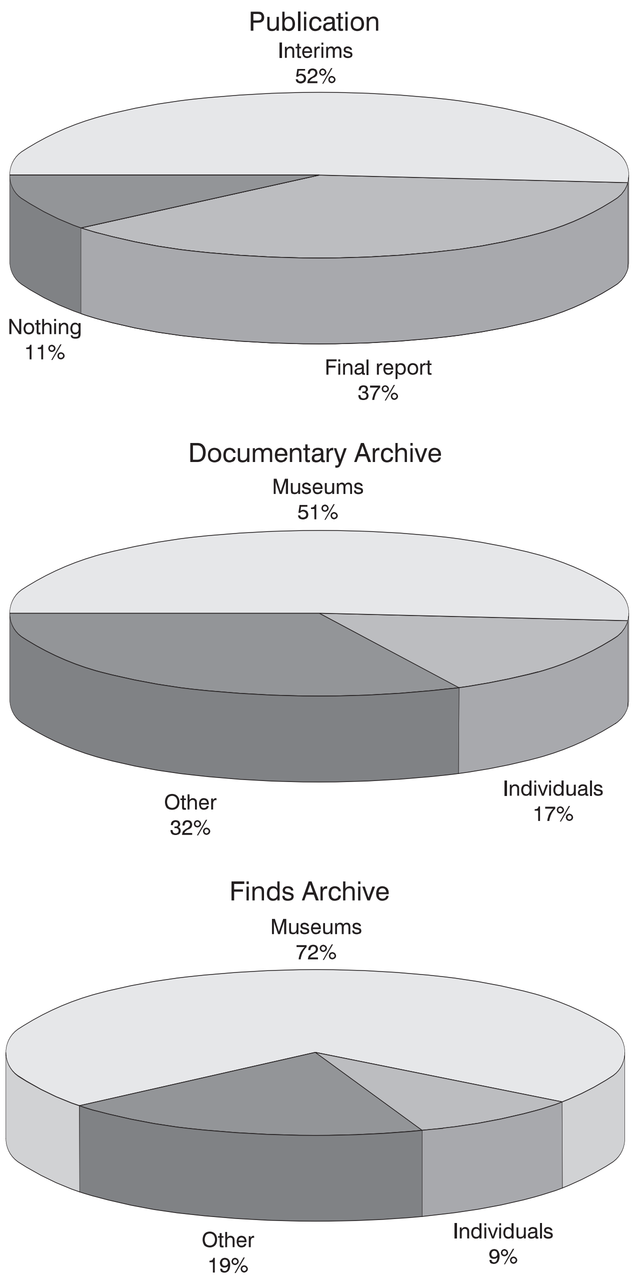

Figure 2. Publication and Archive Locations for Excavations undertaken in England between 1940 and 1980 (as of March 1994).

4 Access to Information on Excavations and Archives

The great diversity of organisations undertaking archaeological work, the range of publications and archive locations, combined with the increase in small-scale evaluations published in limited circulation copy, make access to primary data very difficult for researchers. I think there can be no doubt that archaeological collections can be an under-utilised resource.

In 1991 the Society of Museum Archaeologists undertook a survey covering access to museum archaeological collections in Britain. The survey found that requests to view collections were disappointingly small. 12% of museums, mostly those with very small archaeological collections, had received no requests to view the collections over the previous 12 months. Just over half (53%) received up to 10 requests a year. Only 3 museums received over 100 enquiries a year — and this figure may have been doubtful because some museums did not distinguish between archaeological and non-archaeological enquiries.

Overall a picture emerged of few individual requests to view collections, which were most likely to be restricted to specialist researchers (Merriman 1993).

Several years have passed since the SMA survey was undertaken and hopefully a similar survey undertaken today would show that the position has improved considerably. However there can be little doubt that locating material and gaining access to it can still be difficult and that computerisation of finding aids for archaeological finds and documentary archives has great potential for improving this situation.

The ability to identify collections of excavated material by period or site type is a valuable tool for regional or national research. MONARCH will not give detailed finds lists, but can provide a high-level index to what is in which museum or other repository. For example The Medieval Ceramics Studies Group requested a printout giving details of repositories and publications for several thousand excavated medieval sites in England as part of the Survey of Medieval Ceramics Studies in England, the results of which have recently been published (Mellor 1994).

An example of the difficulty of locating material recently appeared in the newsletter of the Prehistoric Society concerning the archives of Benjamin Harrison (Cook/Jacobi 1994). Harrison, who was born in 1837 and died in 1923, was a collector and recorder of archaeological finds of all periods in the county of Kent in Southeast England. In 1890 he excavated a site at Oldbury, which is still Britain's only significant open-air site of the Middle Palaeolithic. He donated the finds from this site to the British Museum. Recent research on this collection has highlighted the necessity of locating any of Harrison's surviving records and British Museum staff appealed for information through the newsletter of the Prehistoric Society.

A search of the archive records in the RCHME's database identified records from Harrison in several different institutions in Southern England, including the Pitt Rivers Museum in Oxford, Maidstone Museum, Croydon Natural History and Scientific Museum, the Guildhall

Museum in Rochester, the Tunbridge Wells Museum and Art Gallery, and the Surrey Archaeological Society collections at Guildford. Computerisation has allowed our information on the location and nature of Harrison's archives to be extracted quickly and this information has now been passed to staff at the British Museum and a brief note published in PAST (Sargent 1995).

Benjamin Harrison's archive demonstrates how widely dispersed records of any one individual or site can become and our own systematic surveys of excavations and other archaeological archives show how this pattern can be repeated for most sites of regional or national significance in England.

It also demonstrates some of the current problems with access to information, particularly for those involved in cultural resource management working within the time constraints imposed by developers or the planning system. For many the option of writing to a newsletter editor or any traditional form of gathering primary information is just too slow.

In many cases I suspect computerisation and online access to museums, regional and national databases is the only means by which this data will become widely available and used. I would expect online access to the RCHME's information on monuments, archives and excavations and to similar resources such as the British Archaeological Bibliography or regional databases to provide a significant increase in the use of such resources.

5 Trends in Archaeological Fieldwork

The growth of developer funded work in recent years and changes in planning guidance, particularly the introduction of PPG 16, have led to increasing discussion on research frameworks and research to monitor new trends in archaeological fieldwork. In England research has been commissioned into the growth and effectiveness of archaeological assessments (English Heritage forthcoming), and funding bodies are beginning to compile database information on projects and research objectives to monitor achievements against policy objectives and improve strategic planning (an example of this is the Management Information System being developed by the Archaeology Division of English Heritage).

The structure of MONARCH and our database information on events and archives as well as monuments are beginning to allow us to examine some of these trends in archaeological fieldwork.

Research 'fashions' in Bronze Age studies and their impact on our knowledge of the period were examined in 1992 in an article in Antiquity by Michael Morris based substantially on analysis from the excavations data in MONARCH (Morris 1992).

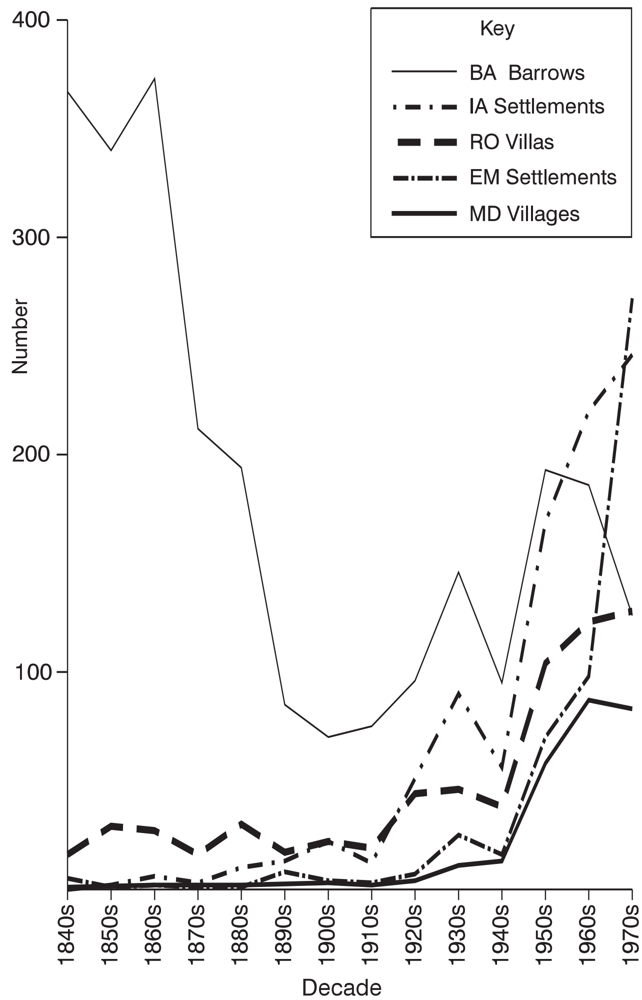

Figure 3. Number of Excavations for Specific Site Types by Decade between 1840 and 1980.

It is possible to examine trends for any period, site or intervention type utilising data in MONARCH. Figure 3 shows excavation trends in England from the early 1840s for specific monuments types and periods, namely Bronze Age barrows, Iron Age settlements, Roman villas, Anglo-Saxon and other Early Medieval settlements, and Medieval villages.

Comparison with figure 1 shows how these partly reflect broader national trends in excavation, particularly the growth in excavations between the wars and the exponential increase from the end of World War II through the 1970s. However, there are some significant differences. The most marked of these is the very different trend in the excavation of Bronze Age barrows, with sharp falls in the number of excavations undertaken in the late nineteenth century and again in the 1960s and 1970s. This reflects the late nineteenth century trend away from barrow digging; the development of a more systematic and therefore more intensive approach to excavation of individual barrows; and the government sponsored programme of barrow excavation in response to destruction by agriculture in the 1950s and early 1960s, which was subsequently curtailed. The post World War II intensification of research on Iron Age, Early Medieval and Medieval sites is also apparent. The excavation of Early Medieval settlements and Medieval villages reflects other aspects of data retrieval from MONARCH and research trends, as the term settlements covers both rural and urban site types which have been excavated whilst the term villages does not. The trend line for the excavation of Early Medieval settlements therefore includes the large number of excavations started in the 1960s on historic urban centres such as York, Southampton and Winchester.

6 Conclusion

In conclusion I hope I have demonstrated to you the value of computerised data at a national level on excavations and archaeological archives, and of database structures which can link this information to monuments but which also allows them to be analysed as discrete datasets.
I have concentrated on MONARCH, England's national database and examples from archaeology in England but hope that you will also find that these examples have relevance elsewhere and for local or regional databases as well as databases at national level.

7 Access to the NMR

The MONARCH database on which this article is based can be consulted by contacting NMR Customer Services, National Monuments Record Centre, Kemble Drive, Swindon SN2 2GZ (Telephone 44 (0)1793 414600 or Fax 44 (0)1793 414606)

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The MARS Project – an interface with England's past

1 Introduction

The full title of the MARS Project is the Monuments at Risk Survey. This project is funded by English Heritage, the national body responsible for archaeology in England. In response to a number of studies carried out during the 1980s which underlined the need for quantified, nationwide information (Darvill 1987; English Heritage 1991; IAM 1984; RCHME 1993), this three-year project was commissioned to undertake a large-scale, but rapid, survey of the condition and potential of England's archaeological resource. The purpose is to establish a baseline for the future. The results may stimulate work on national and regional scales to identify further the threats to England's archaeology, and to develop cultural resource management techniques. MARS is not an attempt to identify particular monuments under extreme threats, nor is it an attempt to identify particular areas under special risk. MARS is attempting to understand the national picture, the range of threats, the impact on groups of monument classes; for example, what proportion of upland sites are threatened by changes in agricultural activity; and whether prehistoric sites are being greatly affected by urban growth.

The history of MARS dates back to a pilot study, also funded by English Heritage, undertaken in the county of Wiltshire during 1989-90, in which methods of data collection and techniques of data analysis were tested. The project designs of both the pilot study and MARS have been open to consultation by professional archaeologists, and a considerable period of review and discussion was allowed between the presentation of the results of the pilot study and the commencement of MARS (Darvill 1991).

One aim of MARS is to provide information about the state and potential of England's archaeological resource. This includes identifying the scale and nature of the resource; the range of methods of recording archaeology, and the levels of recording for single monuments, archaeologically defined landscapes, and historic urban areas. This kind of information is not routinely gathered on a national scale, the last attempt was in 1984 (IAM 1984), but it is essential in order to develop any strategy for the future management of sites and monuments on a national scale. The simple questions MARS is aiming to answer include identifying how many monuments are recorded in England, and which periods they are from. Some of the problems relating to the concept of a national database for England are discussed by Fraser (Fraser 1993).

MARS has three main research and data collection areas. The most labour intensive is the combined efforts of field survey and aerial photographic teams which are examining the current and previous condition of the recorded sites and monuments within a 5% random sample of the land area of England. This is an area of 6500 km^2 which is thought to contain around 20,000 known archaeological sites. A 5% sample was chosen after analysis of the results of the Wiltshire-based pilot study (Darvill 1991: 123-126). A 5% sample is needed to obtain a sufficient number of sites with information from aerial photographs from the last 50 years. The efforts of the aerial photographic team are concentrated on the last 50 years because the aerial photographs from before the 1940s are not widespread enough to give a coherent picture of change to the archaeological resource. These two strands are supported by a survey of the recorded resource, generating data to support the sampled part; and by case study research into the effects of monument and landscape type on the value of data retrieved by archaeological methods. This section is best described as a national survey of sites and monuments records.

Enough has been suggested above to indicate that MARS is utilising the computerised resources of many bodies; the individual county, district, borough, and city sites and monuments records (SMRs), and the resources of the Royal Commission on the Historical Monuments of England (RCHME). MARS makes extensive use of computers for the manipulation, analysis, and the recording of data. All of the MARS computers run Windows for Workgroups as the operating system. The data generated by each part of MARS is stored in a Paradox for Windows database. The relational nature of Paradox is essential to allow recording of information from different SMRs in the same database. The information about sites is held in a variety of ways by the various SMR databases. The data from SMRs is organised to a standardised Paradox format so that the field surveyors can enter data directly into laptop computers, saving time and rewriting. Being part of a university has advantages and disadvantages: large discounts are available for some types of hardware and software, but there are some restrictions as to the packages we may use, and in-house technical support is not necessary targeted towards areas which concern the project.

2 The National Survey: an 'audit' of the recorded resource

The National Survey is attempting to understand the development of England's recorded resource. The first public records were those of local societies and museum indexes. However, the most important as a national record was the data systematically collected by the Ordnance Survey after 1948. The Ordnance Survey material later formed the backbone of many of the SMRs in England. The report of the Walsh Committee recommended that 'A consolidated record of all known field monuments should be held by the County Planning Authorities so that they may be aware of all such monuments in their areas.' (Walsh 1969: § 7). As a result of this report registers and records have been developed since the 1970s on a local scale by counties, districts, boroughs and cities to index archaeology (Burrow 1985). Fifty-six were identified in 1994 as being the current holders of definitive records for specific areas; whilst it was recognised that some museums and private bodies hold extensive archaeological indexes these have been excluded, largely because the information they contain is included within the local authority managed systems. A pro-forma questionnaire was developed to 'audit' the contents of these public records. The first question is to ask how many records are held by each organization. MARS acknowledges that records are generated in a variety of forms which do not necessarily reflect archaeological sites and monuments as such; the majority of records are in the form of information relating to land parcels, archaeological events, and archaeological entities, this does not affect the gross counting of records (see Fraser 1993 for further discussion). This is perhaps the most useful measure of how much change has occurred within the record since 1984 (IAM 1984). In 1984 an average of 2.32 per km^2 was recorded, by the end of March 1995 MARS had identified that this density had risen to around 5.20 per km^2, although not all results had been processed. The number of records may have almost doubled, but has the quality of the records changed? The National Survey is also studying the monuments sampled for the field survey in an attempt to understand the kinds of changes which have occurred within the records held in SMRs and whether measures to control quality are evident within these individual records.

Whilst the form of the record may vary, the information held may be of several types. MARS is asking questions about major types of record; monuments, archaeological landscapes, archaeological urban areas, stray finds, and miscellaneous records. Currently there is a ratio of two records referring to monuments to one record of another type. In the future this may change, perhaps towards more archaeologically-defined landscapes which combine monument records; or towards record systems which combine archaeological and environmental data. There are some issues of consistency to be raised when discussing record types because data-standards are always subject to some interpretation by the individual compiling the record or curating the systems. The ratio of monuments to other records, and sub-groups of buildings records, and the numbers of records per period are being used as a comparison to the information retrieved for the field survey and aerial photographic work. These data-fields appear to be fundamental to all systems, and if not completed consistently between systems, are at least completed on most. There is a wide degree of variation for information on more complex issues, for example condition and survival appear to be recorded solely for monuments which have been examined as part of the Monuments Protection Programme (MPP) of English Heritage in many counties, although there are rare exceptions which can generate data for most, if not all, of their recorded monuments. The MPP is the overhaul of the list of scheduled monuments throughout England and it includes the collation of information on the condition of these monuments of national importance so that the resource requirements for future preservation, and the priorities for action can be assessed (Darvill *et al.* 1987).

3 Field Survey: the challenge of the data

England supports 56 SMRs, all using slightly different computerised systems, all interpreting data standards to suit their individual needs. All 46 counties now have SMR databases, the remaining 10 included in the MARS survey are district, borough or city records. This is not a static position, and new databases, particularly those for urban areas are continually being developed in England. Funding for SMR activities comes from a number of sources, the majority currently being funded by the local authorities and supported by English Heritage and RCHME for particular enhancement projects or activities. It is expected that this situation will change as the effects of local government review are felt in England (see also Fraser 1993). Information from the SMRs is exchanged with RCHME who curate the National Archaeological Record (NAR), but because of the diverse methods of record accumulation, the information held by the RCHME is now simply an index to more widely held information. One of the most challenging problems MARS has faced is the extraction of data from

SMRs. One county record is still based on record cards with supporting maps and bibliographic materials, several others are semi-computerised, the computer acting as an index to cards or other materials. One mainframe computer still figures in the curation of archaeological records; while the remainder use a diverse range of software and hardware configurations (table 1 lists the software systems identified). The provision of information about the archaeological remains recorded in the sample for the field survey thus varies from photocopies of handwritten cards, to computer print-outs, to partial and full data sets. The format of information supplied on disk file varied from ASCII text to various database file formats. Thankfully, the dBASE file format has become an accepted standard, easing data transfer between database packages. All of these data sets have to be manipulated to fit into the Paradox database developed for MARS. This has involved hand-typing, some optical character recognition scanning, and the writing of bespoke programs to manipulate data. Supplementary information, for example the location of sites known from aerial photographic evidence, has been gathered from the SMRs by MARS staff. A lot of knowledge is in the form of 'wetware', stored in the heads of SMR officers. This is a very volatile form of storage because people leave jobs, retire, or forget things. It is, however, very important for connecting the basic information held on computer with the written sources and other indexed material that all SMRs hold in addition to their basic list of sites and monuments.

Table 1. Frequency of software programs used for SMR databases in England.

Database system	Frequency of use
Superfile	18
(Paper index)	6
	(1 county and 5 districts)
Oracle (various versions)	6
dBASE IV	4
dBASE III+	4
File Tab	2
FoxPro (2 versions)	2
Monarch	2
PI Open	2
Other software (one each of 13 systems)	13

MARS has learned by experience a lesson it had hoped to avoid, that SMRs can be difficult to use as analytical tools. Currently they are collections of sometimes ambiguous data, which is of varying quality, almost all of which is forced into flat file structures which are not suitable for storing information about archaeological sites and monuments. However, it is complex questions that professional archaeologists, researchers, students and other individuals want answered. We are eager to know how many sites exist in certain types of landscape, and estimates of their condition. These questions were first posed in the 1980s (Burrow 1985: 10), but in many cases we are no closer to having answers. The answers may still be compiled through accumulation of data and site visits, but not yet at the touch of a few buttons. MARS will begin to show the national trends, but local research will be needed to identify sites most in need.

4 Field Survey: methods and results

Field survey teams record measurements and descriptions of the recorded sites as they appear in the field today. In total some 26 key variables are being recorded for each site. These range from monument form and class, through to assessments of survival and decay and perceived threats to monument condition. Each team is provided with summary information about each site from the SMR sources in a database file on a laptop computer, together with printed reports and SMR 1:10,000 map information. Data generated in the field is directly input into the computer system, except during bad weather when laminated paper is used instead. The technological challenge of MARS is to reassemble this information into a central database where it can be related to the information recorded by the aerial photographic team. Computer training has played an important element in MARS, even people with previous experience need time and support to learn and understand new systems.

Results from one of the first areas to be surveyed may be used to illustrate some of the questions which MARS is studying. The Isle of Wight is a small county, 380 km^2 in area, four sample transects were located on the island, and they contained 166 monuments. When the land type is identified it can be seen that the majority of monuments are on land classified as either agricultural buildings or as field crops. When classified by form, it can be seen that the majority of the monuments are standing buildings (fig. 1). This accords with the analysis of the SMR by the National Survey which identified that almost 80% of the monuments recorded within the SMR were buildings, that is, over 65% of the entire SMR. Major impact on the monuments is either widespread or localized, that is all over a monument, or only on a part of a monument. Little peripheral impact, that is around the edges or in the neighbourhood of a monument which may present a long-term threat, is recorded for sites on the Isle of Wight. Only 1% of sites are without any impact at all (fig. 2). The major causes of damage are agriculture and building alterations, (not surprising as most of the sites are buildings) (fig. 3). The significance of the data from the Isle of Wight will

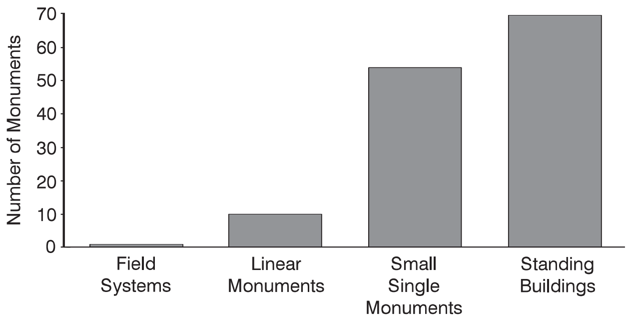

Figure 1. Isle of Wight - breakdown of monuments by form.

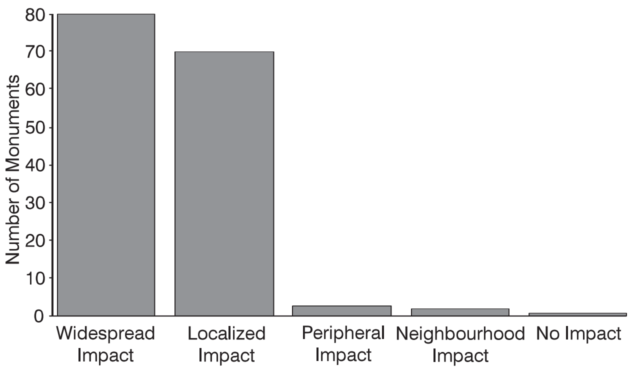

Figure 2. Isle of Wight - breakdown of monuments by impact.

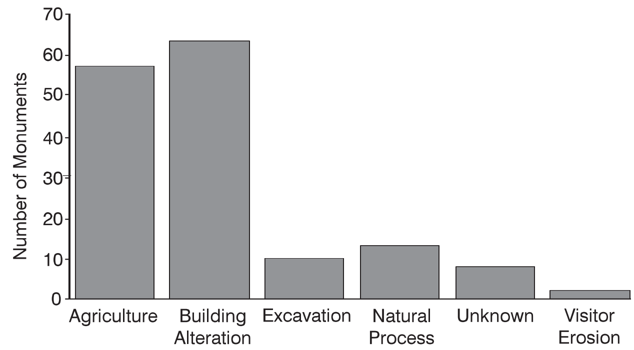

Figure 3. Isle of Wight - breakdown of monuments by cause of impact.

only become apparent when it is analysed with data from other counties on a regional level, and with England as a whole.

5 The future of MARS

The project is aiming to complete data collection during 1995, after which will come a period of intense validation and analysis. The results of MARS will be made available during 1997, and it is hoped that a variety of publications will result, aiming to communicate these results to both professional archaeologists, and others in related disciplines, as well as to students and anyone with an interest in the future of archaeology in England.

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Archaeometry

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Detecting Unusual Multivariate Data: An Archaeometric Example

1 Introduction

There has been much recent interest in the statistical literature concerning the detection of outliers and other unusual cases in multivariate data. This has arisen, in part, because developments in computing power have made possible the application of methodology that is iterative and computer-intensive in nature.

Methods of chemical analysis, such as inductively coupled plasma spectroscopy, increasingly generate large multivariate data sets, of artefact compositions for example, that are subjected to 'standard' methods of statistical analysis such as cluster analysis, principal component analysis (PCA) or discriminant analysis (Baxter 1994).

The performance of these analyses can be affected by unusual cases, such as outliers, in the data. It is good practice to screen the data in advance of applying such methods in order to identify cases that may affect their performance. How cases that are unusual are treated will depend on the context of a study, but it is often sensible to remove unusual cases from subsequent analyses, in order to study the structure in the bulk of the remaining data.

The present paper has arisen as part of a wider programme of study looking at approaches to the statistical analysis of large archaeometric data sets. Here we look selectively at a number of approaches for identifying unusual cases in such data sets, with a view to raising questions about aspects of some of the methodologies that are available.

The data used are the chemical compositions of 250 specimens of glass found in a single post-Roman context in excavations at Winchester. Most of the glass is window glass, mainly light blue-green in colour but including other more distinctive pieces representative of other colours in the assemblage of several thousand specimens. Some samples that were possibly vessel glass were also selected for comparative purposes. For the purpose of this paper the major and minor oxides only, based on the elements Al, Ca, Fe, K, Mg, Mn, Na, P and Ti, will be used. It was postulated, in advance of chemical analysis, that most of the glass would be reasonably homogeneous with respect to such oxides. We have also looked statistically at analyses based on nine trace elements, and on the full set of eighteen variables, and will refer in passing to some of the results of these analyses.

The glass had not previously been analysed statistically and, as part of an experiment, was studied typologically independently of the statistical analysis. The aim was to see whether unusual cases detected statistically were also typologically unusual, without the interpretation of the statistical analysis being affected by a knowledge of the typology.

In the next section a brief review of some approaches to detecting unusual multivariate data is given. We have not attempted a comprehensive review, and refer the reader to the original publications and references given there for technical details. The application of some of the methodologies to the data set described above, and its relationship to the typological analysis, is then discussed.

The concluding discussion, rather than attempting to reach definitive conclusions about the structure of this particular data set, is more concerned to raise issues about how unusual data should be identified and handled. We wonder to what extent fairly 'simple' approaches will often suffice for practical purposes. This is not a question that can be answered without more practical experience of the methodologies discussed here, and others that 'compete' with them.

2 Detecting unusual data

Approaches to detecting unusual multivariate data include the following.

1. Univariate and bivariate data inspection.
2. Inspection of the first and last few principal components from a principal component analysis (PCA) (e.g. Hawkins/Fatti 1984).
3. Influence analyses to identify those cases that have the greatest effect on some specific technique such as PCA (e.g. Brooks 1994).
4. Cluster analysis.
5. The use of Mahalanobis distance, d_j, for the j'th case, where the square of d_j is given by

$$(x_j - \bar{x})^T S^{-1} (x_j - \bar{x})$$

and $\bar{x}$ and S are the multivariate mean and covariance matrix of the $n \times p$ data matrix X of which $\mathbf{x_j}$ is the j'th row. Large values of d_j are intended to identify points remote from the bulk of the data.

Many other statistics have been proposed for detecting unusual data, but Mahalanobis distance, or variants of it, has received the most attention in practice. Its major disadvantage is that $\bar{x}$ and S are themselves affected by unusual observations so that d_j is affected by the cases it is designed to detect, and may fail to do so. Principal component analyses, which are based on an eigen-analysis of S, possibly after standardising the data, suffers from a similar problem.

This has led to a variety of proposals for robust analyses in which estimates of $\bar{x}$ and S are determined, usually iteratively, that are unaffected by outliers. There are two broad ways in which this can be done, either by defining weighting schemes that downweight extreme cases, or by identifying a subset of data uncontaminated by extremes and basing calculations on this. This last idea forms the basis of the paper by Atkinson and Mulira (1993), whose approach is used here. The Atkinson/Mulira approach is similar in spirit to other approaches that have been proposed while being simpler and more practical. It is aimed at the detection of multivariate outliers, rather than directly at the robust estimation of S. Other approaches, not discussed here, aim to estimate S robustly, and then use the estimate in a principal component analysis to detect outliers, for example. The basic idea is as follows.

1. Select p + 1 observations and calculate $\bar{x}$ and S using these.
2. Calculate d_j, increment the sample size by some small integer k, and select a new sample to consist of those cases with the smallest values of d_j.
3. Use the new sample to recalculate $\bar{x}$ and S and then repeat stage 2, selecting $(p + 1 + sk)$ cases at stage s, until the data set is exhausted.
4. Identify and display results for a suitable choice of s.

Reference can be made to Atkinson and Mulira (1993) for a discussion of methods of displaying the results. Here we shall use an index plot of d_j, where calculations for S are based on about 80% of the data. The results we give are not sensitive to variation about this value of 80%, and were virtually the same for several different choices of initial sample, including one specifically designed to include the most obvious outliers. Atkinson and Mulira (1993) suggest statistical guidelines for identifying outliers that assume that the sample from which S is calculated is multivariate normal. As shall be seen this turns out to be far from the case with our data, and we have interpreted the plots subjectively.

3 Analysis

Using the 250 × 9 data set described in the introduction, box-and-whisker plots and dot-plots were used to identify 'obvious' univariate outliers. Let H denote the inter-quartile range; then such outliers were defined to be points more than 3H from the upper or lower quartiles and visibly separate from the rest of the data. This last criterion was imposed to avoid identifying as outliers points in the tail of a long-tailed distribution. According to this definition the following points clearly stand out.

1. (87, 127, 179, 232) with high Ca and Ti;
2. (18, 31, 93, 118) with high Fe;
3. 98 with high Mn and Ti;
4. (141, 234) with low Ca.
5. Additionally it was noted that 20 cases, of which (225, 242) were most prominent, lay in the tails of Mg, K and P, which all had long tailed distributions. These were not designated as outliers but form a distinct cluster of points. The question of whether or not the data should have been transformed prior to analysis is raised by this observation, and we return to it in the final section.

Figure 1 shows two index plots of d_j, the upper plot using S calculated from all the data, and the lower plot using the (hopefully) uncontaminated 80% of the data determined by the Atkinson/Mulira procedure. The lower plot quite clearly suggests 9 cases as unusual and these correspond to the first 9 cases identified by univariate inspection above. The upper plot, which is affected by the unusual data is less clear cut and less easy to interpret.
Note that values of d_j for the unusual cases are much more extreme in the lower diagram.

A plot of the 4'th and 5'th principal components of standardised data also clearly identified the same 9 cases as unusual. An average-link cluster analysis of standardised data with Euclidean distance as the measure of dis-similarity, shown in figure 2, if 'cut' at about 6, separates out the 11 points noted in 1 to 4 above from the rest. If cut at 5 the majority of the cases noted in 5 above are also separated out.

The 9 'obvious' unusual points were removed from the data set and analyses repeated. Cases 141 and 234 then stood out, particularly on the second principal component, and were also removed.

Figure 3 shows the principal component analysis plot for the first two components, undertaken after this removal, and suggests some clustering of the data, with 242 as possibly unusual. The cases in the cluster to the lower right of the plot all belong to the group noted in 5 above.

In summary the Atkinson/Mulira approach, tailored to the identification of multivariate outliers, identifies much the same points as a simple univariate analysis or a cluster

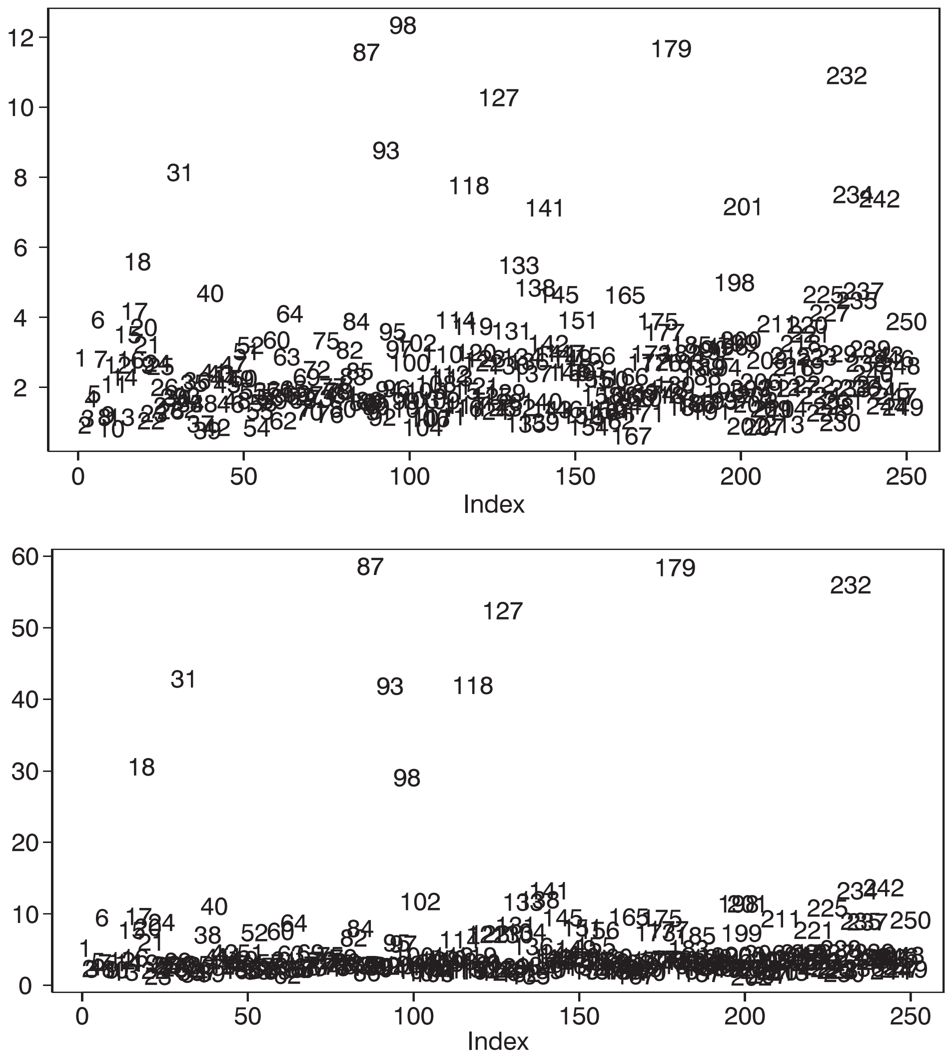

Figure 1. Index plots of Mahalanobis distance for the oxide data with calculations based on all the data (upper figure) and 80% of the data identified by the Atkinson/Mulira procedure. Points are labelled by their index for convenience of identifications.

analysis for these data. Additionally, the apparent clustering in figure 3 suggests that there is not a single homogeneous group against which other specimens can be judged to be 'unusual'. This raises a number of issues about the utility of the multivariate methodology to which we will return after briefly noting the relationship of the statistical analysis to the typological analysis.

4 Typological analysis

The statistical and typological analyses were initially carried out independently of each other. This is not recommended as a general practice but, in the present case, it was of interest to see whether or not the two approaches produced compatible results.

Three of the first group noted previously, (87, 127, 179), are Roman vessel or bottle glass while 232 is heat-affected so a clear identification is not possible. That is three, if not all four, of these cases are typological outliers, compared to the bulk of light blue-green post-Roman window glass.

The same is true of 98, which is an unusual specimen of vessel glass, possibly of Mediterranean origin. The other group of four, (18, 31, 93, 118), is also highly distinctive in terms of colouring (emerald) and stands out from all other specimens.

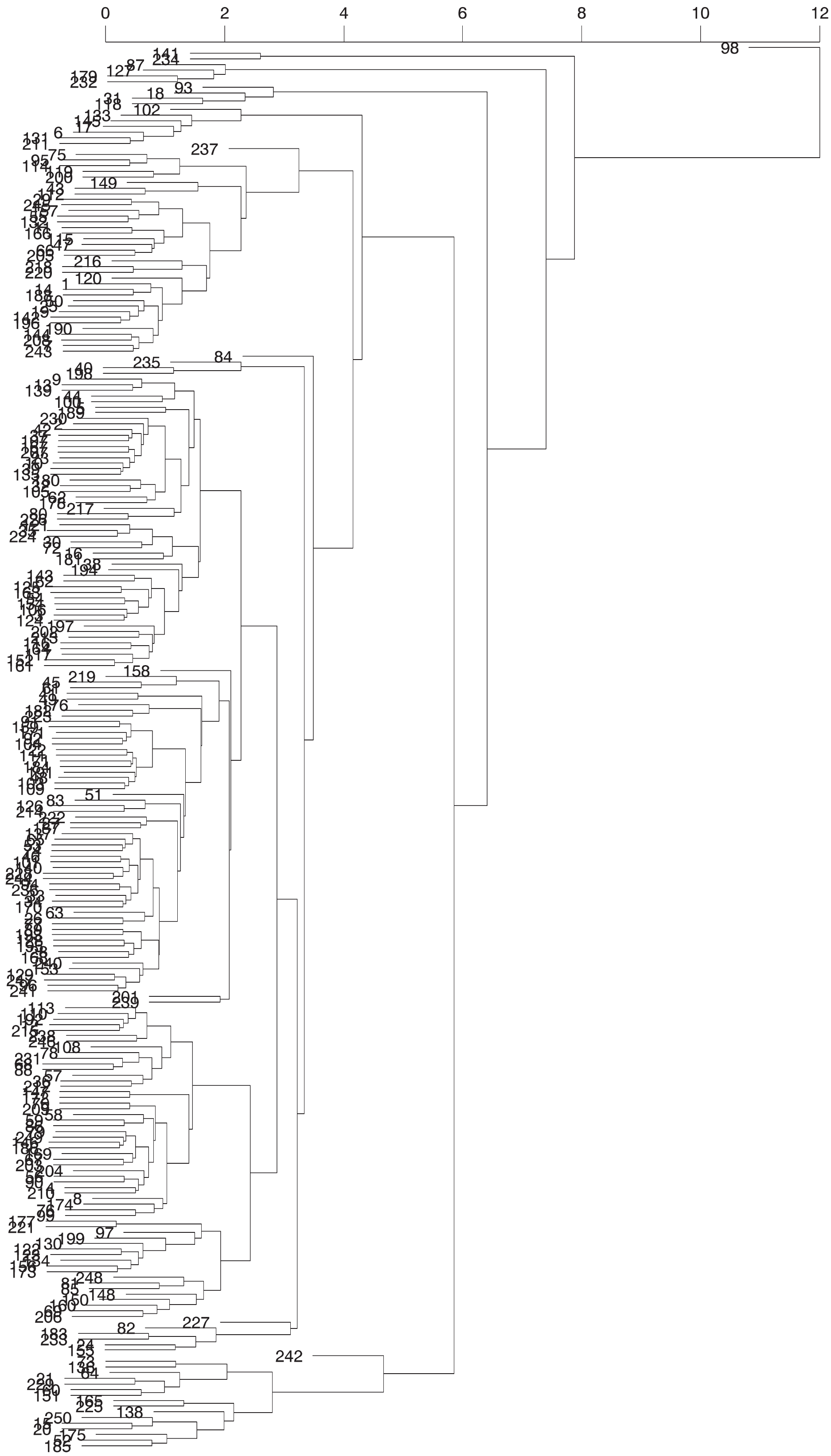

Figure 2. Average link cluster analysis of oxide data.

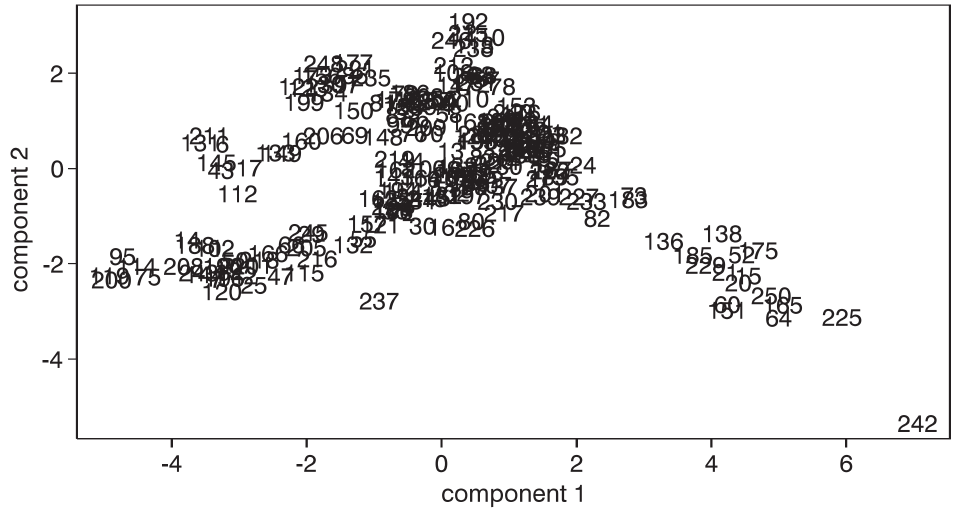

Figure 3. Principal component plot of the first two components using standardised data, after removal of the 11 clearest outliers identified in the text.

Cases (141, 234) were not originally singled out as typologically distinct. On re-inspection they are clearly window glass but the colouring, pale lime-green, is quite unusual.

The 20 or so specimens with high Mg, K and P, which were noted in the univariate and PCA analyses were also not identified as distinctive on a first examination. On re-inspection it appeared that they were mostly more ‘bubbly’ than other specimens, and this may reflect the interaction between composition and aspects of furnace technology connected with the speed at which the glass was heated.

The typological analysis also identified other cases that were either atypical (because they were Roman and/or non-window glass), or which formed small, distinctively coloured, sub-sets of the sample. Though not identified by an analysis of the major/minor oxides the majority of such cases were identified by a similar analysis of the trace elements.

5 Discussion

The work reported here is part of a broader programme that is examining approaches to the analysis of large archaeometric data sets. Only one data set has been discussed and any conclusions drawn from this can only be suggestive. What follows draws on this, and work as yet unreported. It is intended to suggest areas of study which would benefit from further research, and general guidelines that may help in the analysis of large and complex data sets.

1. The statistical analyses reported, and those conducted on the trace elements, have done rather well in identifying typologically unusual cases. It is also the case that most of the unusual data was identified using the simple univariate approaches, or ‘standard’ approaches such as PCA.

   Identification of unusual multivariate data is a technically challenging problem. The simpler techniques identify the really obvious univariate and bivariate outliers, and it may be sensible to omit these from the data before attempting to identify genuine multivariate outliers. In the present example the simpler methods are all that is needed.
2. Cluster analysis can be bad at identifying clusters in archaeometric data, in the sense that the results are often method-dependent. It may, however, be quite good at suggesting outliers. It uses information on all pairs of distances between cases, rather than the distance of a case from the centroid of a sample of data so perhaps this is not surprising.

   In the version of this paper presented at the CAA95 conference it was suggested that cluster analysis, though not as ‘exciting’ as the development of new methodology, could be more widely used for the detection of multivariate outliers. Some discussants noted that, in their experience, it was widely used for this purpose but rarely reported. Commonly, cluster analysis is used to detect clusters, and any outliers detected in the process are noted *en passant*. If cluster analysis is indeed used directly, and often, for multivariate outlier detection its wider reporting would be welcome. We have seen references to the use of single-link, complete-link and average-link cluster analysis as suitable for outlier detection, but know of no systematic study comparing their merits. In particular a comparison with some of the newer methodology that is being proposed would be of interest.

3. The Atkinson/Mulira approach is easy to apply but, like other approaches based on Mahalanobis distance, assumes that a majority of the data form a coherent reference group against which the 'unusual' nature of other data may be judged. Ideally this reference group will have a multivariate normal distribution.
   Identifying the reference group, which may then be used as a basis for robust analyses, is an aim in some of the literature. A theoretical ideal in some cases is that methodologies should be able to deal with up to 50% (almost) of cases that are outlying or unusual with respect to the reference group. In practice, outside of the context of simulated data, the idea of 50% of data being 'unusual' does not seem very realistic, and 20% or so may be a more reasonable limit. Leese and Main (1994), suggest a similar limit in their paper on the detection of outliers using probability plotting methods. They deal with the problem of detecting outliers relative to a known reference group, and such known grouping is not assumed in this paper.
   The presence of grouping, unknown in advance of analysis, is a problem in the application of the Atkinson/Mulira and similar approaches, as suggested by figure 3. Real data are frequently clustered, rather than the bulk forming a coherent group. As a hypothetical example, if we had three equal sized, equally dispersed, and equidistant groups of data in multivariate space there is not a natural reference group against which unusual data may be judged. The outcome of the application of the Atkinson/Mulira method in this case is dependent on the initial choice of cases from which Mahalanobis distance is calculated. One possible way round this difficulty might be to identify any distinct groups in the data, in the first instance, and then identify those cases which are outlying relative to all the groups so identified. This is not a trivial task and also raises the question of sample sizes.
4. The issue of sample size has not been mentioned so far, but is a non-trivial one. Even in ideal circumstances (i.e. a single multivariate-normally distributed set of data) the ratio n/p should be in the region of 3-5 or more for techniques of the kind discussed here to 'work'. (Recommendations vary according to context.)
   Analytical techniques now available will often produce data sets with $p > 20$, and obtaining samples with large n may be costly. If the samples that are obtained have a clustered structure, and so need to be broken down into smaller sub-samples in order to apply methods for multivariate outlier detection, this will exacerbate the problem.
5. The important issues of variable selection and data transformation have been ignored for the purposes of this paper. We have, in fact, looked at the analysis of different variable subsets and logarithmic transformation of the data and found that they give rise to different results in terms of the unusual cases identified. In general none of these results are 'wrong'; it is simply that, depending on the data treatment, different 'unusual' cases are being identified. For example, analysis of the trace elements identifies small and highly coloured groups rich in Cu and Ni, that are not distinctive with respect to the major and minor oxides. Whether such specimens are to be regarded as unusual will depend on the objectives of the research; those cases just noted are unusual in terms of their appearance but not in terms of their major/minor oxide composition.

We offer one further thought here. Data transformation, to normality, is often advocated as desirable without discussion. For some of our analyses this would down-weight the visual impact of specimens in the tail of a distribution, since if the transformation is successful then the specimens will lie in the tail of a normal distribution, and not be worthy of note. However, such specimens may be of distinct archaeological interest (e.g. the 'bubbly' group noted earlier) but may be less evident in analyses where the data have been transformed. The 'bubbly' group is much more evident on a PCA of the untransformed data than on one where the data are log-transformed, for example, but this is another story.

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Extraction and visualisation of information from ground penetrating radar surveys

1 Introduction

The analysis of ground penetrating radar (GPR) data is, for a variety of reasons, an imprecise and time consuming activity. Manual evaluation of the data involves a high level of experience and takes an inordinate amount of time. It often requires that subjective decisions be made by the analyst, and this leads to the introduction of bias (both systematic and non-systematic) into the final results.

Computer analysis of GPR data has, until now, tended to focus either on the use of complex signal processing algorithms in an attempt to remove all sources of distortion from the image (Daniels *et al*. 1988: 298-303), or on simple image enhancement techniques to make the image easier for the analyst to understand (Blake 1995; Daniels *et al*. 1988: 297-298). The former approach, whilst effective in simple scenarios, tends to fall down on more complex sites, whilst the latter fails to remove the subjectivity from the process.

The objective of this paper is to outline and demonstrate an alternative, statistically based, approach to the extraction of information from GPR data. Such an approach requires some measure of the level of *radar activity* at each point of a radar image. Two possible solutions are discussed in this paper — *the sum of squared errors (SSE)* and the *k* measures.

The basic implementation of the technique yields a plan view of the site, which is useful as a first stage of interpretation. The drawback is that it contains no depth information, but a simple elaboration of the analysis allows rudimentary depth information to be extracted from the data in the form of horizontal 'slices' through the site.

In order to illustrate the practical application of the techniques outlined in this paper, two case studies are examined. They are based on survey work done at Worcester Cathedral and at a Bronze Age ring cairn at Stapeley Hill near Welshpool (Stratascan 1994).

2 Activity measure analysis

An analyst might manually examine radar data with the intention of picking out features of interest. The criteria which decide whether a feature is of interest may be very varied. Factors influencing the choice include contrast, coherency, size and shape of features. The interest/no interest decision is obviously a subjective one, hence the need for a high level of expertise, and any way of introducing objectivity into the process would therefore be of benefit in terms of reliability of results. A simple way of addressing this problem is the use of activity measures. Their function is to provide an objective, quantitive assessment of the degree of interest in a chosen region of the radar image. The criteria on which this value is based varies with the particular measure chosen. This paper discusses two of the simpler possibilities.

2.1 Activity measures

Two statistically based activity measures were developed for use with the technique.

The *sum of squared errors (SSE)* measure quantifies the degree of deviation away from the mean intensity of the image. It is given by

$$SSE = \sum_{i=1}^{n} (x_i - \bar{x})^2 \qquad (1)$$

where x_i is the intensity of the ith pixel, $\bar{x}$ is the mean pixel intensity and n is the number of pixels under consideration.

The k measure combines the SSE measure discussed above with second order information on the abruptness of change in the image. It is normalised between 0 and 1 and is given by

$$k = 4SSE/naC \qquad (2)$$

where n is the number of pixels under consideration, a is the sum of the pixel intensities and C (total change) is given by

$$C = \sum_{i=1}^{n-1} |x_i - x_{i+1}| \qquad (3)$$

2.2 Image preprocessing

Before analysis of the radar survey can take place certain preprocessing steps have to be taken. Firstly the images must be cropped to remove any scrap data caused by the antenna unit standing still at either end of the transect (fig. 1). Then the image is scanned to establish the positions of the

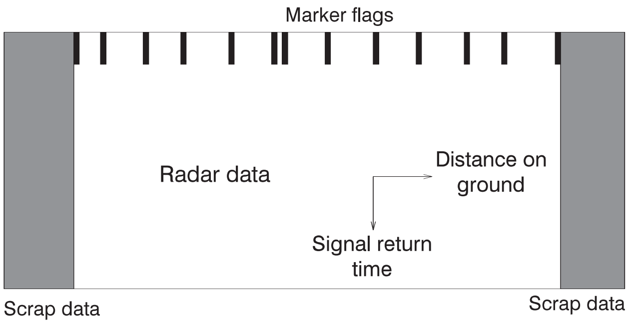

Figure 1. Features of a typical radar image.

ground distance marker flags. These correspond to intervals of one metre on the ground and are inserted manually by the antenna operator. Because the antenna unit is dragged at a non-constant rate (particularly on rough terrain), the markers in the image are generally unevenly spaced.
In order to allow an accurate plan of the survey to be constructed, these irregularities must be removed prior to processing. This is done using simple linear interpolation techniques to rescale all intervals to a standard, pre-determined width. Once the horizontal rectification process has been performed on all of the images, they will be of a standard horizontal scale, and the analysis can continue.

2.3 Activity profiling, mapping and visualisation

The objective of the analysis is to reduce each survey transect (a two-dimensional image) to a single string of values — *an activity profile*. Each value in what is now a one-dimensional string of data represents the level of activity below that point of the transect *for the full depth of the survey*. Activity values are calculated at predetermined intervals along the transects and once profiles have been generated for each transect, the data can be used to build a plan of the activity over the survey area.

The surveying in both of the case studies was carried out along orthogonal transects to produce grids of squares. Three approaches to visualising the activity of the survey area were tested. A problem arises here in deciding which of the two possible activity values at transect intersections to use. Differences in the measured activity values for differently oriented transects could arise for various reasons including calibration drift, asymmetries of the radar beam geometry and random effects caused by terrain and operator error. So far no work has been done to investigate these problems quantitatively. For the sake of simplicity the approach adopted in this paper was to use the higher of the two activity values.

The first method, *the activity grid*, represents each transects activity profile as a grey level strip arranged in a grid on a black background. An example of this technique is shown in figure 2a. Although useful as a preliminary visualisation tool, this approach proves unsatisfactory in one important respect; the use of linear grey level strips on a monotone background can sometimes deceive the eye into seeing spurious linear features in the data.

This potentially serious drawback is overcome by the use of a *simple activity map*, an example of which is given in figure 2b. Here the data is presented as a colour coded map (with the option of contours or pseudo-surface representation). To achieve this a second order surface is fitted to the square grid of points formed by the transect intersection points. The drawback of this approach is that it makes minimal use of the available information. The sampling rate along survey transects is extremely high, but this approach uses only a tiny fraction of the sampled points.

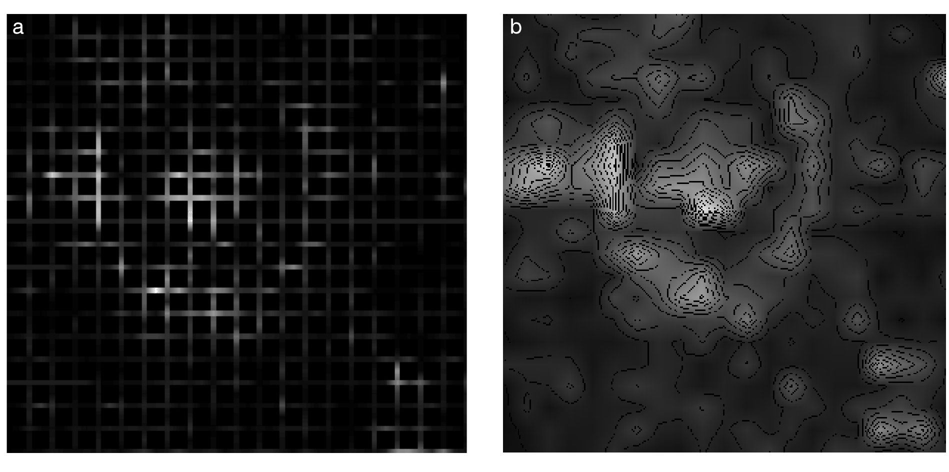

Figure 2. An activity grid and the corresponding simple activity map.

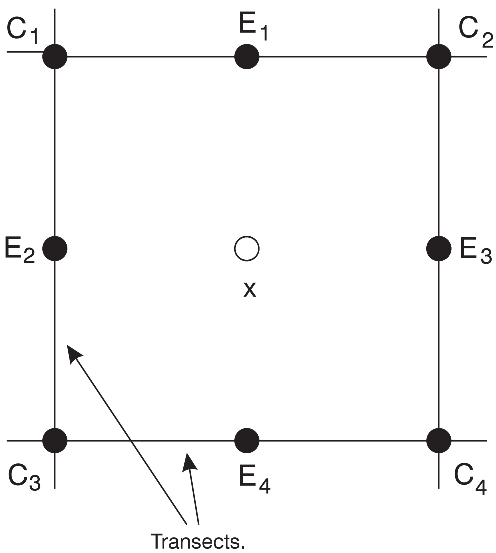

Figure 3. The scale-doubling interpolation algorithm.

The third and more sophisticated approach, *the interpolated activity map*, goes some way to addressing the problem of utilization of data. The interpolation is a two stage process. The basis for the first stage (which effectively doubles the scale) is shown in figure 3 and equation (4)

$$x = 0.5 \sum_{i=1}^{4} E_i - 0.25 \sum_{i=1}^{4} C_i \tag{4}$$

where x is the unknown value, C is the activity value at each transect intersection and E is the activity value midway between transect intersections. This interpolation step produces a square grid at twice the resolution to that used by the simple activity map. The second interpolation step is then identical to that in the previous technique, but produces a map on double the scale.

2.4 Case studies

The following two case studies are used to illustrate the potential of the new technique. For the sake of brevity only the *interpolated* results of the *SSE* analysis are presented. The *k* analysis appears, on the basis of these two studies, to produce similar results with only subtle differences in contrast between the two.

2.4.1 Stapeley Hill ring cairn

Stapeley Hill (OS Ref. SO 313 991) is a small ring cairn of supposed Bronze Age origin. Topographical surveying carried out on the site (Fletcher/Spicer 1990; Spicer 1991), has confirmed the presence of ridge and furrow and field walls. A lit three-dimensional surface representation of the topography of the site from a more recent survey (Stratascan 1994) is shown in figure 4. The vertical heights are exaggerated by a factor of three to emphasise features. Note the edge of a wide ridge in the foreground of the image caused by the remains of an ancient field wall, and behind it the obvious ring structure with a small central mound. Ridge and furrow are also in evidence to the left of the ring cairn (although not so obviously). The scale of the site is 20 m square, north is to the top left.

Radar surveying was carried out at the site in May 1994 using a 500 MHz antenna on a two directional 1 m grid. An

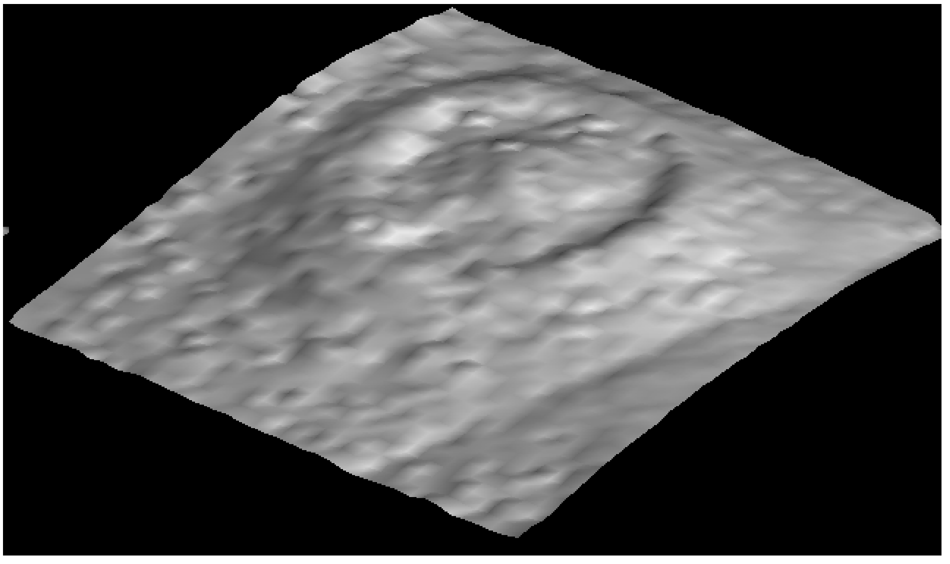

Figure 4. Stapeley Hill - topography.

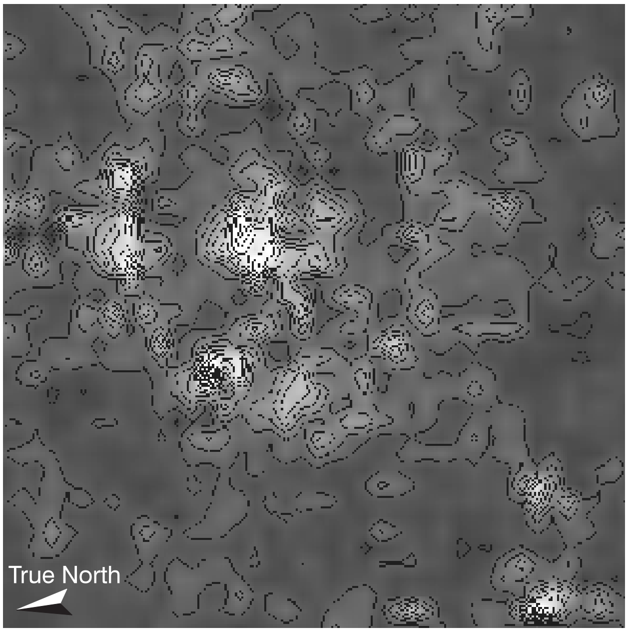

Figure 5. Stapeley Hill - radar activity (SSE).

interpolated activity map of the SSE values for the site is shown in figure 5.

The activity map reveals a rough ring shaped area of enhanced radar activity (top centre of image) with an irregular central feature. A further area of high activity lies at the bottom right of the image and is probably associated with field wall remains. Superimposition of the radar activity map on the topography (fig. 6) reveals good correspondences between radar and topographical evidence for field wall remains, between the positions of the circular bank of the ring work and the circular feature on the radar map, and between the central mound and the central radar feature.

This evidence probably points to the presence of a large proportion of stony material in the circular bank. The activity strength of the bank is weaker on the SE side of the ring. This may be due to the topography of the site (fig. 7) or to possible removal of stone associated with the ridge and furrow or with the field wall. The greater strength and degree of coherency of the central feature may point to the presence of a large, coherent mass of stone — possibly a cist.

2.4.2 Worcester Cathedral

The second case study is based on a survey conducted at Worcester Cathedral which was expected to reveal traces of foundations from a previous structure. The survey covered a rectangular area of approximately 280 square metres and was done on a regular 1 m grid in two directions, again at 500 MHz. The SSE analysis results are shown in figure 8.

The results are not as revealing as those for Stapeley Hill. The most obvious feature is the area of high activity in the top left of the survey. This feature is possibly the high activity end of a linear region of enhanced activity extending from top left to bottom right of the map, though this is by no means certain. This may correspond to the path of an old drainage channel which still retains some moisture. Some regular features can also be discerned at bottom centre and bottom left, and it is tempting to associate these with building foundations.

3 Retrieval of depth information

3.1 Simple stratification

The approach as it stands at this point yields only two-dimensional information in the form of a plan view of the radar activity levels over the survey site. This should, in many cases, provide a coarse indicator of the *presence* of features of interest, but it may be that a more comprehensive, three-dimensional picture of the site is required.

Accurate extraction of three-dimensional information from radar data is a problematic process. Various factors including surface topography and lateral inhomogeneities in the electro-magnetic properties of the soil matrix cause vertical distortions in the data which cannot be easily rectified. A first step towards the extraction of depth information from a survey is to simply ‘stratify’ the radar images and to analyse each layer separately. It should be emphasised that vertical distance on the radar images does not correspond directly to vertical distance below the ground surface but to the signal return time of the radar emissions. This means that what is produced by this process is a series of activity maps which, *approximately* speaking, depict the activity at different distances below the ground surface. Theoretically, the simpler the site, the better this approximation will be.

This approach is similar in nature to that taken by Milligan and Aitkin (Milligan/Aitken 1993: 26-39), but with several distinct advantages. The approach adopted by Milligan and Aitken is limited in scope in that the horizontal (signal return time) slices are produced by direct extraction of pixel values from a *uni-directional* set of parallel radar images. No ‘interest’ values such as the activity values developed herein were employed and no interpolation was attempted since interpolation from a uni-directional survey tended to result in spurious linear features at right angles to the transect direction.

3.2 Case studies

3.2.1 Stapeley Hill

The results of applying the stratification process to Stapeley Hill are interesting. Examination of the images in figure 9 shows that the NE side of the ring shows up clearly only on

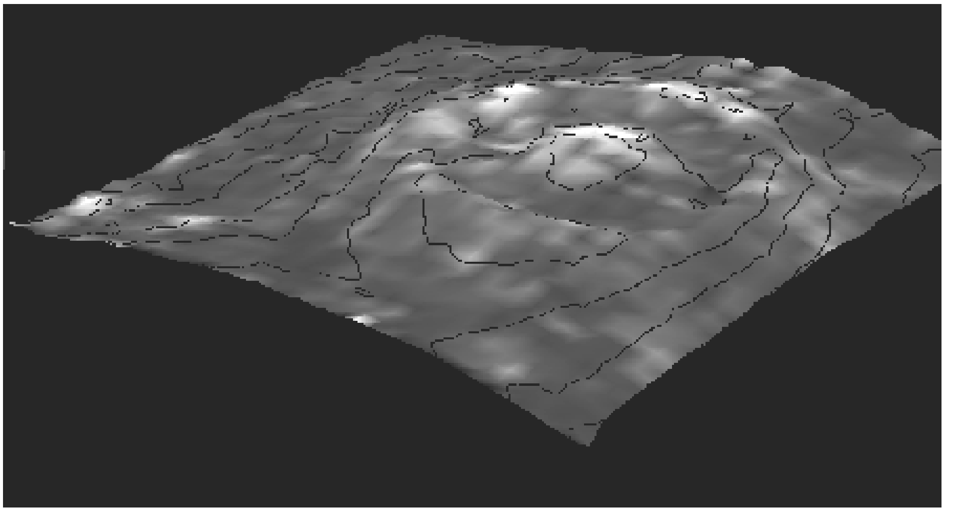

Figure 6. Stapeley Hill - radar activity superimposed on topography.

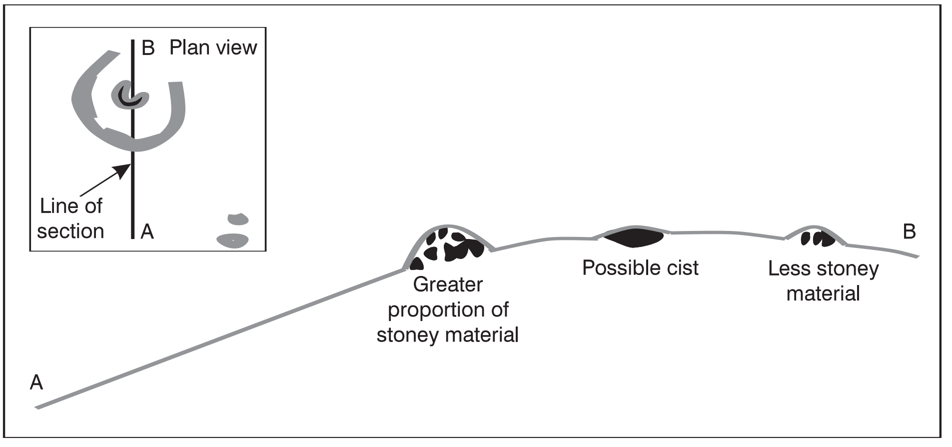

Figure 7. One possible explanation for the discontinuous nature of the radar activity in the bank of the ring cairn.

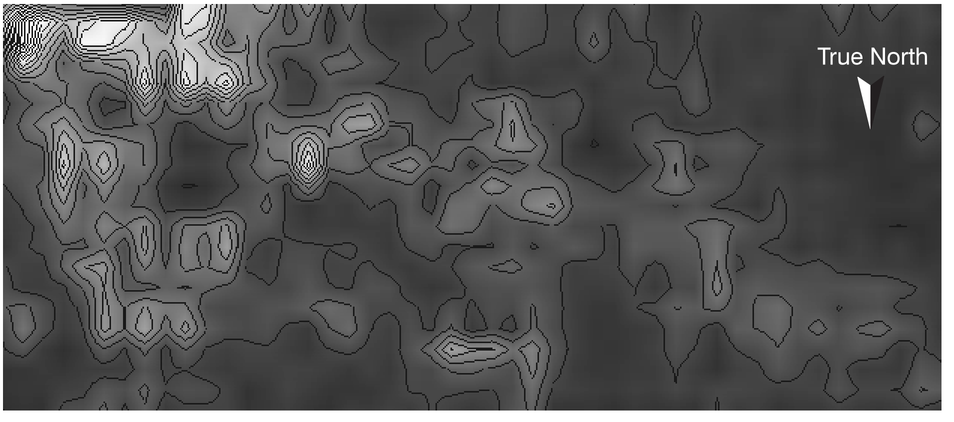

Figure 8. Worcester Cathedral - SSE results.

the first (shallowest) map, whilst the rest of the structure shows up on all of the maps. This lends support to the conclusions that the ring is more substantially constructed on the down slope (NW and W) sides. The central structure does not show up at all in (a), appears very strongly in (b), fades away again in (c), then makes a reappearance in (d). This lends support to the hypothesised presence of a structured central feature i.e. a cist. A further feature of

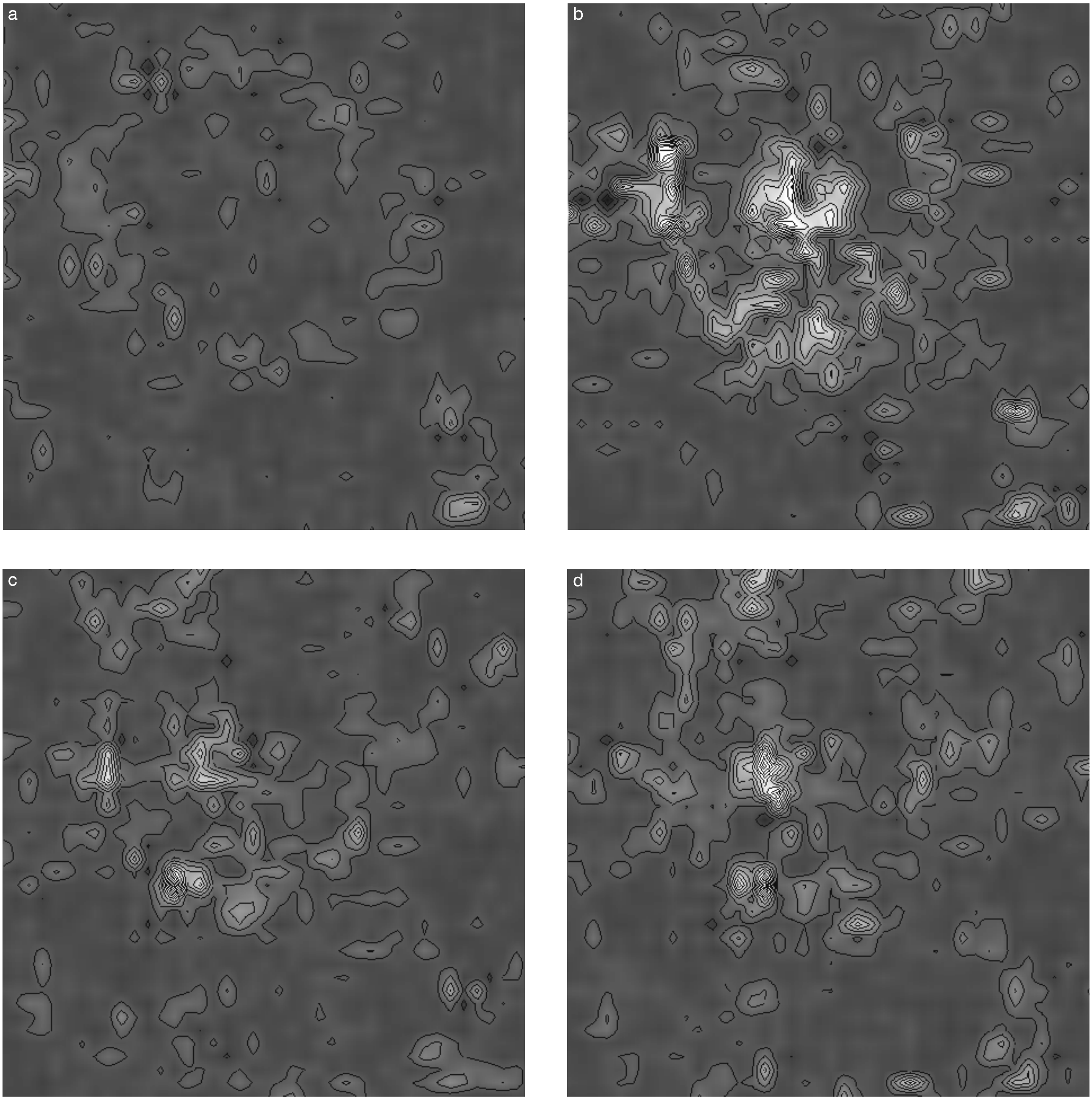

Figure 9. Four consecutive SSE slices through Stapeley Hill.

possible interest is a large anomaly which shows up very strongly in the NW side of the ring at greater depths (in maps (c) and (d)). The radar signatures associated with the field wall appear concentrated mainly at intermediate to shallow depths (map (b)). This would appear consistent with the supposed later origins of the wall.

3.2.2 Worcester Cathedral

The use of the simple stratification method on the Worcester Cathedral data is very revealing. The sequence of maps (fig. 10) going from (a) the shallowest, to (e) the deepest, clearly confirm the presence of the suspected linear feature. This provides a good example of how problems caused by overlapping features in successive strata can be easily and effectively overcome.

4 Further work

4.1 Image filtering and depth information

In order to progress further certain issues need to be addressed. The results obtained thus far, although interesting, are flawed in that the presence of detectable objects in the upper layers of the site tends to affect the activity levels calculated for areas of the radar image which lie below. This is due to the fact that the radar pulse produced by the apparatus is not instantaneous in nature, but consists of a decaying wave train. This leads to a periodic *echoing* effect where 'ghosts' of objects appear in the radar image below the main object signature.

Because these effects are periodic, they should prove amenable to manipulation by frequency domain techniques such as Fourier analysis. The main problem here is that the removal of the unwanted 'ghosting' is not simply a matter of detecting the echo frequency and filtering it from the image. Although this would have the desired effect, it would also mean that the primary signal is filtered out. Further investigation of the problem is obviously necessary.

4.2 Improving data utilization

Data points are available at very small intervals along the transects (so much so in fact, that the data can almost be considered to be continuous). Some attempt has been made to use interpolation techniques to make better use of the available data (section 2.3). In spite of this there is still a great deal of room for improvement, perhaps by treating the data as irregular xyz values and using routines which can deal with this type of data.

5 Conclusions

This paper shows that it is possible to produce simple, quick and, most importantly, objective routines for analysing data from ground penetrating radar surveys. Two statistical measures of radar activity — the SSE and k values — have been developed. Other measures, possibly relying on frequency domain information, have yet to be examined.

A simple extension of the basic technique allows some appreciation of the three-dimensional structure of the survey site to be obtained. As has been demonstrated, this often allows extra inferences and conclusions about the site to be drawn. An initial evaluation detailed in the case studies examined above, indicates that this technique may prove to be an extremely useful tool, but much work still needs to be done in this area in order to iron out difficulties caused by the radar ghosting effect detailed in section 4.1.

It is not possible to say at this stage which measure of activity produces the better results, and work using a known 'model' site is necessary in order to test them.

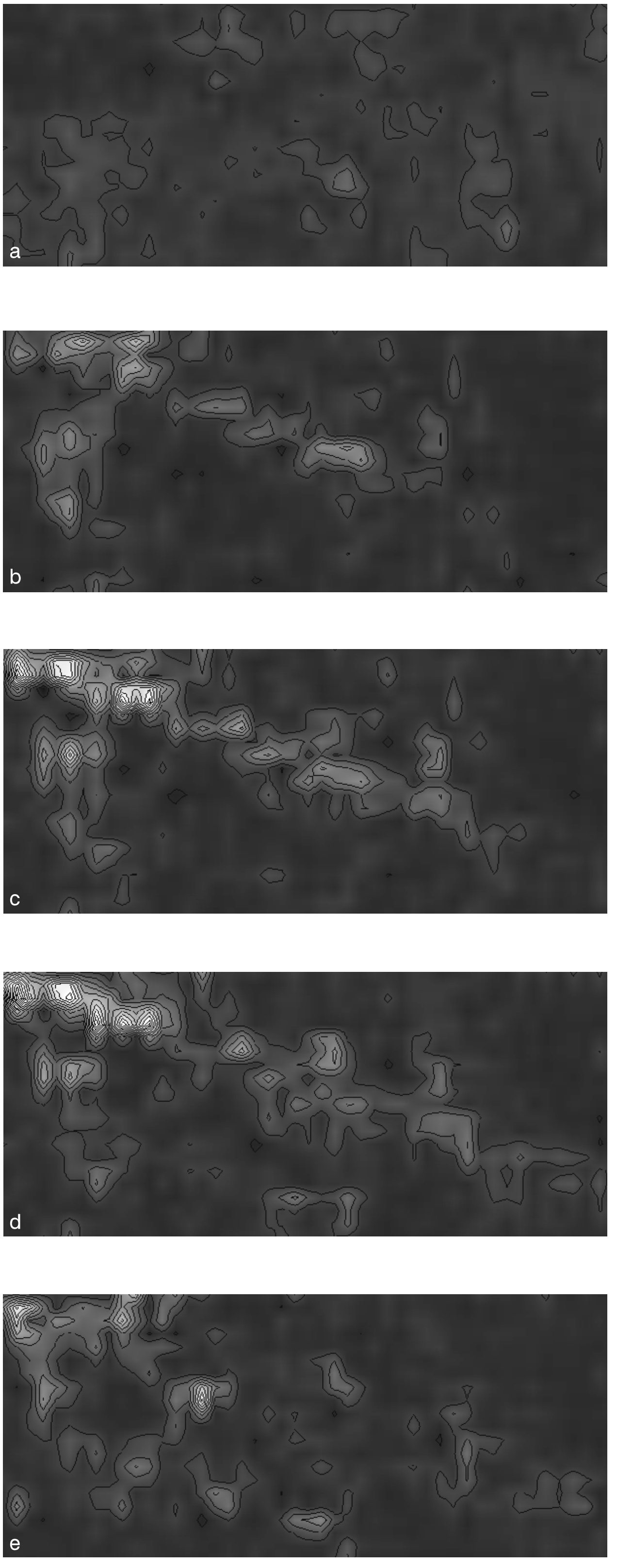

Figure 10. Five consecutive SSE slices through Worcester site.

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Restoration of magnetometry data using inverse-data methods

1 Introduction

Magnetometry has become one of the most popular techniques for the geophysical prospection of archaeological sites. Modern instruments are reliable, easily portable, convenient in use, and reasonably inexpensive. The data are logged automatically and can readily be transferred to a small computer for subsequent processing. Anyone who has received proper training in the operation of field magnetometers can expect to survey a considerable area of ground each day and, provided that conditions are favourable, be able to present the results in an archaeologically meaningful form.

A typical opportunity for magnetometry occurs when ancient ditches or pits have been cut into inert soil, but have subsequently been filled in with material which is magnetically active. The locations of the features can then be detected as induced magnetic anomalies relative to the earth's main field. The response of the magnetometer to such an anomaly is somewhat complicated, presenting a positive lobe along the southern side together with a negative shadow towards the north (Linington 1964). The relative sizes of the positive and negative lobes depend on the mode of operation of the magnetometer (gradiometer or single mobile detector), on the survey's location on the surface of the planet, and on the depth of the archaeological features below the modern ground surface.

Some care has to be taken in interpreting the results of a magnetometer survey, because the actual position of the anomaly corresponds neither to the positive lobe nor to the negative lobe, but is close to the junction between them. This may not be important when the survey reveals only a limited number of well spaced features, but it may cause crucial difficulties if there are many features, overlapping each other at different depths.

The data logged by the magnetometer provide, in effect, a digital image of the site. Such an image differs from more familiar electronic images, such as those derived from conventional photography, only in that it contains both positive and negative readings, whereas in most cases only positive intensities are permitted. Many different methods of image restoration have been developed over the years, and the majority are still valid when applied to images containing a mixture of positive and negative values.

Standard methods of image restoration include spatial filtering, for smoothing and edge enhancement, Fourier transform methods, and construction of the inverse response function. In recent years a number of alternative methods have been developed, based upon statistical estimation techniques, such as the EM algorithm which is discussed in this paper. Such techniques model the distribution of the survey data, on the basis of the known magnetometer response. The magnetic intensity is then estimated from the data, taking into account any reasonable prejudice about the nature of the anomalies. These techniques are known collectively as 'inverse-data methods'.

The aim of our project is to apply suitable inverse-data methods to various types of archaeological magnetic data, and to appraise their success in comparison with standard techniques of image restoration. Some preliminary results are presented in this paper.

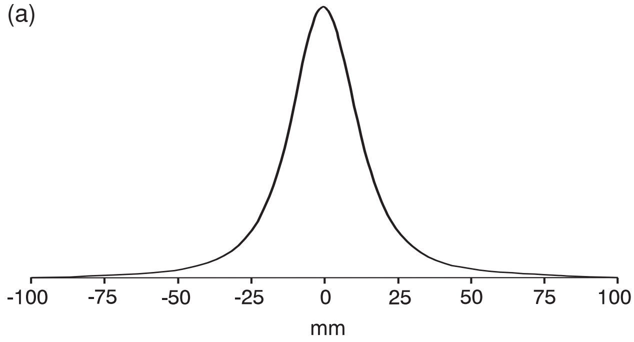
2 Outline of this project

Recognising that the analysis of full-scale archaeological field data presented formidable problems, because of both the size of the problem and the complexity of the response function involved, it was decided that the project should be developed in three distinct stages, each progressing towards the ultimate objective.

Stage I

The analysis of digitised measurements of magnetic susceptibility over the length of earth cores from archaeological sites. These measurements arise from a project undertaken by the Department of Archaeological Sciences at the University of Bradford with the aim of determining the location and depth of the magnetically active regions of a site. Earth cores, extracted from several locations over the site, are passed through a detector coil which allows the susceptibility to be measured continuously along the core; the readings are recorded digitally.

Since the detector coil is sensitive to the susceptibility over a considerable length of the core, its effective response function to the susceptibility of any point in the core has very long tails (fig. 1a). In consequence, the curve of the continuous measurements shows very broad, smooth peaks,



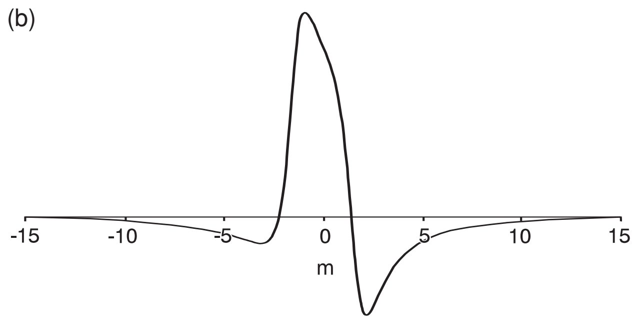


Figure 1. Theoretical response functions for (a) measurements of core susceptibility and (b) line magnetometer measurements.

and responses from different regions of the core may overlap very strongly. Our aim is to account for the broad spread of the response function and to allow the measured susceptibility to be attributed to sharply defined regions of the core, representing distinct epochs in the development of the site.

Since the restoration of susceptibility values is a line problem, it requires relatively little computing power. Furthermore the response function does not possess the positive and negative lobes which normally appear in magnetometry work. Consequently this should provide a fairly straightforward problem on which to test our techniques.

Stage II

Gradiometer measurements along a line transecting linear features. Rather than progress straight to full survey over an extended area of ground, we first look at data from a survey along a line transecting some linear feature, such as a long straight ditch. Here the ground is modelled as a collection of magnetised prisms of rectangular cross-section, and infinite in length in the direction of the feature. The response function has positive and negative lobes, and may vary with location on the planet, the depth of the feature, and the strike (or transection) angle (fig. 1b). Nevertheless the problem is more manageable than full area field survey at Stage III.

Stage III

Gradiometer measurements from area surveys. This type of problem usually involves a large data set and a more complex response function than either of the earlier stages. Hence it is only to be tackled when we have gained considerable experience of the methodology during the earlier stages.

3 Techniques tested during Stage I, using susceptibility data

Two forms of susceptibility data were used for testing restoration methods. The first form was entirely simulated, by convolving a known pattern of susceptibility with a suitable response function, and finally adding some Gaussian noise. The second form came from actual measurements, but made on blocks of material of known susceptibility fabricated to resemble earth cores, rather than on true earth cores. The advantage of using ‘phantom’ data of this type is that the expected answer is known, and therefore the accuracy of the results may be judged.

All the techniques worked much as we would have predicted with the simulated data. The straight Fourier method and the direct calculation of the inverse response function tended to give fragmented results in the presence of noise, for reasons discussed below, but the other methods worked well enough. We therefore decided to concentrate on the ‘phantom’ data, since these should give a fairer indication of how the various techniques would perform in practice.

3.1 Fourier transform methods

It is possible to calculate the (discrete) Fourier transform of the response function, to find its exact inverse, which can then be used to calculate the restored susceptibility. In fact the results are extremely disappointing and have little resemblance to the ‘known’ pattern of susceptibility.
The reasons for this poor performance are well known.
The response function used here is very smooth and has long tails; consequently its Fourier transform has very small amplitude in the high-frequency components. Hence the inverse of the Fourier transform has very large amplitude in those components. Furthermore, since the observed data represent a convolution which includes the smooth response function, they should have very small high-frequency components; any significant component in those frequencies is almost certainly associated with noise. One effect of dividing by the transformed response function is to exaggerate components arising from noise, which often gives rise to unsatisfactory results.

One technique to counteract the exaggeration of noisy components is the use of the Wiener filter (Gonzalez/Wood 1992). The basis of this method is an analysis of the frequency spectrum resulting from the noise, but in practice it is often interpreted as the simple addition of a small positive constant Φ to the denominator of each component of the inverse of the transformed response function. The constant Φ prevents division by near-zero, but it is difficult to provide a prescriptive formula for its optimum value; a suitable value is usually found by subjective trial and error.

3.2 Construction of inverse response function

It is possible to construct the inverse response from a set of simultaneous equations derived from a precisely constrained problem (Tsokas *et al*. 1991). The results are effectively equivalent to the straight Fourier method, and have similar deficiencies. Better results may be obtained by setting up an over-constrained problem, which is solved by minimising a sum of squares. This takes account of the presence of noise in the data and leads to results which are qualitatively similar to those from the application of the Wiener filter in Fourier transforms. Singular value decomposition provides a more stable and more controlled approach to the over-constrained problem, but the results are not markedly improved.

3.3 Maximum likelihood estimation

Our initial trial of inverse-data methods was based on the well established Metropolis-Hastings algorithm (Hastings 1970; Metropolis *et al*. 1953). The calculations proved to be extremely slow and the final results did not show any significant improvement over those discussed above. These conclusions are not entirely surprising since the algorithm was devised in order to solve non-linear problems, whereas the problems of fitting the magnetic data are linear ones. As a result of these observations we abandoned the Metropolis-Hastings method in favour of an alternative statistical technique which has proved to be successful in other imaging applications.

3.4 The EM algorithm

This algorithm was published by Dempster *et al*. (1977) as a summary of various earlier methods, one of the best known of which is the Lucy-Richardson method (Lucy 1974; Richardson 1972). We offer a brief description of the algorithm here, with the intention of publishing more of the mathematical detail elsewhere.

Suppose that the susceptibility profile along the core is divided into m discrete elements, that x_j is the 'true' susceptibility of element j, and that $\hat{x}_j$ is some estimate of x_j. Suppose also that data are observed at n locations, and that y_i is the observed value at location i, whereas μ_i is the expected value when the 'truth' is convoluted with the response function.

Then

$$\mu_i = \sum_{j=1}^{m} h_{ij}x_j \qquad \text{and} \qquad y_i = \sum_{j=1}^{m} z_{ij}$$

where h_{ij} is the response function coupling location i to element j, and z_{ij} is the contribution to observation i from element j. The values z_{ij} may be envisaged as 'unobservable' data whose expected values are $h_{ij}x_j$. The introduction of such 'missing' or 'unobservable' data is an essential requirement of the EM algorithm.

The algorithm defines two separate steps:

E step: (Expectation), where z_{ij} is estimated by its conditional expectation, given the data:

$$z_{ij} = E\,[z_{ij} \mid y_i] = h_{ij}x_j + \frac{1}{m}\,(y_i - \mu_i)$$

M step: (Maximisation), where the value $\hat{x}_j$ is found to maximise the log-likelihood, or minimise the error sum of squares, assuming that the z_{ij} are observed data.

The E and M steps may be combined to give a revised estimate of x_j:

$$\hat{x}_j^{new} = \hat{x}_j^{old} + \sum_{i=1}^{n} (y_i - \mu_i)h_{ij} \Big/ m \sum_{i=1}^{n} h_{ij}^2$$

This equation provides an iterative process where the estimate of each 'truth' element is decoupled from the estimates of the other elements.

Since this simple implementation of the EM algorithm is based on minimising an error sum of squares, the results are essentially similar to those from the Wiener filter or the other least squares methods. In consequence there is a choice of methods leading to similar results:

EITHER The normal equations are set up for a least squares calculation, or the equivalent Fourier transforms are used, both of which involve very large arrays, so that the calculation is *memory intensive*;

OR The EM algorithm may be used as described above, which results in a very slowly convergent iterative process, and hence is *processor intensive*.

The true advantage of the EM algorithm only becomes apparent when the expected results are influenced by pre-existing concepts of their pattern.

3.5 The EM algorithm with penalised likelihood

There are likely to be many different solutions in the region close to the optimum defined by a maximum-likelihood procedure. The solution defined as strictly optimal is unlikely to conform to our prejudices, so preferred solutions are selected by introducing a penalty which favours restorations felt to be more appropriate to the problem.

In the case of the susceptibility, restorations are expected to show features with clearly defined boundaries, and a smooth variation of intensity elsewhere. The EM algorithm can be modified to take account of such a penalty, but strictly leads to a set of non-linear simultaneous equations. A linear approximation may be obtained, however, by replacing the value $\hat{x}_j^{new}$ in the penalty term by the value $\hat{x}_j^{old}$ obtained from the last iteration step. This is known as the OSL approximation (one step late), and has been shown to be valid provided that convergence to the required solution is reasonably slow (Green 1990).

The E step remains the same as in the previous subsection, but a penalised likelihood is introduced into the M step. On combining the two steps, the OSL approximation gives the following iterative formula for the estimated susceptibility:

$$\hat{x}_j^{new} = \hat{x}_j^{old} + \frac{1}{m \sum_{i=1}^{n} h_{ij}^2} \left[\sum_{i=1}^{n} (y_i - \mu_i) h_{ij} - \beta\sigma^2 \left. \frac{\partial\varphi}{\partial x_{ij}} \right|_{\hat{x}_j^{old}} \right]$$

The function φ, differentiated in the right-hand term, defines the nature of the penalty and is often referred to as the *potential function*; apart from this term, the equation is identical to the pure EM algorithm. The value σ^2 is the assumed variance of noise in the data and the coefficient β defines the strength of the penalty. The larger the value of $\beta\sigma^2$, the more likely is the restoration to conform to our prejudices, at the expense of goodness of fit to the data.

One significant advantage of the EM algorithm with the OSL approximation is that it is possible to introduce a penalty without greatly increasing the computational expense. This is not the case with other methods known to us.

4 Results from Stage I

The calculations described in the last section were applied to two sets of *phantom* susceptibility data (fig. 2). The observed data are shown as a solid line, and the underlying 'truth' as a dashed line; the 'truth' line is repeated in subsequent figures.

The Wiener filter was first applied to both sets of data (fig. 3); the solid line represents the answer returned by the calculation. When distinct blocks of susceptibility are well separated their locations are predicted quite well, but their shapes are entirely wrong, since they are quite smooth and contain no sharp edges. There is no meaningful information to enable us to separate the three adjacent blocks in the upper diagram. The side-lobes visible at the edges of the main peaks are a characteristic feature of Fourier analysis. The methods based on maximum-likelihood procedures, including the simple EM algorithm, gave such similar results to the Wiener filter, that we have not illustrated them here.

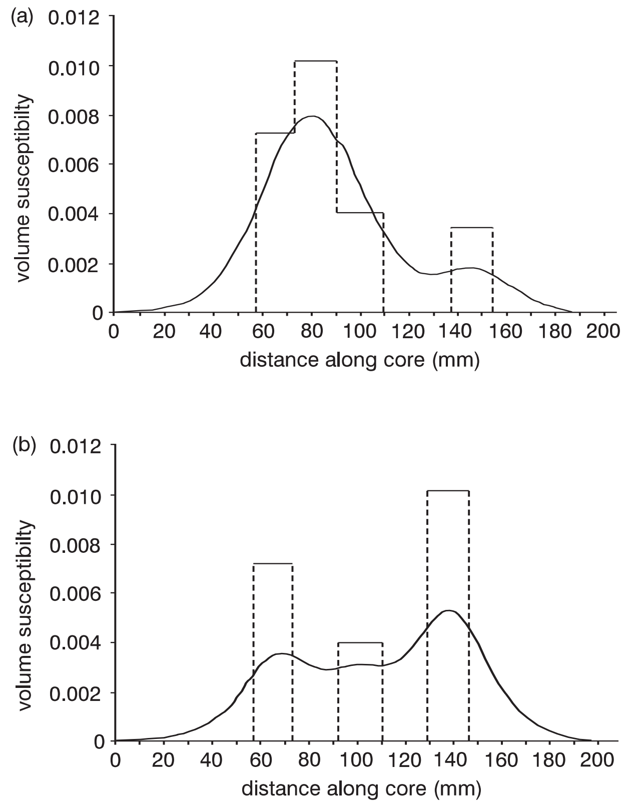


Figure 2. Two sets of 'phantom' susceptibility data (solid lines), measured from synthetic cores constructed from material of known susceptibility (dotted lines).

Using the EM-OSL algorithm for penalised likelihood estimation, we experimented with several different types of potential, of which two were found to give good results. Following the suggestion of Besag (1989), our first choice for the potential function φ was the absolute difference between the values of x_j and its neighbouring elements, so that the penalty was the sum of such differences. A suitable value for the constant $\beta\sigma^2$ was determined by experimental investigation; the final choice was made on the basis of a subjective balance between goodness of fit and the anticipated form of the results (fig. 4).

The separated blocks are more clearly defined than they were with the Fourier and maximum likelihood methods, but there is some filling of the intervals between them. The triple block is not resolved and has the appearance of a broad single block. All the blocks have sloping sides rather than the sharply defined vertical edges shown in the 'truth', indicating that they are made up of a succession of small steps rather than one large step.

In an attempt to eliminate this last problem, we introduced a second potential φ which incorporates a cut

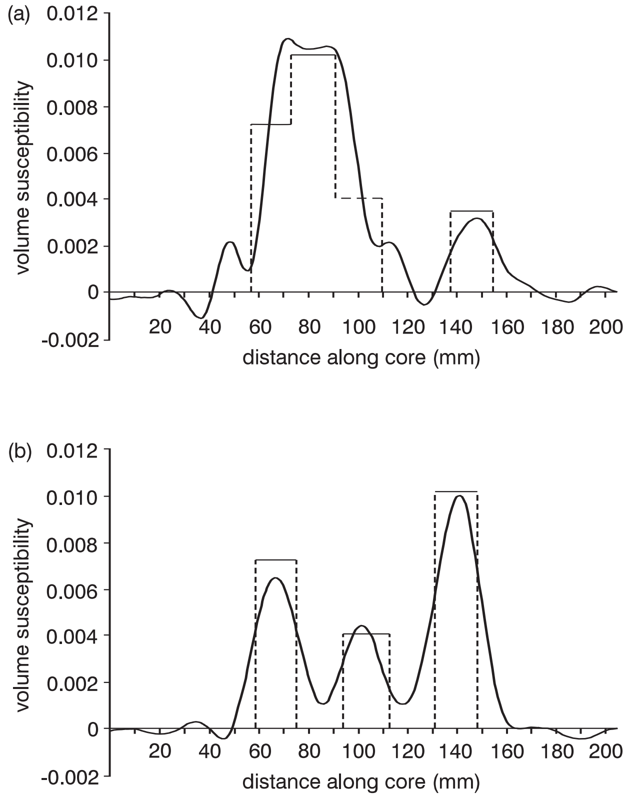


Figure 3. Restored susceptibility (solid lines) from the Fourier method with Wiener filter applied to the data of figure 2.

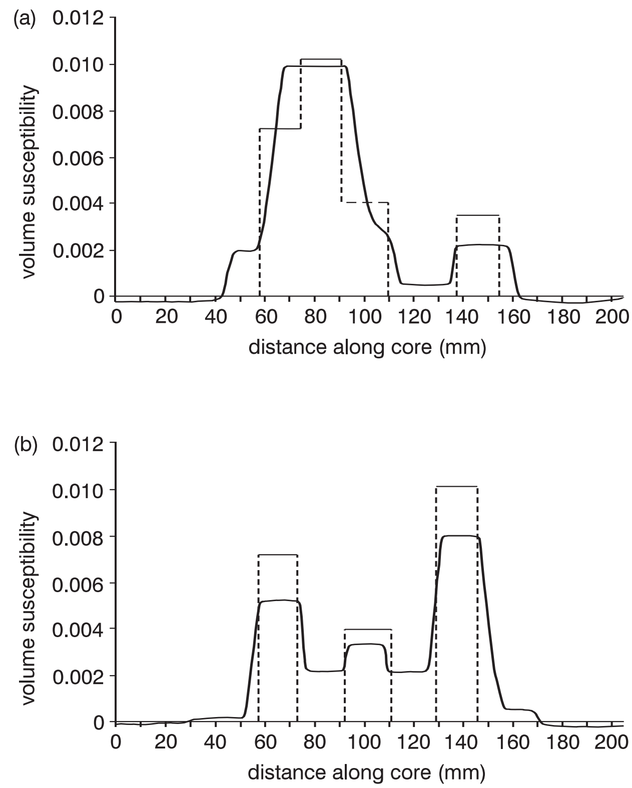


Figure 4. Restored susceptibility (solid lines) from the EM-OSL algorithm applied to the data of figure 2; the potential function is the absolute difference between neighbouring elements.

off, so that a single large step is penalised less heavily than an equivalent series of small steps. In this case, it was necessary to find suitable values not only for the constant $\beta\sigma^2$ discussed above, but also for the parameter defining the cut-off. The blocks are now very sharply defined, with nearly vertical sides (fig. 5). The positions and widths of the blocks are largely coincident with the 'truth', but there is still some filling-in of the intervals between the blocks, and smaller blocks seem to appear on the edges of the main blocks. The triple block is now partially resolved (fig. 5a), but has not been fully accounted for along its left-hand edge.

Of the various methods described above, it is clear that the EM-OSL algorithm seems to produce the most realistic results, particularly when used with the potential function φ which incorporates a cut-off. The general agreement between the results and the assumed truth is excellent, apart from the small blocks on the side of the main blocks and the filling-in of the intervals between blocks. Since the data used here are actual measurements, the precise mathematical nature of the response function is uncertain to an extent. It is possible that the small additional blocks may arise from minor errors in the response function that was used in the modelling.

5 Results from Stage II

Following the successful application of the EM-OSL algorithm at Stage I, using the cut-off penalty function, it was also tested at Stage II. Because of difficulty in locating suitable field data, we decided to work entirely with simulated data, creating various models in which the magnetised features were prisms of infinite length and rectangular cross section, each located at the same depth below the soil surface.

A typical simulation from our tests comprised a large prism of low magnetic intensity juxtaposed with a smaller prism of higher intensity. This magnetic distribution was convolved with the response function (appropriate to the depth below the soil surface, the location of the model on the planet's surface, and the strike angle between the line of survey and the line of the feature) and a reasonable measure of Gaussian noise was added to give the simulated data

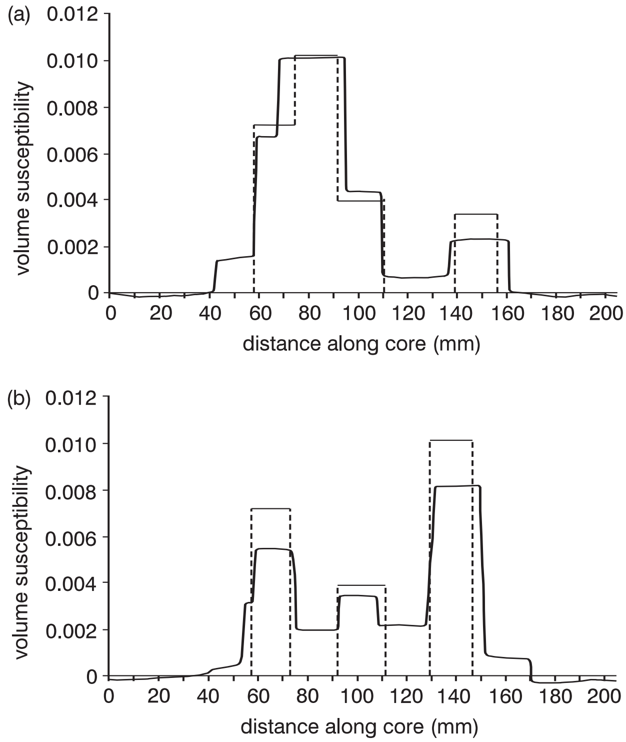


Figure 5. Restored susceptibility (solid lines) from the EM-OSL algorithm applied to the data of figure 2; the potential function incorporates a cut-off, penalising a single large step less than an equivalent series of small steps.

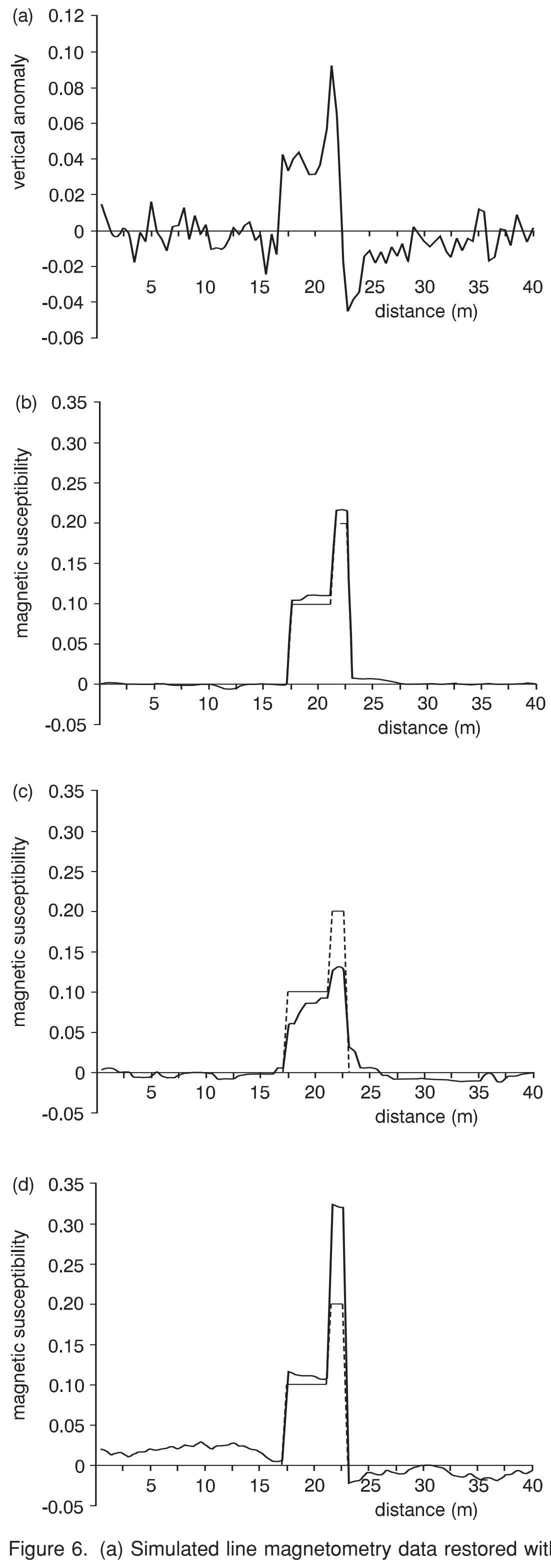


Figure 6. (a) Simulated line magnetometry data restored with EM-OSL algorithm using response functions that assume (b) the correct depth of the feature, (c) too shallow a depth for the feature, and (d) too great a depth for the feature.

(fig. 6a). The result of applying the EM-OSL algorithm to the data can be seen to be in remarkable agreement with the original model (fig. 6b).

Working with simulated data, we were confident that the response function used in the restoration was precisely the same as the one used to create the data. This might be an unrealistic situation in practice, given the wide variation in form of the magnetometer response function. We repeated the restoration of the same data, but deliberately using inappropriate response functions, first a response function which assumed that the magnetic features were above their true level (fig. 6c), and then one which assumed the features were below their true level (fig. 6d). It can be seen that the location and general shape of the simulated feature are recovered reasonably well, but nowhere near as accurately as with the correct search depth. There is also a fair amount of spurious background activity.

In order to test the noise model, whose specification is somewhat problematic for magnetometry data, we repeated the whole simulation, doubling the magnitude of the noise. The signal from the feature is now substantially hidden by the noise (fig. 7a). The general shape of the feature is still recovered by the EM-OSL algorithm, but the details are not as accurate (fig. 7b); there is a fair amount of spurious activity in the background. The results from the searches at the incorrect levels still give some indication of the location of the feature, but are generally inaccurate in other respects (figs 7c, 7d).

6 Questions to be answered

We have shown that the EM-OSL algorithm, maximising the penalised likelihood, produces good results at both Stage I and Stage II, with the 'phantom' susceptibility data and the simulated data for linear traverses. The results suggest that it is now worthwhile to set up the more complicated calculations at Stage III, so that the algorithm may be applied to data from magnetometer surveys over areas of land. Before moving to Stage III, however, a number of questions should be answered.

a. How should the parameter β (or the product $\beta\sigma^2$) and the cut-off parameter in the penalty function be chosen? We have experimented with various combinations of values until finding a set which appeared to give a near optimal restoration. Although the results are relatively insensitive to the choice of these parameters, it is clear that a more objective approach is desirable.
b. How can it be ensured that the response function is appropriate to the physical conditions of the survey? We have shown that the choice of response function for the simulated magnetometry data makes a considerable difference to the quality of the results. This is a critical consideration when moving into 3-dimensional modelling at Stage III, where the response functions are more complicated than those at Stage II.
c. What noise model is appropriate to the data? We have experimented with simple Gaussian models at Stage II, using two different levels of noise, in order to see how the amount of noise affects the quality of the results. The choice of noise model for actual magnetometer survey is problematic, since the signal from features close to the surface is often regarded as noise.
d. Is it possible to predict the vertical depth of restored features as well as horizontal location? The response function from magnetised features differs with depth, as is clearly shown by our experiments in attempting to restore data using the wrong depth. The question is whether it is possible for the EM-OSL algorithm to detect the difference between the response functions sufficiently clearly to attribute a feature to the correct depth. Our experiments suggest that it may be possible, but the results are far from conclusive; further experiments are needed at Stage II, before any depth analysis is tried at Stage III.

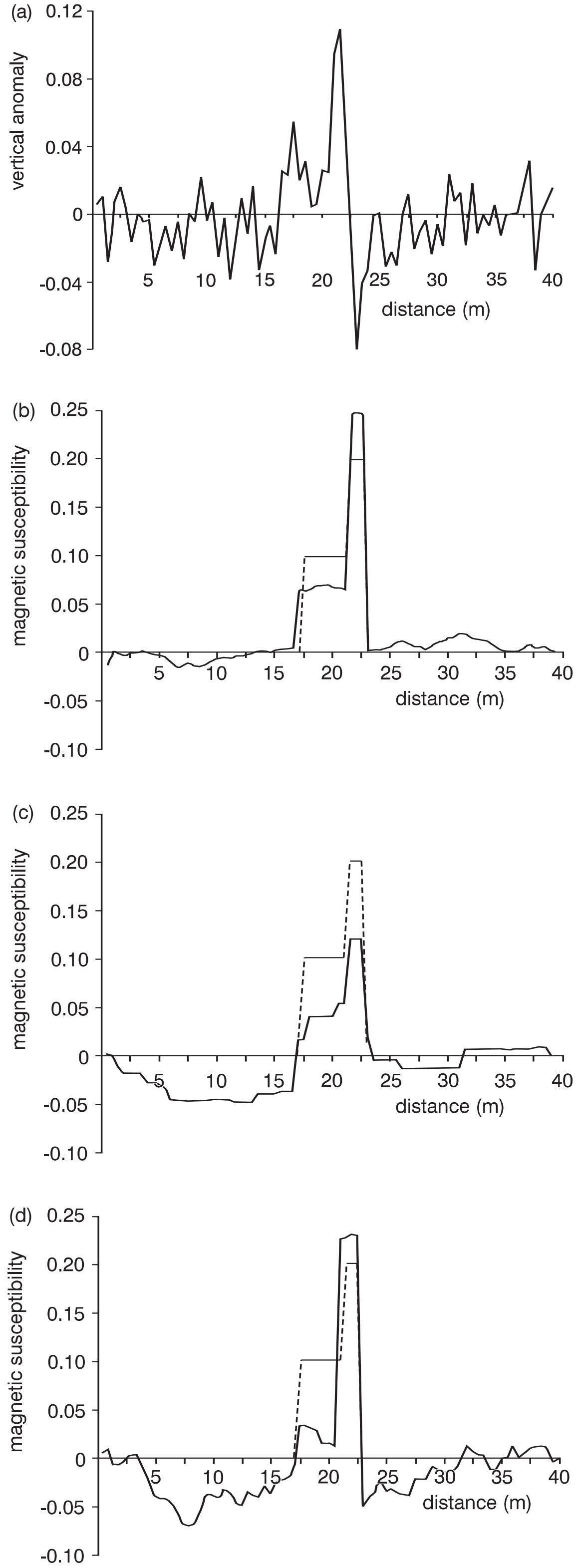


Figure 7. Similar to figure 6, except that noise of doubled intensity has been incorporated into the simulated data.

e. Can a large data set be divided into manageable 'chunks' for calculation? Although each iterative step of the EM-OSL algorithm is calculated quite swiftly, it may still become burdensome if *m* and *n* (the number of model elements and the number of observations) are both large. Since a data set at Stage III may contain several hundred thousand readings, it would be more efficient to work with small subsets. It would then be necessary to ensure that the results at the edges of each portion matched correctly with those of neighbouring subsets.

7 Prospects for Stage III

The good progress through Stages I and II of the project has encouraged us to move on to Stage III as rapidly as possible. It is at Stage III that the project will become widely useful to archaeological geophysicists, allowing access to plenty of field data on which to test our mathematical methods. One important aspect of the usefulness of the techniques is their likely computational cost, which we now consider. With around 80 items of line data, the EM-OSL algorithm requires about 2000 iterations to converge to its final answer, taking about two minutes of processor time on a Sun 4 workstation. It is likely that similar computation times would be achieved on personal computers equipped with the current Pentium processors.

Extrapolating to larger data sets for Stage III, we expect the computational time to be roughly proportional to the size of the data set, although allowance must be made for the more complicated response functions of the 3-dimensional model. A typical field data set of 400 readings over a square grid might take 10 minutes to process on a fast personal computer. If this estimate proves to be reasonable, then it should be possible to process data as rapidly as it can be produced from the field survey.

We conclude that the EM-OSL algorithm is capable of providing the basis for a practical method to restore magnetometry data. We are confident that satisfactory answers to the questions of the previous section will be found, allowing a useful implementation of the technique in general archaeological field survey.

Acknowledgements

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Collection, visualization and simulation of magnetic prospection data

1 Introduction

The majority of our archaeological heritage is buried in the ground and archaeologists are interested in the exploration of the landscape for remains of past human activity. For non-intrusive location of archaeological structures magnetic prospection is an appropriate technique. It is a fascinating discipline under continuous development and has become an important tool of research in Austrian archaeology (Melichar 1990; Melichar/Neubauer 1993; Neubauer 1990). Especially in Lower Austria, we know many archaeological sites easily prospectable by magnetometery. They are mainly situated in homogeneous loess with low susceptibilities ($\kappa \approx 10 - 20 . 10^{-5}$). Sites are commonly close to the surface and are known due to the last twenty years of systematic aerial photography (Doneus 1994; Fenster zur Urzeit 1982). The archaeological features in the landscape generally have geometric properties different from those of the natural surrounding. Most monuments discovered by aerial photography are being steadily and rapidly destroyed by erosion. Those sites cover areas of many hectares. For precise measurements of large areas in a short time we had to develop both apparatus and techniques. High speed, highest achievable accuracy and spatial resolution are required for an efficient collection of magnetic data. Optically pumped magnetometers have proved to be the appropriate instruments for archaeological prospecting. During the last seven years a cesiumgradiometer with automatic position control and data acquisition has been developed and improved continuously. Site surveys have been carried out systematically on various sites all over Austria.

2 Measuring Device and Data Collection

In a cooperation between the Austrian Central Institute for Meteorology and Geodynamics and the Institute for Prehistory we developed an automatically recording cesiumgradiometer device. The magnetic scanning system ARCHEO PROSPECTIONS® used in Austria is mounted on two completely unmagnetic wooden wheelbarrows. The main wheelbarrow carries the two alkali vapour sensors. The two cesiumsensors are fixed in a plexiglas tube for gradiometer array, measuring the difference of the total magnetic field. In this tube the sensors can be positioned at several heights resulting in different gradients. The first sensor at 50 cm and the second at 2 m above groundlevel is the commonly used gradiometer array. To ensure a vertical gradient the tube is able to swing like a pendulum. For this movement in all directions we constructed a kardan. The gradiometer system operates with a specified accuracy of 0.05 nT. With the optically pumped cesiummagnetometer, being an oscillator at a relatively high frequency, 11 readings can be taken per second. To reach a maximum measurement speed in the field, the gradiometer system is connected to an automatic positioning and data recording system. Thus the survey can be carried out continuously without limitations of the apparatus. The data logger and the gradiometer readout unit are mounted on a second wooden wheelbarrow which is connected to the first one by a 50 m long cable. The automatic position control is realized by optical detection of the wheel's rotation. The measuring process is controlled by two audio signals.

For the survey the area of interest is divided into rectangles by using a theodolite and fixed by absolute coordinates. The rectangles themselves are normally measured with 50 or 25 cm grid spacing driving in zigzag. Because the terrain is not always smooth, the count of position impulses from the rotating wheel is varying.
To reduce these errors a test line is measured for every rectangle and the count of position impulses is used for calibration. The system is operated by three persons. Under normal conditions about 8 000 square meters can be easily prospected in one day, that means a recording of up to 64 000 readings per day with a spatial resolution of 0.5 × 0.25 m. Sofar the system has recorded about four million readings.

3 Visualization and data processing

In the field the magnetic data are stored in binary format on a laptop computer. Every measured rectangle is represented by one binary data file and an information file for optional corrections. All data files are arranged by their coordinates to compose the resulting image by using a special grid description file. For visualization of the data various data formats are produced by the developed image composer.

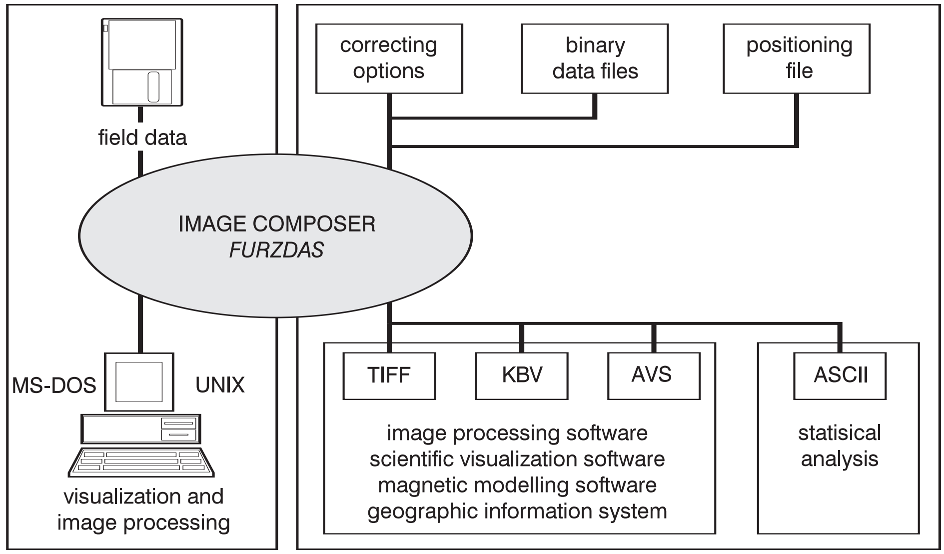

Figure 1. Visualization as a digital image.

TIFF-files can be imported by almost all available digital image processing software for MS-DOS or Windows. Other formats are necessary for input to image processing and scientific visualization software under UNIX on work-stations (see fig. 1).

Every single reading in the field is represented by one pixel on a high-resolution screen. The range of the greyscale is 0 to 254 using 8 bits for representation of one value. For visualization of the mostly very weak archaeological anomalies every 0.1 nT has to be represented by one grey tone. In that way only a range of -12.7 to 12.7 nT can be displayed. Zero nT is therefore given the medium grey tone 127, values bigger than -12.7 nT become white, values smaller than 12.7 nT get black. This is enough because almost all the anomalies of archaeological interest lie in a range of +/- 5 nT. Although the magnetic device operates with high reliability, due to the rough conditions of field-work, several systematic and unsystematic errors occur during data collection.

The first step in data processing is the correction of errors looking like spikes (fig. 2). These single spikes are due to failures of one sensor caused by low batteries, high temperatures (above 35° C) or physical shocks. They are detected in the image and replaced by the median of a 3 × 3 pixel surrounding. Variations in the height of the sondes above the surface are visible as line shifts. They are mainly due to surface roughness of ploughed soil or traces of tractors. Correction is done by detection of shifted lines and following equalization of the running line average.

Another kind of distortion is due to positioning errors of the moving sensors on the lines and appear as stripes (fig. 3). These dislocations are conspicuous in the results of nearly all magnetic prospecting teams and with our equipment and measuring process they occur in a maximum range of 0.25 - 0.75 m. They can be corrected by moving or stretching every second line up and down and computing a correlation measure. The final position of a column is reached at the minimal correlation measure. The result of this correction is a visible improvement of the image quality. These corrections are done automatically during the production of the image file. There are many reasons for these distortions and therefore we developed several methods of correction for the demands of the different range of positioning errors.

For further analysis the picture is inverted to get the anomalies of interest in dark grey tones. The next step uses the histogram of the displayed data to produce a higher contrast. For image enhancement the greyscale is stretched over the frequent data values. After the correction of the greyscale, brightness and contrast are tuned manually to improve visibility of the structures of interest. To reduce noise a median filter can be useful. Experience showed, however, that the corrected raw data without any filtering provide the best representation for the archaeological interpretation. Filtering always results in a loss of small archaeological details.

4 Evaluation of magnetic data

A method for the detection of anomalies by image processing is interactive thresholding. The following use of a contour tracing algorithm points out the anomalous zones. Yet, an interpretation only done by image processing techniques is not satisfying for archaeological purposes.

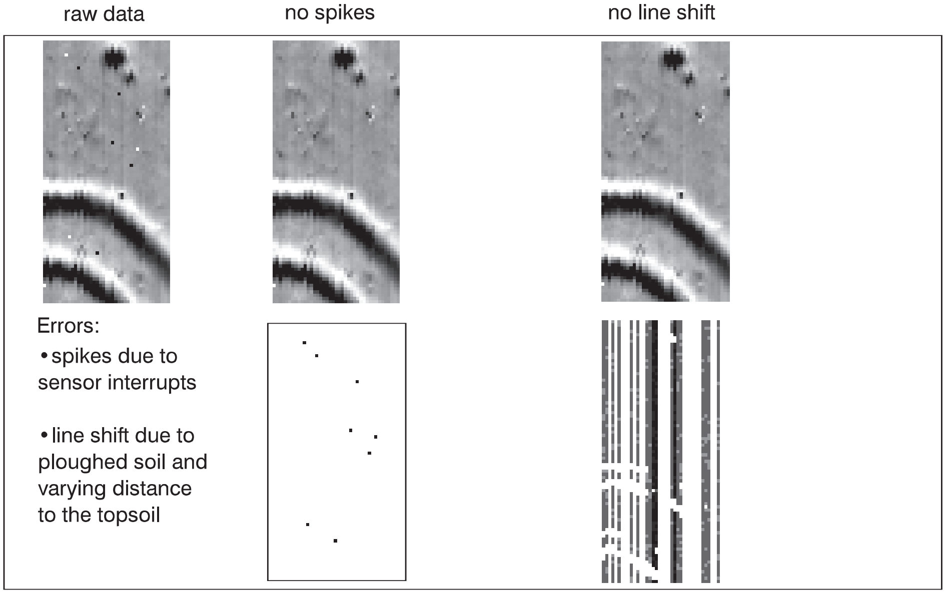

Figure 2. Correction of single spikes and the line shifts.

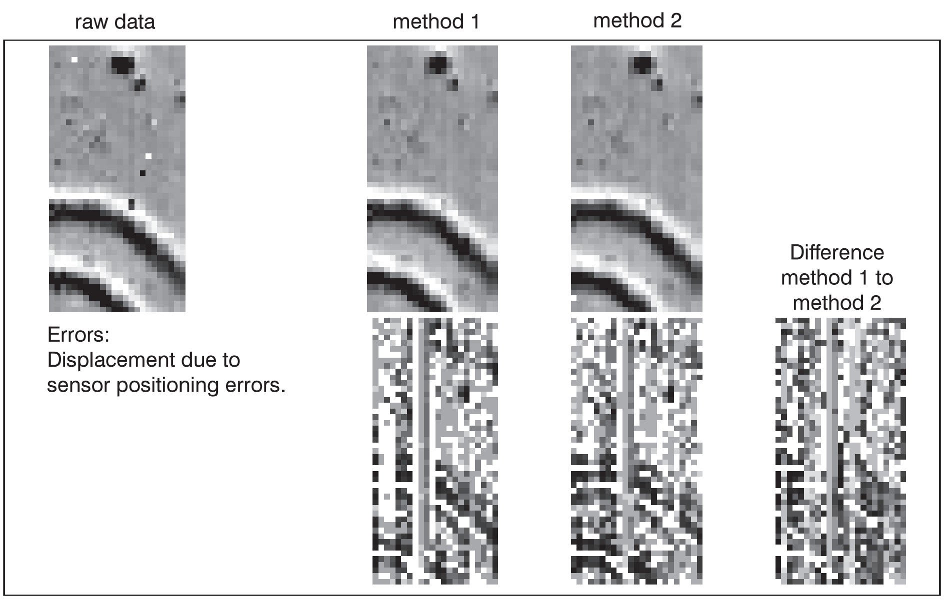

Figure 3. Correction of the displacements in the raw data.

An experienced interpreter is able to line out the archaeological features in a preprocessed image by mental comparison with excavated features. These features are frequently quite complex in shape and often have pronounced geometric forms. Superpositions of anomalies from different sources complicate the interpretation.

The boundaries of detected anomalies of archaeological significance are lined out on the screen overlaying the magnetogram. For the different features detected in the image we create various layers in different colours. Different thematic maps can be easily created from the interpretation layers. The mapped archaeological features

Figure 4. Magnetogram of Puch 1, corrected raw data, range [-7,3,2,7] nT → [white,black].

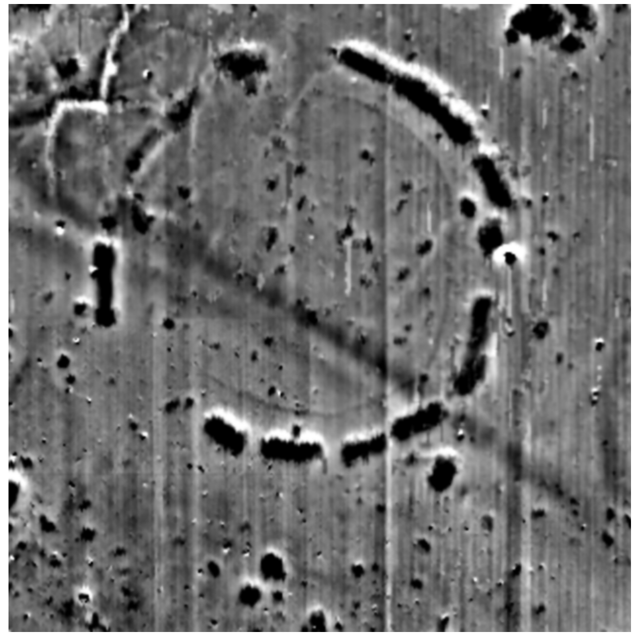

Figure 5. Magnetogram of Puch 2, corrected raw data, range [-5.3,2.7]nT → [white,black].

are then combined with the existing geodetic data by using CAD software (fig. 7). A primary requirement of the archaeologists with regard to geophysical prospection is to produce a presentation of the evaluated data which is understandable to anyone. The output as an interpretation map is a first step to reach this goal. Thus the end product is a map containing geographical information such as field boundaries, roads and contour lines together with the interpreted archaeological features from magnetic surveys. Later on excavation results are easily integrated into the general site context. For the high-resolution output of the magnetogram we use a 35 mm digital film recorder. The maps containing the interpretation are plotted on a A0 ink jet plotter. The produced maps are the most important basic information for the planning of consecutive excavations. In the following we will present three examples of magnetic surveys on large neolithic sites.[1]

4.1 Puch 1

The first example of a magnetic survey is a circular ditch system from the Middle Neolithic, from about 6500 years before present. The monument is known from aerial photographs (Fenster zur Urzeit 1982). The position and orientation of the entrances to the enclosure are of high interest. In the aerial photos they are fairly visible and for Puch 1 the interpretation assumed four entrances (Trnka 1991a). In the summer of 1994 an area of 120 × 120 m was magnetically prospected on a grid of 0.5 × 0.5 m.

In the processed magnetogram of Puch 1 (fig. 4) the two circular ditches are shown up very clearly. The magnetogram of the circular ditch delineates the feature outlines and shows many unknown details. Only two entrances were found in the east and west which are clearly visible. In the northern part of the interior a slight concentric anomaly can be detected. These are the last remains of a wooden palisade inside the enclosure. In the southern part of the magnetogram a decrease in the intensity and width of the ditch anomalies is an obvious sign of a bad state of preservation. Topsoil was removed from this area in modern times and filled into a washed-out river bed. The traces of the refilling are visible in the south of the surveyed area. Small anomalies all over the magnetogram are due to iron debris in the ploughed layer.

4.2 Puch 2

Only 160 m away from Puch 1 another circular ditch system is known from aerial photography (Fenster zur Urzeit 1982; Trnka 1991a). The second ditch system looks quite different from the other known monuments of the middle neolithic period and Puch 2 (fig. 5) was therefore thought to belong to a badly preserved Bronze Age settlement. In the spring of 1994 an area of 160 × 160 m was surveyed with a spatial resolution of 0.5 m.

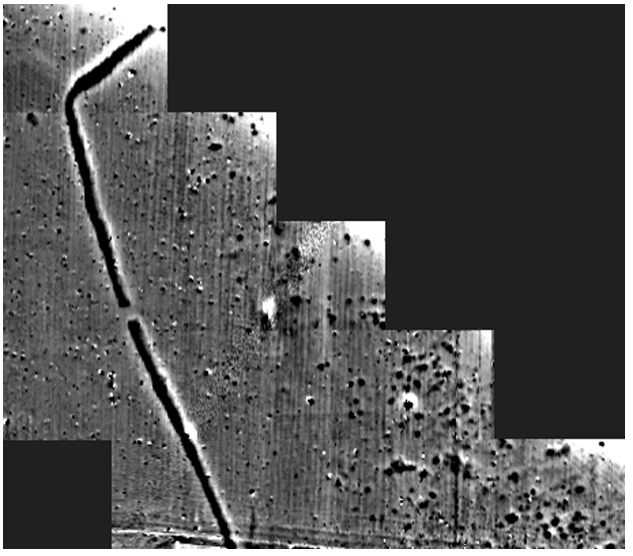

Figure 6. Magnetogram of Weinsteig, corrected raw data, range [-7.3,2.7]nT → [white,black].

The magnetogram shows an interrupted circular ditch. The concentric slight anomaly of a wooden palisade and new excavation results of other monuments underline a neolithic datation also for this ditch. Further research has to provide more information on that specific type of circular ditch systems. Around and inside the enclosure many pit structures were detected. Other anomalies are of geological origin or are due to the boundaries of the old fieldsystem before changing the orientation. These field boundaries respond as filled ditches.

The cross-sections of excavated circular ditch systems are triangular. That is the typical V-shape always observed with middle neolithic circular ditches. The excavated monuments showed that those ditches can be up to 6 m deep and up to 8 m wide. All have at least two and up to 6 entrances in specific orientations. Only well-preserved enclosures show concentric wooden palisades in the interior. Normally the posts were put into a small ditch. The filling of the ditches contains polychrome painted pottery (Lengyel) of high quality, animal bones and sometimes female statuettes. The enclosures must have been of cult use, for all kinds of rituals or meetings. Some have burial pits in the centre or pits with deer burials in the entrances. Because of the orientation of the entrances and lines of posts several prospectors and archaeologists suggest that they were also used for astronomical observations. Anyhow, these circular ditches represent the oldest and largest monumental structures known in European archaeology. Magnetic prospection is the most suitable method for the archaeological exploration of the 35 circular

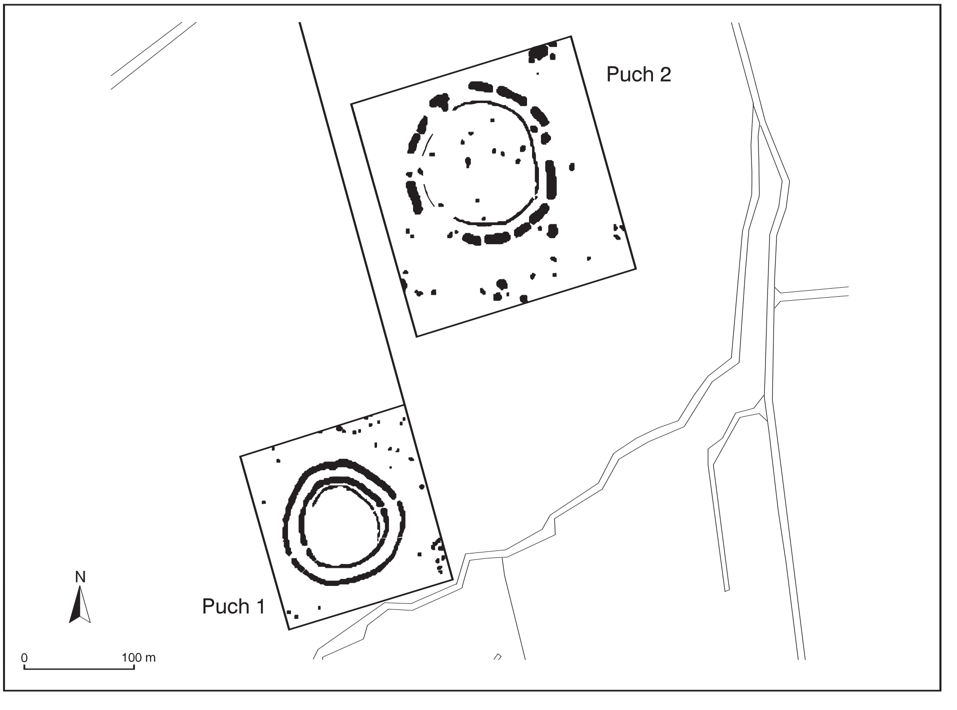

Figure 7. Interpretation map of the middle neolithic circular ditch systems at Puch.

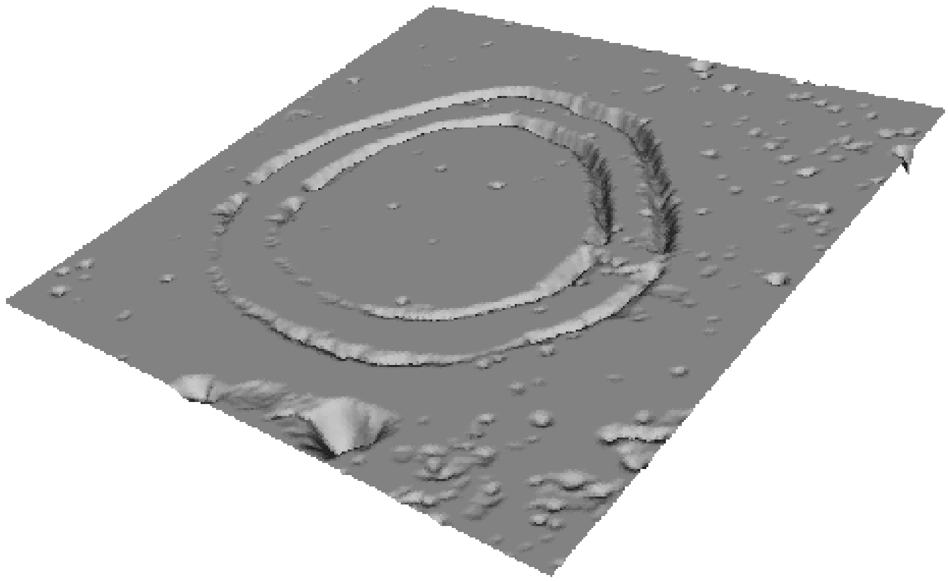

Figure 8. 3-D model of the reconstructed ditches and pits of Puch 1.

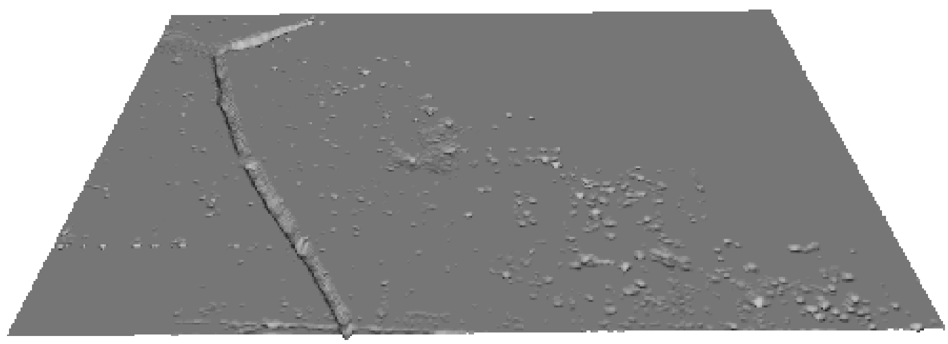

Figure 9. 3-D visualization of the reconstructed ditch and pits of Weinsteig.

ditch systems known in Austria (Melichar/Neubauer 1993; Trnka 1991a).

4.3 WEINSTEIG

Weinsteig is a fortified settlement known again from aerial photography (Fenster zur Urzeit 1982). The habitation is surrounded by a ditch of rectangular plan view with large dimensions of 725 × 350 m (Trnka 1991b). A first survey in the summer of 1994 (fig. 6) covered the northwestern part of the site with an area of 2.72 ha. The ditch is again clearly visible in the magnetogram and a first entrance could be discovered. Many structures, mainly pits can be seen inside the fortification. At this site massive erosion could be detected in the slopes. Only the flat top of the hill where the site is situated shows traces of habitation. Surface findings suggest an early neolithic datation for the extended monument (probably Late Bandkeramik). 3-D modelling of the ditch showed a U-shaped ditch (fig. 9) which seems to be typical of early neolithic fortifications. The surveys will be continued in the next few years.

5 Simulation and 3-D modelling

To understand the development of the prehistoric cultural and economic activities archaeologists try to obtain as much relevant information as possible. For this purpose, large numbers of similar sites must be identified, normally by aerial photography. Evaluation of further details can be done by non-destructive magnetic surveys prior to any excavation. Excavations are always coupled with an irreversible destruction of the investigated archaeological

Figure 10. Aerial photography of Puch combined with a plan view of the modelling of Puch 1 and the magnetogram of Puch 2.

structure. It is also the most expensive way of evaluating archaeological data. Therefore it is desirable to try and build a model of a monument including all relevant and known information prior to any excavation. In our case magnetic prospection data offers the possibility of reconstruction by modelling the subsurface. A model of the basic physical phenomena is constructed and changed until the measured data are accounted for with minimum error (Eder-Hinterleitner 1994). Prior to that, heuristics are used to separate components of the measurements due to archaeological sources from other than natural or modern origins. This is done by a classification algorithm which outputs a probability for each reading. The probabilities are used to separate archaeologically relevant anomalies from others.

The reconstruction algorithm is able to handle a survey of hundreds of thousands of readings at a calculation time of a few hours on modern workstations. The final result is a 3-D model (fig. 8) of the surveyed monument in a resolution of at least the used grid spacing. By input of a 3-D model, a magnetogram can be simulated. Variations of the primary model and the produced magnetograms can be used for training interpreters. The different outputs of magnetometry can also be combined with the aerial photography. In this example (fig. 10) we integrated the magnetogram of Puch 2 and a plan view of the 3-D modelling of the double ditch system of Puch 1.

6 Archiving

The ultimate goal of archaeological prospection is the generation of a visual information system based on all archived prospection data (Scollar 1990). Therefore, all relevant information including aerial photographs has to be digitized. For practical considerations we prefer orthophotos for archiving which are produced by combining digital elevation models and scanned images.

The digital terrain or elevation model (DEM) is measured directly from the aerial photograph with an analogue stereo-interpretation device (Kern DSR14) or with an automatic recording tachymeter in the field. The elevation data is rendered and combined with the outlined interpretations of archaeological features or is used as input to the orthophoto software. Scenic views can be produced by mapping the orthophoto on a perspective view of the digital elevation model. With this technique virtual views of monuments of thousands of years old again become available to archaeologists.

All data together form the basic information material of a database, *the prospection archive* of the Institute for Prehistory at the University of Vienna. For the realization of the already mentioned visual archaeological information system we use GIS-technology (ARC/INFO). From this information system the archaeologist can obtain results by searching either geographically, by type of site or by period. The information from the database and the evaluated aerial photographs or geophysical measurements can then be treated by methods of spatial statistics. That permits the analysis of associations between sites of similar and different types or periods, time or spatial trends and the significance of geographical distribution. Our ultimate aim is the realization of a visual geographic information system which can be used by anyone interested in the study or protection of the buried remains of our past.

note

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Reconstruction of archaeological structures using magnetic prospection[1]

1 Introduction

Archaeological structures in the ground cause small anomalies in the earth's magnetic field due to different magnetic susceptibilities compared to the surrounding ground. These anomalies are measured by high precision magnetometers (Neubauer 1990, 1991). The measured data are preprocessed and displayed as images and manually interpreted by experts (Scollar 1990). The archaeological interpretation of magnetic anomalies is very difficult for several reasons:

1. it is a 2-dimensional projection of a 3-dimensional world;
2. the anomalies of nearby structures may be superimposed;
3. there is always a large amount of noise in the measurement caused by the susceptibility variance of the top soil, by geological structures and by other sources.

Although an expert can estimate whether there is an anomaly of an archaeological structure or not and the probable kind of structure, he or she can estimate only rough dimensions (depth, size, ...) of these structures.

We introduce a method to estimate the position, shape and size of buried archaeological structures by reconstructing a 3-dimensional magnetic model of the subsurface. Our method inverts the idea of simulating magnetic anomalies of archaeological structures of arbitrary shape by dipole sources. A magnetic model of the subsurface is built with homogeneous dipole sources of equal size in a regular grid with different magnetic susceptibilities for different materials (soil, stones, bricks, etc.). The distribution of the dipole sources is automatically arranged so that the differences between the magnetic anomalies of the model and the measured data are minimized.

While the computational costs for the calculation of the anomalies of a subsurface-model are negligible for today's computers, the inverse problem, the determination of the parameters of the subsurface-model is, also with known magnetic properties, a non-deterministic problem with great computational costs. We use the forward modelling method for calculating the anomalies of the modelled archaeological structure and determine the parameters of the model according to an optimization criterion. A special optimization algorithm which is fast enough to find good solutions with the computational power of conventional workstations within a few hours is used.

The reconstruction of filled ditches of the neolithic ring ditch system Puch 1 in Lower Austria is used to demonstrate this method (Trnka 1991). The preprocessed magnetic anomalies of Puch 1 are shown in figure 1. The differences between the total intensities of the earth's magnetic field in 0.5 m and 2.0 m are measured by a cesiumgradiometer in a 0.5 m regular grid. The measured area is 120 m × 120 m, the image therefore has 241 × 241 measuring values. This measurement was carried out by ARCHEO PROSPECTIONS® (Melichar/Neubauer 1993).

2 Method

Figure 2 gives a general view of our method and the data flow through it. After collecting the data in the field they are preprocessed to remove errors.

The reconstruction starts with a classification of the preprocessed data. The classification computes the probability for each data value that does not originate from the expected archaeological structure.

Then, by using the data and the classification the expected archaeological structures are reconstructed. No assumptions about the position and shape of the expected archaeological structure are made, except that the result has to be *smooth*. Therefore this first reconstruction is called *free*.

The free reconstruction is used to determine the nearly exact horizontal positions and a rough estimation of the depth of the expected structures. The detected structures and a modelling of the shape of the expected structures are used to reconstruct the exact position, depth and shape of the expected structures. As the shape of the expected structures and the positions are restricted, the second reconstruction is called *constrained*.

Both reconstruction steps use the same optimization algorithm but the optimization criteria are different. The constrained reconstruction uses a finer spatial resolution.

3 Subsurface model

The subsurface is magnetically modelled by homogeneous dipol sources of equal size in a 3-dimensional regular grid.

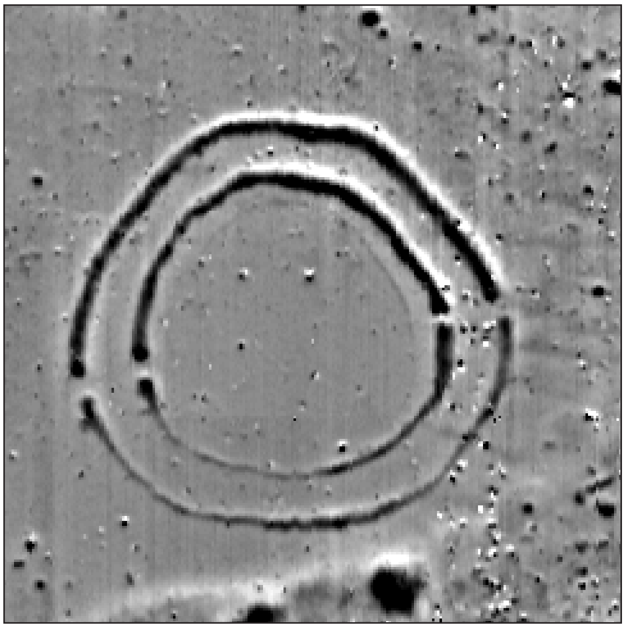

Figure 1. Preprocessed magnetic anomalies of Puch 1. [-4,8]nT → [white, black].

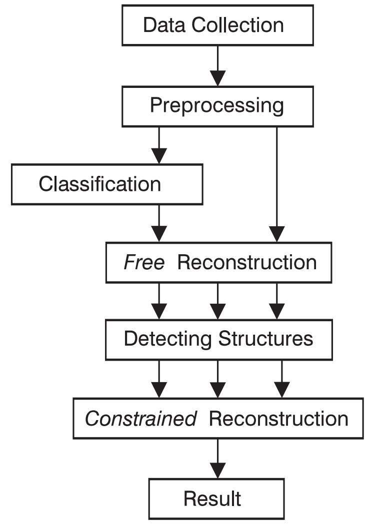

Figure 2. Method of reconstruction.

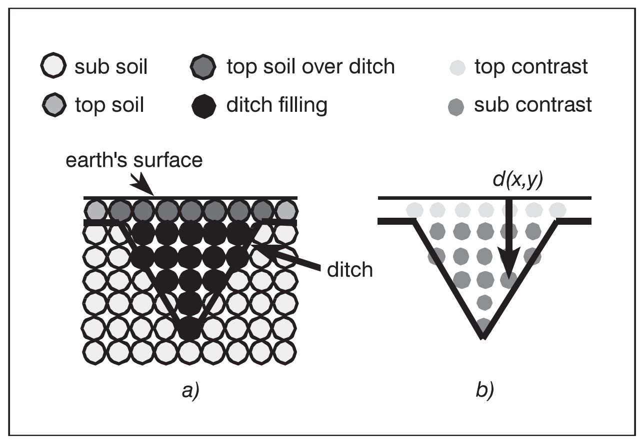

Figure 3. a. Profile of a ditch subsurface model with dipole sources; b. Susceptibility-contrast model of a ditch.

This method was proposed by I. Scollar to simulate anomalies of archaeological origin (Scollar 1969). The advantage of this method is that it is easy to calculate the anomaly of structures of any shape and any susceptibility distribution with any accuracy. The disadvantage, the computational costs for very accurate simulations, becomes less important due to the rapid progress of the power of computers.

Figure 3a, as an example, shows the profile of the modelling of a filled ditch. Each dipole source represents a cube whose sides are 0.5 m long according to the measuring grid of the prospection which was also 0.5 m. Susceptibility measurements of neolithic ditches in Austria lead to a model with four different layers and four different susceptibilities k:

1) top soil (k_t),
2) top soil above and near the ditch (k_d),
3) sub soil (k_s),
4) filling of the ditch (k_f).

The model can be simplified by subtracting horizontal layers which produce a constant magnetic anomaly. Therefore the top soil and the sub soil are removed. The result is a model of the filled ditch with the susceptibility-contrasts (top-contrast k_{tc}, sub-contrast k_{sc}) in an non-magnetic surrounding (fig. 3b).

$$k_{tc} = k_d - k_t \qquad k_{sc} = k_f - k_s$$

This simplification speeds up the computation of the anomalies because only the parts of the subsurface with a ditch are modelled.

Although there is remnant magnetization in the soil, only induced magnetism is considered for the model. It is assumed that the field vector of the ditch anomaly has the same direction as the field vector of the earth magnetic field (Oehler 1987). The remnant magnetization of the ditch is modelled by a higher susceptibility for the induced magnetization.

The magnetic anomaly (A_M) of a ditch is calculated by

$$A_M(x_s,y_s) = \sum_{x_d} \sum_{x_d} \sum_{z_d=0}^{d(x_s,y_s)} Fk(x_d,y_d,z_d)\ VM(x_s,y_s,x_d,y_d,z_d)$$

The subscript s stands for the positions of the sensor(s) and the subscript d for the positions of dipole sources. F is the total intensity of the earth's magnetic field. V is the volume and k the susceptibility-contrast of the dipole source. d is the depth of the ditch at the place (x_s, y_s). The influence of each dipole source on the measuring device is described by M.

For a gradient measuring device with one sensor in 0.5 m and one in 2.0 m M is calculated by (Linnington 1972):

$$M(x_s, y_s, x_d, y_d, z_d) = D(x_s - x_d, y_s - y_d, 0.5 - z_d) - D(x_s - x_d, y_s - y_d, 2.0 - z_d)$$

$$D(x,y,z) = \frac{x^2(3\cos^2 I - 1) + z^2(3\sin^2 I - 1) - y^2 - 6xz\sin I\cos I}{(x^2+y^2+z^2)^{\frac{5}{2}}}$$

D is the anomaly produced by a single dipole source and I is the inclination of the earth's magnetic field. The declination of the earth's magnetic field is neglected.

This model is used for the *free* reconstruction where a first rough estimation of the ditches is calculated by a 0.5 m resolution in the depth. For the *constrained* reconstruction the dipole sources are divided into 5 slices to enhance the resolution to 0.1 m.

4 Reconstruction problem

The reconstruction problem is to find the distribution of the dipole sources of the subsurface model to minimize the difference between the model-anomalies and the measured data. All other parameters, the susceptibilies of the dipole sources, the inclination and the total intensity of the earth's magnetic field, are assumed to be known and constant.

To reconstruct ditches according to our susceptibility-contrast model, the depth d of the filling of the ditch at each measuring point (x_s, y_s) determines the position and shape of the ditch (fig. 3b). It is thus possible to estimate the shape of the ditch by estimating the depth-points d.

Our reconstruction problem is to estimate $d(x_s, y_s)$ for all measuring values by minimizing the square of the difference (E_D) between the model-anomalies (A_M) and the measuring data (A_D):

$$E_D = \sum_x \sum_y (A_D(x,y) - A_C - A_M(x,y))^2$$

A_C is the constant anomaly of the measuring device produced by the removed horizontal layers and all other influences on the sondes. A_C is equal to the mean value of all measuring values.

Two problems appear when using this minimization criterion:

1. The least-square-criterion is not a robust criterion. Big anomalies not caused by a ditch or noise lead to unrealistically deep ditches.
2. The intensity of the anomaly of a dipole source decreases with the third power of the distance of the dipole sources to the measuring device. Thus, deep structures like deep parts of a ditch have very little influence.

Two extensions of the minimization term E_D to solve these two problems are described in the following.

4.1 Robustness

A weighting of the least-squares term is used to make the criterion robust. The weights $w(x,y)$ are a preclassification of the anomalies and represent the correctness of each data value. The weights have values between 1 and 0. 1 stands for a correct and 0 for an incorrect data value. By multiplying the data fitting (E_D) by these weights, anomalies which definitely do not originate from the expected source are neglected. E_D is extended to

$$E_D = \sum_x \sum_y w(x,y)\,(A_D(x,y) - A_C - A_M(x,y))^2$$

For anomalies of ditches, the possible maximum and minimum value (A_{min}, A_{max}) of an anomaly caused by a ditch and the difference between each data value and its four neighbours b are considered. The limits A_{min}, A_{max}, b_{min}, b_{max} are determined interactively for each prospected site.

$$\begin{aligned} b(x,y) = \; & \log(\mathrm{abs}(4A_D(x,y) - A_D(x-1,y) - A_D(x+1,y) \\ & - A_D(x,y-1) - A_D(x,y+1))) \\ w(x,y) = \; & 0 \textit{ if } b(x,y) > b_{\max} \vee A_D(x,y) < A_{\min} \vee A_D(x,y) > A_{\max} \\ & 1 \textit{ if } b(x,y) < b_{\min} \wedge A_D(x,y) > A_{\min} \wedge A_D(x,y) < A_{\max} \\ & (b(x,y) - b_{\min})/(b_{\max} - b_{min}) \textit{ otherwise} \end{aligned}$$

Figure 4 shows the weights used to reconstruct the ditches of Puch. Black areas prevent a fitting of the data.

4.2 Regularization

To get plausible results the *smoothest* result is selected by regularizing the parameters which are optimized. A regularization term E_R is defined describing the relation of each parameter to its neighbours. E_R is multiplied by α to regulate the influence of the regularization. The new minimizing term E_G is calculated by:

$$E_G = E_D + \alpha E_R$$

The depth d of ditches cover a surface representing the border between the ditch filling and the sub soil. Due to the decreasing influence of a dipole source with the third power of the distance between the dipole source and the measuring sensor(s), ditches with too deep positions near too flat ones may occur. To avoid such unplausible ditches the depth d is regularized by smoothing the free reconstruction.

$$E_R = \sum_x \sum_y (2d(x,y) - d(x-1,y) - d(x+1,y))^2 + (2d(x,y) - d(x,y-1) - d(x,y+1))^2$$

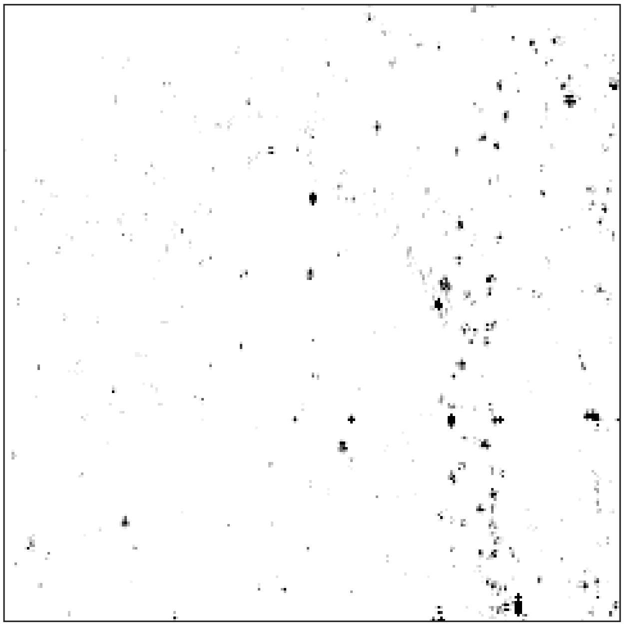

Figure 4. Classification w of Puch 1; [0, 1] → [black, white].

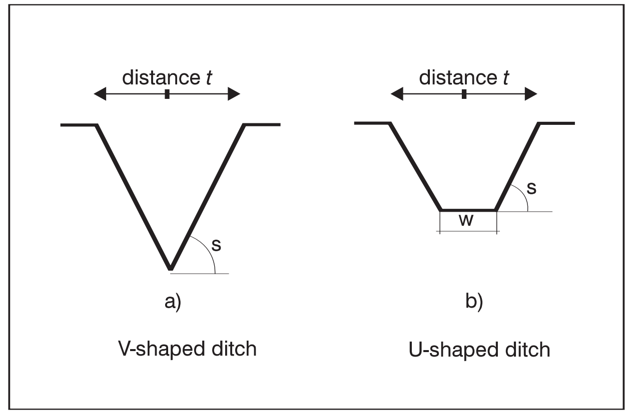

Figure 5. Ditch profile model.

4.3 Modelling

For the constrained reconstruction the expected structure is modelled. A new regularization term E_R describes how close the reconstructed and the modelled structures are. A rough estimation of the position and size of the expected structures is necessary to have good starting solutions for the annealing process.

The ditch profile model assumes that the direction and the middle of the ditch are known and that the ditch is symmetric. The normal distance t of each position (x,y) to the middle of the ditch is computed. By using t, the relative difference between each depth d and its four neighbours can be calculated locally. This local information is necessary for optimizing in subimages (see below).

For a V-shaped ditch (fig. 5a) only the slope s, for a U-shaped ditch (fig. 5b) also the width w of the bottom of the ditch has to be defined. No assumptions about the true depth d are made. The ditches are modelled from the bottom to the top. This model takes into account that filled ditches are eroded from the top to the bottom. The new regularization term E_R for a V-shaped ditch (for areas above a ditch) is:

$$E_R = \sum_x \sum_y \sum_{i=1}^{4} diff_i^2(x,y)$$

$$\begin{aligned}
diff_1(x,y) &= d(x-1,y) - s(t(x,y) - t(x-1,y)) - d(x,y)\\
diff_2(x,y) &= d(x+1,y) - s(t(x,y) - t(x+1,y)) - d(x,y)\\
diff_3(x,y) &= d(x,y-1) - s(t(x,y) - t(x,y\text{-}1)) - d(x,y)\\
diff_4(x,y) &= d(x,y+1) - s(t(x,y) - t(x,y+1)) - d(x,y)
\end{aligned}$$

The middle of the profile and the direction of the ditch are calculated in the detecting structures step (fig. 1). The detection of ditches is described below.

5 Optimization algorithm

For reconstructing ditches by using the susceptibility-contrast model, the depths d have only discrete values. Therefore the minimization problem is a combinatorial optimization problem. But this optimization problem has some further special conditions:

1. Many parameters have to be determined. The number of parameters is equal to the number of measuring values ($p = n \times m$).
2. The parameters have only a few discrete values. The number of different values (v) is ~10 for the free reconstruction and ~50 for the constraint reconstruction.
3. There are v^p different solutions. For the site Puch 1 with an area of 14,400 m^2 there are $10^{58,081}$ different solutions for the free reconstruction. (It is not possible to evaluate all of them!)
4. The parameters have a limited spatial relation due to the decreases of the magnitude of the magnetic field of a dipole source with the third power of the distance.

A partially iterative random search algorithm called *leaped annealing* is used to find a solution to this optimization problem (Eder-Hinterleitner 1994). Leaped annealing is similar to *simulated annealing* (Kirkpatrick *et al*. 1983; Romeo/Santigiovanni-Vincentelli 1991). Both have a term T, called temperature, which decreases with the progress of the algorithm and which determines the ability to leave a local minimum. The higher the temperature the easier it is to leave a local minimum. Whereas this is done in simulated annealing by accepting worse solutions temporarily, in leaped annealing it is done by changing the

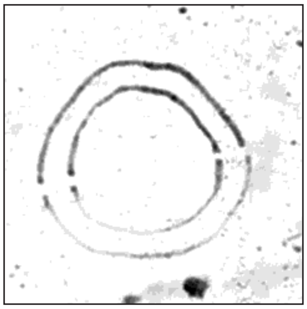

Figure 6. Free reconstruction of Puch 1; d: [0, 2] m → [white, black].

Figure 7. Ditches at depth d = -0.5 m.

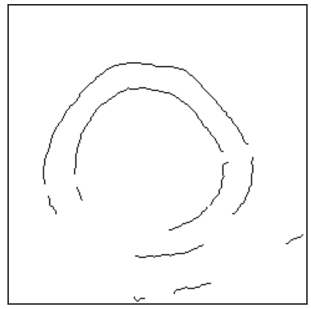

Figure 8. Middle line of the detected ditches.

Figure 9. Distance t to the middle of the ditch; [0, 5] m → [black, white].

possible distance of the new solution to the old one. While the solution has to move up and down along the optimization-function in simulated annealing, it jumps from one random place to another and it never has to accept a worse solution in leaped annealing. At the beginning of the leaped annealing algorithm every possible state in the search space can be reached from every other state in one step.

The annealing process is not applied to the whole image at once but to subimages of 2 by 2 pixels in size due to the limited spatial relations of the dipole sources to each other. These subimages are optimized separately but in parallel to consider the mutual influence. The splitting into subimages reduces the solution space and is necessary to reach every possible state from every other state in one step. The algorithm converges as fast as possible when only about 10 percent of the subimages are changed during each iteration. With leaped annealing only 10^4 of $10^{58,081}$ possible solutions have to be evaluated to get a *good* result.

The algorithm is used for both the free and the constrained reconstruction.

6 Reconstructing ditches

The method is demonstrated by the reconstruction of the neolithic ring ditch system Puch 1. The result of the magnetic prospection survey is visualized in figure 1, the classification in figure 4. The magnetic parameters for the reconstruction are:

F = 48000 nT $\quad$ I = 65° $\quad$ V = 0.125 m^2

k_{tc} = 70 10^{-5} $\quad$ k_{sc} = 100 10^{-5}

The result of the free reconstruction is visualized in figure 6. It can be clearly seen that the upper half of the ditch is well preserved while the lower half is mostly destroyed. The regularization leads to a smooth ditch, yet, the ditch is too wide at the top and not deep enough in the middle. The varying shape of the ditch is caused by the inhomogeneous susceptibilies of the ditch filling. Although the ditch is too wide, it is well located. Many pits are also reconstructed.

6.1 Detecting ditches

To localize the ditches the result of the free reconstruction is first convolved with a 5 × 5 mean filter for smoothing. Then a threshold (fig. 7) at d = -0.5m is taken. The black areas are an estimation of the shape of the ditch after removing the A-horizon.

The middle of the ditch (fig. 8) is calculated by thinning the threshold image and removing short lines. Figure 9 visualizes the normal distance t of pixels which are above the ditch using the middle line (fig. 8) and the thresholded image (fig. 7). To overcome the disadvantage of the discretization in a 0.5 m grid the normal distances t are calculated with subpixel precision. The normal distances to a regression line calculated by using the next five pixels on the middle line are computed.

6.2 Constrained reconstruction

The constrained reconstruction uses the modelling of the profile with a discretization of the depth d of 0.1 m. A V-shaped ditch with a slope s=45° is modelled. The 3-dimensional visualization (fig. 10) gives a realistic impression of the remains of the ditches. In the best preserved areas the ditches are 4.5 m wide and 2 m deep. The two entrances are between 3 m and 5 m wide. The extensive destruction of both ditches towards the front was caused by soil removal when the site was graded. The soils removed fill the large pits at the very front of the reconstruction.

The many small pits look like flat basins due to the smoothing of the depth d. A modelling of the expected shape of the pits would lead to more realistic results.

The remains of the palisade, which can be seen partly in the anomalies, are not reconstructed due to the large horizontal grid of 0.5 m.

The whole reconstruction procedure, the determination of 58,081 parameters, of Puch 1 requires 2 hours of processing time on a Sun SPARCstation 20.

7 Conclusion

We present a method for the reconstruction of a 3-dimensional magnetic subsurface model with dipole sources. The reconstruction problem is formulated as a minimization problem. The difference between the model anomalies and the measured data as well as a regularization or modelling term are minimized by determining the distribution of the dipole sources using an iterative random search annealing algorithm. Although the optimization problem has a very large solution space, a practicable method by dividing the problem into many small subproblems is achieved. Dividing into subproblems offers the possibility of using massive parallel computers to speed up the annealing process by the number of available processors.

The method has two reconstruction steps to combine the following characteristics:

1. no assumptions about the location of archaeological structures are necessary,
2. pre-information about the expected archaeological structure can be integrated into the reconstruction process.

The first step determines rough positions and depths of the expected structures by using a rough subsurface model. The second one uses a finer resolution and a modelling of the expected structures to estimate the exact positions, depths and shapes of the archaeological structures.

The ring ditch system Puch 1 is modelled, reconstructed and visualized to demonstrate the method.

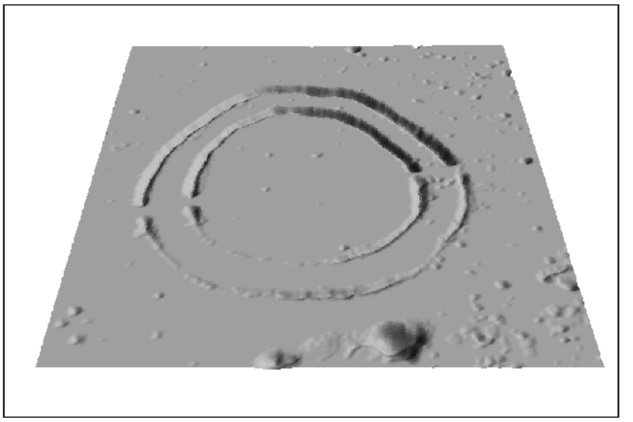

Figure 10. 3-dimensional visualization of reconstructed ditches of Puch 1.

This procedure can be easily applied to other archaeological structures, like pits, walls, etc. New regularization and modelling terms have to be developed, but the modelling with dipole sources and leaped annealing for solving the resulting optimization problem can also be used.

Acknowledgement

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note

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Phil Perkins

An image processing technique for the suppression of traces of modern agricultural activity in aerial photographs

1 The problem

Agricultural activity can make buried archaeological sites visible from the air. Ploughing creates soil marks and sowing creates crop marks. However, mechanised agriculture also creates other patterns in the soil or in crops. Ploughing leaves regular furrows and mechanised sowing leaves fine alignments of plants in the field and fertilisation or pesticide treatments can leave regular tractor tracks across fields. Traces of this agricultural activity are also visible from the air and may mask or confuse archaeological crop marks or soil marks. Archaeologists have employed image processing to aerial photographs for many reasons (Booth *et al*. 1991) and it offers some hope of enhancing this particular form of 'noise'.

A first approach in such cases where there is unwanted fine detail, such as furrows, is to convolve the image using an averaging filter. This removes fine detail in the image leaving coarse detail visible. However, the filter is indiscriminate and has the effect of blurring everything in the image equally. Certainly it removes traces of sowing and tractor tracks but it also corrupts the crop marks which are clearly visible in the data which have been removed from the image in the filtering process (fig. 1).

What is required is a filter which can discriminate between the regular traces of agriculture and the less regular traces of archaeological structures. Edge suppression filters offer some hope but in practice the edges of the archaeological features are also suppressed, reducing their legibility.

2 A solution

A solution to this problem is possible if we consider the image in the frequency domain as a sum of phase shifted sine waves. Determining which sine waves to use is the major concern of Fourier Analysis. Information about the amplitude and phase shift of the sine waves can be encoded as a Fourier transform, and since it is discrete sampled data we can use the Fast Fourier Transform. The image may now be filtered in the frequency domain as we might in the

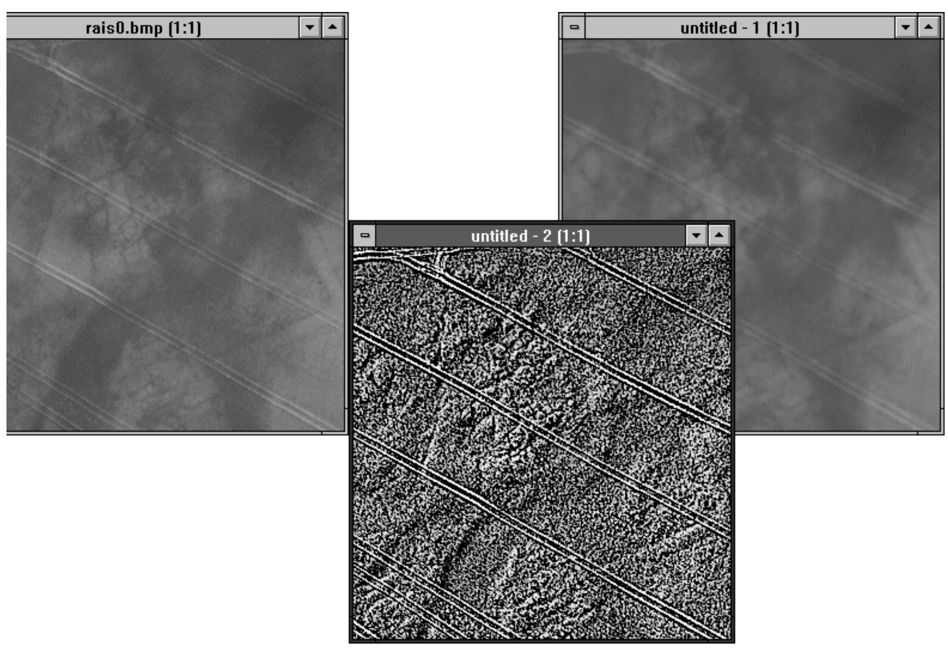

Figure 1. Left: the original photo. Right: blurred image after applying a 3×3 averaging filter. Centre: an equalised image of the difference between the before and after images. Many of the traces of the tractor tracks and alignments of plants have been removed and so are visible in the difference between the two images, however the crop mark itself is also visible and so has been corrupted.

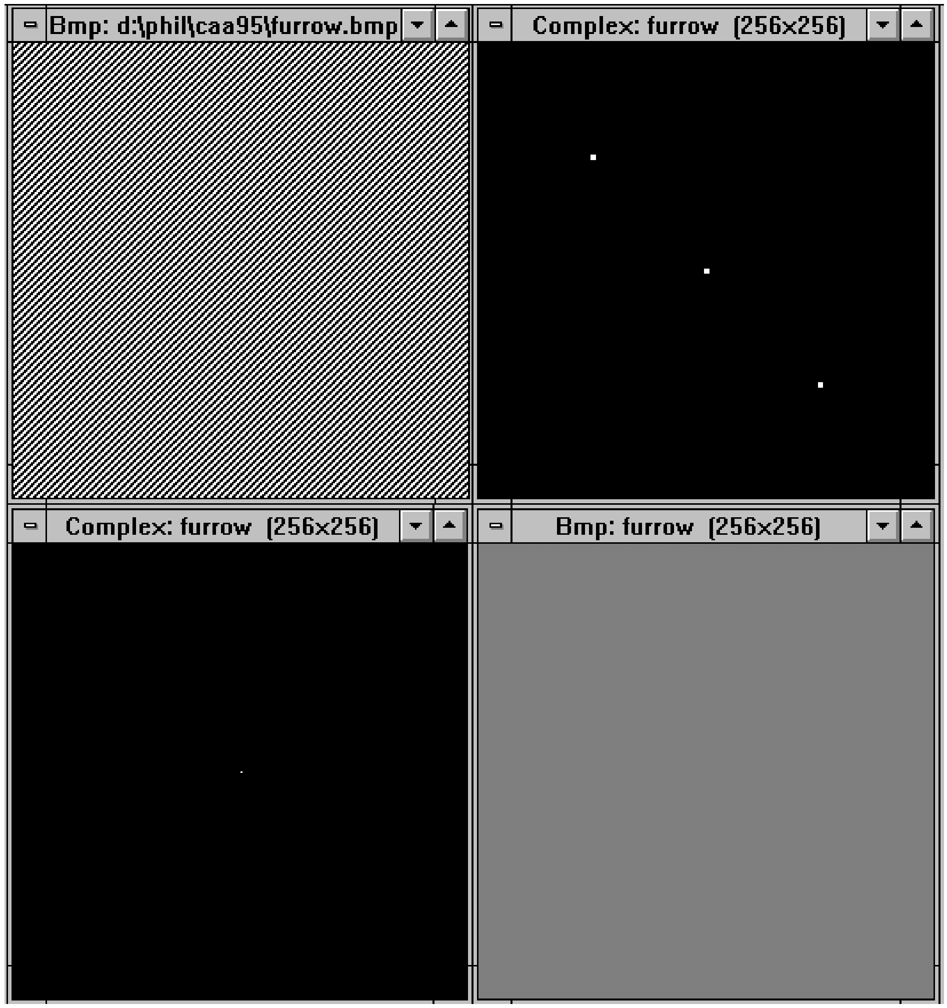

Figure 2. Frequency filtering applied to a data set simulating a ploughed field. Top left: simulated data. Top right: Fast Fourier Transform of simulated data. Bottom left: Fast Fourier Transform filtered by hand. Bottom right: Inverse Fast Fourier Transform of filtered simulated data.

spatial domain. Truncation of the high frequencies is equivalent to blurring the image in the spatial domain, that is the high frequencies are filtered out (the technique is fully described in theory in the context of antialiasing in Foley *et al*. 1990: 623-46). Filtering in the frequency domain allows the possibility to selectively filter the transforms of the coarseness or fineness of regular patterning along with the orientation of features in the spatial (unfiltered) domain.

2.1 Simulated data

In order to test the effects of frequency filtering and explore its impact on defined signals, a simulated data set consisting of a 256 × 256 pixel field of black and white diagonal lines representing furrows at 45° was created (fig. 2 top left). When transformed to the frequency domain with a Fast Fourier Transform the image appears as three bright dots aligned at 45° (fig. 2 top right). Filtering this image by hand these outlying peaks of high frequency are removed (fig. 2 bottom left). The Inverse Fast Fourier Transform applied to transform this filtered image back to the spatial domain results is a uniformly mid-grey field — the furrows have been effectively removed by filtering out their frequencies (fig. 2 bottom right). The filtering is extremely effective on such a simple image. However, add a simulated round barrow to the simulated field (fig. 3 top left) and the Fast Fourier Transform of the image appears much more complex (fig. 3 top right). Filtering out the frequencies known from the previous experiment to remove the traces of the furrows only (fig. 3 bottom left) and applying the Inverse Fast Fourier Transform (fig. 3 bottom right) effectively removes the traces of the furrows. The simulated round barrow, which was originally uniformly grey, rather than furrowed, has taken on zebra stripes due to the fact

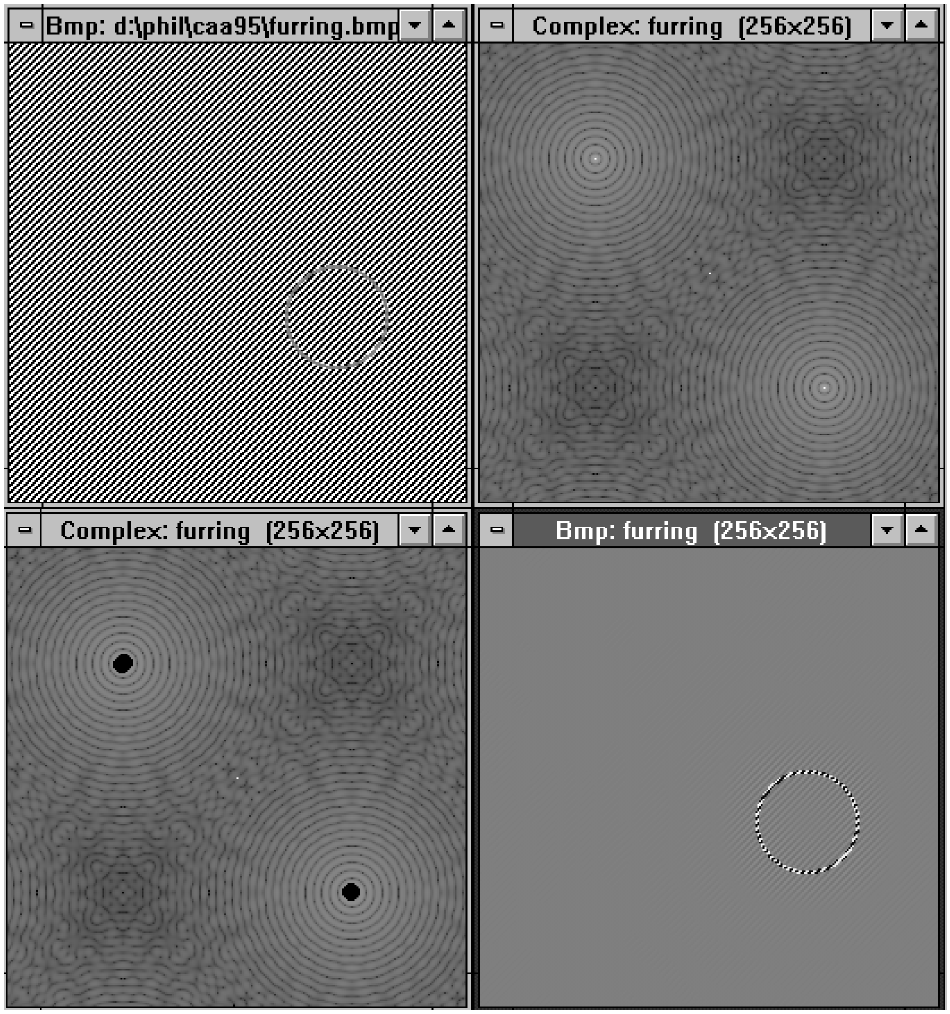

Figure 3. Frequency filtering applied to a data set simulating a ploughed field with a circular soil mark. Top left: simulated data. Top right: Fast Fourier Transform of simulated data. Bottom left: Fast Fourier Transform filtered by hand. Bottom right: Inverse Fast Fourier Transform of filtered simulated data.

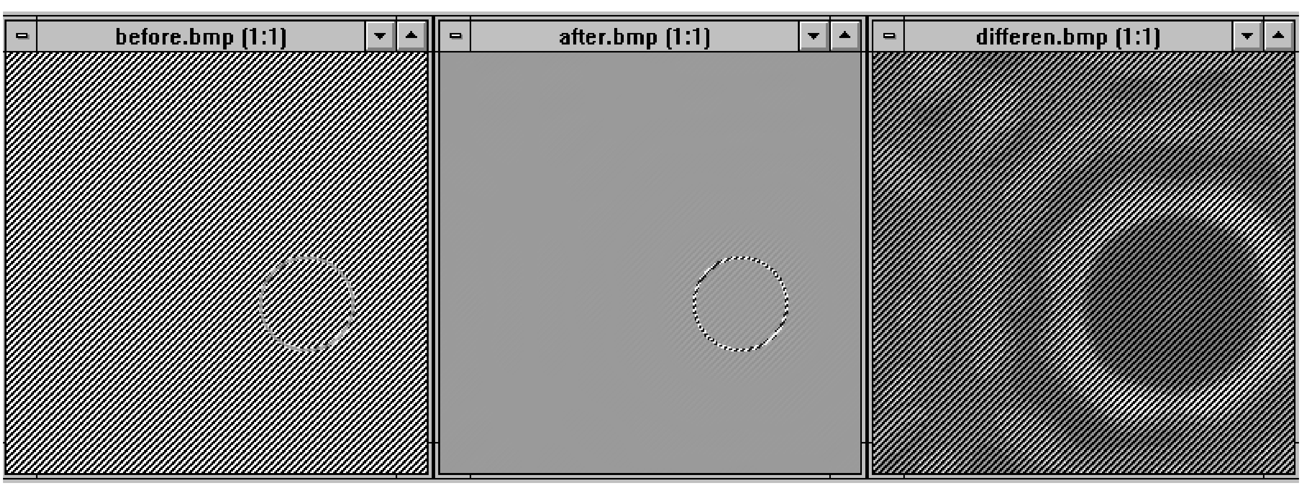

Figure 4. The simulated data of a ploughed field with a circular soil mark is shown before filtering (left) and after filtering (centre). The equalised difference between the two (right) shows, in an exaggerated way, the nature of the part of the signal that has been filtered out.

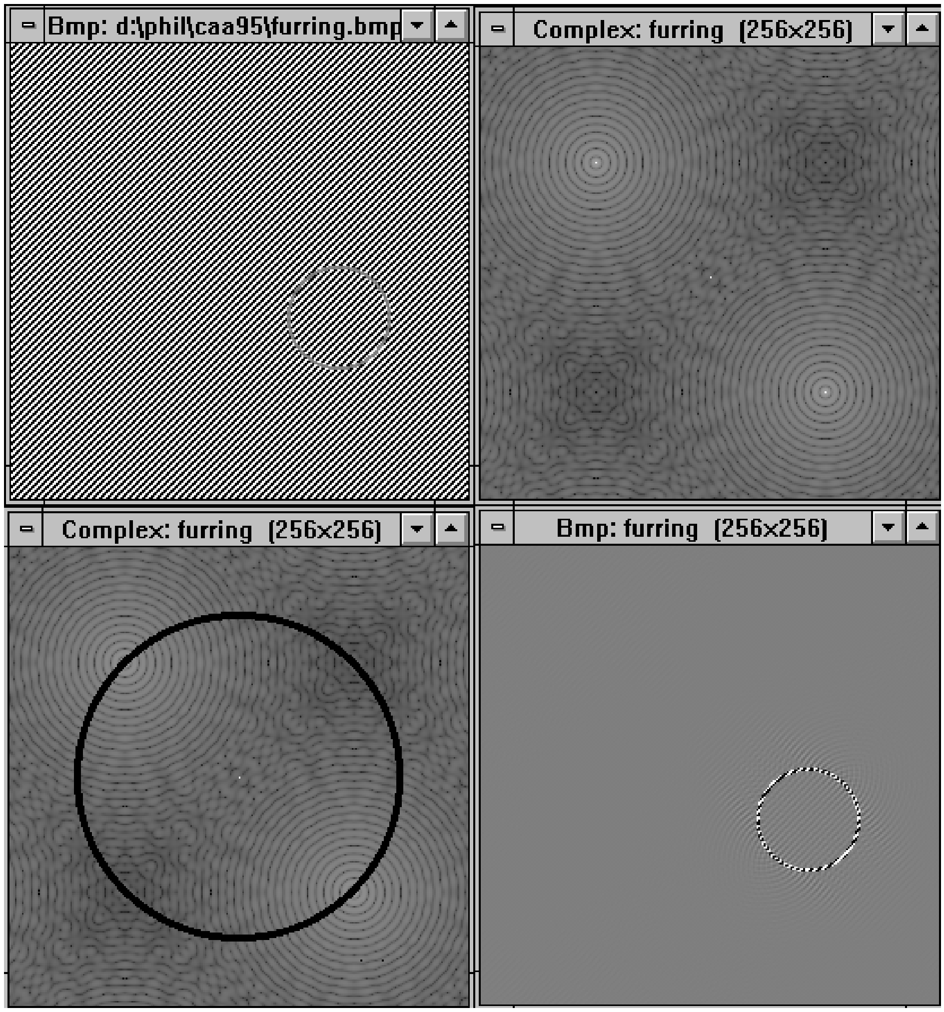

Figure 5. Frequency filtering applied to a data set simulating a ploughed field with a circular soil mark. Top left: simulated data. Top right: Fast Fourier Transform of simulated data. Bottom left: Fast Fourier Transform filtered with a band stop filter. Bottom right: Inverse Fast Fourier Transform of filtered simulated data.

that the values representing the furrows have been subtracted from it too. Around the ring there is some 'rippling' in the uniform grey of the field indicating that the technique is not perfect when more complex images are filtered. This is visualised in figure 4 where the simulated data is shown before (left) and after (centre) filtering and the equalised difference between the two (right) shows, in an exaggerated way, the nature of the part of the signal that has been filtered out.

Other filters instead of a heuristic hand filtering may also be applied to transformed images. For example a band stop filter, i.e. stopping the frequency which coincides with the peaks in frequency representing the furrows is applied in figure 5. The results are similar but the 'rippling' around the ring has a different form. The Fast Fourier Transform of a simulated complex crop mark (fig. 6 top left and right) can be seen to be more complex and less structured than the simple simulation. The filtering is still effective but the 'rippling' effects become more apparent closer to the simulated soil mark (fig. 6 bottom left and right).

Using real world data, figure 7 illustrates a variety of filtering strategies applied to the same photograph. The first column on the left shows at the top the image before filtering and below the Fast Fourier Transform of the image. The second column shows at the top a heuristic filter removing only low frequencies, in the centre is the

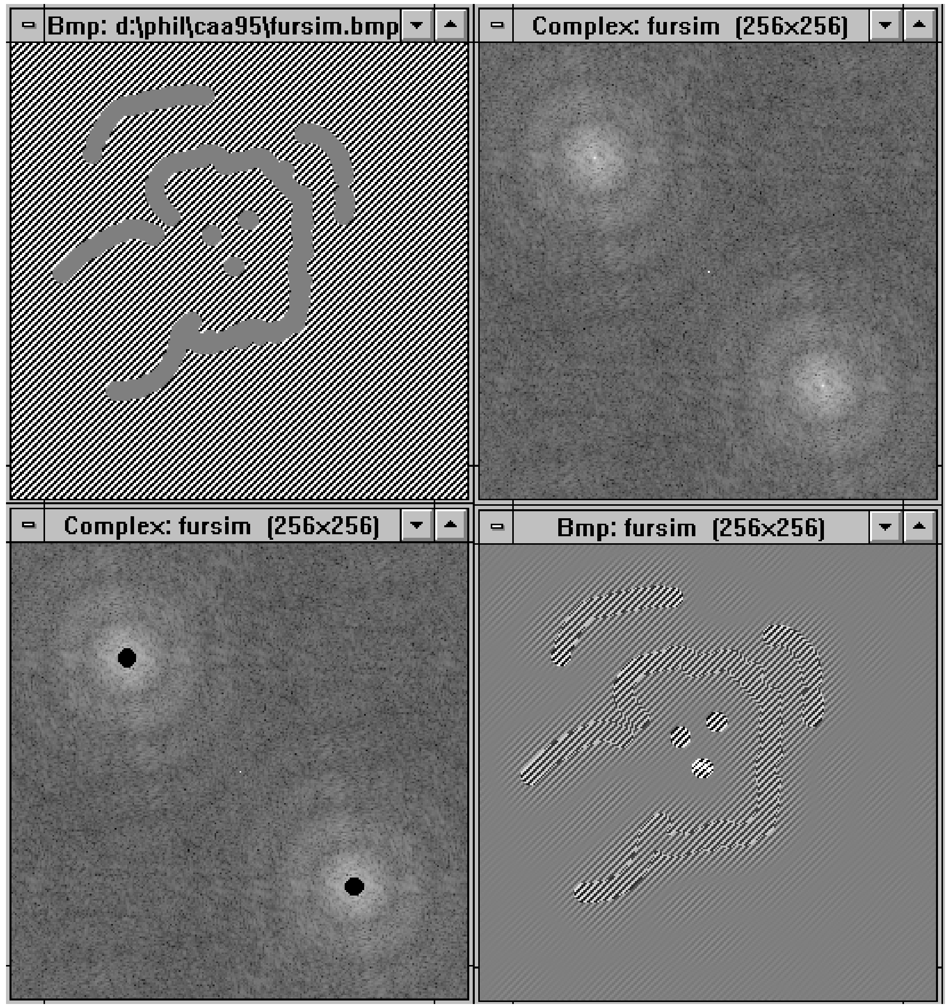

Figure 6. Frequency filtering applied to a data set simulating a ploughed field with a complex soil mark. Top left: simulated data. Top right: Fast Fourier Transform of simulated data. Bottom left: Fast Fourier Transform filtered by hand. Bottom right: Inverse Fast Fourier Transform of filtered simulated data.

filtered image and at the bottom an equalised image of the difference between the image before and after the filtering. Similarly the third column removes middle frequencies and the fourth only high frequencies. The fifth column on the right removes all frequencies with a particular frequency. Different filtering strategies may be adopted according to the nature of the noise to be removed from the image.

The Fourier Transform can only be applied to single band data, e.g., greyscale images only. To filter 'true' colour images it is first necessary to split the image into individual channels, in this case at Gussage All Saints red, green, blue. Each channel is then filtered separately and then the three filtered images may be recombined from the channels to produce a 'true' colour filtered image (fig. 8). Although differing parts of each band are filtered out when used carefully the technique does not impair the colour balance of the image.

3 Conclusions

This technique of filtering images of aerial photographs in the frequency domain has been found to be effective in the removal of systematic 'noise' in the images. It has been used in experiments to remove traces of ploughing thereby enhancing soil marks, traces seeding in young and mature crops, and tractor or machine tracks. It has been tested on images of regular olive groves but with limited success.

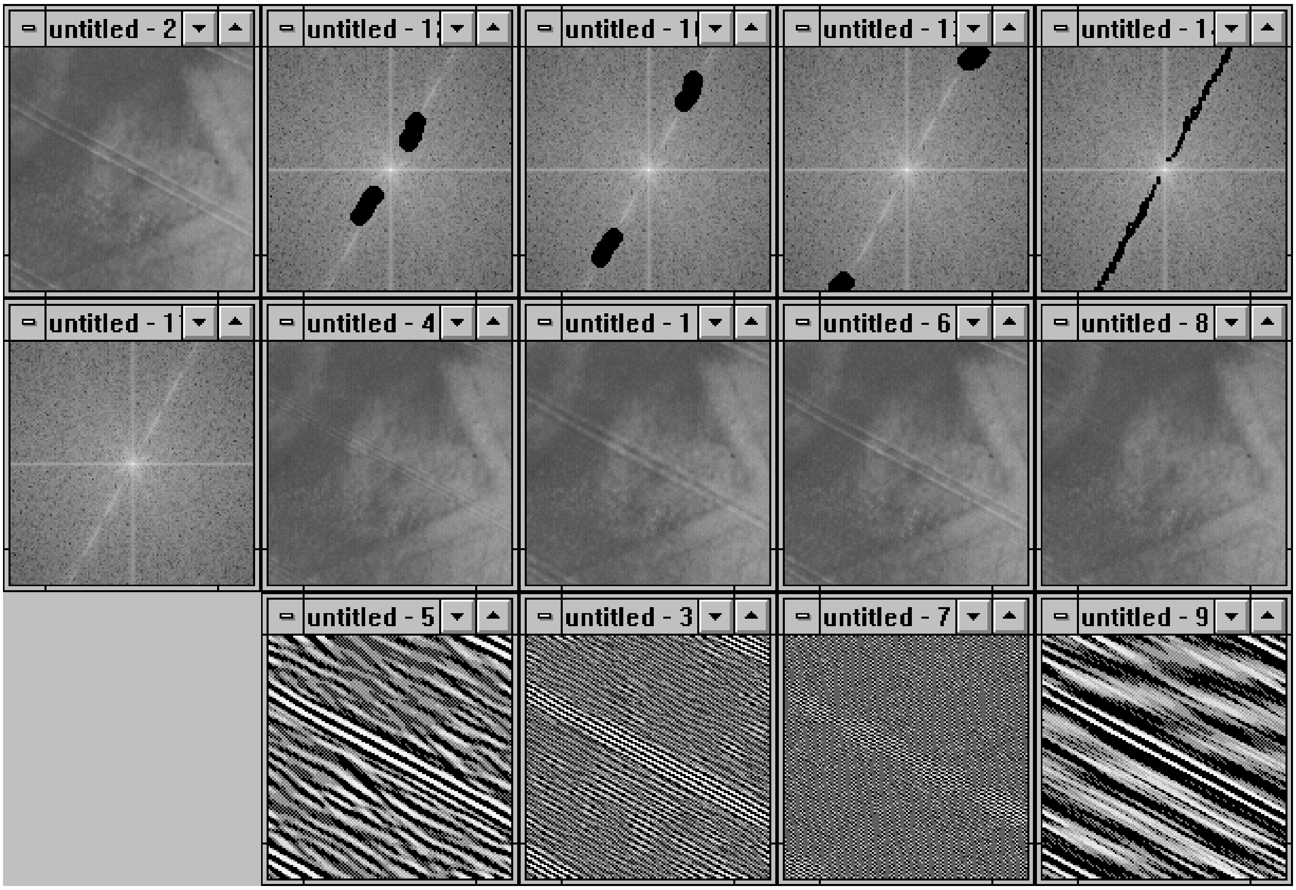

Figure 7. A variety of filtering strategies applied to the same photograph. The first column on the left shows at the top the image before filtering and below the Fast Fourier Transform of the image. The second column shows at the top a heuristic filter removing only low frequencies, in the centre is the filtered image and at the bottom an equalised image of the difference between the image before and after the filtering. Similarly the third column removes middle frequencies and the fourth only high frequencies. The fifth column on the right removes all frequencies with a particular frequency.

Such filtering has its limitations: the mathematics requires the image to be a perfect square, and large squares are computationally intensive. Most significant is that the filtering will only be effective on certain images. The 'noise' in the image, e.g. ploughing, needs to be reasonably regular in its linearity, spacing and orientation for good results to be obtained. The filtering will work on any square image, but if there is no regular 'interference' in the image, the Fourier Transform of the image becomes relatively even and offending frequencies become difficult to identify and filter out.

The technique has only been tested on aerial photographs to date but other forms of remote sensing, particularly those prone to banding due to systematic instrumentational mis-alignment or those that also detect agricultural phenomena might also benefit from filtering in the frequency domain.

Technical note

Large images were processed on a Sun Sparc IPX running IP an image processing suite which uses VIPS an image processing library written in C and developed as part of the VASARI Project at Birkbeck College. Smaller images were processed using a combination of Aldus PhotoStyler and ProFFT V. 1 a project developed by Marius Kjeldahl and four other students learning C++ at the Norwegian Institute of Technology, Trondheim, running on a variety of Viglen PC's.

Acknowledgments

Thanks are due to Blaise Vyner who provided many of the aerial photographs used to experiment with the technique and to Kirk Martinez who introduced me to the frequency domain.

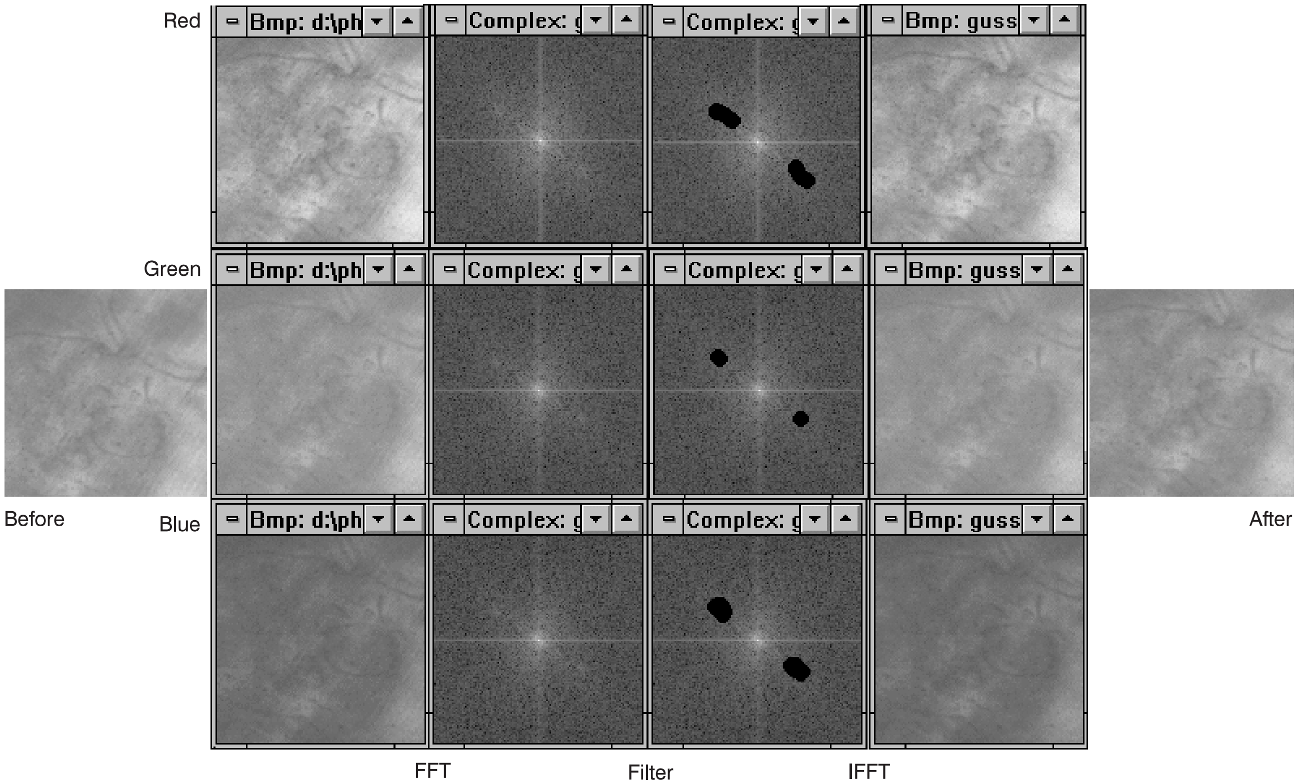

Figure 8. To filter ‘true’ colour images split the image into individual channels. Each channel is then filtered separately and then the three filtered images may be recombined from the channels to produce a ‘true’ colour filtered image. This image is of the Iron Age enclosure at Gussage All Saints (Original © Crown Copyright).

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Statistics and Classification

Clive Orton

Markov models for museums

1 Introduction

This paper is a sequel to studies of the use of sampling methods in the assessment of the condition of museum collections, carried out at the Museum of London (Keene/Orton 1992) and the British Museum (Leese/Bradley 1995). These studies looked mainly at the problem of obtaining a 'snapshot' of the condition of a collection at a point in time; this paper looks at the related problem of monitoring changes in condition over time.

The methods described below arose from a request from the Horniman Museum in south London for advice on the statistical aspects of monitoring the condition of the Museum's collections, following a 'census' of their condition (Walker/Bacon 1987). The design work was mainly done in 1991, but for various reasons (including the subsidence of the Ethnographic Gallery) has not yet been fully implemented. As the Museum is now fully engaged in preparations for its Centenary in 2001, it seems useful to publish 'the story so far' without waiting for full implementation.

2 Background

The Museum has three separate collections: ethnography, natural history, and musical instruments. In each collection, objects are stored by location code (e.g. type of object) and within that, by broad provenance. In the course of the census, information had been recorded on the condition of every object, on a four-point scale of priority: G (good), F (fair), U (urgent), and I (immediate), reflecting the need for remedial treatment. These correspond roughly to the four conservation priorities of the Museum of London survey (Keene/Orton 1992: 163) — Little, Low, High and Urgent — but the precise definitions may differ. Objects were generally recorded individually, i.e. one to each line of the census form, but the records for some types were 'bulked', e.g. recorded as 'F(X5), G(X20)' (meaning five objects in fair condition and twenty in good condition) on one line. It was believed that, for most types, the objects included in a 'bulk' record could be recognised individually in any subsequent survey. Exceptions are the eggs and fossils groups of the natural history collection; a different approach is needed for such groups (see below).

3 Aim

The aim was to design a system of sample surveys which would enable the condition of the collections to be monitored annually. Particular attention was to be paid to:

i. locating problem areas in stores ('hot spots'),
ii. identifying problem materials, with implications for specialist help,
iii. assessing long-term trends, e.g. suitability of particular stores,
iv. assessing staffing implications.

Points (i) to (iii) are inter-related, in that 'hot spots' are likely to occur where the environment is wrong for the type of material stored there, while 'problem materials' are usually only problems in terms of long-term preservation if they are in the wrong environment. The long-term suitability of particular stores will depend on material types and their needs. In museums which do not store objects by function and type, these points will be less interconnected.

It is not practical to carry out a census every year, nor is one needed in order to meet these aims. The need is for sample survey methods which will enable (a) the numbers of objects currently in each of the four priorities, and (b) the rate of movement of objects from one priority to another, to be estimated for each type of object.

4 Model

Objects must at any point in time be in one, and only one, of the four priorities. They may at any time move from a priority to a higher priority (i.e. their condition may worsen), but they cannot (without intervention) move to a lower priority. We cannot observe this process directly: all we can observe is the condition of selected objects at fixed intervals of time (in this example, the interval is one year). This situation can be modelled as a Markov chain (Cox/Miller 1965: 84), in which the probability of objects moving from one priority to another is expressed as a matrix of 'transition probabilities' p_{ij} from state i to state j over the fixed interval. The 'states' of the statistical theory correspond to the priorities described above.

For any chosen group, we say that the number of objects in the census, held at time 0, is $N(0)$, of which $N_i(0)$ (i = 1, …, 4) are in the i th priority (G, F, U, I). The number $N_j(t)$ in the j th priority at time t is given by

$$N_j(t) = \sum_i N_i(t\text{-}1)p_{ij},\ i = 1, \dots, 4;\ j = 1, \dots, 4;\ t = 1, 2, \dots,$$

or in matrix notation $\boldsymbol{N}'(t) = \boldsymbol{N}'(t\text{-}1)\boldsymbol{P}$.

The transition matrix $\boldsymbol{P}$ is initially given the form

$$\boldsymbol{P} = \begin{matrix} p_{11} & p_{12} & p_{13} & p_{14} \\ 0 & p_{22} & p_{23} & p_{24} \\ 0 & 0 & p_{33} & p_{34} \\ 0 & 0 & 0 & p_{44} \end{matrix}$$

where $\sum_j p_{ij} = 1$ for i = 1, …, 4.

This model is a simplification, and in real life further factors would have to be taken into account:

1. gain of objects: at any time, new objects may be added to the collections,

2. loss of objects: at any time, objects may be removed from the collection, either by disposal, by temporary absence (e.g. for display, or for loan to another museum), or because they have decayed irretrievably. Depending on the exact meaning given to the priority 'immediate', one might say that any object in priority I in year t will have decayed irretrievably by the year $t + 1$ (or perhaps $t + 2$?). This could be modelled by introducing a fifth priority D (= dead)), with a transition probability p_{45} depending on the definitions (e.g. p_{45} = 1),

3. remedial action to individual objects: surveys of collection condition are set in a context of programmes of conservation work designed to maintain or improve the overall condition of a collection. Thus the 'below diagonal' elements of the transition matrix $\boldsymbol{P}$ will not in practice be zeros. However, there are benefits in using survey data to monitor condition 'without treatment', and to write in transition probabilities reflecting actual or planned treatment programmes.

4. remedial action to stores: as one aim of monitoring is to improve overall storage conditions, it would be surprising and disappointing if the transition probabilities did not change over time, with the aim being to increase the 'diagonal' elements and decrease the 'above diagonal' ones. This means that the transition probabilities should be re-estimated at each survey, to see whether improvement has in fact taken place.

The fourth point might seem to invalidate the use of the Markov chain model, since that model assumes that the transition probabilities are independent of time (Cox/Miller 1965: 84). However, the model can be usefully employed to predict the future condition of a collection on assumptions of (for example) no intervention, or intervention at a set level of conservation of objects, and to assess the likely impact of different programmes of intervention.

The predictive abilities of a Markov chain model arise from its independence from time. Since $\boldsymbol{N}'(t) = \boldsymbol{N}'(t\text{-}1)\boldsymbol{P}$, the matrix $\boldsymbol{P}$ can be estimated by comparing $\boldsymbol{N}(0)$ (the census) with $n(1)$ (results from the first survey). This can be used to predict, or more correctly project, $\boldsymbol{N}(t)$ as $\boldsymbol{N}'(0)\hat{\boldsymbol{P}}^t$, although it must be realised that, as t increases, errors in the estimate $\hat{\boldsymbol{P}}$ will accumulate through successive $\boldsymbol{N}$ s, which will therefore become less and less reliable. Although they are not to be believed, such projections have considerable descriptive, political and management value. They can provide a dynamic description of condition: not just the present state, but also incorporating rates of change. For example, one could use the formula to project the date by which a certain proportion (e.g. 50%) of a collection will be in priority 4 (immediate), and hence (for example) the likely half-life of the collection. Such a figure could be used to highlight a need for additional resources, and the effect on such a date of the application of extra resources could be calculated. Projections made on the basis of successive surveys could show whether the collection is 'gaining' or 'losing' ground, according to whether the expected life (or half-life) is increasing or decreasing.

It has been pointed out that in standard Risk Assessment models the risk is assessed as:

Risk = Threats + Vulnerabitities + Asset value.

In the museum context, the 'asset value' of an object is made up of its historic value, its uniqueness, and its relevance to the institution. The overall condition should in principle be weighted to take account of this, since a collection in which a few valuable objects were deteriorating rapidly, while the rest were relatively stable, would be in worse condition than the raw data would imply. This has not been attempted in this survey; it would be straightforward to take account of variations is asset value between types, but much more difficult for variation within types.

5 Sample design and implementation

5.1 Sampling: theory

It seems reasonable to make each group or location code (see above) correspond to a stratum in the statistical sense, and to use stratified random sampling methods. Results can then be obtained separately for each group (type of object) and aggregated to give an overall picture of the collection.

For any one stratum, we suppose that the population at the time of the survey is N, and that a sample of size n is selected. For the objects in this sample, we know both their priority at the time of the census and their priority at the time of the survey. The number in the i th priority at the census we call $n_{i.}$, the number in the j th priority at the survey we call $n_{.j}$, and the number in the i th priority at the census and in the j th at the survey we call n_{ij}.

Then we can estimate the transition probabilities $\{p_{ij}\}$ by

$$\hat{p}_{ij} = n_{ij} / n_{i.}$$

and the numbers N_j in each priority by

$$\hat{N}_j = \sum_i N_i \hat{p}_{ij},$$

adjusting if necessary to allow for acquisitions and disposals.

It can be shown (see below) that this approach to the estimation of the Nj, known as *ratio estimation*, will give better estimates than the simpler approach $\hat{N}_j = N (n_{.j} / n)$, at least for the sorts of values of $\{p_{ij}\}$ that are likely to be encountered.

Results can be aggregated across groups to give figures for the entire collection.

This approach is very straightforward, but it assumes that the census is followed by a single survey. Our aim is to carry out a series of surveys at regular intervals, thus leading us to the theory of *repeated sampling*. Sampling on two or more occasions is discussed in detail by Cochran (1963: 341-352), who lists three aspects that one may wish to estimate:

1. the change in $\boldsymbol{N}$ from one occasion to the next,
2. the average value of $\boldsymbol{N}$ over all occasions,
3. the value of $\boldsymbol{N}$ for the most recent occasion.

Our interests are likely to lie in 1 and/or 3, but not in 2.

He gives the optimum sampling strategy for each case (*ibid.*: 342) as:

for 1, it is best to retain the same sample throughout,

for 2, it is best to obtain a new sample on each occasion,

for 3, equal precision is obtained by keeping the same sample or by replacing all of it. Replacing part of the sample may give better results than either of these.

He then goes on (*ibid.*: 345-352) to discuss sampling on more than two occasions, showing that if we are only interested in need 3, it is best to replace 50% of the sample on each occasion (*ibid.*: 347), but if we are also interested in need 1, we should increase the proportion retained to, for example, 75% (*ibid.*: 349). This increase ‘produces only small increases in the variance of the current estimates and gives substantially larger reductions in the variances of the estimates of change’ (*ibid.*). He suggests retaining 2/3, 3/4 or 4/5 of the sample from one survey to the next if one is interested in needs 1 *and* 3.

In the event, a retention rate of 2/3 was recommended to the Museum, i.e. one-third of the sample would be replaced at each survey, so that the selected objects would be surveyed on three occasions each (except for those ‘dropping out’ after the first or second survey).

I had not appreciated at that time (1991) the complexities that this would bring about in the estimation of transition probabilities after the first survey. Since the priority of each object in the current survey is known from both the census and the current survey, transition probabilities from the census to the current survey can be estimated without difficulty. But since one-third of the sample in the current survey did not participate in the previous survey, estimating transition probabilities from one survey to the next is more difficult.

The approach suggested at the time was to divide the sample into a ‘matched’ part (observed in the current and the previous survey) and an ‘unmatched’ part (observed for the first time since the census in the current survey), denoted by suffices u and m respectively. Transition probabilities between the k th and l th surveys are denoted by $\boldsymbol{P}(k, l)$, and the census is called survey 0. I suggested forming one estimate from the matched part:

$${}_m\hat{\boldsymbol{N}}'(t) = \hat{\boldsymbol{N}}'(t\text{-}1)\, \hat{\boldsymbol{P}}(t\text{-}1, t)$$

and one from the unmatched part:

$${}_u\hat{\boldsymbol{N}}'(t) = \boldsymbol{N}'(0)\, \hat{\boldsymbol{P}}(0, t)$$

These could be combined by weighting them according to the inverses of their variances (a standard variance-minimising technique). Revised estimates of $\boldsymbol{P}$ could then be obtained from the combined estimates of $\boldsymbol{N}(t)$.

The estimation of the transition probabilities from such data has been approached more thoroughly by Klotz and Sharples (1994). In a remarkably parallel study (the development of coronary disease in cardiac transplantation patients), they show that maximum-likelihood estimators of the transition probabilities can be obtained, but only by iterative methods (Newton-Raphson approximation).

A more practical problem is that the transition probabilities may well change from one survey to the next. Indeed, we hope they will change (for the better), as this indicates improvements in the management of the condition of the collection. Therefore, only the matched sample should be used in estimating current transition probabilities, since including the unmatched sample may bias the outcome. From this it follows that the matched sample should be as large as possible, say 4/5 of the total sample, rather than 2/3 as recommended above. I would be reluctant to recommend retaining the entire sample for each successive survey, unless there were plans to hold a census at regular intervals (e.g. 5- or 10-yearly).

As mentioned above, it was decided to use stratified sampling with the groups as strata. This raises the question of 'optimum allocation': should the same proportion of each stratum be chosen for the survey, or could better results be obtained by choosing different proportions?

The question of optimum allocation when sampling for proportions has been discussed by Cochran (1963: 106-109). Since transition probabilities relate to proportions of objects in a priority that change to another priority, this is a useful approach. He concludes that there is little difference in precision between optimum and proportional allocation unless the proportions are (a) very small (e.g. ≤5%) and (b) vary widely from one stratum to another (e.g. from 0.1% to 5%), and that 'the simplicity and the self-weighting feature of proportional allocation more than compensates for the slight loss in precision' (*ibid*.: 109). Elsewhere he comments that 'The simplicity and self-weighting feature of proportional allocation are probably worth a 10-to-20% increase in variance' (*ibid*.: 102).

The calculation of optimum allocation would be very difficult in our situation, as we are sampling for several proportions (not just one) which are weighted in a complicated way. Also, there is no *a priori* evidence of large systematic differences between strata (although they may be revealed as work progresses). The simple approach of proportional allocation was therefore recommended.

The recommendation might have been different for a museum with a predominance of ceramic and/or stone objects in its collections. Many such objects, unless in a weakened state on arrival, are unlikely to suffer deterioration other than from mechanical damage or a general storeroom disaster. They could therefore be sampled less intensively than more vulnerable objects, either by using a smaller sampling fraction or perhaps by sampling less frequently.

5.2 Sampling – practical issues

Theoretical considerations are only part of the story. The design of a sampling scheme must also take account of the fact that it will be undertaken by museum staff, or possibly temporary staff on short-term contract, who cannot be expected to have any statistical expertise. This means that any scheme should be as simple as possible, and appear straightforward and reasonable to the user. It should also be designed so that the analysis is straightforward. These points reinforce the decision to use the same sampling fraction in all strata (proportional allocation).

They also point towards a scheme of systematic sampling in each stratum, as was used in the Museum of London survey, with simple instructions for the replacement of a proportion of the sample at each survey.

The design was presented to the Museum as a 'rotating panel', selected systematically. The selected objects were to be numbered 1, 2, 3, 1, …, as they were selected, so that after the first year all the '1s' would be replaced, the next year all the '2s', and so on. Replacement would be by the next object at the same location; if the last object were to be replaced, it would be by the first. This approach would maintain the systematic nature of the same and make its implementation simple.

5.3 Bulk sampling

The strata which have been identified as having 'bulk' records (see above) have to be treated differently, both for selection and estimation. The practical problem is that it is not reasonable to expect a surveyor to remember which of a tray of (say) 200 bird eggs were in which condition at the census. The suggested solution was to treat the 'unit' (i.e. whatever grouping of objects had been entered on one line of the census form) as the unit of sampling, instead of the individual object. Systematic sampling would be used to 'select' an object, but the entire unit to which it belonged would then be sampled for the sample. This is the technique known as sampling 'with probability proportional to size' (i.e. of the unit), abbreviated to pps (*ibid*.: 308).

6 Estimation

The formulae used for estimating numbers currently in each priority, and the transition probabilities, were given above. However, they should not be presented to museum staff in this form. Ideally, specialist software covering sample design, selection, data input and analysis, should be provided, analogous to the Rothamsted General Survey Program (Anon 1989). Neither the time nor the resources were available for this task, so a spreadsheet was designed for calculating numbers in each priority, their standard deviations, and the transition probabilities. A second spreadsheet was needed to perform the calculations for the bulk samples, because they require rather different calculations.

The use of these spreadsheets has not been tested; for reasons given above I would now place more emphasis on the short-term transition probabilities and in detecting trends in them.

7 Conclusions

Statistical sampling techniques have potentially an even greater role in monitoring changes in the condition of museum collections than they do in establishing the conditions at a point in time, because the scale of resources that can be devoted to a 'one-off' census is not likely to be available on a regular (e.g. annual) basis. Modelling the varying conditions of a collection can help in the design of regular surveys, as well as suggesting novel statistics which may be of use for management or political purposes. Statistical nicety needs to be tempered with practicability to achieve a design which is reasonably efficient and which can be implemented by staff whose expertise lies elsewhere.

Acknowledgements
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Heuristic classification and fuzzy sets. New tools for archaeological typologies

1 Introduction: from sherds to pots

Although Classification Theory has a long history in archaeology, sherd fitting has always formed an unsolved problem. Determining form from part of a vessel is limited by the fact that potters made vessels for different purposes starting with a few basic shapes. Since potters work by combining standard elements — base, bodies, rims, handles and so on — it is not always possible to infer the complete form from the fragments present in a deposit, because rims and bases of similar size and shape might actually have come from vessels of differing size and shape (cf. Montanari/Mignoni 1994; Orton *et al.* 1993). If one is trying to study pottery forms using only sherd material, then the definite absence of certain features may become as important a point to record as their presence. The usual assumption that all attributes have equal importance is wrong in that case. Therefore, we cannot describe different shapes distinguishing the individual aspects that determine relevant attributes for each aspect of the complex, because not all attributes are present in the sherd; 'relevance' cannot be computed when a part of the required information is missing.

2 The 'brittleness' problem

To classify a pot as a member of a type can be seen as a formal proof of the expression: 'pot *a* is member of Type *A*'

As logical proof we use the mechanism called logical implication. Suppose we have 5 attributes to determine the shape of Type *A* vessels. The logical implication needed to fit any sherd to the shape is:

```
IF      object i has
                attribute 1
        AND     attribute 2
        AND     attribute 3
        AND     attribute 4
        AND     attribute 5
THEN
        object i has shape Type A.
```

Let us call this rule 'proof *P*'. Archaeological descriptions (attributes) are elements of *P* because they are used in the proof. An element of proof, such as *attribute 5* (for example, ORIENTATION OF PROFILE) may have any number of instances (for example: ORIENTATION OF PROFILE = 30°, 45°, 90°, 180°, etc.). However, an element must have only one instance in each proof. When we are dealing with a fragment, and information about that element of proof is lacking, we assign a MISSING instance to that attribute.

Suppose only 2 attributes have been measured in the sherd. Following formal *modus ponens* this production rule cannot be fired; object *i* cannot be assigned to shape Type *A*. If we consider items one through five to be of equal importance, and we have to delete attribute 3 to 5 (because only attributes 1 and 2 are present in the sherd), the typology would malfunction and sherds are not classified because they do not present enough descriptive information.

This problem can be defined as the *brittleness problem*, that is, the inability of standard typologies to give a 'partial answer' in a graceful way (Sypniewski 1994). The cause of brittleness in typologies and classificatory systems is the use of an inadequate assumption about data. If we assume all necessary truths to express the idea of logical necessity are equally important to a proof, we are saying, in effect, that unless we can demonstrate all necessary truths we cannot prove what we are trying to prove. This is the problem of brittleness.

To solve the problem we can consider that *any* element of *P* can be used in the proof. We do not require all attributes but only the *necessary* elements of *P* to be present in the sherd. No reason exists why we cannot use the accidental elements of *P* in the proof, but they cannot substitute for one or more missing necessary attributes. This scenario provides a first glimpse into the definition of *importance*: Some elements of *P*, while legitimate members of *P* do not contribute to the actual proof (they are missing in the sherd). If we remove all members of *P* that are accidents or are unnecessary for *P*, we are left with P^1, which is composed of the necessary elements of *P*; all of them contribute to the proof. The theory of importance (Sypniewski 1994: 26) says that not all members of P^1 necessarily contribute to the proof process in the same way or to the same extent. The extent of that contribution is demonstrated by the importance weight of every attribute or element (E_i). Any E_i that has a larger importance weight than an E_j is more important to a particular P than E_j. An element of proof that is irrelevant has an importance weight of 0.0; the same value has an attribute with missing value.

It is important to realise that no item of data has an intrinsic importance weight. All weights are relative to some P. Also note that a particular situation may provide elements whose combined importance weights exceed 1.0. In those cases more data are available than is strictly necessary for a proof.

The degree to which an attribute contributes to prove a typological assignment is determined empirically. When we gather the data or knowledge we need for our classification, we will, as a by-product, gather information about the elements of a proof. If we introduce this material into a matrix, we will see that some bits of information fill one cell of the matrix and some bits fill more than one cell. The number of cells filled with a particular piece of data or knowledge is a rough gauge of the importance of that particular piece of data or knowledge. As a general rule, *the more often a particular piece of data or knowledge appears in our hypothetical grid or matrix, the less important it is* (Sypniewski 1994: 29). We can say that if two proofs differ only by one item of data or knowledge, then this piece of knowledge is the most important item for that proof.

Consequently, a strong importance weight is equivalent to a branch point in a decision tree.

3 Fuzzy Logic: a way to solve the problem of 'brittleness'

Starting from the idea that every sherd is a certain proportion of the whole pot it once formed part of, we can (in theory) assign a weight or importance to attributes, and compute them to obtain a class assignation. In this chapter we will study how to describe importance weights through fuzzy numbers, and how to translate classification functions as membership function to fuzzy sets (Bezdek/Pal 1992; Cox 1993; Dubois *et al*. 1994; Klir/Folger 1988; Kosko 1992; Zadeh 1965).

Fuzzy logic deals with uncertainty. It holds that all things are matters of degree. It measures the degree to which an event occurs, not whether it occurs. Mathematically fuzziness means multivaluedness or multivalence and stems from the Heisenberg position-momentum uncertainty principle in quantum mechanics. Multivalued fuzziness corresponds to degrees of indeterminacy or ambiguity, partial occurrence of events or relations. In 1965 Lofti Zadeh introduced the concept of *fuzzy set*, as a way to represent the logical nature of categories. Fuzzy sets are constituted by elements, however those elements are not crisp instances of the categories but elements that belong only *to a certain degree*. The essence of fuzzy logic is then the notion of fuzzy membership as a continuous value measuring the elementhood or degree to which element *x* belongs to set *A*.

We can translate logical implications (proof of classificatory assignments) using fuzzy production rules, where the output of the rules is a fuzzy set, whose members are the elements of the proof. Each element, as a member of a fuzzy set, has a fuzzy membership value or importance weight. For instance,

IF	object *i* 's PROFILE is concave	(0.875)
	object *i* 's RIM has shape *B*	(0.358)
	object *i* 's MAX. DIAMETER is on top of the pot	(0.47)
THEN		
	object *i* has shape *Type A*	

The values in the rule's antecedent are *fuzzy*, because they belong to a fuzzy set. This value is not the confidence we have in that information, but the importance this element of a proof has in type *A*'s logical implication. To evaluate these rules, fuzzy logic software computes the degree to which each rule's situation applies. The rule is active to the degree that its IF part is true; this in turn determines the degree to which each THEN part applies. Since multiple rules can be active simultaneously, all of the active rules are combined to create the final result. At each cycle, the full set of logical implications is scanned to see which fires. A rule or logical implication will fire when its condition made up of a (fuzzy) logical combination of its antecedents, results in a non zero value. Each rule therefore samples its inputs and calculates the truth value of its condition from the individual importance weight of each input. In this way, the fuzzy membership function of each element acts as a kind of restriction or constraint on the classification process.

Let us imagine that *P*, a proof for a classificatory assignment, is a set. Then *P* = {attribute 1, attribute 2, attribute 3, attribute 4, attribute 5}, where each attribute or descriptive feature are the elements of proof needed to prove *P* (for example, to prove *Type A*). We can assume that *P* is a fuzzy set, and consequently, each element has a membership value. Given the fact that *P* is fuzzy, the membership value for each element is a continuous number between 0 and 1, meaning the importance weight of that attribute in the logical implication described by *P*. In this case, fuzziness is only a general methodology to compute the sum of partial implications. I do not think that archaeological types have to be intrinsically *fuzzy*, but the sherd fitting process will only be computed if that type is described in a fuzzy way: if we do not know how an instance relates with its type, the relationship remains fuzzy. Inferences made using incidental associations ('always' in archaeological classification) are inherently uncertain. And some associations are 'less' uncertain than others.

Fuzzy logic permits ambiguous instances to be included in a fuzzy set through a membership value. The degree of membership is given by the membership function, which has a value between 0 and 1. The interpretations is that 0 means no membership (or that the instance is certainly not in the set) and 1 denotes complete membership (or that the instance is certainly in the set), and a value in between denotes a partial or uncertain membership. Fuzzy logic thus overcomes a major weakness of crisp sets: they do not have an arbitrarily established boundary separating members from non members.

Fuzzy systems directly encode structured knowledge but in a numerical framework, where each rule stands for an input-output transformation, where inputs are the antecedent of fuzzy rules, and outputs are their consequent. In our case, inputs are the descriptive features we can measure on sherds, and outputs are an assignation of the sherd to an artefact or class of artefacts. Most fuzzy systems represent inputs and outputs as membership functions whose interactions are the bases for rules. The fuzzy input and desired output ranges are based on fuzzy set values and used to create a matrix called *fuzzy associative memory*. When actual input values enter the system, the entire memory fires at once, producing multiple outputs. Each input's membership in the fuzzy input sets must be calculated — this is called the truth value or importance weight. The information from all inputs is then applied to the rule base, which results, for each system output, in several fuzzy outputs. Since system inputs have multiple fuzzy values and each can be involved in the triggering of multiple rules, since each rule can have several fuzzy input values for its antecedents and each rule also can produce several outputs, and since each output itself has multiple fuzzy values, this process becomes quite complex.

A *Fuzzy Cognitive Map* (FCM) is a special type of *fuzzy associative memory* where the variable concepts are represented by nodes, which can also be called *conceptual states*, and the interactions by the edges, or *causal events*. Consequently, FCMs model the world as a collection of classes and causal relations between classes. Each node is a fuzzy set (fig. 1). In our case, logical implication between different elements of a proof is represented by fuzzy causal flows. The fuzzy cognitive map tries to represent the way a scientist thinks, because the nodes (concepts) affect each other, either directly or indirectly and either positively or negatively (Kosko 1986, 1992; McNeill/Thro 1994; Taber 1991).

The logical structure of an FCM allows each state (or node) to have any value between 1 and -1:

- +1 meaning that the originating or causing state results in a complete increase in the target or affected state;

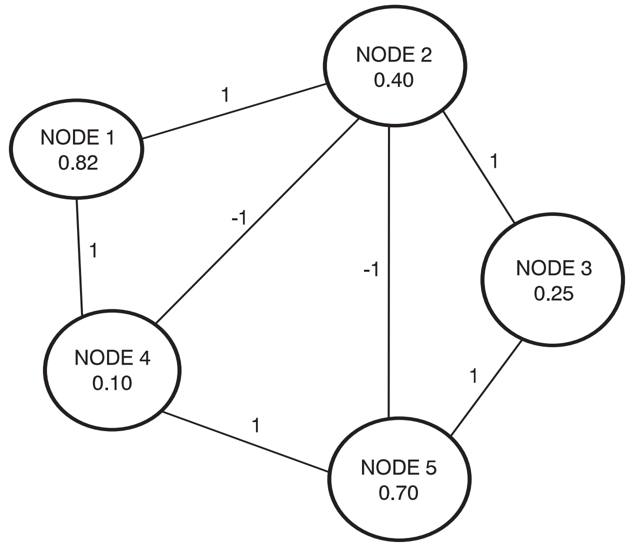

Figure 1. A Fuzzy Cognitive Map.

- -1 meaning that the causing state results in a complete decrease in the affected state;
- 0 meaning that the causing state does not change the affected state.

The number is the degree of causation and ranges from a negative one through zero to a positive one. Zero means no causal effect. Negative importance weights are used to say that some proof element instantiation tends to disprove or reduce the likelihood of a proof. Disproofs can be active or passive. To be an active disproof, the instantiation of some element of proof E_i must have an importance weight that is a negative number. Therefore, the system will subtract effectively the value of its importance weight from the current proof value V. A passive disproof, on the other hand, is simply a proof element that is not available (MISSING), and because it has not been observed, it is never added to V.

Disproofs can be calculated using a formula for fuzzy entropy:

$$\frac{\text{degree of overlap between every pair of outputs}}{\text{degree of underlap between every pair of outputs}}$$

Overlap is the result of logical intersection between types, whereas the *underlap* can be defined as the union between them (Kosko 1992; McNeill/Thro 1994).

As in a neural network, each state or node is 'squashed' through an activation function. In other words, each state value is a modification from the previous value during each forward step of the dynamic map. Each state's value is the result of taking all the event weights pointing into the state, multiplying each by the causing state's value, and adding up all the results of these multiplications. The results are then squashed so that the result is between 0 and 1 (0 and 100%). This multiply- and sum-process is a linear operation; that is, the new activation value for a fuzzy set (output node) is a weighted sum of all membership values for that set. If the unit's input is less than some threshold level (0.00 in our case), then the new activation value is equal to that unit's minimum activation range (also 0.00). Otherwise, if the inputs are positive (greater than the threshold 0.00), then the new activation value is set equal to the inputs.

FCM nodes act as binary neurones in a neural net. They sum, weight and threshold the causal energy that flows into them through the fuzzy causal edges. The states in an FCM are *state machines*, that is, they receive some input from somewhere (other units in the network), use it, change and 'export' a value. Given the fact that these states are linked in a graph, each one receiving unique inputs from other states, changing as a result, and affecting some other states. Time is a component of this architecture, because dynamic action continues as long as one state is able to effect a change in another one. This function (or *gain*) determines the high and low values of a cycle and can affect the map's operation. The higher the gain is, the more exaggerated the cycle.

Before activation all elements for all the possible proofs in the system are zero because none of them is active. You begin with a static diagram of the system. It shows the assumptions of the model. Then you set up an initial condition and perform iterated vector-matrix multiplication until a limit cycle is found. The limit cycle shows how the system behaves. In other words, vector matrix multiplication changes the state to something else. What we get as a result is a classification assignment.

4 PYGMALION: using Fuzzy Logic to classify Phoenician pottery

PYGMALION is the code name for a joint project, currently under way at the Universitat Pompeu Fabra Dept. of Humanities and the Universitat Autònoma de Barcelona Dept. of Prehistory. The goal is to create a computer system able to classify Phoenician pottery (800-550 BC), and to derive chronologies, production characteristics and exchange networks from descriptive features of archaeological material. PYGMALION release 0.1 is a prototype version to study the logical properties of the full-scale Expert System (PYGMALION release 1.0). This prototype is a Fuzzy Cognitive Map acting as a pattern recognition machine for pottery sherds.

The process of recognising a pattern is the classification of a sample into one or more predefined categories. If the pattern is successfully associated with a previously known type, the pattern is said to be recognised. At the end, the system should provide a confidence estimate in the classification; for example, the system is 75% confident that this sherd is part of a Type *A* pot and 25% confident that it is a type *B*. This confidence estimate is a measure of the degree to which the pattern-recognition system believes that the pattern data belongs to the specified class. To carry out this task, PYGMALION is implemented as a graph with evaluated nodes and evaluated arcs that represent relational structures among types. The aim is to decide whether the reality represented by a sherd qualitative description matches prior knowledge about the whole pot incorporated into the graphical model.

4.1 Describing shape

Defining the shape of an object can prove to be very difficult. Pottery shape is influenced by a large number of factors. The decisions made by the potter, the tools and materials available and his/her skill in manipulating them all contribute to the finished product. While many practical shape description methods exist, there is no generally accepted methodology of shape description. The principal disadvantage of most pottery shape description systems is that they cannot be applied to the sherd material which forms the majority of the pottery recovered from archaeological sites (see amongst others Kampffmeyer *et al.* 1988; Orton *et al*. 1993; Rice 1987).

We have designed a new 'qualitative' descriptive framework, based on modern theory of robot vision (Biederman 1987; Saund 1992; Sonka *et al*. 1993).

Representation of visual shape can be formulated to employ knowledge about the geometric structures common with specific shape domains. We seek representations making explicit *many* geometric properties and spatial relationships at many levels of abstraction. Therefore, the problem of visual shape representation is to determine what information about objects' shapes should be made explicit in order to classify sherds as parts of whole pots. Knowledge about the pottery making process can be built into a shape representation in the form of a descriptive vocabulary making explicit the important spatial events and geometrical relationships comprising an object's shape.

The decomposition approach is based on the idea that shape recognition is a hierarchical process. Shape *primitives* are defined at the lower level, primitives being the simplest elements which form the region. Then, an object's shape will be analysed largely in terms of the spatial arrangement of labelled chunks or fragments of shape. A decomposition of the contour, for instance, uses its structural properties, and a syntactic graph description is the result. This graph is constructed at the higher level–nodes result from primitives, arc describes the mutual primitive relations. Particular shape fragments are labelled by individual *shape tokens* instantiated in the appropriate type. Each token is tagged with the characteristics (location, orientation and size) of the archaeological item it denotes. That is to say, a shape is described simply in terms of *primitive-edge* tokens placed along the bounding contour at the finest scale.

We are working with a contour-based object description method which uses as input information the properties of object boundaries. The contour or border of an object is the set of pixels within the region that have one or more neighbours outside that object. In other words, the contour or profile is the set of points at the limit of the object. We are dealing with partial segmentation looking for non-disjoint subregions in the contour. That is, the existing border is divided into separate regions that are homogeneous with respect to a chosen property. *Curvature* is that property. As profiles are a continuous series of pixels, curvature can be defined as the rate of change of slope. The curvature scalar descriptor (or boundary straightness) finds the ratio between the total number of boundary pixels (length) and the number of boundary pixels where the boundary direction changes significantly. The smaller the number of direction changes, the straighter the boundary. Contour primitives are delimited by the gradient of the image function that is computed as the difference between pixels in some neighbourhood. The evaluation algorithm (not fully implemented in PYGMALION 0.1) is based on the detection of angles between line segments positioned by boundary pixels in both directions (fig. 2).

Consequently, we are representing a boundary using segments with specified properties. If the segment type is known for all segments, the boundary can be described as a chain of segment types. The problem lies in determining the location of boundary vertices. Boundary vertices can be detected as boundary points with a significant change of boundary direction using the curvature (boundary straightness) criterion.

Once segmented, contour parts can be described qualitatively. Our approach is based upon the psychological theory by I. Biederman (Biederman 1987). He proposes to use only four qualitative features in describing objects. We have translated his ideas into the following components:

- CONTOUR: straight or curved
- CURVATURE: convex or concave
- COMPLEXITY: number of contour primitives
- ORIENTATION: in a 8-neighbourhood area.

The prior knowledge we have about the contour of a pot allows us to know the starting point (INIT) and the ending point (BASEX) of the border (fig. 3). The process is then a decomposition of the external *and* the internal profile in its primitive curves. We begin describing the *body* of all whole pots we know by looking at the right and the left profile and determining symmetry or asymmetry. The *exterior profile* and *interior profile* are described by detecting the

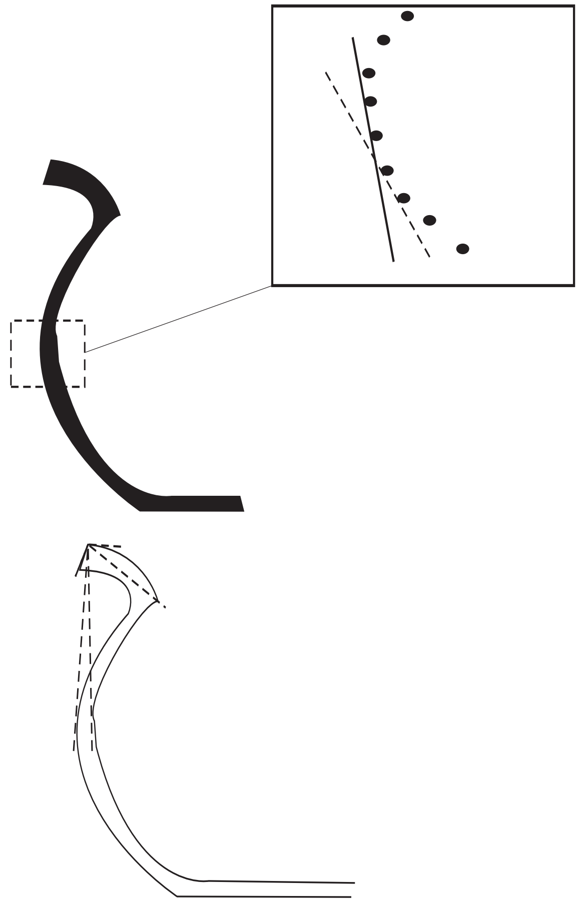

Figure 2. Describing the curvature of a contour.

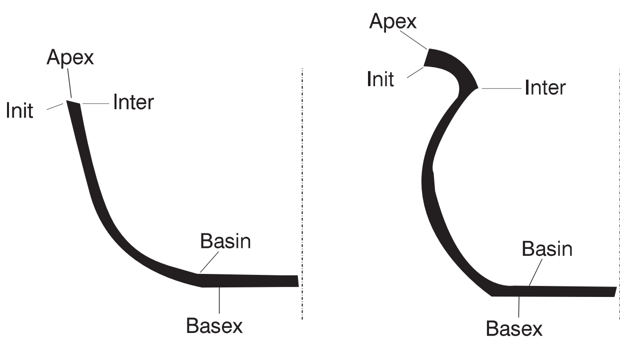

Figure 3. Main points for dividing contour into segment.

number of 'curvatures'; they can be continuous or discontinuous. *Exterior and interior discontinuity* is defined by counting the number of profile primitives after detecting more than one 'curvature'. We consider also the *shape of exterior and interior profile* (straight, concave or convex) if there is only one curve; or the *exterior and interior profile primitives shape* if discontinuity is present. The *location* (the place where curvatures have been measured) of all profile primitives is also a very useful attribute: between rim and body, at the centre of the body, at the centre of the rim, etc. The *maximum diameter location* (in the upper part of the pot, at the centre, at the rim etc.) helps to distinguish some types; and the same is true for some different descriptions of *orientation: external profile orientation, internal profile orientation, rim orientation*. Finally, *rim shape* (geometric form from APEX to INTER) is evaluated. All orientations are calculated according to an 8-neighbourhood window (fig. 4).

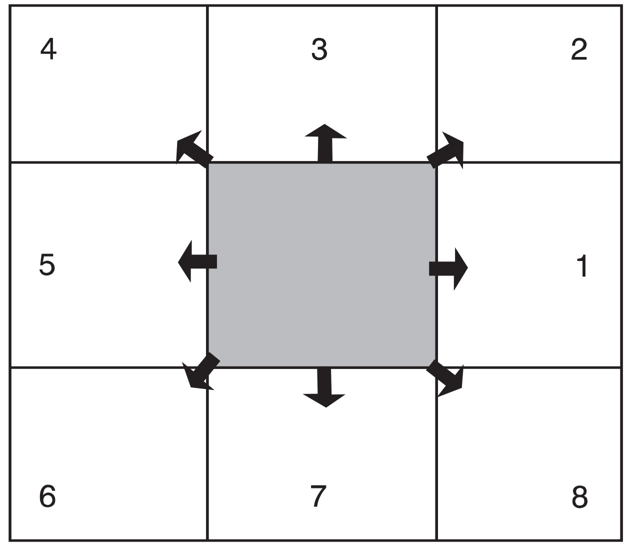

Figure 4. A schema to fix orientations of contour segments.

4.2 BUILDING A *FUZZY COGNITIVE MAP*

Any object, even with non-regular shape, can be represented by a collection of its topological components. Topological data structures describe the pot as a set of elements and their relations. These relations are represented using a Fuzzy Cognitive Map, containing the object structure. The elementary properties of syntactically described objects are called primitives; these primitives represent parts of contours with a specific shape. After each primitive has been assigned a symbol, relations between primitives in the object are described, and a relational structure results. However, given the indeterminacy of PYGMALION inputs (incomplete pots) we have decided not to use arcs representing binary relations such as *adjacent to, to the left of, above,* etc., but a fuzzy cognitive map where arcs represent the importance weight of primitives (nodes).

The actual version of our program is a continuous-state model, because every node may have any value between 0 and 1. A negative weight (between -1 and 0) means the element is a disproof for some particular type. This value is less than the unit's threshold, consequently, the goal of negative weights is only to deactivate units previously activated.

PYGMALION 0.1 contains 54 units or nodes. 36 of these are input nodes and represent qualitative information introduced by the user; 18 nodes represent the answer of the system, or the outputs of the classification (fig. 5). Input nodes are connected among themselves using negative weights. That is to say, there are relationships between elements of different fuzzy sets. There is only a single membership link between every element (attribute) and the fuzzy set (type) it belongs to. Negative links also connect fuzzy set units (output nodes) among them, because some sherds cannot be part of two very different shapes. Negative links among output units represent the degree of overlapping *allowed* by the classificatory system. For instance, there is no degree of overlapping between a carinated bowl and an amphora; however the degree of overlapping between two different kinds of plates can be very high. In the prototype presented here, all output units are linked by the same negative weight: the maximum activation level for a unit (1.00) divided between the number of competing units.

Causal energy flows synchronously between elements and sets (fig. 6). That means that there is no control of rigid timing signals. Instead, each element (node) in PYGMALION sends fuzzy membership values and importance weights as it is ready (as there is input information for it). As long as the element and the type are set up to send and recognise the right combination, the membership message will get through. In general, the signal being sent from one node to another is equal to the activation value of the first node multiplied by the weight from the first to the second. The FCM performs these computations every time the network is *cycled*. When we cycle the network, we give each input node some information from an archaeological description. Given the fact that we are processing sherds, not all inputs are activated. The aim is to obtain a degree of activation on the output nodes, even though input activation is incomplete. Negative links and asynchronous updating help in this process. The program stops when all activations have been distributed around the network.

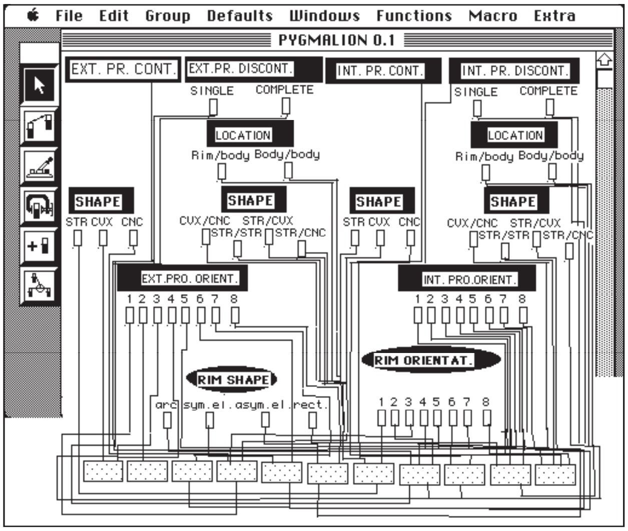

Figure 5. An ideal representation of PYGMALION Cognitive Graph.

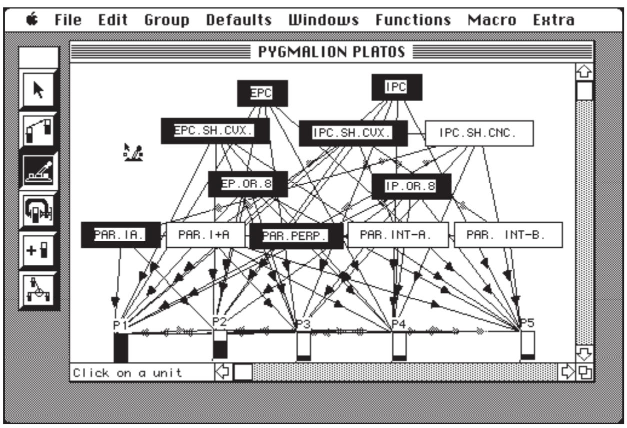

Figure 6. A subset of PYGMALION 0.1 Fuzzy Cognitive Map.

4.3 Determining importance weights

The importance weights assigned to a particular item or data or knowledge are, in a sense, always relative. These numbers have to be *fuzzy* because not all elements of a proof will have a fixed importance weight. Therefore, the importance weight of all nodes in the FCM must be determined in relation to the elements of other proof sets. For instance it is more important to know the shape of a rim when distinguishing between a bowl and a plate than if we were distinguishing between a bowl and an amphora.

The importance weight of any item of data or knowledge has been calculated from empirical evidence and its environment. By environment, we mean the number and nature of the proofs possible in the specific domain of discourse in which the data are being used. To determine the weight of an item of data, we must determine whether it does not depend on any other item of data. However, in any collection of data patterns, some individual data items will appear in more than one data pattern. This enables us to say that one data pattern is similar or dissimilar to another depending on how many individual data they have in common. The more they share, the more similar they are and vice versa.

Then, their importance weight can by calculated by the ratio of their non-occurrence in all fuzzy sets.

- if an element *attribute* x_i of the proof set *Type A* completely proves *Type A* without condition, then *attribute* x_i has an importance weight of 1.0; otherwise *attribute* x_i has an importance weight less than 1.0 under all circumstances.
- for every *attribute* x_i that is shared by all conflicting proof sets *Type N* , *attribute* x_i has an importance weight of 0.0; otherwise *attribute* x_i has an importance weight greater than 0.0 under all circumstances.

Weights have floating-point values such as 0.5, 0.2, 0.9 according to their importance weights in a proof. Those values have been calculated dividing the number of types with that feature between all types in the classification. We are doing some experiments with more complex measures of 'importance', such as *entropy*. Table 1 shows a subset of importance weights between the elements of the proof (descriptive features) and axioms to be proved (Types). The first row shows the effect of attribute 1 on all types. The second row shows the effect of the second attribute on the types. The matrix is square, since we have a place for the effect of each attribute on all types.

Table 2 shows negative weights or disproofs among elements. They have been calculated from the degree of overlapping among fuzzy sets. For instance, a continuous convex shaped internal contour appears sometimes in pots with coincident parametric points; however, it is impossible to see a continuous convex shaped internal contour with the INTER parametric point below the INIT parametric point. Coincidences have been tabulated as a 0.00, and discrepancies as a -1.

The Fuzzy Cognitive map topology can be described using a set of specific variables (see figs 7a, b).

4.4 Using the Fuzzy cognitive map to identify incomplete pots

PYGMALION 0.1 is being used to validate a typology for Phoenician open forms. We have worked with a data set of nearly 200 whole pots from Phoenician sites in the southern Iberian Peninsula (mostly Toscanos, Trayamar, Almuñecar, Cerro del Villar). Validation is carried out by comparing the

Table 1. Fuzzy membership values between elements and fuzzy sets.
Abbreviations: E.- external; I.- Internal; P.- Profile; C.- Continuous; SH.- Shape; STR.- Straight; CVX.- Convex; CNC.- Concave; ORIENT.- Orientation; PAR.- Parametric Points. IA.- Inter = Apex. I+A.- Inter ≠ Apex. PERP.- perpendicular to Init; INT-A.- Inter above Init; INT-B.- Inter below Init.

	P1	P2	P3	P4	P5
EPC	.2	.2	.2	.2	.2
IPC	.2	.2	.2	.2	.2
EPC.SH.CVX	.2	.2	.2	.2	.2
IPC.SH.CVX	.5	.5	0	0	0
IPC.SH.CNC	0	0	.3	.3	.3
EP.OR.8	.2	.2	.2	.2	.2
IP.OR.8	2	.2	.2	.2	.2
PAR. IA	.5	.5	0	0	0
par. I+A	0	0	.3	.3	.3
PAR. PERP.	1	0	0	0	0
PAR. INIT-A	0	0	1	1	0
PAR. INIT-B	0	0	0	0	1

Table 2. Negative Weights among elements (descriptive features).
Abbreviations: E.- external; I.- Internal; P.- Profile; C.- Continuous; SH.- Shape; STR.- Straight; CVX.- Convex; CNC.- Concave; ORIENT.- Orientation; PAR.- Parametric Points. IA.- Inter = Apex. I+A.- Inter ≠ Apex. PERP.- perpendicular to Init; INT-A.- Inter above Init; INT-B.- Inter below Init.

	IPC.SH.CVX	IPC.SH.CNC	PAR.IA.	PAR.I+A	PAR.PERP.	PAR.INT-A	PAR.INT-B
IPC.SH.CVX	0	-1	0	-1	0	-1	-1
IPC.SH.CNC	-1	0	-1	0	-1	0	0
PAR. IA	0	-1	0	-1	0	-1	-1
PAR. I+A	-1	0	-1	0	-1	0	0
PAR.PERP.	0	-1	0	-1	0	-1	-1
PAR.INT-A	-1	0	-1	0	-1	0	-1
PAR.INT-B	-1	0	-1	0	-1	-1	0

classificatory assignments made by the program to assignments made by experienced archaeologists.

Once we confirm the quality of the *answers* proposed by our *automatic archaeologist*, we will begin introducing descriptions for incomplete pots. PYGMALION 0.1 then computes partial membership functions and proposes a fuzzy assignment. Of course, *natural archaeologists* have to use these assignments and decide what has more sense, that a sherd be 55% of Form 3 or 45% of Form 13.

5 The concept of heuristic classification

When using fuzzy logic tools to build classification systems, we have proceeded through identifiable phases of data abstraction, heuristic mapping onto a hierarchy of pre-enumerated solutions, and refinement within this hierarchy. We have obtained a classification, but with the important twist of relating concepts in different classification hierarchies by non-hierarchical, uncertain inferences. This combination of reasoning has been called *heuristic classification* (Clancey 1985). The heuristic classification model builds on the idea that categorisation is not based on purely essential features, but rather is primarily based on *heuristic*, non-hierarchical, *but direct* associations between concepts.

Heuristic classification is a method of computation, not a kind of problem-to-be solved. In other words, it is a way to solve an archaeological problem (sherd fitting to form) and not a new philosophy about archaeological classification. We must not confuse what gets selected at the end of the FCM — what constitutes a solution — with the method for computing the solution. A common misconception is that there is a kind of problem called a ‘classification problem’. Heuristic classification as defined by W. Clancey (1985) is a *description of how a particular problem is solved by a particular problem-solver*. If the problem solver has a priori knowledge of solutions and can relate them to the problem description by data abstraction, heuristic association, and refinement, then the problem can be solved by classification.

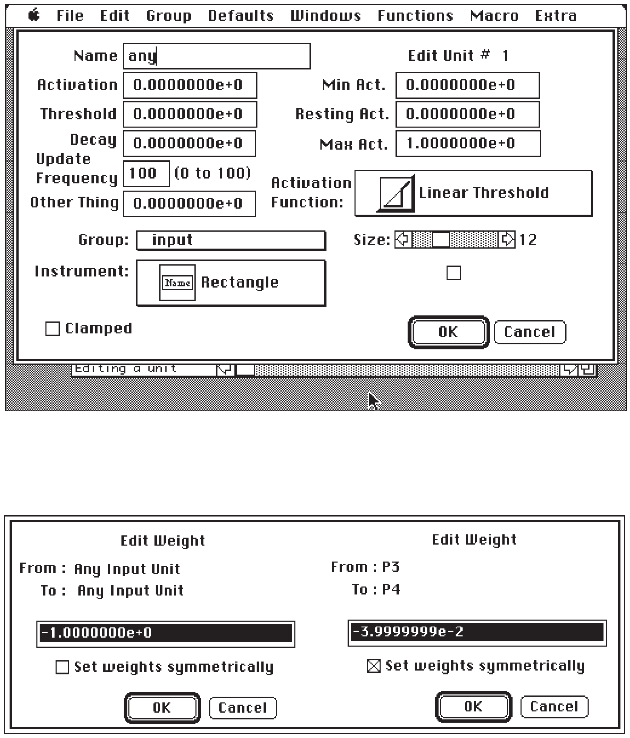

Figure 7. a. An FCM node's topology. b. Two different FCM weights' topology.

Often problems of classification are not amenable to solution by heuristic classifications because possible final states cannot be practically enumerated, exhaustively learned or for some reason a previously used solution is just not acceptable; solutions must be constructed rather than selected. However, even when solutions are constructed, classification might play a role.

In this paper we have described what an expert system does by describing it in terms of inference-structure diagrams (Fuzzy Cognitive Maps). This demonstrates that it is highly advantageous to describe systems in terms of their configuration, *structurally*, providing dimensions for comparison. A structural map of systems reveals similar relations among components, even though the components and/or their attributes may differ.

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Dmax based cluster analysis and the supply of coinage to Iron Age Dacia

1 Introduction

The analysis of Roman Republican coin hoards presents a number of statistical opportunities and problems. For example, the well-dated nature of the material provides an excellent test for seriation techniques. Conversely, the inherent time gradient will dominate a correspondence analysis (CA). Figures 1 and 2 present the sample and variable maps from a CA of 241 coin hoards, each of which has more than 30 well recorded denarii, dating from 147-2 BC (Lockyear 1996: section 8.2.3).[1] As can be seen, the 'horseshoe effect' dominates the results (Lockyear 1996: section 8.2.2). Although some interesting points can be made from these maps, the dominant gradient is time — other information is masked. Mixing hoards from different periods in one analysis does not 'aid interpretation', *contra* Creighton (1992: 32-35).[2]

One possible solution is to examine small subsets of the data, each with a restricted range of dates. The hoards presented in figures 1-2 were subdivided into 22 groups, each of which was analysed using CA (Lockyear 1996: section 8.3). This revealed many interesting aspects of variation in these hoards, often linked to the region from which the hoards were found, and some general observations are given below.

However, one particular question arose which suggested that some form of cross-period comparison would be useful. This paper will outline this question, and then will discuss the solution devised by the author in detail. Finally, the results and archaeological conclusions will be briefly presented. Full details can be found in Lockyear (1996); details of the data and the archaeological results and conclusions will be published elsewhere. Additional information including figures, tables and the data are available via the World Wide Web (http://caa.soton.ac.uk/caa/CAA95/LockyearA/) or from the author.

2 The problem

As Crawford notes:

> 'One of the most remarkable phenomena within the pattern of monetary circulation in antiquity is the presence of large numbers of Roman Republican denarii, for the most part struck between about 131 and 31 [BC], on the soil of present-day Romania, roughly ancient Dacia.'
>
> Crawford 1985: 226

What makes this phenomenon remarkable is that Dacia was not incorporated into the Roman Empire until the Trajanic Wars (AD 101-102, 105-106). The situation is further complicated by the evidence for the copying of denarii by the Geto-Dacians (Chiţescu 1971b, 1980, 1981; Glodariu *et al*. 1992; Lupu 1967) although the scale of the copying is disputed (cf. Chiţescu 1981; Crawford 1980). The date at which the denarii arrived in Romania has also been a topic of some debate. Mitrea (1958) has argued that there are three phases of the 'penetration' of denarii: the end of the second century BC, 90-80 BC and 49-30 BC. Many other scholars have basically agreed, although some have argued for 'more than a sporadic penetration of denarii into Romania by the year 100 BC (Chiţescu 1971a). Some Romanian scholars have disagreed. Preda (1971: 74) argues for a date after 80 BC; Babeş (1975) argues for a mid-1st century date based on the excavated finds from Cîrlomaneşti. Crawford (1977, 1985: 226-235) argues for a date from the mid or late 60s, and quite rightly notes that the periods claimed by Mitrea, and others, for the arrival of large numbers of denarii into Romania correspond to periods of high levels of official coin production. In her final work, Chiţescu maintained that these new alternatives were wrong and that the 'penetration' of denarii must have started by 100 BC (Chiţescu 1981). Poenaru Bordea and Cojocărescu (1984) argue that the majority of denarii arrived between *c*. 75 BC and *c*. 65 BC.

Before any interpretation of *why* these coins were there, and why they were copied, these basic questions need to be addressed. As part of a wider project, the author has been constructing a database of Roman Republican coin hoards. At the time of writing this database contained detailed information of 420 hoards, some 87,240 coins. Of these, 126 hoards were found in Romania. By analysing these hoards in the context of others from the rest of Europe, some important observations could be made.

- Although 13 of the 126 hoards from Romania date before 79 BC, the biggest hoard from Iclănzel has only 18 well identified denarii (ICL[3]; Chirilă/Grigorescu 1982). The small size of these hoards makes it likely that there is a large discrepancy between their closing dates and the true date of their deposition. Lockyear (1993:

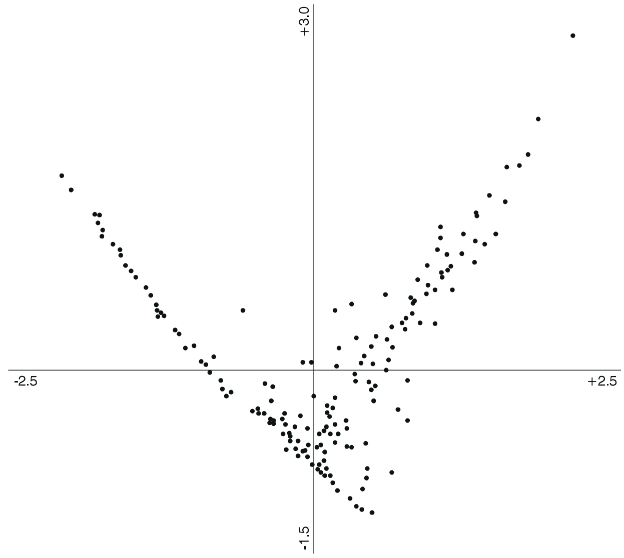

Figure 1. Sample map from CA of 241 Roman Republican coin hoards dating from 147-2 BC each with 30 or more well identified denarii. Data points are hoards. First (horizontal) and second axes of inertia.

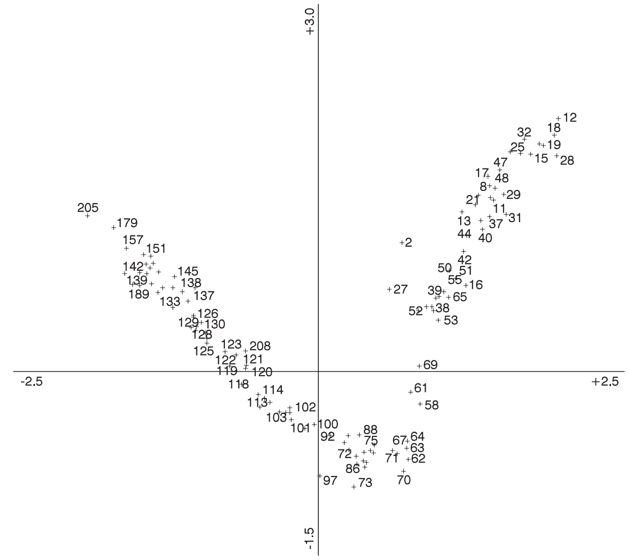

Figure 2. Species map from CA of 241 Roman Republican coin hoards dating from 147-2 BC each with 30 or more well identified denarii. Data points are years of issue. First (horizontal) and second axes of inertia.

373-375) discusses the problem of hoard size and dating in detail.

– Romanian hoards with closing dates in the 70s BC are very similar in structure[4] to Italian hoards of the same date. For example, cf. Zătreni (ZAT; Chiţescu 1981: No. 215) with San Mango sul Calore (MAN; Pozzi 1960-1961: 162-172).
– By the 50s BC Romanian hoards are archaic[5] in structure when compared to contemporary hoards from Italy. For example, cf. Dunăreni (DUN; Popilian 1970) with Mesagne (MES; Hersh/Walker 1984).
– In the 40s and 30s BC the pattern is more complicated with Romanian hoards being quite variable, but always more archaic than contemporary Italian hoards.

We can conclude that denarii did not arrive in this region in significant quantities, if at all, prior to 80 BC. The structure of hoards from the 70s suggests that significant supplies started at that time. The differences between Italian and Romanian hoards in the following decades suggest that the supply of coinage to Romania was not constant and did not reflect supply to Italy.

At this stage it seemed that further information concerning the supply of coinage to Romania could be gained by comparing hoards across date ranges. Various methods were considered. Comparisons were made by running CA on all hoards and then using the colour plotting facilities of WinBASP.[6] Although it was possible to see the sorts of comparisons needed in this fashion, it was difficult to produce some form of grouping in the continuum displayed. The methods used by Creighton (1992: section 2.5, 78-103) were rejected as they lack any sound statistical foundation. The problem appeared to be one which could be addressed by cluster analysis providing that the resulting clusters are viewed as subdivisions of a continuum of variation, not as clear, unequivocal groups.

3 Dmax based cluster analysis

Cluster analysis is a range of techniques with the basic aim of subdividing a set of objects or assemblages into subsets. There is no ‘best’ method of achieving this — see Orton (1980), Shennan (1988) and Baxter (1994) for the use of the technique in archaeology. In this particular case, the aim was to produce a moderately large number of subsets in order that we could examine the grouping of hoards and see if this provided us with any further insights, especially as regards the supply of coinage to Romania.

Some form of hierarchical agglomerative cluster analysis seemed appropriate. In this form of analysis, the analyst firstly has to choose a similarity or dissimilarity coefficient. Most standard texts list three common measures, Euclidian, squared Euclidian and city-block distance (e.g. Shennan 1988, 198-202). Many others exist for different data types. For example, SPSS allows for the use of χ^2 or Φ^2 as measures for count data (Norušis 1993: Chapter 5 especially 128, 133).

In this case, the variables used to describe the hoards are of an ordinal data type — the coins grouped by date of issue. For example, the Cosa hoard (COS; Buttrey 1980) has 2004 coins and closes in 74 BC. It has 9 coins of 211 BC, 3 of 209, 1 of 207, 4 of 206 and so on until… 32 of 74 BC. The author therefore wanted a measure which would:

a. not be over-influenced by rare issues especially if those rare issues were defining a hoard's closing date;
b. make full use of the ordinal nature of the data.

None of the software available to the author provided such a measure.

The author has had occasion to compare hoards using the Kolmogorov-Smirnov statistic, a significance test suitable for ordinal data (Shennan 1988: 55-61). This test involves calculating $Dmax_{obs}$, defined as the maximum difference between two cumulative proportion curves, and then comparing it to a critical figure for the significance level desired. Mass comparisons using this method (e.g. Lockyear 1989: section 2.2) were unsatisfactory for a number of reasons. For example, the large number of comparisons used in that study would lead to some results being significant by chance — the problem of multiplicity (Mosteller/Tukey 1977: 28f.). More importantly, we already know that the hoards are drawn from a global coinage pool with major regional variations and therefore should expect differences.

$Dmax_{obs}$ can, however, be viewed as a type of dissimilarity coefficient suitable for ordinal data, just as χ^2 can be used for nominal data. Dmax could, therefore, be used in cluster analysis, or some form of multidimensional scaling, as a dissimilarity coefficient. At the time of the analysis, the author did not know of the use of Dmax in this fashion.[7] No theoretical objections were raised by statisticians consulted[8] and it was decided to try the method and see if the results 'made sense' in the context of what was already known about these hoards.

Two hundred and seventeen hoards were selected from the database, closing between 147-29 BC, all with 30 or more securely identified denarii. The 23,436 dissimilarity coefficients were calculated using a dBASE program, and then converted into a triangular matrix. The only software available to the author which would allow the input of a user calculated dissimilarity matrix was MV-ARCH (Wright 1989). The matrix was therefore input to the HIERARCH module of that package for clustering. Output was produced on a plotter using the HIERPLOT module.

Seven types of clustering algorithm are available in MV-ARCH. Single-link cluster analysis (Shennan 1988: 213-214) tends to produce dendrograms with a strong chained effect (Baxter 1994: 158), especially when the technique is applied to data which does not have strong grouping. With this data set the chaining was such that the results were not usable. Ward's method (Shennan 1988: 217-220) produces strong clusters even from random data (Baxter 1994: 161-162) and again, the results from this data set were difficult to use.[9] Theoretically, Ward's method should only be used with squared Euclidian distance (Baxter 1994: 156). Wright (1989) strongly recommends the use of between-group average linkage despite the objections of Jardine *et al*. (1967). This method did indeed produce usable results (fig. 3) and it is these which will be discussed below. Calculation of some diagnostic statistics such as the cophenetic correlation coefficient (Shennan 1988: 230-232) would have been useful but these are not offered in the MV-ARCH package, and derivation from the dendrogram is not a viable proposition given the size of the matrix. Other validation techniques are not necessarily appropriate given that we are already aware that we are subdividing a continuum, although one method suggested by Aldenderfer (1982), comparison to other multivariate methods, had already been applied in the form of the CAs discussed above.

The final question of how many clusters to examine is not easy to answer in any problem. In this case, as noted above, we are slicing up a continuum, not identifying clear groups, and thus any decision is somewhat arbitrary, and the application of techniques such as Mojena's stopping rule (Aldenderfer 1982: 64-65) would be inappropriate. It was decided to cut the dendrogram at two levels, at 20%[10] and 30% dissimilarity.

4 Discussion of the results

4.1 ARCHAEOLOGICAL RESULTS

The groups derived from the dendrogram given in figure 3 are presented in tables 1, 2, and 3. In the following discussion groups derived at a 20% dissimilarity are called 'groups', groups derived at a 30% dissimilarity are called 'supergroups'. A detailed list of the hoards used, and their group membership, is given in Lockyear (1996: table 10.1) and on the CAA WWW server.

An initial examination of the clusters revealed patterns which were in accord with the results of the CAs discussed above. For example, group *a* (table 1) contained three hoards, all of which closed in 32 BC, and all of which contained substantial numbers of legionary denarii (*Roman Republican Coinage* [RRC], Crawford 1974: No. 544).[11] A CA of all hoards dating to 32 BC showed that these three hoards were extremely similar (Lockyear 1996: section 8.3.19).

Group *b*, however, contained 40 hoards and had a range of closing dates from 82-32 BC. A more detailed

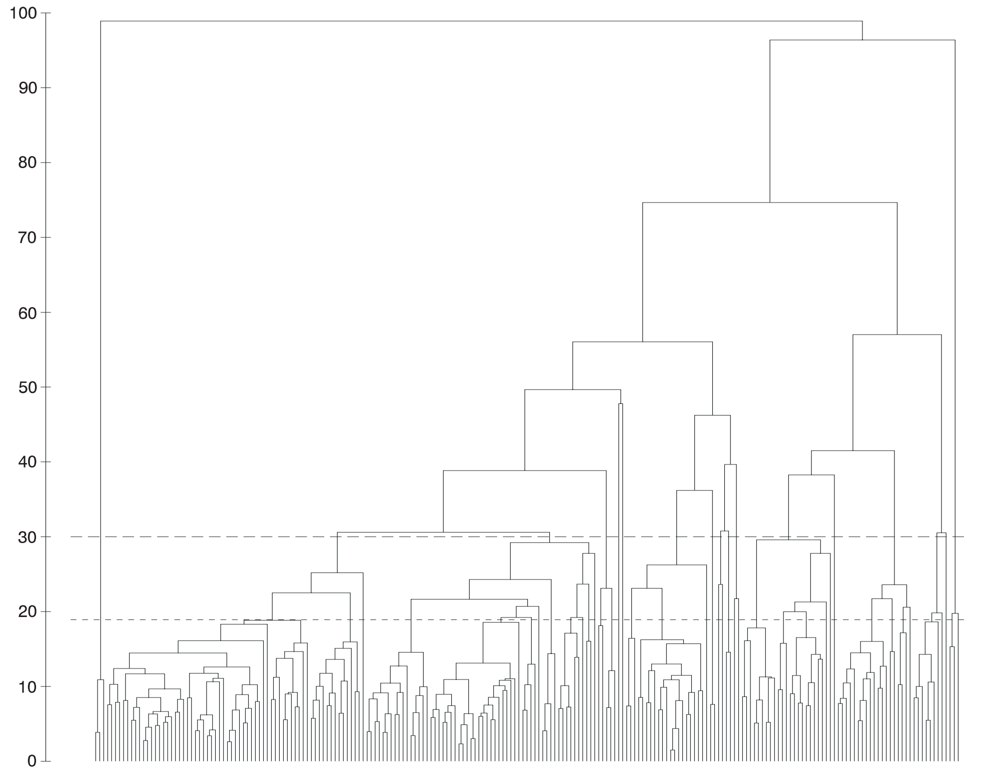

Figure 3. Dendrogram from average link cluster analysis of 217 Roman Republican coin hoards using Dmax as a dissimilarity coefficient. Short-dash line shows the cut to create the "groups" discussed in the text, long-dash line the "supergroups".

examination showed that of these hoards, ten came from Italy and Sicily. Of these ten, one closed in 82 BC, the remaining nine closed in the 70s BC. Twenty-one hoards in group *b* came from Romania, nine from other countries including Spain, Portugal, France, Greece, Elba and the former Yugoslavia. The non-Romanian hoards all closed in the 70s BC; the Romanian hoards close anywhere between the 70s and 32 BC with fifteen hoards from the 50s-40s BC.

In contrast, most hoards from the 40s occur in groups *f* or *g-i*. In the former group, 14 out of 16 hoards are from Italy, and 8 of those close in the 40s BC. Groups *g-i* contain 12 Romanian hoards, 9 of which close in the 40s BC.

Group *j* only contains four hoards all of which close in the 50s, three of which come from Italy, and again this is in accord with the results of the CAs (Lockyear 1996: sections 8.3.11-8.3.12). Hoards of the 50s are generally rare due to the low numbers of coins struck in that decade. Despite this, there are nine hoards from Romania closing in that decade but seven of these have been assigned to group *b*, and one each to groups *d* and *g*.

A detailed examination of the rest of the groups continued to reveal consistent patterns (Lockyear 1996: chap. 10) and therefore the groups made archaeological sense, especially when the hoards contained within them were examined by country of origin (table 2). Comparison of these results with the results of the 22 detailed CAs also showed a high level of agreement.

The broader pattern can be made clearer by examining the supergroups (table 3). Two supergroups are of interest, Β and Γ. Supergroup Β contains 64 hoards of which 16 come from Italy, and 31 from Romania; the Italian hoards close 82-71 BC whereas the Romanian hoards close 79-32 BC with a median of 56 BC. Group Γ contains 57 hoards of which 29 come from Italy and 17 come from Romania. The range of closing dates was surprisingly large for the Italian hoards: 80-29 BC, although the median was 46 BC. Consulting the agglomeration schedule it was found that groups *f-i* and *k-n* merged at a level of 29%. Splitting supergroup Γ into two along these lines resulted in supergroup Γ_1 containing 47 hoards, and supergroup Γ_2 containing 10 hoards. Supergroup Γ_1 contained 46 hoards of which 22 came from Italy with a range of 58-29 BC and a median of 46 BC. It also contained 14 Romanian hoards with a range of 54-29 BC and a median of 42. Supergroup Γ_2 has seven Italian hoards closing 80-72 BC and three Romanian hoards closing in 74, 62 and 49 BC. The only Romanian hoard not in supergroups Β or Γ was Işalniţa (ISA; Mitrea/Nicolaescu-Plopşor 1953) which occurs in supergroup Ν with Italian hoards of 101-82 BC, despite closing in 41 BC.

Table 1. Summary of cluster analysis results at a dissimilarity of 18.9%. Columns three and four give the next cluster to which the listed cluster joins and at what dissimilarity level. The final two columns give the range of ‘end dates’, and the median. Hoards CST and GRE omitted.

				‘end dates’	
cluster	number of members	next cluster	level	range	median
a	3	b-ρ	95.229	32-32	32
b	40	c	18.992	82-32	71
c	10	b	18.992	81-63	76
d	13	b-c	22.474	82-32	74
e	1	b-d	25.041	-	74
f	16	g-i	21.676	48-29	42
g	22	h	19.338	55-39	46
h	4	g	19.338	47-29	44
i	1	g-h	20.736	-	29
j	4	f-i	24.180	58-55	57
k	6	l	19.338	74-49	73
l	1	k	19.338	-	74
m	2	k-l	23.590	80-79	79h
n	1	k-m	27.501	-	79
o	2	p	23.063	87-81	84
p	3	o	23.063	87-82	86
q	1	r	46.556	-	46
r	1	q	46.556	-	74
s	3	t	23.055	40-29	29
t	17	s	23.055	46-29	41
u	1	s-t	26.034	-	46
v	2	s-u	35.522	49-48	48h
w	1	x	23.550	-	41
x	1	w	23.550	-	41
y	2	w-x	30.365	32-29	30h
z	1	α	21.736	-	43
α	1	z	21.736	-	45
β	9	γ-ζ	29.218	118-86	109
γ	3	δ	20.073	104-85	101
δ	9	γ	20.073	112-83	102
ε	1	γ-δ	21.310	-	104
ζ	1	γ-ε	27.495	-	115
η	1	β-ζ	37.474	-	113
θ	13	ι	21.723	100-82	92
ι	2	θ	21.723	46-41	43h
κ	3	λ	20.640	101-92	100
λ	1	κ	20.640	-	92
μ	7	ν	19.929	125-112	121
ν	1	μ	19.929	-	130
ξ	1	μ-ν	30.108	-	136
π	2	ρ	19.885	147-141	144
ρ	1	π	19.885	-	146

From both the groups and the supergroups we can make a number of broad generalisations.

1. Within the groups/supergroups, Italian hoards are of broadly similar dates. Each decade has at least one group associated with it. This reflects the dynamic nature of the Italian coinage pool with new coins entering the system, coins being lost from the system, and a reasonable speed of circulation to distribute coinage around the system.

Table 2. Cluster analysis – date ranges and median ‘end date’ for groups by region. Ordered by median ‘end date’ for Italian (including Sicilian and Sardinian) hoards. Hoards CST and GRE omitted.

	Italy			Romania			Iberian peninsula			total		
group	total	range	median	total	range	median	total	range	median	total	range	median
ρ	1	-	146	-	-	-	-	-	-	1	-	146
π	2	147-141	144	-	-	-	-	-	-	2	147-141	144
ξ	1	-	136	-	-	-	-	-	-	1	-	136
ν	1	-	130	-	-	-	-	-	-	1	-	130
μ	5	125-112	121	-	-	-	-	-	-	7	125-112	121
β	6	118-86	115	-	-	-	3	109-101	104	9	118-86	109
δ	3	102-83	100	-	-	-	6	112-101	106h	9	112-83	102
κ	3	101-92	100	-	-	-	-	-	-	3	101-92	100
γ	2	101-85	93	-	-	-	1	-	104	3	104-85	101
λ	1	-	92	-	-	-	-	-	-	1	-	92
θ	11	100-82	92	-	-	-	2	100-100	100	13	100-82	92
p	2	87-82	85h	-	-	-	-	-	-	3	87-82	86
o	2	87-81	84	-	-	-	-	-	-	2	87-81	84
d	1	-	82	9	79-32	74	2	74-74	74	13	82-32	74
m	2	80-79	80h	-	-	-	-	-	-	2	80-79	80h
c	5	81-74	79	1	-	63	2	74-74	74	10	81-63	76
n	1	-	79	-	-	-	-	-	-	1	-	79
b	10	82-71	74	21	77-32	54	4	78-71	74	40	82-32	71
l	1	-	74	-	-	-	-	-	-	1	-	74
k	3	74-72	74	3	74-49	62	-	-	-	6	74-49	73
r	1	-	74	-	-	-	-	-	-	1	-	74
j	3	58-55	56	-	-	-	-	-	-	4	58-55	57
g	7	55-42	51	11	54-39	42	2	51-46	49h	22	55-39	46
v	1	-	48	-	-	-	-	-	-	2	49-48	49h
α	1	-	45	-	-	-	-	-	-	1	-	45
z	1	-	43	-	-	-	-	-	-	1	-	43
t	8	46-38	42h	-	-	-	2	46-44	45	17	46-29	41
f	12	48-29	42	2	42-29	36h	1	-	42	16	48-29	42
s	1	-	40	-	-	-	1	-	29	3	40-29	29
a	1	-	32	-	-	-	-	-	-	3	32-32	32
y	2	32-29	31h	-	-	-	-	-	-	2	32-29	31h
e	-	-	-	-	-	-	1	-	74	1	-	74
h	-	-	-	1	-	47	1	-	46	4	47-29	44
i	-	-	-	-	-	-	-	-	-	1	-	29
q	-	-	-	-	-	-	-	-	-	1	-	46
u	-	-	-	-	-	-	1	-	46	1	-	46
w	-	-	-	-	-	-	-	-	-	1	-	41
x	-	-	-	-	-	-	-	-	-	1	-	41
ε	-	-	-	-	-	-	1	-	104	1	-	104
ζ	-	-	-	-	-	-	1	-	115	1	-	115
η	-	-	-	-	-	-	1	-	113	1	-	113
ι	-	-	-	1	-	41	-	-	-	2	46-41	44h

2. Romanian hoards can be divided into two broad classifications:
   – Class One hoards are mainly similar to Italian hoards of the 70s BC (supergroups B, Γ_2, N);
   – Class Two hoards (supergroup Γ_1) are generally similar to Italian hoards of the 50s-30s BC, although of the Italian hoards that close in this time period, those which occur in supergroup Γ_1 are more archaic than Italian hoards of the same date which occur in supergroups H, Θ and Ω.
3. At a more detailed level, Class Two Romanian hoards tend to occur in groups together, e.g. group *g*, whereas

Table 3. Cluster analysis supergroups - date ranges and median 'end date' for supergroups by region. Hoards CST and GRE omitted. †Only one hoard, from Sardinia (BER), closes in 82 BC; without this hoard the group range is 101-88.

		Italy			Romania			Iberian peninsula			total		
supergroup	group	total	range	median	total	range	median	total	range	median	total	range	median
Α	*a*	1	-	32	-	-	-	-	-	-	3	32-32	32
Β	*b-e*	16	82-71	74h	31	79-32	56	9	78-71	74	64	82-32	74
Γ	*f-n*	29	80-29	49	17	74-29	46	4	51-42	46	57	80-29	46
Γ_1	*f-i*	22	58-29	46	14	54-29	42	4	51-42	46	47	58-29	46
Γ_2	*k-n*	7	80-72		3	74-49	62	-	-	-	10	80-49	74
Δ	*o-p*	4	87-81	84h	-	-	-	-	-	-	5	87-81	86
Ε	*q*	-	-	-	-	-	-	-	-	-	1	-	46
Ζ	*r*	1	-	74	-	-	-	-	-	-	1	-	74
Η	*s-u*	9	46-38	41	-	-	-	4	46-29	45	21	46-29	41
Θ	*v*	1	-	48	-	-	-	-	-	-	2	49-48	48h
Ι	*w-x*	-	-	-	-	-	-	-	-	-	2	41-41	41
Κ	*y*	2	32-29	30h	-	-	-	-	-	-	2	32-29	30h
Ω	*z-α*	2	45-43	44	-	-	-	-	-	-	2	45-43	44
Λ	β-ζ	11	118-83	101	-	-	-	12	115-101	104h	23	118-83	104
Μ	η	-	-	-	-	-	-	1	-	113	1	-	113
Ν	θ-λ	15	101-82†	92	1	-	41	2	100-100	100	19	101-41	92
Ξ	μ-ν	6	130-112	123	-	-	-	-	-	-	8	130-112	123
Π	ξ	1	-	136	-	-	-	-	-	-	1	-	136
Υ	π-ρ	3	147-141	146	-	-	-	-	-	-	3	147-141	146

Italian hoards in the same supergroups mainly occur in separate groups, e.g. group *f*. This suggests variation at a detailed level.

My interpretation of this pattern is as follows. The main influx of coinage to Romania from Italy is in the late 70s and early 60s BC. Thereafter, the supply of coinage is at a much lower level and Romanian hoards become archaic in structure. The similarity between Romanian hoards in these periods is due to the similarity of the coinage pool from whence the coins were withdrawn. Hoards closing in the 70s BC have a high probability of actually being concealed in the 60s and 50s BC as there were few coins struck in those decades, and even fewer imported to Romania. During the 40s BC a second influx of coinage enters the area. This second influx is not simply a result of the increased levels of coin production at this time. This influx results in some hoards looking similar at a general level to contemporary hoards in Italy, but at a detailed level having some differences leading to an archaic structure. Other contemporary hoards, however, continue to have a structure similar to hoards from Italy from the 70s. This suggests that the circulation of coinage in Romania was slow and erratic.

This pattern also gives us a context for the copying of coins in Romania. If the original influx of denarii into Romania resulted in those coins obtaining a specific and important role in some aspect of Dacian society, the lack of supply from the late 60s to the mid-40s may have stimulated the production of the copies. Indeed, this author has yet to detect copies in the early coin hoards examined whereas copies have been detected in later hoards such as Poroschia (PRS; Chiţescu 1980) which closes in 39 BC (Lockyear 1996; Lockyear *et al*. forthcoming).

What is more difficult is to suggest a context for these periods of import. Romanian scholars generally suggest that trade was the major reason (e.g. Mitrea 1945). Crawford (1977, 1985) suggests that the slave trade, in conjunction with Spartacus' revolt and the suppression of piracy, was the primary cause although this suggestion has met with some hostility from Romanian scholars (Chiţescu 1981; Poenaru Bordea/Cojocărescu 1984). The latter influx is only partly due to the large numbers of coins minted at that date — an observation given more weight by the fact that the huge legionary issue is, comparatively, not very common in Romanian hoards. The Akornion inscription, from Dionysopolis on the Black Sea Coast (Dittenberger 1917: No. 762; Sherk 1984: No. 78), records a meeting between Akornion acting as emissary for Burebista (the 'first and greatest of the Kings in Thrace', lines 22-23 of the inscription), and Pompey, at some point during the Civil Wars. Although Burebista is an ill-known figure, and unfortunately communist propaganda used him extensively, clouding further what is actually known, he does seem to

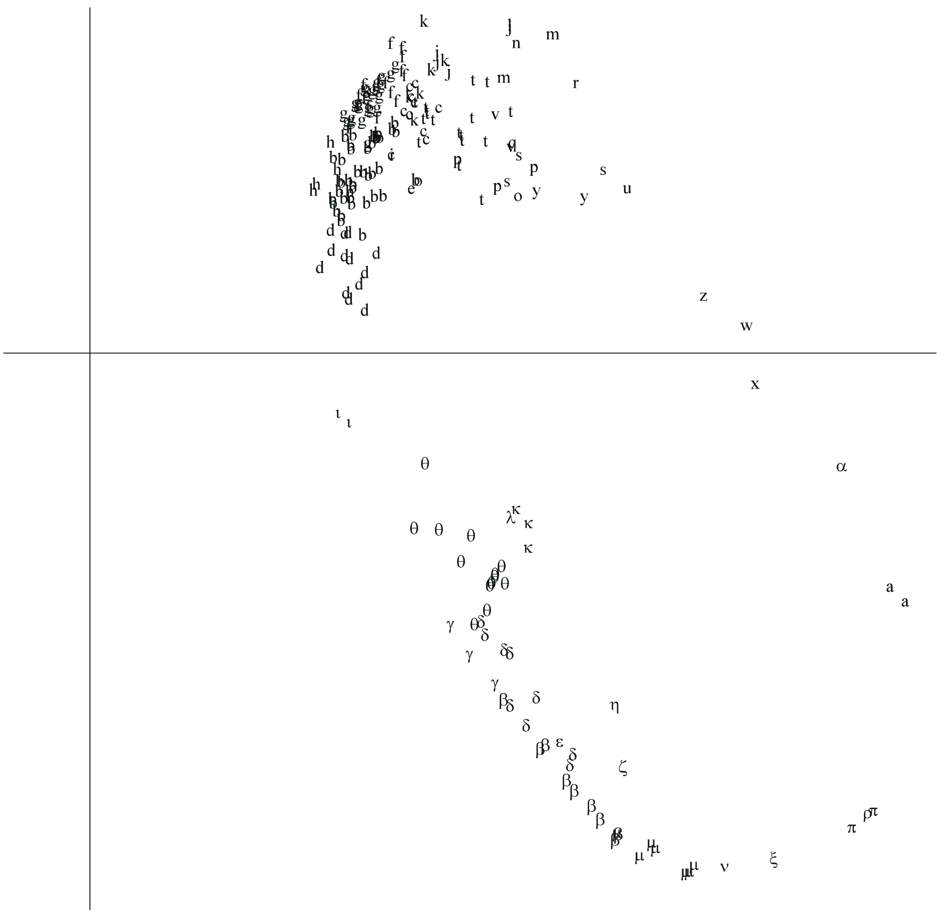

Figure 4. Map from Principal Co-ordinates Analysis of the same 217 hoards analysed using cluster analysis. This analysis has also used Dmax as a dissimilarity coefficient. Data points are hoards; the point symbol is the group membership from the cluster analysis (table 1); first (horizontal) and second axes.

have been in a powerful position in Dacia for a short period.[12] The Akornion inscription shows that he had some influence in the Black Sea region, whereas Strabo (*Geography* 7.3.11, 7.5.2) records a campaign beyond the river 'Parisus' (Παρίσου, probably the Tisza in modern Hungary). It *may be* that Pompey paid Burebista to keep out of the civil wars. Much of this is, and will have to remain, at least for the moment, unsatisfactory speculation, and still leaves many archaeological questions unanswered. For a more detailed discussion see Lockyear (1996; forthcoming).

4.2 Statistical Results

Although it is dangerous to suggest the validity of a statistical method solely on the basis of the archaeological credibility of its results, this cluster analysis using $Dmax_{obs}$ as a dissimilarity coefficient has produced results which make sense in archaeological terms. Comparison to the 22 CAs showed consistency between the two types of analysis.

A check on the results was undertaken by using the same matrix of dissimilarities and performing a principal co-ordinates analysis, also known as classic metric multi-dimensional scaling. This was performed using the Dirpcord module of the Mv-Arch package (Wright 1989). Figures 4 and 5 are the first and second, and the second and third axes from this analysis; the data points are the groups from the cluster analysis. As is expected, the results do not entirely match those of the cluster analysis but there is large degree of similarity which lends confidence to the results as a whole.

The measure also appears to be robust. Included in the analyses were three hoards which were thought to contain extraneous coins or to have other data problems. The Castelnovo hoard (cst; Crawford personal records) appeared odd in the CA of hoards from 46 BC (Lockyear 1996: section 8.3.14) and contained only three coins dated after 71 BC, which is highly unusual for Italian hoards of

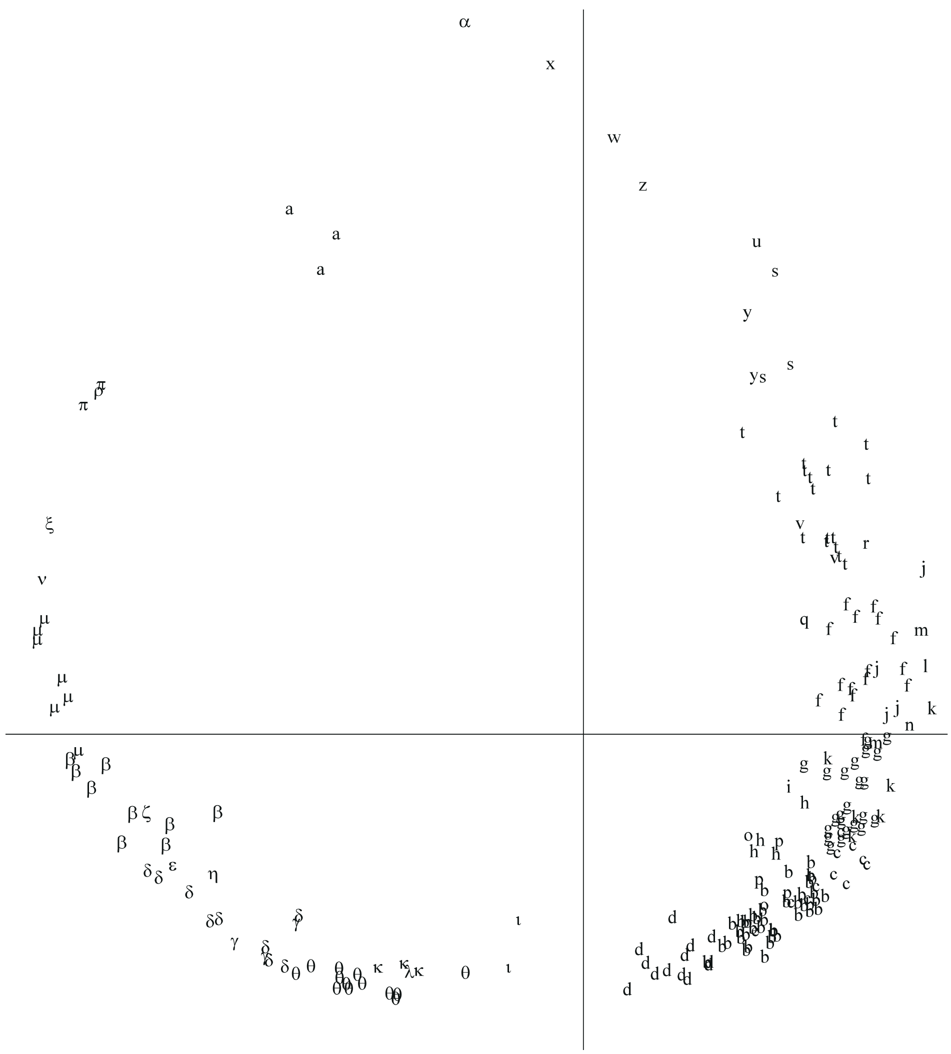

Figure 5. As for figure 4 – second (horizontal) and third axes.

46 BC. This hoard was placed in group *b* with other Italian hoards of the 70s BC, and would be dated to 71 BC if the three aforementioned coins are omitted. The Torre de Juan Abad hoard (JUA; Vidal Bardán 1982) contains two coins of 82-79 BC which were thought by Vidal Bardán to be extraneous; without them the hoard dates to 105 BC. With or without these two coins, this hoard is placed in group *δ* which consists of other hoards of that date. Finally, the San Gregorio di Sassola hoard (GRE; Cesano 1903) appeared to close in 44 BC but was placed in group *g* with 7 other Italian hoards, and 15 hoards from elsewhere. Six of the Italian hoards date from 55-49 BC, one from 42 BC. A re-examination of the database showed that a couple of coin types had been wrongly entered by myself and the correct closing date for San Gregorio is in fact 58 BC. Conversely, there is no obvious explanation for the Piedmonte d'Alife hoard (PIE; Crawford 1969: No. 406, data from Crawford's personal records) having such an archaic profile that it is grouped with hoards from 58-49 BC.

Leese has used Dmax as a similarity coefficient in two papers (Leese 1983; Middleton *et al*. 1985). In the former paper she compares the size distributions of inclusions in pottery thin sections using Dmax as a dissimilarity coefficient; the results reflecting sherd groups originally defined by other criteria. In the latter paper she compares different methods of counting grains from ceramic thin sections using Dmax, called Kolmogorov-Smirnov distances (K_{ij}), input to non-metric multidimensional scaling. Again, significant grouping is displayed on the resultant plot (Middleton *et al*. 1985: fig. 6).

Leese (1983: 52) suggests that the area between the two curves, rather than Dmax, could be used. This is the procedure used by Creighton (1992). Using the area between the curves would be space dilating, analogous to using squared Euclidian distances instead of Euclidian distance. In Leese's paper she has control over the number of grains in each sample and is able to ensure an adequate sample size. In the analysis of hoards, the number of coins in a hoard is beyond the analyst's control although a lower size bound has to be set. Small hoards will have a jagged cumulative proportion line and thus will create a large area between the lines; larger hoards will have smoother lines and the distortion will be less. Although this problem of sample size will affect both the area measure and Dmax, the former method will exaggerate the problem. Creighton sets his lower bound at five coins which creates severe problems with his analysis. My results, using a lower bound of 30 well identified denarii and Dmax, are not affected by variations in hoard size.

Dmax has also been used in other situations. Geman *et al.* (1990) use the measure in texture based image segmentation. They compare the distribution of gray scales between blocks of pixels using this measure.

5 Conclusions

Dmax has been successfully used as a dissimilarity coefficient suitable for ordinal data in cluster analysis or multidimensional scaling although a theoretical appraisal of its properties (cf. Sibson 1972) is still needed.

The cluster analysis performed has significantly added to our understanding of the supply of Roman Republican denarii to ancient Dacia, roughly modern Romania, although the archaeological and historical explanation of the pattern revealed will continue to be the subject of some debate. However, the solution of the basic aspects of the 'Romanian problem' means that the debate now has firmer foundations and can focus on the more interesting aspects of Dacian society, and its use of these coins.

Acknowledgements

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notes

1 The analysis was undertaken using CANOCO (Ter Braak 1987-1992) and the plots produced using CANODRAW (Smilauer 1992). The analysis was performed using symmetric scaling and no transformation of the original variables was performed. The first axis has an eigenvalue of 0.460 explaining 18.5% of the variation in the data set; the second axis has an eigenvalue of 0.305 explaining 12.3% of the data set. Given the size of this data set, these figures are quite acceptable.

2 In his analysis, Creighton is performing Principal Components Analysis, not cluster analysis as stated. Also, for unstated reasons, he uses percentages rather than the original counts and thus needlessly introduces the problem of compositional data (Aitchison 1986).

3 Hoards mentioned in the text are followed by a three-letter code in SMALL CAPITALS; these codes are the unique identifiers from the author's *Coin Hoards from the Roman Republic* (CHRR) database and allow cross-reference to that database, the material deposited on the WWW, and previous publications (e.g. Lockyear 1993). The CHRR database will be made publically available (Crawford and Lockyear forthcoming).

4 The 'structure' of a coin hoard in this paper refers to the pattern of representation of coins in a hoard, grouped by their date of manufacture. Creighton uses the term 'age profile' (Creighton 1992). The term derives from the statistical literature where the aim of some multivariate techniques is described as looking for 'latent structure' (Wright 1989).

5 The terms 'archaic' and 'modern' were coined by Creighton (1992). In this paper, a hoard with an archaic structure has relatively more old coinage than other contemporary hoards; a modern hoard has relatively more new coins than other contemporary hoards; an average hoard is a hoard which has a structure between the two extremes.

6 The Windows version of the *Bonn Archaeological Statistics Package*.

7 Subsequent to the analysis and the presentation of this paper, Morven Leese kindly drew my attention to her papers (Leese 1983; Middleton/Freestone/Leese 1985) which used Dmax as a dissimilarity coefficient. Note however, that Leese uses the term *Kolmogorov-Smirnov distance* to denote Dmax as used here, and *Dmax* to denote the maximum diameter of inclusions in pottery fabrics.

8 Consultation included a posting to the statistics mailing list ALLSTAT.

9 The dendrograms from both these analyses are available on the CAA web server.

10 The initial examination of the results was performed using the dendrogram only. When the detailed results were compiled the agglomeration schedule was consulted, and it was found that the 'cut' had been made at 18.9%. As the level of the cut was arbitrary, it was decided to continue with these groups.

11 This coinage, produced to pay the troops prior to the battle of Actium, is dated by Crawford to 32-31 BC. In all cases where a cointype has a range of dates, the earliest date is used. Hence, these three hoards close in 32 BC, but are almost certainly not concealed until 31 BC or very soon after.

12 Little is written in English about Burebista. Crişan (1978) gives an account, in English, of what is known, although much of the book is speculative.

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MATLAB Routines for Kernel Density Estimation and the Graphical Representation of Archaeological Data

1 Introduction

Histograms are widely used for data presentation in archaeology, but have many potential limitations. They are appropriate for variables where the measurement scale is continuous (e.g., length, height). The scale is divided into a set of contiguous intervals; the frequency count of observations in each interval is obtained; and the count is represented graphically by a bar whose *area* is proportional to the frequency. Although not essential, it is usual for intervals to be defined to be of equal width, in which case the height of a bar is also proportional to the frequency. We shall refer to this common interval width as the *bin-width*.

The choice of bin-width is essentially an arbitrary one. A second arbitrary choice is the starting position of the first interval to contain any data, and we refer to this position as the *origin*. It is well known (e.g., Whallon: 1987) that the appearance of a histogram can depend on both the choice of origin and bin-width. In particular, the archaeological interpretation of a histogram depends on the appearance which can be markedly affected by these two arbitrary choices.

A common use of histograms in archaeology is for comparative purposes; for example, comparing the distribution of the ratio of length to breadth of flint flakes from different contexts. Arguably, histograms are usually inefficient for this kind of purpose, and better methods such as the use of box-and-whisker plots exist (Cleveland 1993). Generalisation of the histogram to display the joint distribution of two variables is sometimes desirable, but is unwieldy and requires lots of data.

Kernel Density Estimates (KDEs), which at their simplest can be thought of as smoothed histograms, avoid many of these problems. They have been little used in archaeology, notwithstanding Orton's (1988) implicit reference to their potential. One reason is undoubtedly that the methodology has not been readily available in the packages used by archaeologists. A possible second reason is that archaeologists may find the mathematics underlying the methodology forbidding.

In this paper, after describing briefly the methodology, routines for implementing KDEs in the MATLAB package, that have been developed by the first author, are described. We illustrate the utility of these routines using several archaeological examples.

2 The Mathematics of KDEs

2.1 Univariate KDEs

Unless otherwise stated the sources for the material in this and the next section are either Wand and Jones (1995) or Silverman (1986).

Given n points $X_1, X_2, \ldots, X_n$ a KDE can be thought of as being obtained by placing a 'bump' at each point and then summing the height of each bump at each point on the X-axis. The shape of the bump is defined by a mathematical function — the kernel, $K(x)$ — that integrates to 1. The spread of the bump is determined by a window- or bandwidth, h, that is analogous to the bin-width of a histogram. $K(x)$ is usually a symmetric probability density function (pdf).

Mathematically, this gives the KDE as

$$\hat{f}(x) = \frac{1}{nh}\sum_{i=1}^{n} K\left(\frac{x-X_i}{h}\right)$$

Compared to the histogram the shape of $\hat{f}(x)$ does not depend upon the choice of origin, but is affected by the bandwidth h. Large values of h over-smooth, while small values under-smooth the data. Choice of both h and $K(x)$ is discussed later. Generalisations to higher dimensions, d, are relatively direct. For descriptive use only the case d=2 is likely to be of widespread interest, and is considered in the next section.

2.2 Multivariate KDEs

The representation of the KDE as a sum of 'bumps' is easily extended to the higher dimensional case. We shall restrict our attention to the case of bivariate data points of the form (X_i, Y_i). The kernel now becomes a function of two variables, $K(x,y)$, which again integrates to 1 and is usually radially symmetric. (For example, the bivariate normal pdf.) The mathematical representation of the KDE, $\hat{f}(x,y)$, depends, in general, on a 2 by 2 symmetric positive definite matrix, $\mathbf{H}$. In this paper we shall only consider the case where $\mathbf{H}$ is diagonal, i.e.

$$H = \begin{bmatrix} h_1^2 & 0 \\ 0 & h_2^2 \end{bmatrix}$$

With this simplification the representation of the bivariate KDE, $\hat{f}(x,y)$, is given by

$$\hat{f}(x,y) = \frac{1}{nh_1h_2} \sum_{i=1}^{n} K\left(\frac{x-X_i}{h_1}, \frac{y-Y_i}{h_2}\right)$$

where h_1 and h_2 are the window-widths in the X and Y directions.

The smoothing parameters h_1 and h_2 control the amount of smoothing in the two co-ordinate directions. If $h_1 = h_2$ then we can think of the 'bumps' of the kernel function as being spherically symmetric (with circular contours). On the other hand, if $h_1 \neq h_2$ then the 'bumps' have elliptical contours with the ellipsoidal axes parallel to the two co-ordinate axes. A further generalisation (not considered here) introduces an off-diagonal value h_3 to the symmetric matrix **H** and allows the ellipsoidal axes to have arbitrary orientation. Whilst taking $h_1 = h_2$ clearly makes understanding and implementation rather more straightforward, the fact that this involves the same amount of smoothing in each co-ordinate direction is regarded as a serious shortcoming (Wand/Jones 1995: 105). In the routines described below the user has the option to interactively vary the smoothing parameters, using one, two or three values of h as discussed above. The default number of smoothing parameters is two.

3 MATLAB Implementation

Here we describe, by way of examples, routines for performing exploratory data analysis using KDEs. These routines have been implemented in MATLAB, a scientific computing environment which has developed a strong user base in Further and Higher Education institutions, particularly in Departments of Mathematics and Engineering. Many such departments have copies of the package available for general use. MATLAB is particularly useful in applications involving numerical matrices and graphical presentation. Multivariate data is most naturally represented as a matrix of values, where columns indicate different components. This matrix representation of data, when coupled with MATLAB's matrix manipulation and programming capabilities, provides a powerful, accessible platform for mathematical and statistical programming and algorithm development.

Powerful graphics facilities are available within the standard package and the Graphical User Interface (GUI) is programmable also. This feature means that software can be designed to be user-friendly, with an assumption of little knowledge on the user's part. Windows, menus, sliders, buttons etc. can be used to create an interface familiar to anyone who has worked within a Windows environment, and quickly learned by those who have not. We have taken advantage of these features to develop a suite of routines allowing the user to interactively vary the kernel function, the smoothing parameter(s) and various aspects of the graphical depiction of the resulting KDEs, including contouring in the bivariate case. The use of mathematical packages such as MATLAB to create such Windows based software is a new and hitherto underexploited option for users with specific applications in mind. While a significant amount of effort must be invested in the production of such routines, we believe that the portable and re-usable nature of the software justifies this effort.

All of the figures in the remainder of section 3 were generated either using these routines exclusively, or in combination with basic MATLAB commands for plotting multiple images (fig. 1).

3.1 Example: The univariate case

In practice the choice of kernel function makes little difference to the appearance of the KDE. Figure 1 shows four KDEs generated using the same value of h, yet with different kernel functions. The names of the kernels are given in the graphs and their mathematical definitions in Silverman (1986). These data represent the rim diameters of 60 Bronze Age cups from Italy (Source: Baxter 1994: 233-234), based upon Lukesh and Howe (1978)).

Each of the kernels used in figure 1 has *bounded support*, meaning that the kernel function is non-zero only for the range $x \in [-1,1]$. In practice this makes the 'bumps' that form the KDE spread out rather less than the more commonly used normal kernel, which has *infinite support*. Compare the KDEs of figure 1 with those of figure 2(c), also obtained using $h = 2.5$ but using the normal kernel. It is clear that the KDE obtained using the normal kernel oversmooths relative to those KDEs produced with finite support kernel functions (for the same value of h).

In contrast to variation of the kernel function, the degree of smoothing (controlled by h) is of crucial importance in density estimation. If h is too large we 'oversmooth', erasing detail. If h is too small we 'undersmooth', and fail to filter out spurious detail. Several methods of automatically choosing an *optimal* (in some sense) value of h exist, though a subjective choice is often equally valid.

Some simplistic methods of automatically choosing h depend upon an assumption of normality in the data. If this assumption is not valid 'oversmoothing' often results. This explains the oversmoothing apparent in figure 2(c), which was obtained using the rim diameter data; a near 'optimal' value of h and the normal kernel. It is clear from figure 1 that this data is far from normal in structure. For the reasons outlined above, it is important to have the facility to

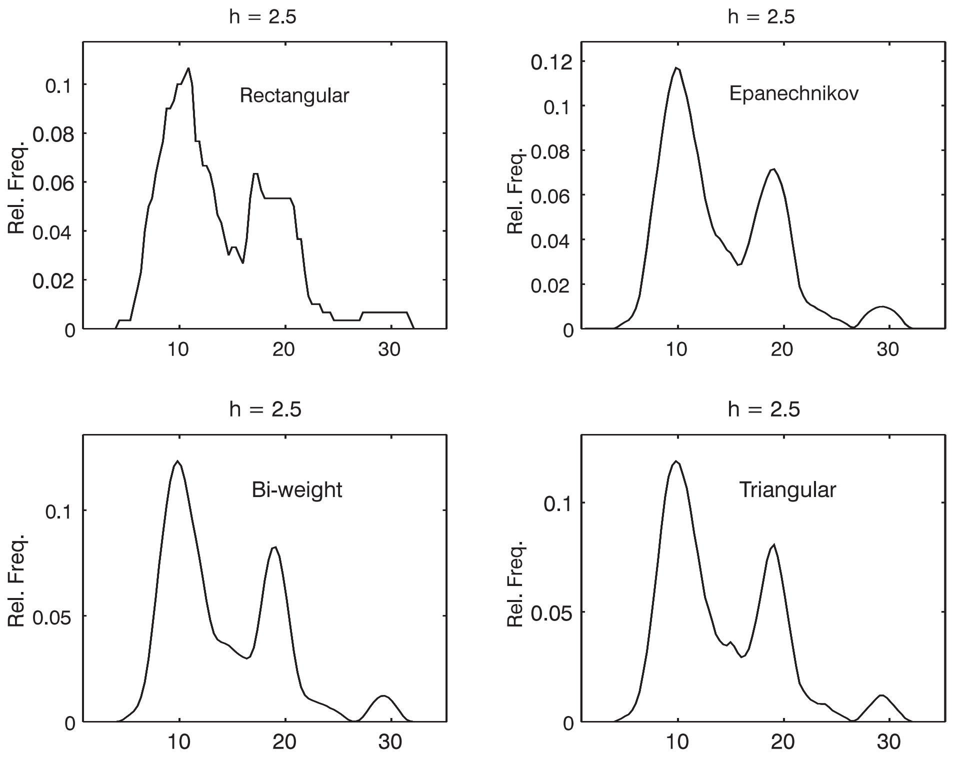

Figure 1. The effect of varying the kernel function.

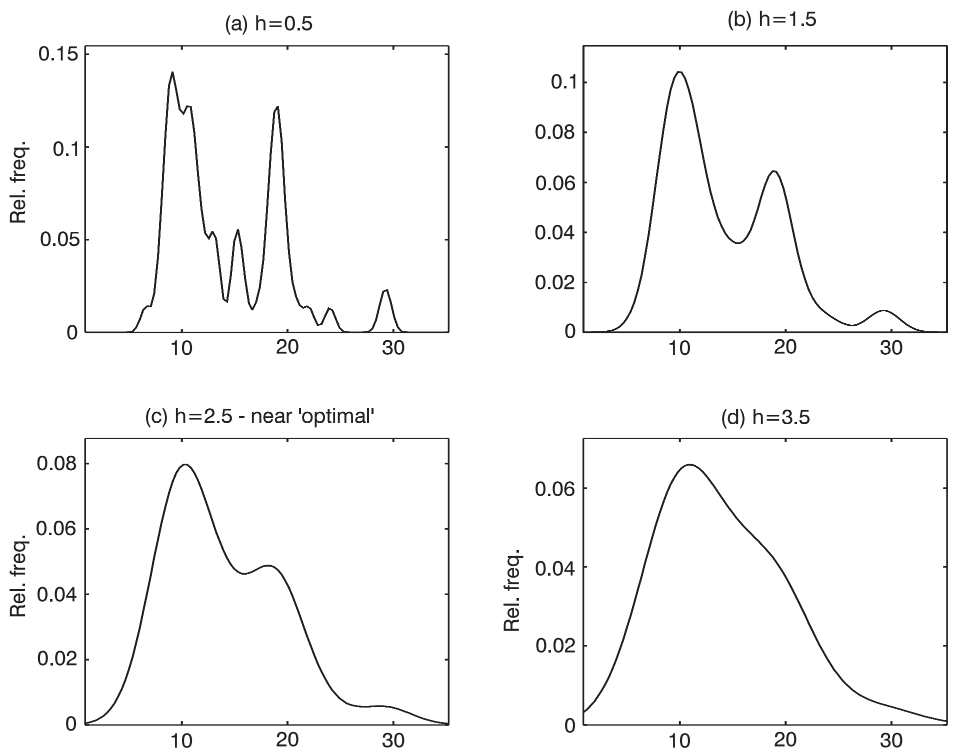

Figure 2. The effect of varying h.

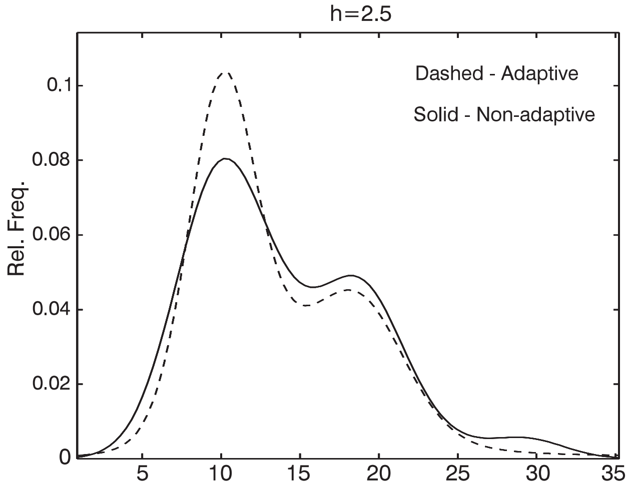

Figure 3. Adaptive Kernel Density Estimation.

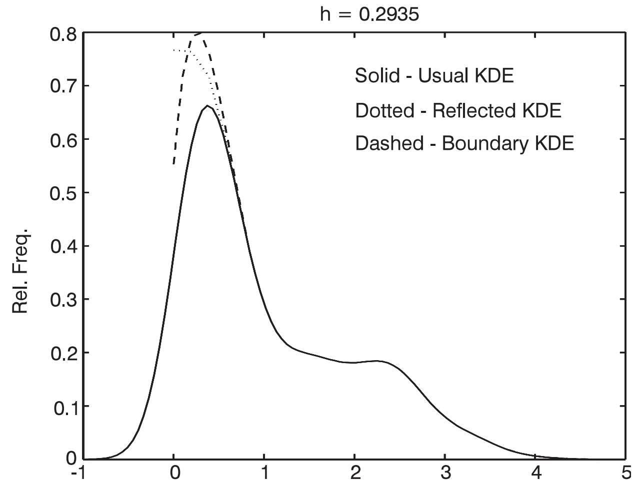

Figure 4. Bounded and Unbounded KDEs.

interactively vary the smoothing parameter *h*. Where an 'optimal' value is automatically used by a routine, it is sensible to reduce this value and recompute the KDE. The boundary between over- and undersmoothing is quite large in our experience, and a visual inspection of KDEs obtained using various values of *h* should quickly lead to a satisfactory value of *h* being found. In this respect it is helpful to be able to overlay several KDEs on the same axes, or to use subplots as in figures 1 and 2. Each of these methods is supported.

3.2 Adaptive methods

The basic idea of *adaptive* methods is identical to that described above, i.e. we construct a KDE by placing kernel functions at the observed data points. The difference is that here we allow the smoothing parameter, *h*, to vary from one data point to the next. More specifically, we use a larger value of *h* for observations in regions of low density, in particular for observations in the tails of the distribution. The intention is to reduce the effect of outliers on the KDE.

This procedure requires that we can first identify data points which lie in regions of low density. This can be achieved by initially computing a *pilot estimate* of the KDE by the standard methods of section 2. An adaptive KDE can then be constructed based upon this information. See Silverman (1986: 100-110) for a detailed discussion. Figure 3 shows both adaptive and non-adaptive KDEs for the cup diameter data and the normal kernel.

3.3 Bounded data

If the data represents some measured quantity, for example the rim diameter data considered above, then it makes little sense to use a density estimate which is positive for negative values of *x*. However, if the data set includes data points near zero, it is inevitable that the kernel or 'bump' associated with such data points will stray into the region where *x* is negative. This is especially true of the normal kernel function, since it has infinite support.

A natural, simplistic way of dealing with this situation is to reflect the part of the KDE to the left of zero in the line $x = 0$. Figure 4 shows three KDEs. The solid curve was produced using the normal kernel and an 'optimal' value of *h* as described in section 2 above. This density estimate has the undesirable property that it overlaps the line $x = 0$. In contrast, the KDE represented by the dotted curve in figure 4 was produced by reflecting the appropriate portion of the solid curve in the line $x = 0$. The data in this case represents the Na_2O content of a sample of 361 fragments of French medieval glass. Clearly this quantity cannot be negative.

More advanced methods of dealing with so-called 'bounded' data exist. In particular, there are classes of 'boundary' kernel functions which take into account the proximity of the boundary and ensure that it is not crossed. These boundary kernels have the unusual property that $K(x)$ may be negative for some *x*. In addition to the simple reflection method, we have implemented a boundary kernel method as described in Jones (1993). In figure 4 the broken line represents such a KDE.

3.4 The bivariate case

Just as in the univariate case the choice of kernel function makes little difference to the appearance of the final KDE, though for completeness we have provided a

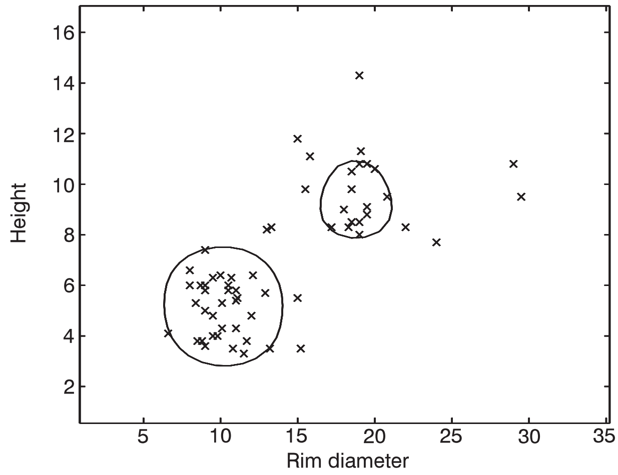

Figure 5. A 75% contour for the Bronze Age cup data.

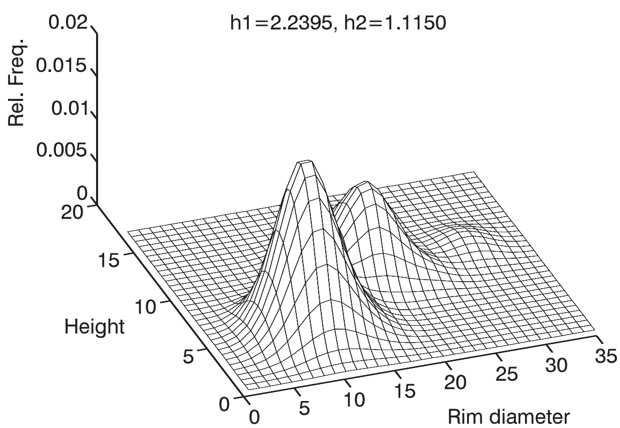

Figure 6. The KDE used to generate the contour of figure 5.

choice of four commonly used bivariate kernel functions. On the other hand, the choice of smoothing parameters again *does* have a significant effect. Our routines automatically choose values for h_1 and h_2 based upon the univariate method of selection for each of the two components considered separately. However, interactive subjective choices by the user are also supported.

An important use of bivariate KDEs is in contouring. Since a KDE is a *function*, we can apply standard contouring methods based upon the height of the function. In addition, we have found some useful applications of a new contouring method reported in Bowman and Foster (1993) (see Baxter/Beardah 1995; Baxter *et al*. 1994 for more details). This method consists of forming a KDE, then ranking the data points by descending density as estimated by the KDE. The contour enclosing *p*% of the data is then formed by drawing a contour line corresponding to the value of the kernel estimate of a data point *p*% through the ordered list. Since this technique involves calculation of the KDE at each of the data points it can be computationally expensive for large data sets. Figure 5 shows a 75% contour overlaid upon a scatter plot of data representing the rim diameter and overall height of 60 Bronze Age cups from Italy. The contour encloses the 'most dense' 75% of the data set. Figure 6 shows the bivariate KDE (obtained using the bivariate normal kernel and 'optimal' values for h_1 and h_2) which was used to generate the contour shown in figure 5.

Our routines allow interactive variation of the smoothing parameters h_1 and h_2 as well as the type of kernel function. In addition, the resulting KDEs and percentage contour plots can be viewed from any angle by means of sliders.

Acknowledgements
We conclude by acknowledging the contribution of Miss K. Bibby to this work and by inviting interested parties to obtain the software by contacting the first named author.

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A computer model of Roman landscape in South Limburg

1 Introduction

Edelman and Eeuwens (1959) proposed that the landscape of south Limburg (fig. 1) reveals the effects of a Roman centuriated land survey. This idea attracted some support (Lambert 1971: 48), but it is not generally accepted.[1] Despite this, we should keep an open mind. The hypothesis is difficult to dismiss on theoretical grounds, and it is supported by empirical results which show anomalies in the distribution of Roman sites, similar to those observed in other areas of centuriation.

The centuriation grid (fig. 2) can be located accurately by calculation (Peterson 1993: 43-47). The module is 711.61 m and the orientation is N 42.064° E. One point is located at the Limbricht St-Salviuskerk (186680, 336320) which, according to Edelman and Eeuwens (1959: 53), stands 'precies aan een hoekpunt' (precisely at a corner).

Their evidence for the centuriation is of five sorts: firstly a large number of existing boundaries have a consistent orientation; secondly major boundaries or roads are spaced at multiples of 2400 Roman feet (hence they could represent remnants of major divisions, or *limites*, of the grid); thirdly several medieval churches are positioned on these hypothetical *limites*; fourthly the orientation of some of these churches accords with the proposed grid, and fifthly Roman villas are positioned in a non-random way near the *limites*.

Some of their views can be supported by inspection. Maps show that existing roads, paths and boundaries coincide with the hypothetical *limites* of the centuriation, and on the ground it is clear that several of these features do not conform locally to natural topography.

Quantitative approaches may also be used, and are likely to provide a more secure basis for judgement. An earlier study was that of J.A. Brongers, B.M. Hilwig-Sjöstedt and E. Milikowski, who conducted a numerical analysis of the distribution of the orientation of boundaries. They concluded that the dominant orientations, which vary from place to place, are better related to the morphology of different parts of the landscape than to any overall general Roman influence on the parcelling in the whole region. However, they do not say that there is no centuriation, but that the information cannot be extracted solely from an analysis of modern parcel boundaries (Brongers, pers. comm.).

2 Quantitative study of site distribution

Since this earlier quantitative study was inconclusive, and since, in any case, undateable boundaries may not be seen as a good source of evidence, another approach is adopted here. This measures the claimed association between the grid and Roman sites of all types, including villas, using a database already independently assembled by Martijn van Leusen (1993: 105), using information from the Netherlands State Archaeological Service (ROB). In 1992 it held about 1300 records, of which 491 referred to Roman sites, including villas. This is a large data set which had not been collected together to suit Edelman and Eeuwens' hypothesis. It may therefore be used to test their claim. Given that many Roman (and later) sites are expected to be associated with the *limites*[2], we can examine the distribution of distances of sites from the grid lines, when compared to the distribution of distances which would be expected if the points are scattered uniform randomly with respect to the grid. It seems reasonable to assume that, for a large grid, this latter distribution would arise. The sites may be non-randomly related to natural features, but there is, in many places, very little relationship between these features and the grid (fig. 5).

The Kolmogorov-Smirnov single sample test may be used. The test statistic, D+, is the largest positive difference between the number of points observed at a given distance from the lines of the grid, and the number of points which would be expected on the basis of the null hypothesis (Lapin 1973: 422). In this case it is the maximum value of

$$\left| \frac{i}{n} - (1 - (1 - x_i)^2) \right|$$

where x_i is the distance of the i^{th} point in order of distance from the grid lines (Peterson 1993: 69).

Tables of critical values of D^+ show with what confidence we can reject the null hypothesis. One such table, giving values for sample sizes up to 100 was first presented by Miller (1956). For larger samples the critical value, D^+_α for a given probability, α, can be calculated

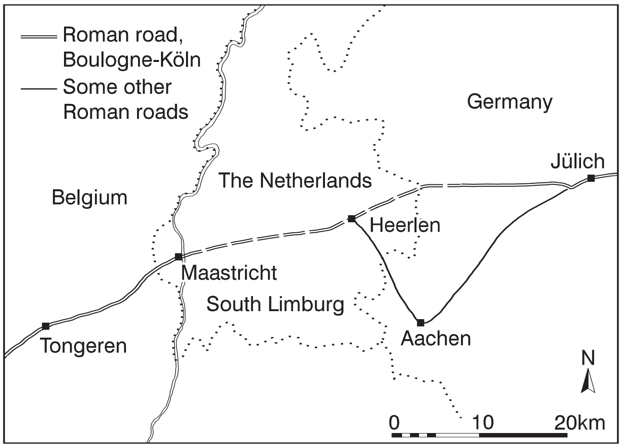
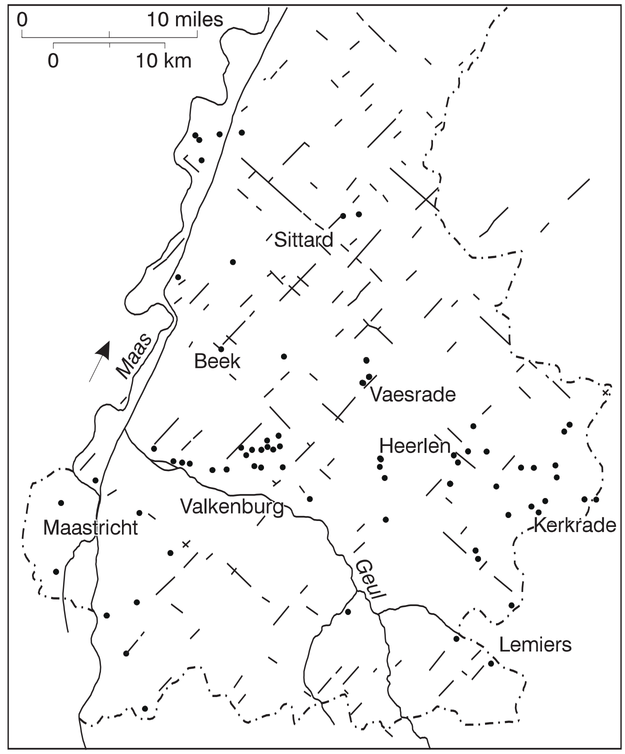


Figure 1. Situation of South Limburg.



× Remnants of decumani and cardines
• Remains of Roman buildings, mainly villas

Figure 2. South Limburg Roman grid (after Edelman and Eeuwens (1959)).

using a version of the asymptotic formula given by Miller, which was originally due to Smirnov:

$$D^{+}_{\alpha} = \frac{\sqrt{\dfrac{-\log_{e}\alpha}{2}}}{\sqrt{n}}$$

We can calculate values of the numerator of this expression for commonly used significance levels (table 1).

Each numerator value divided by the square root of the sample size gives the critical value of D^{+}. So, for example, if we have 400 observations (square root = 20) the critical value for the .005 significant level is .082. If the D value for the observations achieves this then we can say that the observed distribution would have occurred with less than 0.5% probability on the basis of the null hypothesis.[3]

3 Treatment of the data and initial results

The 491 Roman records were most kindly supplied by Martijn van Leusen, who was not aware of the parameters which had been calculated for the hypothetical grid (and who has no responsibility for my conclusions). They were transmitted as a text e-mail message and read directly into a Microsoft works database (fig. 3).

Prior to performing the tests no attempt was made to modify the data in any way. It was clear that some coordinates referred to the same site, which might for example have both signs of habitation (bewoning) and graves (graf). It was supposed that an objective way of treating the data would be to ignore these cases, on the assumption they were not likely to bias the result of the tests in any particular direction. Several sets of data were tested (table 2) These calculations were performed originally by purpose-written programs on a DEC VAX minicomputer, and again more recently by a Microsoft Excel spreadsheet. Very similar results were obtained in both cases.

In this table, the column headed 'Near %' gives the percentage of the sites in each category which lie in the half of the area nearest to the *limites*. For this category the value of distance is less than 0.29289.

'Significance Level' indicates which critical value of D is exceeded for the particular number of records. There is clearly some approximate inverse correspondence between this and the measure of bias.

The first line of the table shows that if we take all the data, making no attempt to alter or analyse it in any way, we can say that (as a formal result) there is less than a 0.25% chance that the 491 values are drawn from a set of points distributed at random with respect to the hypothetical survey grid. In other words, it appears that the odds are more than 400:1 against the hypothesis of random distribution.[4] The relatively high significance of this D value must be attributed to the large size of the population, since the degree of bias towards the grid lines is low.

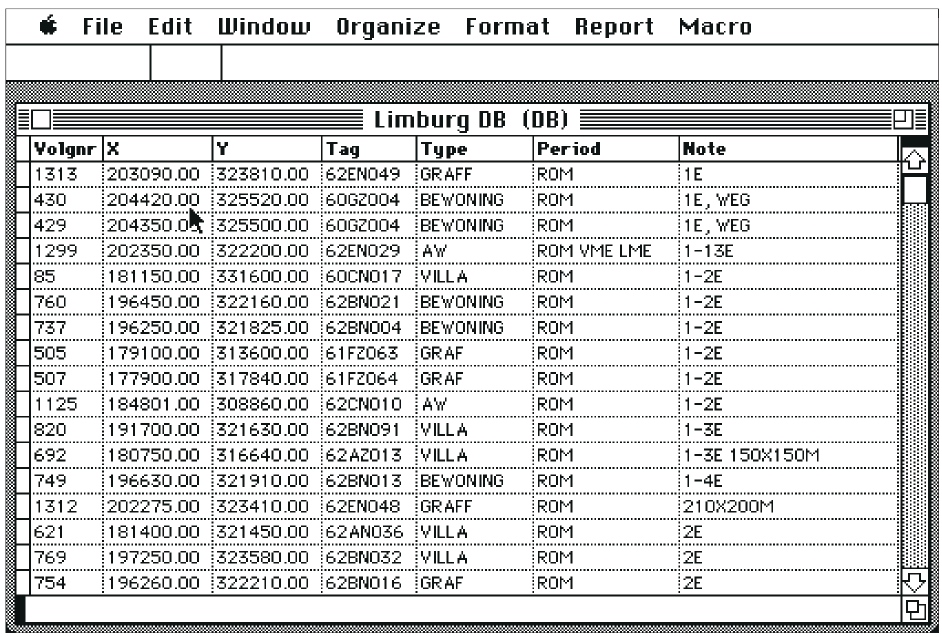
The D values for properly defined subset populations were also considered, since, according to David Clarke

Table 1. Numerator values for calculating significance levels of D+.

Probability of rejection (α)	.1	.05	.025	.01	.005	.0025	.001	.0005
Numerator Value ($D^+_\alpha \times \sqrt{n}$)	1.07	1.22	1.36	1.52	1.63	1.73	1.86	1.95

Table 2. Some Kolmogorov-Smirnov test results for Limburg data.

	Type	No.	D	Near %	Signifance level
1	All types of record	491	.0825	56.4	0.0025
2	All types (definite and not IA)	419	.0846	56.8	0.0025
3	Definite dwellings (not IA)	85	.1793	62.4	0.005
4	All dwellings	107	.1223	57.0	0.05
5	All villas	153	.1198	56.9	0.025
6	Definite villas	135	.1045	54.8	0.1
7	Temples	2	.8007	100	0.05


File Edit Window Organize Format Report Macro

Limburg DB (DB)

Volgnr	X	Y	Tag	Type	Period	Note
1313	203090.00	323810.00	62EN049	GRAFF	ROM	1E
430	204420.00	325520.00	60GZ004	BEWONING	ROM	1E, WEG
429	204350.00	325500.00	60GZ004	BEWONING	ROM	1E, WEG
1299	202350.00	322200.00	62EN029	AW	ROM VME LME	1-13E
85	181150.00	331600.00	60CN017	VILLA	ROM	1-2E
760	196450.00	322160.00	62BN021	BEWONING	ROM	1-2E
737	196250.00	321825.00	62BN004	BEWONING	ROM	1-2E
505	179100.00	313600.00	61FZ063	GRAF	ROM	1-2E
507	177900.00	317840.00	61FZ064	GRAF	ROM	1-2E
1125	184801.00	308860.00	62CN010	AW	ROM	1-2E
820	191700.00	321630.00	62BN091	VILLA	ROM	1-3E
692	180750.00	316640.00	62AZ013	VILLA	ROM	1-3E 150X150M
749	196630.00	321910.00	62BN013	BEWONING	ROM	1-4E
1312	202275.00	323410.00	62EN048	GRAFF	ROM	210X200M
621	181400.00	321450.00	62AN036	VILLA	ROM	2E
769	197250.00	323580.00	62BN032	VILLA	ROM	2E
754	196260.00	322210.00	62BN016	GRAF	ROM	2E

Figure 3. Initial part of database of Roman archaeological records for South Limburg.

(1978: 150), 'One important corollary of the aggregate or composite nature of archaeological entities is that such populations exhibit their own specific 'behavioural' characteristics which are more complex than the simple sum of the characteristics of the components and more predictable than that of the individual components. One of the main tasks therefore, is to detect and trace these persistent regularity patterns in archaeological data and to use these predictable regularities as tests for real data. If the real data displays the regularity predicted then it should fulfil some already established conditions. If the real data departs from the predicted pattern then some conditions are not fulfilled and the nature of the discrepancy may suggest the divergent conditions responsible for the anomaly.'

Clarke seems to be suggesting that we can split up the data and observe the discrepancies to see if they suggest divergent conditions. Only one variable is being measured in this case (the distance of sites from *limites*), but we can consider predefined subset populations (those have already been defined by attribute values in the database). This does nothing to invalidate the result obtained from the population as a whole, and may provide us with additional useful information.

One subset of the data is obtained if we exclude sites with previous Iron Age use, together with sites not certainly identified or not certainly Roman. For this set (table 2, line 2) the bias towards the grid lines increases slightly, but otherwise we gain little new information.

Another way of selecting subsets is by the type of site. Settlement sites are called 'bewoning' (dwelling) or 'villa'. Definite Roman dwelling sites with no Iron Age occupation on the same site (see line 3) have a very definite bias towards the *limites*. Their distribution is approximately 20 times more unlikely than that of dwelling sites in general (see line 4). This seems to confirm our expectation that, in general, sites with signs of Iron Age habitation will not be significantly associated with the grid, and that their inclusion in the set of Roman dwelling sites will reduce its apparent degree of association.

For villas (table 2, lines 5 and 6) we see the opposite. The more certainly they are villas, the less anomalous is their distribution. This apparently paradoxical result may not be totally due to a reduction in the sample size. It has been suggested (Peterson 1993: 75) that some genuine villas, as opposed to Roman dwellings of lower status, would be deliberately placed away from *limites*.

These results are shown in graphical form (fig. 4). The continuous lines show the levels of significance for D^+.

Finally, table 2 also gives a D value for the two temples in the area. The significance of this is high because, to the accuracy of 10 m with which grid location is determined, the temples both lie on *limites*. This was predicted, following the example of other centuriations and written evidence on the practice of the Roman land surveyors.

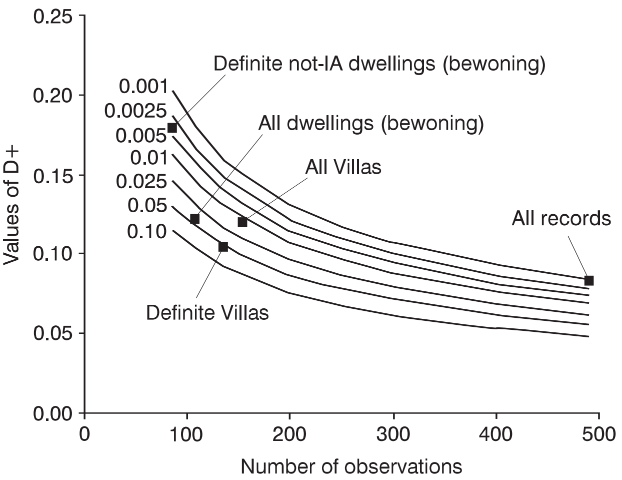


Figure 4. D values for all records for different types of settlement.

4 Studies of a sample area

Willems (1987) considers in greater detail the area of Heerlen (Coriouallum), near the centre of South Limburg, in which there are 118 database records, including data on 52 settlement sites. There are relatively few possible traces of *limites* in existing landscape features, but the D value for records of all types, which is significant at the 5% level, gives us no reason to think that the area is different from South Limburg as a whole. This independently selected sample thus seems suitable for tests of two alternative hypotheses on the origin of the landscape.

Willems' view (1987: 50), in reference to his map of Roman site distribution in the area (fig. 5), is that 'Waar het landschap door beken wordt doorsneden is ook heel fraai te zien dat op elk plateau daartussen steeds een villa ligt. Er was dan ook geen sprake van een kunstmatige landindeling — (*centuriatie*) maar men paste zich aan het landschap aan.' (Where the landscape is cut through by streams it is very satisfying to see that on each intervening plateau there is the site of one villa. There is thus no question of an artificial land allotment (*centuriation*). Rather, the sites are related to the [natural] landscape.)

Willems' hypothesis is, therefore, that natural topography, and nothing else, has determined settlement locations. If this is really so, then it seems to be influencing settlement distribution in a way normally associated with centuriation, as the Kolmogorov-Smirnov statistic indicates. Assuming for a moment that the villas really are located on the plateaux between streams, could the spacing and orientation of these plateaux be in some way peculiar? Perhaps they are regularly spaced at about 710 m, and by some strange chance the grid (which was determined by distant and independent features) happens to coincide with their crests. This seems unlikely. We already have evidence of a number of differently oriented, naturally induced, parcel boundaries in different parts of South Limburg, which implies that the natural topography does not have significant uniform orientation or regularity. In fact, on this map there is little evidence of the grid coinciding with natural topography. Only in the northwest corner is this so; but there we see *limites* coinciding with the valleys of streams, not with plateaux.

Could these difficulties be caused by the assumption that Willems' claim is true? Does a close look at the map confirm that the villas really are on the plateaux? The answer is 'only in some cases', for we can see villa sites (A-E) which appear to be on the boundary between 'beekdal'

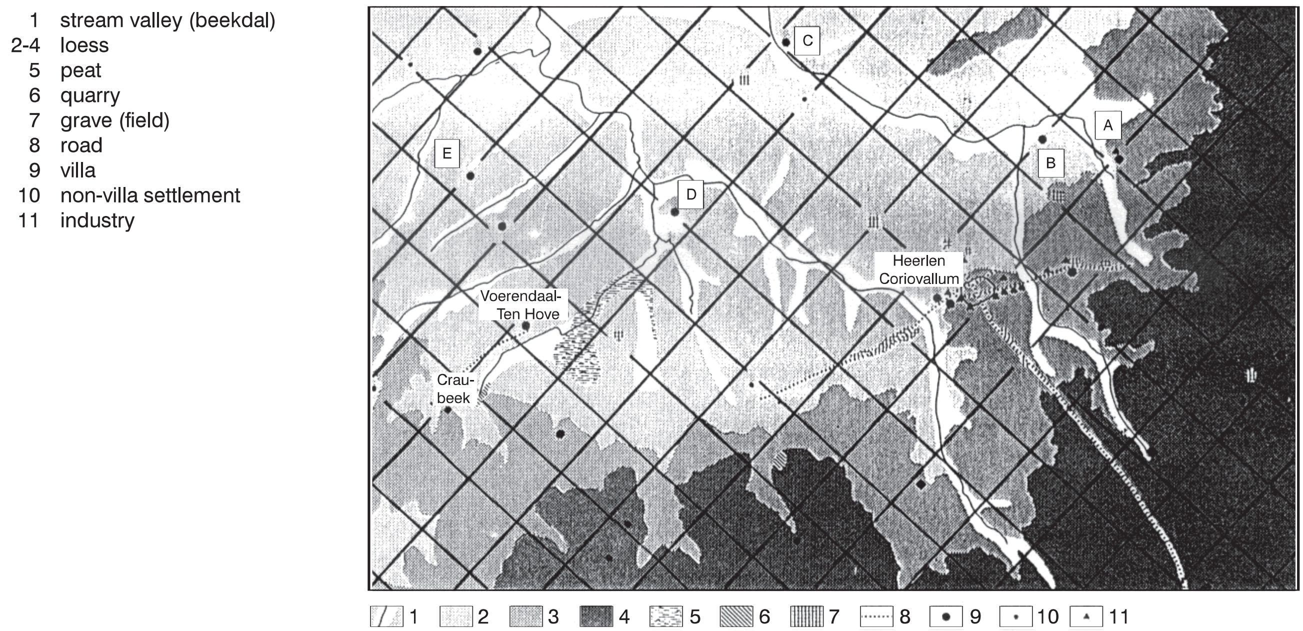


Figure 5. Roman sites in the area of Heerlen (after Willems 1987), with theoretical *limites* superimposed).

(stream valley) and loess. The villa at point E is a case in point, despite the fact that it also lies on the plateau between two other streams. Thus Willems' statement about villa siting in relation to the natural landscape results from a particular interpretation of the data. He did not draw the centuriation on his map. He was thus not in a position to see the coincidences of settlements and *limites* to the west and north of Heerlen, and in particular those counter-examples to his theory of environmental influence which might be better explained by the presence of the centuriation.

However, it is not just a question of interpretation. Judgements also vary according to the evidence which is presented, as we can see if we compare the settlement sites (villas and dwellings) on the database with those Willems shows on his map. Willems' map of sites can be matched to a reduced copy of the Topographische Dienst 1:25,000 topographic map, which includes the Dutch survey grid. When duplicates had been eliminated from the data base, it was possible to identify those database sites most closely corresponding to Willems' map features. Hence we can identify the discrepancies in the data, including settlements on the database which he does not show, and settlements shown by him which are not on the database (see table 3).

D values can also be calculated (fig. 6). It is curious to see how the database records (the author's data source) give the highest D value (P< 0.01), and the map points (Willems' source) the lowest. In fact, the distribution of the

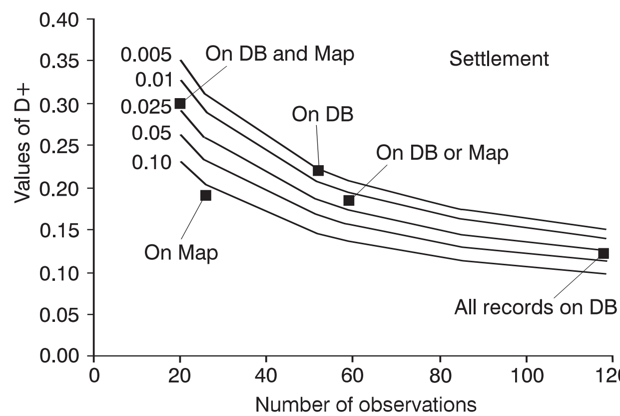


Figure 6. Comparison of D values for settlement in the Heerlen area on Database (DB) and on Willems' (1987) map.

latter with respect to the centuriation could not be regarded as significantly different from random. Nevertheless, there are 20 records, those in both sets, about which there is agreement. An independent arbitrator who selected these would find that they have a significantly high D value. The idea that they are randomly distributed with respect to the grid can be rejected at odds of 40:1.

So, if we select from Willems' sites only those which are independently confirmed, we find that they do not speak against the idea that the centuriation exists.

Table 3. Comparison of Willems map and Database data.

Volgnr	Tag	Coordinates X	Y	dist.	Type (DB)	(Map)	Notes
767	62BN030	19010	32090	61	BEWONING	N G V	N G V = non villa settlement
846	62BN111	19048	32435	64	BEWONING	N G V	
840	62BN108	19085	32069	47	BEWONING	N G V	
746	62BN011	19108	32315	7	VILLA	VILLA	Nearest of four Volgnr
824	62BN094	19120	32450	54	VILLA	VILLA	Nearest of two Volgnr
864	62BN127	19140	32310	248	VILLA	-	
843	62BN109	19145	32262	89	VILLA	VILLA	
818	62BN091	19166	32163	18	VILLA	VILLA	Voerendaal, nearest of two Volgnr
810	62BN081	19206	32044	311	VILLA	VILLA	
860	62BN123	19207	32165	164	?BEWONING	-	
771	62BN035	19215	32130	108	VILLA	-	?Error, in area of "veen" (bog)
819	62BN091	19215	32165	110	VILLA	-	
770	62BN034	19240	32070	64	BEWONING	-	
		19260	31910			N G V	
869	62BN131	19278	31965	41	BEWONING	N G V	
868	62BN130	19335	32278	109	VILLA	VILLA	
836	62BN104	19412	32095	22	?VILLA	N G V	
835	62BN103	19452	32460	110	VILLA	VILLA	
870	62BN132	19458	31926	216	?BEWONING	N G V	
855	62BN119	19470	32400	24	?BEWONING	N G V	
907	62BN163	19501	32017	4	?BEWONING	-	
831	62BN099	19593	31990	78	VILLA	VILLA	
772	62BN037	19595	32030	10	VILLA	-	
733	62BN001	19597	31995	74	BEWONING	-	
		19610	32190			VILLA	?A generic point
737	62BN004	19625	32183	76	BEWONING	VILLA	
778	62BN043	19628	32178	93	BEWONING	-	
777	62BN042	19630	32160	75	BEWONING	-	
779	62BN044	19640	32180	2	BEWONING	-	
764	62BN025	19640	32240	175	BEWONING	-	
780	62BN045	19642	32190	90	BEWONING	-	
792	62BN056	19645	32186	80	BEWONING	-	
760	62BN021	19645	32216	303	BEWONING	-	
739	62BN006	19650	32185	94	BEWONING	-	
743	62BN010	19652	32180	46	BEWONING	-	
789	62BN052	19657	32197	122	BEWONING	-	
784	62BN048	19660	32180	14	BEWONING	-	
776	62BN041	19660	32185	20	VILLA	-	
793	62BN057	19660	32190	53	BEWONING	-	
816	62BN088	19660	32205	154	BEWONING	-	
761	62BN022	19660	32207	167	BEWONING	-	
749	62BN013	19663	32191	38	BEWONING	-	
753	62BN015	19670	32180	88	BEWONING	-	
785	62BN049	19670	32195	12	BEWONING	-	
775	62BN040	19690	32215	2	BEWONING	-	
847	62BN112	19698	32208	108	BEWONING	-	
769	62BN032	19725	32358	15	VILLA	VILLA	
		19760	32210			VILLA	
806	62BN073	19780	32215	41	BEWONING	-	
		18790	32150			N G V	?Badly plotted Volgnr 806
		19810	32330			VILLA	
833	62BN101	19839	32026	192	VILLA	-	
808	62BN076	19845	32020	188	VILLA	VILLA	
925	62BZ015	19900	31865	117	BEWONING	VILLA	
748	62BN012	19906	31955	114	BEWONING	-	
		19940	32080			N G V	
814	62BN085	19980	32133	142	VILLA		
834	62BN102	19990	32126	21	VILLA	VILLA	

5 The trustworthiness of the Kolmogorov-Smirnov test results

The statistics of Roman site distribution in general, and especially the distribution of settlement in the area of Heerlen, seem to provide evidence against the well-established belief that the centuriation of Limburg does not exist. We must therefore examine them carefully for possible flaws. For this purpose a number of simulations were run, generating a further 812 Kolmogorov-Smirnov D values.

First, duplicate grid references were eliminated, giving 456 (rather than 491) data items. For this set the probability of observing the D value at random was 1:280, rather than 1:802. This reduction in significance suggests that an 'objective' approach to the data, as used originally, may give a misleading result. Clearly, the significance of a particular D value will be increased by maintaining the same cumulative distribution of observations, while increasing their number. For this reason the settlement data for the Heerlen area were processed to remove duplicates. Another surprise was that a shift of origin of the grid — from that originally used to another point calculated using the grid parameters — produced a noticeable change in the probability of the D value. For the 491 original data items it changed from 1:802 to 1:594. For 456 unique sites it changed from 1:280 to 1:222. These changes are probably caused by the precision of calculating grid intersection coordinates, which is only to 10 m.

Following a suggestion by Irwin Scollar, it was tested whether the same grid, with the same origin points, might fit the data just as well at other angles. All possible angles (42.064° ±45°, at intervals of 1°) were tried, using both data sets for the original origin and the reduced set for the shifted origin. This produced 267 D values for other angles. Of these, seven were less probable than 1:89 — that is about twice as many as expected — and two were less probable than the values observed at 42.064°. A further simulation was run with 456 randomly generated grid references in a 4 km by 4 km square. Again there were 3 trial runs, each covering 90°. The results showed 40 D values with a probability of less than 1:5 — roughly the expected value. However, there were five D values which were less probable than 1:90. This is again more than expected, but further work would be needed to see if the difference is significant.

The conclusion for the tests on the whole data set is that the significance may be exaggerated by a factor of two, but the reason for this is currently unknown. The practical implication is that the p values for the significance levels given above (table 2) should be doubled. Despite this, inferences drawn from the figures are unchanged.

Similar simulations were conducted on the Heerlen data. For 3 runs of 90° each, there were 52 D values with a probability of less than 1:5 and 31 with a probability of less than 1:10 — very near the expected values. However, excluding the values for 42.064°, there were five values with a probability less than 1:89. Hence, looked at from random angles, these site coordinates have the characteristics of random data, but the lowest probabilities obtained in 'real' trials may be not totally reliable. Nevertheless, the test results (fig. 6) are still useful, even if the significance level p values are doubled.

6 Proposals for further work

To test Edelman and Eeuwens' hypothesis further, even more data would be useful. This might be obtained from areas of the centuriation lying outside the modern day borders of the Netherlands, which would have to be located on other national maps. Dutch maps use the national rectangular coordinate system (as does the ROB database), but they also include in the margin the lines of the UTM zone 31 kilometre grid. From this the parameters of the centuriation may be recalculated. Hence coordinates for the grid intersections may be calculated and plotted for Belgium, which uses UTM grids.

Similarly the centuriation grid may be extended to Germany, using slightly different methods. The geographic coordinates of two intersection points of the centuriation could perhaps be calculated from their UTM zone 31 coordinates, and then used to calculate the equivalent Gauss-Krüger (GK) coordinates for German maps, by means of Scollar's (1989) computer programmes. Alternatively, it is easier in practice to plot intersection points, already plotted on overlapping Dutch and Belgian maps, at the same positions on the German maps. Coordinates can then be read directly, and the angle of the centuriation calculated in terms of north in the local GK grid.

Preliminary results show that near Aachen (fig. 1) some existing topographic features and the former main road from Aachen to Jülich have the same orientation as the hypothetical grid. This is also true of three of the four villas (Gaitzsch 1987) which were excavated in the Hambacher Forst, east of Jülich, between that place and Köln. Wolfgang Gaitzsch in another article (1986: 427) concludes that 'Die regelmäßigen Eingrenzung der Wohn- und Wirtschaftsbereiche ist der Ausdruck einer planmäßigen Limitation des Nutzlandes der CCAA' (the regular boundary layout of living and working space is the expression of a planned *limitatio* [i.e. Roman land survey] of the productive land of CCAA [Köln]). Further data on site location in this area could be used to test the compatibility of Edelman and Eeuwens' with Gaitzsch's hypothesis.

7 Conclusions on the objections to the centuriation hypothesis

There are two principal theoretical objections to the centuriation hypothesis. The first is that a large centuriation such as that of South Limburg could not exist and that it could not extend so far. This view is mistaken. A larger and much less visible system existed in an equally marginal situation in the empire, in southern Tunisia (Trousset 1978). Not only was it very large, but it ignored tribal boundaries, which were established in the area of the existing survey. So, we may, with Monique Clavel-Lévêque (1993:19), be sceptical that a centuriation could cross a Roman provincial boundary which in this case is thought to lie at about Aachen (King 1990: 212), but such a thing is possible. As Tate (1992) has suggested in the case of Roman surveys in Syria, 'Juxtaposés ou superposés, ces réseaux ne dépendent pas des *limites* entre provinces, cités ou finages de villages. Ils occupent des aires si vastes qu'ils ne peuvent avoir été construits que par ordre d'une autorité supérieure, ...'. So, according to him also, surveys ignored provincial boundaries. There is thus no theoretical objection to the extension of the South Limburg centuriation across the border, even if we knew precisely where it was.

The second objection is the one Willems raises. In short, if natural features explain settlement location, then an alternative explanation is false. This is mistaken in practice, because close examination of the map of sites — in conjunction with the database — does not confirm that they are really located according to some simple environmental constraint. It is also mistaken in principle. Even if a convincing demonstration had been made that settlement in the area of Heerlen is strongly influenced by natural topography, the centuriation could not be ruled out. Surely, we must allow the world to be a complex reality in which many factors act at the same time to influence human actions, a world in which human beings, by use of their intellect within a cultural framework, manage to satisfy different types of constraint simultaneously.

Much of 'hard' science seems to be founded on a mistrust of complexity, on a feeling that simple answers are most likely to be true and on the acceptance of William of Occam's principle that explanations need not be expanded beyond what is necessary. This is not appropriate to the study of landscapes which have been worked and reworked by man. They need a more open approach, such as that advocated by Lawson and Staehali (1990), which fits the author's experience of Roman systems of land management (Peterson 1993: 255). If investigation methods were framed in this spirit, we would be more suspicious of attempts to give such simple answers and we would more easily avoid the self-destructive over-application of Occam's razor.

notes

1 It is surprising that sceptics include Oswald Dilke (1971: 140), who discussed other equally controversial systems in favourable terms.

2 This association is hardly in doubt. It may be for symbolic reasons, as in the case of Roman temples marking the survey lines. It may also be economic, since *limites* existing as means of communication, i.e. roads or canals, provide low cost access. There are very clear examples, such as sites in the northern *Ager Cosanus* dated to the 2nd century BC, which have been found 'only on the major axes of the centuriation' (Attolini *et al*. 1990: 145). Again, according to Caillemer and Chevallier (1954: 458), 'Des routes, des voies ferrées, des pistes d'aérodrome, des *limites* de commune s'orientent de même pour éviter de couper les cultures dont les contours correspondent toujours à la répartition antique du sol; il arrive souvent que des grandes fermes modernes soient situées à l'emplacement de ruines romaines, dans l'angle de centuries.' It should, however, be noted that these are extreme cases in which all or most sites are on or near *limites*. Other cases are less clear. They may require statistical techniques in order to measure the association.

3 If we were interested in both positive and negative values of D, we would calculate the critical values, D_α using the very similar asymptotic formula (Rohlf/Sokal 1969: 249):

$$D_\alpha = \frac{\sqrt{\dfrac{-\log_e 1/2\alpha}{2}}}{\sqrt{n}}$$

However, in this case it seemd most appropiate to follow Lapin in considering only positive values, since this is the deviation from randomness which has meaning in the context of our theory. Lapin's published critical D values for a sample of 100 (taken from Miller), are then close to values calculated using Smirnov's formula.

4 According to the calculations described above, the chance of such a high D being seen at random is about one in 800.

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Time versus Ritual – Typological Structures and Mortuary Practices in Late Bronze/Early Iron Age Cemeteries of North-East Caucasia (‘Koban Culture’)

1 Introduction

In North Caucasian archaeology the Late Bronze Age and Early Iron Age, covering the period of the 14th to 4th century BC is one of the most prominent periods of archaeological research. The cultures of this era are predominantly known for their outstanding metallurgy which is shown in the quantity of weapons and adornment of the burials. As early as the 19th century AD the enormous wealth of these burials led to ‘archaeological’ activities, looting rather than excavating being the predominant method of this time. This resulted in the huge collections of Caucasian bronzes in European museums (Virchow 1881). Only in the 30s of the present century did real scientific research begin with excavations and chronological studies (Kozenkova 1990; Krupnov 1960).

Despite the exceptional number of graves and the long-lasting tradition of Soviet and foreign research, some problems remain regarding the historical interpretation of this material. Archaeological research has particularly been dominated by chronological and spatial discussions (Kossack 1983; Kozenkova 1990; Krupnov 1960, 1962). Differences in spatial distribution of items and in burial customs have been used for marking different ‘cultures’ or subgroups within such ‘cultures’ (Krupnov 1962). Interpreted against the historical background (Herodotus, Book IV), they have been seen in the light of ethnic movements such as the Scythic expansion during the 8th century. Other questions, e.g. on social organisation and the mode of production and exchange have never been the focus of research although they have been discussed before (Iessen 1941; Černych 1992: 275-295).

Reconstructing the way of social communication of the Late Bronze Age/Early Iron Age tribes, as expressed in the wealth of the burial goods, the mode of building such tombs and the exchange of prestige items, may be one way of answering such questions. Spatial distribution of graves, different degrees of wealth and energy expenditure for the funeral of the individual person as well as differences in grave good types, quality and number usually constitute the set of criteria which is used by archaeologists to examine the way of social communication during the funeral act, reflecting the main principles of social structuration of the burying community (Bietti-Sestrieri 1992; Saxe 1970; for critique of such analogies see Härke 1993; Pader 1982; Steuer 1982). The Seržen’-Jurt cemetery which is one of the largest and best published graveyards of the north Caucasian Koban culture forms an excellent case to study such patterns. Statistical methods can be used to identify structures as statistical patterns in the archaeological record. Multivariate analyses could be an instrument giving multicausal explanation for such patterns (Bietti-Sestrieri 1992; Müller 1994).

2 The cemetery of Seržen’-Jurt (Čečeno-Ingušetia) as an example for analysing ritual behaviour in the late Bronze/Early Iron Age of NE-Caucasia

The cemetery of Seržen’-Jurt is situated at the edge of the northeastern Caucasian mountains where a small river leaves the hilly zones of these mountains (fig. 1). It is closely connected with a nearby settlement which covers about 0.5 ha. The settlement with approximately 10 houses could have existed for 550 years — as indicated by several radiocarbon dates covering the period from 1350 to 800 BC (Kozenkova 1992: 67). The graveyard can be dated to the Late Bronze Age, the end of its use to the beginning of the Early Iron Age. This is some time before the end of the 9th century BC. Obviously burials had taken place for about 300 years (Kozenkova 1992: 73).

The cemetery extends over an area of 2000 sq m. It was excavated during the late sixties and early seventies and published by V. Kozenkova (1992). It contains about 100 graves, inhumations in rectangular tombs with flexed bodies, orientated mostly towards the NE. The burial equipment is quite large and usually consists of bronze or iron items — adornment, weapons, a few tools — and large quantities of ceramic vessels. Eleven graves are additionally equipped with horse offerings, similar to those which have been reported from antiquity (Herodotus, Book IV: 70) to the beginning of the 20th century by ethnographic researchers (Nioradze 1931). Spatial structurations of the cemetery can be assumed to be in six separate groups of graves, two of which are quite large (fig. 2).

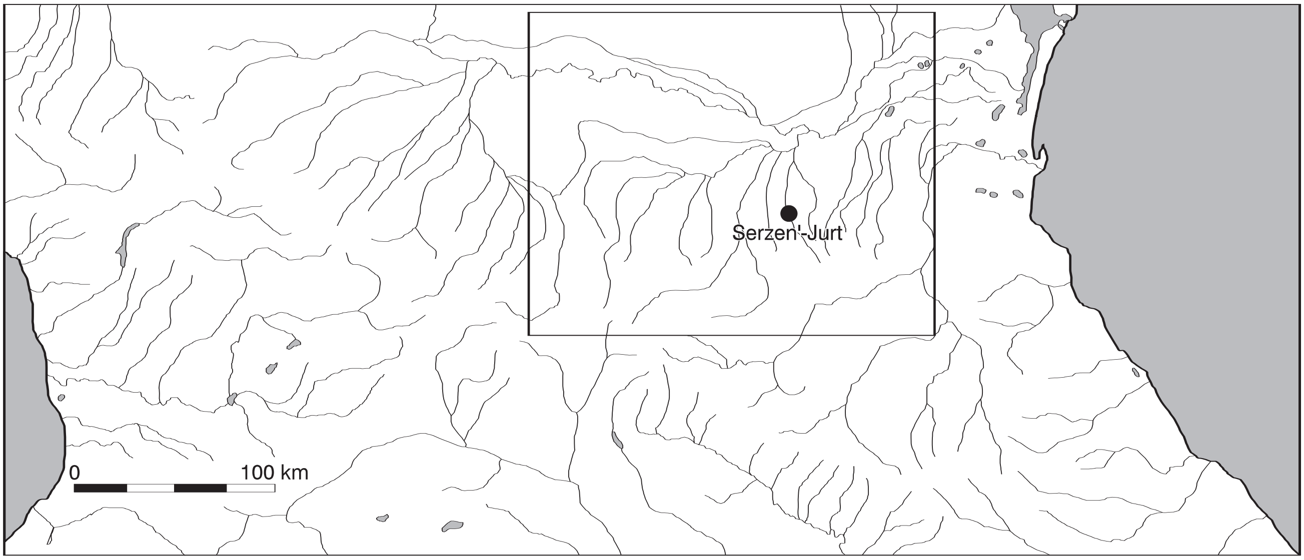

Figure 1. Location of Seržen'-Jurt.

Although no anthropological investigation of the skeletal remains has been carried out, the difference of gender seems quite clear from the material equipment of the inhumations. From the size of the skeletal remains it also has been possible to determine several burials of children or juveniles (Kozenkova 1992: 11-14). Following this distinction a representative part of the Seržen'-Jurt population is supposed to be buried here. However, attention must be drawn to the relations of the settlement and graveyard. If the assumption is correct that 10 households, i.e. families, had occupied the settlement for over 500 years, the 100 graves of the cemetery could not represent the whole of the ancient population. As there are no other burial places known from the surrounding area with the exception of some burials in pits within the settlement itself, it can be supposed that special criteria, e.g. social status or religious motives, are responsible for the deposition of only some individuals in the burial ground.

2.1 Seriation and correspondence analysis of stylistic types as a proposed chronological background

The deposited objects in the graves can be divided into three functional classes. These classes concern the personal adornment in its function as funerary costume, weapons and tools as technical equipment, ceramic sets and jewellery as goods from 'everyday life' (Reinhold 1995).

The statistical basis for analysing the grave goods from the Seržen'-Jurt cemetery are 1280 objects which can be assigned to 140 stylistic types. The classification of the objects follows the method described by Hodson (1990) for the classification of the Hallstatt cemetery. For seriation and correspondence analysis the Bonn Archaeological Statistic Program (BASP) has been used (Herzog/Scollar 1987). In addition, the significance of the results has been checked by using the statistical tests of the SPSS package.

Following the model described by Djinjan (1985) the parabolic structure of the correspondence analysis has been used to suppose normally distributed data which could be correlated with a continuous process of production and/or deposition of items (Bakker 1994). Non-parabolic geometric structures could point to non-linear processes of production/deposition (Djinjan 1985), e.g. special ritual needs for a proper burial which corresponds to the culturally determined ideology of the burying community.

Non-linear structures as mentioned above are the visible results of typological seriation of the funeral goods. The correspondence analysis shows the typological proximity of the inventories (fig. 3). It is dominated by two types of ceramic vessels which occur in large quantities in 62% of the graves in combination and in another 12% of the burials as single pottery forms. Excluding these types the structure is dominated by the distance of the few Early Iron Age inventories and the fission of the armed and non-armed Late Bronze Age burials (fig. 4). The distinction of gender represented in armed males and non-armed females and males is obviously shown at this level, apart from the general differentiation of the Late Bronze and Early Iron Age.

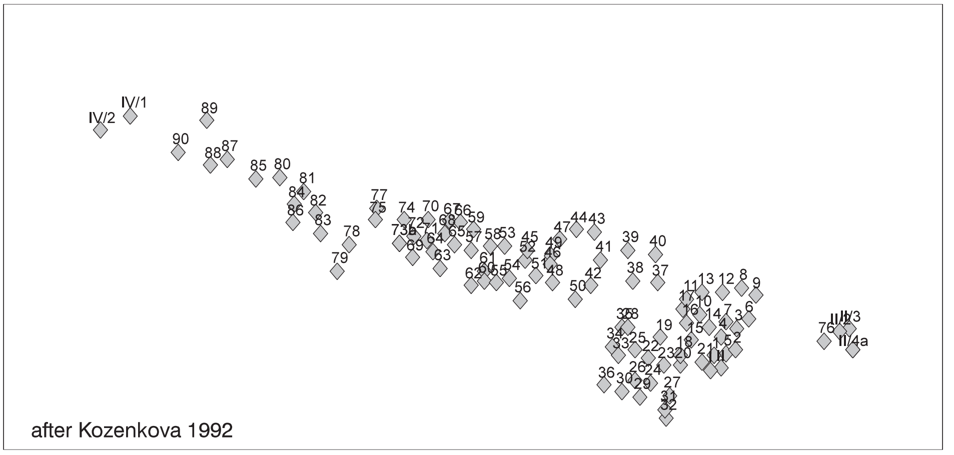

Figure 2. Spatial distribution of the Seržen'-Jurt cemetery.

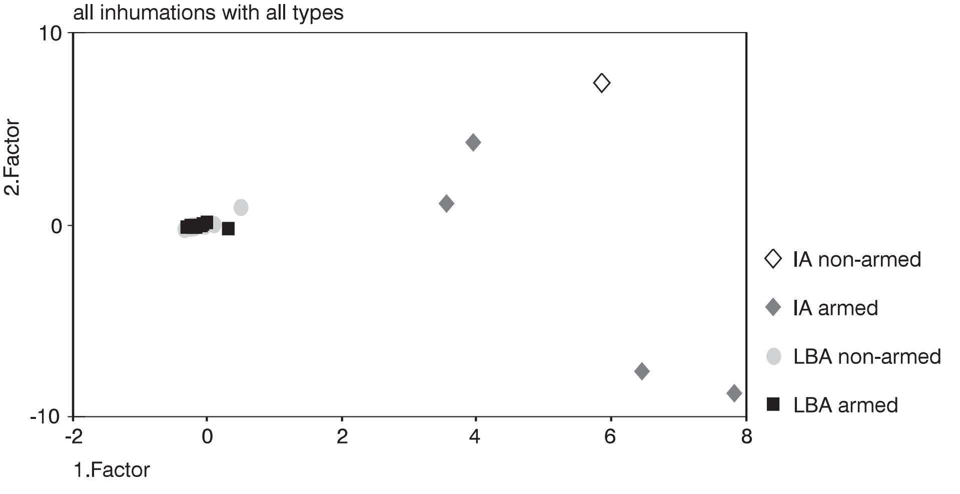

Figure 3. Correspondence analysis Seržen'-Jurt. All inhumations with all types.

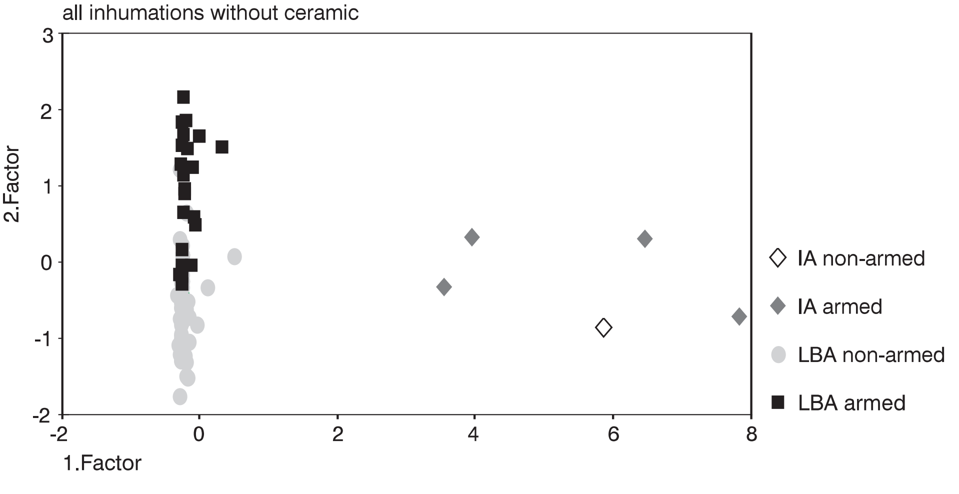

Figure 4. Correspondence analysis Seržen'-Jurt. All inhumations without ceramics.

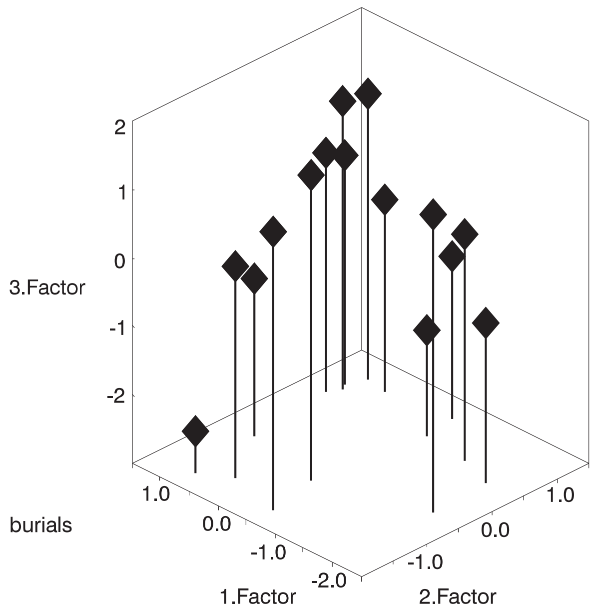

Figure 5. Seržen'-Jurt. LBA armed inhumations without common types.

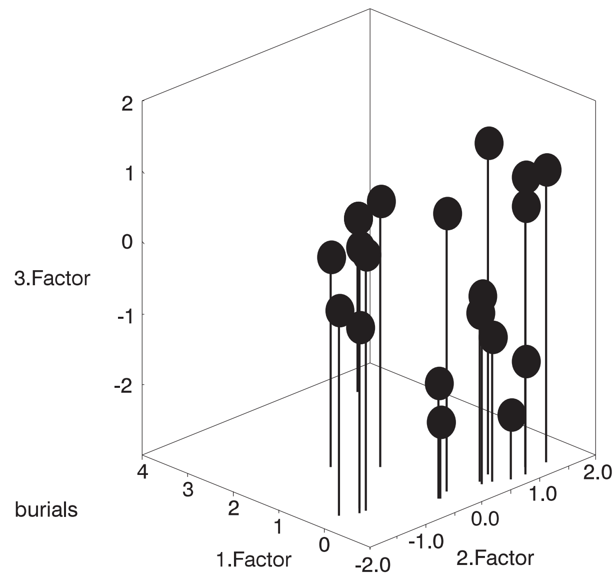

Figure 6. Seržen'-Jurt. LBA non-armed inhumations without common types.

In separate seriations both armed and non-armed Late Bronze Age data are still dominated by types occurring in more than 25% of the inventories. Just by reducing the database once more a parabolic structure is obtained which can be interpreted as a sign of continuous, normally distributed production/deposition (figs 5, 6).

Summarising this evidence it can be pointed out that the complete database of the Late Bronze Age burials is dominated by very frequent types occurring in nearly all graves which compel to reduce the database by 95% of the ceramic vessels and by 53% of the metal items to receive a statistical result which can be interpreted in terms of a chronological order. However 21% of the grave goods are single types and therefore excluded. At this point of the analyses it becomes clear that several components underlie the assemblages of the inventories of which chronology is just one.

2.2 Functional classes as structuration criteria

The second level of classification focuses on the functional classes. By using hierarchical cluster analysis, the differentiation between armed and non-armed males again becomes quite clear. In addition several other significant correlations are visible which can be identified by using a simple table of clusters of different costume groups or clusters of weapons. Six main costume groups can be identified, composed of bracelets and head-dresses (fig. 7). Five of these are correlated with the non-armed, obviously female group of inventories and one group is correlated with armed individuals but occurs also without arms. They are supposed to represent male individuals. Compared with the typological database the main components of these costume groups are identical to the excluded types in the seriation set.

In addition to the costume groups seven combinations of arms can be identified. They consist of different types of weapons — lance, axe or daggers — in combinations of three, two or one types. The complete set of arms correlates also with the horse burials and marks the outstanding male burials. When these groups are mapped into the typological correspondence analysis the sets with two or more arms cluster in one part. The less wealthy sets, i.e. the ones with just one weapon cluster in another (fig. 8). An explanation of this division is provided by chronology but also by social differences in the status of the buried men.

2.3 Social differentiation by wealth

Classification of wealth is generally influenced by subjective criteria such as the number of items, presence of exotic goods, gold or other (for a critique see Eggert 1991). To get a more objective indication of the individual wealth of the single burials compared with the other graves, it will be necessary to construct an independent value by statistical means (Jorgenson 1990; Müller 1994). As basic data for this calculation were used the number of items, the plurality

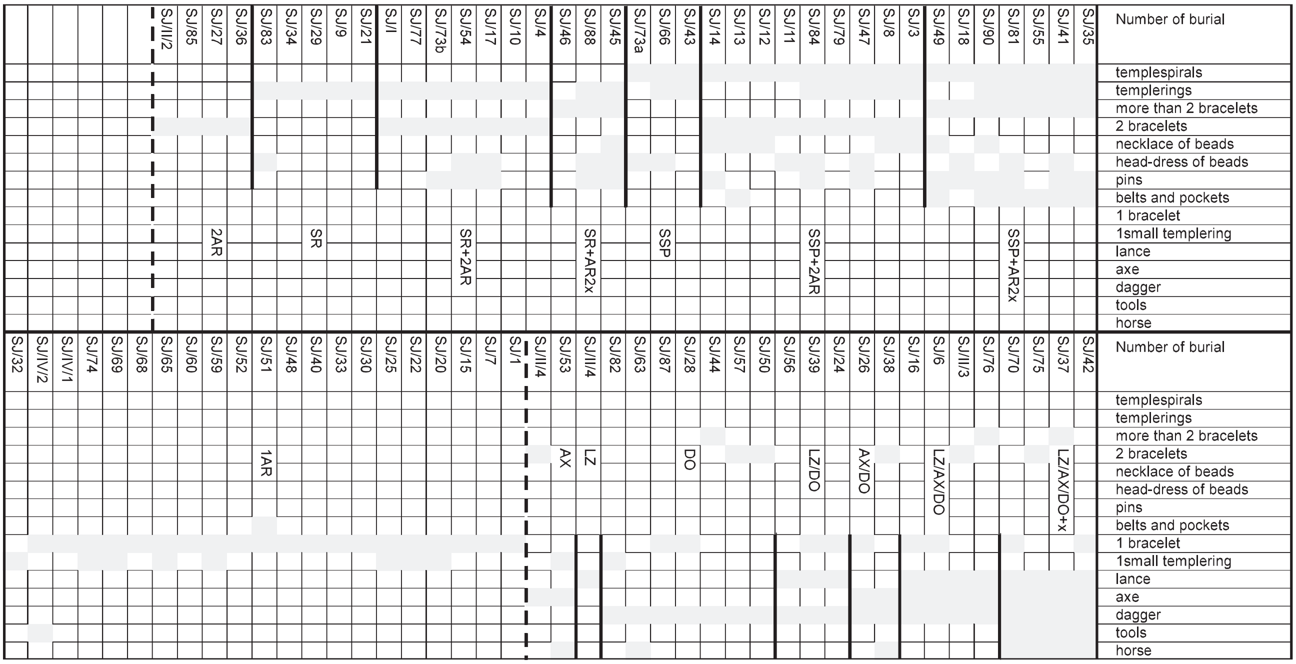

Figure 7. Table of graves versus grave goods.

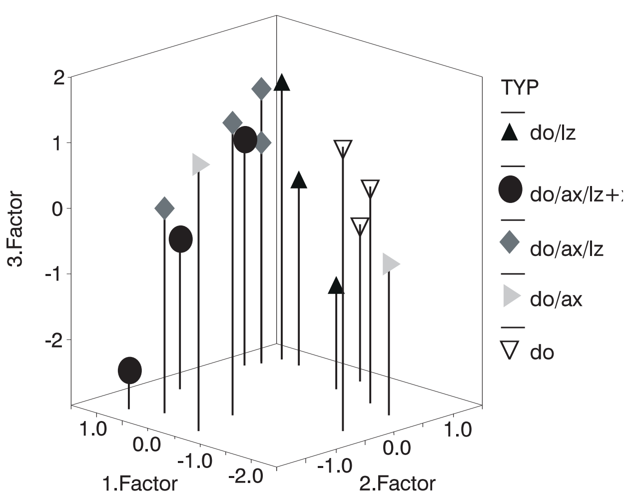

Figure 8. Seržen'-Jurt. LBA armed inhumations with different equipment.

of functional classes, the weight of metal, the plurality of material used, the scarcity of material and the expenditure of energy required for the building of the tomb (quantity of excavation calculated with 0,3 m³/person/h (Müller 1991)). All values were calculated in percentages.

Separating the different clusters of gender, several remarks can be made in relation to the functional groups mentioned. The differences between rich and poor graves do not coincide with the differences of gender. The average wealth of both genders is nearly the same (but note that individual types have not been weighted). Differentiation takes place within the gender group and can be related to the different functional clusters, costume groups for females and combinations of arms for males.

A second aspect applies to the kinds of grave goods. Male individuals obviously had been equipped with more ceramic vessels than females. The female graves contain more bronzes on average, in number as well as in weight, especially of the individuals with large temple finery (fig. 9). Moreover the distances between outstanding and poor graves is even larger within the male group of graves. The lowest social index is closely connected with the unarmed males, i.e. the group with just one bracelet. The same applies to the female group with temple rings and two bracelets and those with temple spirals and two bracelets. Both cluster with the next higher levels of wealth (fig. 9). The wealthiest graves are those of the well-equipped males and the females with large temple spirals and sets of bracelets. It is noteworthy that the best armed males with horse burials do not belong to the richest group of graves.

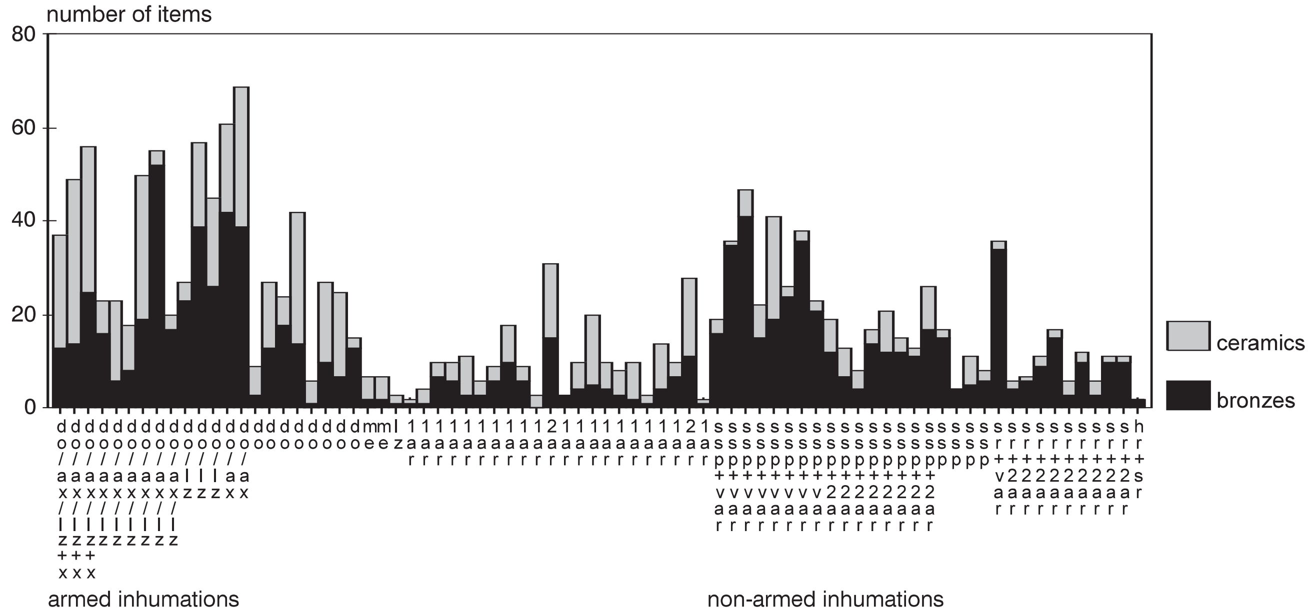

Figure 9. Seržen'-Jurt. Armed inhumations and non-armed inhumations.

3 Conclusion

The interpretation of the inventories at Seržen'-Jurt in terms of a social communication process seems to be quite clear. Without anthropological investigation one cannot be sure of gender and age of the deceased but the general differentiation into armed male and non-armed female individuals is supported by other cemetery material of the Koban area which were examined anthropologically
(see e.g. Krupnov 1960: 404-420). The interpretation of the costume and weapon groups determined e.g. by age is more difficult. If one regards the temple spirals and the number of bracelets or the number of arms as a sign of age, the determination of the Seržen'-Jurt society by gender and age classes would be a logical conclusion. The different stages of wealth and the other socially determined groups follow a normal distribution by number as well as by distribution in the cemetery. With one exception, all grave groups contain more or less the same number of individuals in costume or armament groups. The exception is the smallest unit of the cemetery with just four graves (fig. 2). Three of these are very wealthy male burials with horses. Except for this outstanding group the rest of the burials, though well equipped, are nearly on the same level of energy expenditure for their burial.

The longlasting use of several types of costumes, the uniformity of the costumes and their avoidance of individuality corresponds with the use of costumes in recent societies (Hirschberg 1988: 425). Costumes are also reported to be one of the most prominent signs of social differentiation and age groups (Müller 1994; Pader 1982; for a sociological background see Bourdieu 1976; Elias 1976).

Most notable is that the types used to signify social categories — bracelets, ceramics and other — and the composition of the inventories by socially determined patterns dominate over the chronological development of the whole Late Bronze Age sequence. Things did not change very much for more than 250-300 years and when they did change it was significant (Reinhold 1995). The traditional customs handling deceased people counteract the changes in production over this time span. The ritual behaviour which was obviously based on a fixed frame of ritual acts including the burial in traditional costumes, with traditional armament and fixed sets of ceramic vessels, must be taken into account in the interpretation of Late Bronze Age sites in this area in general.

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Predicting the ritual? A suggested solution in archaeological forecasting through qualitative response models[1]

Hamlet *A man may fish with the worm that hath eat of a king, and eat of the fish that hath fed of that worm...*
King *What dost thou mean by this?*
Hamlet *Nothing, but to show you how a king may go a progress through the guts of a beggar.*

1 Introduction

The analysis of mortuary practices is critical in the archaeological interpretation of the structure of social relations of production of prehistoric communities. Patterns of association between the different dimensions of the funerary ritual (grave goods, sex and age categories of the deceased, burial structure and burial position) are one of the pillars of a good part of current interpretation of the evolution of social structures in European Prehistory.

Quantitative methods have largely contributed to the interpretation of the funerary record in terms of social structure; significance tests, cluster analysis and multivariate techniques are commonly used in order to test the existence of different funerary categories and infer their social correlates. This paper intends to discuss further the question of how quantitative techniques can improve the archaeological knowledge of past social structures through the analysis of the funerary record. The *statistical models* discussed here fall into the group of Qualititative Response Models (henceforth called QRMs), which have mainly been studied by biometricians and econometricians but apparently have received little attention from archaeologists. The *archaeological problem* that provides the empirical background for testing the model is the funerary record of the southwestern Iberian Peninsula Bronze Age (*c*. 1700-1100 BC). The development of social complexity in the Early and Middle phases of Bronze Age in SW Iberia remains poorly understood; in this context, it seems clear that, in comparison with recent trends prevailing in the study of the synchronic southeastern (Argaric) Bronze Age, little or no debate has taken place in the past on the theoretical and methodological basis of the empirical evidence.

2 The problem

Common patterns shared by a set of necropoleis located in southern Portugal (Algarve and Alentejo) and western Andalucia, suggest that from *c*. 1700 BC onwards, a transition takes place from a communal-based structure of social relations of production to a ranked social structure where individual roles and leadership are more clearly defined in the mortuary ritual.

On the one hand, in some necropoleis the pre-eminence of specific individuals is underlined by means of the construction of a stone ring and *tumulus* structure around and over the burial. Thus, three basic categories of tombs are visible in the SW Bronze Age in terms of architectural features, namely central burials with a complete stone ring and *tumulus* (type A), peripheral burials with a tangent stone ring and *tumulus* (type B), and peripheral burials with no stone ring and *tumulus* (type C). In necropoleis such as Atalaia (Schubart 1975), Provença (Farinha/Tavares 1974) or Alfarrobeira (Varela 1994) all three types are found, while in the vast majority of necropoleis so far explored, only burials of type C have been identified (Amo 1975; Schubart 1975).

On the other hand, from *c*. 1700 BC on, prestige items such as bronze halberds, swords, daggers and ornaments given as grave goods, as well as engraved stones depicting metal weapons (appearing only in some tombs of southern Portugal), suggest the growing military character of social leadership. The military character of grave goods during this period, however, seems sharply limited if compared to the intensity and extent of weapon-oriented grave goods in other areas of Iberia or Europe. The fact that the amount of metal prestige items found in the funerary contexts of SW Iberia is very low, is perfectly coincident with evidence drawn from settlements suggesting that copper mining and metalworking in the southwest pyritic belt was rather limited between *c*. 1700 and 1100 BC (see for example Blanco/Rothemberg 1981; Hurtado/García 1994; Monge Soares *et al*. 1994)

Therefore, if compared with the Middle and Late Copper Ages, the initial stages of the Bronze Age in SW Iberia seem to involve an increase in internal ranking, different evidence suggests, however, that this increase in social inequality should not be regarded as a transition to a stratified model of society.[2] First, the statistical distribution of prestige items across the burial categories does not assume a stratified pattern; second, unlike in Argaric societies, infant burials are not provided with prestige items, which suggests that social roles are still acquired and not ascribed by birth (García 1992, 1994); third, the fact that many tombs with engraved *stelae* depicting weapons were not supplied with *real* weapons suggests that the leadership is more founded on an ideological than on a material basis — weapons as symbols rather than as a means of coercion supporting a stratified pattern of access to subsistence resources (Barceló 1991).

Hence, if the presence or absence of metal prestige items (weapons and ornaments) in burials is a key indicator in the inference of social status in archaeology, the obvious relevant question arising would be the following: to what extent would it be possible to *predict* the presence or absence of metal items in the tombs *in terms of probability*, having previously achieved some prior knowledge about the trends underlying a given set of data? In other words, under what conditions (i.e. patterns of association between variables) is the probability higher of a metal artefact being found in a specific empirical context?

A previous general approach based on quantitative methods conventionally used in archaeology (Aldenderfer 1987; Carr 1989; Shennan 1988) suggested the existence of some interesting patterns affecting metal artefacts distribution within the funerary record of the SW Iberian Bronze Age.[3] After a cluster analysis based on the Group Average method, three categories (rich, semi-rich and poor necropoleis) were delimited according to the mean values observed for the frequency of different artefact types — not only bronze items — in necropoleis (fig. 1A). Also, a number of categories was defined on the basis of the mean frequency of a series of architectural attributes (fig. 1B). No classes were defined *within* the necropoleis in terms of artefact distributions, not even where there were different architectural types present (scarcity seems to be shared by almost all members of the communities as far as the funerary ritual was concerned).

The three basic levels of artefactual wealth defined were then used as a basis to test the association between funerary patterns and environmental factors such as soil type or land agricultural capability. A correspondence analysis suggested that a general positive association existed between the potential agricultural capability and the cemeteries where metal artefacts are more frequent (fig. 2). This might suggest that the use of costly metal status symbols depended on the general capacity for surplus production within the community — see two spatial (geographical) views of the bronze items frequencies in figure 3. Yet, a much more interesting — predictive — approach to this problem can be achieved by means of the QRMs described below.

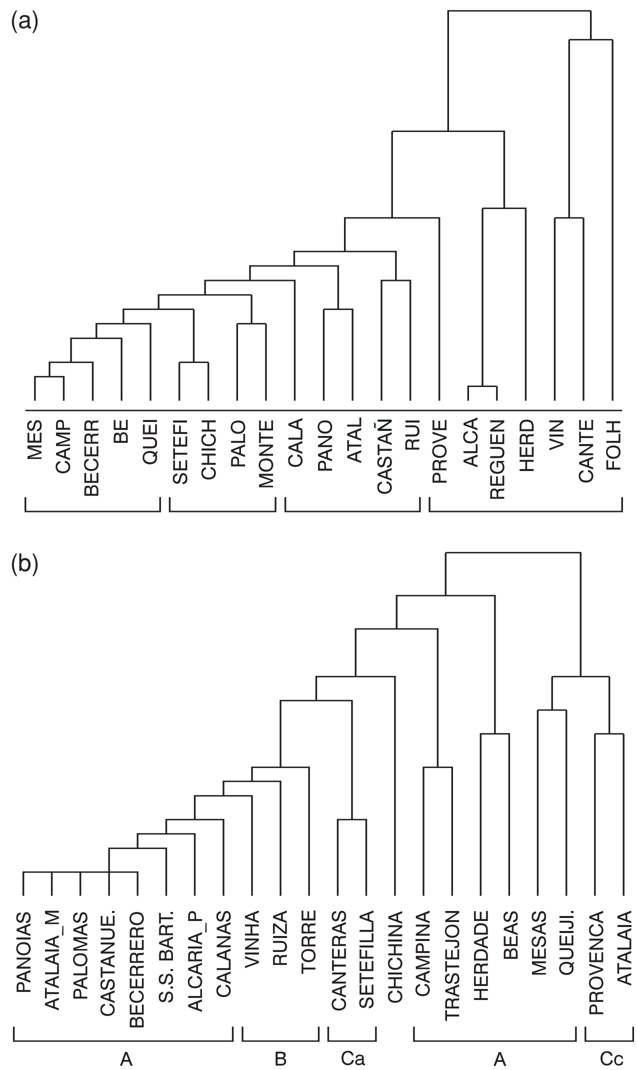

Figure 1. Two cluster analyses for necropoleis from the SW Iberian Bronze Age.

3 The model (the suggested solution)

3.1 Why QRM?

Prior to the development of a rather tedious algebra, a justification should be given about why QRMs have been chosen to examine the archaeological phenomenon described above. This might be achieved by proceeding along two lines of reasoning: one theoretical, since the referents pointed out by the theory must be taken into account; and another technical, since this type of model is regarded here as a potentially valuable tool to be applied in archaeological analysis.

Regarding the theoretical aspect, a brief description of how these models became useful in other Social Sciences can be of help. The use of QRMs was extended in the

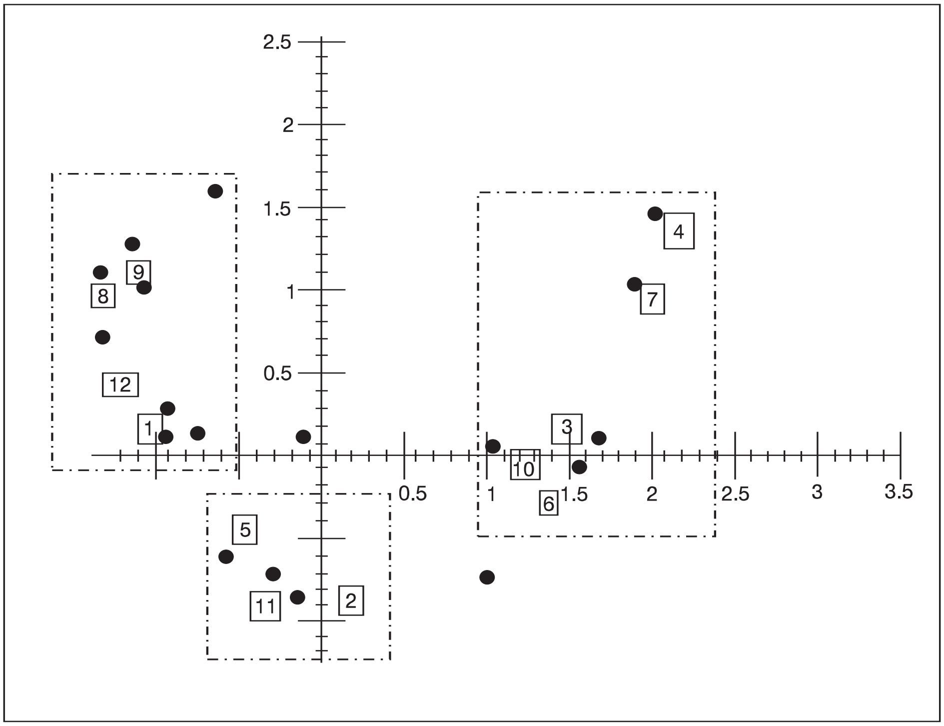

Figure 2. Correspondence analysis for the necropoleis.

sixties by biometricians, who faced the problem of making predictions about some events where the observed values had a discrete form, (i.e., presence/absence of an attribute or, yes = true, no = false). One model, which became very popular in Biology, was that where QRMs were used to predict the effectiveness of an insecticide: a QRM could explain in terms of probabilities whether an insect would remain alive (that is, yes = true = 1), or would die after having been exposed to a given dosage of insecticide (independent/causal variable). Bypassing the evident lethal aspects of the model this example suffices to compare the applicability of these models in Natural and Social Sciences. In an excellent survey, Amemiya (1981) suggested that the QRMs could be used to explain the behaviour of a utility-profit maximizing rational economic agent. For instance, when one has to model the problem faced by a householder of whether to buy or not to buy a car, and to explain this decision with the level of income, taxes, availability of other transport means, … the final choice relies upon a utility maximizing consumer, conditioned by a budgetary and a time restriction. An insect does not enjoy the possibility of choosing to be or not to be. That may be one of the basic differences of the meaning of these models in the Natural and Social Sciences: the nature of the dynamics of the variables involved in a theory.

Amemiya's survey also provides a sample of articles that could surprise a reader not familiar with these issues, since applications are quoted from labour markets, unionized workers, and consumption of non-durables, to criminology, efficiency of educational programs, etc.[4]

Finally, with reference to the technical aspect (*why* and *how* these models could be applied in archaeology) previously mentioned, QRMs provide an elegant tool for solving an elementary problem in archaeological multivariate analysis:

a. It is known that many of the data sets used in archaeological analysis are coded in a discrete form; for instance, if the value of the *aggregate production* cannot be measured through the archaeological record — as Econometrics is supposed to be able to do for modern and present records — the only feasible approach to the construction of a *Bronze Age econometric model* would be a discrete form index (proxy variables) compressing variables referring to different levels of production (for example, metal prestige items).
b. The former aspect would not be a technical-statistical problem at all whenever variables are used as causal regressors in the multivariate analysis. However, if predictions are intended to be over a discrete form

Figure 3A. Surface trend map.

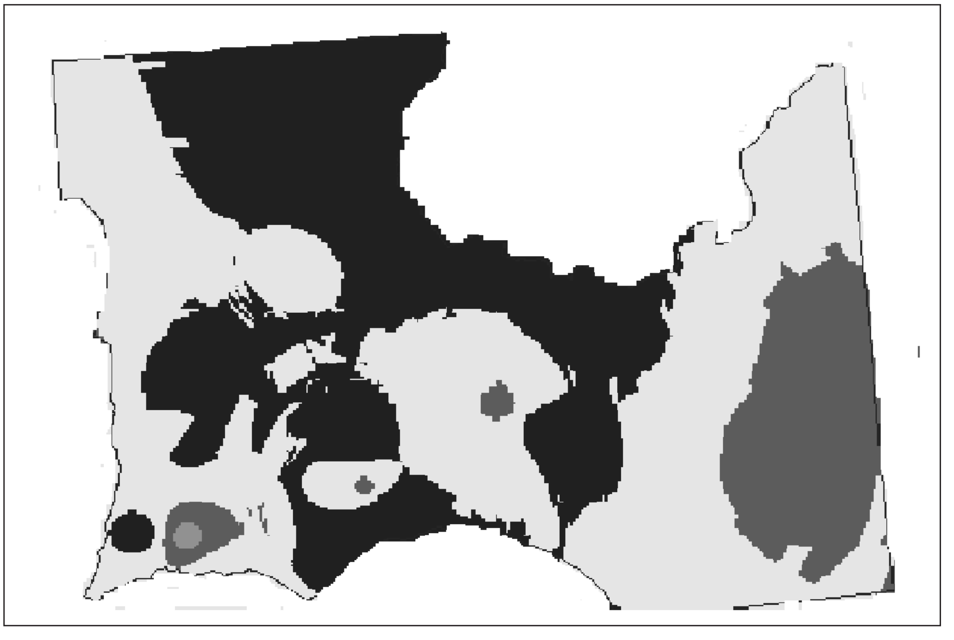

Figure 3B. Interpolation map.

variable, the traditional least square estimation fails to give an answer. For example, a variable reflecting a structure of true or false, (and then, 1 or 0, respectively), cannot be used as dependent variable in a linear model estimated by least squares as will become clear below.

In our opinion, QRMs can easily overcome this problem, improving the efficiency of data analysis and, therefore, hypothesis testing. Thus, an attempt is made to obtain a prediction about a discrete dependent variable (M1-M2) by using a QRM against the dataset mentioned above.

3.2 Mathematical set-up of the model

Let us think of a discrete variable m (say m = *presence of metal elements in a burial*), showing a dichotomous form 0 or 1, ($m \in \{0, 1\}$), that is a boolean structure, this means that m adopts value 0 when a certain property is absent (metal element not found in the archaeological record), and, consequently, value 1 when the property is present. Furthermore, this variable is stochastically distributed according to a discrete Bernouilli model with probability p, that is:

$$\begin{aligned} m &\sim B(p)_{m=0,1} = p^{m}(1-p)^{1-m} \\ E(m) &= p = P(m=1) \\ Var(m) &= p\,(1-p) \end{aligned} \qquad (1)$$

where $E(.)$ denotes the expected operator, $P(.)$ stands for probability, and $Var(.)$ is the variance. Since a Bernouilli model is regular, one can use the statistic $\Sigma x_i / n, (i=1,...,n)$, that is the sample arithmetic mean, as an efficient estimator for p.

Assume now that we have to relate this variable to a set of k independent variables, X. Suppose further that we have been asked whether this variable will adopt value 1 under certain conditions X_i, that is, forecasting whether the property will be present. A first answer could be given using a simple linear (probability) model of the form:

$$\begin{gathered} m = \alpha + \beta' X + u \\ E(u) = 0 \Rightarrow E(m) = P(m=1) = \hat{\alpha} + \hat{\beta}' X \end{gathered} \qquad (2)$$

where u is the error term. Hence, one can use the classical least square method to estimate the set of k+1 unknown parameters involved in the equation (2), and then use the model to set a prediction. Note that now the predicted values of m will not necessarily be 0 or 1, but rather will be in the interval (0, 1). Next, we would interpret these predicted values in terms of probability.

However, this method involves serious limitations since it produces several problems, namely:

1. *A heteroscedasticity problem*, since it can be proved that the error term variance is equal to

   $$Var(u) = p(1-p) = E(m_i)\,[1-E(m_i)] = [\hat{\alpha} + \hat{\beta}' X]\,[1 - \hat{\alpha} - \hat{\beta}' X] = Var(m)$$

   and, hence, the ordinary least squares estimators from equation (2) are inefficient. A weighted least square procedure is then needed. Goldberger (1964) proposes to estimate $m=\alpha+\beta' X + u$ by least squares, then compute a weight of the form

   $$\hat{w}_i = \sqrt{\hat{m}_i(1-\hat{m}_i)}$$

   and finally regress $[m_i / w_i]$ on $[x_i / w_i]$. However, as has been noted by other authors such as Maddala (1989), the product $m_i(1-m_i)$ in the root, can be negative, and hence the operativeness of this weighted procedure is invalidated .

2. *Predictions may still fall outside the [0, 1] interval*, and, consequently, the outcome cannot be interpreted in terms of probability:

   $$\hat{m} = \hat{\alpha} + \hat{\beta} = E(m|z = \alpha + \beta' X) = P(m = 1|z = \hat{\alpha} + \hat{\beta}' X)$$

3. *The distribution of the error term is not normal*, (Maddala 198: 16-18), implying that the classical hypothesis tests, where construction relies on the assumption of normality of the error term, are no longer valid, unless we also assume that the explicative variables have a multivariate normal distribution. This suggests that the problem should be modelled using a non linear instead of a linear model.

What is the solution? In the remaining part of this section some basic ideas were borrowed from the literature on QRMs in order to provide an answer. In section IV a case is examined where the dependent variable, m, is a dummy variable taking the value 1 when a metal element has been found inside an individual burial, and 0 otherwise. A set of variables serves to explain the presence/absence of such elements: a discrete index for agricultural capability of the land where the necropolis is located, the volume of the tomb, and some dummy discrete variables (namely, a dummy for ceramic typology, and other dummies indicating the presence/absence of other funerary items near the burial). Thus, prediction about m is interpreted as the propensity of a burial to contain a metal element (hence the *metal detector*). Two models, PROBIT and LOGIT, are an appealing suggestion to the problems not solved by the linear probability model aforementioned. The basic difference between PROBIT and LOGIT relies on the assumption made about the stochastic distribution of the error term u in equation (2) as will be seen below.

Let m^* be some continuous but *latent* variable. We have just said that this variable is to be interpreted as the 'propensity of a burial to be accompanied by a metal item'. But, instead, we observe a discrete dummy variable m according to

$$m = \begin{pmatrix} 1 \; if \; m^* > \psi \\ 0 \; if \; m^* < \psi \end{pmatrix}$$

where ψ is a certain threshold, above which one can say that there is a metal element, $m=1$. This concept of a threshold is relevant when interpreting the results as probabilities. Imagine, for instance, that the variable whose realizations we are observing is the score record of a class of students, and we have classified this into two categories: *passed*, whenever the student has been scored *at least with a five over ten*, and *failed* otherwise. In the first case the variable would be valued as 1, and 0 for the second one. In this example the threshold ψ would be equal to 5. Nevertheless, and without loss of generality, let us assume that $\psi = 0$. The model becomes as

$$m^* = \alpha + \beta' X + u$$

And the probability of a metal element is

$$P(m=1) = P(m^* > \psi=0) = P(\alpha + \beta' X + u > \psi = 0)$$
$$= P\,[u > \psi - (\alpha + \beta' X)] \quad (3)$$
$$= 1 - F\,[(\psi - (\alpha + \beta' X)] = 1 - F\,[-(\alpha + \beta' X)]$$

where $F(.)$ is the cumulative distribution of the error term u.

Once it is assumed that this cumulative distribution is symmetrical, specification (3) becomes clearer since we can write that $F(-Z) = -F(Z)$ and therefore it can be written that $P(m=1) = 1-F(-(\alpha + \beta' X)) = F(\alpha + \beta' X)$. Recall that, through specification (1), the variable m_i, presence of metal elements, follows a Bernouilli model with probability p, $m_i \sim B(p)$. It is important to note that the present model is intended to be based on the fact that the realizations m_i are independent from burial to burial, otherwise the mathematical set up would be much more complicated. Thus, let us assume that the different realizations m_i's are independent of each other. Consequently, the likelihood function can be written as

$$\mathfrak{L} = \prod_{m_i=1} P(m_i=1) \prod_{m_i=0} Pm_i=0) = \prod_{m_i=1} P(m_i=1) \prod_{m_i=0} [1-P(m_i=1)]$$

Finally, the difference between PROBIT and LOGIT models relies upon a different cumulative distribution of the error term u. If the cumulative distribution is normal, taking the form:

$$F(\alpha + \beta X) = P(m=1 \,|\, \alpha + \beta X) = \int_{-\infty}^{m^* = \alpha + \beta X} \frac{1}{\sqrt{2\pi}} e^{-\frac{u^2}{2}} du$$

this is just the PROBIT, or normit, specification. While the LOGIT model is set when the error term distribution follows the next logistic distribution, that is:

$$P(m=1 \,|\, \alpha + \beta X) = F(\alpha + \beta X) = \frac{e^{\alpha + \beta X}}{1 + e^{\alpha + \beta X}}$$

Note that both distributions are bounded by 0 and 1. The normal distribution has a variance equal to 1 (see that it has been normalized, so $\sigma^2=1$), and the logistic distribution variance is equal to $\pi^2/3 = 3.2898$. Using these properties, one can approximate the estimated regressors of both distributions by multiplying the β's estimates obtained from the PROBIT distribution by $\pi/\sqrt{3} = 1.8138$. Amemiya (1981) proposes to multiply it by 1.6, since he finds that, by trial and error, this value provides a better fit to the data.

Due to the proposals of the present paper, we will not further discuss the point of how to choose one or the other model, since the exercise we are to develop next does not involve such a problem. As a reference, we will quote the work of Chambers and Cox (1967) where a hypothesis test is proposed for distinguishing the correct model.

4 The test (the metal detector)

4.1 Variables and data

A sample of 144 tombs from 19 SW Iberian Bronze Age necropoleis has been selected for this study (fig. 4A, the original data are available via the CAA World Wide Web server (http://caa.soton.ac.uk/caa/CAA95/Garcia/)).
All tombs that were considered seriously altered by the excavators have been excluded altogether, so that all the information processed in the following analyses has been recorded from unaltered contexts. The total amount of artefacts found in these 144 tombs is: 23 metal artefacts, 74 pots, 5 lithic artefacts and 3 necklace beads (fig. 4B)

The dependent variable (presence/absence of metal artefacts) has been divided into two main groups: ornaments (rings, armrings or diadems) and weapons (halberds, daggers or swords), that is to say highly ideological prestige items (M1), on the one hand, and arrow points and pointed tools, less ideological items (M2), on the other hand.

Four main axes of variability are taken into account as potentially explicative of the presence/absence of metal items (dependent variable), namely size and structure of the burial, category of the deceased, other (non-metal) grave goods and soil attributes. These four axes of variability contain 10 variables that are regarded as independent across the study:

Two variables are regarded as representative of the general size and structure of the burial:

– Volume (VO). Continuous variable measured in cubic metres (length × width × depth)
– Ring/*tumulus* (AT). Discrete binary variable: 1 (presence) 0 (absence)

It is assumed here that both the volume of the funerary chamber and the presence/absence of a ring and tumulus provide an indication of the investment of labour made in the construction of the burial.

Another two variables account for the biological status of the deceased:

– Sex. Discrete binary variable: 1 (male) 0 (female)
– Age. Discrete binary variable: 1 (adult) 0 (infant)

Other grave goods are included in order to examine whether the presence of metal items is dependent or not on the presence of other artefactual categories:

– Pottery class 1 (CE1). Discrete binary variable: 1 (presence) 0 (absence)
– Pottery class 2 (CE2). Discrete binary variable: 1 (presence) 0 (absence)
– Lithic artefacts (LT). Discrete binary variable: 1 (presence) 0 (absence)
– Necklace beads (CU). Discrete binary variable: 1 (presence) 0 (absence)

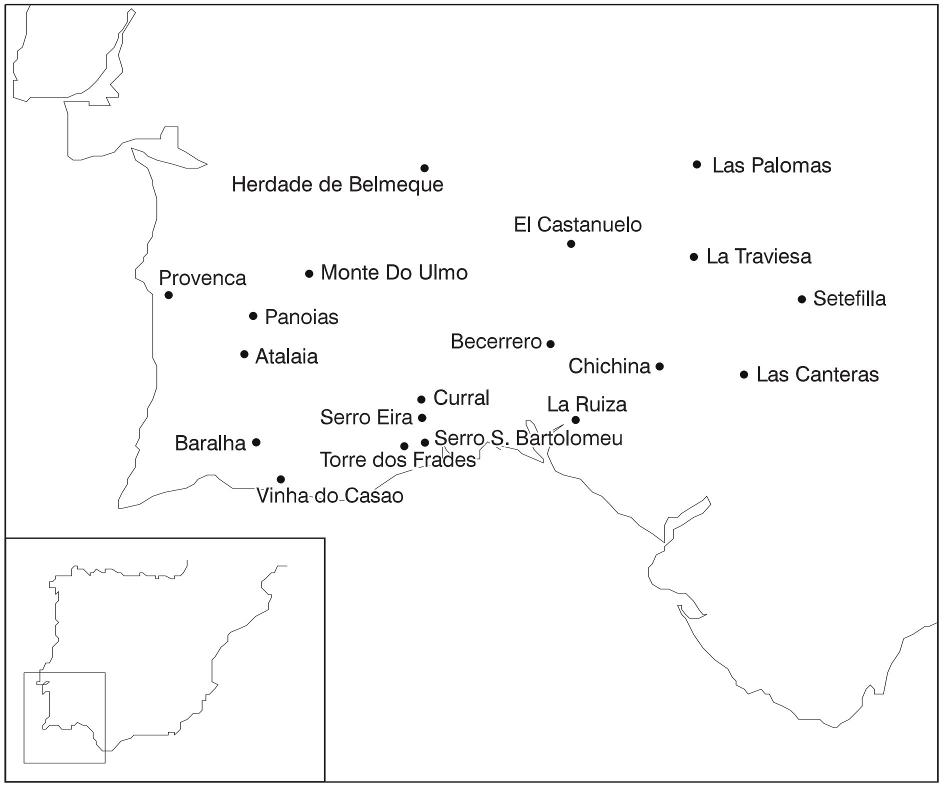

Figure 4A. 19 SW Iberian Bronze Age necropoleis.

Finally, two variables have been used to examine the relationship between the presence/absence of metal items and environmental factors, under the assumption that the production of an agricultural surplus would stimulate the production and/or consumption of metal prestige items among social elites. The soil attributes were measured according to D. Rosa and J.M. Moreira (1987) for Western Andalucia and by A.M. Soares (1984) for southern Portugal. Land agricultural capability (CA) is a discrete ordinal variable that provides an indication of the potential productivity of the soil in terms of a number of geographic parameters (see D. Rosa and J.M. Moreira (1987) and A.M. Soares (1984) for a description). Four categories are considered: class 0 for no agricultural capability, class 1 for moderate or poor agricultural capability — severe limitations —, class 2 for good agricultural capability — some limitations — and class 4 for excellent agricultural capability — no limitations — (fig. 5A). For some tests however, these four categories have been simplified into two (A for classes 0 and 1 and B for classes 2 and 3) in order to compress the variability as much as possible. The lithology (LI) is coded as discrete nominal variable with four classes: class 1 for shales, graywackes and sandstones, roughly matching the SW pyritic belt, class 2 for sands, rounded pebbles, poorly consolidated sandstones and clays, class 3 for argillaceous marls and class 4 for sandy argilles, sand and conglomerates (fig. 5B).

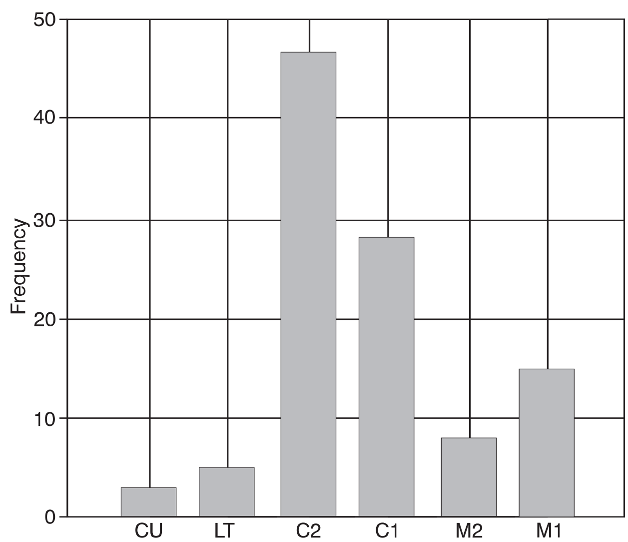

Figure 4B. Different artefact classes for the 19 SW Iberian Bronze Age necropoleis.

Figure 5A. SW Iberian peninsula land agricultural capability.

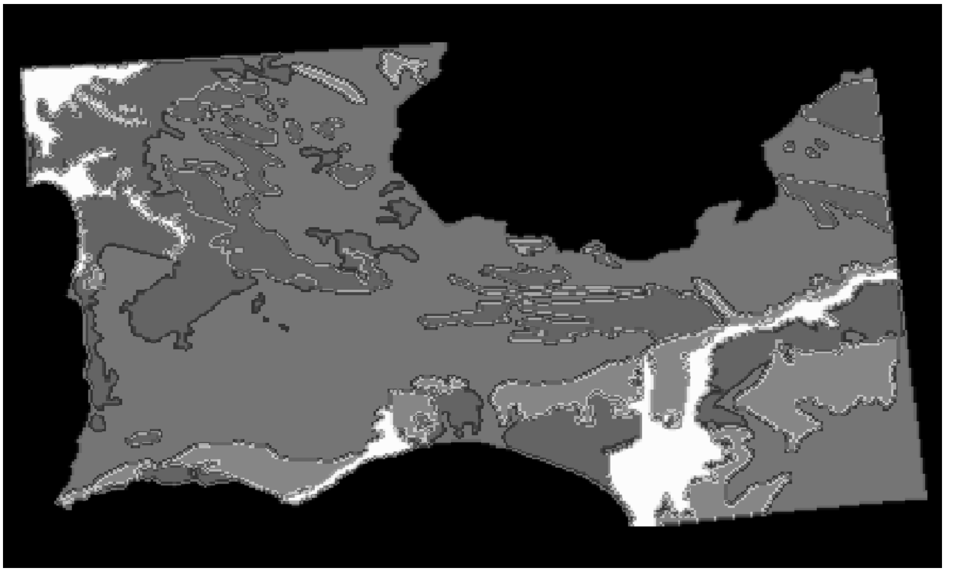

Fig. 5B. SW Iberian peninsula lithology.

4.2 Testing

In this section, a test of the models described above is made against the data described in section 4.1. The ultimate purposes of this test are, firstly, to provide an indication of what variables explain better the presence or absence of metal in the burials (variables M1 and M2), and secondly, to give a numerical prediction of the probability of a metal artefact being found under certain conditions. As already discussed, since the dependent variable is discrete taking only two values, 1 or 0, predictions can only be given, and can only be interpreted, in terms of probabilities. Hence, if the observations are 1 or 0, and if the forecast values for the limited dependent variable falls in the interval (0,1), the traditional measures for the goodness of fit, likewise the R^2, will no longer be useful in explaining the validity of an estimated model. That is the reason why the R^2 will be too low compared with traditionally obtained R^2s for the linear least square regression. Further discussion on the goodness of fit and its alternative measures can be found in Maddala (1983, 1989).

Table 1 expresses the results of a PROBIT regression of M1 over the set of variables (AT, CE1, CE2, LT, CU, AGR). Three estimations have been run in order to set the proper structure of the model, the (***) symbol denoting that the corresponding variable has been deleted for that particular estimation (the removal criterium has been given by the *t-ratio* content together with the coefficient associated with each variable). A first interesting result emerging from these tests is that the most significant variable among the estimations is land agricultural capability (expressed in the dummy variable AGR), which is coincident with the pattern emerging from the correspondence analysis mentioned above. The *sign* of some of the parameters is also of interest: for instance, the parameter associated with CE1, the ceramic category 1, is always negative for both model 1 and 2 (deleted for model 3 due to its low significance level expressed by the t-value). On the contrary, CE2 is always positive and significant, showing a strong positive correlation with the limited dependent variable. This could be interpreted in the sense that ceramic category 2 is associated with a higher social *status*, therefore setting a grave good pattern with metal prestige items. Variables LT and AT do not seem to help much in predicting the ritual in model 1 (t-values around 0) and they have subsequently been removed from models 2 and 3, (both in this first PROBIT and the next, as in the rest of the tables presented below).

Similar results hold for the first LOGIT estimates (table 2). Again, the most significant variable is land agricultural capability, and the same variables are deleted in the three estimated models. The sign of the parameters do not contradict the results of the PROBIT estimation.

One interesting thing to note in both table 1 and table 2 is that variable CU displays a good significance in explaining the presence/absence of metal elements. Nevertheless, when the variables AT and LT have been removed, the t-ratio for CU falls below the acceptable range (1.6 as a rule of thumb). Why? This is a problem of multicollinearity among the variables, since they are probably highly correlated. This is a perverse effect that makes it very difficult to separate the partial effect of each variable from the explained one.

Finally, note that PROBIT and LOGIT estimates can be compared by multiplying the first one by 1.813, (*verbi gratiæ*, the parameter associated with AGR in model 1 PROBIT is 1.331, multiplied by 1.813 gives 2.414, which is very similar to the LOGIT estimate of 2.289).

The fact that all the variables that have been included in these models are of discrete form, could be regarded as a source of criticism from a purely statistical point of view. Due to this limited form, the number of possible outcomes is limited to 2^K, where k is the number of variables included in the regression. Thus, for the first model where k is equal to 6, the number of possible cases that an archaeologist can face is limited to 64 (16 and 4, for models 2 and 3, respectively). This produces the problem that the prediction is again a limited discrete prediction. Furthermore, and due to the multicollinearity problem aforementioned, whenever there is a strong statistical association among the variables included in the model, the number of possible outcomes, is less than could be expected (for instance, at first glance the data matrix indicates a relationship between variables LT and CU).

The next step will be to include the only continuous variable considered in the present paper to predict the presence/absence of metal items, namely, the log of the volume of the tomb. The results for PROBIT and LOGIT are presented in tables 3 and 4. Very similar conclusions are obtained from these new estimations. See, for instance, the low significance level of the coefficient for CU whenever variables AT and LT have been removed. It seems possible to conclude that the set of variables AT, LT, C1 and CU fail to *predict the ritual*, that is to say, fail to *predict the presence of metal prestige items*. In terms of social organisation this is a quite an interesting point, as the presence of funerary monuments (stone rings and *tumuli*) does not correlate with the presence or absence of weapons and ornaments.

Yet, a contradictory result arises since the coefficient for AGR displays the poorest significance level of the set of variables included in the last model (the t-ratio is not significant in any of the three models). In fact, the only significant variable in this case is the grave's volume (VOL). This could be explained both by the fact that VOL is the only continuous variable included in the *metal detector model*, and by a multicollinearity problem involved in the distinct partial correlations between the set of the explanatory variables. The same conclusions apply to the LOGIT estimations.

However, two more sets of partial estimations have been run in order to check the validity of the results described sofar. This has been done by estimating a new model for M1 over CA, (note that the index for land agricultural capability is now measured as an ordinal variable 0-1-2-3, and not as the dummy AGR), and another model for M1 over VOL (tables 5, 6).

The coefficients R^2s are just too low to consider any of the models as definite, the main conclusion to be drawn being that the partial t-ratio for variables CA and VOL are sufficiently significant to consider both variables as explicative for M1. Despite this low R^2, a simple forecasting exercise is carried out (as a *metal detector*), to show how this coefficient should be interpreted. To do this, the PROBIT model presented in table 5 has been chosen. Here, the only explicative variable for the presence of metal items is the discrete index for agricultural capability. Table 7 presents the probabilistic computations for the four categories:

The last two columns are very similar except for CA=1 due to the sampling, that is, the models in table 5 have been constructed from a sample of 143, of which 112 correspond to category *CA = 0*, 14 to CA = 1, 7 to CA = 2, and 10 to CA = 3. On the other hand, the limited dependent variable M1 has a value 1, presence, 8 times in the category CA = 0, none for CA = 1, 2 for CA = 2, and finally there are 4 in

Table 1. PROBIT model for M1.

	MODEL 1		MODEL 2		MODEL 3	
	Coefficient	t-Value	Coefficient	t-Value	Coefficient	t-Value
constant	-1.779	-4.942	-1.813	-6.913	-1.844	-7.371
ring/*tumulus*	-0.136	-0.347	***	***	***	***
pottery class 1	-0.195	-0.439	-0.146	-0.334	***	***
pottery class 2	0.710	2.087	0.651	2.002	0.696	2.184
lithic artefacts	-5.892	0.120	***	***	***	***
necklace beads	1.561	1.574	0.447	0.568	***	***
dummy variable	1.331	3.010	1.199	3.254	1.213	3.314

Table 2. LOGIT model for M1.

	MODEL 1		MODEL 2		MODEL 3	
	Coefficient	t-Value	Coefficient	t-Value	Coefficient	t-Value
constant	-3.075	-4.349	-3.185	-5.904	3.243	6.346
ring/*tumulus*	-0.448	-0.558	***	***	***	***
pottery class 1	-0.311	-0.358	-0.215	-0.255	***	***
pottery class 2	1.293	1.957	1.166	1.850	1.243	2.026
lithic artefacts	-13.582	-0.084	***	***	***	***
necklace bead	2.876	1.789	0.746	0.485	***	***
dummy variable	2.289	2.896	2.122	3.213	2.154	3.298

Table 3. PROBIT model for M1.

	MODEL 1		MODEL 2		MODEL 3	
	Coefficient	t-Value	Coefficient	t-Value	Coefficient	t-Value
constant	-0.716	-1.224	-0.724	-1.496	-0.862	-1.929
ring/*tumulus*	-0.188	-0.429	***	***	***	***
volume	0.873	2.588	0.922	2.769	0.864	2.722
pottery class 1	-0.445	-0.792	-0.389	-0.701	***	***
pottery class 2	0.634	1.573	0.561	1.486	0.616	1.674
lithic artefacts	-5.336	-0.106	***	***	***	***
necklace bead	1.816	1.788	0.953	1.154	0.982	1.188
dummy variable	0.571	0.994	0.421	0.850	0.390	0.790

Table 4. LOGIT model for M1.

	MODEL 1		MODEL 2		MODEL 3	
	Coefficient	t-Value	Coefficient	t-Value	Coefficient	t-Value
constant	-1.283	-1.155	-1.290	-1.394	-1.501	-1.777
ring/*tumulus*	-0.491	-0.569	***	***	***	***
volume	1.560	2.473	1.67	2.704	1.591	2.691
pottery class 1	-0.587	-0.578	-0.514	-0.508	***	***
pottery class 2	1.198	1.521	1.011	1.339	1.114	1.524
lithic artefacts	-12.633	-0.075	***	***	***	***
necklace bead	3.372	2.016	1.822	1.246	1.865	1.276
dummy variable	0.913	0.865	0.634	0.686	0.590	0.636

Table 5. PROBIT model and LOGIT model.

	Probit model		Logit model	
	Coefficient	t-Value	Coefficient	t-Value
constant	-1.5306	-8.616	-2.7062	-7.288
Land agricultural capability	0.3909	2.867	0.72841	3.012
R^2 =		0.0777		

Table 6. PROBIT model and LOGIT model.

	Probit model		Logit model	
	Coefficient	t-Value	Coefficient	t-Value
constant	-0.3555	-1.171	-0.5810	-1.148
volume	0.9921	3.586	1.8357	3.676
R^2 =		0.1320		

the category CA = 3. Thus, there are a total of 14 cases where M1 has taken value 1. The sample used to construct these models has been drawn from a bigger sample of 374, and the selection criteria were to choose those tombs where we could know, at least, the volume, the presence/absence of the ceramic typology, and, of course, those which had not been expoliated. 24 tombs of the 374 were of type CA = 1, and 5 of them contained a metal item. Note that none of these 5 have been included in the reduced sample of 143. However, let us have a look at what is going to happen when we remove the observations for CA = 1, and we estimate a PROBIT model:

$$M1^* = \underset{(-8.248)}{-1.4623} + \underset{(3.057)}{0.41287}CA$$

The normal probability values in table 8 have approached the observed values of the last column in table 7. Thus, this estimated probability can be considered as the marginal propensity of a determinate area to contain burials with metal elements. But, what about a prediction for CA = 1? It is easy to see that the latent variable adopts a value of M1* = -1.4623 + 0.41287 = -1.04943, and the table for the cumulative normal distribution indicates that this happens with a probability of 0.1492 (= *P(M1=1 conditioned to CA = 1))*. Therefore, if 24 tombs out of 374 fall in the category of *CA = 1*, the metal detector predicts the existence of about 4 metal items (that is, $0.1492 \times 24 = 3.58 \simeq 4$), the real number of observations being 5. The proximity between the predicted and the observed values is therefore clear (the metal detector works!).

Of course, this is only a simple example where there is only one explicative discrete variable, showing only four possible states, and, hence, implying that, again, the predictions of a discrete binomial variable are discrete as well as the observations.

Finally, note that our insistence on the significate of the R^2 coefficient stems from the fact that it cannot be interpreted in the same sense as in the traditional least square regression, since the meaning and source of the residuals are quite different. Some authors refer to this as the *R^2 syndrome*.

5 Conclusions

From a methodological point of view, an attempt has been made in this paper to increase the predictive capacity of archaeological reasoning through econometric experience. A case study has been chosen where some previous indications existed about the pattern of association and dependence among the relevant variables (*i.e.* that previous knowledge has served as a basis for hypothesis testing). This predictive view has been constructed on discrete variables with only two states {0,1}. Furthermore, the PROBIT and LOGIT models have allowed us to construct an innovative (predictive) view of the pattern of relationships among the variables in terms of the t-statistic (*i.e.* estimated value divided by the standard error).

On an empirical level, the presence of bronze prestige items in Bronze Age tombs is closely related to the variables VO, CE2 and CA, that is to say, to the size of the burial chamber, a set of carinated pots and the general agricultural potential of the soil where the community was settled. Alternatively, the presence of bronze items is not dependent on the variables AT, CE1, LT, CU and LI, that is to say, presence of ring/tumulus structures, a set of non-carinated pots, lithic artefacts, necklace beads and lithology class of the soil (associated with availability of mineral resources). For the sake of simplicity, and in order to keep the lenght of this article within reasonable limits, only those tests considered more relevant have been included and discussed.

Table 7. Probabilistic computations for four categories.

	m*= α + β CA	Normal Probability	Observed %
Land agricultural capability = 0	-1.5306	0.0629	0.0714
Land agricultural capability = 1	-1.1396	0.1272	0
Land agricultural capability = 2	-0.7486	0.2271	0.2857
Land agricultural capability = 3	-0.3576	0.3603	0.4

Table 8. Probabilistic computations for three categories.

	m*= α + β CA	Normal Probability
Land agricultural capability = 0	-1.4623	0.0718
Land agricultural capability = 2	-0.6366	0.2622
Land agricultural capability = 3	-0.2237	0.4115

Remark

The data in this paper were processed with the MV-ARCH (Wright 1989), Idrisi (Eastman 1990) and LIMDEP (Greene 1990) systems.

notes

1 For the original data, please refer to the CAA World Wide Web server on http://caa.soton.ac.uk/caa/CAA95/Garcia/.

2 Recent literature on the European Bronze Age displays rather diverse and contradictory applications of terms such as *stratified society*, *class society* and *state*. The term *stratified society* is used here in opposition to *ranked society,* according to the definition given by M. Fried (1967). However, and unlike Fried, we conceptualise the *stratified society* as an equivalent to *class society* and therefore to the *state* itself (Hindess/Hirst 1975).

3 Study carried out within a wider dataset of 31 necropoleis and 321 tombs (Garcia 1992) from which the sample used in this paper has been drawn.

4 It could be objected that the above mentioned survey is rather old, and that recent developments in econometrics have followed different trends. But we still are in favour of QRM since many of the areas mentioned by Amemiya in 1981 are receiving nowadays important contributions. See also Nelson (1987) for an introductory treatment on QRMs.

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Johannes Müller

The use of correspondence analysis for different kinds of data categories: Domestic and ritual Globular Amphorae sites in Central Germany

1 Methodological assumptions

Usually in prehistoric archaeology the application of seriation methods aims at the detection of continuous, normally distributed changes within the material remains of the past. Primarily reciprocal averaging and correspondence analysis are used to separate chronological phases, spatial differences and functional developments (e.g. Baxter 1994; Ihm 1978; Madsen 1988). The analyst presumes the classical situation of a unimodally distributed innovation pattern: at the start of a development new types or influences are represented only by a small number of artefacts out of the total. In the middle of the type's history an increasing production rate is visible. In a third and last phase the 'old fashioned' tools or decoration types are once again represented by small numbers, and finally no indication of the type remains.

I would like to name this simple approach a 'battleship' paradigm (compare Ford 1962). It combines the idea of a standardisation of human behaviour with a functional approach to the detriment of the influence of many different depositional processes.

Nevertheless, this paradigm had a huge impact on the use of correspondence analysis in archaeology. Because the first and second eigenvectors form a parabolic curve in the case of normally distributed data ('a horseshoe'), many analysts are acquainted with the manipulation of their data input: we are producing 'horseshoes' and discounting types and values which destroy the clear symmetric structure of our thinking and our results.

However, we have to admit the following mismatches:

1. The innovation of new techniques, new symbolic expressions or new ritual approaches to life produces a wide variety of expression in material culture. There might be a normally distributed representation over time, but there might also be an abrupt appearance of many artefacts at the beginning, a few in the middle and again many at the end of a development. Ethnoarchaeological case studies describe so many different distribution patterns of artefact types during time that do not have anything in common with unimodal models (Hodder 1982; Pétrequin/Pétrequin 1993). We might term this the 'effect of multimodal appearance'.
2. For example the acceptance of changes might be different in prehistoric communities, which produced the material remains of our case studies. Hence, the results are a nonlinear representation of conservative and non-conservative activity areas of our spatial record. Thus the 'spatial effect of activity areas' disarticulates the archaeologically available data.
3. Especially non-industrial societies handle artefacts in different ways, dependent on spheres of intercommunication. In the sphere of production artefacts have different distribution patterns from the ritual sphere of burial. Household organisation has a different distribution than the communal order. As a result, the handling of artefacts is non-normally distributed due to the 'effect of social spheres'.
4. To concentrate on funeral sites, the distribution of artefacts in single graves might be different, or analogous to contemporaneous burial customs of the same community. The burial items might be a representation of the goods which were available during the lifespan of the dead person. Or they might be especially produced for the day of the funeral ritual and represent the production options of daily work, or they might be the personal gifts of members of the funeral party to the deceased. The multiple possibilities for variations in funeral rituals, which are practised today by small non-industrial communities, are just as probable for prehistoric societies. Again, a non-normal distribution of artefacts is the result of this 'effect of burial variability'.
5. Last but not least, depositional processes are responsible for non-normal distributions. For example the fill of Linearbandkeramik pits might represent the original assemblage that was deposited as rubbish by the community in a period of less than fifty years. As no earlier ceramic-producing community lived on LBK-sites, the fill usually lacked non-LBK ceramics. But on sites where domestic activities took place for centuries, the fill of pits is full of pre-pit remains. The assemblages cannot represent normally distributed patterns but only skewed curves. We call this the 'effect of passive rubbish'.

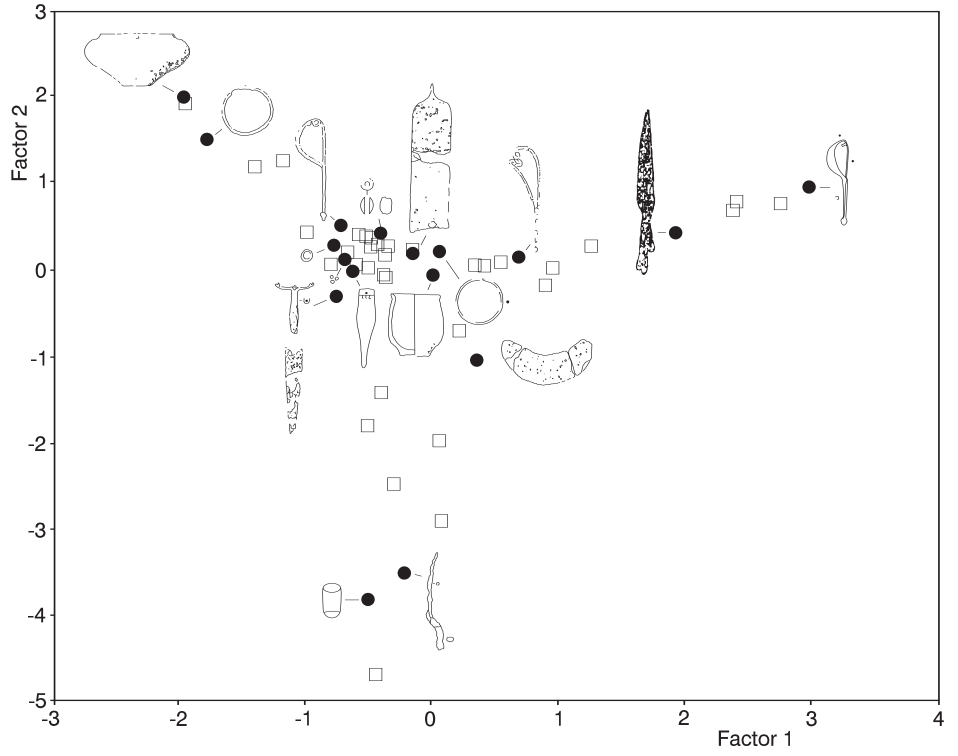

Figure 1. Scatterplot of the 1st and 2nd CA-eigenvectors for Hallstatt male burials of the Magdalenenberg, Southwest Germany.

6. Another effect, which probably destroys a 'horseshoe' in the mathematical representation, is the problem of interregional contacts. Interregional seriation was ironically called the 'Doppler effect in archaeology' by Deetz and Dethlefsen (1965) or the 'Horizon distortion effect' by Bakker (1994). 'This effect is caused by the fact that the propagation of style features over large regions takes time, and takes often different speed... While assuming that similarly styled, locally made pottery has everywhere the same date the researcher grossly distorts the chronological perspective' (Bakker 1994: 66).

As a result, artefact assemblages must not be seen as the residuals of a single closed system, where a closed archaeological system is defined as an archaeological deposit that can be precisely described in terms of units of time, location and type of deposit. Artefact assemblages represent open systems, which are significantly influenced by different channels of information on prehistoric societies and are affected by different depositional and post-depositional processes.

Obviously, the patterning of prehistoric material is not necessarily 'unimodal'. The majority of artefact deposits are not normally distributed in time and space. Therefore, we cannot test for and should not manipulate our data to form a 'horseshoe'. But at the same time they are not necessarily randomly distributed.

The interpretation of eigenvectors should therefore be done without any manipulation of the data, following an idea of Djindjian, which he expressed in 1985: the residuals from any predicted normal distribution pattern constitute a large quantity of information about prehistoric societies: every kind of figure, which appears in scatterplots of eigenvectors, may indicate unique approaches to prehistoric processes, e.g. divergence, double evolution, breaks etc. (Djindjian 1985).

An example of such a non-random distribution and functional variability, which is observable in the CA-eigenvectors, is displayed for the male graves of the Magdalenenberg, West Germany (Müller 1994: fig. 26). The scatterplot shows a threefold pattern (fig. 1):
Factor 1 separates the burial items on different arms and fibulae, which on the one hand describe graves without weapons but which include ceramics, and on the other burials with daggers and lances. Factor 2 separates the graves with fibulae from graves without fibulae, but instead with iron needles and miners hammers. As the pattern contradicts chronology, it is probable that sociological differences between richly and poorly equipped male graves as well as different male roles are reflected.

With such an approach in mind, the author would like to analyse Globular Amphorae sites of Central Germany and tackle the results of correspondence analyses.

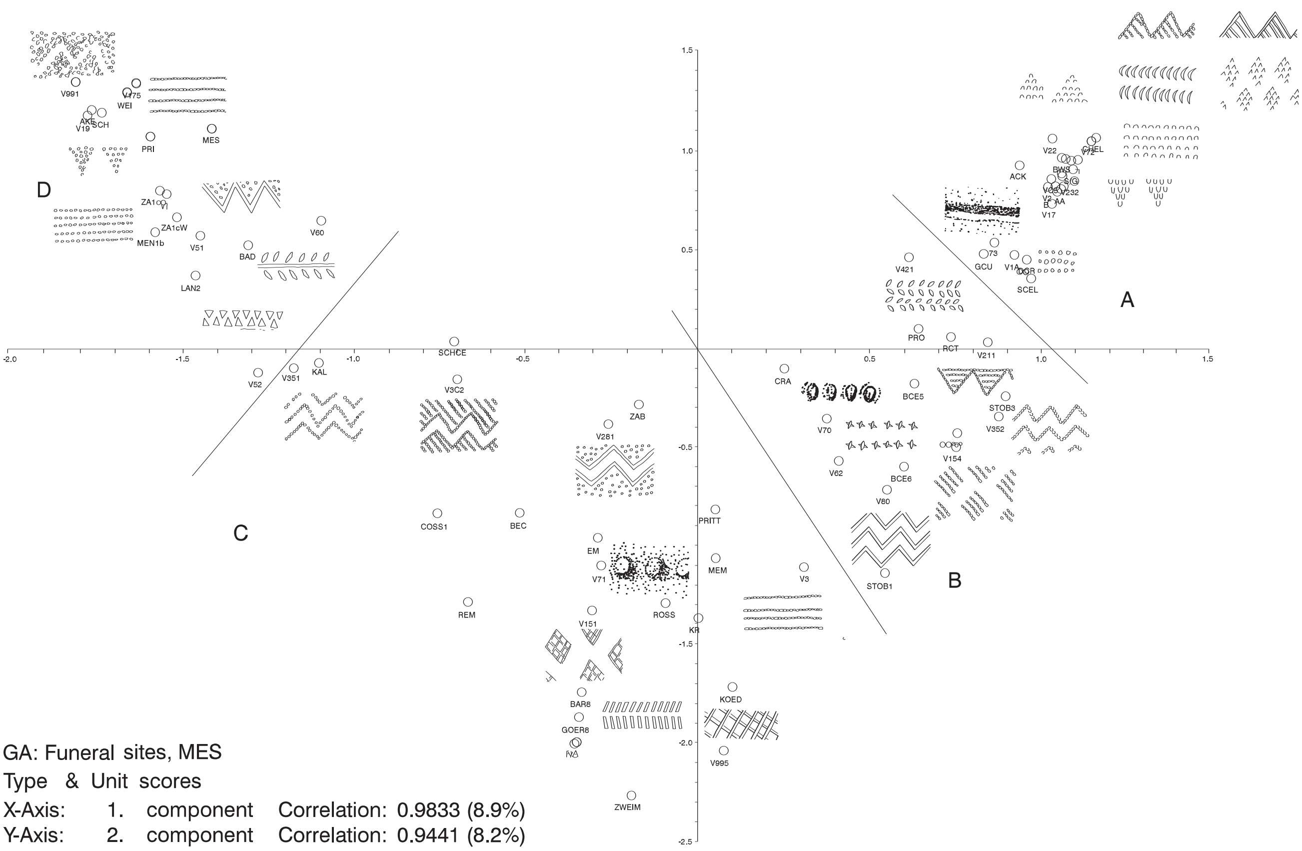

Figure 2. Scatterplot of the 1st and 2nd CA-eigenvectors for Globular Amphorae burial sites. The decoration motifs describe four assemblage groups A-D.

2 Central German Globular Amphorae

During the Neolithic, Central Germany displays regional traditions of social differences, which are discernible in settlement hierarchy as well as in grave construction. Within such a framework wider influences play an important role (Beier/Einicke1994). Until now, the representation of such widespread phenomena as Corded Ware pots or Globular Amphorae has not been investigated in detail with respect to the contemporaneous local and regional substrata. In this paper I would like to discuss results of CAs, which are prepared for Globular Amphorae (GA) sites.

Apart from Bernburg-Walternienburg, the earliest phase of Corded Ware and the latest Alttiefstich and Salzmünde Globular Amphorae are present in different kinds of funeral and domestic sites between 3200 and 2600 cal BC. While Globular Amphorae represent a general phenomenon of Late Neolithic societies, which spans from the Ukraine to the western Baltic sea, clear differences are observable from region to region (Nortmann 1985). Until now a chronological differentiation of GA has not been demonstrated by research. Interaction with Bernburg has been discussed, but not explained (Beier 1988: 40-46). Yet, important inter- and intraregional differences are on record.

Correspondence analysis was chosen to investigate the similarities and dissimilarities, firstly between the decoration pattern of the assemblages of single and multiple burial sites, including cattle graves; secondly, between the assemblages of domestic structures, mainly pits; thirdly, between both domestic and funeral sites in a combined seriation. It was hoped to discover a relation between ritual and domestic sites. With respect to the basic assumptions, non-continuous results were expected along with normal distributed artefact patterns.

3 The recording system for decoration

Until now, Globular Amphorae pots of Central Germany have been analysed only by classification systems that underline the connection between pot shape and decoration and interrelate decoration patterns in a hierarchical order (Beier 1988; Meyer 1993). In this study I prefer a classification system that decodes the ornamentation as independent, equally weighted design elements. These elements appear on every shape and — ideally — in every position on the pot. 93 design motifs were classified, and their presence stored in a data bank for each assemblage.

4 CA of the Globular Amphorae funeral sites

For the purpose of the analysis, only closed or nearly closed assemblages are used. From 177 sites with 204 funerals only 66 single, multiple or cattle graves fulfil the condition that they are not disturbed by later intrusions and/or are properly reported. The correspondence analyses describe a 'horseshoe structure' for the first and second eigenvectors (fig. 2). By the exclusion of vertical line ornaments, the first component has a correlation of 0.98, the second of 0.94. Four clusters of decoration elements and corresponding assemblages are detectable in the graph: assemblage group A with a high degree of curved and angular dots; B with angular bands and diamonds of corded lines; C with incised diamonds and D with punctate decoration, e.g. triangles.

What do the clusters indicate? Stratigraphies and mixed assemblages of GA sites with older and younger Bernburg or Corded Ware prove the chronological character of the observed sequence with A being the oldest and D the youngest association. Based on C14 dates this development starts around 3200 cal BC and ends around 2600 cal BC (Müller in prep.).

Beside the chronological effect, other differences are visible, if we plot special aspects of artefact distribution into the graphical display. For example the third eigenvector shows different loadings, especially concerning cluster D (fig 3). The burial association helps us to describe lower loadings of Factor 3 as a representation of multiple burials, whereas higher loadings are mainly of single burials. Furthermore, some chronological order of the funeral rites is visible: cattle graves only appear during the phases A, B and C, while double and multiple burials are only known from C and D. Similar developments are visible with items or indicators of ritual behaviour: the range of the number of associated vessels is the highest in A, the lowest in D (fig. 4). In A-C parts of cattle are deposited in human graves, in C-D only caprovids. The range of the number of adzes in A is higher than in D. Otherwise, no differences are visible with respect to sex or age. All results mentioned have been tested with the χ^2 and Fisher's F test.

In summary, the sequence reflects the socio-chronological development of the Globular Amphorae society or of the practice of Globular Amphorae funerals within a regional social framework: the process starts with elaborated differences of grave furniture and the rite of cattle graves. It changes around 2800 cal BC to the practice of rather less 'expensive' sheep/goat associations, a reduction of the differences between grave items and an emerging practice of double and multiple burials. Perhaps the change to Corded Ware graves that started around 2800 cal BC in Central Germany represents a new ritual system of status expression during the funeral rite for important members of the communities.

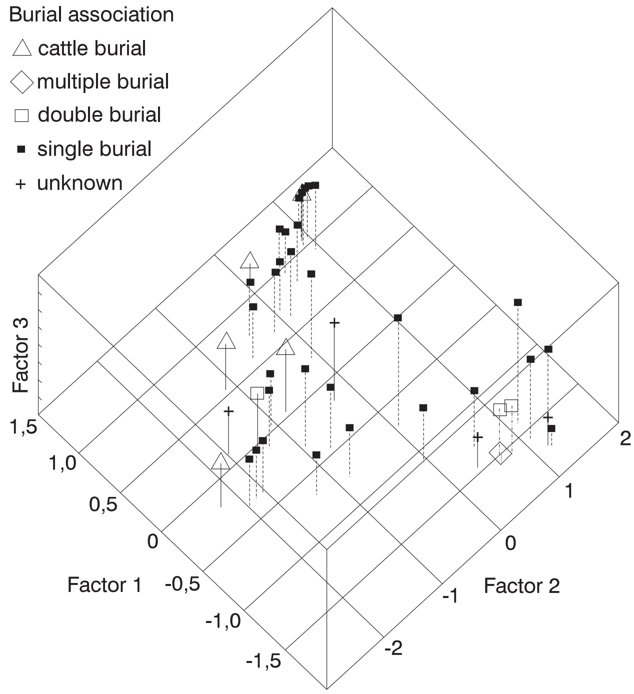

Figure 3. Plot of three CA-eigenvectors for Globular Amphorae burial sites. Different burial associations are indicated.

5 GA ceramics in domestic structures

There are only a few settlements where GA forms the only ceramic tradition. Normally, GA ceramics are found on Bernburg sites (Beier 1988). In all, only 40 pit structures have been evaluated as 'geschlossene Funde' (closed finds). Although only 30 sites are useful for the analyses, a clear sequence appears within the ordered matrix of the first eigenvector. The scatterplot of the first and second eigenvectors (not illustrated) does not display a horseshoe, but a 'cloud' along the first axes. Still three clusters of pottery design are visible: SA with incised diamonds, partly with curved and angular dots, SB with partly curved and angular stabs and plastic decoration and SC with angular bands. Again, the association of mixed assemblages and the stratigraphic order at Görschen (Beier 1988: 132) point towards a chronological interpretation.

6 GA: Domestic and funeral sites

The common seriation of both domestic and funeral sites with GA has a twofold problem: on the one hand the two types of sites possess different depositional histories that result in different qualities of chronological closeness. On

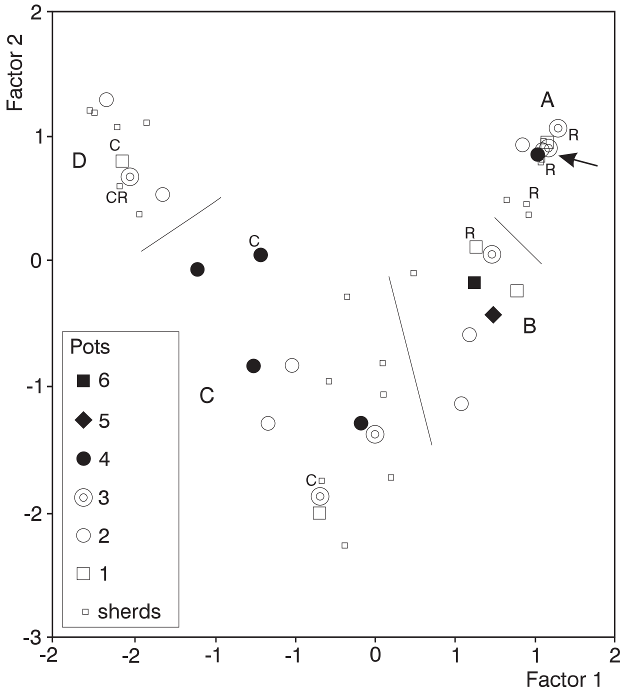

Figure 4. Scatterplot of the 1st and 2nd CA-eigenvectors for Globular Amphorae burial sites. The number of pots per grave, bones of caprovides (C) and cattle (R) and the burial with the highest number of adzes (arrow) are indicated.

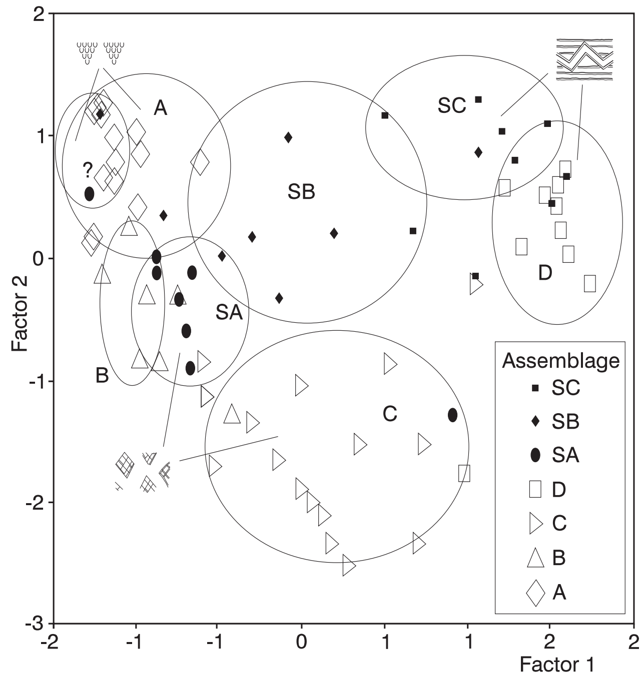

Figure 5. Scatterplot of the 1st and 2nd CA-eigenvectors for Globular Amphorae burial (open symbols) and domestic (filled symbols) sites. The assemblage groups and some characteristic decoration motifs are shown.

the other hand the change within the social life of things, here perhaps the change of symbolic expressions used on pottery may lead towards a different value of things.

In spite of this there exists the chance to investigate the mode of symbolic change within the society or at least a part of the society.

The result is displayed in figure 5. Again we find the horseshoe structure of funeral sites with their sequence of decoration clusters and the stretched structure of the domestic assemblages with their sequence of domestic clusters. It seems interesting that the sequences overlap and are correlated, because parts of the domestic dots form a part of the parabolic structure.

We observe the following sequence:

1. The funeral A group and two domestic sites represent the beginning of the common sequence with motifs of curved and angular dots.
2. The domestic SA group with incised diamonds follows along with the funeral B group on the parabolic structure, followed by the funeral C group with incised diamonds.
3. As a parallel the domestic B group is contemporary with the funeral C group. It is of interest that the assemblages with angular and curved stabs are distributed with negative values, while those without these attributes have positive values.
4. The funeral D group and the domestic C group form the final part of the sequence on the right hand side.

There is no question concerning the chronological order which appears here. Obviously, the interrelation of symbolic expressions is different in domestic and funeral sites. While ‘Bogen/Winkelstich’ is no longer used in funeral rites, it is still present on some domestic sites. In contrast, incised diamond motifs first appear on domestic sites and are later introduced (and restricted) to the funeral sites.

7 Conclusion

Having equipped ourselves with a time scale, we can turn to the question: what happened? Obviously, the changing role of ceramic decoration is visible in the distinction between domestic and funeral pottery. The denotation of the symbolic expression of the ceramic decoration changes. Perhaps this is related to the changes of ritual behaviour within the GA sequence and the appearance of Corded ware.

With respect to methodology, correspondence analyses of different site categories can be applied for the modelling of such changes.

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Simulating hunter-gatherer colonization of the Americas

1 Introduction

Simulation modelling of the Palaeoindian expansion into the Americas was pioneered by Paul Martin, who proposed an 'overkill' model in 1967. Taking demographic parameters from a compilation of data by Joseph Birdsell (1957), he calculated that humans reproducing at a rate of about 3.5% per annum, with directional migration southwards at an average rate of 16 kilometres per year, would have reached Tierra del Fuego 1,000 years after entering the land south of the ice sheets. His model had a dense 'front' of pioneers overexploiting the megafauna in their path, and moving on to leave a faunally depauperate environment occupied by humans at merely one tenth of that initial population density (Martin 1973). With James Mosimann, he developed this 'overkill' model in a later paper in 1975, in which it was demonstrated that hunters with unchecked population growth and moderate or heavy kill rates, or alternatively a focus on preferred mammoth and mastodon prey, could push their prey species into extinction throughout North America in a period of 300-500 years (Mosimann/Martin 1975). Calculations of the velocity of expansion of the front were also made in this paper, and reinforced the finding that rapid growth (2.5 to 3.5% per annum) was a necessary condition of very rapid expansion, although a slow growth model was summarized in which pioneers reached the Gulf of Mexico 1,157 years after entry at Edmonton, with an intrinsic growth rate of only 0.65%.

In our own work, we have been concerned to evaluate the effect of spatial habitat variation, and of the distribution of geographical barriers to dispersal, on the rate and routes of expansion of pioneer Palaeoindian populations. Such effects have generally been omitted in previous models, which have used averaged habitat values applied to the whole continental land area; but their importance has nonetheless been noted. Mosimann and Martin (1975: 306) observed that 'while we acknowledge their importance in an ideal model, we do not attempt to [...] incorporate the inevitable local differences in carrying capacity at the time of invasion.' Whittington and Dyke (1984: 462), who developed the Mosimann and Martin model, also observed that 'a better approximation of reality than uniform population densities would be a model that allows for interactions between megafaunal and human populations whose densities were based on the distribution of various resources. Since this would be a radical departure from Mosimann and Martin's simulation, a reformulation of the model was not undertaken.' Finally, Belovsky (1988: 353) also set the parameters for his own simulation of Palaeoindian expansion so that 'rather than tracing the growth of the human population from vegetation type to vegetation type across the two continents, an average primary productivity was used.'

2 The simulation model

In modelling the effects of barriers and habitat variation on the rate of expansion of pioneer human populations, we have departed radically from the simulation paradigms of these workers. We have discretized both time and space for our simulations, using a two-dimensional lattice in which each cell has cell-specific fixed values for the habitat terms, and an updated cell-specific value for the human population size. The update algorithm is a discretized approximation of a continuous differential equation describing the process of demographic expansion. For our initial phase of work, we have been using a discrete approximation of R.A. Fisher's classic equation for the 'wave of advance' of advantageous genes (Fisher 1937), which has already been generalized to the case of animal range expansion and is widely used for this purpose in biogeography. Fisher's model is also the basis for Ammerman and Cavalli-Sforza's work on the expansion of Neolithic colonists in Europe.

The Fisher equation is:

$$\frac{dn}{dt} = f(n;K) + D\nabla^2 n \qquad (1)$$

where $n(\mathbf{r},t)$ denotes the local human population density (number per unit area) at time t and position $\mathbf{r} = (x,y)$. The diffusion constant D (in km^2 yr^{-1}) and the carrying capacity $\mathbf{K}$ are functions of position. The function

$$f(n) = \alpha n\,(1 - \frac{n}{k})$$

describes the rate of population increase, and is the logistic function widely used in theoretical ecology (Murray 1990); the quantity α denotes the annual population growth rate.

We approximate time differentials at particular sites by finite differences (Press *et al*. 1986):

$$\frac{dn(\mathbf{r},t)}{dt} \approx \frac{n(\mathbf{r},t+\Delta_t) - n(\mathbf{r},t)}{\Delta_t} \tag{2}$$

Typically we use $\Delta_t = 1$ year.

Space differentials are similarly approximated by finite differences:

$$D\nabla^2(\mathbf{r}_0) = h^{-2}\sum_\alpha w_\alpha D_\alpha[n(\mathbf{r}_\alpha)-n(\mathbf{r})], \tag{3}$$

where for a given position $\mathbf{r}_0$ the sum is taken over nearest neighbour sites $\mathbf{r}_\alpha$ on the lattice, and where the lattice size is h. There are two types of neighbour sites: those along the lattice axes and those along the diagonals. The sum is weighted appropriately with parameters w_α; this parameter is typically 2/3 for sites α along the lattice axes and 1/6 along the diagonals. The effective diffusion parameter D_α', appropriate to motion between the sites $\mathbf{r}_0$ and $\mathbf{r}_\alpha$, is given by

$$D_\alpha' = \sqrt{D(\mathbf{r}_\alpha)D(\mathbf{r}_0)}.$$

In practice in any given simulation, only two values of D are used: $D = D_0$ and $D = 0$, the latter representing the fact that the particular cell is inaccessible.

The crucial input parameters for the model are then the carrying capacity K, the so-called Malthusian parameter α and the diffusion constant D. D represents the degree of mobility of an individual (e.g., Ammerman/Cavalli-Sforza 1984). In general individuals will move from their birth place a distance λ during their lifetime τ. The square of this distance will in general be proportional to the time available; the constant of proportionality is the diffusion constant D:

$$D = \frac{\lambda^2}{4\tau} \tag{4}$$

The differential equation (1) in the case of constant D and K, and for populations which can only move in one rather than two dimensions, predicts that there will be a population wave of advance, with the frontier travelling with velocity (Ablowitz/Zepetella 1979):

$$\nu = 2.04\sqrt{D\alpha} \tag{5}$$

Our discretized model gives accurate results so long as the natural length scale in this equation

$$\xi = \sqrt{\frac{D}{\alpha}} > h$$

Otherwise the simulated velocity is faster than that predicted analytically. For simulations with h ~ 50 km with 0.005 $\mathrm{yr}^{-1} < \alpha < .05\ \mathrm{yr}^{-1}$, and with $D > 10\mathrm{km}^2\ \mathrm{yr}^{-1}$, our discretized lattice yields consistently accurate results (fig. 1).

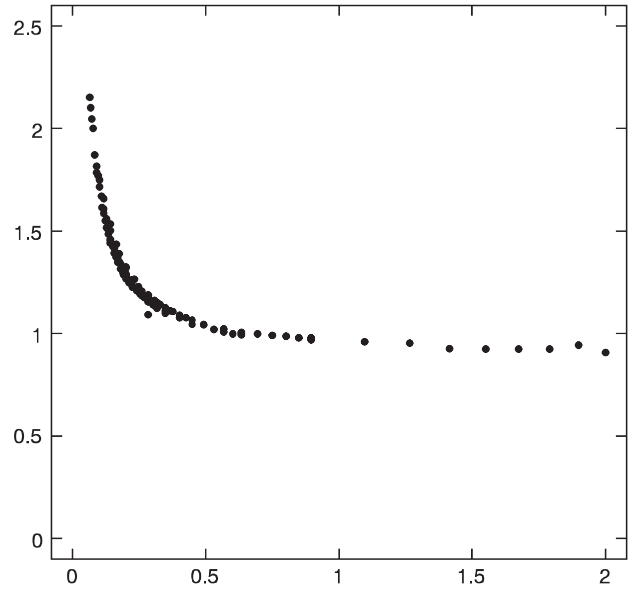


Figure 1. Ratio of simulated to theoretical velocity of expansion of the front, plotted against the 'natural length scale' (the independent variable). The latter is given by dividing $\sqrt{(D/\alpha)}$ by the cell dimension (in these simulations, 50 km).

We note also a methodological point; in principle (even if in practice this will be difficult!) we may have independent estimations of D, α, K and ν. We predict that ν will be independent of K and dependent on D and α according to equatation (5). If these predictions are not borne out — if, for example, the values of D and α required to be consistent with archaeologically sensible values of ν are not themselves plausible — we are bound to use more sophisticated models of population movement, for which the Fisher equation, at least in its naive form, would no longer be helpful.

3 The use of geographic information in the lattice model

For the first set of experiments, we have used a projected representation of the surface of North America and its surrounding oceans, rasterized from an interpolated surface generated in IDRISI from the original vector format point file as a grid of cells coded for their accessibility to a diffusing population. Sea and other impassable areas are '0', colonizable land is '1'. Population can either diffuse into the cell, or not. The projection transformation (Transverse Mercator, meridian 90° W., scale factor = 1) was selected to avoid distortion of area and orientation, and the interpolated vector file was used to generate raster output with a cell size of approximately 50 km by 50 km. To make it easier to understand the real time output to

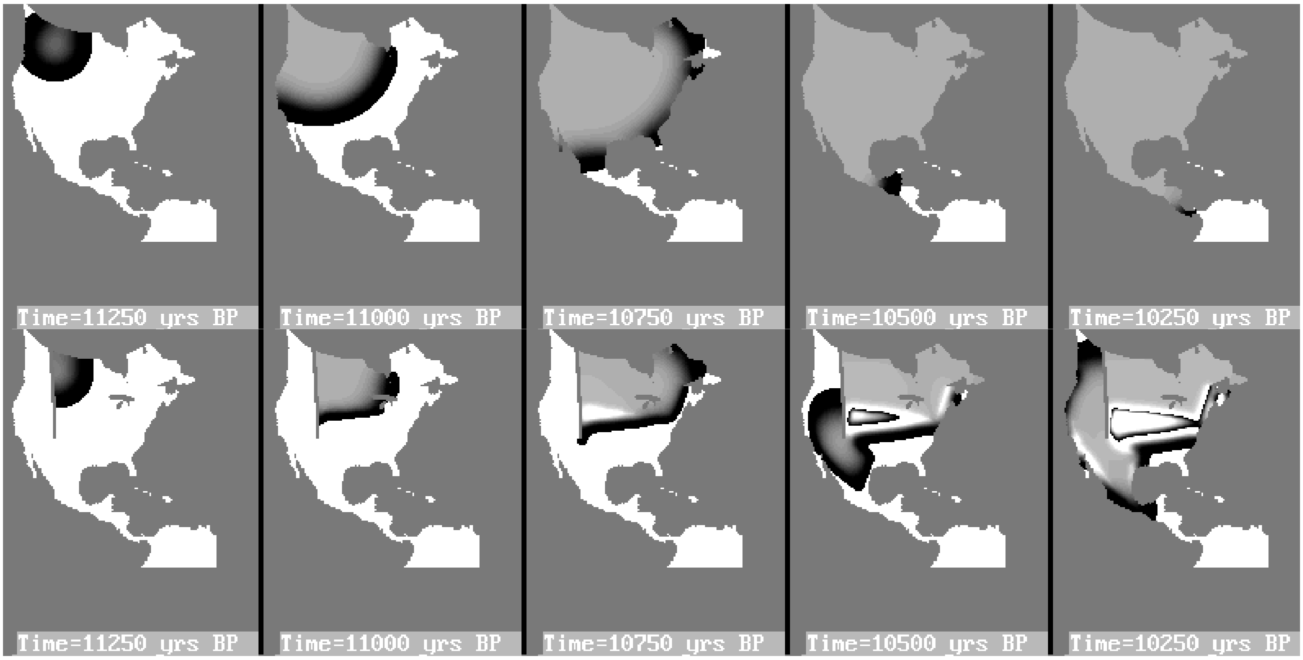
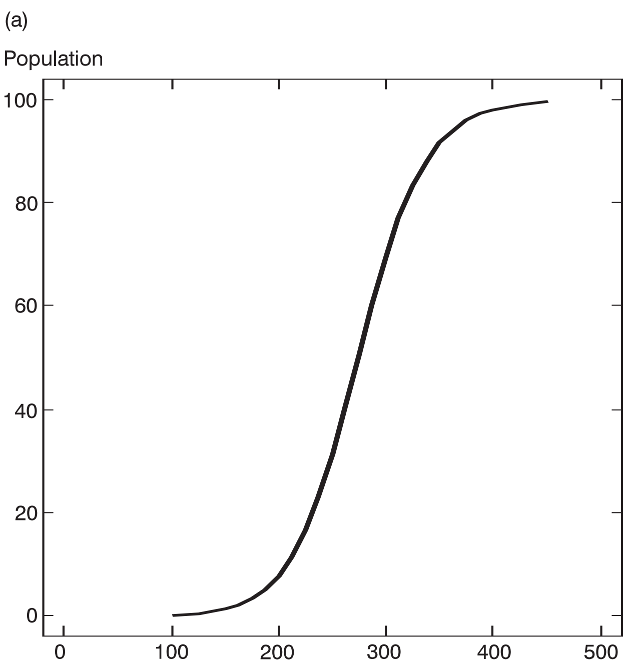


Figure 2. Screen capture shots of the travelling wave at t = 250, 500, 750, 1000 and 1250 years. Seed population at Edmonton. Carrying capacities: 0.04 p.p.km^2 (background), 0.2 p.p.km^2 (coasts and plains). Population growth rate = 0.03 p.a. (background), 0.01 p.a. (coasts and plains). Dispersal rate = 400 km^2 p.a. (background), 100 km^2 (coasts and plains).



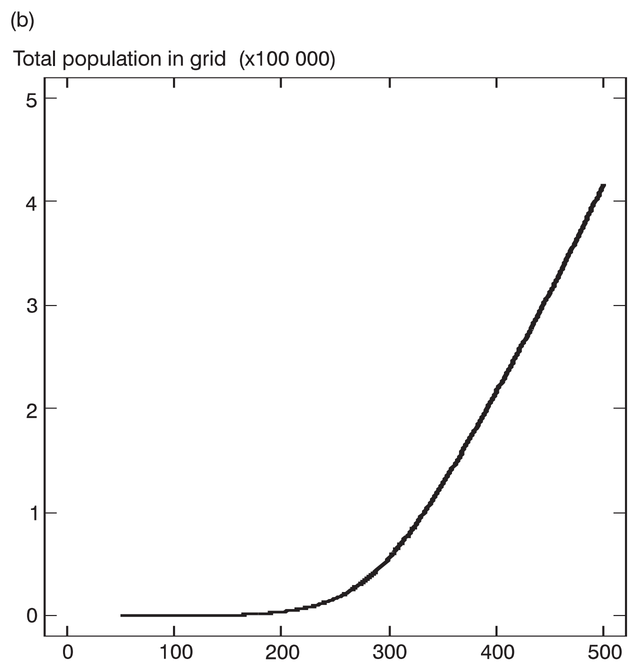


Figure 3. Population growth curves for (a) a sample cell and (b) the whole grid, for a sample set of conditions (α = 0.03, D = 500). K = 100 persons per cell.

screen while the simulation is running, barrier cells are coloured blue — since they are mostly sea — while cells where people can go are coloured green (since they are nearly all areas of land surface with significant primary plant production). Population densities on the colonized portion of the accessible surface are grey-scaled, making it easy to follow the expansion of the front as it is updated and written to screen in real time during the simulation (fig. 2). Figures 3 (a) and (b) show the curves for increasing population in a single cell and in the whole colonizable portion of the grid, against time, for an example set of values for the demographic parameters. It is evident from these that while the population in each of the cells follows a logistic growth curve, the growth curve for the total population is exponential. This is what we would expect from the original model.

The simulations shown in figure 2 also demonstrate the effects of varying the barrier locations and the demographic parameters as cell-specific attributes. The first series represent demographic expansion over a homogeneous plane, while the second series has barriers at the Rockies and the Great Lakes, and two categories of habitat with covariation in the carrying capacity (κ), mobility (*D*) and growth rate (α) terms. The varying times taken to first colonization of points on the surface if they are located beyond such hypothetical barriers, or in habitats with differing carrying capacities or disease ecologies, will clearly be detectable in archaeological radiocarbon dating of earliest cultural remains at such locations. Thus the simulation model is capable of generating archaeologically testable predictions about the effect on demographic expansion of spatial heterogeneity in barriers and in vegetation zones.

4 Future development of the model and its applications

These initial results are now being extended in a second phase of development of the model, in which ice sheet locations and vegetation mosaics at successive periods in the earliest Holocene of the Americas will be reconstructed by a palaeoecologist and used to predict spatial variation in Palaeoindian carrying capacities, and more extensive sets of simulations will be run to generate alternative predictions about possible effects of such spatial variation on colonization rates and routes.

Young and Bettinger (1995), in a study which independently developed the same demographic diffusion equation to model late Pleistocene human demic expansions, suggest that the high values of α and *D* needed to generate the observed velocity of Palaeoindian expansion into the New World under the conditions of Fisher's model are nonetheless biologically plausible. They suggest values for α of 0.03 and for *D* of 1000 km^2/yr (which would mean the travelling front would reach Tierra del Fuego in about 1,500 years). We believe that such values for the diffusion constant are, in fact, biologically implausible for almost all hunter-gatherer social systems for which recent ethnographic parallels exist. It is essential to remember that the diffusion term denotes mobility which is random with respect to direction: it is not a term denoting 'directional migration'. The value for *D* chosen by Young and Bettinger (1995) implies a lifetime mean dispersal distance for all individuals of about 300 km from the place of birth, or of about 600 km for the dispersing sex where diffusion is due to dispersal from the natal group by all members of one dispersing sex. It is difficult to see how such a high level of lifetime mobility, random with respect to direction, could be adaptive in a landscape that was also sustaining such a high net population growth rate. We therefore suspect that the rate of colonization of the Americas was driven by some further dynamic, such as directional migration by 'over-exploiters' up a gradient of herbivore prey densities in a very fragile ecosystem, and we are currently exploring new models which can be implemented in the existing discrete time and space simulation paradigm.

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An Archaeofaunal Ageing Comparative Study into the Performance of Human Analysis Versus Hybrid Neural Network Analysis

1 Introduction

This paper briefly reports on the completion of the first phase of a project that began in 1991 to develop a prototype computer system that could perform archaeofaunal ageing from a set of sheep mandibles. The computer system uses artificial intelligence models known as neural networks to analyse images of mandibles to assess their degree of wear and relative age (Gibson 1992a, 1992b, 1993).

In order to assess the performance of the computer system in relation to its human counterpart a comparative study that involved the analysis of a sample set of sheep mandibles by archaeologists, non-archaeologists and the computer system was undertaken. A overview of the results is presented here.

2 Overview of the comparative study

Age at death data of common domestic ungulates can be used to formulate an interpretation of the economy and exploitation of the livestock on a site. A number of approaches to age estimation are based on the analysis of teeth attrition. The age of an animal can be estimated by grouping its teeth into a set of wear stages based on the amount of attrition. In general, older animals have a greater degree of wear.

There are two commonly used methods of age estimation using attrition, namely Payne (1973) and Grant (1982). Payne has studied the wear stages of Anatolian sheep and goats and as a result has devised a methodology for age estimation. A more widespread study, that includes the common ungulates of pig, sheep/goat and cattle, has been undertaken by Grant.

Both methodologies concentrate on the third premolar (m3 or dP4), the fourth premolar (P4) and the three permanent molars (M1, M2, and M3). An archaeological sample can be aged by comparing the wear pattern of each tooth with the wear stages, in the form of ideograms, outlined by either methodology. This analysis results in a *tooth wear stage value* for each tooth. These values are then used to produce a *mandible wear stage value* that represents the relative age of the sample. Statistical analysis is then carried out to group all mandibles on the site into relative age stages which can be interpreted by examining the kill-off patterns to suggest the method of animal husbandry (Payne 1973).

It is the above process of analysing the mandibles to determine age at death that has been implemented on a PC using both traditional artificial intelligence techniques and hybrid neural network models (see Gibson 1992a, 1992b, 1993). Neural networks are computing paradigms that attempt to model the cognitive phenomena of the human brain so that complex problems can be solved. In doing so, they exhibit a number of intuitive characteristics such as learning, generalisation and abstraction (see Wasserman 1989 for an explanation).

In order to establish the performance of the system a number of willing participants have been asked to attribute age to a set of mandibles using both Grant and Payne methodologies. These results have then been compared with each other and against the computer application. The aim has been to study how different the results are between each participant and between the computer system and the participants in order to determine the degree of subjectivity and accuracy. The analysis has been divided into two parts, namely

– Human *vs*. Human Comparison
  Establishes the inter-observer performance
– Human *vs*. Computer Comparison
  Establishes the computer's performance in relation to the humans' performance

Measuring the performance of humans provides a guide to establishing the reliability of the computer system. In the course of identifying the performance of human analysis a number of interesting points have been highlighted regarding the methodologies involved and the human's use of the methodologies.

The participants were a cross section of people with varying degrees of archaeological experience. The set of people also had a spread of experience in terms of the two archaeofaunal ageing methodologies. A number of the group are acknowledged experts in the use of the archaeofaunal techniques under study. In contrast, a number of the group had never before used these techniques to age animal remains. In all eleven participants undertook the study.

The sheep mandibles used for the comparative study were taken from two sources. The first set was supplied by the Environmental Archaeology Unit (EAU) at the University of York with the assistance of Dr Keith Dobney. The second set was kindly lent by Prof. Don Brothwell from his own collection.

The aim of the selection of mandibles was to provide as wide a range of wear stages, and teeth morphologies as possible without overburdening the participants. Consequently, a sample set of 22 mandibles was selected that had a combination of missing teeth, unerupted teeth, teeth in early stages of wear and teeth in moderate stages of wear. A group of mandibles was selected that appeared to be in the same state of wear. Finally, some teeth had been subject to disease.

3 The human *vs.* human comparison

In order to carry out the comparative study a questionnaire was designed to record the results of the participants' analysis and to determine facts about the participant that would be useful in the analysis, such as archaeological experience, number of years using each methodology and the preferred method. The participants were asked to age each mandible in any order using both methodologies and record the results on the questionnaire sheet. For teeth that the participant could not record they were asked to use a **?** for unsure wear stages, **X** for present but unrecordable and a - for missing teeth.

A computer database system using DATAEASE was devised to record the results of the analysis. The source of the data entered into the database was used to produce a data file that could be analysed by another computer program, written in QBASIC, that presented the results in a manner that helped to answer the underlying objectives of the study.

4 Devising a method for analysing the results

Before analysing the data the main objectives of the analysis had to be made clear. To determine the performance of the human participants a number of questions needed to be addressed as part of the analysis, for example,

- Are some mandibles easier than others to age?
- Which are the most difficult mandibles and why?
- Which is the most difficult tooth in the set and in general and why?
- Which is the wear stage that causes the most disagreement and why?
- Are the experienced participants of the methodology more consistent in their interpretation than those with less experience?
- What are the factors that determine ease of observation?

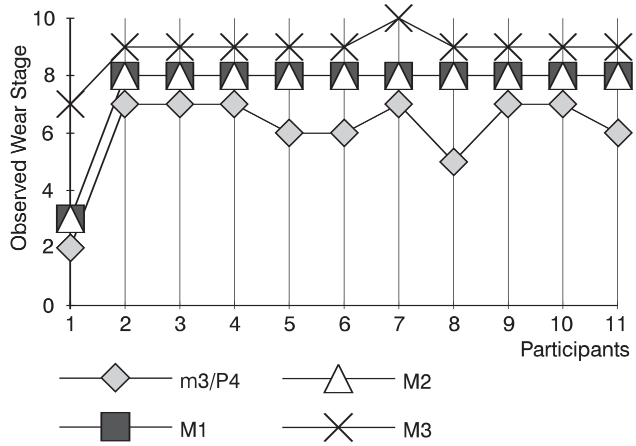

Figure 1. The Participant's Observed Wear Stage Values for Sample 2, where true wear stage values for m3 is 7, M1 is 8, M2 is 8 and M3 is 9.

- Is there any relationship between the analysis of left and right mandibles to ease of observation and general agreement?
- Which of the methodologies provides the most consistent results and why?

To answer the above questions it was necessary to establish a means of objectively analysing all the results from the participants. Keeping the objective of inter-observer comparison in mind, it was obvious that a true wear stage value for each measurement had to be used as a basis for comparison. In other words, for each of the results recorded there must be a real value by which to compare the actual observed wear stages. This *'true' wear stage value* can be calculated using the mode of the participants results where *'true'* effectively means 'expected in this study'. By taking the absolute value of the difference between the true wear stage and the observed wear stage it was possible to determine the amount of discrepancies between observers. Figure 1 shows a subset of the actual results using the Payne methodology illustrating discrepancies between observers.

Using the calculated discrepancy it was possible to determine the percentage agreement of tooth wear stages and mandible wear stages across participants. In addition, it was possible to rank the performance of the participants. This formed the basis for determining the reliability of the methodologies.

5 Analysing the data

At first glance the ranked results would appear to indicate a range of difficulties in the analysis of teeth and mandibles. On the whole both methodologies seem to

perform quite well in some areas and badly in others.
It is hard to objectively state what causes such difficulties. Are they related to structure, colour, orientation of the mandible; degree of experience of the participant, speed of recording, lighting in the room at the time of analysis or to the sequence in which the mandible was examined? These questions may demand exact answers but only speculative reasons can be given through examination of the teeth and mandibles.

Firstly, there seems to be no real problem in identifying the teeth types since there were no values in the teeth columns that were invalid. Also, there is no evidence to suggest a correlation between the percentage agreement and a left or right mandible. In addition, the teeth that resulted in the most agreement were those that were missing or unerupted. All these facts suggest that the human is good at recognising simple shapes and manipulating them in order to achieve the requirements of the analysis. This may seem an obvious statement to make but such tasks are very complicated to implement using a computer. Therefore, a machine must match this performance if it is to be of any practical use.

The presence of calculus on the tooth does not appear to affect observations provided it does not obscure any important tooth structures that would differentiate wear stages. Humans have the ability to ignore such 'noise' in the analysis of surface patterns and structures, something that a computer finds more of a problem. The only time that it may affect results is when the calculus appears at a transition point from one wear stage to another.

A general observation for the overall percentage agreement graphs is that there is less accuracy in the earlier wear stages. Perhaps this is because

1. there are more features to match,
2. less distinction between wear stages since there are more wear stages in the early years, or
3. the enamel/dentine distinction is often harder to determine.

In contrast, there appears to be more accuracy in the later wear stages. Well-worn stages seem to be easier to identify perhaps because the features on the surface of the tooth are simple. The smaller distinctions between wear stages are more difficult to pick up. When the break is only partially worn a discrepancy can occur. It appears that both methodologies suffer from this problem.

In general when the tooth does not fit a single wear stage then the percentage agreement drops. The smaller the transition between wear stages, the greater the disagreement. Therefore, visual clues based on distinct structures that are evident in the ideograms are an important element in identifying wear stages. The clarity of the enamel/dentine border is also important in the identification of wear stages.

It appears that any disfigurement of the occlusal surface of the tooth caused by a disease may affect the estimation of a wear stage depending on the degree of deformation. For example, one of the sample's M3 teeth was slightly deformed and the structure of the cusps was not as represented in the ideograms. This made establishing a wear stage rather difficult and was reflected in the percentage agreement for both methods.

To establish the overall estimate of the agreement for mandibles the average of agreements for the teeth of each mandible was considered for both methodologies. On the whole both the Payne and Grant faired similarly, with Grant gaining better agreement than Payne on some occasions and vice versa. However, the overall average agreement for Payne was 70.4% and for Grant 69.1%. Figure 2 shows a comparison of percentage agreement between Payne and Grant approaches.

To determine whether experience had any bearing on the analysis the participants were ranked for the results of mandibles, and each tooth. Again, it can be stated that experience has no real influence on the establishment of age. This conclusion is gained by examining the experience of individuals and noting where they rank in the group for each tooth. The top five were not always the most experienced.

Although this study has aimed to cover all aspects that may lead to misinterpretation of results it obviously has not been able to address all of them. There has been no consideration to the sequence in which mandibles were analysed to see if this had any influence on the results. The influence of broken and partial teeth has not been fully addressed, although they were considered in part. A larger group of participants would perhaps provide a more general and global view. Also, the effects of speed were not analysed.

This study has shown that there is not always 100% agreement in the results of observers. In addition, it has suggested why there may be discrepancies in the data. However, the main purpose of the study has been to provide a set of data that can be compared to the computer system to measure its performance.

6 The human *vs.* computer comparison

The key to the success of a neural network based system is the reliability of the data that is presented to it during the training stage of the system's development. The testing of the system is an integral part of its development and requires data that contains representative examples of all general cases that the neural network would be expected to cope with during its active operational running. Therefore, the system was trained using a series of images of

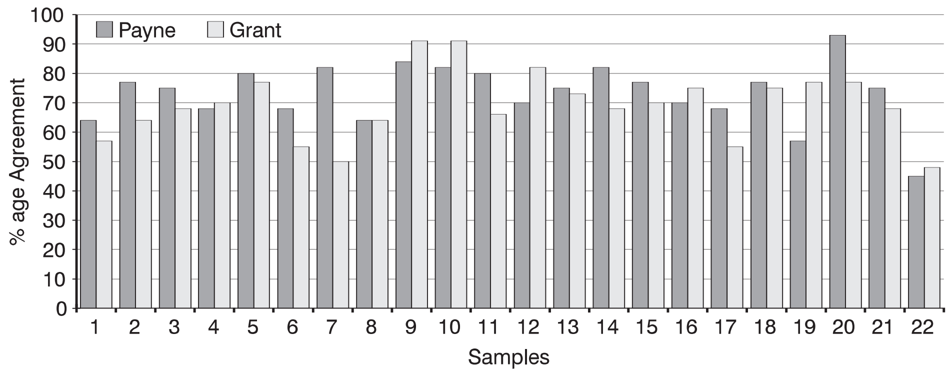

Figure 2. Comparison of percentage agreement of Payne and Grant.

mandibles with various degrees of wear. Once the system had been trained the mandibles given to the participants were presented to the computer and the results compared.

The system was measured against the participants and found to have an overall performance of 65.2% agreement. Of those results that did not match the system was only one or two wear stages out from the participants agreement. Like the human participants the system appeared to have difficulty in assessing early wear stages whilst having greater success with later stages. Again, this could be linked to the smaller transitions in some of the early wear stages. The performance of the system when faced with disfigurement of the occlusal surface was equal to that of the participants. It appeared to produce acceptable answers on the basis of what it saw and what it had learnt.

By comparing the system's performance to the overall percentage agreement of the Payne and Grant methods the result above is encouraging. However, we must be cautious not to overestimate the success of the system. It is important to note that in preparing the images for analysis, effort was made to ensure that the mandibles were presented in such a way that the system would not get confused. The success of the system relies heavily on the quality of the image. Giving the system images that had mandibles in a bad orientation or obscured by calculus deposits deteriorated the acceptability of the results. The human overcomes this problem by moving the mandible into the best position for analysis; something which is difficult to implement using a computer.

It has been seen that the system does not perform well when it is trained using a small number of examples, typically ten. By increasing the number of training examples the system shows greater tolerance to situations that it has not seen before. In one session the system was approaching a rate of 70% success in comparison to the results expected with a training data set consisting of 50 images. However, too many training examples saturate the system and its performance drops. Therefore, it is questionable whether the system will perform much better than currently measured without restructuring its basic architecture.

7 Conclusion and future

The human *vs.* human comparative study has illustrated that there is a degree of subjectivity in the analysis of age estimation using both methodologies. It has identified some areas where the subjectivity originates. Furthermore, it has shown that although the comparative study was carried out rigorously there are areas that the study has not been able to address. Although, the study has taken a *small* number of participants it has still been useful as a means of comparing the computer system.

The human *vs.* computer comparative study shows that given the correct conditions the system can perform acceptably in relation to the human participant. However, the human participants are still better adapted to undertaking this type of subjective analysis.

The next stage of the project is well on the way to implementing a system capable of interpreting kill-off patterns of sheep in order to ascertain their exploitation. Again, it will be necessary to undertake a comparative study to determine the performance of the computer system in terms of its human counterpart.

Acknowledgements

The author would like to thank all the participants who took part in the comparative study. In addition, the loan of the mandibles by Dr Keith Dobney and Prof. Don Brothwell is appreciated. The support by Dr Julian Richards, University of York and Dr Terry O'Connor is gratefully acknowedged. Finally, the author is thankful for his parents' support and help.

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Image Processing Strategies for Artefact Classification

1 Introduction

It need hardly be stated that the identification of objects (usually artefacts) is a fundamental requirement for the practice of archaeology. In particular, when the identification takes the form of assignment of the artefact to a classification (pre-existing or not) the information associated with the artefact is greatly increased. In the case of assignment to a pre-existing classification, the task may be called recognition, but the procedure(s) are the same. Classification, which may be defined as the division of a set of artefacts into subsets containing objects that are more like each other than other members of the set (Doran/Hodson 1975: 159), is very closely related to identification/recognition.

Identification has traditionally been carried out by experts in the field. The task requires a large amount of training and experience, because although in many cases specific features are diagnostic of a particular class of artefacts, the identification often rests on a visual judgement by the worker. Of course every method has its pros and cons, but for our purposes the most important disadvantage of the traditional approach stems from the limitations of the human brain when it comes to large data sets. Humans find it difficult to think of more than 3 or 4 things simultaneously, let alone several hundred (or even tens of thousands as is often the case with pottery). Large data sets also take time for the human to consider, introducing the possibility that fatigue may affect the results. A third factor is the lack of repeatability of this method. As the results depend on human judgements, there is no guarantee that a different person will produce the same result, or that the same person will produce the same result at a different date. We have been looking at ways of producing an automatic aid to classification that will alleviate these problems.

Much work has been done on computer-based classification in archaeology (e.g. Doran/Hodson 1975; Gero/Mazzullo 1984; Main 1988; Wilcock/Shennan 1975). However these methods have not been as successful as might have been hoped when applied to practical situations.

Our work has concentrated on using the shape information contained in images of the artefacts. Shape is an important factor in identification. Visual identification as we have implemented it, requires a 2 stage strategy (see fig. 1). The first stage is to use an image processing algorithm to extract shape information from the image. This information may then be used individually to identify the object, or when this information is extracted for a set of objects, to classify that set. It should be noted that the image processing algorithms can be used on any shapes, not just whole objects. Thus, although the case study in this paper is concerned with the identification of the profile shapes of whole artefacts (pots), the methodologies used can equally well be applied to other categories of shapes, such as partial/broken artefacts, or surface decoration motifs.

Figure 1. The 2 stages of visual identification and classification.

In the remainder of this paper, we describe and compare the abilities of several different strategies that have potential for classifying a set of artefacts on the basis of their profile shapes. These strategies are different combinations of alternative algorithms for each of the two stages of the procedure, both for extracting the shape information, and for identifying the object statistically on the basis of this information.

2 SMART

The first part of the work was to create a visual lookup front-end for a database. Such a system could be used by the excavator in the field to help identify newly-excavated objects. A prototype of this interface was implemented as the System for Matching ARTefacts (SMART see fig. 2; Durham *et al.* 1995). This uses a pattern matching algorithm known as the generalised Hough transform (GHT) to compare the unknown image to a set of known library images. The GHT calculates a value for the similarity between two images. The similarity of the

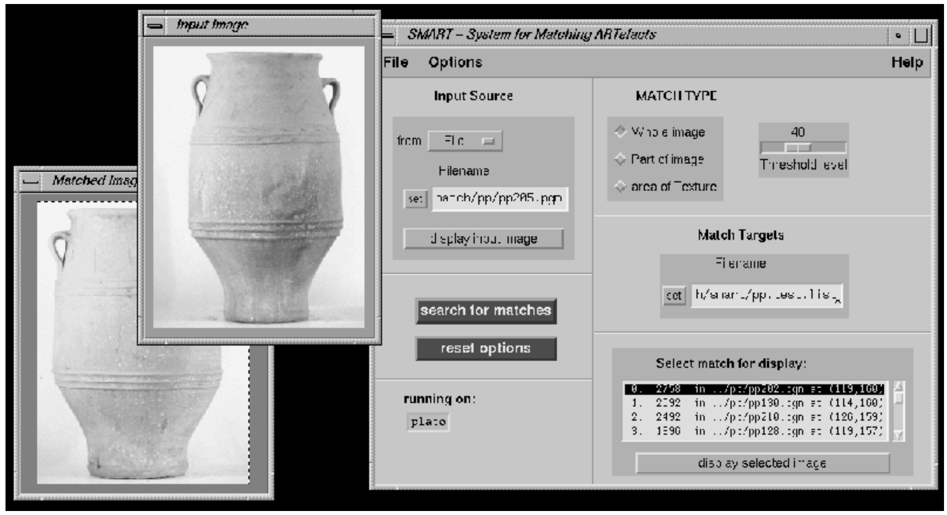

Figure 2. The SMART interface.

unknown image to each of the library images is calculated, and a ranked list of the library images is displayed.
It should be noted that the system does not assign the unknown image to a specific class, but indicates which library images have shapes most similar to the unknown.

In the SMART identification method, the calculation of the similarity values is the first of the 2 stages mentioned above, the ranking of the list is the second. To extend the method to classification, only one set of images is used. Every image in the list is compared to each of the others, and the table of similarity values so produced is used to classify the artefacts (Durham *et al.* 1994).

The GHT gives good results but is very slow, especially when classifying large sets of objects. This is because it calculates a relationship between two images which needs to be done for each possible pair in the set (in the classification case this calculation is Order $\mathbf{n}^2$). It would be much quicker if the shape information calculated were a property of the individual images rather than a comparative measure between images. This would only require the calculations to be made **n** times, and would have the added bonus that the information could be calculated in advance, as it is a property of the individual image itself and will be independent of the other images. Thus the incorporation of a new artefact would only require a single set of calculations to be made.

Many such measures exist, but the one we have concentrated on is shape moments. These are statistical characteristics of the shape, based on the arrangement of its parts. Many different moments can be calculated, and the more that are used, the more detailed the description of the shape will be. An infinite set of moments will completely describe the shape (cf. Fourier harmonics). In practice it is sufficient to use a subset of lower-order moments to give a fingerprint for each shape with the desired level of detail.

A commonly used set of moments is the set of invariant moments (Sonka *et al.* 1993: 228ff). When considered together these moments provide a description of the shape that is translation-, scale-, and rotation-invariant (that is, the result will be the same irrespective of where the shape is, what size it is and which way up it is in the image). These moments have been used successfully to identify aeroplanes, etc. (Cash/Hatamian 1987; Mertzios/Tsirikolias 1993). However early experimentation revealed that the invariant moments were inappropriate for symmetrical shapes, such as pot profiles as they consist of combinations of a few low order moments most of which are zero for symmetrical shapes. A simpler form of moments, known as normalised central (NC) moments do not suffer from this problem as they may be calculated to any order. However, they do not possess the property of rotation-invariance, but this is not a problem if care is taken to ensure that all the shapes have the same orientation.

In our 2-stage scheme for visual identification, the GHT or the moments are used to do the first stage: to extract the shape information. Several techniques can be used to perform the identification based on this information. The GHT produces a single number for each comparison, so a simple ranked list can be used here as related above. A set of moment values can be thought of as a set of features of the shape, and the object can be identified by the use of classical statistics such as the well-known k-nearest neighbour method (looking at its nearest neighbours in the feature space defined by the moments, the neighbours being known examples). Alternatively, the moments can be used as the inputs to a back-propagation neural network, which is

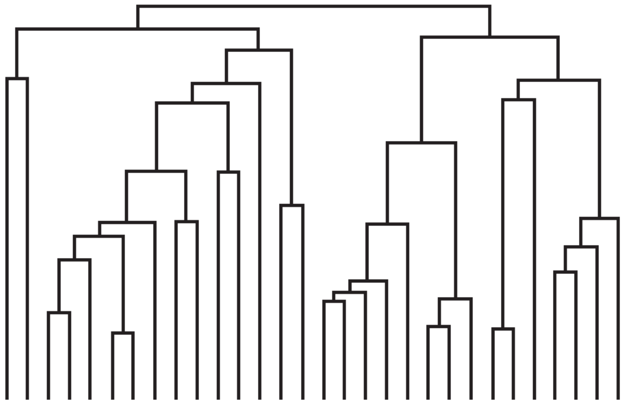

Figure 3. GHT dendrogram.

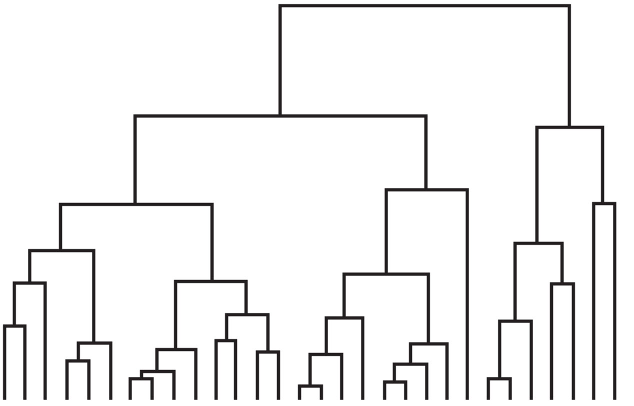

Figure 4. NC moments dendrogram.

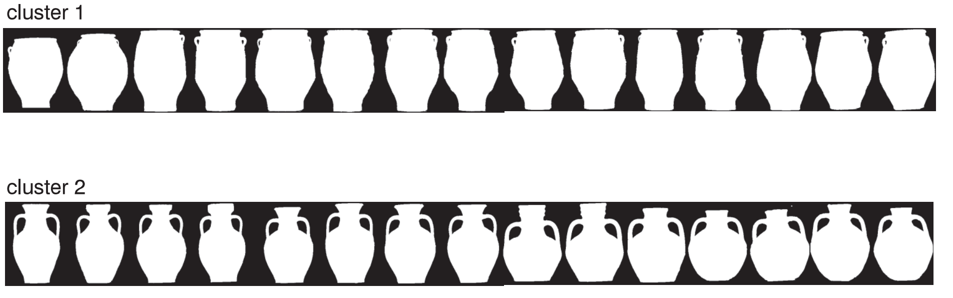

Figure 5. GHT group assignment.

trained to identify shapes using known examples. Both of the methods have been implemented, and their performances were compared to the GHT method.

3 Testing

To compare the methods a set of 30 pots were used. The pots are modern, from Crete, and have been classified by a human (S.J. Shennan) into two groups. These groups are obvious to even the untrained eye, the pithoi being jars with very small handles, and the amphorae having large handles. Although the methods are quite capable of using the raw images, the images were pre-processed to give a solid shape. This was easily accomplished by extracting the edge map of the image, then joining the gaps in the profile, filling in the interior of the shape and removing noise from the background, using an image painting package. Thus the images used were ideal shape representations, and the quality of the images would not affect the results. The first 7 NC moments were calculated for each image and the neural net which was used had 7 input nodes, 2 output nodes and 4 nodes in the hidden layer. The 3 methods were compared using the leave-one-out method, where each member of the set is identified on the basis of the others, and the percentage of correct identifications is recorded.

4 Results

The relative performances of the 3 methods were as follows:

GHT	100%
NC moments - k-nearest neighbours	97%
NC moments - neural net	63%

It can be seen that the NC moments were slightly less successful than the GHT when used with the k-nearest neighbours method. The neural net results were rather poor, but this work is still at a very preliminary stage and it is expected that further work on this will produce better results by using a different net topology and experimenting with different parameters in the back propagation algorithm.

The reasons for the different performances of the GHT and the NC moments becomes apparent if the shapes are classified on the basis of these methods. As mentioned above, the shape information derived in the first part of the

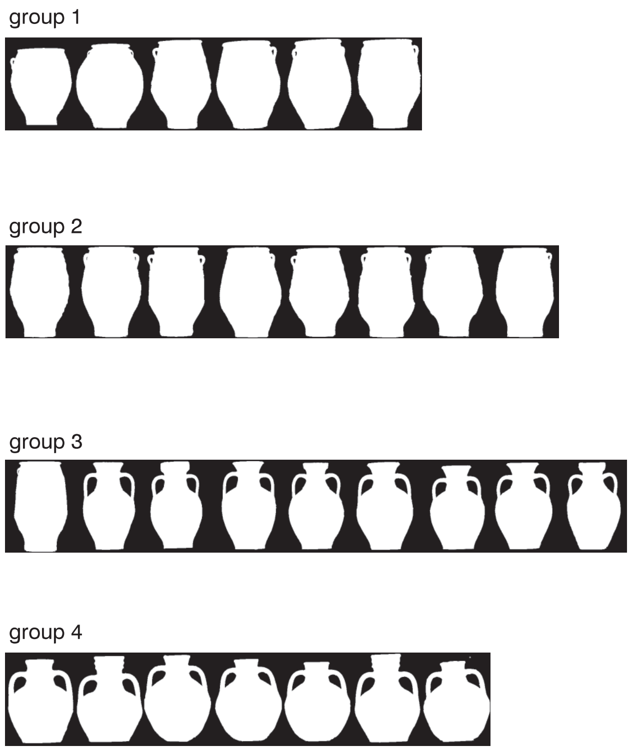

Figure 6. NC moments group assignment.

identification procedure can also be used to classify the objects. To do this the second stage is to use Principal Component analysis and Hierarchical Agglomerative cluster analysis (Shennan 1990: chs 12, 13) to group the objects into clusters based on the shape information. The Principal Components extracted from the shape information variables are used for a Group Average Cluster Analysis. (More details of this procedure can be found in Durham *et al*. 1994). The relationships between the pots are shown in the accompanying dendrograms (figs 3, 5).

The GHT successfully divides the shapes into two groups, which correspond exactly with the pithoi and amphorae (figs 3, 4). The level of resolution of the GHT is demonstrated by the fact that the two shapes on the extreme left of the dendrogram are in the pithoi group, but are markedly separated from the other pithoi. From inspection of the pithoi cluster in figure 4 it can be seen that these two pots on the left are noticeably different from the rest, while still being obviously pithoi.

On the other hand, the shape information from the NC moments does not produce such a clear classification (figs 5, 6). The pots are divided into 4 groups. Two of these correspond to pithoi and two to amphorae. However, one of the amphorae groups (group 3, the third from the left) is classified as being more similar to the pithoi than to the other amphorae. In addition, one of the pithoi has been classified in this group. This is because the set of moments used does not give a sufficiently detailed description of the shape to make the necessary distinction. The moments can only distinguish that group 3 are tall and thin, groups 1 and 2 tall and fat and group 4 are short and fat, but cannot distinguish more subtle differences. The use of more, higher-order moments should alleviate this problem.

5 Conclusions

We have shown that automatic identification and classification of artefact shapes is feasible, if rather slow, using the GHT. Our preliminary results suggest that other methods exist that have a performance approaching that of the GHT, and will be much quicker to use. These results promise to produce a practical tool for automatic classification of artefact shapes in the foreseeable future.

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A new tool for spatial analysis: 'Rings & Sectors plus Density Analysis and Trace lines'

1 Introduction

Intrasite spatial analysis of Stone Age sites has often involved the use of quite complex mathematical or statistical procedures (e.g. Blankholm 1991). The present authors felt that the output of such techniques is often unsatisfactory and difficult to interpret. Therefore, they wished to develop more transparent ways of dealing with horizontal distributions of artefacts. Out of this desire, the computer program 'Rings & Sectors' (R&S) was created; it is designed as a simple tool for intrasite spatial analysis.

R&S comprises four techniques: ring and sector analysis, trace lines, and density analysis. Furthermore, it offers many options for creating distribution maps. The program has been designed in such a way that non-specialists in the computer world can easily work with it without having to go through time-consuming learning processes. This has been achieved by applying two basic principles. The first is that it is a what-you-see-is-what-you-get program; the maps, graphs, etc. on the printer output are exactly as on your screen (except for some minor details). The second principle is that we have tried to keep the screen as clear as possible by removing all superfluous information and by applying a top-down order wherever possible, so that the user automatically encounters all possibilities of the program.

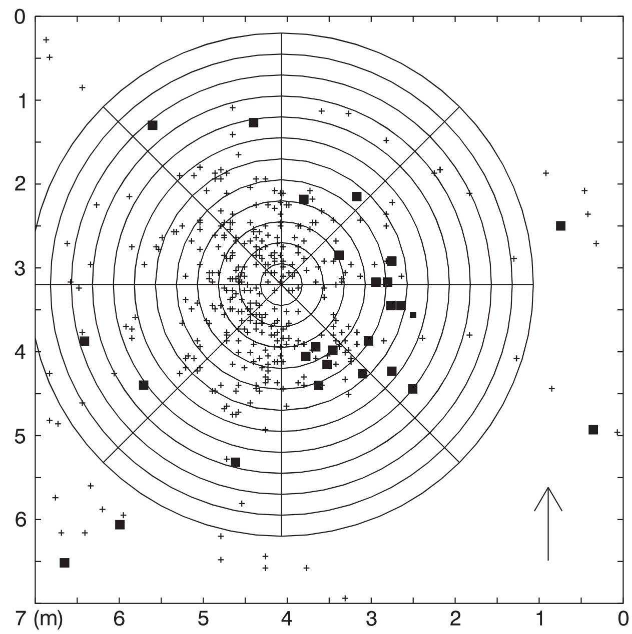

Figure 1. Distribution map of the tools (crosses) and the cores (squares) at the Magdalenian site of Pincevent, unit T112. The core symbols have been filled. A ring and sector system radiates from the centre of the hearth; in this case 8 sectors, and 12 rings of 25 cm width were employed.

2 Ring Analysis and Trace lines

The Ring & Sector Method was especially developed for Stone Age sites with a central hearth, more or less in the middle of an artefact scatter. In principle, however, it can be applied to any site with a suitable central point (Stapert 1992). The idea behind the Ring & Sector Method is that the hearth was a focal point in the daily life of a small group of people. It attracted many activities, and also played an important role in social life. Therefore, using rings and sectors around the hearth centre seems to be a 'natural' way of charting spatial patterns in such situations (fig. 1).

An attractive aspect is that the method is closely related to Binford's 'hearth model', based on ethnoarchaeological research (Binford 1983). Binford described a characteristic pattern of 'drop and toss zones' around outdoor hearths. The drop zone was located in the site-half where the people sat and worked most of the time, windward of the hearth in order to avoid the smoke. It can be shown that in the case of Late Palaeolithic sites with outdoor hearths, the drop zone was generally located in the tool-richest site-half.

In a ring analysis, the frequencies of artefacts are counted per distance class. One of the most important applications of the Ring & Sector Method relates to the question whether a hearth was located inside a dwelling or in the open. The ring distributions of tools from the analysed sites are found to be of two different types: unimodal and multimodal. Unimodal ring distributions point to hearths in the open (fig. 2). Artefacts that were tossed away were not stopped by tent or hut walls, with the result that ring frequencies gradually decrease away from the hearth.

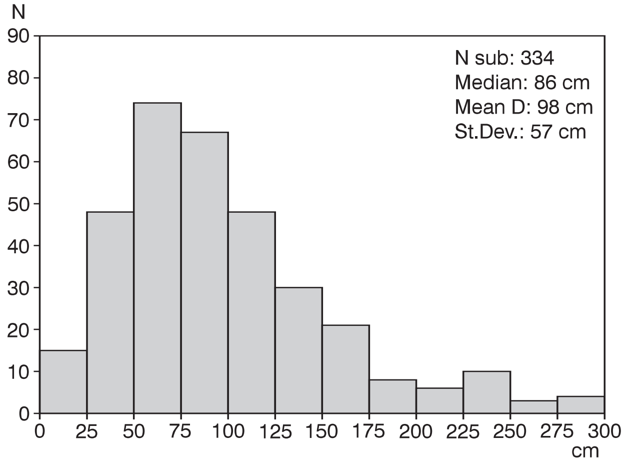

Figure 2. Ring diagram of the tools at Pincevent. The ring width can be changed to any size, so that the best resolution for any site can be found. Here rings of 25 cm have been used. The result is a unimodal graph which points to a hearth in the open air.

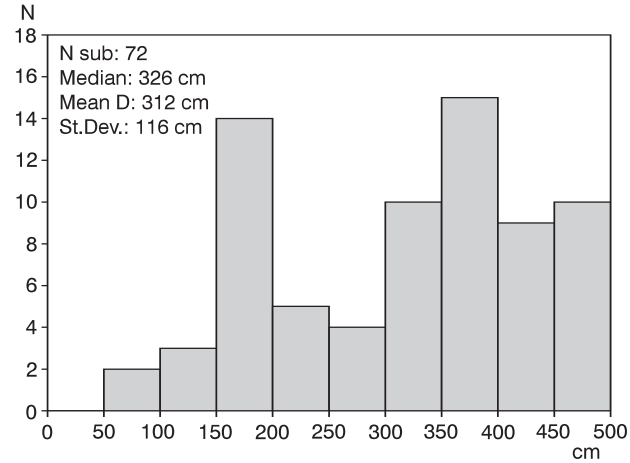

Figure 3. Ring diagram of the backed bladelets in the NW quarter of the Magdalenian site Gönnersdorf II. Bimodal or multimodal ring distributions indicate a hearth inside a dwelling. The first peak is the drop zone, where the people were sitting and working; the second peak is caused by the barrier effect of the tent wall. By executing a ring analysis for a series of sectors, a reliable reconstruction of the tent wall can be obtained (see also Boekschoten/Stapert 1993: fig. 10).

Multimodal ring diagrams are thought to be typical for artefact distributions created inside dwellings. Figure 3 shows the ring diagram for the backed bladelets in the NW quarter, up to 5 metres from the hearth centre, at the Magdalenian site of Gönnersdorf Concentration II. The first peak represents the drop zone near the hearth. The second peak is caused by the barrier effect of the tent wall. We concluded from a series of diagrams such as this that the tent had a diameter of about 7 metres (Boekschoten/Stapert 1993: fig. 10).

When a ring analysis is done for all 4 quarters, or even for 8 sectors, it will be possible to produce a reliable reconstruction of the tent wall. It should be noted that if a tent was not exactly circular, or when the hearth was located eccentrically, a ring analysis for all sectors taken together may produce an unintelligible diagram.

One of the advantages of the computer program Rings & Sectors is that one can establish the optimum level of resolution, by exploring the whole scale of measurements: from fine- to coarse-grained. In this way the best parameters for any site may be found. Our experience is that one should preferably choose a ring width between 20 and 50 cm, depending on the number of artefacts. Too narrow a ring will lead to fragmentation of the curve and obscure its character; too wide a ring may give a meaningless or even misleading picture.

An alternative way of analysing distance data is the trace line. The artefacts are ranked according to their distance from the hearth centre; in the bottom left corner the artefact closest to the hearth is plotted; in the top right corner the farthest one. This results in characteristic S-shaped curves for artefact scatters around fireplaces

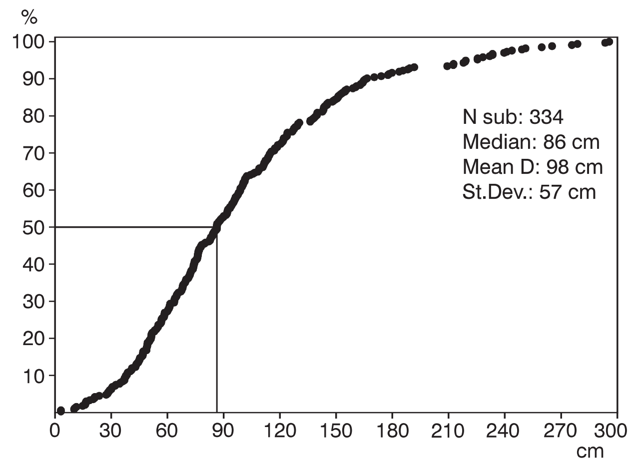

Figure 4. Trace line of the tools at Pincevent. The trace line is an alternative way of displaying distance data; the artefacts are ranked according to distance from the hearth. Characteristic S-shaped curves result for hearths in the open air. The advantage of trace lines over ring diagrams is that no class division is needed; they are therefore more precise. The median is indicated in the diagram.

in the open (fig. 4). The steep part of the S-curve coincides with the only peak in the corresponding unimodal ring diagram: the drop zone. At tent sites, 2 or 3 S-shaped curve-parts will follow each other in the trace line (fig. 5). The first 'S' reflects the drop zone. The second one is caused by the tent wall which will have been located just after the end of the steep part. The third S-shaped

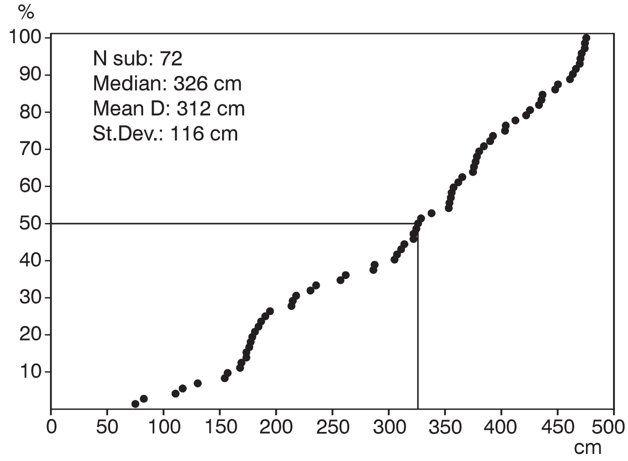

Figure 5. Trace line of the backed bladelets in the NW quarter of Gönnersdorf II. At tent sites, three S-shaped curve-parts follow each other. The first steep part, between 150 and 200 cm, represents the drop zone; the second, between 300 and 400 cm, is caused by the barrier effect of the tent wall; the third, between 450 and 500 cm, may indicate a door dump.

curve-part, if present, represents the door dump, outside the tent entrance. The advantage of trace lines over ring diagrams is that no class division is needed. It is therefore a more precise method for establishing the position of the tent wall.

3 Sector Analysis

Once it has been established whether the hearth was in the open or in a tent, a new series of questions may be approached. Figure 6 immediately makes it clear that in Pincevent (T112) the western site-half contains most of the tools. As stated above, in the case of outdoor hearths the tool-richest half is the half where people were sitting and working most of the time. We can therefore now reconstruct the prevailing wind direction during occupation: from the west. We call a diagram such as figure 6 a sector graph, which in fact is a combination of a bar graph and a pie chart. The centre of the circle represents the hearth, around which, in this case, 16 sectors are positioned. The frequencies of the artefacts are counted for each sector. The centre has the value zero; the circle represents the mean number per sector. Sectors with a frequency higher than average are given a black bar protruding outwards. Sectors below the mean have a bar protruding inwards. In this way a powerful visual presentation of the data is achieved.

One may wish to perform an analysis of the richest half only. The program is then able to calculate the position of this richest half. It will count the tools in 72 sectors of 5 degrees, and establish the richest site-half.

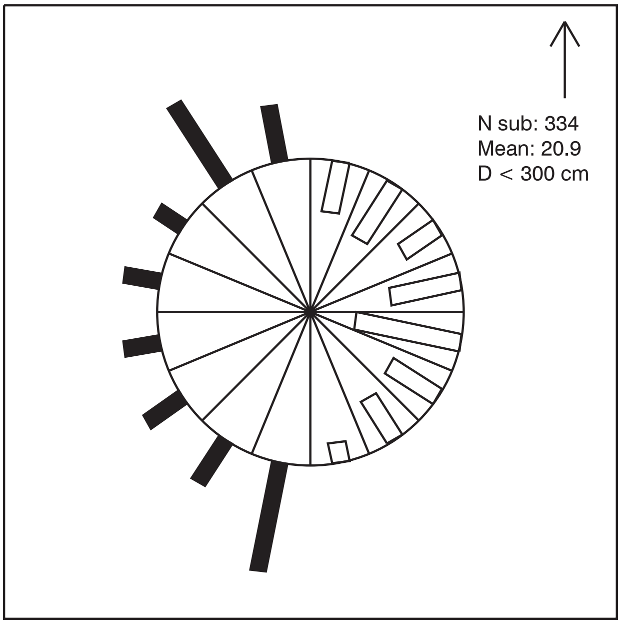

Figure 6. Sector graph of the tools at Pincevent. The centre of the circle represents the centre of the hearth. Sectors with frequencies higher than the average get black bars protruding outwards; sectors with frequencies lower than the average get a white bar protruding inwards. The circle represents the mean. It is immediately clear that in Pincevent the western half is the richest site-half.

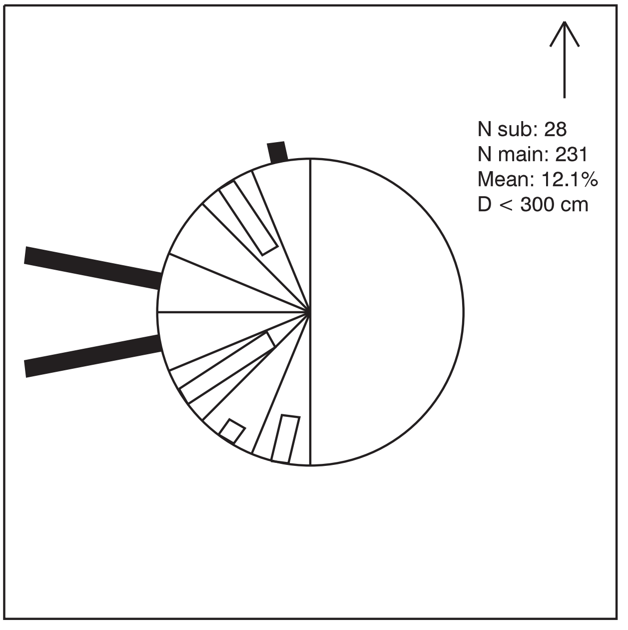

Figure 7. Pincevent, comparative sector graph of the scrapers, shown here as a percentage of the tools. The “mean” is the percentage of the scrapers in the richest site-half only.

The program Rings & Sectors offers the possibility of selecting two groups of artefacts for analysis; a 'main-selection' and a 'sub-selection'. The actual analysis is carried out on the sub-selection, which preferably should be part of the main-selection. One can compare the two sets of data, both in ring and sector analysis, and in density analysis. The frequencies of the sub-selection are then presented as percentages of the frequencies of the main-selection. This 'comparative option' may be very useful in bringing out locally occurring high proportions of, for example, tool types. Figure 7 shows the tool-richest half at Pincevent T112 (calculated by the program), with the scrapers presented as a percentage of all tools per sector. It is immediately clear that there are proportionally many scrapers in the two sectors in the middle, while they are underrepresented in most of the remaining sectors. In this case, the circle indicates the percentage of scrapers in the richest site-half (called 'mean' in the diagram).

For sector analysis, several optimizing techniques have been included in the program. Apart from the possibility to calculate the richest site-half (see fig. 7), the program also offers options to calculate the 'richest sector' and the 'highest contrast', by rotating the sectors. These calculations can be done both 'absolutely', on the basis of the sub-selection only, and 'comparatively', in which case the sub-selection is presented as a percentage of the main-selection.

With a given number of sectors, the richest sector option seeks the sector system in which (at least) one sector has the highest possible frequency (or percentage). The option 'highest contrast, absolute' seeks the sector system that maximizes the sum of the squared numbers of artefacts in the sectors: $\sum(n^2)$. The 'comparative' option maximizes the sum of the differences between the observed percentage and the overall percentage in all sectors (fig. 8).

4 Density Analysis

Density analysis is a generally applicable technique not requiring a central hearth. Over the excavated terrain a system of square cells is positioned, which can be of any size. Grids with cells of 50 × 50 or 100 × 100 cm are most common as such cells often form the basic excavation units. Inside these cells black circles are placed, the size of which reflects the relative frequency of artefacts in the cells. Figure 9 shows a density map of the tools at Pincevent (T112); a grid size of 50 cm was used.

Just as in the case of the Ring & Sector Method, the program offers the possibility to establish the optimal resolution for density analysis. In figure 10 the same data have been used as in figure 9, but here the density map is based on a grid size of 25 cm. This clearly gives much more detail.

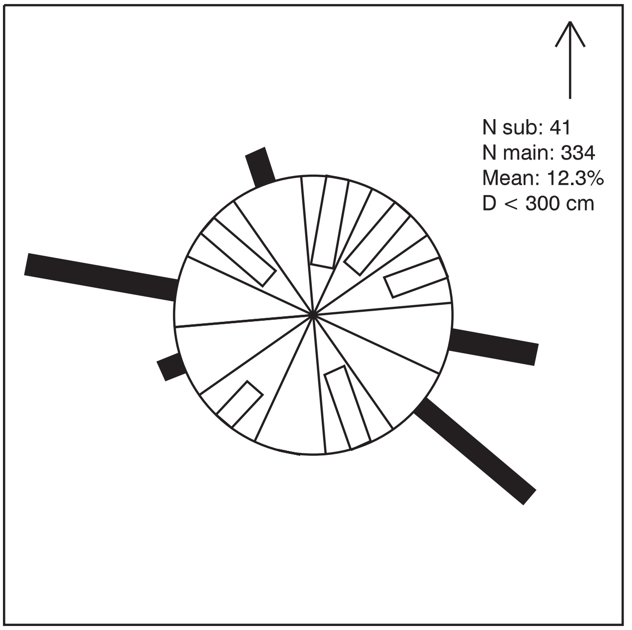

Figure 8. Pincevent, sector graph of the scrapers as a percentage of all tools. The graph has been optimized by rotating the sector system, so that the highest possible contrast is obtained.

The program includes several options for the parameters of density maps, in order to make these maps more analytical. It is possible, for example, to use three different systems of class division (Cziesla 1990):

1. the linear class division, which simply divides the highest cell frequency by the number of classes (fig. 10);
2. the peripheral class division, which emphasizes the lower frequencies; class intervals grow according to a square power function (fig. 11);
3. the central class division, which emphasizes the higher frequencies; class intervals decrease according to a square root function (fig. 12). All detail is lost in the latter case, but it may be useful for stressing certain activity areas characterised by high local densities, such as flint-knapping locations or dumps.

Cziesla (1990) advocates the linear option for class division. The visual effect of density maps, however, depends on the surface areas of the circles and not on their radius. Therefore, the surface areas of the circles in the peripheral option are in fact linearly proportional to the cell values (or to be more precise: to the maximum values of each class). Consequently, the linear option results in a 'central' display of the data (and the central option is in fact super-central; see Stapert/Boekschoten in press).

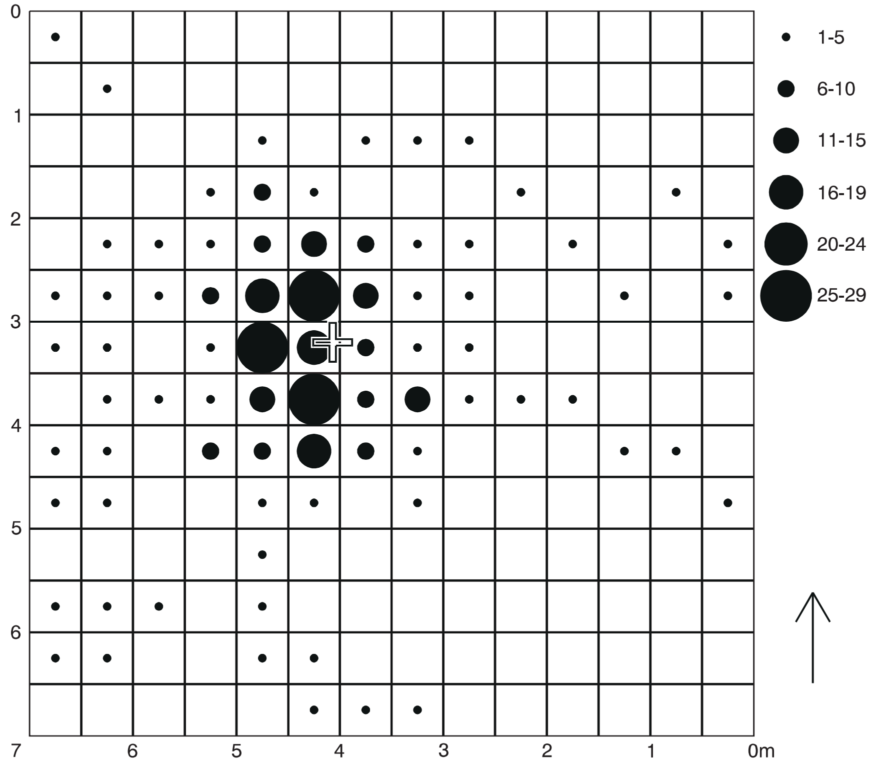

Figure 9. Pincevent, density map of the tools. The cross indicates the centre of the hearth. A grid size of 50 cm was used. Note that with a linear class division, a maximum cell value of 29, and 6 classes, there will be always one class with an interval of only 4, instead of 5.

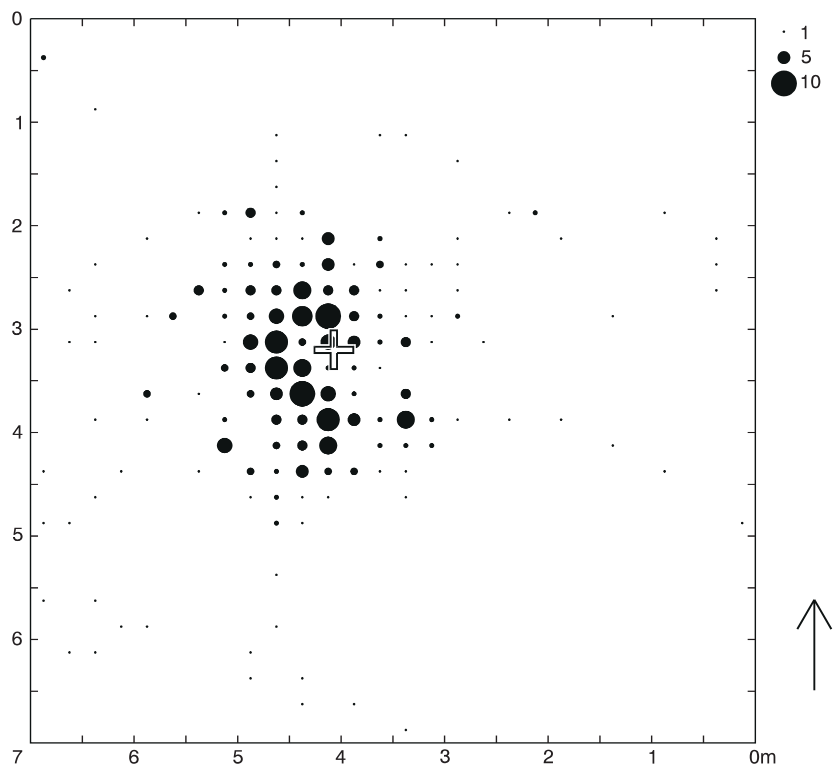

Figure 10. Pincevent, density map of the tools, based on a grid size of 25 cm. The program Rings & Sectors allows the use of any grid size for density maps, so that the optimum level of resolution may be established. Note that the grid lines were omitted in this picture. No classes were used in this case. Linear.

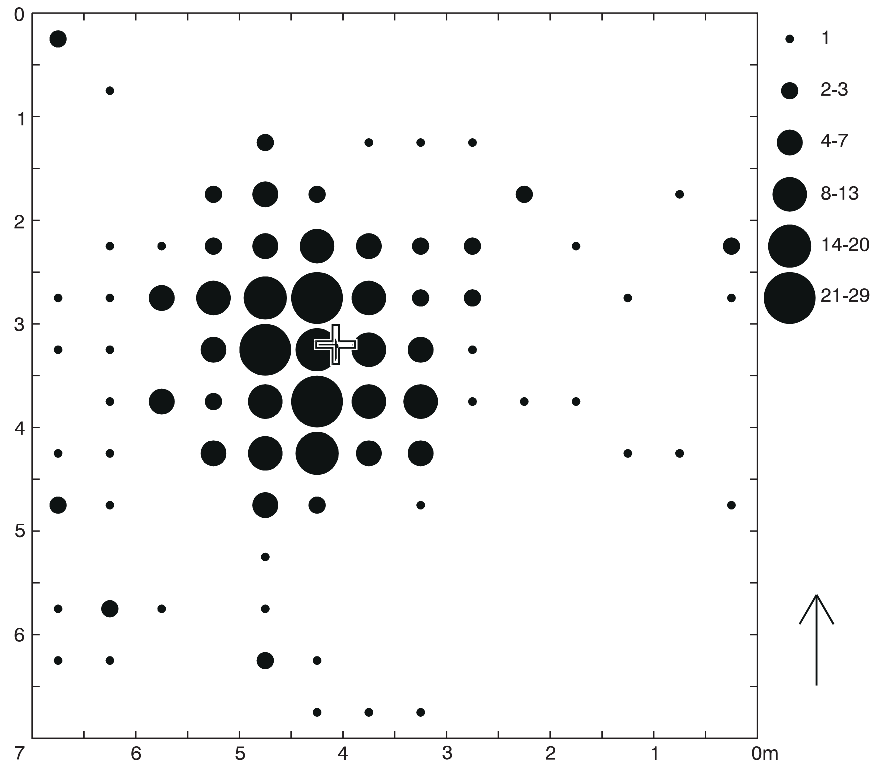

Figure 11. Pincevent, density map of the tools, based on a grid size of 50 cm. In this case a peripheral class division is used, resulting in relatively many classes for the lower frequencies and relatively few for the higher frequencies; this makes the map relatively “black”.

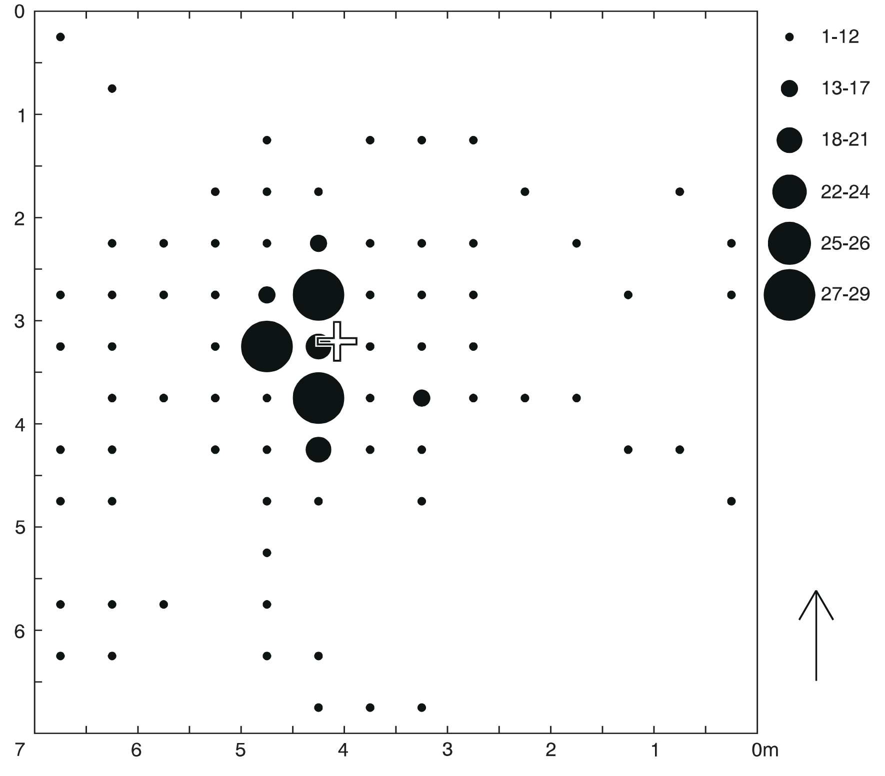

Figure 12. Pincevent, density map of the tools. In this case the size of the circles is defined by the central class division which emphasizes the higher frequencies.

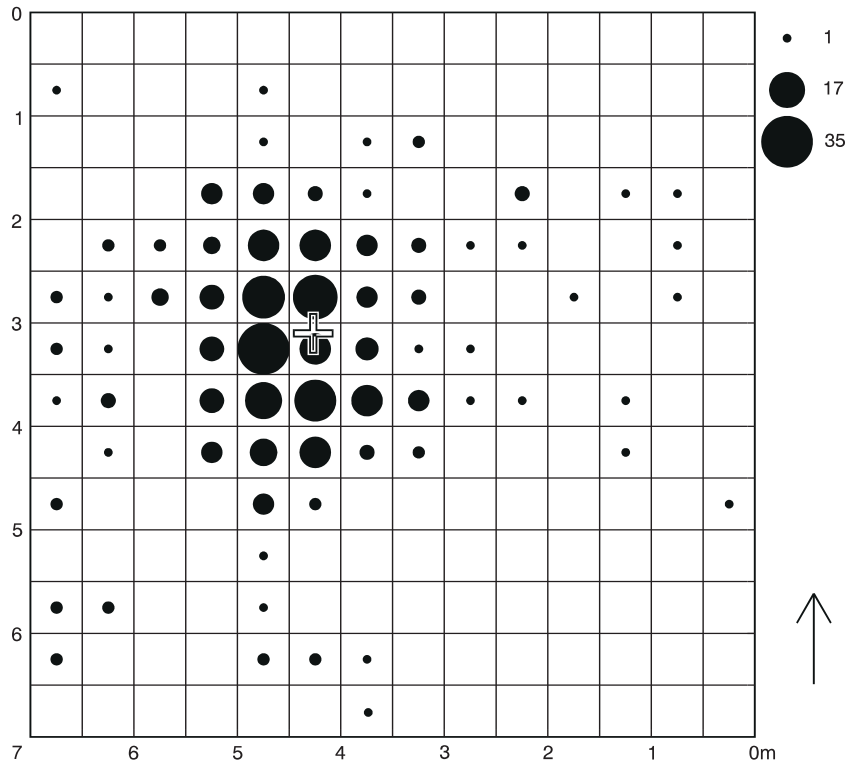

Figure 13. Pincevent, density map of the tools. In this picture, the richest cell option was used. The richest cell now contains 35 artefacts instead of 29 as in the standard position (see fig. 9). In this case no classes were used. To the right the minimum, median, and maximum cell values are shown. Peripheral.

In the computer package Rings & Sectors one can choose from 0 to 10 classes. In case one or more classes are used, the radius of the circles changes in a linear way, but the class intervals (contents) may vary, depending on how the class boundaries are calculated (linearly, peripherally or centrally). If, however, one chooses to use no classes, the diameters of the circles are calculated as a proportion of the highest cell value, for each frequency. Again, one can choose between the linear, peripheral and central options; in the latter cases the diameters of the circles are transformed by square root or square power functions, respectively. Figures 10, 13 and 14 are density maps without a class division.

In our opinion, the peripheral option without class division results in the clearest, and — more importantly — the most 'honest' pictures.

As in the case of sector analysis, the program offers several options for optimizing density maps. It is possible to move the grid freely over the excavated area; this of course only makes sense when artefact locations were measured individually. The most straightforward optimizing technique included in the program is the richest cell option: the grid is moved by the program so that the richest possible cell is found. This can be done either with absolute frequencies of the sub-selection, or comparatively (the sub-selection expressed as a percentage of the main-selection: see below). Figure 13 presents the same data as in figure 11, but using the richest cell option (absolutely). The richest cell now contains 35 artefacts, instead of 29 as in the standard grid position; an increase of 21 %. This procedure results in 'standardizing' a density map, so that different sites can be compared in a more meaningful way. One could also say that in this way a density map is 'focused', so that the sharpest picture is obtained (in fig. 13, there is only one cell in the highest class, in figure 11 there are three). When using the 'highest contrast option', the program calculates the grid system for which the sum of squared cell frequencies is maximized.

The program offers several alternative ways to calculate class divisions. For example, one can suppress extreme values, as advocated by Cziesla (1990), or one can manually define class intervals in whichever way one desires.

A special utility is the frequency map (fig. 14), which is a numerical representation of the density map.

5 Proportion maps

One may wish to know not only the frequency distribution of the artefacts (of a specific group) over the cells, but also their proportion, relative to a greater population (for example, the percentage of scrapers, relative to the

N sub 357

2													
	1												
				2		1	1	1					
			3	6	2				3			1	
	1	1	2	7	13	6	2	2		1			2
1	1	4	8	17	29	11	3	3			1		1
1	1		4	28	18	10	5	1					
	1	4	3	12	29	9	13	1	1	1			
1	1		7	8	19	6	5				1	1	
2	1			5	3		1						1
				1									
1	2	1		1									
1	1			2	1								
					1	1	1						

Figure 14. Pincevent, frequency map of the tools. The actual cell values which form the basis of density maps are shown.

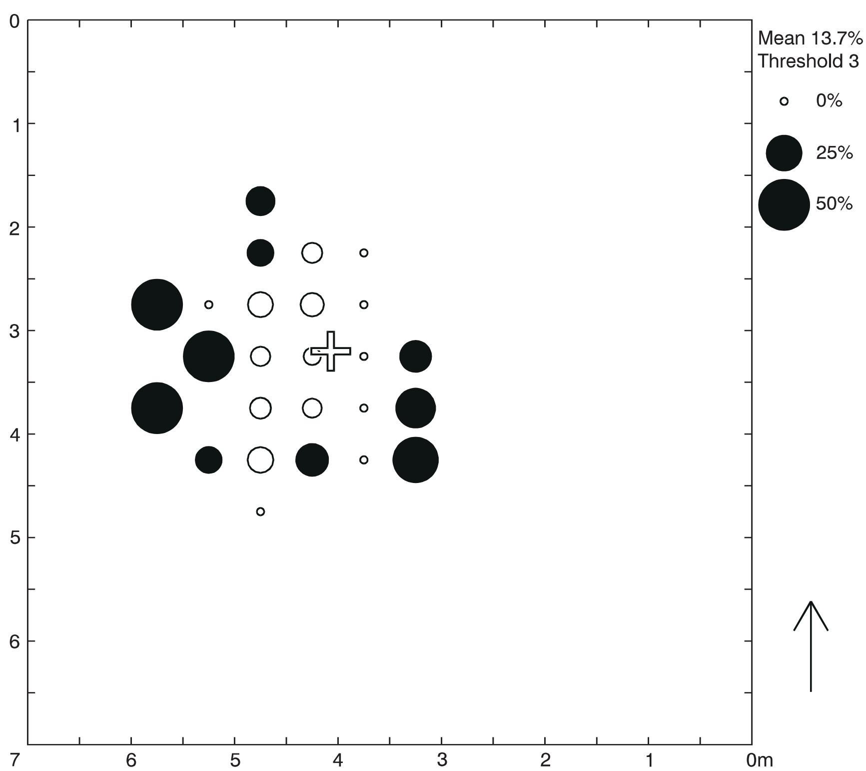

Figure 15. Pincevent, proportion map of the scrapers shown as a percentage of the tools. Black circles represent cells in which the percentage is higher than that over the whole site; open circles represent cells with a percentage lower than average. This map makes it clear that the scrapers occur particularly at some distance away from the hearth. In this case a threshold value of 3 was chosen; this means that only cells with 4 or more tools (in the main-selection) are shown. Again, the peripheral option without classes was used.

total number of tools). As noted before, the program allows 2 selections. These selections can be compared to each other in a so-called proportion map (fig. 15). In such maps, cells with black circles have a percentage that is higher than the proportion over the whole site. Open circles indicate cells containing less than the overall percentage (indicated to the right of the map: 'mean'). In this way, areas with higher or lower percentages than average are immediately visible.

A problem of proportion maps is that cells with low frequencies easily dominate the whole picture; all cells with only 1 artefact will result in either 0 or 100 percent. To avoid this problem, the program allows you to give a threshold value. Cells with a number of artefacts (in the 'main-selection') equal to or lower than this threshold value are not shown on the map. As can be seen in figure 15, only cells close to the hearth pass the threshold (and contain at least 4 tools).

The program is able to optimize proportion maps by moving the grid. For example, it can find the grid position with the highest possible proportion in one (or more) cells. It is also possible to calculate the grid in which the sum of the difference between the percentage over the whole site and the observed percentage in all cells is maximized. The result will be that cells with a low percentage of an artefact type and cells with a high percentage contribute more to the position of the grid than cells with a value around the mean.

6 Cartography

Cartography is, of course, the most basic tool for the analysis of any spatial distribution. The program always starts with a distribution map as a basis for all subsequent analyses, so that one remains aware of the raw data that are being analysed.

There are several options for producing distribution maps. Three selections can be made:

a. The sub-selection, to which only one symbol (out of 19) can be attached; in this way any group of artefact types can be given the same symbol.
b. The main-selection; here one can assign symbols within a record field (artefact type, burnt/unburnt, broken/unbroken, etc.). Every category of artefacts within any field may have its own symbol. One can easily switch between several fields.
c. The fill selection, in which artefact types can be selected that must have filled symbols in the map. For example, all tools may be selected in the main-selection, with a different symbol for each tool type; in the fill selection one can then choose those artefacts that are burnt. Many other combinations are possible, so that clear and analytical maps of different types can be produced.

7 Summary

The program Rings & Sectors supports four techniques for spatial analysis that are considered by the authors to be transparent: ring and sector analysis, trace lines, and density analysis. Furthermore, it offers many options for creating distribution maps. The program makes it possible to explore the whole scale of measurements from coarse- to fine-grained. In this way the optimal level of resolution for any site can be established, a prerequisite for meaningful quantitative approaches.

All results, whether maps, tables or diagrams, can be printed out on laser printers.

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Susan Holstrom Loving

Estimating the age of stone artifacts using probabilities

1 Introduction

This article describes an application of the Bayesian approach to estimate the age of lithic artifacts collected by surface surveys in West Central Italy (fig. 1). Although the application refers to very specific circumstances and cannot be directly transferred to a different situation or region, the general procedure may be useful as a way to systematically pull together disparate information to assign materials to classes.

2 The archaeological problem

The problem was to estimate the age of lithic artifacts collected on the surface of older land formations during archaeological surveys of the Agro Pontino (Voorrips *et al*. 1991), the Fondi Basin (Bietti *et al*. 1988), and the area around Cisterna (Attema 1993) in West Central Italy (fig. 2). Physical geographers from the University of Amsterdam, who mapped the soils in the area, established the relative ages and surface stability of various formations (Sevink *et al*. 1982: 1984). Subsequent research provided absolute dates for some of the older formations with stable surfaces (Hearty/Dai Pra 1986; De Wit *et al*. 1987), which is where Palaeolithic materials could be found coming up in the plough zone. On these stable surfaces one would not expect to find sites for excavation, but instead recover a portion of a fossil archaeological landscape in the form of a palimpsest of artifacts discarded over thousands and thousands of years.

Some of the stone artifacts collected could be assigned to tool types that are considered chronologically diagnostic in the region. These artifacts were used to date sets of aggregated fields, termed sites, in a very general way, i.e., Middle Palaeolithic, Early Upper Palaeolithic etc. This is a standard procedure for dealing with lithic scatters, at least in America (e.g. Bamforth 1986) and Northern Europe (e.g. Arts 1989). Information published about the coastal area north of the Agro Pontino, where surfaces are also rather stable, led us to believe that we, too, could identify changes in site distribution over time in this way. In working with the materials, however, it became apparent that this would not be possible.

As part of the survey project and fulfilment of requirements for his doctorate, Kamermans (1993) conducted a land evaluation study of the region using artifacts collected by the Agro Pontino survey. Basing himself on presence/absence of periods represented at sites, determined by the presence of chronologically diagnostic tools and cores in the region, as stated above, he found that all the apparent differences in land use throughout the Palaeolithic could be explained by intervening geological processes. Thus, he concluded that the region was regarded as a single unit, at least for resource exploitation, throughout the Palaeolithic.

Figure 1. Location of study area.

In the course of my investigation of the Agro Pontino materials, I found that there seemed to be so many sites with more than one chronological component that it would be unlikely that we should discover any spatio-temporal differences using presence/absence of components at sites.

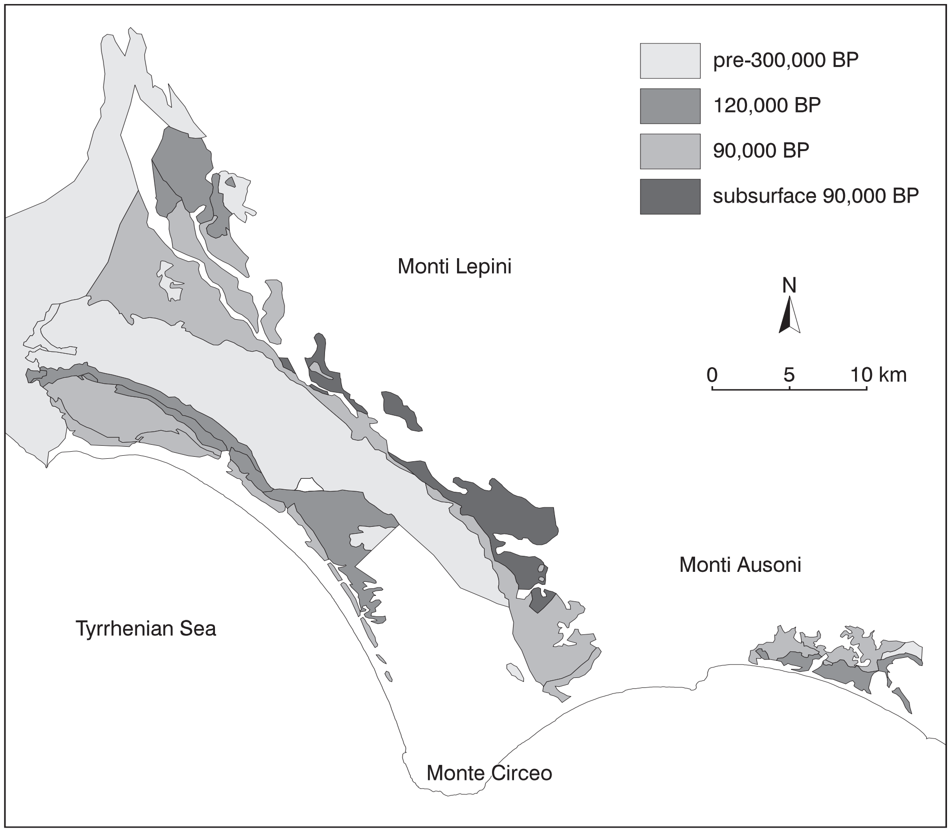

Figure 2. Distribution of older formations in the study area.

This aspect of the archaeological record of the Agro Pontino is brought into relief by comparing it with a more extensive sample along the Tyrrhenian coast. Mussi and Zampetti (1984-1987), two Italian researchers, had compiled the association of three Palaeolithic cultures — Mousterian, Aurignacian, and Epigravettian — represented in 49 sites along the coast from the Tevere to the Monte Circeo, including several on the Agro Pontino.

A set of chi-square tests on the co-occurrence or lack of it between these cultures shows that associations are due to chance (fig. 3), whereas the associations between the three cultures in sites on the Agro Pontino are all more than expected and the probability that this is due to chance is less than .05 in each case. Thus, the archaeology of the Agro Pontino appears to be quite different from the coastal area in general.

This situation meant that the evidence for differential use of the landscape within a cultural period and any changes through time would require an estimate of age at the level of the individual artifact rather than at the level of the site or location. To my knowledge, this had never been done with surface artifacts.

3 Expertise for estimating the age of artifacts

A recent article by Buck and Litton (1991) not only encouraged archaeologists to use Bayesian approaches, but provided a clear description about how to do so. Their idea that prior probabilities and additional data collected were forms of expertise was absolutely crucial. Bayes's theorem provides a way to pull together various kinds of expertise.

We did have or could collect various types of information, or forms of expertise, that might contribute to estimating artifact age.

3.1 Age of land surfaces and archaeological cultures in the region

The first type of information was the age of land surfaces in the area (fig. 2). Absolute dates for the latest tuff deposits are .338 Myr BP, stage 9-10 (?) (Fornaseri 1985) and for the Latina level are .54 Myr BP, stage 15 (De Wit *et al.* 1987). Minturno level deposits, including the beach ridge and associated aeolian sands, the coastal and inland lagoons, and the travertines, were dated to the last interglacial, *c.* .12 Myr BP, stage 5e, and Borgo Ermada level deposits, the beach ridge and coastal and inland lagoons,

Table 1. Approximate ages of geological formations on the Agro Pontino and archaeological cultures in West Central Italy.

Years BP	Formation	Archaeological culture
9,000		*Mesolithico*
12,000	Late Glacial aeolian sands	- - - - - - - - - - -
		Epigravettiano
20,000		- - - - - - - - - - -
		Gravettiano *Aurignaziano* *Uluzziano*
35,000		- - - - - - - - - - -
90,000	Borgo Ermada level	*Pontiniano*
120,000	Minturno level	- - - - - - - - - - -
		Musteriano *Acheuleano*
350,000	Colli Albani tuff	
550,000	Latina level	

were dated to about .09 Myr BP, stage 5b (Hearty/Dai Pra 1986).

Table 1 shows the temporal juxtaposition between the archaeological cultures and the age of land surfaces. Given the approximate ages of archaeological cultures, the Lower Palaeolithic *Acheuleano* and Middle Pleistocene Middle Palaeolithic *Musteriano* and *Pontiniano*, would be restricted to the tuff and Latina levels.

3.2 Typology and technology of lithic artifacts recovered from excavations

The second source of information was the artifacts recovered from major excavations in the area reported in the literature (table 2). Altogether, the information conveyed by the excavators constitutes a kind of collective expertise for the area. The completeness and detail of the reports, however, vary considerably, and, of course, the typologies used to describe the materials also vary according to whether the assemblages are Lower or Middle Palaeolithic or Upper Palaeolithic. In the more complete reports diverse kinds of information are offered. In addition to counts of typed tools are counts of different types of cores, counts of different types of debitage (flakes, blades, bladelets, burin spalls, etc.), counts or indices of Levallois flakes, and in some cases, counts of Pontinian scrapers (Middle Palaeolithic side scrapers with Quina retouch), which is a kind of 'stylistic' category.

As an archaeologist wanting to tap this expertise for my particular problem, I asked, 'given the contents of excavated sites, what is the probability that a particular

Open air and cave sites along the Tyrrhenian coast, West Central Italy (N = 49)

Musteriano	*Aurignaziano* present	*Aurignaziano* absent
present	17 (17.6)	4 (3.4)
absent	24 (23.4)	4 (4.6)

Chi-square = 0.19, df = 1
Approximate $p = .65$

Epigravettiano	*Aurignaziano* present	*Aurignaziano* absent
present	13 (10.7)	12 (14.3)
absent	8 (10.3)	16 (13.7)

Chi-square = 1.76, df = 1
$p = .18$

Surface scatters on older formations in the Agro Pontino and Fondi Basin (N = 208)

Musteriano	*Aurignaziano* present	*Aurignaziano* absent
present	68 (52.6)	82 (97.4)
absent	5 (20.4)	53 (37.6)

Chi-square = 24.7, df = 1
$p < .05$

Epigravettiano	*Aurignaziano* present	*Aurignaziano* absent
present	59 (41.8)	60 (77.2)
absent	14 (31.2)	75 (57.8)

Chi-square = 25.61, df = 1
$p < .05$

Figure 3. Comparison between sample on the coast of West Central Italy as compiled by Mussi and Zampetti (1984-1987) and sample from surfaces of older formations on the Agro Pontino and Fondi Basin.

artifact collected on the surface of the Agro Pontino comes from each of the 7 archaeological cultures?'.

The first step in the application was to construct probabilities for tool and core types etc., from the excavation reports available. This was done in three steps:

1. The Middle and Upper Palaeolithic type lists (Bietti 1976-1977; Bordes 1961) were combined to create a single type list that could incorporate the more common types. The artifact illustrated in figure 4 will be used as an example. It is typologically and technologically an end scraper on a flake. All Middle Palaeolithic end scrapers, Bordes types 30 and 31, most of which are made on flakes, were put into the same category as Upper Palaeolithic end scrapers on flakes, Bietti type 3.
2. Then, for each archaeological culture, counts of tool types were summed across the sample for that culture and percentages calculated.
3. Then, two probability tables were constructed, which were made conditional on the age of the land surface (table 3). The first table, to be used for artifacts found on tuff soils and the Latina level, was made by summing the percentages for each type across all seven

Table 2. Archaeological cultures represented in excavated sites in West Central Italy (compiled from: Bietti 1976-1977, 1984a, 1984b; Kuhn 1990; Piperno/Biddittu 1978; Segre-Naldini 1984; Taschini 1967, 1979; Tozzi 1970; Vitagliano/Piperno 1990-1991; Zampetti/Mussi 1988).

Archaeological culture	Site	Absolute dating, BP
Mesolithico	Riparo Blanc	8,565 ± 80
Epigravettiano	Peschio Ranano	9,730 ± 150
Epigravettiano	Riparo Salvini	12,400 ± 170
	Palidoro	15,900 ± 150
Aurignaziano	Grotta Barbara	
	Fosselone, level 21	
Pontiniano	Grotta Breuil	36.6 ± 2.7 (Kyr)
Must. denticulato	Fosselone, level 27	
Pontiniano	Grotta di San Agostino (levels 1 to 3)	54 ± 11 to 43 ± 9 (Kyr)
Pontiniano	Grotta Guattari (levels 1-5)	77.5 ± 9.5 to 54.2 ± 4.1 (Kyr)
Pontiniano	Grotta della Cava	
Pontiniano	Grotta dei Moscerini (levels 39-25)	96 ± 1 to 79 (Kyr)
Pontiniano	Monte delle Gioie	
Pontiniano	Sedia del Diavola	
Musteriano	Torre-in-Pietra, level d	
Acheuleano	Torre-in-Pietra, level m	

Table 3. Prior probabilities that an end scraper on flake is associated with different archaeological cultures (based on 103 end scrapers on flakes reported in the literature).

Archaeological culture	If found on Latina level or tuff:	If found on Minturno or Borgo Ermada level:
Acheuleano	.11	-
Middle Pleistocene *Musteriano, Pontiniano*	.04	-
early Upper Pleistocene *Pontiniano*	.03	.04
middle Upper Pleistocene *Pontiniano*	.08	.09
Aurignaziano	.30	.35
Epigravettiano	.03	.04
Mesolithico	.41	.48

archaeological cultures and dividing each percentage by the sum to give the probabilities. The second table, to be used for artifacts found on the surfaces of other formations was constructed the same way, but only five of the archaeological cultures were used.

With this information, prior probabilities were assigned to all survey artifacts that could be put in one of the listed classes conditional upon the age of the land surface where they were found. The end scraper in figure 4 was found on soils in travertines, which developed during the Last

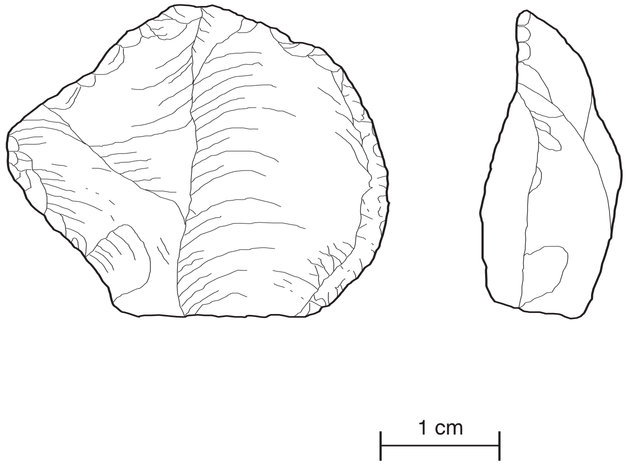

Figure 4. An end scraper on flake collected on travertine soils in the Agro Pontino.

Interglacial, in the same period as the Minturno level, *c*. 120,000 BP. Thus, the prior probabilities for it are found in the second probability table in table 3.

3.3 Technological attributes of lithic artifacts

The third source of potential information was technological change in lithic manufacture. Lithic specialists (e.g. Cotterell/Kamminga 1987; Crabtree 1972b; Faulkner 1973; Parry 1987) have shown that changes in such things as core platform preparation, flake profiles, flaking angles, types of fracture etc., can reflect changing techniques and tools used for lithic manufacture, which would certainly have occurred over the long period of time represented in this region. There was also reason to suspect that approaches to flaking the local raw materials changed during the Middle Palaeolithic in this region (Kuhn 1990, 1990-1991).

After selecting variables potentially relevant in a technological sense from publications by lithics specialists, I collected the data from about 900 flakes and 400 cores from four excavated collections housed in Rome. These collections were Grotta Guattari, dated from about .78 through .50 Kyr BP, level 3 of Grotta Breuil, dated to about .36 Kyr BP (both in Schwarcz *et al*. 1990-1991), part of the Aurignacian in Riparo Salvini and part of level 21 Grotta dei Fossellone (Blanc/Segre 1953; not dated radiometrically) and the *in situ* portions of Riparo Salvini (collected by A. Bietti; not dated radiometrically), dated to about 12,400 BP (Avellino *et al*. 1989). Probability tables were constructed using the chronologically significant technological variables or combinations of them that emerged from the analysis of the collections. The probabilities were derived directly from the data itself or from models that fit the data.

Unfortunately, it was not possible to study samples from all seven archaeological cultures, and it was necessary to collapse categories to middle Middle Palaeolithic and earlier, late Middle Palaeolithic, Early Upper Palaeolithic, and Late Upper Palaeolithic and later (table 4). The probabilities for tool and core types were recalculated to fit these four temporal categories. If samples from the other cultures — i.e. Lower Palaeolithic, Middle Pleistocene Middle Palaeolithic, and Mesolithic — are analysed technologically, then this will no longer be necessary.

The next step in the application was to calculate posterior probabilities for all items that had acquired a prior probability in the first step and that could be coded for the relevant technological variables listed in the technological probability tables. In doing so, it was assumed that these two sets of probabilities were independent of each other. This was necessary because I had no information about the relationship between tool types and the technological variables.

The end scraper on a flake found on soils developed in Last Interglacial travertines (fig. 4) has adjusted prior probabilities for four archaeological temporal categories as shown in table 5. Technologically, this artifact is a conchoidal tertiary flake with a smooth prepared platform, with dorsal flaking oblique to the direction from which the flake was struck, and with no ventral features, i.e. an eraillure scar or fissures, and no signs of abrasion adjacent to the butt on the dorsal side. The probabilities for a flake with these characteristics occurring per temporal category provide additional information. The posterior probabilities are calculated using Bayes's Theorem. So, the end scraper, which has prior probabilities in favour of Late Upper Palaeolithic or later changes to probabilities in favor of Early Upper Palaeolithic.

All other artifacts with technological attributes that were chronologically significant according to the analysis of excavated materials and had no prior probabilities were assigned prior probabilities on the basis of these attributes or combinations of them.

3.4 Patina of flint artifacts dependent on age, flint texture, and soil parent materials

The fourth and last source of information about age of surface artifacts in the Agro Pontino region was degree of patination. That the glossy patina on many of the artifacts collected by the Agro Pontino survey might be related to age of artifacts was suggested by Dick Stapert of the University of Groningen when he first saw them. So that this might be investigated, all artifacts were coded by comparing them with four items showing different categories of glossy patina — none, slight, medium, and heavy. Theoretically, glossy patination develops as

Table 4. Probabilities that an end scraper on flake comes from four temporal categories.

Archaeological culture	Original probability	Temporal category	Adjusted probability
if found on Latina level or tuff:			
Acheuleano	.11	middle Middle Palaeolithic or earlier	
Middle Pleistocene	.04		
Must. & Pont.			.18
early Upper Pleistocene	.03		
Pontiniano			
middle Upper Pleistocene *Pontiniano*	.08	late Middle Palaeolithic	.08
Aurignaziano	.30	Early Upper Palaeolithic	.30
Epigravettiano	.03	Late Upper Paleolithic or later	
Mesolithico	.41		.44
if found on Minturno or Borgo Ermada levels:			
early Upper Pleistocene *Pontiniano*	.04	middle Middle Palaeolithic or earlier	.04
middle Upper Pleistocene *Pontiniano*	.09	late Middle Palaeolithic	.09
Aurignaziano	.35	Early Upper Palaeolithic	.35
Epigravettiano	.04	Late Upper Palaeolithic or later	
Mesolithico	.48		.52

Table 5. Effect of additional information about technological features for estimating the age of the end scraper on a tertiary flake (based on 348 tertiary flakes examined from excavated collections).

	prior probabilities	probabilities based on technical features	posterior probabilities
middle Middle Palaeolithic or earlier	.04	.11	.01
late Middle Palaeolithic	.09	.36	.13
Early Upper Palaeolithic	.35	.39	.55
late Upper Palaeolithic or later	.52	.15	.31

superficial projections of silica are dissolved by soil water and deposited in superficial depressions on the surface of a fracture of flint, creating a glassy appearance. Important properties of the soil that promote or hinder solution of silica are pH and temperature in conjunction with the amount of organic compounds and aluminum ions (Luedtke 1992; Rottländer 1975). A few years ago, a loglinear model was found incorporating degree of patination, three archaeological periods, and three different kinds of sediment showing that these variables were probably interrelated in our samples (Loving/Kamermans 1991).

In examining the materials, we had also noted that more coarsely grained flints seemed to have less patina. According to geologists, it is probable that differences in the texture of the fracture surface seen macroscopically is due to porosity and clustering of quartz crystals in the stone as well as texture and that these properties affect both rates of weathering and appearance (Luedtke 1992).

Artifacts that had acquired a .6 probability or more for one of the four temporal categories in the previous steps of the application were used to build new loglinear models predicting for degree of patination based on age, sediment,

Table 6. Probabilities derived from loglinear models predicting degree of patination from age, type of sediment and stone texture (based on 1417 artifacts collected by surface survey).

Materials found in soils developed in travertines, aeolian and littoral sands:	light patina			heavy patina		
	fine-grain	medium-grain	coarse-grain	fine-grain	medium-grain	coarse-grain
middle Middle Palaeolithic or earlier	.18	.23	.24	.29	.30	.31
late Middle Palaeolithic	.23	.24	.24	.27	.29	.29
Early Upper Palaeolithic	.17	.22	.24	.30	.32	.33
late Upper Palaeolithic or later	.42	.31	.27	.14	.08	.07

Table 7. Effect of additional information about patina and texture for estimating the age of the end scraper on flake example.

	prior probabilities based on tool or core type and technological features	probabilities based on patina and texture	posterior probabilities
middle Middle Palaeolithic or earlier	0.01	.30	.03
late Middle Palaeolithic	.13	.29	.19
Early Upper Palaeolithic	.55	.32	.75
late Upper Palaeolithic or later	.31	.08	.02

and texture. Incorporating texture in the models showed that it had more effect than the type of sediment and as much effect as age of the artifact on the degree of patination; furthermore, texture of raw material is associated with the age of the artifact, so we even learned something we had not known before. After selecting the models that best fit the data, probability tables for age of artifacts given, degree of patination, texture, and type of sediment on which they were found were constructed from the models. There are two models. One for soils developed in tuff and lagoonal clays and a second one for all other soils (table 6).

The end scraper on a flake (fig. 4) was found on soils developed in travertine. It has a medium texture out of three categories — fine, medium, coarse — and a heavy degree of patination out of two categories — light and heavy. Based on these properties alone, it would have about equal probabilities of coming from one of the first three categories, but a very low probability of coming from the fourth category — Late Upper Palaeolithic or later.

The next step in the application, then, was to calculate posterior probabilities for all artifacts with prior probabilities that had not been used for analysis to construct the last set of probability tables. Again, it was assumed that information for prior probabilities was independent of the added information. The additional information for the end scraper on flake gives it a much higher probability of dating to the Early Upper Palaeolithic (table 7).

All other flint artifacts collected by the survey from older surfaces that had not acquired probabilitistic estimates of age in the previous steps were assigned probabilities deriving from each of the temporal categories using this last set of probabilities tables.

4 Computerized aspects of the application

Calculating posterior probabilities as other sources of information become available is an extremely tedious procedure. Thus, a small computer program was written by Albertus Voorrips (University of Amsterdam) that allowed probabilities to be typed in and then performed the necessary calculations. This made it easier to 'walk' a sample of artifacts through the estimation procedure to see how the application performed.

A schema was drawn up to order the decisions used in the application. The order was generally the same as presented in the preceding section, but was adjusted to accommodate certain logical and archaeological precedents. For example, artifacts used for developing the models for degree of patina retained the probabilities used before the analysis. Likewise, certain technical attributes, most of them metrical, restricted an artifact to fewer chronological categories.

The schema was the basis for Voorrips to write a computer program to route the approximately 9000 artifacts collected by the surveys through the decision pathways, identify the appropriate probability tables, do the necessary calculations, and write out the final probabilities.

5 Assignment of artifacts to temporal categories

The final step in the application was to assign individual artifacts to one of the four temporal categories on the basis of their final probabilities. Since I do not know a way to determine a significant departure from a uniform distribution, a value of .6 or more for any one category seemed reasonable to accept as a best estimate.[1] In this way, about 4000 artifacts, a little over 40%, were assigned to one of the four temporal categories. By collapsing temporally adjacent categories into General Middle Palaeolithic and General Upper Palaeolithic, an estimate of age could be made for an additional 10% of the artifacts.

6 Discussion

These results made it possible to use counts and densities, to correct for time by calculating discard rates, and thereby to begin to see some patterning in possible use of the area. Although the data are now more tractable than before, there are certain drawbacks to the application. For one, there is no independent means of checking the validity of the results. For another, many decisions were made to construct the probability tables, and other archaeologists might do it slightly differently, which would most probably alter the outcome. Just how 'stable' the results that I obtained are is a matter for future investigation incorporating information from other or new analyses in the probability tables.

The procedure is most suitable for situations where the certainty about assignment to a class is low. If prior probabilities for an artifact belonging to a class are low, they will remain low unless additional information assigns low probabilities for the other classes. If, on the other hand, probabilities for belonging to two or more classes are about equal, additional information incorporated into the procedure will either increase the certainty of assignment of an artifact to one of the classes or it will maintain the initial uncertainty, showing that for that case the additional information is irrelevant for assignment to a class.

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note

1 Bob Laxton suggested that Monte Carlo techniques might be used to establish probabilities for various probabilities under different numbers of classes.

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Application of an object-oriented approach to the formalization of qualitative (and quantitative) data

1 Introduction

'Archaeology is the discipline concerned with the recovery, systematic description and study of material culture in the past.' (Clarke 1968)

This description of the targets of archaeological research, given by David Clarke in the fundamental 'ANALYTICAL ARCHAEOLOGY', allows us to single out the three main phases of the approach to the material culture in archaeology: the recovery phase, represented by surveys and excavations; the systematic description phase, operated through the classification of the data obtained from surveys and excavations; and the study of the results deriving from the two preceding phases, in order to obtain a deeper comprehension of the social, economical, and technological development of a certain area over a certain period.

The present work is oriented towards an enhancement of the conceptual and methodological tools for the management of the second phase which, compared to the others, shows a much lower degree of maturity. The problem appears even more urgent if we think that this phase occupies a conspicuous share of the archaeological research. In fact, according to K. Chang (1967), 'it is reasonable to estimate that 80 or 90 percent of an archaeologist's time and energy is spent in classifying his material.' The acknowledged importance of this aspect of research has led, along the history of archaeological studies, to the production of a large number of publications oriented towards the design of a methodological approach which could be universally accepted. Unfortunately, unlike what happened, for example, to the techniques of archaeological excavations, any such attempt has, sofar, inevitably failed.

The target of this work is to carry forward a new proposal which, supported by advanced tools of analysis borrowed from the information technology and specifically designed to perform this task, could guarantee a reasonable chance of success. The paper is structured in two main parts: the first part shows a synthesis of the history of classification theory in archaeology, for providing a frame of reference for the problem; this synthesis is followed, in the second part, by a description of the informatic tool the use of which is proposed, together with a brief example of the implementation of this tool, to a case study.

2 A historical outline of classification in archaeology

With the benefit of hindsight it is possible to identify four main phases in the history of archaeological thought concerning classification problems. For a better understanding of the fourth phase, currently active, it is necessary to give a brief examination of the key points which have characterized the previous three.

2.1 THE 'INTUITIVE' PHASE

The first phase, defined as 'intuitive', represents the period of the history of classification in which the artifact analysis is performed on a totally empirical base. This phase, the higher expression of which is represented by the work of Oscar Montelius (1874, 1885, 1899), was characterized by the production of increasingly refined typologies, but without any need, from the archaeologists, to explain the principles on which the typologies were built: 'Montelius was not concerned in a methodology for determining types, whose existence he implicitly accepted' (Klejn 1982).

2.2 THE 'SUBJECTIVE' PHASE

The second phase is represented by the emergence, in the early thirties, of the awareness of the fundamental importance of a clearer exposition of the principles on which typologies were based (Gorodzov 1933; Kluckhohn 1939). During this phase typology is recognized as a substantially subjective operation (Brew 1946; Krieger 1944), but the lack of conceptual tools able to formalize a qualitative-based approach led to a general dissatisfaction with the traditional model and, consequently, to the search for a new paradigm which could offer a greater warranty of formalization. In fact the subjective phase, though having recognized the importance of an explicit formalization of the constituent elements of typologies, failed to provide a classificatory paradigm able to handle the problem.

2.3 THE 'POSITIVIST' PHASE

That paradigm has instead been envisaged, by the supporters of the mathematical approach to artifact study and classification, in the numerical codification of attributes to be analysed by means of statistical techniques (Bordes 1950; Brainerd 1951; Ford 1949; Robinson 1951). Imported from natural and social sciences, where they had been utilized with success, statistics seemed to offer what archaeological research needed: a tool of formal analysis which used standardized and explicit mechanisms, thus ensuring a greater comprehension of the conceptual paths followed by analysts and, consequently, a possibility of verification and replication of the single analysis.

The fifties provided a stage for harsh epistemological disputes between the supporters of the traditional approach (Ford 1954) and the proponents of the new techniques of analysis (Spaulding 1953). These disputes ended with an explosion of popularity for the quantitative approach, leitmotif of the third phase (Binford/Binford 1966). Though moving from a sound principle, for a number of reasons, this approach has proven of a little practical use in archaeological research.

2.4 The contemporary scene

Since the loss of popularity of the quantitative paradigm (Aldenderfer 1987; Christenson/Read 1977; Thomas 1978), archaeologists have become very cautious in dealing with the problems of classification (Seitzer 1978) and, consequently, very few have been the proposals of new or revolutionary approaches to classification (Kampfmeier 1986). In fact the current phase has not yet produced an algorithm which could have enough impact to characterize it.

At this stage it appears necessary to stress two key points which constitute the conceptual base on which the present research has been structured. The first point concerns the traditional approach that, if failing at a theoretical level for its poor possibilities of formalization, has shown a demonstrable empirical value and does not need any improvement at a technical level, in fact, as Thomas has put it: ‘To propose a computer technique for deriving morphological types presumes that traditional methods have failed, and nobody has demonstrated that yet’ (Thomas 1978). The second point refers to the need, stressed by the proponents of the quantitative approach, of a tool of analysis able to produce formal descriptions: such a need is even more impelling now than it was thirty years ago.

The conclusion drawn from these considerations is that an integrated reformulation, thus allowing the formalization of typologies operated through a traditional methodology, could offer a reasonable possibility of solving the paradigmatic disputes which have characterized more than sixty years of typological debate.

The present work represents an attempt to produce a synthesis between the two approaches. In fact the model presented hereafter agrees with the definition of typology as a subjective task but, at the same time, believes in the necessity for a rigorous formalization of the principles on which each typology is based. The target therefore results in a subjective but formal and explicit approach to artifact typology. This paradigm is made complete by the support of a tool of analysis which has been borrowed from computer science.

3 The ‘Mosaico’ Project

The ‘Mosaico’ Project has been developed in Italy within the CNR (National Research Council), and consists of an environment for conceptual modelling according to the paradigm Object-Oriented (Coad/Yourdon 1991; Khoshafian/Abnous 1990). This modelling, performed using the formal language TQL++ (see sec. 6), has the structure of a knowledge base (KB). The system allows the formal description of any kind of entity using attributes both qualitative and quantitative, whatever the epistemological position of the user. It is however necessary to exhaustively explain the conceptual path chosen for the entity definition.

Mosaico assists the analyst in the formal and correct description of the application domain, operating a syntactical and semantical verification of given definitions. Following this procedure it is possible to avoid those little ‘arrangements’ performed by authors in the presence of practical inconsistencies of typologies not perfectly formulated at a theoretical level.

4 Terminological specifications

Before going any further, it is necessary to clarify some key points of this method.

To begin with a clear definition of the three key words mentioned above, Typology, Taxonomy and Classification, will be given. These terms are currently used in archaeology but their meanings vary according to the different epistemological positions of the various authors, for that reason the definitions given here are drawn from Artificial Intelligence.

- Typology: The word ‘typology’ specifies the definition of a conceptual entity, the ‘type’, which describes a group of similar phenomena, the ‘class’, by means of a number of attributes considered to be ‘significant’, together with the type and range of values that those attributes can assume in order to consider a certain phenomenon as a member of that specific group.
- Taxonomy: In the real world phenomena do not have isolated lives, rather they are organically connected with other phenomena by a network of hierarchical relationships. These relationships can be of various kinds, but for what concerns the present work, just one type will be taken into consideration: the Generalization/

Specialization relationship (also called 'ISA' relationship). The word 'Taxonomy' is used to indicate the organization of gen/spec relationships between all types within a certain application.
– Inheritance: As previously stated, the various entities are interconnected through a network-type organization of generalization/specialization relationships forming a hierarchical structure, graphically expressed by an inverted tree. This has at its root a very general type which is then refined using two mechanisms: 1) Restriction of the range of values for one or more attributes; 2) Addition of new attributes. The mechanism of inheritance simplifies and speeds up the definition of more specialized concepts further down the tree. In fact the ISA relationship requires only to show the differences from the more generalized concept as all the rest are equal by default.
– Classification: Compared with the two concepts explained above, the term 'classification' appears very easy to define. It indicates the operation of assigning a phenomenon (be it an object, a decoration, a culture, or else) to a certain class by matching the types and values of its attributes to the types and ranges given in the definition of types.

5 Description of the system

The target of Mosaico is to support the designer in the formal and correct specification of an application domain and in the rapid prototyping of the application software. The fundamental component of the Mosaico System is the 'type' intended as the abstraction of a group of objects in a particular application domain. In other words an archetypal representation describing common aspects of individuals belonging to the same group. In Artificial Intelligence types are also referred to as 'entities'.

In Mosaico, the KB is organized using a hybrid methodology: 'Frames' are used to represent concepts and a 'Semantic Network' to define relationships between frames (Colombetti 1985; Giarratano/Riley 1989).

In structuring a KB much like a database we have two main levels of organization: the schema definition and the input of actual data. In the Mosaico environment the two levels are referred to as 'intensional' and 'extensional' respectively. At the intensional level the entities are described by listing their characteristic properties and defining the hierarchical relationship between each other. At the extensional level, on the other hand, are stored the instances of the entities represented at the intensional level. The instances are entered by associating values to the properties listed in the corresponding entities.

The operation of type definition is performed by using a conceptual language specifically conceived: 'TQL++'.

6 'TQL++': a Conceptual Modelling Language

TQL++ (Type Query Language). Because of the complexity of the whole model we will present just the aspects more likely to be useful for the needs of an archaeologist attending to artifact classification.

TQL++ has been conceived for the description of the entities of specific application domains; the static definition of a type is structured in five main sets:

– Structural Specification
– Properties Typing
– Integrity Constraints
– Hierarchical Organization
– Type Specialization

6.1 Structural Specification

The type structural specification consists in supplying the list of properties and, for each of them, the type corresponding to the values that they can assume.

<type-name> := [<prop-name> : <prop-type>
<prop-name> : <prop-type>]

Properties can be single or compound: a single property can have just one value associated to it; a compound property can be either 'multivalued' or 'structured'. In the first case it is possible to associate more than one value to it, whereas in the second it is not possible to associate any value directly to it. Structured properties have 'subproperties' and values will be associated with them (unless they are structured themselves as well).

6.2 Properties Typing

A property type is used to show the kind of value it can assume when ascribed to an application object. The properties of a hypothetical type of vase, for example, could be: 'id' (number for object identification), 'max_h' (for maximum height), 'max_w' (for maximum width), 'dec' (for decoration). Those properties shall be typed showing that the values for 'id' should be integer numeric values *(integer)*, those for 'max_h' and 'max_w' should be real numeric values *(real)*, whereas for 'dec' the values should be indicated through a string of characters *(string)*.

The indication of a property type *(typing)*, can either use a base type such as *integer* or *string*, or it can be more precisely specified by the user through some property typing tools. Here follows the description of the two simpler property typing tools offered by the type specification language TQL.

Listing: Through a listed set, it is possible to explicitly indicate allowed values for a given property (this construction is used mainly with categorical variables). For example to the property 'dec' we can associate the values: 'painted' or 'scratched'; this implies that for any object of the type 'vase', the property 'dec' can assume just one of the two indicated values:

vase := [..., dec: (painted, scratched), ...]

Range: Like the previous case this construction allows the indication of the values that a given property can assume, but without listing them all. The present construction can be used for continuous variables, in which case it suffices to indicate the minimum and maximum values allowed (it is also possible to use the extreme values):

vase := [max_h: (3...150), max_w: (5...80)]

Tuple: Typing through tuple is requested when a property is structured. In this case the property is defined by its subproperties, referred in the associated tuple:

vase := [..., dec: [lip_dec: string, body_dec: string, base_dec: string], ...]

Sofar the possibilities have been listed that the language TQL++ offers to type the properties that define the information structure of an entity, and consequently of the objects associated to it, which all together form the corresponding *class*. In the following paragraph, the possibilities of imposing constraints in the phase of type definition will be shown. Although those constraints may be of different sorts, they will have to be respected by all object introduced in the KB.

6.3 Integrity Constraints

TQL has been conceived with a particular consideration for integrity constraints and it appears to be very powerful in this respect. As stated above, because of the complexity of this language, many of the TQL features will not be mentioned in this exposition but, for sake of clarity, will be limited to the following:

i. Typing constraints: As already explained, giving the type of a property implies itself a limitation to the values that the corresponding objects can assume. Thus, having indicated that, for instance, the maximum height of a vase is of type *real* provokes an automatic checking by the system and an error message in case of an attempt to input a datum inconsistent with the correspondent typing like, for example, a string of characters.
ii. Domain constraints: these constraints are associated with either the listing or the range of a property value. Here the allowed values are explicitly indicated by the user through those two typing tools.
iii. Functional constraints: It has been previously stated that properties can be single or multivalued. It is assumed for default that a property be single, like for instance the identification number of an object. However in the phase of typing, the property type is enclosed in curly brackets. If for instance we want to express that a vase can have multiple types of decoration or be undecorated we have:
vase := [..., dec: {string}, ...]

After having performed the structural specification, together with the properties typing and the description of integrity constraints, the type definition ends with its hierarchical allocation within the whole knowledge-base structuring which is based on a conceptual tool borrowed from semantic networks: namely the ISA relationship.

6.4 Hierarchical Organization

In a knowledge-base, and more precisely in the K-Schema, it is possible to organize the type definition within an ISA hierarchy. That is basically a generalization/specialization relationship between types. For instance we can declare that: 'cup ISA vase'. Intuitively this statement shows that all the characteristics of 'vase' are encountered in 'cup' as well, although the latter could have additional characteristics which are not necessarily encountered in all vases. This principle is often referred to as *principle of inheritance* because the type cup *inherits* all the characteristics of the type vase.

In the extensional level the ISA relationship turns into an inclusion relationship between classes. The example shows that the class of cups is contained in the class of vases. These qualitative considerations are rigorously described by the language, through strict criteria that guide the building of ISA hierarchies.

6.5 Type Specialization

As already stated, the ISA relationship implies that the type being defined be a specialization of the types appearing under ISA. Moreover, the principle of *inheritance* is also used to obtain a more compact schema description. Inheritance can be single or multiple, if in the ISA construction appear one or more supertypes. We talk instead of *absolute* inheritance when the properties of the supertype are inherited without being modified.

Having given a type, the creation of a subtype is performed through specialization. The mechanisms of specialization must always be respected in defining a type using the ISA construct. Those mechanisms are explained in the following sections and are of two basic sorts: specialization by specification and specialization by restriction.

i. Specialization by specification: This mechanism of specialization requires the addition of new properties to those already defined in the supertypes (which, as stated above, are inherited by the subtype). If the supertypes are two or more and have properties in common, inconsistencies can arise. This is a critical point in multiple inheritance, the problem has already been faced in the literature and there are different ways to solve it, but their description goes beyond the scope of this paper.

ii. Specialization by restriction: The mechanism of restriction allows to refine in the subtype one or more properties already defined in the supertype (this mechanism is called *overriding).* The overriding is performed essentially on the two property typing tools mentioned above: the explicit listing of allowed property values in the case of categorical variables and/or the range of allowed property values in the case of continuous variables.

7 Architecture of the system

The design of an application starts with the definition of the schema and proceeds by verifying its syntactic and semantic correctness. The schema contains the definition of the types of the application domain which describe the structure of objects and the relative integrity constraints. The cycle definition/verification can be iterated several times and, at each cycle, the schema is expanded progressively. Finally, a prototype for the designed application is generated. Each of these design steps corresponds to a subsystem of Mosaico: *Editor-Browser, Semantic Verifier, Code Generator, Functional Verifier, ODB Manager, and Stand Alone Prototyper*. These subsystems will now briefly be described.

1. Editor-Browser (EdiBro): This subsystem provides all the tools necessary to compose the specifications of an application domain, according to the OO paradigm (see sec. 4). As already stated a domain is described through the definition of its types. Types can be defined *ex-novo* or imported from a type library, in which case they can be refined and subtyped. New types can be inserted in the type library for future use.
2. Semantic Verifier (SemVer): By using the Semantic Verifier it is possible to check the syntactic and semantic correctness of the developed KB. The first step of the semantic verification is the parsing of the TQL++ specification. If any errors are detected at this level, the designer can go back to the *EdiBro* subsystem and change the incorrect type definitions. Otherwise the TQL++ specification is first translated into *Intercode* (an internal representation of the specification), and then semantically checked by using theorem-proving techniques. The Intercode is also used for the final, executable code generation, as described below.
3. Code Generator (CodGen): The Code Generator is devoted to the production of executable code, implementing a rapid prototype of the designed application (or part of it). This is done by mapping Intercode into a computer language (also called *object language*). The designer can generate the rapid prototype by choosing from the following languages: C++, Prolog, and O2C.
4. Functional Verifier (FunVer): This subsystem allows the user to run the prototype and monitor the execution.
5. ODB Manager (ODBman): To actually test the application it is necessary to populate the object database. This subsystem allows for the initial generation of a set of test objects (i.e. the specification of an ODB), by using the language Lobster (Missikoff/Toiati 1993). Once created, the ODB is processed to check its correctness, by matching the objects with the corresponding type definitions (declared in the schema). If no error occurs the ODB is loaded and its content can be used by the prototype during execution.
   The ODB Manager also provides a *Query Tool* to retrieve data interactively from the database. The querying is performed by using the same language conceived for the data definition: TQL++.
6. Stand Alone Prototyper (MOSAP_Gen): After the application has been semantically and functionally verified, the stand alone prototype, referred to as MOSAP (MOsaico Stand Alone Prototype), can be generated. In particular, MOSAP_Gen takes the Intercode representation of the application, generated by CodGen, as input and produces the executable prototype as output. A stand alone prototype is an autonomous executable program. It can be installed on a machine different from the one on which Mosaico runs.

In developing the specification of an application, the designer can interact with all Mosaico subsystems. The interaction is guided by the iconic interface described below. The only component implemented in the interface to date is represented by the EdiBro subsystem, through which it is possible to specify a KB using the language TQL++.

8 The iconic interface of Mosaico

The development of good user interfaces based on the iconic paradigm is a difficult task, since sound techniques, which guarantee that the interface will be easy to learn and easy to use, are still lacking. In the development of InterMos, the iconic interface of Mosaico, the methodology Iconit has been applied (Constabile/Missikoff in press). Iconit distinguishes two major design phases: (i) the design of the interface scheme and (ii) the detailed design of the windows. By interface scheme (also called dialog scheme)

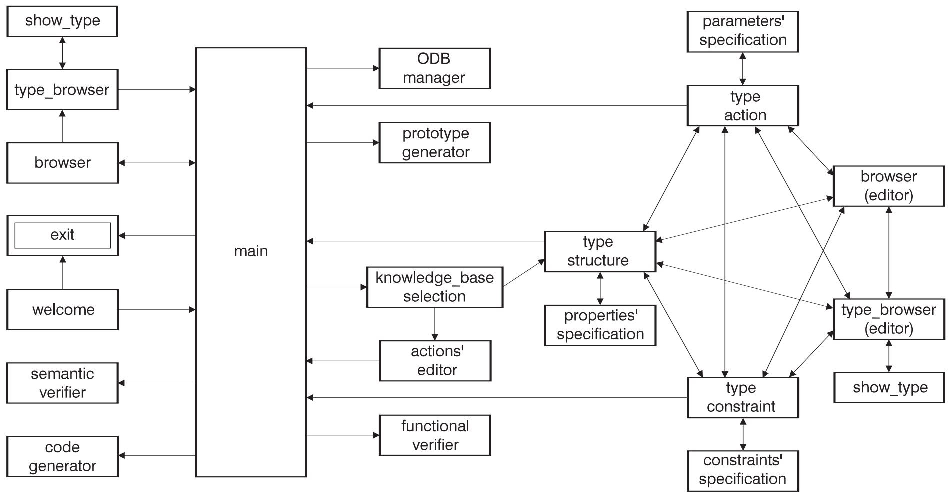

Figure 1. A partial ISTD (Interface State Transition Diagram) of Mosaico.

is meant the design of the overall interface organization, which refers to both the content and sequencing of the windows, omitting the description of each window appearance

8.1 The interface development methodology

Existing tools for interface design are mainly targeted at the construction of the windows and do not address explicitly the definition of the dialog scheme. Usually, the designer sketches the overall structure of the interface on paper, using some diagrammatic representation of the window organization and sequencing, and then creates and implements the interface windows, which are linked explicitly one to another. The consequence of this approach is that any modification in the interface organization, after the implementation, requires the recompilation of a certain number of windows. This is one of the reasons why we believe that it is useful to separate the two issues, thus creating the specific windows independently, and later organizing them in the interface as indicated by the dialog scheme. According to this approach, we have conceived a methodology which allows for an explicit separation of the two above design phases, in particular the first phase produces the dialog scheme (referred to as ISTD: Interface State Transition Diagram) and the second one the set of windows.

8.2 The ISTD of Mosaico

Once a preliminary analysis of the entities and functions required by the target system is performed, it will be possible to start the first phase of the interface development, namely the ISTD (Interface State Transition Diagram) definition. A partial ISTD of Mosaico is shown in figure 1. Note that the ISTD is fully specified only for the Browser and Editor components. In the diagram, it is possible to distinguish the root, corresponding to the initial WELCOME window (fig. 2), in which a password must be provided by the user. If the password is correct, there is a transition to the MAIN window (fig. 3), in which the user can choose the subsystem of interest; this choice will determine a transition to a specific window. If the user chooses the Editor subsystem, the interface prompts the user with the name of the KB to be edited, and then performs the transition to the TYPE STRUCTURE window (fig. 4). From this window the user has several options: 1) edit a type (thus remaining in the same window); 2) call the Browser (e.g. for loading a type defined in another schema); 3) go back to the MAIN window (see the links in the ISTD in fig. 1) and so forth.

Once the ISTD has been designed, the interface windows corresponding to the ISTD nodes are also created. Some functionalities of the developed interface are shown in the next section through a working example.

8.3 Interacting with the system

It will now be shown with an example how the EdiBro subsystem works. A prototype of Mosaico, with the interface, has already been developed on a Sun workstation and the figures included here are hard copies of the screen.

The case study is represented by the conceptual structuring of the type ‘Fibula’ (and of some of its specializations), using materials from the Villanovan cemetery of Quattro Fontanili near Veii, in Southern Etruria. A particular interest derives from the fact that the materials have been

Figure 2. The initial WELCOME window of Mosaico.

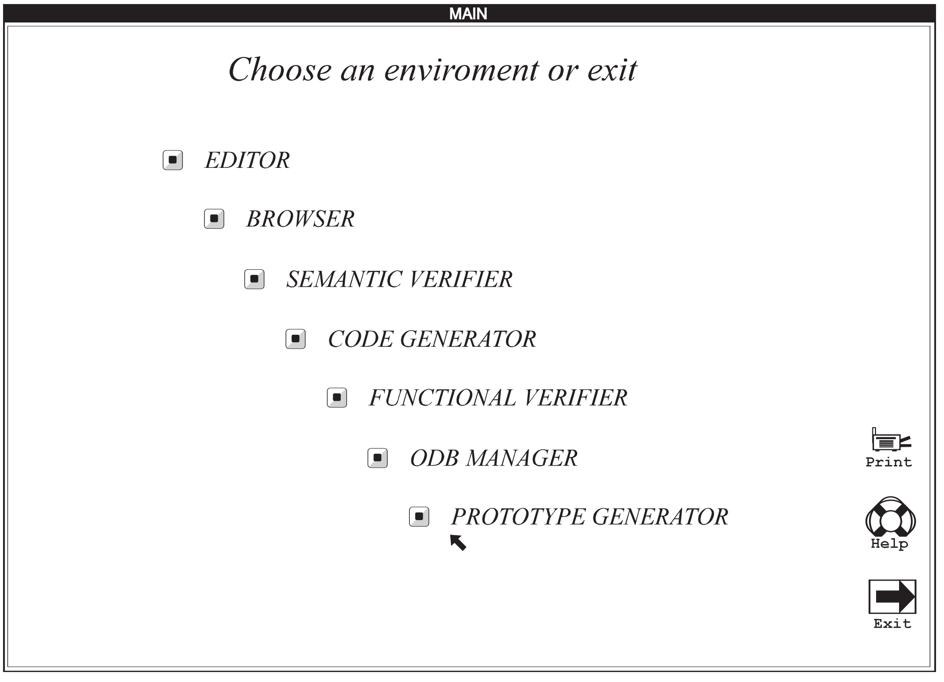

Figure 3. The MAIN window of Mosaico.

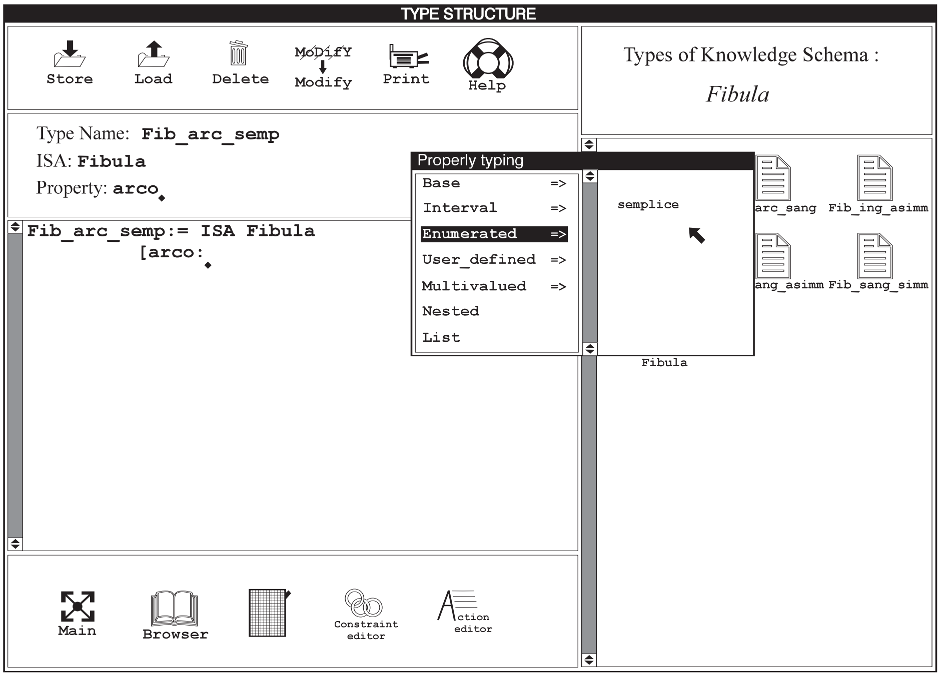

Figure 4. The TYPE STRUCTURE window of Mosaico.

previously studied by several authors (e.g. Close-Brooks 1965; Toms 1986; Kampfmeier 1986; Guidi 1993), making a comparison possible between the various approaches and results. The description of materials has been performed on the basis of *Die alteren italienischen Fibeln,* written by J. Sundwall in 1943, and the *Dizionari Terminologici*, published by the Italian Ministero dei Beni Culturali in 1980. Such a description is developed according to a hierarchy of attributes which generates, consequently, a hierarchy of types progressively more specialized.
The attributes hierarchy is the following:

1. form of the arco (bow);
2. decoration
3. form of the staffa (catch).

Supposing that the user wants to define a new type for the KB, the Editor is selected from the MAIN window and the TYPE STRUCTURE window appears (fig. 4). The structure of this window, composed of several panes, is the same for all Editor windows, so that the user will keep a consistent view. On the right side, the types already defined for the current KB are shown. In our example seven types have already been defined, namely: Fibula; Fib_arc_ing (fibula ad arco ingrossato); Fib_arc_sang (fibula ad arco a sanguisuga); Fib_ing_simm (fibula ad arco ingrossato e staffa simmetrica); Fib_ing_asimm (fibula ad arco ingrossato e staffa asimmetrica); Fib_sang_simm (fibula ad arco a sanguisuga e staffa simmetrica); Fib_sang_asimm (fibula ad arco a sanguisuga e staffa asimmetrica).

The top and bottom panes on the left side of the window contain some icons. The icons in the top pane indicate four operations: 1) *store,* for storing the current type into the KB schema; 2) *load,* for extracting an already defined type; 3) *delete,* for eliminating a type from the schema; 4) *modify*, for updating some characteristics of an existing type.
The usual *help* icon is also in this pane.

In the bottom pane, the icons indicating navigational actions are included. A navigational action allows the user to move to other windows of the interface. Going from left to right, the first icon allows to go back to the MAIN window, the second one calls the Browser, the third one goes to the TYPE STRUCTURE window (in fig. 4 it is not active because the TYPE STRUCTURE window is the current one), the fourth and the fifth icons go to the other two windows of the editor, for editing constraints and actions respectively. Such icons, in the same position in all windows, are shown in reverse when not active.

Figure 4 shows the creation of the type ‘Fibula’; the first operation to perform is to enter a value for the property ‘type name’. According to the TQL++ syntax, one or more supertypes can be specified using the ISA construct. After that it is necessary to proceed to the properties definition; in doing this, the user is helped by the interface which translates the definitions in the TQL++ syntax, thus alleviating the user from knowing all the syntax details.

10 Conclusions

In the previous pages a new classificatory paradigm has been presented that could contribute to drawing the archaeologists' attention again to an aspect of archaeological research characterized, in recent years, by a substantially static period. The reason for this is to be found, we believe, in the climate of disillusionment which took place after the loss of popularity of the quantitative paradigm, proposed by the new archaeologists to assure a good degree of formalization in the process of typology production.

The appearance of information methodologies allowing the formalization of classifications performed on a mainly qualitative base, opens up new perspectives able to offer reasonable possibilities of solving this fundamental and aging debate.

An application of the techniques described in this paper to the material from the Villanovan cemetery of Quattro Fontanili is however in progress, and the relative results will be the subject of a further and more extensive publication.

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Geographic Information Systems I

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Between the lines: the role of GIS-based predictive modelling in the interpretation of extensive survey data

1 Introduction

Extensive field survey (such as fieldwalking and geophysical prospecting) yields information of a fundamentally different nature to intensive investigations. The resulting information lacks the spatial and chronological detail of intensive investigation such as excavations but generally provides greater spatial extent and chronological depth. As a result, field survey provides data with an appropriate spatial and chronological resolution to explore landscape and offsite approaches (e.g., Foley 1981) to archaeological explanation, and to focus attention on the long term effects of the activities of individual human agents within the entire landscape.

However, it is rarely possible within a field survey project to obtain total coverage by fieldwalking. The reasons for this are numerous but the most obvious is that fieldwalking is not generally appropriate unless the area is being actively ploughed, bringing artefacts to the surface. Areas of meadow or woodland within a generally agricultural landscape will therefore not be walked. The resulting data is therefore extensive but discontinuous, requiring the archaeologist to ‘fill in the gaps’, by estimating how the observed artefact densities might extend outside the surveyed areas.

One of the ideal tools for this kind of analysis is the Geographic Information System (GIS). This provides the archaeologist with the tools to visualise individual artefact types and to explore relationships within the survey data and between the survey data and other landscape indices. The application of GIS to archaeology has now been discussed by a number of authors (see e.g. papers in: Allen *et al*. 1990; Harris 1986; papers in: Lock/Stančič 1995; Wheatley 1993, 1995 for further details), therefore no general introduction to GIS will be provided here. Instead this paper will concentrate on how some of the methods which GIS makes possible might be of benefit in the interpretation of extensive survey data, in this case densities of lithic remains recovered during fieldwalking.

2 The Stonehenge Environs Project

The data used for the investigation is a subset of that collected under the direction of Julian Richards for the Historic Buildings and Monuments Commission for England (HBMC or English Heritage) between 1980 and 1986, generally referred to as the Stonehenge Environs Project (Richards 1990). This data was kindly made available in digital form by Wiltshire County Council Museums Service. The Stonehenge Environs surface collection database covers a series of irregular shaped areas to the east of the river Avon and immediately surrounding the Stonehenge monument itself. The total surveyed area is approximately 7.1 square kilometres, consisting of around 6500 50 m walked transects taken at 25 m intervals. In the course of the project a total of 102,175 pieces of worked flint were collected (Richards 1990: 15). The extent of the surveyed areas is shown in figure 1.

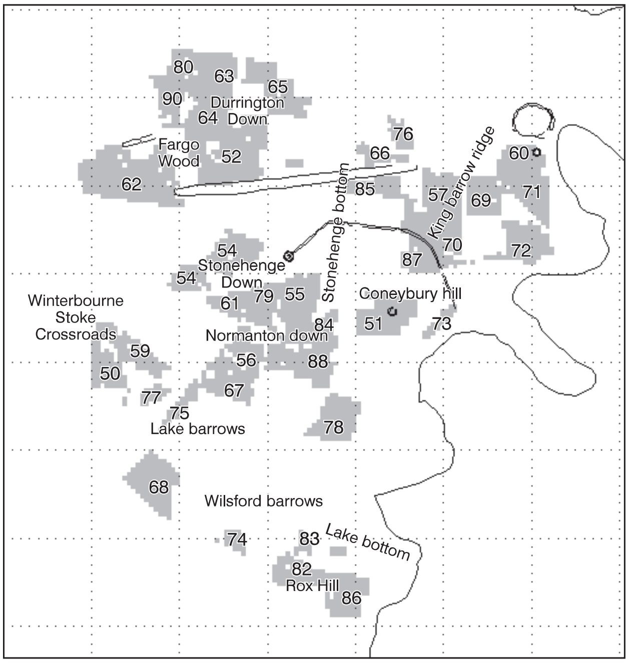

Figure 1. Area represented in the Stonehenge environs database, showing most of the original fieldwalking area numbers (from Richards 1990) and locations mentioned in the text. The grid on this and all subsequent images is the OS National grid, 1 km intervals.

Figure 2. Mapped distributions of total flint densities (left) and the mean-filtered flint densities (right).

Four categories of lithic information (counts of flint flakes, flint cores, burnt flint and retouched pieces) were uniformly present in the database together with total flint density. No details of ‘type fossils’ (arrowheads, scrapers or other tools) were sought, as the aim of the study was to extract as much information as possible from the majority of the flint data, rather than the minority.

Inspection of the lithic densities revealed a level of random ‘noise’ in each of the images. This is to be expected in a sample of this type, and represents the chance effects of obtaining unrepresentatively high or low values in the samples for some land units. To reduce the effects of the noise within the images, a second series of data themes were generated by applying a 3×3 mean filter to the images. In order to avoid the distortion which would arise due to edge effects in this case, a basemap of only those cells which had been sampled was used to force the filter to regard cells outside the basemap as ‘no data’ rather than zero values. Figure 2 shows the density of all flint within the study area, together with the mean filtered version.

3 Previous work

No computer facilities were available for this type of analysis as part of the Stonehenge Environs Project, and the original analysis took the form of plotting the densities of flint categories in categories derived from a frequency histogram of the flint densities (Richards 1990: 16). Using the procedure advocated by Hodder and Orton (1976), the inflexions of this distribution were used to estimate classes for plotting as distribution maps using different sized symbols for the different classes. These distribution maps then formed the basis of the interpretation of the lithic data and the main findings were detailed by Richards (1990) — these are not discussed in detail here for brevity.

Some analysis of the flint density data was undertaken by Maskell (1993), who entered a subset of the data from the paper record to a database, and then undertook some analyses with the IDRISI GIS. Maskell’s main conclusions were that the flint density data exhibited spatial auto-correlation (high values in one location made it more likely that high values would occur in neighbouring areas) and that there may be a relationship between aspect and the presence of some categories of flint artefacts.

4 Values at unsampled locations: prediction from correlates

The fieldwalking data can be mapped and analysed in its ‘raw’ form, but its discontinuous nature makes it difficult to estimate how the lithic densities varied in the unsurveyed areas. One approach to ‘guessing’ the lithic densities at these unsurveyed locations would be to use spatial interpolation techniques which rely on the spatial structure of the artefact densities themselves, and to assume that the pattern which is observed within the survey data persists outside the surveyed areas. Techniques for interpolating surfaces from point data include polynomial trend surface analysis, linear and non-linear contouring, topographic interpolation with splines, inverse distance weighting and optimal interpolation methods such as 'Kriging'. Interesting though these are, however, each has problems when applied to data of this type, and none of these methods are the subject of this paper. Instead, it is the aim here to examine the extent to which *predictive modelling* techniques can be used to perform the same task, and whether these offer any advantages over spatial interpolation in this context.

In contrast to spatial interpolation, a predictive model tries to estimate values at unknown locations by making use of the correlations of the observed variable with other spatial variables. In situations where the values of these correlates are known for unknown locations, then this may be used to predict the values of the observed variable outside the sampled locations.

Predictive modelling was primarily developed within the context of North American archaeology (see e.g., Carmichael 1990; Kohler/Parker 1986; Kvamme 1983b, 1985a, 1985b, 1988, 1990; Sebastian/Judge 1988; Warren 1990a, 1990b for examples) initially to aid the management of an extensive, and only partially known archaeological resource. In recent years some of the simpler types of predictive models have been imported for cultural resource management use within European archaeology (e.g., Brandt *et al*. 1992; Van Leusen 1993). These have generally been rule-based models, implemented with map-algebra techniques. The map-algebra expressions which describe the predictions have either been entirely deductive in nature or inductive only to the extent that the weightings for the equations were derived from ratios of expected to observed numbers of sites in given classes of the predictors.

Far more promising for the interpretation of complex archaeological patterns and remains are predictive models which are based on multiple regression techniques in which the relationship between the archaeological dependent variable and the predictors (independent variables) is automatically obtained from multivariate statistical computation. Such an approach has many advantages, particularly that regression procedures provide estimates of the influence each supposed predictor has on the result, and of the total extent of the variability within the result which is accounted for by all the independent variables (Shennan 1988).

5 Multiple regression

Initially, a straightforward multiple regression will be attempted, treating total lithic density as the dependent variable, and a variety of possible correlates as independent variables. Filtered values of lithic density will be used as the dependent variable because it is held that these more closely represent the true form of the population from which the samples were drawn. Densities of retouched, burnt flint and cores provide rather low ranges of values which are therefore more prone to the effects of chance in sampling. The difference between the total flint densities and total flake densities is minimal, and therefore the experiment attempted to predict the total flint densities.

Two types of independent variables were selected as possible correlates: environmental indices and indices describing the relationship to cultural features of the landscape. Environmental variables employed described the topography (elevation, slope, aspect), soil class, geological substrate and proximity to water sources. These seemed likely to have influenced the densities of lithics either through the choices of the human individuals who dropped the flints, or through differential recovery rates.

Three cultural indices were also included in the analysis in the belief that the location of ceremonial monuments may have had considerable influence on the activities of the people responsible for leaving the lithic debitage, and consequently on the form of the scatters. One of the criticisms raised of predictive models (by e.g., Wheatley 1993), has been that of environmental determinism. The most obvious feature of the cultural landscape is the existence of earthen burial monuments, in the form of earlier Neolithic long mounds and later round mounds. There is now some evidence (Lock/Harris forthcoming; Wheatley 1995a) that the locations of these monuments has had some influence on the activities of contemporary and later generations of people. Three variables intended to reflect cultural aspects of the landscape were introduced as possible predictors of lithic density. These were density of round barrows, distance to long barrows and visibility of long barrows.

It is not the intention to devote much space to the details of multiple regression analysis here. However, it should be pointed out that one of the requirements of linear multiple regression analysis is that the dependent and independent variables are approximately normally distributed. If they are not, then appropriate transformations such as logarithmic or square root transforms must be applied to generate new, normally distributed variables (Shennan 1988). Frequency distributions for all the possible dependent variables were examined. Each of the histograms reveals the skewed nature of the flint densities. The transformed distributions for total flint and flake densities, however, are markedly different and although both exhibit a minor skew to the right and a suggestion of bimodality the distributions are apparently quite close to normal (fig. 3).

Frequency distributions of the independent variables were also examined, and appropriate transforms applied to obtain approximately normally distributed variables. Although

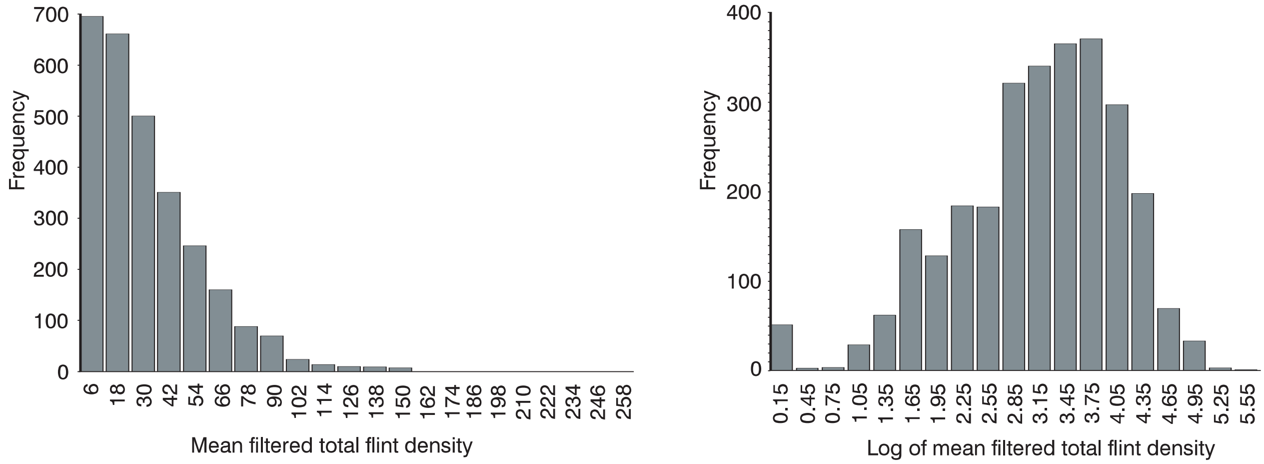

Figure 3. Frequency distributions of mean filtered flint density (left) and the ln mean filtered flint classes (right) showing some skewness and possible bimodality.

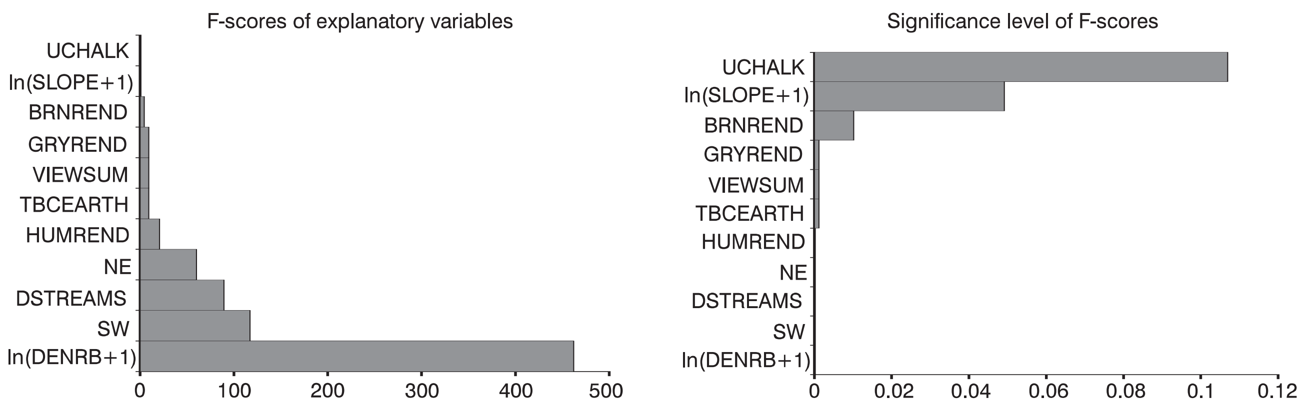

Figure 4. Explanatory power of the variables remaining in the regression expressed as F-scores (left) increasing with explanatory power, and significance of F-scores (right) reducing with explanatory power. Note the dominance of the ‘density of round barrows’ index.

some care was taken to approximate normality, it should be noted that results were not ideal, particularly in respect of skewness within some of the predictors. Consequently there must remain a suggestion that this may have biased the result a little. However, although not recorded here in detail, regressions omitting the most doubtfully normal variables did not produce significantly different results which supports the notion that the independent variables’ skewness was not influencing the general result. Categorical variables (geology and soil class) were dissembled into dummy variables, and introduced into the regression. Further details of individual predictors are not given here for brevity but may be found fully described in Wheatley 1995a.

5.1 Application of the model

A stepwise linear multiple regression was then undertaken, a summary of the results is given in table 1. This procedure examines each variable as it is included in the model to identify to what extent it contributes to the model. Independent variables were only included in the regression if they proved significant at the 0.15 level. The flint densities show significant correlations with 11 of the variables, which in reality represent 7 of the selected variables once the dummy variables for geology and aspect have been counted out.

The partial correlation coefficients (r^2) and F scores for each variable (fig. 4) show that the density of round barrows index has the greatest explanatory power within the

Table 1. Summary of stepwise multiple regression model for total flint density.

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEP	4.48422092	0.13117657	755.88447063	1168.59	0.0001
LOGSLOPE	-0.07334661	0.03547191	2.76557247	4.28	0.0388
DSTREAMS	-0.03190818	0.00284291	81.48413338	125.97	0.0001
VIEWSUM	0.01457195	0.00420610	7.76370920	12.00	0.0005
LOGDENRB	-0.48342903	0.03451878	126.86697985	196.13	0.0001
GRYREND	0.41090168	0.08041348	16.88931830	26.11	0.0001
BRNREND	0.16700804	0.03942703	11.60594984	17.94	0.0001
TBCEARTH	0.44753602	0.07039656	26.14250292	40.42	0.0001
UCHALK	0.14062157	0.08714878	1.68412841	2.60	0.1067
NE	0.33501178	0.04170020	41.74820486	64.54	0.0001
SW	-0.36472949	0.03930261	55.70483453	86.12	0.0001
Bounds on condition number:		1.852364,	134.823		

All variables left in the model are significant at the 0.1500 level.
No other variable met the 0.1500 significance level for entry into the model.

Summary of Stepwise Procedure for Dependent Variable LOGMTOT.

Step	Variable Entered	Variable Removed	Number In	Partial R**2	Model R**2	C(p)	F	Prob>F
1	LOGDENRB		1	0.1524	0.1524	348.0545	464.8721	0.0001
2	SW		2	0.0373	0.1897	221.2244	118.7974	0.0001
3	DSTREAMS		3	0.0277	0.2174	127.3268	91.5275	0.0001
4	NE		4	0.0182	0.2356	66.4410	61.4242	0.0001
5	HUMREND		5	0.0067	0.2423	45.3233	22.7708	0.0001
6	TBCEARTH		6	0.0033	0.2456	35.7845	11.4115	0.0007
7	VIEWSUM		7	0.0032	0.2488	26.6531	11.0514	0.0009
8	GRYREND		8	0.0032	0.2521	17.4324	11.1841	0.0008
9	BRNREND		9	0.0019	0.2540	12.9419	6.4831	0.0109
10	LOGSLOPE		10	0.0011	0.2551	11.0785	3.8633	0.0495
11		HUMREND	9	0.0005	0.2546	10.7186	1.6400	0.2004
12	UCHALK		10	0.0008	0.2554	10.1158	2.6036	0.1067

model, alone accounting for some 15% of the variation in lithic density while the aspect variables, distance to stream courses, soil indices and visibility of long barrows also carry limited explanatory value. Surprisingly perhaps, slope accounts for very little of the variation in lithic density (around 1%) and elevation even less.

Probably the most significant statistic within the result however, is the model correlation coefficient r^2 of 0.2554, or around 25% for all 7 explanatory variables. This indicates that the independent variables can account for only around one quarter of the variation within the lithic density, leaving three-quarters of the variation unexplained by the model. This is a very low value for r^2 from a regression analysis of this type, but a number of experimental modifications to the analysis through exclusions of independent variables and cases failed to obtain a value higher than around 27% and as none of these minor experimental alterations improved the methodological rigour of the analysis they are not discussed here in detail.

Accepting the low correlation coefficient for the time being, the model may now be used to express the predicted lithic density at all locations in the landscape, and then be translated into a prediction map (fig. 5 left) through a map-algebra operation. This provides mapped predictions of lithic densities for all locations in the study area.

5.2 Discussion of the model

The overall character of the prediction shows that the model generally predicts rather low values for flint throughout the sampled area, with the prediction never

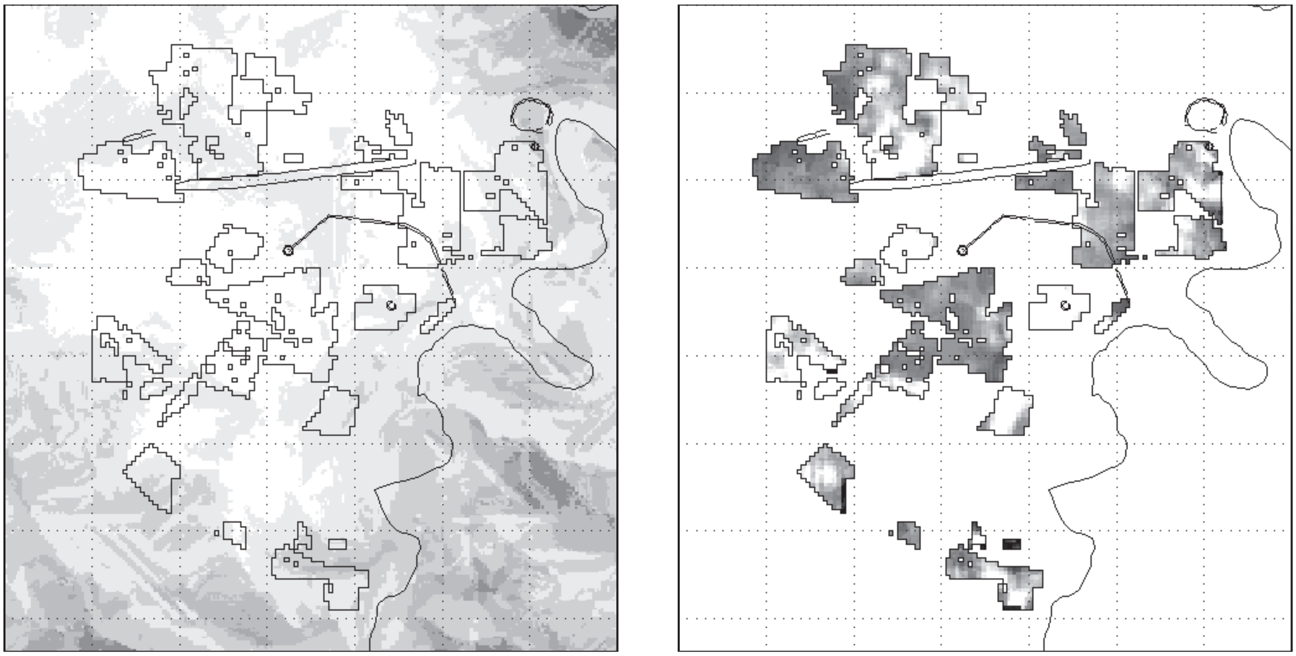

Figure 5. Mapped result of the multiple regression analysis (left) and the residuals from the regression (right).

reaching more than around 80-90 within the convex hull of the data points. The model seems to provide a fairly close approximation of the observed densities for the region around Normanton Down, and shows slightly higher predictions (although never approaching the true densities) for the surrounding areas. The areas of high density north of the Cursus, around Coneybury Henge and north of Stonehenge Down also show up as marginally higher values although, again, these do not approach the real densities for these areas.

One of the most obvious features of the model are the high values which are predicted for many areas away from the sampled region, for example in the northeast and southwest corners of the image. It may be that the variable most influential in the regression (density of long barrows) is the main factor. It is, for example, a measure which may be particularly prone to edge effects: the model predicts high flint densities at low round barrow densities, and the edge areas of the map may underestimate that index. It is also possible, however, that the model is actually rather ‘over-trained’ in regard to this variable. The variation of lithics with round barrow density may, at the scale of the sampled area, be as described in the regression equation, but at a larger scale be entirely the reverse. In other words, within the general cluster of monuments on Salisbury Plain the density of lithics is indeed higher in the gaps between the monuments, but nevertheless the flint densities at the edge of the study area might also be expected to decline rather than increase with density of monuments. The high predictions away from the core of the study area seem best explained in this way, therefore, and, put simply, it is that the model has no experience of lithic densities at the edge and extrapolates unreasonably high densities as a result.

The main conclusion which may therefore be deduced from the experiment is that while some of the ‘shape’ of the distribution is modelled within the core of the study area, this is clearly a poor model in the sense that it fails to adequately account for a large proportion of the variation within the dependent variable and in that it cannot be used outside the scope of the area for which it was designed.

The residuals of the regression were obtained within the GIS by subtracting the result of the application of the regression equation from the original observations in the form of the mean filtered density map. The result is shown in figure 5 (right), coded to show areas for which the model underpredicts and areas for which the model overpredicts. This supports the interpretation presented above, that the model fits adequately the areas which exhibit a low-level and low variation of lithic density. Thus the Normanton Down areas are a good fit, as is the peripheral area southwest of Fargo Wood (62). Practically all the very high areas of flint appear as high residuals. It seems, therefore, that the model explains the regular and therefore predictable variation within the lithic values which might be termed 'background' variation. The areas which show high residuals must then be interpreted as 'unpredictable' areas which deviate dramatically from the trend.

It is worth making the point that the lack of success of this approach should not be taken to devalue the experiment itself. The failure of the model to adequately predict absolute values for flint densities with the available independent variables is, of itself, an interesting finding.

6 Logistic multiple regression models

One reason for the lack of success of this model may be the choice of the dependent variable: total flint density at any given point in the landscape may not be closely related to the chosen independent variables because it is archaeologically the result of a compound of different activities involving manufacture, use and discard of flint artefacts.

However, most of the other flint variables do not show sufficient range of variation to be used as dependent variables in linear multiple regression analysis. Logistic regression, unlike linear multiple regression, can be used to predict presence/absence of particular classes rather than interval level values. Using logistic approaches, it is therefore possible to turn to the flint classes with low variability, and overall low values, such as core and retouched pieces density, and to define some characteristic of these variables which may be worth predicting.

6.1 Core: retouch ratios

It is possible to postulate, as a broad generalisation that those areas with high levels of cores in comparison with retouched pieces generally represent areas in which *manufacturing-related* activity dominated. Conversely, that areas with high levels of retouched artefacts represent areas in which *discard* activity was more common than procurement or manufacture. These might be termed 'discard areas' without prejudicing any interpretation of such activity (the discard could be structured symbolically or domestic and functional for example). It follows that if the proportion of cores to retouched pieces is spatially patterned, this might be evidence for persistent use of the landscape for different activities. If there is no evidence of differentiation between the distributions of cores and retouched pieces then it may be that flint was manufactured, used and discarded generally in the same places.

This ratio of cores to retouched pieces is biased towards the distribution of cores (the maximum density of cores is 39 pieces per 50 m^2, while the maximum count for retouched pieces is just 13), but an unbiased variable can be obtained by dividing the counts for each variable by these maxima. The result varies around 0 for areas with similar 'normalised' core and flake densities, is positive below 1 for areas with higher core values than retouch, and negative below -1 for areas with higher values for retouch than core. Positive values can roughly be equated with 'manufacturing areas' and negative ones with 'discard areas'. In practice the index varies between about -0.5 for 'discard areas' and 0.5 for 'manufacture areas'.

Mapping this variable (fig. 6 left) and mean-filtering it as above (fig. 6 right) clearly confirms an area of high core/retouch ratio north of the cursus, and also several clusters of low value. It is obviously tempting to interpret the latter as 'domestic' sites, but it should be remembered that what is actually revealed are areas in which, over an extended period of time, more discard activity took place than manufacturing. They may be domestic sites of some type, but equally they may represent deliberate discard of artefacts at these places as part of ritual or ceremonial activities. The high values around the Avenue are particularly suggestive in this respect.

6.2 Use as dependent variables

While the distribution of total flint densities may be the result of many different activities (each with different correlates), the core/retouch variable can be used for the differentiation of these activities into separate variables. Consequently it may be possible to use this variable for predicting which activities might be expected in which parts of the landscape.

To this end two normalised core/retouch ratio thresholds were set which allowed the production of binary maps indicating those areas which seem to have been used for manufacturing activity (fig. 7 left) and those which seem to have been used for discard (fig. 7 right). The aim of setting the thresholds was to obtain two variables which provided a clear distinction between these areas. After a little experimentation, values of 0.9 or less were classed as discard areas, while areas of 1.1 or above were classed as manufacture areas.

6.3 Application of the models

The same independent variables were adopted for the logistic regressions as for the linear multiple regression experiment, the only modification to the procedure for the linear multivariate model was that all variables were used untransformed because the logistic procedure does not require normally distributed variables (Rose/Altschul 1988). The output from the LOGISTIC procedure provides a summary of the results of the regression and gives the parameter estimates for those independent variables remaining in the model (tables 2, 3).

These intercept and parameter estimates were then used to generate an estimate of the *probability* of the event represented by the dependent variable for all locations

Figure 6. 'Normalised' core:retouch ratio index (left) and the same index mean-filtered as for total flint (right).

Figure 7. Manufacturing areas (left) defined as areas where the 'normalised' core:retouch ratio is below 0.9, and discard areas (right) where the ratio is above 1.1.

Table 2. Summary of logistic multiple regression model for 'manufacture areas'.

Step	Variable Entered	Variable Removed	Number In	Score Chi-Square	Wald Chi-Square	Pr > Chi-Square
1	DLBARS		1	78.6853	.	0.0001
2	DRIVER		2	88.4108	.	0.0001
3	ELEV		3	86.4427	.	0.0001
4	CHALK		4	28.1790	.	0.0001
5	SLOPEF		5	42.2459	.	0.0001
6	SE		6	33.7102	.	0.0001
7	NE		7	98.5428	.	0.0001
8	BREND		8	14.5768	.	0.0001
9	DSTREAMS		9	20.9877	.	0.0001
10	VIEWSUM		10	9.1127	.	0.0025
11	DENSRBAR		11	4.6568	.	0.0309

Analysis of Maximum Likelihood Estimates.

Variable	Parameter Estimate	Standard Error	Wald Chi-Square	Pr > Chi-Square	Standardized Estimate
INTERCPT	3.6050	2.1878	2.7152	0.0994	.
ELEV	0.1080	0.0320	11.3757	0.0007	0.574173
SLOPEF	0.5415	0.0710	58.1830	0.0001	0.749372
NE	-2.8268	0.3715	57.8992	0.0001	-0.638711
SE	-2.5466	0.3264	60.8808	0.0001	-0.692974
CHALK	-6.9748	1.2567	30.8042	0.0001	-0.835570
BREND	-1.3809	0.2650	27.1575	0.0001	-0.380738
DSTREAMS	0.1549	0.0289	28.6652	0.0001	0.526867
DRIVER	-0.0547	0.0110	24.7250	0.0001	-0.748168
DLBARS	-0.1525	0.0189	65.4072	0.0001	-1.015312
VIEWSUM	0.2034	0.0577	12.4014	0.0004	0.476920
DENSRBAR	0.0666	0.0296	5.0416	0.0247	0.425465

Association of Predicted Probabilities and Observed Responses

Concordant = 93.2%	Somers' D = 0.874
Discordant = 5.8%	Gamma = 0.883
Tied = 1.0%	Tau-a = 0.085
(390630 pairs)	c = 0.937

within the study area. This is achieved by the use of the cumulative logistic distribution function (Kvamme 1988: 371). Both models were therefore returned to the GIS, and the parameter estimates were used to solve the logistic equation from the landform and cultural overlays for all locations. Unfortunately, the difference in sample sizes between nonsites and sites produces a prediction heavily biased to the prediction of the larger sample: in this case nonsites. This is often undesirable, but it is possible to correct for the sample size bias after running the model by adjusting the intercept parameter by the natural log of the ratio of the sample sizes (Kvamme 1983b) and this adjustment was made to both of these models.

6.4 Manufacturing model

The *manufacturing* model (mapped as fig. 8 left) is complex result, incorporating all of the independent variables to generate the response. The probability of a site being a manufacturing site is increased by lower slope, lower elevations, easterly aspects, presence of chalk rather than clay with flint or valley gravel, proximity to shelter, low visibility of long barrows, low density of round barrows, greater distance from the Avon and presence of brown rendsina soil.

Geographically, the manufacturing model generally shows high values where they would be expected close to the region of the sampled areas: north of the Cursus (area 52) and around the southern rim of Normanton Down

Table 3. Summary of logistic multiple regression model for 'discard areas'.

Summary of Stepwise Procedure

Step	Variable Entered	Variable Removed	Number In	Score Chi-Square	Wald Chi-Square	Pr > Chi-Square
1	BREND		1	94.3617	.	0.0001
2	DLBARS		2	38.0198	.	0.0001
3	VIEWSUM		3	29.1272	.	0.0001
4	NE		4	23.2454	.	0.0001
5	DRIVER		5	19.0265	.	0.0001
6	DENSRBAR		6	20.4722	.	0.0001
7	ELEV		7	10.0973	.	0.0015
8		VIEWSUM	6	.	0.0711	0.7898
9	TBCEARTH		7	9.6831	.	0.0019

Analysis of Maximum Likelihood Estimates.

Variable	Parameter Estimate	Standard Error	Wald Chi-Square	Pr > Chi-Square	Standardized Estimate
INTERCPT	6.1250	1.3314	21.1635	0.0001	.
ELEV	-0.0521	0.0123	17.9639	0.0001	-0.276782
NE	-1.0030	0.2136	22.0439	0.0001	-0.226632
BREND	-2.7628	0.3861	51.1922	0.0001	-0.761737
TBCEARTH	2.7358	1.0944	6.2491	0.0124	0.420462
DRIVER	0.0383	0.00625	37.5140	0.0001	0.524288
DLBARS	0.1045	0.0108	93.1905	0.0001	0.695530
DENSRBAR	0.1170	0.0187	39.2001	0.0001	0.747777

Association of Predicted Probabilities and Observed Responses

Concordant = 87.5%	Somers' D = 0.757
Discordant = 11.8%	Gamma = 0.762
Tied = 0.7	Tau-a = 0.063
(336660 pairs)	c = 0.878

(south of area 67). Low values on Normanton Down (61, 79, 55), around Coneybury (51), south of Durrington Walls (60, 71, 69) and at the eastern end of the Cursus (76, 66 and 85) are also consistent with the data.

However the model predicts manufacturing areas in an unlikely proportion of the area southeast of the river. Examination of the equation, and of the independent variables suggests that the high values in the southeast are primarily influenced by the distance to long barrows and the density of round barrows indices. Both show extreme values in this area, and both have the type of dual relationship discussed above in relation to the linear multiple regression model. The area of high value in the northwest of the study area may be related to distance from the river Avon, although this seems to be also partly an effect of the distance to long barrows index.

For the same reasons as for the linear regression therefore, it seems likely that predictions away from the surveyed areas are unreliable and the model must be regarded as internal to the cluster of monuments rather than portable.

6.5 Discard model

The probability of a location being a discard site is increased by the presence of brown rendsina soils and absence of calcareous earths, higher altitudes, northeastern aspect, proximity to the Avon, low density of round barrows and low distance to long barrows. Both density of round barrows and distance to long barrows decrease the probability, which is curious as the two are inversely related. This is in contrast with the manufacturing area model, although the effects of these two variables may be

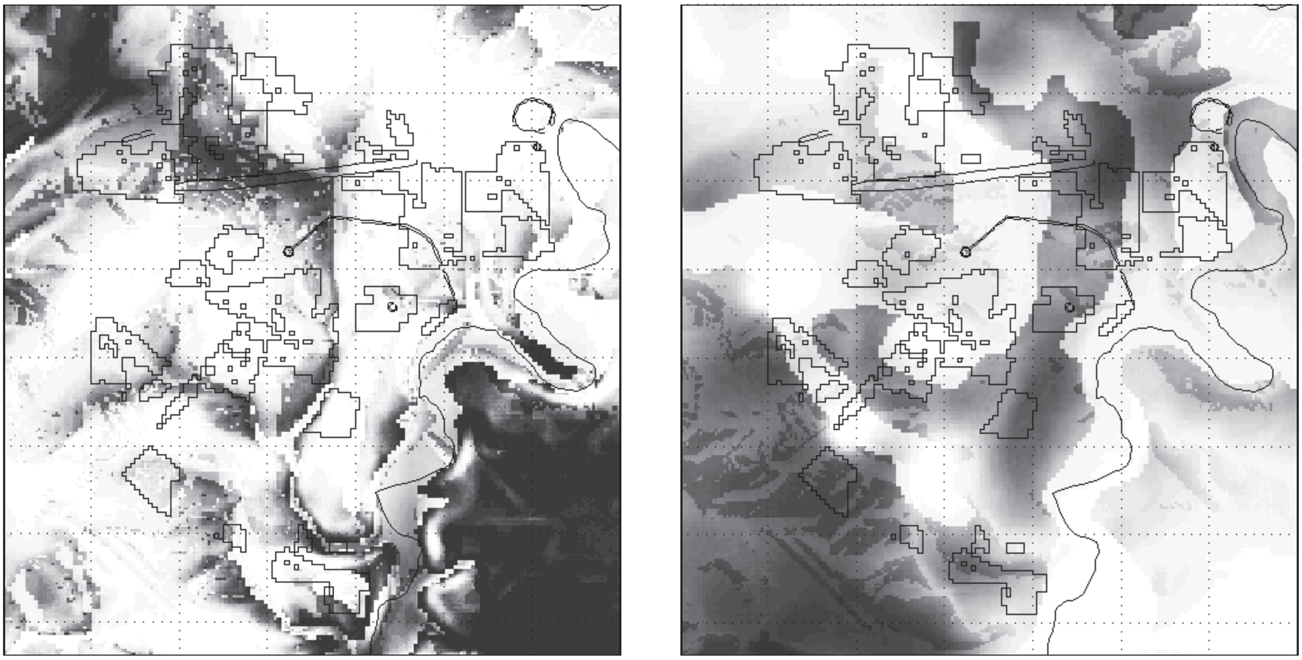

Figure 8. Probability of any location being a manufacturing area (left) or a discard area (right) according to the intercept-adjusted logistic regression equation.

marginal compared to soil. The marginal influence within the model of the cultural variables is enforced by the lack of long barrow visibility which shows insufficient correlation to appear in the model.

In spatial distribution (fig. 8 right), the 'discard' model also shows some encouraging features: high probabilities of discard sites around the elbow of the avenue (87), south of Normanton Down (67) and south of Winterbourne Stoke Crossroads (50) each seem to fit the data. Low probabilities north of the Cursus (52) contrast with the high values of the manufacturing model as should be expected as this forms the major axis of variation between the two areas selected as dependent variables.

6.6 Optimisation and assessment of performance

Assessment of the degree of confidence which should be placed in the predictions is difficult. In an ideal situation, further samples would be taken throughout the study area and the results compared with the predicted outcome for those locations. This is rarely possible, however, and it is perhaps slightly ironic that in situations where this were possible, there would then be rather less point in constructing a model.

One source of data concerning model performance is the ratio of observed responses to predictions within the data itself, and this is provided with the output from the procedure. In the case of these models, this indicates that the manufacturing area model makes 93% correct predictions against nearly 6% incorrect, while the discard area model is a poorer fit with 87.5% correct against nearly 12% incorrect predictions. However this is widely recognised as an extremely optimistic assessment of the performance of the probability model and Warren (1990b) recommends withholding a random control sample of observations from the prediction and then comparing the predictions with these controls. Carmichael (1990), used the control procedure advocated by Warren and found that a 72% correct prediction rate amongst the sites used for prediction produced only 55% correct prediction amongst the controls.

In this case, however, the samples are grouped tightly together within walked areas so that any randomly selected subset of points would still have fallen within the same surveyed areas as the cases included in the study. Intuition, and experience with the linear regression model suggest that these are likely to be the best performing areas of the model. Consequently little confidence could be held in any assessment of the model based on such a sample of sites, and it was felt that insufficient benefit would probably be obtained to offset the removal of the cases.

One method to assess the performance of the model is to force it to predict the same percentage of the surveyed area

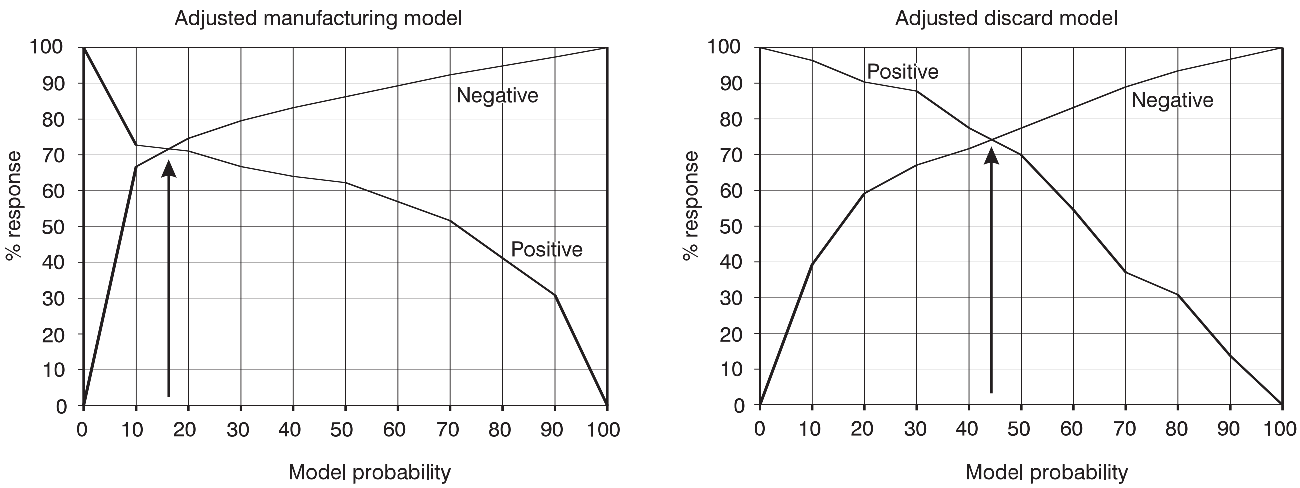

Figure 9. Cut-off points for the intercept-adjusted manufacturing model (left) and for the intercept-adjusted discard model (right) based on the probability which results in an equal proportion of correct positive and negative responses.

as a positive response as occurs within the sample data, and then comparing this prediction with the actual result — a procedure analogous in many ways to the examination of residuals of linear regressions. To 'force' the prediction, a threshold was selected for each probability map which generated the same percentage of positive responses within the worked areas as the original dependent variables.
An appropriate threshold was obtained from cumulative frequencies of the probability maps for the surveyed areas. The result of this procedure can then be compared with the original dependent variable, with four possible outcomes. The model may (1) correctly predict no site, (2) correctly predict a site, (3) incorrectly predict a site or (4) fail to predict a site.

It remains to decide on an appropriate threshold for prediction of sites from the adjusted models. It has already been seen that prediction of the 'correct' number of positive responses will not provide a good prediction of presence. Increasing the threshold which is used as a prediction increases the number of incorrect predictions of negative responses but also increases the number of correct predictions of positive responses. The optimum solution must therefore be sought from the models, and occurs when the proportion of correct predictions for positive responses is equal to the proportion of correct predictions for negative responses. This probability value is referred to as the cut-off point for the model, and can be obtained by graphing the observed proportions of correct positive and negative responses against the predicted probability. Observations for these graphs were made by repeated application of the models at appropriate intervals. The point where the positive and negative response curves cross provides both the optimum point of the model and the percentage of correct predictions. From the graphs in figure 9 it can be seen that this cut-off point for the manufacturing model occurs at 15%, where the model correctly predicts 71% of positive responses (manufacturing areas) and 72% of negative responses. For the discard model, the cut-off occurs at 44% where the model predicts 73% of positive responses (discard areas) and 74% of negative responses. The four alternatives within the known data values are mapped as in figure 10 left (manufacture) and right (discard).

6.7 Using the logistic models

The final models provide a method for assessing how likely it is that any location within the landscape would contain a lithic assemblage with either of two particularly interesting characteristics. Clearly the most obvious application of such a model is to the management of the archaeological resource in which they might be used as a method for assessing the relative impacts of alternative courses of action on the (unknown) archaeological resource. However, although using them for this purpose is valid, the models must be understood before they can be best utilised.
For one thing, the predictions for manufacturing areas in the far northwest and southeast of the study area are spurious, and should be disregarded. An alternative model may be developed for areas which are marginal or outside the cluster of monuments, but these two are not applicable for the reasons outlined above.

The models can be used to make predictions in a sophisticated way. The optimum predictions which were obtained from the cut-off points of the models may not be

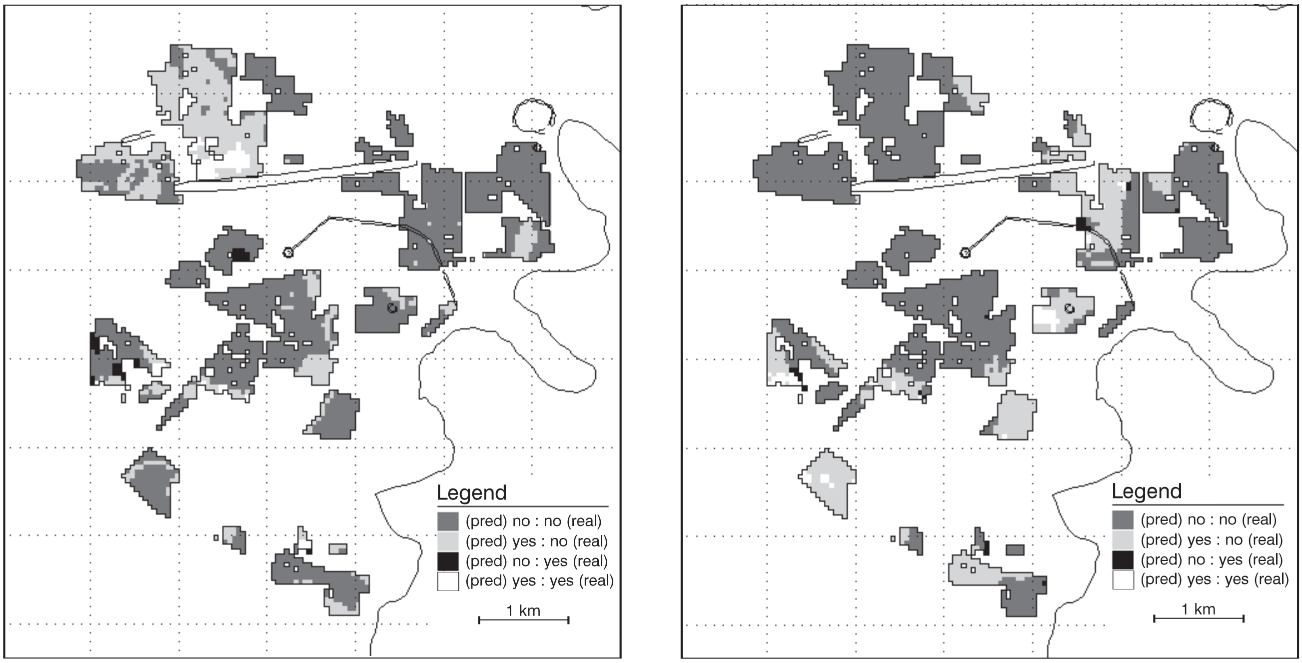

Figure 10. Comparison of predictions made at the selected cut-off points with the observed archaeological values for presence of manufacturing areas (left) and discard areas (right).

the most useful predictions from an archaeological point of view and alternative thresholds might be chosen in order to predict more sites at the expense of nonsites. Given enough resources, of course, an archaeological management strategy would not require a model at all but include provision to survey all areas. In reality, however, management strategies are constrained by resources which in turn restrict the area which may be surveyed. Depending on this, thresholds may be defined which progressively reduce the area which needs to be surveyed, while maximising the likelihood that the interesting areas will be within them. For example, although the manufacturing model predicts roughly 70% of the sites at the cut-off point of 45%, a threshold of 20% may be selected to obtain a prediction which accounts for 90% of the manufacturing areas at the expense of predicting 40% of the non-site areas as manufacturing areas also.

7 Conclusions

It was the aim of this paper to examine whether or not predictive modelling approaches provide a reasonable alternative to spatial interpolation techniques in the analysis of lithic density data. The result of the attempt to use linear multiple regression to predict the lithic densities from correlated variables is, from this point of view, disappointing. That only 25% of the variability within the flint data can be accounted for in this way suggests strongly that the types of deterministic models applied with some success in some North American situations may be inappropriate within complex cultural landscape settings such as this. It is particularly revealing that the majority of the predictive power of the model (low though that is) is accounted for by cultural indices, particularly the density of round barrows, rather than the indices of landform which have been used in other contexts. Although some of the failure of the linear regression to account for the variation in the lithics might be due to the compound nature of the dependent variable, and the explanatory power of the logistic regression models is far more difficult to assess, it is likely to be of the same order as the multiple regression because the same predictors were used for both.

In both cases, the portability of the models is compromised by the use of predictors which seem to have complex relationships with the data. The extreme predictions which occur outside the convex hull of the surveyed areas in both the linear multiple regression model, and both logistic models seem best explained as ‘over-training’, in the sense that the model is too specifically related to the variation *within* the cluster of monuments to provide a useful estimate of the density of lithics *between* monument clusters. In a sense this is a problem of scale: at the local scale, the relationship between density of monuments and activity may be that the activity takes place away from monuments while at a regional scale this relationship cannot be sustained.

Although untested at present, one way of circumscribing this may be to restrict the variability of the independent variables to that which is found within the data itself through reclassification and in this way restricting the prediction to variation which is within the 'experience' of the regression. Alternatively the independent variables may be left in an unclassified form so as to include the maximum information in the regression, but the prediction may be restricted to the maximum and minimum values of those variables which are observed within the archaeological data.

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The contribution of GIS to the study of landscape evolution in the Yorkshire Dales, UK

1 Introduction

This paper sets out the background to the application of GIS to a long-term research project on archaeological landscapes in the Yorkshire Dales. A pilot project has identified roles for both GIS and CAD software in providing a digital map-based environment for storing and analysing data from fieldwork. The facilities offered by the software will support new approaches to investigating the landscape, but the increased sophistication of GIS software in particular places greater demands on the quality of the data being analysed. The pilot project has helped to clarify long-term goals, introduce new goals and develop strategies for data collection.

The study area is in the Yorkshire Dales, in the uplands of northern England between the Stainmore Gap in the north and the Aire Gap in the south. The highest point is Whernside at 736 m OD, and the area includes the highest hillfort in England on the summit of Ingleborough (723 m). Within this study area, the pilot project has concentrated on an area 10 × 12 km between the northern end of Wharfedale and Wensleydale, roughly between the villages of Buckden and Bainbridge. This area reflects the general topography of the Yorkshire Dales — long, narrow glacial valleys dissecting areas of upland. The nature of the Dales landscape suggests that GIS software will be particularly useful: extremes of topography are concentrated within a relatively small area, and provide an important backdrop to the development of settlement patterns from prehistoric times to the present day. Environmental data relating to climate, vegetation and geomorphology constitute a suite of variables that is now a traditional element of locational analysis in archaeology. GIS software offers the ability not only to store the large amounts of data involved, but also to develop new ways of visualising the complex interaction between them. Given the marginal nature of the study area in terms of subsistence exploitation, small changes in environmental variables can be expected to have a significant impact. There is no arable production in the study area at present, for example, but extensive field systems show that cultivation penetrated high into the Dales in the past. The pilot project focused attention on the nature of the archaeological evidence in the study area, and the role of GIS in supporting future developments. These two issues are considered below.

2 The nature of the archaeological evidence

Twenty years ago Challis and Harding wrote in their review of the north of England in later prehistory: 'The present state of archaeology in the limestone areas is desperate. There is no individual site report yet available despite numerous small excavations. Publications are of a generalised and imaginative nature.' (Challis/Harding 1975: 184). The traditional model of later prehistoric settlement in the region was based on the belief that '..the capacity of the Pennine dales to support population was severely limited. Semi-nomadic pastoralism was the only practicable way of life.' (*ibid.:* 185). This view has a long history, arising from the work of Wheeler at Stanwick, and Piggott's description of 'Celtic cowboys and shepherds, footloose and unpredictable, moving their animals over rough pasture and moorland...' (Piggott 1958: 25).

Recent work has begun to challenge this picture of northern England towards the end of the prehistoric period. Evidence from Stanwick shows a greater emphasis on mixed agriculture (Haselgrove *et al.* 1990), but this important site lies in a relatively rich lowland area on the fringes of the Dales. Within the upland area the Swaledale Ancient Land Boundaries Project has identified extensive field systems and a permanent settlement pattern originating in at least the middle Iron Age (Fleming/Laurie 1990, 1992). Other work in the Dales area is adding to the evidence for a widespread settled landscape first identified by Arthur Raistrick (Raistrick 1939).

One of the major problems currently facing any investigation of the archaeology of this area is the lack of chronological data. The identification of sites as 'Iron Age/Romano-British' is frequently based on comparison with sites that were explored in the last century without reference to stratification, or excavations earlier this century before the availability of radiocarbon dating. Fleming's excavation of a house platform at Healaugh in Swaledale has indicated the unexpected chronological depth that may be awaiting a closer examination of settlements and field systems (Fleming/Laurie 1990). The earthwork evidence associated with past settlement in the Yorkshire Dales is impressive in its extent and complexity, but it represents a palimpsest of landscape evolution from at least the Bronze Age to modern times. Patterns of exploitation have changed, for example, from Mesolithic hunting to later prehistoric farming, and large-scale sheep farming on monastic holdings in the Medieval period. Alongside this must be set the exploitation of stone and mineral resources from prehistoric to industrial times. All of this evidence can potentially be located in space and time, but the only incontrovertible data currently available describes spatial location. The statistical analysis of spatial patterning within the evidence is still a goal for the future, and data collection towards this goal must encompass more than just the morphological classification of archaeological remains (Fleming 1976). GIS software can play an important part in the management of the multidisciplinary data that are essential for future investigations, and the rest of this paper considers its role in relation to the particular problems that arise in the Yorkshire Dales.

3 The role of GIS

The requirements of cultural resource management and academic research provide the rationale for the use of different levels of functionality within a GIS. The collection of spatially-referenced data on antiquities continues the tradition of Sites and Monuments recording that is now an integral part of the planning process for new building development. Within the Yorkshire Dales study area there are several organisations whose interests impinge on the management of archaeological remains, mainly through control of the planning process and the provision of subsidies to support traditional farming practices. The full functionality of a GIS is perhaps not essential for these management purposes, since CAD software is capable of providing adequate map-based output of known archaeological evidence matching specified criteria. For research purposes, there is an additional requirement to manipulate data from a range of different sources in order to analyse the archaeological evidence, and GIS software provides useful tools for this task.

The pilot project has identified important considerations for defining the structure of a spatially-referenced data set, one of the most important being the flexibility to accommodate increasingly detailed data from a variety of sources. Existing archives use six or eight figure National Grid References to record data from maps and aerial photographs commonly at 1: 10 000 scale, and some of the conventions used in these archives may not transfer easily into a GIS environment. Multiple entries with identical locations are allowed, for example, as well as the use of a single grid reference to represent an area of poorly defined archaeological evidence. Examination on the ground can add considerable detail to the evidence visible from aerial photographs, and excavation and sampling will contribute still further to what is visible on the surface. The minimum resolution of the software is a single pixel, and the scale that this represents on the ground obviously needs to reflect the level of detail expected in the data.

There is a practical problem in parts of the study area in the reverse process of working from data derived from maps and photographs to specific locations in the field. The National Grid is an abstract system that is not visible on the ground, and in remote moorland with few obvious natural features it can be difficult to identify eight-figure grid reference locations precisely. A hand-held Global Positioning System has been used in the pilot project to overcome this problem, but in some cases the accuracy and precision of such a system may be far greater than that used in the original record. Many entries in the Sites and Monuments record are based on field observations that were recorded as annotations on 1: 10 560 maps, and where the evidence is very slight or of doubtful identity it can be extremely difficult to find it on the ground. This process of field checking is an important continuing process. It would not be wise to build sophisticated GIS models using data that had not been subjected to such an assessment, and so a record of the checking process itself becomes part of the data set.

An improvement in the quality of surveyed field data will enable questions to be raised about the definition of individual ‘sites’ and their inter-relationships within archaeological ‘landscapes’. At a functional level of interpretation it is currently impossible to be certain where a ‘site’ begins and where it ends, since spatial association is no proof of contemporaneity. Moreover, small moorland settlements may have been part of a transhumance system that integrated widely separated yet contemporary elements of the settlement pattern. Data structures and manipulative techniques in a GIS will need to be sufficiently flexible to accommodate both present uncertainties and future developments, allowing links between landscape elements to be easily established and updated.

Exploitation models of Dales landscapes will increase in complexity with improvements in chronological data, but these data will themselves carry varying degrees of uncertainty depending on whether they were obtained by, for example, radiocarbon dating or typological comparison. The relative dating of some landscape elements may be based on spatial relationships such as overlapping distributions or differing orientations, as proposed for the field systems at Grasssington (Raistrick 1938). These attributes need to be included in usable form in a GIS environment, so that landscape evolution can be investigated as a dynamic process. The development of temporal functionality within GIS is an area of current interest (Castleford 1992), and the implications for manipulating archaeological landscape data are of obvious importance.

Environmental evidence will play a significant role in understanding the settlement patterns of the Dales. One of the strengths of GIS is the ability to manipulate three-dimensional data, allowing the investigation of the relationship between settlement, environment and topography. Given the marginal nature of the area, settlement models may reflect different agricultural strategies in different climatic conditions. Extremes of altitude are likely to influence exploitation strategies in addition to the basic background of geology and soils. It is common now to see archaeological distributions plotted against these environmental factors by GIS software, but new combinations of variables can be used to model factors, such as exposure, that are likely to have exerted a significant influence on settlement location. There is as yet no clear evidence to link high-altitude sites in the Dales to an expansion of settlement during the climatic optimum of the Bronze Age, which might be expected by analogy with other upland locations in England. Another key area for research is the spread of Anglian and Norse settlement, and the extent to which it filled in, supplanted or extended existing Romano-British settlement patterns, and this too may be related to the attractiveness of different locations for settlement. GIS software can be used to model the distribution of 'favourable' settlement areas using varying criteria, comparing different models with the observed distribution of relevant sites. This is currently limited to a static, synchronous approach, and the analysis of evolutionary processes remains a challenge for the future that may exceed the capacity of a GIS.

The definition of different boundaries to study areas can have a significant effect on the results of spatial studies (Martlew 1981: 37). Our modern perception of the Dales landscape tends to influence approaches to investigating its archaeology. In the uplands between the Dales, the growth of peat has undoubtedly masked some of the archaeological evidence, and further fieldwork is necessary to confirm that blank areas on the distribution maps are indeed archaeologically sterile in terms of settlement evidence. Lithic scatters are often encountered in this zone, but their study is seriously biased by the long tradition of flint collecting that exists in this area. It has been estimated that four fifths of the flint implements recovered have not been reported or provenanced (Roger Jacobi, quoted in Spikins 1993: 9) Particular concentrations of detailed evidence may be nothing more than a reflection of modern archaeological activity, and this needs to qualify any GIS models of past exploitation.

Topography provides a neat division for study areas based on individual dales, with a large proportion of the earthwork evidence surviving on the lower dale sides. Modern lines of communication follow these lower slopes, but it is clear that some Roman routes at least followed the high ground. Focusing on the dense and accessible distributions of sites on the lower ground may possibly introduce a chronological as well as a spatial bias, but this hypothesis remains to be tested. With settlement concentrations on the break of slope between the steep dale sides and the flat, marshy dale floors, the visibility of archaeological evidence may be affected by alluviation, as well as by subsequent use of the same restricted zone. This must also qualify work with GIS models, but as yet there is little in the way of hard data on which to assess archaeological visibility.

As well as influencing the results of spatial analyses, boundaries are an important aspect of landscape evolution. Documentary evidence provides hints of land use back to early Medieval times within administrative units that have changed over time, and the record includes detailed lists of topographical features and artificial markers along disputed boundaries. Identifying these boundaries in the field, and investigating the surviving evidence for land use associated with different areas, can help to identify different chronological phases in the evolution of the landscape. GIS software is capable of manipulating different subsets of the data, once the boundaries have been located by a combination of documentary research and fieldwork.

4 Conclusion

Traditional quantitative methods of spatial analysis are not appropriate at the current stage of investigation into the evolution of the Yorkshire Dales landscape. The quality of the archaeological evidence is not yet good enough, both in terms of chronology and the detailed morphology of sites. A small-scale pilot study has shown that GIS software offers considerable potential through visualisation and modelling, rather than statistical techniques. The topographical extremes in the study area, and its marginal character for agriculture, are likely to mean that environmental factors will have played a significant role in landscape evolution. Data representing the physical and environmental background can be manipulated in a GIS to produce new, composite variables for inclusion in hypothetical models, and subsets of the data can be selected to take account of different subdivisions of the landscape in the past.

The clearest result of the pilot study is that significant improvements must be made not only in the quality of archaeological data, but also in the quantity of supporting data that must be included in an investigation of landscape evolution. The value of GIS software lies in its capacity to support new ways of modelling and analysing spatial data, beyond simply acting as a sophisticated graphical output system for standard database queries. Continuing fieldwork will improve the data set, and while GIS software has much to offer at this early stage of the project, it too must continue to develop if it is to support more complex models of landscape evolution in the future.

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Extending GIS Methods for Regional Archaeology: the Wroxeter Hinterland Project

1 Background

In September 1994 a 3 year research project to study the Roman town of Wroxeter and its hinterland was started at the University of Birmingham Field Archaeology Unit (BUFAU). The project is funded jointly by the University and the Leverhulme Trust, and aims to take forward many aspects of regional archaeological research in Britain, including the application of GIS and remote sensing in both the design and analytical stages, the close involvement of the local community, and the study of urban-rural relations. This paper, the first in a series that will describe the progress of the Wroxeter Hinterland Project, sets out our intentions and preliminary results, concentrating on innovative uses of GIS.

1.1 The research area

Wroxeter, located between the modern towns of Shrewsbury and Telford (county Shropshire; see fig. 1), was the Roman Civitas capital (named *Viroconium Cornoviorum*) of the Cornovii, an Iron Age tribe that is thought to have lacked a centralised structure before the arrival of the Romans in the mid-first century AD (fig. 2). Yet, at 64 hectares, Wroxeter has the fourth largest walled area in Britain and preliminary geophysics results have already shown it to be much more densely settled than was thought previously. How could such a large and, given the splendour of its public buildings, rich town develop and prosper in a region that was both economically and politically peripheral? What was its economic and social basis? These are questions that can only be answered by a study of the towns' hinterland, the area that must have contained some of the pre-Roman tribal elite, and must have formed the main economic basis for day-to-day life in the town. This hinterland must have extended at least as far as the nearest major natural boundaries and the next nearest minor towns - an area of some 30 by 40 km.

1.2 The archaeological evidence

A compilation of existing archaeological records has resulted in a database of some 1600 pre-Norman Conquest (AD 1066) 'sites', the bulk of which belongs to the Iron Age and Roman periods. Very little targeted surface archaeological research has been done in the area, the records consisting mainly of reports of chance finds and of crop or soil marks discovered by aerial archaeology (Whimster 1989). Site distributions may be heavily influenced by differential preservation and visibility effects, and reporter bias.

2 Use of GIS in the Project

The Wroxeter Hinterland Project is designed to study the settlement history and the various processes of Romanisation in the study area from the Later Pre-Roman Iron Age down to the sub-Roman period. The design incorporates GIS at a number of levels:

- as a data management tool, to hold data sets originating at multiple sources (from County records to satellite imagery) as a georeferenced map 'stack';
- as an image processing and mapping tool, to process and interpret non-invasive prospecting data ranging from surface geophysical surveys to airborne remote sensing;
- as a modelling tool for describing both the archaeological landscapes in the study area and our imperfect knowledge of those landscapes;
- as a spatial analysis tool, to study the contributions made to archaeological knowledge by a variety of non-invasive prospecting methods.

2.1 Data management

To keep on top of the data collected and generated by the project, GIS is used to collect, hold, and analyse all available archaeological records, vertical and oblique aerial coverages, a variety of geophysical and remote sensing data sets, and a number of maps representing environmental variables. This use of GIS is non-controversial and is now beginning to be accepted as the standard for regional archaeological research.

2.2 Image processing

The WHP will have remotely sensed data covering the whole (Landsat TM) or part (airborne TM and CASI) of the study area, vertical and oblique air photographic data covering large parts of the study area, and surface

Figure 1. Location of the Wroxeter Hinterland Project research area.

Figure 2. Map showing approximate pre-Roman tribal territories in Britain (after Millett 1990: fig. 16).

geophysics data covering sample areas. Whereas the data for the hinterland will be used as a control on existing records, special high resolution imagery will be acquired for the town of Wroxeter itself in order to produce high quality mapping. Existing maps of the town (fig. 3) have been produced almost exclusively on the basis of air photographic evidence, and have not had the benefit of modern photogrammetric techniques for accurate mapping.

Evidence taken from vertical and oblique APs, from ground-based geophysical measurements and aerial remote sensing, and from excavations can now be collated, using GIS technology, to produce a georeferenced graphical database of Wroxeter and its direct environs (stretching approximately 500 meters outside the town defences). Processing this imagery with the GIS in preparation for mapping will involve algorithms ranging from stereo-DTM generation to orthorectifying transformations and enhancements in the spatial and frequency domain. The processed imagery will then be ready to be digitally mapped off screen.

By interpreting and mapping the archaeological features present in the resulting georeferenced and enhanced image database in both a topological, a functional, as well as a chronological sense, digital vector maps can be produced that represent the spatial structure, the functional structure, and the chronological development of the site. These might form the basis for a Digital Interactive Atlas of Viroconium, allowing users to query any of the Project data layers and to display the results.

2.3 Modelling

The authors, having written earlier about the pitfalls of current GIS applications (Gaffney/Van Leusen 1995; Van Leusen 1996), intend to develop innovative GIS solutions to the problems of modelling archaeological landscapes, both in the environmental and in the cognitive vein. We feel that GIS models should derive most of their use from either confirming or refuting theoretical constructs, and previous applications were lacking in that respect. Even more importantly, any model that is based on real archaeological data should explicitly deal with the biases that are inherent in such data, and we intend to use GIS to model such biases.

2.3.1 Linking Archaeological Theory and GIS

GIS modelling will be applied to our main research question, which concerns the impact of Romanisation on the late Iron Age tribal society of the Cornovii. Taking current models of this process by Millett (1990) as our starting point, we intend to extend GIS methodology into the largely uncharted territory of non-environmental data.

The problem of urban-rural relationships in archaeological research is a general theme within many periods and areas of study. Such analyses have a specific resonance within Roman studies where urbanisation, twinned with Romanisation, has long been a suitable topic for research. The reasons for this are not hard to discern, especially in those provinces — including Britannia — where there is an apparent lack of urban traditions or where pre-Roman trends towards urbanisation were weak, and the development of towns and cities is interpreted as only one variable in the process of Romanisation. The study of Wroxeter and its hinterland is just one example of this research theme in action, but it can also be neatly grouped with the recently growing number of regional or 'landscape' studies in archaeology.

There is a complex web of interactions between any urban centre and its (normally directly adjacent) rural hinterland. This complexity extends into the functional, geographical, and chronological domains: which activity grew up when and where, and why? Even modern towns are notoriously difficult to study as living organisms, and a dead town such as Wroxeter, for which evidence of any sort is patchy at best, would seem to present insurmountable problems. However, we should measure our efforts not against an ideal, but rather against current archaeological practice. Hypotheses about the origins of Roman towns in general should be tested against the evidence generated by the project, and refined.

Millett (1990; see tables 1, 2) has presented such hypotheses. In particular, his models of early Roman impact on native society and of settlement dynamics during the later Empire should be amenable to testing. In order to avoid a lapse into brute force implementations of environmental models, we will attempt to extract culturally significant and spatially referenced information from the existing archaeological records and compare this with the more traditional economic indicators.

We have argued elsewhere that patterning in 'cultural' data should be as amenable to GIS analysis as is economic patterning (Gaffney/Van Leusen 1995: 370-371). For example, we can conceive of Romanisation as the combination of a wide variety of spatially variable cultural markers distributed across the landscape. On this basis we should be able to use architectural, morphological and artefactual data to construct maps depicting the spatial dispersal of status and degree of Romanisation across the landscape. These can then be compared with maps derived on a purely economic/environmental basis, and the differences between them should provide us with pointers to the social processes at work in the town/hinterland relationship. Inversely, we will construct models of status distribution based on archaeological theory, and test these against existing and newly acquired data.

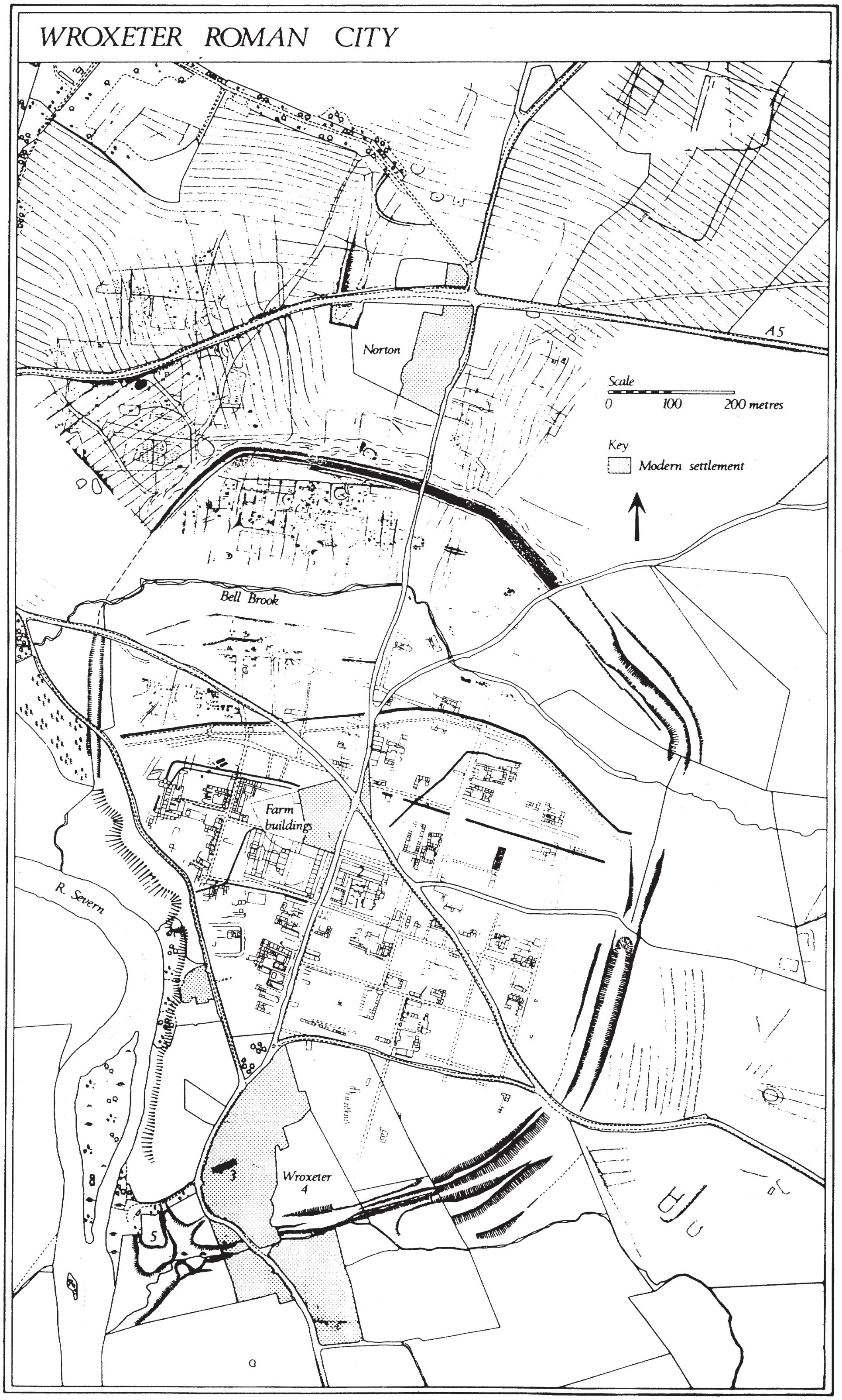

Figure 3. Topographic and archaeological features at Wroxeter, as mapped from air photographic evidence by D. Wilson (after Barker 1990: Fig. 3).

Type of LPRIA society	Nature of Roman impact	Type of Romanized society	
Centralized & hierarchical (e.g. oppida & coinage)	Reinforcing (i.e. élites adopted)	Successful towns & early villas	e.g. Catuvellauni
	Destructive (i.e. élites replaced or prolonged military occupation)	Poor urban growth & slow villa development	e.g. Iceni
Decentralized & egalitarian	Reinforcing (i.e. stimulation to nascent élite)	Delayed & limited, but successful towns & villas	e.g. Cornovii
	Destructive (i.e. prolonged military occupation)	Military zone with limited town & villa growth	e.g. Carvetii

Table 1. Simplified model of Roman impact on native societies (after Millett 1990: Table 4.3).

The seeming lack of highly romanised buildings (‘villas’) in the hinterland and the contrast with the relative opulence of the urban area is a case in point. It seems reasonable to assume that the Roman urban elite was essentially a continuation of the existing Iron Age elite. However, where are the original settlements associated with such groups? Emerging evidence for LIA activity within the town area indicates that the primary conduit for social display and development even then was via the urban centre. What conditions both prompted and allowed such a development? The lack of similar change in the countryside is intriguing given that we must assume that agricultural productivity supported urban advancement. Will these contrasts permit us to isolate the pre-existing social relations that allowed one part of the community to invest in the town, apparently at the cost of other groups or, alternatively, are we seeing a ‘resistance’ to Roman culture by some indigenous groups? Or are we just being wrongfooted by the limited visibility of ‘villa’ structures in the current Shropshire landscape?

2.3.2 Bias modelling

Since both theoretically derived and data-driven models in archaeology are ultimately based on our knowledge of the archaeological record, keeping control over the quality of our basic data is of prime importance in the Wroxeter Hinterland Project. This control is achieved in two ways:

– by assessing and then compensating for biases in the text based and mapped data; and
– by providing independent mechanisms of control with which to test the validity and power of the models we develop.

The sources for our archaeological data — national and county records, previous studies and surveys — are of wildly varying quality. The archaeological record is ‘filtered’ by formation processes, visibility and reporting biases, and past and current recording practices. For example, enclosures identified from aerial photographs (largely undated but generally ascribed to the Iron Age on morphological grounds), give us high-quality mapped data, but at the same time we may be sure that differential visibility and recording are biasing the distribution of these data to such an extent that they cannot be used prima facie to build or test models on. By modelling the biasing factors (differential soil responses, geological processes, land use both past and present, accessibility) and using them to compensate for the bias, we hope to arrive at a more credible distribution map for these and other data.

To further assess the quality of our mapped archaeological data (acquired from both existing records and our own field work) we have instituted a programme of fieldwalking based around 3 transects centred on Wroxeter and cutting

Early Empire
Concentration of élite power at *civitas* centre
Villa development near these centres
Social competition at centres
Taxation collected at centres
Production concentrated near centres
Trade concentrated on centres

Late Empire
Social control continued at centres, stifling economic growth
Competition moved to villas which surround centres
Taxation collected at various places, causing decentralization
Peripheral areas showed economic growth
Producers at boundaries fed goods into several *civates*

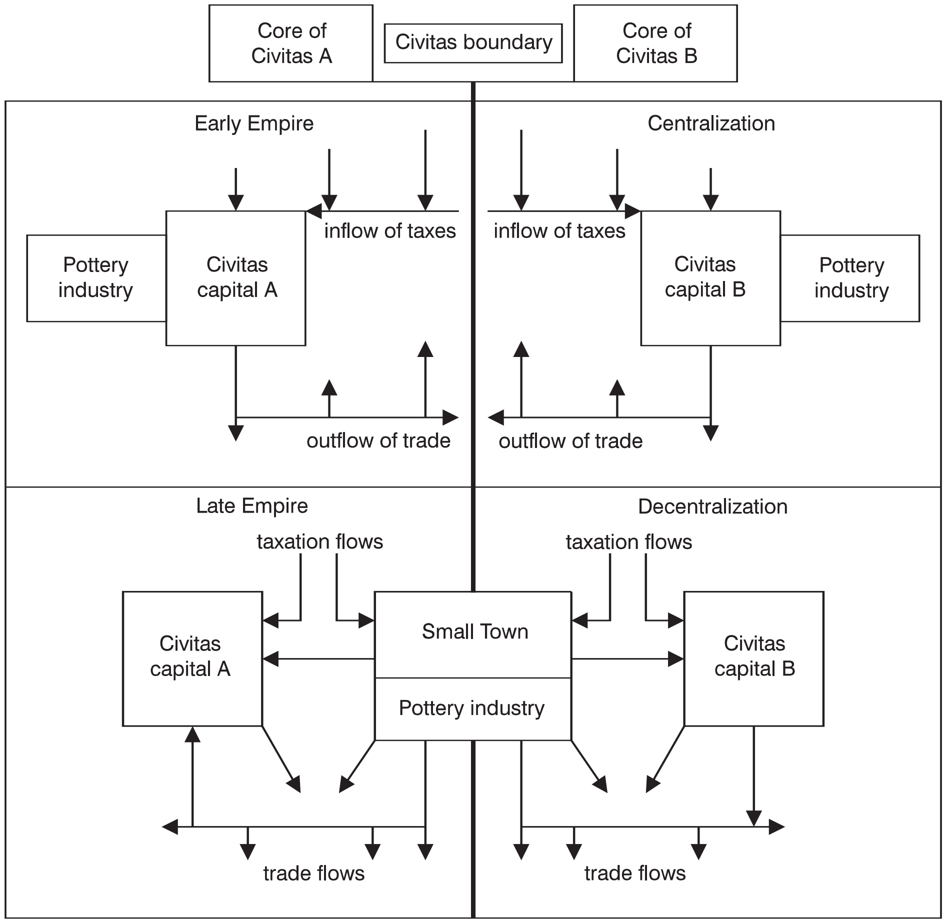

Table 2. Simplified model of the influence of taxation on settlement centralisation (after Millett 1990: Table 6.3).

across the study area’s dominant topographic features (fig. 4). The choice of transect and orientation was dictated by the need to study the variation of activity (as opposed to simply settlement) with distance from the urban centre (Gaffney *et al.* 1985). Using a continuous grid retrieval system based on the UK national grid it will be possible to sample circa 10% of the transects’ area. This should allow the team to study distance dependant site and non-site activity within the transects.

Equally, the mapped environmental data which is normally used in regional GIS models and which is largely based on the availability of printed map sheets of variables such as soil types, geology, hydrology and land use, suffers from a number of flaws including ignoring small-scale variation in the landscape, and employing cartographic conventions such as choroplethe mapping to represent data that vary continuously across the landscape. These biases we hope to compensate for by returning to the original field observations on which the maps were based, and constructing higher-quality maps from these.

2.3.3 Project management

GIS models will also be used to steer project development, for instance in determining our programme of test excavations of enclosures — the major archaeological feature in the area, about which little is known for certain. Several hundred enclosures exist in the project area, over one hundred of which have been classified on morphological grounds by Whimster (1989). We expect these features to reflect some of the upheaval caused by the advent of the Romans and the growth and eventual decline of Wroxeter, and will use GIS to study their distribution and to target specific enclosures for excavation.

2.4 Spatial Analysis

One of the aims of the Wroxeter Hinterland Project is to provide a laboratory for research into non-invasive prospecting methods. In general, not much is known about the precise relations between non-invasive prospecting data, such as magnetometry, and the underlying archaeology, or

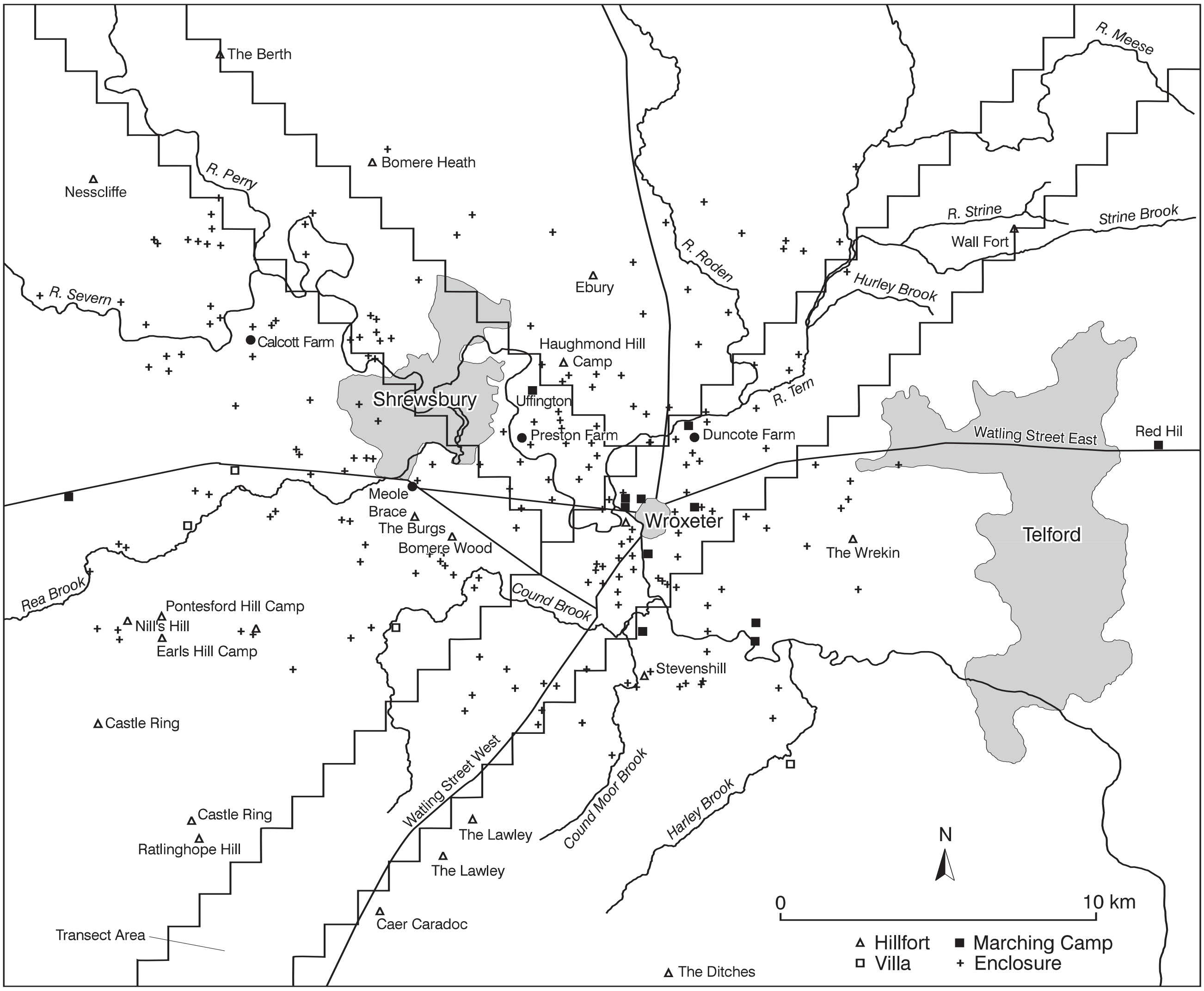

Figure 4. Field work and remote sensing transects for the Wroxeter Hinterland Project are used to collect control data across the main geological axis of the terrain (NE-SW) and along the Severn Valley (NW from Wroxeter).

about the relative contributions to archaeological knowledge of the plethora of non-invasive techniques that are currently available (David 1995). We intend to explore these questions in collaboration with Dr Kenneth Kvamme (currently at Boston University), by conducting extensive testing and multivariate analysis of techniques ranging from ground based resistivity, gradiometer, GPR and seismic to airborne photography, multispectral scanning, and thermal imaging. We expect multivariate analysis of properly georeferenced data to tell us how various techniques are correlated to each other, and how much information they contribute to the final picture. This should allow us to make some practical decisions as to which technique will be the most efficient in the given circumstances.

3 Regional Archaeology and the Local Community

It is an unfortunate fact that, in Britain at least, it has become increasingly difficult to allow the close involvement of the local community in major archaeological research projects. Places for field work are generally taken by students that need the experience, and requirements of efficiency and planning have made it increasingly difficult to use volunteers for any but the most circumscribed work. The Wroxeter Hinterland Project is changing that by stressing the importance of involving the local community, not only in field work, but also in finds and computer processing and generally assisting the research team. Since all its field work is funded by charities, it is remarkable that, one year into the project, we have over 200 volunteers working for us as field workers, map digitisers, office staff, geophysics teams, and even as a pilot. These people are mostly untrained but are very keen to learn, and it is possible to work with them throughout the year — not just when term time has ended.

We try to keep these volunteers up-to-date by issuing a bimonthly newsletter and by organising regular meetings and open days at which volunteers mix with project staff and each other. The success of this strategy leads us to think of extending volunteer involvement to conduct a full scale Parish Survey of the area, a huge task which would be impossible to contemplate with just two project staff available.

4 Concluding remarks

The Wroxeter Hinterland Project is an ambitious undertaking and is unusual in a number of ways. It is attempting to study one of the more arcane, and hotly debated, social processes — Romanisation — using technological and theoretical approaches in a manner never previously attempted. The project incorporates a complex group of data sources within a single 'critical' database, some of which have never been used in an archaeological context before, whilst others have rarely been integrated in such a comprehensive manner. Finally, the project, despite its highly technical and academic base, is being carried out with the explicit aim of encouraging public participation and aims to involve local communities at every level.

There is obvious risk in such an innovative approach, and we cannot expect to be fully successful on all counts, but preliminary results have been extremely promising and we hope to be able to confirm this at the 1996 CAA conference.

5 Envoy

The project team maintain World Wide Web pages at *http://www.bham.ac.uk/BUFAU/Projects/WH/* which provide an up-to-date review of activities and a means of directly contacting the authors.

Acknowledgements

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Gary R. Lock

Multi-dimensional GIS: exploratory approaches to spatial and temporal relationships within archaeological stratigraphy[1]

1 Introduction

All archaeological phenomena are located within a time-space continuum. The need to recognize the infinite multi-dimensionality within that continuum has been argued elsewhere (Harris/Lock 1995). This paper focuses on those aspects of multi-dimensionality which are relevant, indeed fundamental, to the recording and interpretation of archaeological stratigraphy. It will be argued that since the first attempts to scientifically record excavations, and even with the application of modern analytical techniques such as the Harris Matrix and various digital database or CAD methods, the three-dimensional representation of stratigraphical archaeological units and the relationships between them has been an illusive goal. It was not until very recently, with the advent of software that can store and analyse three-dimensional volumetric forms, that the technological capability has existed to achieve that aim.

The growth of GIS applications in archaeology over the last few years has been remarkable (Allen *et al.* 1990; Lock/Stančič 1995). It is now very apparent, however, that the continued imposition of a two-dimensional abstraction of reality within GIS represents a serious deficiency and has limited the uptake of GIS, particularly within archaeology. This two-dimensional emphasis in archaeology is partly due to the continuation of traditional manual and 2-D CAD-based approaches to the handling of archaeological spatial data in the form of maps and plans. The continuation of this into GIS presents severe limitations in functionality when examining multi-dimensional data. To date, where an application warrants the inclusion of a third or fourth dimension, such as depth or time, then the approach has been to construct, integrate, and analyse within a stacked vertical series of two-dimensional geographies. Often, 2.5-D graphics are achieved by draping two-dimensional coverages over a wire-frame Digital Elevation Model of a landform or other surface. Such quasi three-dimensional graphics should not be confused with true three-dimensional functionality which incorporates three independent axes along x, y and z (Raper 1989a).

Given these constraints it is not surprising that the majority of GIS applications in archaeology have occurred at the inter-site, regional scale. It is here that GIS functionality is at its strongest in identifying distribution patterns and exploring latent relationships between sites and their environs. Time, and subsequently change through time, is represented by a series of period coverages. We demonstrated such an approach several years ago with the analysis of 500 sq. km of landscape around the later prehistoric site of Danebury, England (Lock/Harris forthcoming a). This study organised the archaeology into seven period coverages spanning approximately five millennia. The temporal analytical capabilities are thus crude when compared to the potential of three-dimensional functionality which we presented in a later paper (Lock/Harris forthcoming b). The latter approach details a probability model which allows for the combination of disparate pieces of archaeological site information of varying date and accuracy. This effectively results in a series of ‘columns’ representing the third, or temporal, axis showing the probability of use for each site at any point in time.

At the intra-site scale there are relatively few applications of GIS. Again temporality is generally treated as a categorical variable and analysis mirrors the standard manual procedures using phase plans. This is illustrated by the study of excavations at the Romano-British town at Shepton Mallet, England (Biswell *et al.* 1995) in which seven archaeological phases are condensed into three periods for analysis and discussion. In this paper we seek to explore the recording and interpretation of excavated units through the use of GIS for it is within the three-dimensional world of stratigraphy that the real limitations of current approaches and technologies are most manifest.

2 Recording archaeological stratigraphy

The principles of archaeological stratigraphy were adopted from the ideas of 19th century geologists and based on the Law of Superposition as viewed in vertical stratigraphical sections. Pioneers of objective excavation recording methods, such as Sir Mortimer Wheeler in the 1930s, retained the vertical section drawing as their main tool for the interpretation of stratigraphical relationships. This places the analytical emphasis firmly on vertical relationships which equate with temporal development in terms of archaeological interpretation. The limitations of this approach are implicit in the attempts of Wheeler to record in the horizontal dimension through the development of his 'box' method of excavation. By recording horizontal surfaces at succeeding depths, together with conjoined vertical sections running in different directions, Wheeler was essentially attempting to record the three-dimensional spatial and temporal relationships that occur within the volumetric space that constitutes archaeological stratigraphy. It is argued below that despite the development of analytical tools such as the Harris Matrix and computer-based recording systems, the limitations of modern stratigraphical recording methodologies are the same today as those experienced by Wheeler five decades ago. The essential three-dimensional volumetric form and three-dimensional relationships of strata, or 'contexts', are coerced into two-dimensional recording and analytical frameworks.

The move toward area excavation during the 1960s, with the corresponding reduction in the importance of sections, was one attempt to address the three-dimensional complexity of deposits 'from the top down'. It was not until the mid-1970s, however, and the introduction of the Harris Matrix that a methodology designed to represent such complexity became available. Despite the subsequent impact of the Harris Matrix, not least the stimulation of considerable discussion concerning the theory and practice of stratigraphical recording and interpretation, it is still a tool incapable of representing the true multi-dimensionality of the data being analysed. In the first, and only, collection of papers addressing wide-ranging applications of stratigraphy generally, and the Harris Matrix in particular (Harris *et al.* 1993), the Matrix is claimed to have 'changed the paradigm of stratigraphy from a two- to a four-dimensional model' (*ibid.*: 1). This claim is based on the assertion that a section shows two dimensions of each deposit (thickness and length) while the Harris Matrix shows four dimensions by adding width (horizontal extent) and time (relative ordering). This said, it is difficult to see how the symbolic representation of contexts within a Harris Matrix, usually by standardized boxes containing a context number and joined by lines, represents the thickness, length and width of each individual context. However, while this is a powerful tool for establishing the relative ordering of a stratigraphical sequence and displaying it symbolically, its primary limitation is that it remains locked into the confines of the two-dimensional diagram.

Closely related to the methodology of the Harris Matrix is that of single-context recording in which the plan, stratigraphic relationships, and descriptive characteristics of each context are recorded individually. While this approach eases the interpretation and recording of the stratigraphic sequence context-by-context, an unexpected improvement has been the application of computer-based methods resulting in new means of display and visualization. Such systems, Hindsight for example (Alvey 1993), utilize the layering capabilities of CAD software to record each context as a separate drawing (layer), link it to a database record, and then produce composite plans by overlaying selected layers. This not only reproduces a conventional composite plan in digital form but also enables the creation of exploded stratigraphical sequences to show vertical relationships. As noted by Alvey (*ibid.*: 221), there has been a reluctance to adopt the Harris Matrix by some archaeologists because of the necessity to reduce three-dimensional volumes of soil, with concomitant three-dimensional relationships, to two-dimensional symbols with two-dimensional relationships. The advantage of exploded stratigraphic columns, such as produced by Hindsight, is that the relative shape and size of each context is retained, albeit only in plan and without any depth, while portraying their horizontal and vertical relationships in a very simplistic manner.

The use of CAD software for excavation recording is becoming commonplace. These applications are almost always confined to two-dimensional drawings despite claims to the contrary. Alvey (1993) refers to the Hindsight exploded column as 'the 3-D model' and Beex (1995) combines CAD plans and sections to produce a (hollow) box-like representation of an excavation trench referred to as 'a full three-dimensional reconstruction' (*ibid.*: 106). As will be demonstrated, it is misleading to claim three-dimensionality for software that does not have independent x, y and z axes. Such truly three-dimensional software has been used by Reilly (1992) to demonstrate the visualization powers of volumetric solid modelling and rendering as applied to hypothetical stratigraphy. The difference between a true 3-D approach and the CAD work is immediately obvious in the ability of the former to slice volumetric contexts along any of the three axes to reveal the interior. Even so, Reilly's work emphasizes that the visualization approach lacks the analytical functionality associated with GIS and topological relationships.

3 Multi-dimensional GIS

The archaeological emphasis on two-dimensional representation of three-dimensional phenomena through the use of scientific visualization, CAD/CAM, 2.5-D techniques, and solid volume modelling, is indicative of the search for approaches to manipulate and analyse archaeological phenomena in three dimensions. While these approaches possess powerful capabilities for exploring multi-dimensionality, they lack the full functionality provided by the use of three independent axes and true 3-D capabilities. To date, however, GIS has been firmly rooted in a two-dimensional abstraction of reality. Quasi 3-D approaches used in GIS, in which the third dimension is treated as a variable, should not be confused with true 3-D systems in which multiple attribute data may be recorded for any unique combination of three-dimensional space represented along three independent axes. Necessarily, real-time dynamic visualization of graphical images, solid volume rendering, mathematical modelling, and database management must remain important features in any 3-D system, but what is needed in addition is the fundamental common topology. Three-dimensional topology would permit spatial queries such as 'what is next to', 'what surrounds', 'what is above, below, to the side of', 'what is the value of the object at this location', and 'what are the relationships between this feature to surrounding features'. In addition, spatial analysis and 'what-if' modelling can also be pursued. In instances where multiple property values exist in three-dimensional space then 3-D GIS would be particularly apposite for archaeologists seeking to address the long-standing issues of how to handle multi-dimensional data which have both depth and temporal dimensions.

The development of software which possess the characteristics of true three-dimensional functionality has largely spawned out of the commercial world of petroleum and gas exploration (Fisher/Wales 1992; Raper 1989a, 1992; Smith/Paradis 1989; Turner 1989). Geology has substantive needs for three-dimensional capability especially for oil and gas exploration and reservoir analysis, coal seam modelling, hydrogeology, contaminant plume analysis, and hazardous waste site evaluation (Mahoney 1991; Smith/Paradis 1989; Turner 1989; Turner/Kolm 1991). Three-dimensional GIS applications in geology are also sometimes referred to as Geoscientific Information Systems (GSIS) to distinguish them from their 2-D counterparts (Turner/Kolm 1991: 217). The underlying needs of geologists has been to construct spatial models of continuous surfaces and to understand and model the spatial relationships between structural units and the interaction between them, as for example in the flow of fluids (Fisher/Wales 1992). Like archaeology, geology shares many similar needs with regard to portraying and analysing three-dimensional data from a variety of spatial data sources and seeking spatial relationships between stratigraphic units and features. Traditionally, geologists have relied heavily upon 2-D representations of subsurface features such geological maps, cross sections, fence diagrams, block diagrams, and isometric surfaces (Jones 1989; Kirk 1990). A three-dimensional interpretation of this data has invariably been inferred from combinations of these 2-D representations. Analytical capabilities and simulated 'what-if' scenarios have therefore remained limited. The development of software to digitally represent geological structure for oil and gas exploration has opened the door toward extending 2-D GIS capability into the realm of true 3-D.

Currently, there exist three basic approaches to representing multiple property data which vary continuously across a three-dimensional volume. These approaches are based on data structures using volumetric or geocellular methods (Jones 1989); surface piecewise patches welded by parametric polynomial functions (Fisher/Wales 1991); and triangulated tessellations (Belcher/Paradis 1992; Smith/Paradis 1989). For the most part three-dimensional GIS data structures have their counterpart in 2-D GIS representational structures. The move from 2-D planar to 3-D solid geometry is only now becoming possible because of the widespread availability of 3-D graphics software and the hardware needed to support 3-D graphical display. Three-dimensional capability adds considerable storage and computational overheads to GIS software and the continued development of more powerful computer architectures and 3-D visualization capabilities has contributed considerably to the growth potential of 3-D GIS.

The voxel data model, which provides the basis for Dynamic Graphic's Earthvision software, involves the 'spatial occupancy enumeration' of a cube or other regular polyhedral cell by an object (Belcher/Paradis 1992; Denver/Phillips 1990; Jones 1989; Pack/Bressler 1990). A voxel is defined as a rectangular cube bounded by eight grid nodes. In the 2-D GIS world this representation has its immediate counterpart in the 2-D raster data model. These representations may comprise a three-dimensional array of voxel centroids with associated attribute data, or an array which defines the exact region of space occupied by an object. Mathematical representations of property surfaces based on each grid node's value can be calculated using three-dimensional minimum tension algorithms.

Jones (1989) refers to the extensive storage demands of such data structures and their spatial inexactitude because of the dependency on the size of the regular voxel cell and the lack of precise spatial boundaries between objects. Such concerns have been levelled equally at raster GIS data structures, particularly in comparison with the vector data model alternative. In the same way that raster compression techniques such as run-length encoding and variable cell decomposition, such as bintrees or quadtrees, have been developed to overcome these limitations (Samet 1984, 1989; Shaffer *et al.* 1990), so too are similar techniques applicable to the 3-D data model. Thus the use of octrees, based upon the regular and recursive decomposition of voxels into homogeneous units, have been developed for 3-D data structures (Kavouris/Masry 1987). Octrees provide good addressing procedures which can be enhanced through the use of tesseral addresses (Diaz/Bell 1986). They also possess good set operation capabilities and the ability to integrate and link other types of volumetric data such as point, line, and polygonal-solid data (Kavouris/Masry 1987). Storing boundary data at minimal voxel resolution is, however, less satisfactory, though as Jones (1989: 23-28) points out the use of 'flat' voxels, vector octrees, and multi-resolution representations provide differing mechanisms to overcoming these problems. A number of geological applications have utilized Earthvision or earlier software versions for mapping subsurface mine fires (Vasilopoulos 1989), atmospheric applications, oceanographic studies (Manley/Tallet 1990), and petroleum resource analysis (Belcher/Paradis 1992; Fried/Leonard 1990; Lasseter 1990).

A second data structure approach has been to spatially define objects in terms of their geometry and boundary surfaces (Houlding 1988, 1989; Jones 1989). Three-dimensional component modelling, as utilized by Lynx Geosystems software, has been developed to meet the needs of the mining industry by defining extensive irregular seam deposits (Houlding 1989). Component modelling of solid shapes is achieved through combining 3-D solid modelling and geostatistics to define upper and lower stratigraphic surfaces. By using surface descriptions, component modelling seeks to overcome perceived boundary and data storage limitations of voxel-based models (Houlding 1988). The modelling process is based on establishing a set of triangular platelets in which plate vertices are obtained from known control points based on geological elevation and seam thicknesses (Houlding 1989). In the use of such tesselations, component modelling draws close comparison with 2-D Triangulated Irregular Network (TIN) tessellation methods. Plate thickness, size, and orientation are determined linearly along the axes defined by the vertices. Upper and lower seam boundaries record local variations in thickness and also define continuous and possibly irregular surfaces. Volumetric calculations are based on the triangular plate facets and seam thicknesses and irregular solids can be intersected volumetrically. Aggregated regional units can be constructed from the set of tesselations and the problems generated by discontinuities such as faulting are relatively easily handled by using control points at the seam-fault intersection. The complexity, variation, or even simplicity of a geological structure, can be captured by varying the density of the control points and by defining the specific control points which make up plate vertices.

A third approach, employed as one of their approaches to solid modelling by Intergraph Corporation, involves the construction of 3-D surfaces and solids through the use of mathematically defined surfaces. NURBS (Non-Uniform Rational B-Splines) can describe large complex surfaces by a single uniform mathematical form. The technique was originally developed to define large complex surfaces for use in the design of complicated machine and industrial parts (Fisher/Wales 1990, 1992). It has since been extended into medical and physical research. Since the same common mathematical method is used to represent all entities in the system, the functional integration of geo-objects, surfaces, defined solids, and attributes can be achieved. The method combines wireframe, surface, and solid modelling and has been largely explored in the context of geological applications (Fisher/Wales 1990, 1992). The basis for NURBS rests upon the use of low order polynomials to describe small, relatively simple, sections of a surface based on a series of known data values. The use of piecewise parametric polynomials overcomes many problems which arise from seeking to fit a global surface through all known data points: not least the problem of oscillations which arise from the use of higher order polynomials (Fisher/Wales 1992: 88). These low-order polynomial patches are subsequently 'quilted' and stitched together by the use of mathematical parametric polynomial B-splines. These splines also overcome patch edge irregularities and discontinuities by using control points near the edges of the patches to produce a smooth continuous surface along the 'knot' vector.

4 Three-dimensional GIS and archaeological stratigraphy

To demonstrate the potential capabilities of 3-D GIS for archaeological applications a series of 3-D archaeological structures, stratigraphical units, and relationships were explored using Dynamic Graphic's Earthvision software. The selection of a voxel-based minimum tension algorithm was initially perceived by the authors as being best-suited to meet the needs of archaeologists. Certainly the heavy focus of available 3-D GIS systems on geological applications, surface generation, and volumetric assessment was not initially considered to be fully sympathetic with the needs of archaeology. The voxel model was, however, viewed as more flexible in its potential ability to deal with the variety of archaeological phenomena although many of these decisions were based on preconceptions and have yet to be validated or dismissed. The decision was also made to focus in this paper on intra-site applications even though the use of 3-D GIS for inter-site archaeological applications promises to open up a significant research frontier which for reasons of scope will not be considered here. The Earthvision software comprises a number of interactive software libraries which enable data input, editing and manipulation, surface and volume modelling, grid and analytical operations, mapping, and 3-D visualization. Data input comprises x, y, z coordinates and property values. This varied according to the subject matter as to whether coordinates defined leading vertices along horizontal or vertical profiles of an object or were randomly distributed, as in the use of the bore-hole data. Minimum tension modelling was used to calculate a three-dimensional grid which formed the basis from which to define specific volumes or solids. In a number of instances the model was constrained in x, y, or z so that the polygonal solid matched the boundaries of predefined stratigraphic units. In this way the boundaries of certain units could be delimited where applicable by curtailing the influence of data values in adjacent layers or volumes. For example, in a number of instances the boundaries of certain volumes were forced to conform to the surface boundaries of units existing above or below the solid. In other cases the model was unconstrained and allowed for freely calculated, nonconforming boundary surfaces.

The examples used for this paper were selected primarily to demonstrate some of the basic capabilities of 3-D GIS. Studies of a more analytical nature which demonstrate the greater functionality of these systems are yet to be undertaken. Of greatest import in the following examples, over and above developing data encoding and modelling within the system, is the use of the real-time dynamic visualization capabilities available within the systems. We urge readers to bear these powerful capabilities in mind as the following examples are introduced.

In all, three examples are utilized to demonstrate the application of three-dimensional GIS to stratigraphic recording and analysis (shown as Figures at url: http://www.geo.wvu.edu/www/4dgis/welcome.html). The first example portrays a stratigraphic sequence representing a wall with associated foundation trench in which the wall subsequently collapses and is covered with extraneous debris. The example is taken from a standard and well-known text on archaeological excavation techniques (Barker 1994: 230). The Harris Matrix and exploded stratigraphic units were used to define the superpositional relationships and the units were reproduced within the 3-D system. The example, though simple in appearance, conceals numerous complexities in the way in which solid forms are constructed, classified, rendered, and displayed. The importance of visualization as an analytical tool is amply demonstrated when a series of these cut-away images are displayed and azimuth, perspective, and rotation are applied in viewing the solid geometry. The example demonstrates slicing capabilities in which layers or stratigraphic units are stripped away to expose other 'hidden' units, the surrounding undisturbed land has been 'removed' so as to expose the construction more clearly. The ability to peel away solids to reveal underlying solid geometry and unit relationships is further demonstrated in the following examples. Volumes for these units can be calculated, though again it should be stressed that these examples do not demonstrate the full functional capabilities of multi-dimensional GIS for these capacities are only slowly being developed. It should be borne in mind, however, that these stratigraphic units possess topological relationships which provide the basis for going beyond purely visual analysis to apply the full range of GIS functions in the third dimension.

The second example, also taken from Barker (1994: 228), is a section of Norman construction within Worcester Cathedral, England. The stratigraphy beneath the Norman structure is complex although within the software the spatial and temporal relationships between contexts are clearly visible from the cross-sectional views. As demonstrated before, the capability exists to remove undisturbed ground and surrounding contexts to reveal the intricate 'spatial footprints' of the holes, graves, and columns. In many respects, reconstructing structures and archaeological contexts as in the first two examples are among the more difficult features to reconstruct in a voxel-surface system such as Earthvision. The features are geometrically well-defined and solid-surface models must be forced to replicate these as accurately as possible. The interpolative capability of the system is thus constrained to operate within well-defined margins.

The third example is of a dataset representing the results of an area survey around a suspected Romano-British settlement (provided by James Dinn of Hereford and Worcester Archaeological Unit). Here the interpolative and visual capabilities of the system are fully employed. The data are based on a number of irregularly spaced bore-holes distributed across the site. The layers generated comprise present-day ground surface, Romano-British ground surface, a prehistoric ground surface, and three soil horizons, extending in total to a depth of over one meter. The 3-D interpolated surfaces are sliced and cut to reveal the spatial extent and the relationships within and between the historic landscape surfaces and the soil horizons. The dynamic representation of this data as slices are made in the X, Y, and Z planes provides a powerful interpretative capability. Furthermore, the ability to slice based upon a unit's value, or isosurface, contributes even greater understanding to the interleaving that existed between the historic surface features and recorded soil horizons. In addition to these horizons, phosphate and magnetic susceptibility readings were recorded indicating concentrations, or 'hot spots', of possible human and animal activity. Again, progressive slicing in the major planes as well as by isosurface, reveal fascinating insights into the complex three-dimensional patterns and relationships present in the data. The patterns revealed in the phosphate and magnetic susceptibility analyses can be correlated with the Romano-British and prehistoric ground surfaces. The dual representation of both depth and temporality is displayed well.

5 Conclusion

Given the limited analysis intended for these demonstration projects perhaps the most impressive capability to arise from the experience of encoding and building the 3-D representations lies in the importance of dynamic visualization. The ability to strip away surrounding materials and contexts, and to examine information within these volumes is an extremely valuable process. Unfortunately, this experience does not reproduce well within the constraints of image reproduction displayed here. The graphical interactivity of the system to rotate, change azimuth, to slice and view the stratigraphic units in x, y, or z dimensions or combinations thereof, to produce 'chairs', and to undertake a variety of other graphical manipulation, provided an extremely valuable aid to exploring and understanding the sequences displayed. Furthermore, one of the most valuable visualization techniques was the ability to strip away features and stratigraphic units based upon the value of the isosurface. Thus, for example, the Romano-British ground surface and its relations with other adjacent temporal land surfaces could be identified with relative ease as the surrounding surfaces were stripped away based upon their isosurface value. Similarly, the varying densities of phosphate or magnetic susceptibility could be identified based on the incremental stripping away of lesser or greater concentrations of surface values. The combination of these visualization techniques provided a very powerful interpretive user-environment and in their own right represent a major addition to the archaeologist's arsenal of tools.

Other reflections on the role of 3-D GIS for analysing archaeological stratigraphy are more mixed. This response is due in part to the limited analytical role afforded the GIS because, with the exception of the Hereford and Worcester study, the spatial relationships of the various contexts had been predetermined at an earlier point during the excavation and recording process. It is normal practice to record a context's stratigraphical relationships on-site and any subsequent analysis is usually limited to ordering those relationships to form the Harris Matrix. As a result, the spatial techniques enjoyed by users of 2-D GIS, specifically to buffer, overlay, cluster, classify, and to undertake spatial analysis, are available in the 3-D environment and yet their utility is likely to be very project specific and limited to intra-site applications. Where appropriate the power of the 3-D system for spatial analysis will be considerable, for example the ability to seek spatial relationships between artifacts at the intra-context level could be substantial.
In other instances that utility will be more limited, certainly in comparison with the utility of the 3-D graphical tools, because of the nature of the excavation process itself.
The full impact of 3-D GIS capability will certainly have to be evaluated beyond the current confines of an end of project analysis stage. The potential to develop linkages to the Harris Matrix would also appear promising, but again, if this is predetermined at the excavation phase then such capability is likely to be somewhat redundant. GIS capability to handle three-dimensional data is not far from being a reality and is likely to unleash many exciting and innovative avenues of enquiry for archaeologists. Though this paper has focused primarily on intra-site stratigraphy several other application areas in archaeology are apparent, not least in the extension to 3-D inter-site temporal analysis (Harris/Lock 1995). Such technological capabilities portend the possible enhancement, if not replacement, of traditional hand-drawn or CAD-generated plans and sections by three-dimensional GIS. Further development is clearly required to explore the functional capabilities of GIS, such as buffering, overlay, and networking capabilities, in the third dimension. A major constraint continues to be the age-old problem facing archaeologists to obtain precise recordings of archaeological phenomena whilst contending with the very real resource pressures which exist, particularly in modern rescue excavation work. Such financial exigencies, however, should not completely dampen the pursuit of innovative archaeological investigation.

note

1 For the figures, please refer to the CAA World Wide Web server on http://caa.soton.ac.uk/caa/CAA95/Harris/.

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The use of GIS as a tool for modelling ecological change and human occupation in the Middle Aguas Valley (S.E. Spain)

1 Introduction

Recently the use of GIS has become a widely accepted way of dealing with spatial phenomena in archaeology (see e.g., Allen *et al.* 1990). Current research has focused on regional settlement studies and it is clear that the number of applications will continue to grow in the coming years. However, the use of GIS for the reconstruction of past socio-natural environments has two clear limitations: the techniques available in GIS cannot adequately deal with temporalities, and secondly, the representation of social structures in GIS is problematic, partly as a consequence of lack of theoretical context in archaeological GIS applications (Wheatley 1993) and because of the massive availability of environmental cartographic data.

As demonstrated in Verhagen *et al.* (1995), the full potential of GIS for archaeologists still has to be explored, but it is also clear that GIS cannot operate as the single means of analysis for questions relating to prehistoric settlement patterns. For the Middle Aguas Project, an effort will be made to resituate GIS as a part of an integrated modelling framework that will be used to evaluate dynamic models of human-environmental interaction, thereby trying to give GIS its place in a larger theoretical and methodological context. This paper presents the first results of a study in erosion modelling that will be part of the larger modelling effort.

2 The Middle Aguas Project

The Middle Aguas Project is an international, multidisciplinary research project funded by the Directorate General XII of the Commission of the European Union. Its main research goal is the understanding of the variability and magnitude of palaeo-environmental change in the Middle Aguas Valley in southeast Spain (province of Almería) over the past 6000 years. The project mainly builds on previous archaeological research in the area (Castro Martínez *et al.* 1993) and the results of the Archaeomedes Project (Van der Leeuw 1994). Unlike Archaeomedes, which focused on the larger geographical context of the Vera Basin and aimed to study the development of land degradation in the Mediterranean during the Holocene, this project is much more concerned with the local dynamics of human occupation and its relation to the development of socio-natural systems.

2.1 Environmental context

The study area concerned is, for the purpose of this project, referred to as the Middle Aguas Valley, although this is not a physiographically correct name. The area, located on the southern edge of the Vera Basin (fig. 1), covers about 16 by 10 km. The climate is characterized by hot, dry and sunny summers and a mild winter. Precipitation is characteristically in the form of torrential showers or *gotas frias* in autumn and spring. The area is located in one of the driest regions of the European continent with a rainfall of generally between 250 and 300 mm per annum. It should be borne in mind that annual rainfall figures may vary greatly because of the high irregularity of rainfall in the Mediterranean in general (see McGlade 1994). Although the conditions for vegetation do not seem very attractive, the area is in fact very rich in botanical species.

The area shows a considerable variability in topographical features. Elevation ranges from sea-level to 934 meters at the summit of the Sierra Cabrera. Slope steepness is generally considerable in the central area of the sierra, which consists of relatively hard metamorphic rocks of Triassic, Permian and Devonian age. The northern edge of the sierra is formed by softer limestones, marls, sandstones and conglomerates dating from the Miocene and later. This area is characterized by badlands and isolated hills. In the lower parts of the Rio Aguas Valley unconsolidated Quaternary fluvial deposits are found, with dispersed remnants of river terraces. In areas protected from erosion on the flanks of the Sierra Cabrera colluvial deposits are found (Kampschuur/García Monzón 1974).

Agricultural land use nowadays is mainly concentrated along the Rio Aguas, with barley, vegetables and fruit trees being the main crops. The main attraction of this area is the combination of deep soil profiles, flat terrain and easy irrigation. On the older river terraces irrigation is less frequent, and the main crops here are barley, wheat, almonds and olives. The shallower soil profiles on the northern flanks of the Sierra Cabrera are used less for

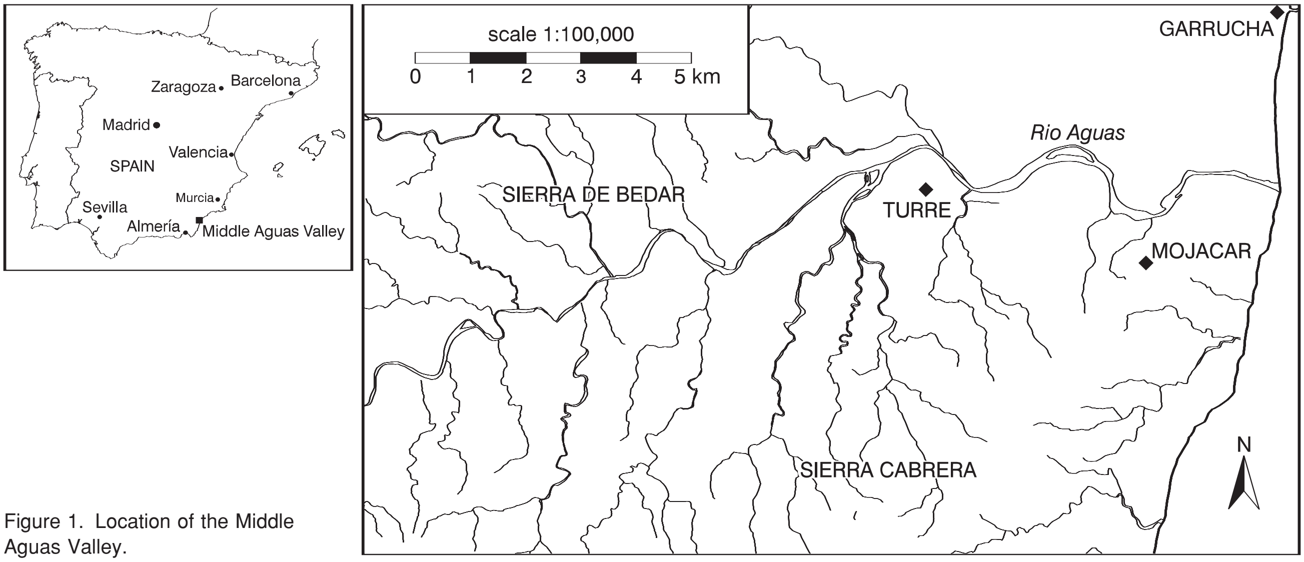

Figure 1. Location of the Middle Aguas Valley.

agriculture. These soils are extremely dry and vulnerable to erosion. Where the slope is more gentle, these soils tend to be used for the cultivation of almonds and olives, and sometimes barley. The ubiquitous terracing found at intermediate altitudes in the Sierra Cabrera is a remnant of the subsistence practices that existed until very recently in this area and date back as far as the Arabic period. In the *ramblas* (dry river beds) terraces were constructed that helped catch the water and fine sediment that comes down via these *ramblas* during rain storms. These terraces have been used to grow olives, almonds and barley but this terracing system is now mostly abandoned. Much of the remaining area was until recently used as grazing land for goats, but this practice has almost come to an end.

2.2 Archaeological context

The archaeological record of the area indicates that, generally speaking, before the *reconquista* of the area by the Spanish in AD 1492, four 'ecohistorical' periods can be distinguished (McGlade *et al.* 1994). Human occupation evidently started in the Neolithic around 4000 BC. This first occupation phase seems to be characterized by a subsistence strategy of low intensity and high diversity. Only a few settlements have been reported, and they seem to have been short-lived. There is no sign of environmental perturbations in this period, either as a consequence of the diversified land management or as a function of the low population density.

The ensuing period (3000-700 BC) shows a marked contrast in the way the landscape was exploited, and evidences the establishment of social inequalities. Together with an increasing population, the landscape seems to have been subjected to increasing geomorphic instability and aridification. This eventually led to a change in subsistence strategies, culminating in barley monocropping during the Late Agraric period from 1800-1565 BC, accompanied by a shift from the lowland areas to higher ground as well as larger population concentrations in a few settlements. The Argaric system then collapsed, and population densities declined to the level of pre-Chalcolithic occupation. By *c.* 1400 BC, the original deciduous woodland had transformed into a deforested garrigue landscape.

The third period (700 BC-AD 718) again shows a change in exploitation strategies: the area is colonized first by the Phoenicians and their Punic successors and later by the Romans. At first, settlements are concentrated along the coast, where intensive ore mining took place, resulting in deforestation. The Romans introduced their own agricultural system, based on the production of a surplus, which survived until the arrival of the Arabs. This system constituted the most intensive agricultural exploitation of the region until modern times. In this period, the whole area can be seen as a zone of extraction, where resources were being used for the benefit of other parts of the Mediterranean. The result of this strategy was an increasing land degradation and aridification, although the system did not collapse.

The Arabic conquest in AD 718 again induced a change in subsistence strategies with the introduction of irrigation. The production system in this period was organized in such a manner that it could provide sufficient means of subsistence to each social unit, and seems to have been relatively well adapted to the environmental circumstances, an achievement that was never reached in succeeding periods.

3 Erosion modelling and archaeology

One of the key elements in the process of land degradation in the Mediterranean is obviously (water) erosion. The first interest in erosion came from agronomers, seeking to predict the consequences of erosion for agricultural land use. Various quantitative models to predict soil loss through erosion have been proposed over the years (see De Roo 1993), which have demonstrated that the process of erosion is a complex, dynamic phenomenon which can be observed at various spatial and temporal scales. Until now no attempt has been made to apply currently available quantitative erosion models to past phases of erosion. It is assumed here that these quantitative erosion models may have two major contributions to archaeology. Firstly, the results of the model may be interpreted in maps of zones where archaeological remains have or have not been preserved, and may therefore be helpful in field surveys and in the interpretation of the observed settlement patterns. Secondly, the erosion model may be able to provide insight into the development of erosion through time by means of scenario building. Using archaeological, palaeo-ecological and palaeo-pedological data, we can attempt to identify the dynamics of erosion in the past and its influence on human-environmental interaction.

In the Middle Aguas Project, the erosion model will be used as part of a larger modelling effort that aims to reconstruct the palaeo-environment of the Middle Aguas Valley for some selected cultural phases and areas. The approach chosen heavily depends on two techniques, namely GIS and ecological dynamic modelling (see McGlade 1995). During the Archaeomedes Project, both have proved their use as tools for 'experimental archaeology', but the incorporation of a spatial element into the dynamic modelling and, conversely, a temporal element into the GIS was not possible within the scope of Archaeomedes. An important objective of the research in the Middle Aguas Project is to implement this connection of GIS and dynamic modelling. Erosion modelling, as a relatively well-developed branch of modelling, is considered a good starting point for this integration that will provide useful data on the erosion processes in the Middle Aguas Valley over the past 6000 years.

3.1 Different types of erosion models

Several distinctions can be made between erosion models. The first and most obvious one is between quantitative and qualitative models. Models that apply a formula of some kind are referred to as quantitative. The best known example is the Universal Soil Loss Equation or USLE (Wischmeier/Smith 1978), which aims to predict soil loss on the basis of five empirically established parameters. A quantitative model however is not necessarily more reliable than a qualitative model: in the case of the CORINE erosion assessment methodology (Commission of the European Communities 1992) the application of a qualitative model was preferred over a quantitative one for reasons of data availability and resolution. In fact, the USLE has been rather suspect for a number of years as the empirically established parameters were only valid for certain parts of the USA. This has led to a wave of so-called physically based models that try to predict soil loss on theoretical grounds.

Secondly, there is a fundamental difference between so-called lumped erosion models and distributed models. Distributed models are models which take into account the spatial component of erosion, and have become more popular with the increasing availability of GIS software and more powerful computers. The third distinction that can be made is between 'static' and dynamic models. The first category aims at providing predictions of soil loss: the procedure followed is essentially a one-way sequence. Dynamic models on the other hand incorporate the idea of change, using time series and feedback loops (see e.g., McGlade 1994). Sofar, there are no models available that are quantitative, distributed *and* dynamic.

3.2 Practical implications

If we want to use an erosion model of any kind, we will have to define within which limitations it will have to operate. When considering experiments for modelling erosion in the past, it will be clear that a spatial scale is required that is compatible with the scale of a settlement's exploitation zone. Currently, a number of modelling approaches is only considering soil loss on the spatial level of hill slopes or fields, which introduces an element of uncertainty in the results of the models for larger areas.

Secondly, as we are not so much concerned with the precise prediction of soil loss in kg/ha, but rather with the identification of the spatial and temporal development of the erosion dynamics, it is not necessary to use models that aim at extreme accuracy. Especially the available physically based models require a very large amount of input data, that can only be obtained through time-consuming field measurements and experiments. It was shown by De Roo (1993) that this investment in time does not necessarily yield an equal improvement in the modelling results.

Most models available at this moment do not fulfil these criteria, not to mention the fact that they do not incorporate the equally important process of sedimentation. However, there is little use in developing another 'new' model when time and money do not allow us to validate it. Therefore, it is proposed to evaluate one or more existing models and see how these can be integrated with GIS and dynamic

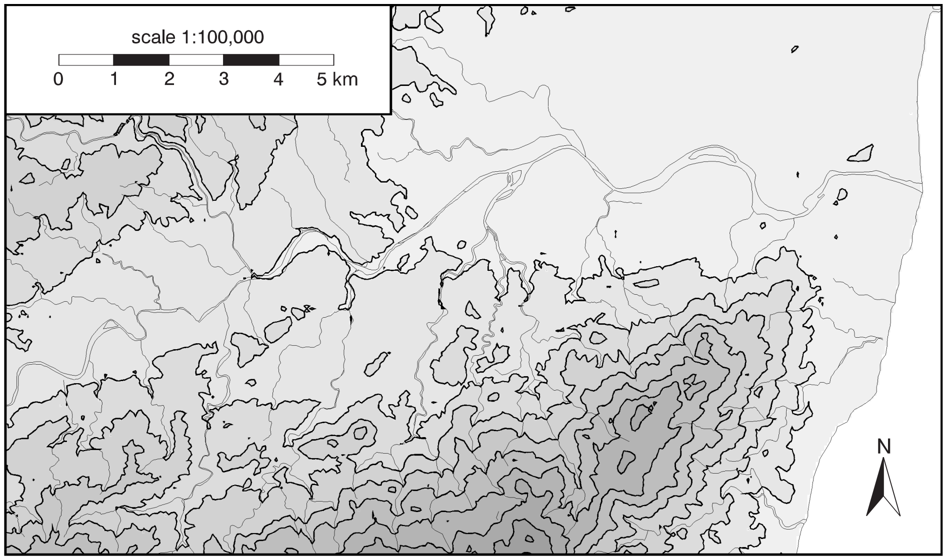

Figure 2. Digital Elevation Map of the Middle Aguas Valley. The contour interval is 100 metres.

modelling. Relatively simple models like the Revised Universal Soil Loss Equation or RUSLE (Renard *et al.* 1987) are supposed to yield realistic results in a wide range of circumstances. It is supposed that these models can therefore be relatively easily adapted to an environment of dynamic modelling procedures.

3.3 Parameters involved and their assessment

Erosion can be thought of as a product of three factors: erosivity, erodibility and transport of eroded material. Of these three, erosivity is synonymous with climate: the kinetic energy of rainfall is the process that starts (water) erosion. Climate operates at a spatial and temporal scale which justifies its interpretation as a constant over long periods of time and usually also over relatively large areas. The climate pattern itself however can be highly variable, especially in an area like the Middle Aguas Valley. Values for the intensity of erosive rain are difficult to obtain, and even more so data on the temporal distribution of these intense rainstorm events.

Erodibility, or the sensitivity of the surface to erosion, is dependent on the vegetation, soil and terrain slope. Plant cover, responsible for the protection of the surface, changes over the year and through the years, which makes it a difficult factor to incorporate in a model that aims to monitor soil loss on a larger time scale. With the aid of remote sensing, the current plant cover can be estimated, but for an archaeological experiment the application of palaeo-botanical data will be inevitable.

Slope, which determines whether eroded material can be transported, is relatively easily and accurately determined using a Digital Elevation Model (DEM) and is a supposedly independent variable over relatively long time periods. For the Middle Aguas Project, a DEM (fig. 2) has been interpolated using regularized spline with tunable smoothing and tension (Mitášová/Mitaš 1993) from 1:10,000 topographic maps (vertical contour interval 10 m) and is expected to be of good quality, although of course the situation in the past may have been different.

The soil factor is usually given most consideration in current models, as it is the most difficult to assess given the enormous spatial variability of soil types. The soil characteristics themselves that determine the rate at which soil can be eroded can only be assessed through soil mapping. The principal constraint of using standard soil maps is their limitation to chloropleth mapping, which ignores (or at least does not quantify) the considerable spatial variability within mapping units, hence the focus of most researchers on the improvement of methods to estimate this variability (see e.g., Burrough 1993). The existing soil map 1:100,000 of the area is clearly insufficient for the estimation of the desired parameters, and additional data will have to come from satellite imagery and field survey.

Lastly, for the estimation of the transport of water and eroded material, several methods of determining cumulative overland flow from DEMs have been incorporated in various GI systems. This is basically a hydrological problem; the transport of water is a function of rainfall, infiltration and runoff, and the transport of eroded material is determined by the amount of overland flow generated and the transport capacity.

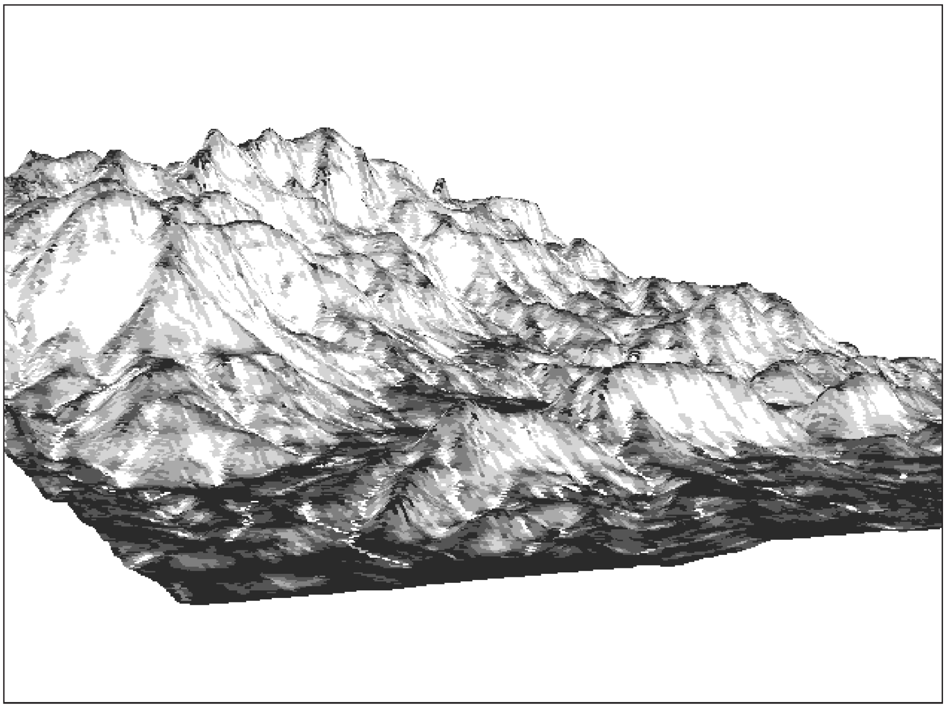

Figure 3. Map of sediment transport capacity draped on DEM. View from the NNE on a section of the Sierra Cabrera around La Alcantarilla of approximately 3 by 4 km. Pixel size is 10 by 10 metres, vertical exaggeration 1.5 times. Light colours indicate high transport capacity rates, dark colours indicate low values.

3.4 Some preliminary results

The collection of the necessary environmental data will be an ongoing part of the project, and at this moment not all the desired data is available to present a complete erosion model. However, it was possible to produce some first results with regard to topography. The main objective of a distributed erosion model is to adequately model the transport of sediment through space. With the advent of better interpolation methods for elevation data and more sophisticated techniques for the calculation of derivatives (gradient, aspect and curvature) it is possible to arrive at more realistic interpretations of the sediment transport than was formerly possible within the context of e.g. the RUSLE. In the RUSLE, the so-called LS or *length-slope* factor, which is equivalent to the sediment transport capacity, was calculated without the inclusion of flow convergence and divergence, and could only be applied to areas experiencing net erosion (Mitášová *et al.* in press). In order to give a more realistic estimation of transport capacity, Moore and Burch (1986a) proposed to use the 'unit stream power based LS factor' that incorporates the upslope contributing area. The potential for erosion and deposition (Moore/Burch 1986b) could then be defined as the change in sediment transport capacity in the direction of flow. Using the techniques described in Mitášová *et al.* (1995) it was possible to create maps of transport capacity and erosion potential for a selected region on the north flank of the Sierra Cabrera. The upslope contributing area, defined as the area from which the water flows into a given grid cell, can be computed by determining the sum of grid cells draining into a cell. The *r.flow* program in GRASS, developed by Mitášová and Hofierka (1993), provides an improved method of determining this upslope contributing area and takes into account the fact that water flow converges in channels. The application of this parameter to the unit stream power based LS factor calculation, shows that transport capacity (fig. 3) dramatically increases in stream channels, and decreases on concave slopes where deposition is supposed to occur, which gives a far more realistic interpretation of the erosion potential of a landscape than using the standard tools in GRASS for determining cumulative overland flow. We may be able to use these maps for the identification of zones where the regime of erosion and deposition has changed through time.

The maps show that in areas of decreasing gradient local deposition may occur, even in the higher reaches of the sierra. It should therefore be possible to simulate the effects of terraced agriculture, which effectively diminishes the transport capacity.

The method for determining upslope contributing area is restricted by the accuracy of the DEM: a pixel size of 2-10 m is desired, which limits its use for larger areas, and the tracing of overland flow stops at barriers or points with zero gradient. Most DEMs however, especially in highly irregular terrain like the Sierra Cabrera, will contain interpolation artefacts like pits and bumps in places where in fact flow is not obstructed. This means that for a realistic modelling of transport capacity the DEM should be near perfect, which involves time consuming post-processing in order to eliminate the undesired interpolation errors.

4 Concluding remarks

The results presented here show that there is a still a long way to go in order to make quantitative erosion modelling accessible to archaeologists, and even a longer way to integrate it into a dynamic modelling framework. Nevertheless, the potential of the existing techniques is promising as is shown by the modelling of sediment transport capacity. The main problem encountered in making these techniques operative will be the availability of data: the existing information on soils, vegetation, climate and topography will in most cases be insufficient for quantitative erosion modelling studies, and requires the input of knowledge from other disciplines. On the other hand, once these conditions are fulfilled, the use of such models may help clarify the history of erosion and deposition of an area and provide new insight into the way in which human subsistence strategies and environmental circumstances influence each other. It is expected that the Middle Aguas Project will give us an excellent opportunity for this kind of experiments.

Acknowledgements

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Federica Massagrande

The Romans in southwestern Spain: total conquest or partial assimilation? Can GIS answer?

1 Introduction

The Guadalquivir Valley, in Andalucía, southwestern Spain, was fully 'Romanised' by the 1st century AD[1], or was it? The classical view of the Roman archaeology of the area, based mainly on Latin sources, is that in the 3rd century BC the Romans entered the area to fight the Carthaginians, whom they defeated in 206 BC, over the control of the Mediterranean. Afterwards they settled in the Guadalquivir Valley where they established a fully Roman society and way of life, completely overriding the local Iberian culture, whose structure and organisation disappeared forever (Amores Carredano 1982: 245). In 197 BC the Roman province of Hispania Ulterior, of which the Guadalquivir Valley formed the core part, was created.

This view is typical of the archaeology of the Roman expansion, seen as the uninterrupted conquest and colonisation of new territories to be added to the Empire, with conquered populations being replaced by Roman or Romanised people bearing a completely Roman culture. This imperialistic view of the Roman expansion in the Mediterranean and later in continental Europe has led to a separation between the Roman archaeologists and the prehistoric archaeologists, with the consequence that pre-Roman cultures cease to be studied at the time of Romanisation, while similarly, no attention is paid to the influence of pre-existing cultures and trade networks on the organisation of Romanised areas (see Dyson 1991).

This paper explores this issue in the modern province of Seville through the use of GIS and tries to assess how true this view of the colonisation of the Guadalquivir Valley is. Since the only way to obtain enough data to cover a large part of the province of Seville was to use the non-systematic survey data from the local archaeological units, there are important issues of data quality and data validation, which have already been discussed elsewhere (Massagrande 1995a, 1995b) and will not be repeated here. The scope of this paper is limited to trying to assess the development of the Roman settlement pattern in time and the distribution of different types of diagnostic pottery in the province of Seville.

2 The archaeological data set

The data used in the study were collected over a number of seasons in non-systematic surveys and were kept on paper cards at the *Dirección General de Bienes Culturales* in Seville. These data were integrated with data from the non-systematic surveys of M. Ponsich (1974, 1979, 1987 and 1991) and the systematic surveys published by several authors (Amores Carredano 1982; Escacena Carrasco/ Padilla Monge 1992; Ruiz Delgado 1985; Durán Recio/ Padilla Monge 1990).

3 The Guadalquivir Valley

The study area covers a large part of the province of Seville. The size of the region covered by the study is 143 (east) × 108 (north) km. The coordinates of the southwest corner of this area are 29SQA545893, and those of the northeast corner are 30SUG450880 (U.T.M.). Most of the study area consists of the fertile valley of the river Guadalquivir, with the first foothills of the Sierra Morena to the northeast and hills to the southwest. Apart from these two areas of higher ground, the study area is almost completely flat and well-drained.

By the late 1st century BC, the Guadalquivir Valley (Roman Baetica) was one of the main producers of oil, corn and wine in the Mediterranean. These products, despite competition from Africa, were exported to various parts of the Roman empire. To the north the rich mines of the Sierra Morena were easily accessible.

4 The Software used

The information about the site contents and coordinates was stored in a dBASE III+ file. The GIS package used was Idrisi 4.1. The χ^2 and Kolmogorov-Smirnov tests were carried out using custom produced programs in dBASE III+ language, while the Correspondence Analysis was carried out using MV-ARCH. The Correspondence Analysis plots were produced using Gnuplot.

5 The analysis – the Roman site distribution pattern

A number of tests were carried out to investigate the relationship between the Roman settlement pattern in the

Guadalquivir Valley and various background variables. The variables considered were:

- soil type
- agricultural potential
- distance from the nearest Roman town
- distance from the navigable rivers, and
- distance from Roman roads

All this information was available as Idrisi image maps. The distances from the towns, rivers and roads were calculated as cost surfaces, while the way the agricultural potential map was obtained is described below.

5.1 The soils

The first test to be carried out was a χ^2 test between the soil map and the number of sites occurring on each soil type. The area covered by each soil type was used to calculate the expected values in the χ^2 test. A binary mask of the province of Seville was used to exclude from the analysis those areas for which information was not available. The result of the test shows a significant relationship between the position of Roman rural sites and the soil type on which they occur. This test was also carried out for the settlement distribution for the three chronological bands Republic, Early Empire and Late Empire, and separately for high-status sites and low-status sites (a discussion on what defines high and low status sites can be found in Massagrande 1995b). The result was that, generally, there is a relationship between soil type and site location. This is true both for low status and high status sites for the Early and Late Empire, but not for the Republic. However, when the observed number of sites is compared to the expected number of sites, it emerges that sites are located preferentially on bad soils. The bad soils have more sites than expected, while the good soils have fewer sites than expected. This pattern is consistent for all types of rural sites in all chronological bands.

5.2 The agricultural potential

It was decided to take this study a step further and to use a more reliable test than the χ^2. Since the χ^2 test is virtually the only one that can be carried out on variables expressed on the nominal scale, it was first necessary to express the cultivation potential of the land in a different way. Though the soil fertility index was available and can be considered a variable expressed on the ordinal scale, it was decided to create an agricultural potential map, which would be a more complete description of the suitability of an area for agricultural exploitation. The agricultural potential map was created using variables such as the soil fertility index, the distance from water and the slope. This information was kept in separate Idrisi layers and was combined using map algebra after weighting the variables according to the requirements for the cultivation of olive trees and corn, which formed the main agricultural production of the valley. The result was an agricultural prediction map in which each cell has a value ranging from 1 to 10, representing the agricultural suitability index. Since the agricultural capability prediction classes can be thought of as an ordinal scale (i.e. class 6 can be thought of as including all the other classes from 1 to 5), it is possible to use the Kolmogorov-Smirnov one-sample test. This approach to testing the relationship of archaeological features to continuous landscape variables such as altitude or distance has been discussed by Hodder and Orton (1976: 226-229). The Kolmogorov-Smirnov test is more sensitive than the χ^2 test and its efficiency is greater as it treats individual observations separately (Cohen/Holliday 1982: 139). The test was carried out on the high and low status sites separately and for the three chronological periods. All the results were negative, except where the total distribution for all periods was tested together. This indicates that although there is a significant overall relationship between site location and the agricultural potential index, this is lost when the data are split into specific subsets.

5.3 The tests on the other variables

Kolmogorov-Smirnov one-sample tests were also carried out to see whether there is a significant relationship between the Roman site distribution and the distance from Roman towns, Roman roads and navigable rivers.

One of the main characteristics of the Guadalquivir Valley in Roman times was the presence of two major waterways, the Guadalquivir and the Genil. It was possible for smaller boats to move between Cordoba and Hispalis (Seville) on the Guadalquivir (Strabo III, 2,3), while west of Seville the river was suitable for larger vessels, so that Hispalis was actually considered a sea port (Silius Italicus, book III, 390). The river Genil, connected to the Guadalquivir, was navigable up to Astigi, modern Écija (Pliny, Naturalis Historia, book III, 2, 10). The two navigable rivers were used as starting points to create a cost distance surface to test the relationship of sites to the waterways of the Guadalquivir Valley. Again, the relationship was tested by means of the one-sample Kolmogorov Smirnov test. The test showed a significant relationship between the high status sites in all periods and the distance from navigable rivers, while the test was significant for the low status sites only for the Early and Late Empire but not for the Republic.

Exactly the same results was obtained for the distance from Roman towns, while the test for distance from Roman roads was significant for the Early and Late Empire only for both the low and high status sites.

5.4 WHAT DOES IT ALL MEAN?

These results indicate that the variables which influenced the Roman site location in the Guadalquivir Valley are those with a social and political implication, rather than the environmental ones. Considering the high status sites, which are more visible archaeologically than the low status ones, it appears that soil type and agricultural potential played a very small part in the location of settlements, while the important elements seem to have been the distance from Roman towns and the distance from navigable rivers. Almost all Roman towns in the Guadalquivir Valley were built on top of earlier Iberian settlements and indeed the Romanisation of the area seems to have been more of an integration of the Roman settlers than a take-over, as has already been argued by Keay (1992). The distribution of sites in the Republic still follows the landmarks which were important in the Iberian period: the Iberian-Roman towns and the rivers Guadalquivir and Genil. Only in the Early Empire do the Roman roads become important for the location of high-status sites, but this is due to the fact that few of them had been built before the end of the Republic.

For the low status sites, the situation is slightly different. The tests are all negative for the Republic, but there is a significant relationship between the low status sites and the Roman towns, the navigable rivers and the Roman roads in the Early and Late Empire. It seems that non-environmental variables were responsible for the location of low status sites, as is the case for high status sites, but this is only apparent from the 1st century AD onwards. Moreover, the fact that pre-existing structures such as the Iberian towns were influencing where the Romans were settling shows that they did not choose the best locations for agriculture, and they were under other types of (socio-political) constraints.

6 The analysis – the distribution of the different pottery types

The distribution of different pottery types was also studied to assess whether the way imported pottery was redistributed changed over time. This was done by counting the number of rural sites with a particular pottery type occurring in the catchment of each Roman town. Such an approach was imposed by the fact that the available data are only qualitative (i.e. we have information on whether a certain material was present at a site, but not in what quantity). The town catchments were calculated using cost distances, equivalent to moving 15 km over a flat (with uniform friction of 1) surface. This figure of 15 km was arrived at from written sources which designate this as the catchment for a market town (Frayn 1993: 77). Where two towns were too close together to have 15 km catchments, the midpoint between the two cost catchments was used to define the border between the two areas of influence. This is in effect a variation on Thiessen polygons taking into account the land form and putting a maximum distance for the size of the catchment. Some of the catchments thus derived did not contain any sites, and these were therefore excluded from the analysis. The most noticeable exclusion is the territory of Hispalis (modern Seville), where no Roman rural sites are found due to a combination of a small catchment, its closeness to other Roman towns, and modern development.

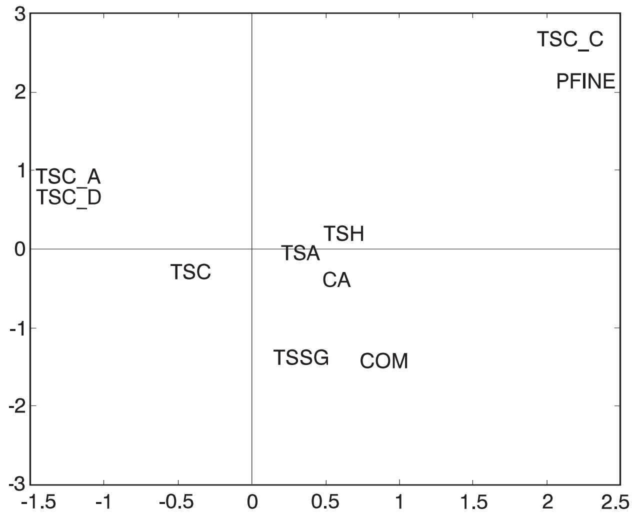

Figure 1. The Correspondence Analysis variable plot. CA = Black Glazed pottery, COM = common pottery, TSA = Terra Sigillata Aretina, THS = Terra Sigilata Hispanica, TSSG = South Gaulish Terra Sigilata, TSC = Terra Sigillata Chiara, TSC_A = Terra Sigillata Chiara A, TSC_C = Terra Sigillata Chiara C, TSC_D = Terra Sigillata Chiara D, PFINE = Thin-Walled ware.

The result was a table containing the number of sites in the catchment of each town with a specific pottery type. This data table was particularly suitable for analysis by Correspondence Analysis (Baxter 1994: 100-139).

The plots of the variables and objects are shown in figures 1 and 2. Figure 1 shows a clear patterning in the data, in particular the division between the Terra Sigillata Chiara A[2] (TSC_A) and Terra Sigillata Chiara D (TSC_D), and the Thin-Walled ware (PFINE) and the Terra Sigillata Chiara C (TSC_C). Another interesting feature is the fact that Black Glaze Pottery (CA) and Terra Sigillata Aretina[3] (TSA), which are similar in date, cluster together, as does Terra Sigillata Hispanica (TSH) which was in use until the 3rd century AD.

Generic Terra Sigillata Chiara (i.e. Terra Sigillata Chiara which has not been further identified as belonging to a specific subgroup) is on the edge of the central group and leans towards the group containing Terra Sigillata Chiara A

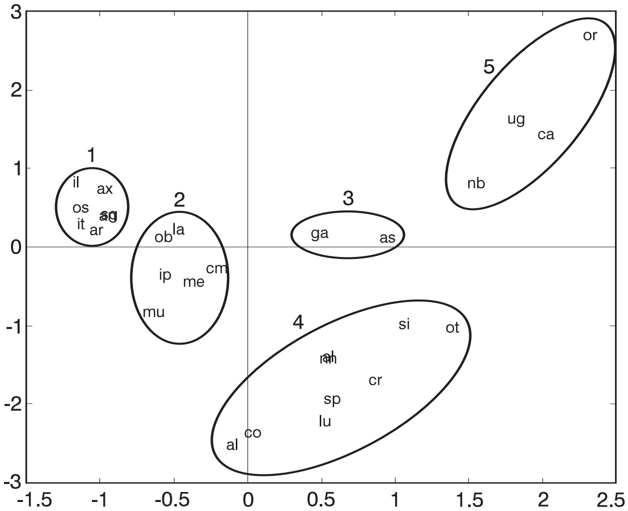

Figure 2. The Correspondence Analysis object plot (towns).

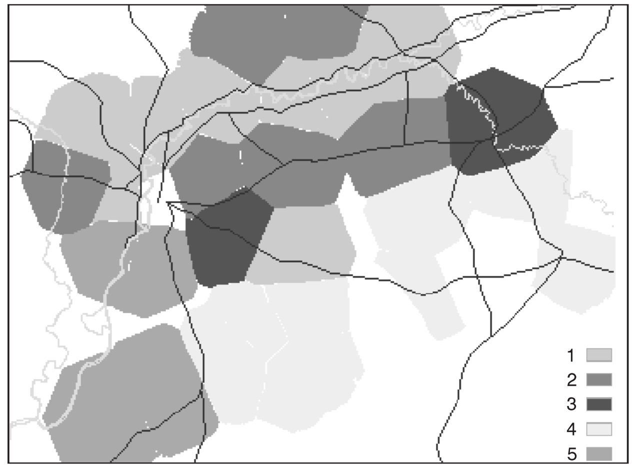

Figure 3. The town territories colour coded as the groups in figure 2, with the navigable rivers (lighter lines) and the Roman roads (darker lines).

and Terra Sigillata Chiara D, well away from Terra Sigillata Chiara C. This might indicate that the Terra Sigillata not identified behaves much more like the two subgroups A and D, rather than subtype C. The interesting fact is that, according to the results of the Correspondence Analysis, Terra Sigillata Chiara C is found at sites where there is no or very little Terra Sigillata Chiara A and D. This is strange, as the subtype C is chronologically located between the subtypes A and D. The three subtypes were produced in modern-day Tunisia, but while subtypes A and D were produced in the same places, subtype C was produced in different workshops. If subtype C was imported from its place of production into the Guadalquivir Valley following different routes from subtypes A and D, it would explain why it is found in different places.

The towns in the object plot (fig. 2) were grouped together in five clusters (numbered 1 to 5) to study the geographical position of towns with similar catchment assemblages according to the Correspondence Analysis. Using Idrisi, the territories of the towns in each of the 5 clusters were differentiated by giving them a different colour (fig. 3).

The object plot shows a concentration of cases in the position corresponding in the variable plot (group 1) to the Terra Sigillata Chiara A and Terra Sigillata Chiara D pottery types. When the towns in this concentration are checked against their geographical position, the relative closeness of their territories to the river Guadalquivir is striking. It was immediately evident that almost all of these towns are either crossed by the river Guadalquivir itself, or are on the Via Augusta which leads directly to Hispalis (Seville). The territories of the towns which correspond in the object plot to the position of Terra Sigillata Chiara (group 2) in the variable plot follow a similar distribution along the Guadalquivir, slightly further away than the territories explained by Terra Sigillata Chiara A and Terra Sigillata Chiara D, but still on major roads directly linking the territory to Seville. Terra Sigillata Chiara A and Terra Sigillata Chiara D appear to be dominant in the northern half of the study area.

On the contrary, the territories explained by Thin-Walled ware and Terra Sigillata Chiara C (group 5) tend to occur to the south of the region, or at least to the south of the distribution of Terra Sigillata Chiara A and Terra Sigillata Chiara D. Remarkably, the two distributions appear to be self-exclusive, as is also strongly suggested by the Correspondence Analysis plots.

The other pottery types, Black-Glazed pottery, Common pottery, Terra Sigillata Aretina, Terra Sigillata Hispanica and South Gaulish Terra Sigillata[4] occur throughout the study area and do not seem to be limited to specific locations as is the case for the Terra Sigillata Chiara subgroups and Thin-Walled ware. The fact that the distribution of Terra Sigillata Aretina is similar to that of Black-Glazed pottery, as can also be seen from the Correspondence Analysis variable plot, might suggest that Terra Sigillata Aretina was distributed along the same routes as Black-Glazed pottery. Black-Glazed pottery was imported into the region from the earlier 2nd century BC, well before the Romanisation, and was distributed along the Iberian exchange network. The similar distribution of Terra Sigillata Aretina and Black-Glazed pottery suggests that these networks were still being used after the Romans first settled the area. Terra Sigillata Hispanica, which was a locally produced ware imitating the foreign forms, also has a very similar distribution to Black-Glazed pottery and Terra Sigillata Aretina, showing that the original exchange network might still have been in use as late as the 2nd century AD while, at the same time, a different redistribution network was used for Terra Sigillata Chiara A and then Terra Sigillata Chiara D.

In the Late Empire the only evidence we have comes from the Terra Sigillata Chiara D, which follows the Guadalquivir network, so that the first two centuries AD can be seen as a period of transformation from one system to the other. There is no information on whether Black Glaze and Terra Sigillata Aretina were being traded along the Guadalquivir, but if they were, they were then distributed more extensively than the Terra Sigillata Chiara A and D. It is also important to note that the Terra Sigillata Hispanica was being produced in workshops at Andujar and Granada and was therefore imported into the Guadalquivir Valley by land, rather than along the navigable rivers. Terra Sigillata Aretina and South Gaulish Terra Sigillata had a strong influence on the form of Terra Sigillata Hispanica and it is likely that this latter ware was traded to the same areas of the pottery it ended up replacing.

Terra Sigillata Chiara was clearly almost only available in the town territories which were directly connected to Hispalis. The majority of the territories in which the Terra Sigillata Chiara subtypes are found depended on towns which were either directly located on the Guadalquivir (such as Axati), or on a major road leading directly to Seville (such as Segida). This also suggests that Terra Sigillata Chiara was brought to the towns and then redistributed to the sites in the town territories from the centre, rather than being brought to the sites directly. This is consistent with the creation of influential Roman centres (coloniae) under Caesar and Augustus linked by an integrated road network. Since the sites which received the Terra Sigillata Chiara A and D are on the Via Augusta or the Guadalquivir, these were the main routes for the redistribution of this type of pottery. Though there are other Roman roads leading south from these towns, it seems that these were not used to redistribute the Terra Sigillata Chiara A and D to the other centres.

7. Model of settlement pattern change in the Guadalquivir Valley

The Romans already had trade contacts with the Iberians in the Guadalquivir Valley during the 2nd century BC. There is archaeological and historical evidence that at this time the Iberian society consisted of a centralised network of towns with dependent rural settlements. In the 1st century BC the Romans first settled the area, but the old Iberian trade network and organisation was still strong and the Romans had little impact on the local society. The Roman rural settlement pattern at this time was already differentiated between high status and low status sites, with the high status sites clustering around the Romano-Iberian towns, while the low status sites were spread wide across the countryside.

The situation changed in the 1st to 3rd century AD. While right at the beginning of the Early Empire it looks likely that the old Iberian exchange network was still being used for the Terra Sigillata Aretina, a new distribution network appears for the Terra Sigillata Chiara A and D, favouring those sites which were on the Guadalquivir or on the Via Augusta. The density of rural sites increased dramatically with new high and low status sites appearing centred around towns. Several of the Iberian towns either had a Colonia of Roman citizens founded on their territory, or were granted Municipium status, making their Romanisation official. Under Augustus most of the towns which became Colonia or Municipium were on the Guadalquivir and seem to have monopolised the distribution of fine Terra Sigillata Chiara A and D which is hardly found outside their territories. These towns were also the key sites in the trade of oil and corn produced in the Guadalquivir Valley.

Between the 3rd and 6th centuries AD the situation changed again and several high and low status sites disappeared. The pattern of disappearance of the high status sites seems to have been different in different parts of the valley. Around the Guadalquivir the situation stayed rather similar to what it was in the Early Empire, with high density sites clustered around the towns, while elsewhere a distributed pattern appears. This is consistent with the appearance of larger estates in the southern part of the Guadalquivir Valley, while the sites along the Guadalquivir were still depending on the towns for their wealth. The low status sites which disappeared were mainly those away from the towns, showing that there might have been a collapse of the large-scale exchange networks with smaller sites having to rely on the services offered by towns to survive.

notes

1 Strabo, *Geography* III.2.15, '*...The Turdetanians* (the Iberian population of the Guadalquivir Valley), *however, and particularly those that live about the Baetis, have completely changed over to the Roman way of life, not even remembering their own language any more*'.

2 Terra Sigillata Chiara is better known to English archaeologists as African Red Slip.

3 Arretine pottery.

4 South-Gaulish Samian ware.

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Recent examples of geographical analysis of archaeological evidence from central Italy

1 Introduction

Geographical information systems have undergone a very great expansion in archaeology during recent years (Allen *et al.* 1990; Lock/Stančič 1995). Important and recent advances in the capabilities of GIS software have opened up new possibilities for data analysis and display. For example, developments in visualisation techniques (McLaren/Kennie 1989; Visvalingham 1994) have provided new approaches in a variety of application areas including archaeology.

The expansion has three, amongst other, important characteristics and concomitant questions. Firstly, readily available GIS software packages, requiring relatively cheap hardware (e.g., PCs), have both facilitated and constrained archaeological use. The packages have been developed for non-archaeological use where, for instance, time is often of a different order of magnitude. Are the current GIS packages entirely suitable for archaeology given their original aims? Secondly, certain assumptions of scale are made in building environmental and archaeological databases for analysis by GIS. For example, the extent to which DEMs provide an adequate realisation of the terrain of a site depends on the availability and characteristics of the original source material (i.e. maps or aerial photographs). How should archaeologists assess the relevant scale for the implementation of a particular project? Thirdly, GIS software has considerably aided the rapid assessment of theoretical questions of a broadly environmental and technological type which were prominent in the 1960s. The data sources are physically and environmentally deterministic and many approaches are technologically deterministic in the way in which certain GIS packages force the use of particular routines/algorithms. In the meantime, archaeological theory has begun to stress other, ideological, dimensions. Can GIS techniques address these more ideological questions?

This paper addresses these three issues in the light of two projects undertaken at the University of Bristol. The first was a project in the Department of Computing Science undertaken to develop a set of bespoke software tools for the exploratory analysis of archaeological and environmental data from the Valley of Gubbio whose first stage has already been published (Malone/Stoddart 1994) and whose analysis is now entering the secondary stage. The second was the work involved in preparing data for a TLTP (Teaching and Learning Technology Programme) project to aid the teaching of GIS, drawing on data from the Nepi area of southeast Etruria, 40 km north of Rome. This is in turn part of a longer term project covering the re-analysis of settlement from a larger area of southeast Etruria, drawing from material collected by the British School at Rome and the Soprintendenza Archeologica per l'Etruria Meridionale.

2 Strategies towards increased flexibility: The Gubbio example

The data for the survey of the Gubbio valley have been published in the form of distribution maps of discrete sites, alongside excavation results, environmental analysis and overall interpretation of the Gubbio valley in comparison with other areas of central Italy (Malone/Stoddart 1994). As outlined in the introduction to the publication, this does not do justice to the information available either from the archaeological or environmental survey. The trial project proposed within computer science was to set up a flexible and interactive system to explore the relationship between pedology and densities of archaeological artefacts (as opposed to discrete sites). As currently implemented the application is relatively simple and allows the overlaying of different types of maps and the graphical representation of frequency of site finds against landscape characteristics.

The aim was to develop a prototype system which would provide a test bed for investigating extensions to the GIS capabilities available in commercial systems. In most cases these existing systems have not been developed with the needs of the archaeological user in mind. For this reason, there is a requirement to specify and implement a set of customised tools for data analysis and display to support archaeological investigations. An important feature of our approach is the opportunity it provides for an archaeologist, computer scientist and geographer to work together in an interdisciplinary framework to develop new techniques for geographical analysis of archaeological data. An important element of this approach is the use of a prototype system to demonstrate these techniques and facilitate communication between potential users and system developers.

2.1 Specification for the Gubbio exercise

A trial area of the archaeological survey was selected for preliminary examination. Environmental data were supplied for the purposes of this exercise in two forms: contour maps and pedological maps. Archaeological data were supplied in the form of quantities of recovered material from point ccordinates which represent an area. The full detail allowed by the field survey collection strategy can be incorporated at a later stage.

These different arrays of information were to be overlayed on top of each other, allowing comparison of archaeological and environmental data. The environmental data can be divided (although not entirely independent) into topographical (height, aspect and gradient) and pedological (soil type, drainage etc.). The maps were to be rescaled and histograms were to be calculated which show these relationships. Figure 1 shows a histogram of finds at different contour levels.

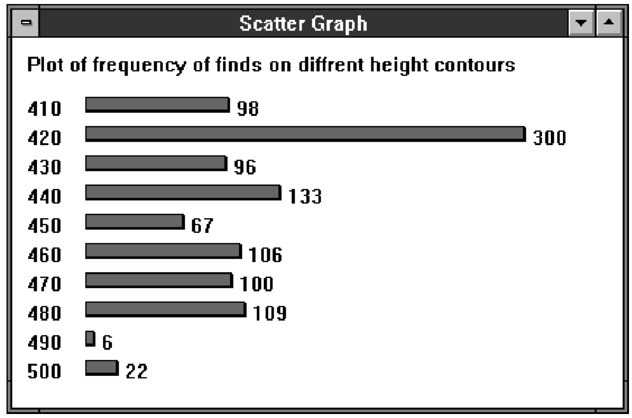

Figure 1. Frequency graph of finds at different contour levels.

2.2 Implementation

The prototype system is PC based, operating under Windows and developed in C++. The user interface is shown in figure 2. An important aspect of the system is the design of this user interface which enables an intuitive easy-to-use point-and-click interface for most of the system functions. Despite recent advances in GIS software, many commercial systems still make extensive use of command languages in which the user has to enter keywords and parameters via the keyboard. The approach developed here makes full use of an object-orientated language within a Windows environment in an attempt to maximise use in an intuitive and fully interactive manner. The use of a graphical user interface (GUI) and visual programming elements allows the user to interact more naturally with complex spatial data such as landscape models.

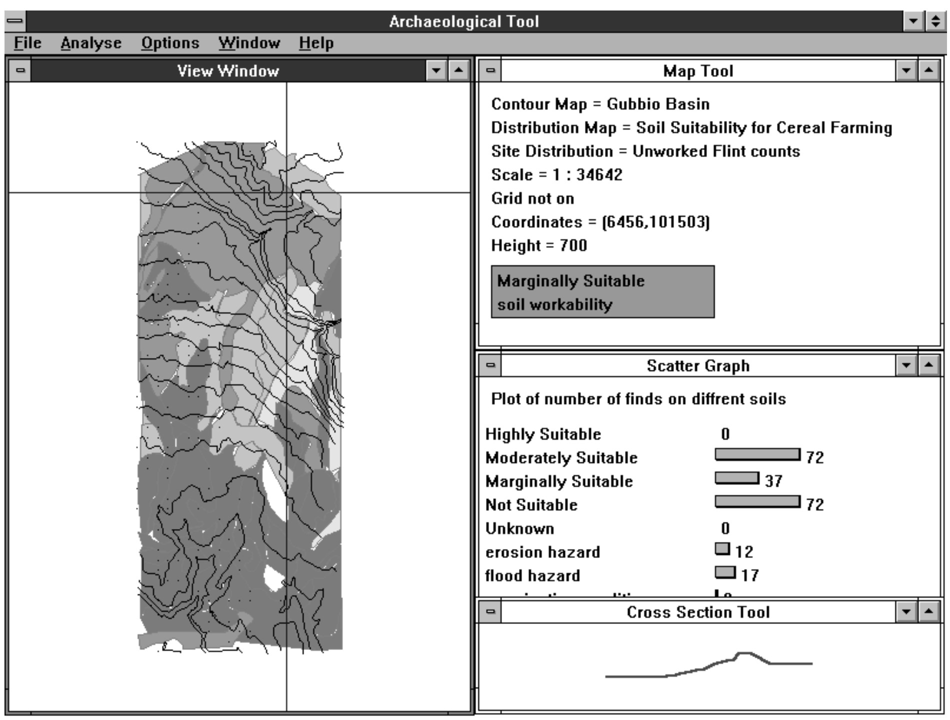

Figure 2. System for analysing information from the Gubbio region.

The limited amount of resources available for the development of this system to date means that we have focused on illustrating a series of possibilities, to stimulate further discussion of the possible uses of GIS in archaeological analysis, rather than concentrating on the development of a polished software system. The system currently scales and rotates maps and plots artefact locations following parameters determined by the operator, as illustrated in figure 3. This is an ongoing project where it is our intention to explore varied presentations of DEMs, with interactive control of interpolation, aspect, gradient and visibility, and to introduce specific types of statistical analysis.

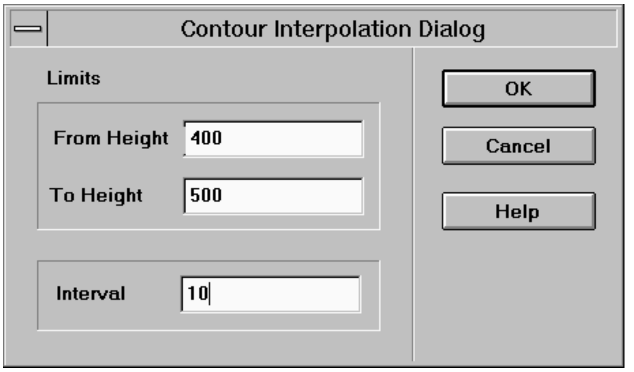

Figure 3. Contour interpolation dialogue box.

3 Strategies towards appropriate scale and ideological analysis: The Nepi example

The grand scale of the study of the South Etruria area is to visualise a changing political landscape over time principally from the middle of the second millennium through a series of major changes: Etruscan and Faliscan state formation, conquest by the Roman Empire, the decline of late Antiquity and the resurgence of the Middle Ages. The specific case study derives from an early stage in this process adopted for teaching purposes in the tutorial of GIS for a nationally funded UK computer aided teaching programme.

The Nepi dataset is characterised by two important facets: a fragmented terrain and a rich, but unsystematic, settlement dataset. The Nepi landscape is volcanic and dissected. The accuracy of the terrain model is therefore crucial. Horizontal distance is no measure of the physical effort in crossing terrain. The volcanic plateaux are apparently flat, but slight differences in height can also have a major effect on intervisibility. The dataset is rich, although in need of considerable data verification. One aspect of the richness is the presence of tomb as well as settlement data. These data have been usually collected by different strategies to the settlement data, but once integrated may allow a new dimension of analysis. It is well known that pre-Roman tombs were placed in visible positions outside towns, but geographical analysis might allow a more detailed analysis of this phenomenon.

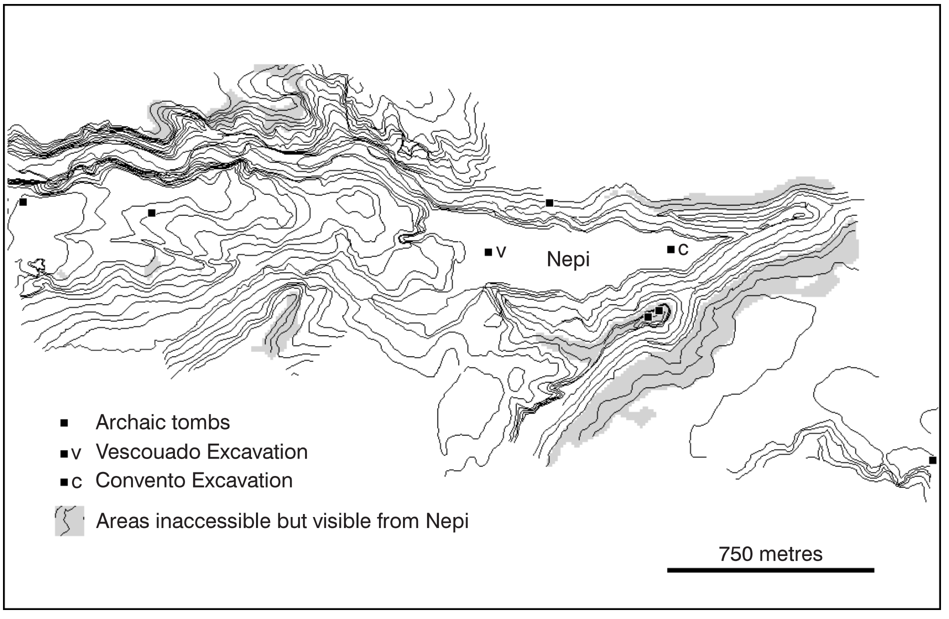

Figure 4. Location of tombs in zones of visibility and inaccessibility.

3.1 Problems of scale

In work on the Nepi dataset, considerable effort was devoted to the elaboration of height data at an appropriate scale. This becomes very important when visibility in this terrain is highly sensitive to small changes in height. The problem in assessing the scale for the analysis became particularly prominent given the difficulty of securing suitable maps which could answer the questions posed by a rich, but methodologically complex dataset. Satellite data are expensive and not necessarily sensitive to the needs of micro-analysis of site location. The most detailed digital data are available at 1:25,000 but still not necessarily sufficiently sensitive and also costly. One approach is to build up coverage from locally available maps at scales of 1:2000 - 1:4000 with concomitant problems of edge matching and error checking. Problems also had to be addressed in replacing cartographic symbols of significant drops in height over short horizontal distances (ravine edges) by digital data. A more satisfactory solution is to constitute the DEM from aerial photographic data, using photogrammetric software and this is currently being investigated.

3.2 Ideology

The rich dataset of tomb and settlement data can be played against each other. Figure 4 shows the concurrence of inaccessibility and visibility from the town at certain points in the landscape. These zones correlate very strongly with the presence of tombs which have a liminal quality in the ideology of the pre-Roman period. More detailed analysis on a broader landscape will allow the precise quantification of this relationship, drawing in minor settlements and roads into the equation.

4 Conclusion

These examples illustrate the need to increase interactivity, sensitivity to scale and broadening of the scope of GIS to less strictly environmental questions. New steps can only be provided by increasing the communication between specialists in different fields of activity and ensuring their mutual understanding.

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Satellite Imagery and GIS applications in Mediterranean Landscapes

1 Introduction

Following the early seventies, when satellite imagery first became readily available, a wide range of professionals, including archaeologists have attempted to utilize satellite images in environmental sciences. An early example of the use of satellite imagery includes that by Quann and Bevan (1977) which identified the Egyptian pyramids from such imagery. However, such examples emphasize the limits of such images — the spatial resolution of the image is usually far larger than the average archaeological site. Satellite images have therefore not been very useful for detecting the direct location of archaeological sites. Despite this, these images can be of enormous help. Archaeologists can use them to define physiographic regions, soil zones etc., and when this data is integrated within a GIS and combined with our knowledge of archaeological sites and distributions, a variety of analyses can be performed on the data (Limp 1987; Lyons/Scovill 1978: 9).

Within GISs, satellite images are treated as a data input source. Where cartographic information is not available or is not of high enough quality, the use of such images is frequently a useful alternative. Any individual can purchase a multi band image of the area of the earth they are interested in and, if used correctly, such images can provide an enormous amount of information about the environment.

The principal subject of this paper is to discuss the use of satellite imagery within archaeological landscape studies and to present some recent results of such work. One such study has been carried out in the central Adriatic where an international team of archaeologist, historians, geographers and other specialists has been studying the archaeology of the Central Dalmatian islands (Croatia) for more then a decade (fig. 1). This research has included the analysis of settlement patterns, colonization, contacts, land use and economy of the prehistoric, protohistoric, Greek and Roman communities who lived in the area. The archaeological data for this work was gathered through field surveys of the islands and extensive archive research. The natural environment data (when available), was largely supplied as thematic maps which were frequently unsuitable for detailed analysis. These contrasts are exemplified by the situation relating to detailed soil maps in the area. That for the island of Hvar (Gaffney/Stančič 1991) was extremely detailed with a refined classification and plotted at a scale of 1:25,000. Unfortunately no other island, with the exception of the island of Brač, possessed such maps. The situation clearly limited comparative analysis between the islands. Satellite imagery therefore suggested itself as an alternative source for such data.

2 Methodology and classification techniques

The classification of Landsat data for the purposes of defining soils and land use categories is invaluable for interpreting agricultural potential, a variable which is frequently used in archaeological landscape studies. The objective of image classification is to identify and portray the image in terms of the object or type of land cover under study. Image classification is probably the most important part of digital image analysis.

Basic to the understanding of multispectral classification is the concept of the spectral signature or spectral response of an object on the ground. The spectral response for a given object is a measure of the amount of electromagnetic radiation it reflects as a function of wavelength. The reflectance of each cover type behaves differently across the wavelength spectrum (Mather 1989). In fact, these spectral responses are often sufficiently variable to enable spectral discrimination of each cover type. It is the apparent uniqueness of the spectral response of each object from which the term 'spectral signature' is derived: as each signature is assumed to be a unique identifier of its owner.

Unfortunately, when performing classification, you do not have the entire spectral signature in an image. Rather, you have a set of signatures that consists of reflectance in a few discrete locations (the bands of the imagery acquired). These incomplete signatures provide only a partial description of an object. The fewer the observations in the spectral signatures with which you work, the less likely it will be to discern an object's signature.

In general, the greater the number of bands or channels, the better the ability to discriminate between objects and classify them correctly. However, simply adding more bands of information does not necessarily yield improved results. Improvement will be recognized only if the

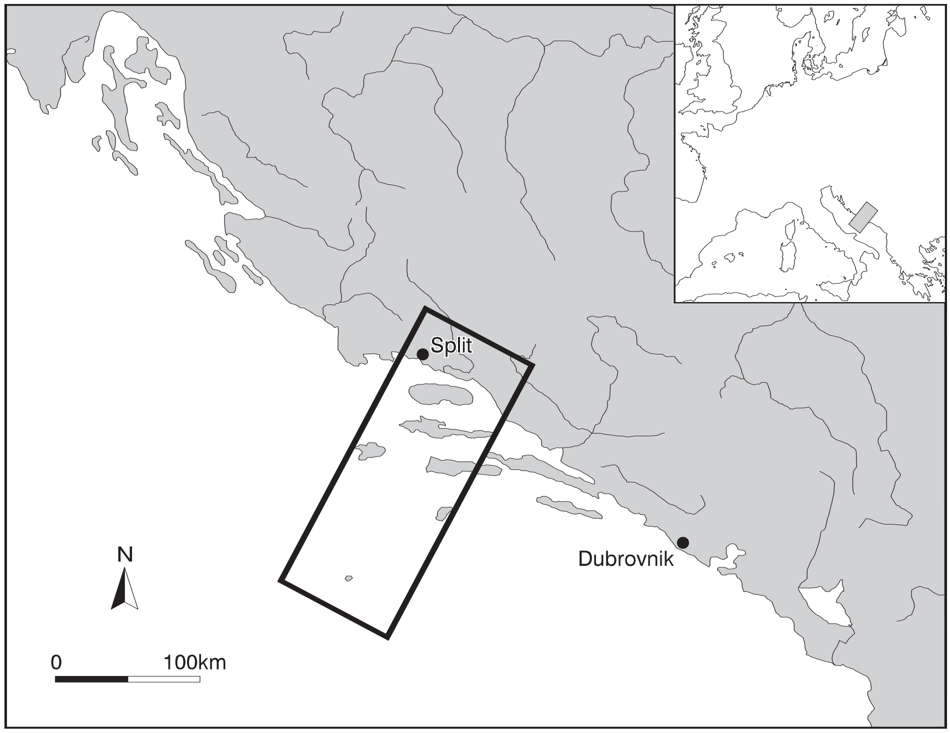

Figure 1. The study area.

additional bands represent new or different information. For this reason one should be wary of using spectral bands that are quite close in wavelength as it is unlikely that the spectral curve would be significantly different from adjacent band(s). Much of the time spent in performing a classification analysis is devoted to gaining an understanding of the spectral behaviour of features of interest in imagery and to determine the combination of bands that offers the greatest spectral separation between image features.

Automated image classification has traditionally been divided into supervised and unsupervised classification procedures. The primary distinction between these two approaches is the manner in which the spectral signatures are generated. In the supervised approach one locates samples of each cover type, in a number of bands, from which the computer can generate spectral signatures. In unsupervised classification, signatures are generated by mathematically grouping the n-dimensional spectral information (PCI 1994). Unsupervised classification is usually used to get an overview of data and provides quick results, for serious studies supervised classification must be implemented.

The process of image classification consists of three main parts:

1. signature generation and editing,
2. classification,
3. analysis and presentation of results.

The first task is done ‘by hand’ during supervised classification and automatically during unsupervised classification. There are several different algorithms for both classification techniques, which can be found in specialized literature on image processing, or in software manuals (see Mather 1989; PCI 1994). We shall not discuss the algorithms here, but it should be mentioned that these range from very simple, e.g. parallelepiped, to very sophisticated techniques which use neural networks and fuzzy logic. Even after classification it is likely that some further improvements can be made on the results and sometimes the procedure has to be repeated with different signatures, training areas or algorithms.

3 The Research

The project under discussion here needed data for the entire region of Central Dalmatia and it was decided to use Landsat TM images. Good quality thematic maps were available only for the island of Hvar and these data were used for a comparative study of the quality of traditional thematic data with that provided from satellite imagery. The Hvar data was compiled for the purposes of a local development plan (Bognar 1990) and included climatological, pedological and geological maps and settlement data. This data was prepared via traditional sampling procedures and was presented in paper format, but was converted to digital format by project staff.

It was intended that the work on Hvar would demonstrate the comparative value of using Landsat data for the purposes of environmental planning, whilst the work on Vis, Brač and other islands would demonstrate the application of new technologies where environmental data was absent. Land use and soil maps were not available for islands other then Hvar and Brač. The island Vis, for example, had been under Yugoslav military control and was closed to foreign visitors until 1991. Most information on the island, including environmental data, aerial photographs, detailed topographic and cadastral maps were classified as restricted. They are therefore not available. Archaeological field work was carried out during 1993 and 1994 to provide detailed archaeological data, and this information will be integrated with Landsat data as it becomes available. This should allow rapid evaluation of land use and the condition of cultural resources.

For purposes of analysis, the Landsat quarter scenes were split into subsets relating to individual island groups. These were:

1. Hvar and the Pakleni islands,
2. Vis, Biševo and Svetac,
3. Brač, and
4. Šolta.

Rectification and geo-referencing of each subset of the 1993 quarter scene was carried out in conjunction with available maps. Although a standard procedure, a number of specific problems was encountered. The only accessible maps available for transformation were produced at a scale of 1:50,000, larger scales being classified. Almost all the maps had been produced during the 1950s, with no major re-survey carried out after that date. It was therefore difficult to locate accurate ground control points that still existed and were not on the coastline (e.g., roads). Several map sheets also displayed a number of significant printing errors. The map sheet relating to the island of Vis was particularly inaccurate with respect to the southern coastline of the island. This latter problem was resolved by the use of ground control points on adjacent islands, i.e. on the island of Biševo. Although the results of such remedial action were adequate for the analysis, it would be desirable to acquire more accurate control points for registration.

Having transformed the 1993 images to a UTM coordinate system, the remaining images were registered using image to image classification. After preparation and geo-referencing, preliminary classification was carried out using the July 1993 image of Hvar. Hvar was chosen for classification because of the relatively large amount of available data for supervised classification. This included: documentation relating to the agricultural development of the island, aerial photographs relating to the Starigrad plain and a development plan completed in 1990 (Bognar 1990; Carter 1990; Poduje 1975).

Although a variety of unsupervised classifications were carried out using the Hvar data, the results were not such that they could be used uncritically. Consequently, supervised classification was carried out using the aerial photographs for the Starigrad plain as a source of training samples. On this basis a total of 7 landuse types were defined. These were:

1. urban areas,
2. areas of bare rock,
3. vineyards,
4. maquis,
5. pine,
6. pasture, and
7. flysch arable zone.

After the classification on Hvar was completed, satellite images of other islands were then processed. Whilst the results from Hvar could be widely used for other islands where there was very little land use data, the results could not be verified without further ground truthing. Despite these problems, it seems worthwhile to compare the results of the Landsat land use analysis with earlier comparative data on land use on Hvar published by Poduje in 1975 and the soil survey published by Bognar as part of the 1990 Hvar Development Plan. For these purposes the Landsat data has been reclassed, as shown in table 1, to allow comparison with earlier quantifiable data.

Table 1. Comparative landuse data for Hvar (area in hectares).

Land Use classes after Poduje (1975)

Arable	Pasture	Forest	Infertile
4,491	9,199	22,630	1,921

Landsat derived landuse classes

Arable	Pasture	Maquis	Pine	Open/Urban
4,928	4,212	10,232	3,997	7,954

Soil classes after Bognar (1990)

Very Good	Good	Poor	Very Poor
6,568	5,924	9,655	9,176

Landsat landuse reclassed for comparison with soil data

Very Good	Good	Poor	Very Poor
4,928	4,212	10,232	11,951

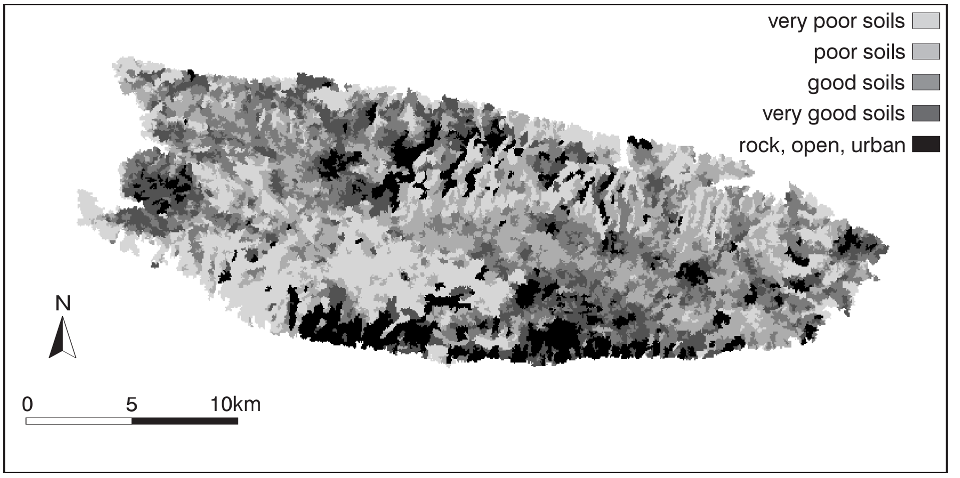

Figure 2. Classification results for July 1993 Landsat TM images of Brač.

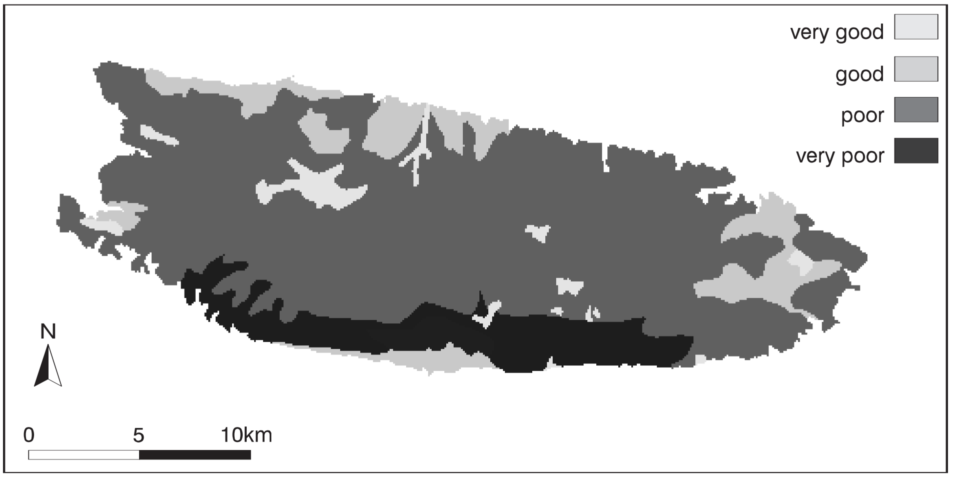

Figure 3. Soil map of Brač after Miloš, 1984.

Several points may be made concerning this data. The first relates to Poduje's data. Comparison of Poduje's data with that derived from the Landsat image illustrates the noted trend within Croatia towards the increasing abandonment of agricultural land. The decline in second class land (pasture) and the concomitant increase in maquis is particularly notable. Poduje's published data provides very detailed information on agricultural production that cannot be replicated with the Landsat data for the reasons given above. However, his data is very poor for non-productive land. The ability of the Landsat data to provide information on the spread of maquis is particularly useful in assessing the move towards climax population following desertion of agricultural land. We must presume that Poduje's data on forests actually contains information on maquis, although this is not indicated in the original publication. One suspects that his forest data was actually derived from a simple subtraction of the area of agricultural land from the total area of the island. The benefit of using a Landsat-based analysis over Poduje's semi-quantitative approach is clear, even at this stage of analysis.

It is more difficult to assess the relationship between the Landsat TM data and that from the Hvar Development Plan, particularly in the absence of an adequate vegetation map. However, there is a relationship between Bognar's qualitative soil data, which we may assume indicates the maximum area of soils of various fertilities, and that derived from the Landsat analysis. Differences probably result from the interpolative methods used to assess soil zones by Bognar and the disappearance of a variety of soil zones within maquis following abandonment. It is expected that the provision of more accurate training areas for Landsat data will ultimately provide a better assessment of areas of land use classes.

However, these results enabled us to develop an appropriate methodology for classification of Landsat TM images on other islands. Classification of the TM subscene covering the island of Brač was then performed and the results were much better then the original soil map which was published with a scale 1:200,000 (Miloš 1984). The results of the classification of Landsat TM image from July 1993 can be compared with the original thematic map in figures 2 and 3.

4 Conclusion and further work

The supporting digital environmental and cultural data has been made ready for rapid incorporation with the Landsat data and this should be reviewed. Digital elevation models for Vis, Brač and Hvar are available. The archaeological data for these islands is also available. The ability to rapidly integrate these data with that from the Landsat images can be illustrated through the interactive analysis of site locations with the spatial data on soil types. Although the project is still not finished and final results are not available at the moment, preliminary results are very encouraging.

1. The Landsat analysis, even at this stage, provides better quantitative data than Poduje's 1975 data for Hvar.
2. The study has already provided data related to one of the major aims in the exercises — quantification of the decline in agriculture on the island (e.g., for Hvar island a fall from *c*. 13,680 hectares in 1975 to 9,138 in 1993).
3. The 1990 development plan did not produce a vegetation plan to a standard that can be compared with the Landsat data. Final classification should therefore be a major contribution to available data for environmental planning on the islands.

Finally, several problems were noted during this analysis. Analysis of the training areas suggested that the signals derived were not homogenous. This probably has a number of causes. The most important are probably the following.

1. The agriculture of the islands is characterized by extreme polyculture. A wide variety of crops may be grown together on the same plot along with subsidiary tree crops. This prevents fine classification of crop types.
2. Arable areas on the islands are typified by the use of very small fields. Nearly 45% of the fields on the Starigrad plain on Hvar island for example are smaller than 30 meters (Fludder/Lister 1966) i.e. less than the size of a Landsat TM pixel.
3. Field boundaries are composed of masses of cleared stones and stone terraces that may be several meters wide and up to 3 meters high. Consequently, even good arable land may be characterized by a mixed signal.

A further complication was indicated by visual inspection of the distribution of land classes within the reclassified 1993 image. This suggested that land classification was less accurate in the mountainous spine of the islands than on the plain. This situation probably results from the necessity to use the available aerial photographic data relating to the Starigrad plain as the sole source of training areas. The plain should, perhaps, be considered an anomalous area. Signals for land use classes from this area may not transfer to similar land use categories situated high on the mountainous spine or on the bevelled upland plain that contains much of the agricultural land in the eastern part of the island. Although many of the problems associated with the data may be relatively minor, consideration of the data suggested that more accurate training areas should be sought. Despite these problems it is hoped that these results have demonstrated the advantage of using satellite imagery for providing natural environment data in archaeological GIS based research.

Acknowledgments

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The long and winding road: land routes in Aetolia (Greece) since Byzantine times

In one or two years from now, the last village of the southern Pindos mountains will be accessible by road. Until some decades ago, most settlements in this backward region were only connected by footpaths and mule tracks. In the literature it is generally assumed that the mountain population of Central Greece lived in isolation. In fact, a dense network of tracks and paths connected all settlements with each other, and a number of main routes linked the area with the outside world.

The main arteries were well constructed: they were paved with cobbles and buttressed by sustaining walls. At many river crossings elegant stone bridges witness the importance of the routes. Traditional country inns indicate the places where the traveller could rest and feed himself and his animals. Today, the old paths are rapidly falling into decay as they are being replaced by bulldozed roads. A score of ancient bridges has been destroyed by the construction of artificial lakes, or is falling into disrepair by neglect. Most of the old inns only survive in the memories of the local shepherds. Some of them have adjusted to modern needs and now serve as gas stations and self-service restaurants.

In this paper we will document the communication system of 'Aetolia' as it existed in the early modern period, where possible tracing it back to the Byzantine period. The material was collected within the compass of the Aetolian Studies Project, in which a multidisciplinary research team is working on the settlement history of this region from prehistoric to modern times. We will classify the routes according to function (trade, transhumance, social/religious contacts) and importance. The reconstruction is based on field work and a variety of written sources. Field observation and oral history support the cartographic evidence, travel literature and military guide books. An inventory of river crossings (arched packhorse bridges, fords, kareli's, rafts and ferries) and former inns (khan's) is presented to indicate the main routes.

1 Introduction

A few years ago Pávlos Bakogiánnis, then member of parliament for the Pindos province of Evrytanía, was assassinated in a terrorist attack. Evrytanía, where he was born, is the northern part of the research area of the Aetolian Studies Project. In 1960 Bakogiánnis had described how his native village of Khelidón was only connected to the outside world by what are called *karélia* (Bakogiánnis 1960: 71). A *karéli* consists of a cable spanning a river from which hangs a case or a rack with a pulley. The traveller either pulls himself and his goods to the other side or is pulled by a helper. When we visited the village in 1988, it could still only be reached on foot. The nearest road was an hour's walk away. Although the village was without electricity, a shuttle service by donkey supplied the local *kafeneíon* with beer and cola.

Since then, the bulldozer has moved on and connected Khelidón to the emerging road system of Evrytanía. There is now only one village left that cannot be reached by car, Stavrokhóri, but according to the president of the community its splendid isolation will soon be lost.

Until well into this century feet and mule back were the only means of transport in the mountains of Central Greece. Of the dozen or more villages in the district of Agrafa in Northern Evrytanía, only one could be reached by road by the mid 1960s (Tsitsá 1967: 18-19). The network of paths and tracks survived until quite recently, but as the bulldozer moves on to lay the foundations of a modern infrastructure, the old land routes are falling into decay. Yet, they live on in the memory of the older inhabitants of the region, who all have walked the old 'high roads' for hours, sometimes for days, to do their shopping in market towns, to take their flocks for hibernation on the plain, to attend religious festivals, to visit annual trade fairs, or to visit relatives in other villages.

For inhabitants of the 'Low Countries', and indeed for plain dwellers in Greece as well, it is very tempting to think of mountain areas as being by nature extremely isolated. This is true only to some extent. The barriers posed by high mountain peaks and (equally important) deep river gorges are often hardly surmountable, but if one inspects the path network in the mountains on a large-scale map, it becomes apparent that all settlements are interconnected by a cobweb of tracks. There are often even several alternative routes from one village to another.

This paper will outline the communication system in the area of the Southern Pindos mountains and its offshoots before the advance of modern traffic. We will concentrate on sources and methods for the analysis of pre-modern surface communication. We will then present results of different approaches, combining considerations of the landscape with literary and physical evidence on *khans* (inns) and bridges.

In order to reconstruct the network of historical routes and paths, we distinguish different motives for travel: trade, transhumance, socio-cultural exchange, and military purposes. The first and main motive for travel was trade. The identification of the main trade centres, their *hinterland* and mutual links determine the principal structure of the communication network. Transhumance forms the second motive for long-distance travel in Aetolia. The seasonal journey from the summer pastures in the mountains to the winter pastures in the plains is an important factor in the transportation network. The third reason for travelling over considerable distances is to attend religious festivals (*panigíria*), which often also have a socio-cultural and economic significance. These annual festivals were often combined with bazars and even served as marriage markets. The fourth function of the network of paths and tracks is military. In different periods of Aetolian history, either liberating or plundering armies traversed the region.

2 Sources and methods for analysis of communication

One of the main objectives of the Aetolian Studies Project is to investigate the changing socio-economic structure of the region from the time of the War of Independence until the Second World War. The development of the infrastructure of roads and tracks is one of the elements of the study. A variety of sources is available for the analysis of the network of land routes in Aetolia: literary sources and maps, oral sources, and physical evidence.

2.1 Written sources: travel literature and maps

The most important written sources on historical land routes in Aetolia consist of the accounts by travellers between the late 18th and early 20th centuries and the maps that were drawn on the basis of their journeys. Among others we mention: Bazin (1864), Dodwell (1819), Leake (1835), Pouqueville (1820-1821), and William Woodhouse (1897).

Moreover, after Greek Independence, the state of affairs in the new Kingdom was registered in various descriptions of and statistical reports on the country (Mansola 1867; Noukhaki 1901; Rankavi 1853; Strong 1842; Thiersch 1833). At the same time, (foreign) cartographers were assigned to survey the land. It was only in 1852 that the first more or less reliable map of our study area was published by the French at a scale of 1:200,000 (McGrew 1985: 130-135). This is the earliest map on which the communication network is represented fairly accurately. Earlier maps, such as those published by Leake and Pouqueville, do not give information on roads, whereas the topography of the Austrian map of European Turkey from 1829 is too distorted to be of any use in this respect.

2.2 Oral sources: interviews

Interviews conducted in about 300 villages in Aetolia over the last ten years form a second source of information on travelling and routes in the research area before the advance of modern traffic, i.e. before World War II. At that time, almost all transport went on foot or by mule. The structured questionnaire used in the Aetolian Studies Project contains questions on various aspects of economic life in the pre-war period (Bommeljé *et al.* 1987).

At several instances of the interview, attention was paid to travelling. In relation to stockbreeding we inquired after the occurrence of transhumance, the location of summer and winter pastures, and the routes of the journey between these areas. With regard to agricultural production, we asked about shortages and surpluses of different products, which products were sold or bought, where and how often. The routes to market places for basic consumption goods were registered. We also investigated the other (non-commercial) functions of central places. Religious festivals and bazars that were attended were noted down.

The answers to these questions offer several indicators which are useful in the reconstruction of the location and function of the most important routes: the nodes in the transportation network (origin and destination), the motives for travelling (trade, transhumance, socio-cultural), the importance, function and frequency of the routes taken.
In order to mark the routes taken, we asked our informants to mention the places they passed and the exact location of river crossings and other noteworthy natural features, such as for instance mountain passes.

2.3 Physical evidence

During the fieldwork campaigns of the project, we collected additional information on the physical condition of the paths, bridges, and *khans* in Aetolia. We walked a number of paths, which appear to be falling into rapid decay now that they are no longer used. Bulldozed roads replace and sometimes destroy the traditional tracks, which usually were well-constructed, roughly paved with stones and supported by foundation walls.

Most bridges have now disappeared. Only a few stone packhorse bridges survive. Several of these have been

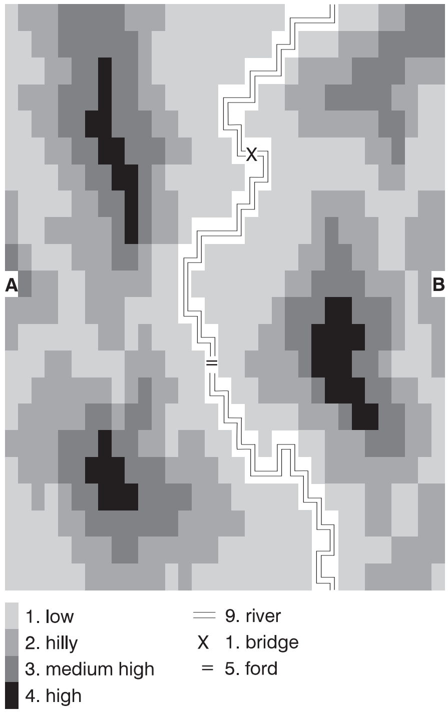


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Figure 1. Difficulty of travelling in hypothetical landscape.

destroyed in the Civil War, when the mountains of the Southern Pindos formed a natural fortress for the guerillas. Some other bridges are submerged in artificial lakes that have since been created in the rivers Akhelóös and Mórnos.

The function of the traditional country *khans*, so important in the time of non-mechanized traffic, has now been taken over by the roadside cafe and petrol station. Only a few of the original buildings are still standing today. In the following section we will give a more detailed account of these elements of infrastructure.

2.4 Methods and models of analysis

There are various methods and models for analysing surface communication. In this paper, we restrict ourselves to a mainly descriptive approach. In an earlier study we have attempted to reconstruct the main flows of communication in eastern Aetolia (the eparchy of Doris) by applying gravity and potential models (Doorn 1985).

Although the gravity and potential models give an interesting image of the flows of communication and aggregate accessibility, the method is too rough for the reconstruction of actual routes. We therefore borrowed another model from natural science, namely the law of the conservation of energy, to substantiate the most likely course of historical land routes, once certain communicative centres and concentrations of population are given. The basic assumption is that man tends to minimize his efforts in order to achieve his goals. With regard to communication this means that he will spend as little energy as possible to reach a certain point in space. In an isotropic plain, he would travel in a straight line if he wanted to go from point A to point B. In Greece, and particularly in Aetolia, plains are uncommon. High mountains and deep river valleys form natural barriers to communication. Routes tend to be defined by the shortest, quickest or easiest way of surmounting the distance and barriers between points A and B.

Imagine a hypothetical landscape as in figure 1. The shortest route from point A to point B would be a straight line, but this would not be the easiest course: the traveller would have to climb two ridges and cross a river at a place where there is no bridge or ford. We could quantify the difficulty of different landscape elements and then calculate the amount of energy needed as the product sum of difficulty times distance. By calculating the energy needed for alternative routes, we could simulate the trial and error process by which in the real world the easiest route is found. Clearly, the route costing minimum energy is the one that in reality would most likely be chosen.

In figure 2 and table 1 this method is used to evaluate the difficulty of several alternative routes from the Gulf of Corinth to the communicative node at the defile 'Stenón', near ancient Kallípolis and modern Lidoríki (eparchy of Doris). The graph and table show that alternative A is the shortest route (22.5 km), but not the easiest one; alternative C is five kilometres longer, but it is quicker because fewer vertical metres have to be surmounted.

Table 1. Quantitative evaluation of three alternative routes Gulf of Corinth - Stenón.

A. Erateini-Stenon via Amygdalea

Km	Height	Slope	Km/H	Hours	Place
0.0	0			0.0	Erateini
1.0	20	2.0	4.7	0.2	Foot of Koutsouros
5.0	800	19.5	1.8	2.5	Kokkinovrakhos (saddle of Koutsouros)
7.0	600	10.0	3.3	3.1	Amygdalea
9.0	475	6.3	4.0	3.6	Agia Trias (begin of Belesitsa valley)
12.0	450	0.8	4.9	4.2	Crossroad Vraila-Malandrino
16.0	425	0.6	4.9	5.0	Crossroad Levka-Pendapolis
20.0	375	1.3	4.8	5.9	Below Lidoriki
22.5	375	0.0	5.0	6.4	Stenon

Total vertical meters: 1225
Vertical meters per km: 54.4

B. Paralia Tolofonos-Stenon via Milea and Avoros

Km	Height	Slope	Km/H	Hours	Place
0.0	0			0.0	Paralia Tolofonos
2.5	40	1.6	4.7	0.5	Below Tolofon
3.0	100	12.0	3.0	0.7	Tolofon
5.5	100	0.0	5.0	1.2	Crossing Xerias
8.0	350	10.0	3.3	1.9	Metokhi
10.5	350	0.0	5.0	2.4	Xerias gorge
13.0	525	7.0	3.8	3.1	Crossroads Makrini-Sotaina
15.0	700	8.8	3.5	3.7	Milea
17.5	1150	18.0	2.0	4.9	Agioi Pandes (Boukhouri)
20	975	7.0	3.8	5.6	Top Avororakhi
21.5	800	11.7	3.1	6.1	Avoros
24.5	400	13.3	2.8	7.1	Mornos
27.5	375	0.8	4.9	7.8	Stenon

Total vertical meters: 1925
Vertical meters per km: 70.0

C. Paralia Tolofonos-Stenon via Sotaina and Vraila

Km	Height	Slope	Km/H	Hours	Place
0.0	0			0.0	Paralia Tolofonos
2.5	40	1.6	4.7	0.5	Below Tolofon
3.0	100	12.0	3.0	0.7	Tolofon
5.5	100	0.0	5.0	1.2	Crossing Xerias
8.0	350	10.0	3.3	1.9	Metokhi
10.5	350	0.0	5.0	2.4	Xerias gorge
13.0	600	10.0	3.3	3.2	Below Sotaina
17.0	550	1.3	4.8	4.0	Vraila
21.0	425	3.1	4.5	4.9	Crossroad Levka-Pendapolis
25.0	375	1.3	4.8	5.8	Below Lidoriki
27.5	375	0.0	5.0	6.3	Stenon

Total vertical meters: 825
Vertical meters per km: 30.0

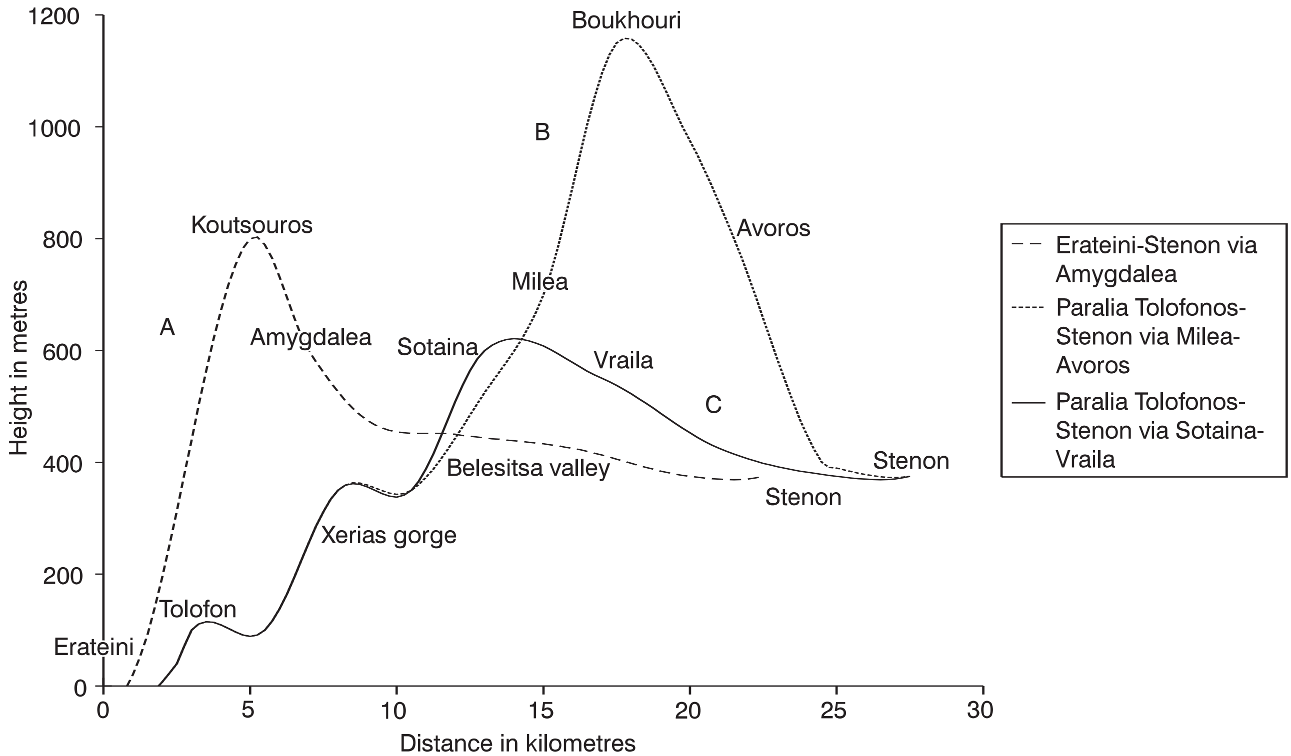

Figure 2. Evaluation of difficulty of three alternative routes Gulf of Corinth - Stenon, Eastern Aetolia (province of Doris).

3 Khans

What the petrol station and motel is for the motorist of today, was the *kháni* for the muledriver or traveller on foot of pre-modern Aetolia. A *kháni* is a modest inn, where the traveller could rest, have a drink, take a simple meal, feed his animals and where he could spend the night. More than this, '*khans*' were important landmarks that indicated the historic land routes and nodes of communication. In combination with the method described above, the presence of inns can be used as an indicator of the importance of routes.

The *kháni* were mostly called on by merchants. All customers shared the same room and slept on the floor. Shepherds on their way to the winter or summer pastures sold cheese and bought food and fodder at the *khan*, but slept outside near their animals. Nowadays, nearly all inns have crumbled into ruin without leaving traces in the stony landscape. However, some of the buildings survived and now function as *kafeneíon*.

On the basis of the literature, maps and interviews, we have documented about 150 inns in Aetolia dating to between 1800 and 1940. The distribution of these *khans* is represented in figure 3. It is apparent from the map that the *khans* are not evenly distributed over the landscape, but form a number of clusters, in particular (but not exclusively) along the main routes of communication, which have been copied from the French military topographical map of 1852.

Many inns were not located within a village, but somewhere at a distant spot in the countryside. Although at first sight the location of many *khans* has nothing special to offer, they tend to prefer sites such as crossroads, mountain passes, and river crossings.

The most striking concentration of *khans* is found in the mountain district of Krávari in central and northern Navpaktía. This is remarkable, because this area was notorious as the 'labyrinth of Greece' (Naval Intelligence Division, vol. III, 1945: 20). Until after the Second World War, there were virtually no roads in this area, and there were hardly any long-distance tracks. The area was avoided by most travellers. Only Woodhouse (*c.* 1890) describes a route from Thérmon to Lidoríki over Plátanos through this poor and sparsely populated district (Murray 1896: 642-646). The section on Aetolia and Acarnania was written by Woodhouse, although his name is not

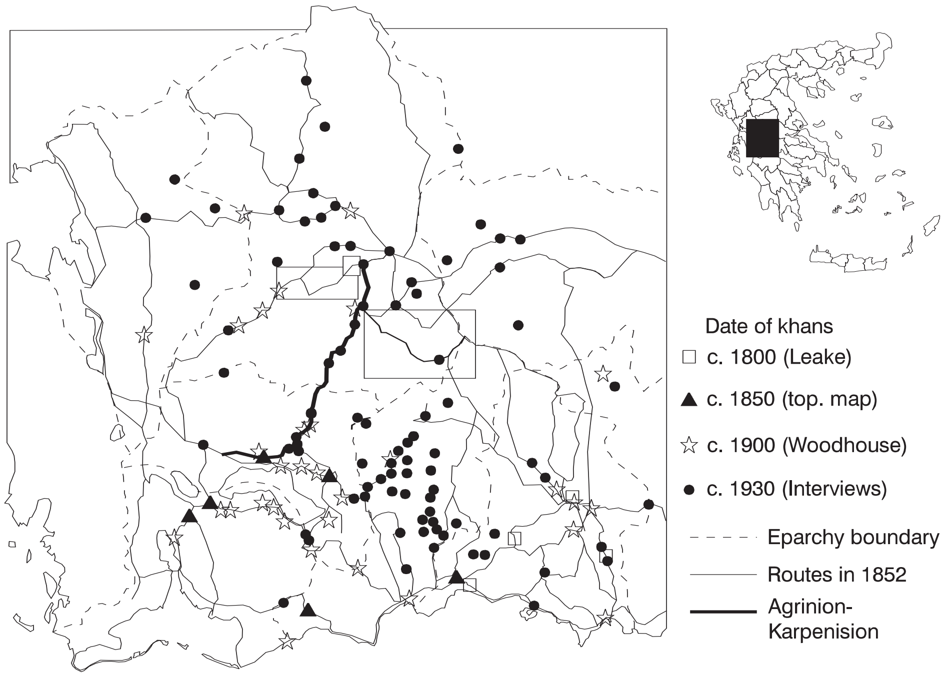

Figure 3. Land routes 1852 and khans 1800-1940, Aetolia.

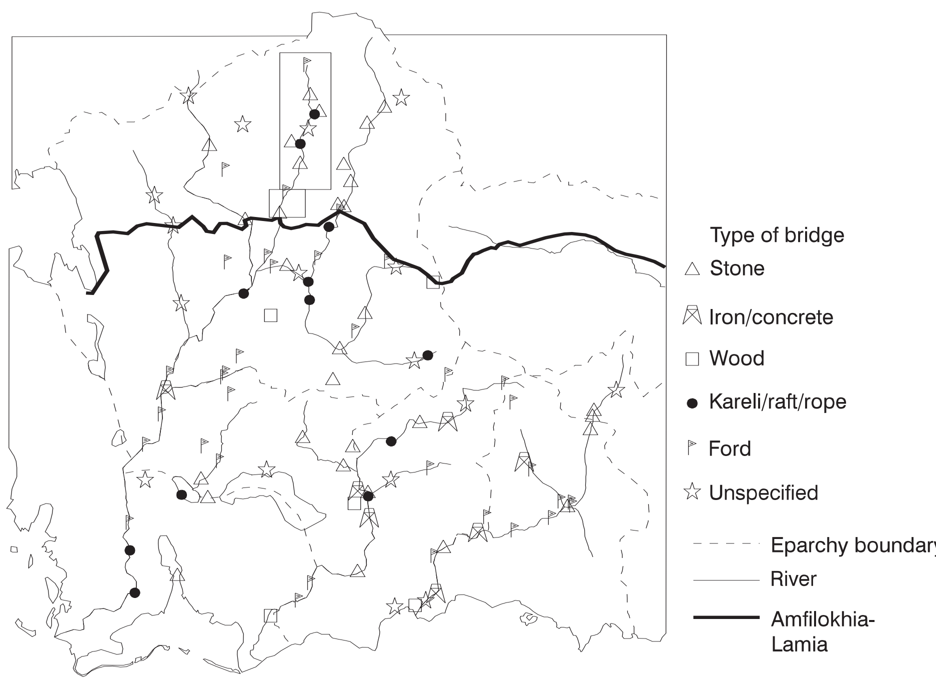

Figure 4. River crossings in Aetolia before WW II.

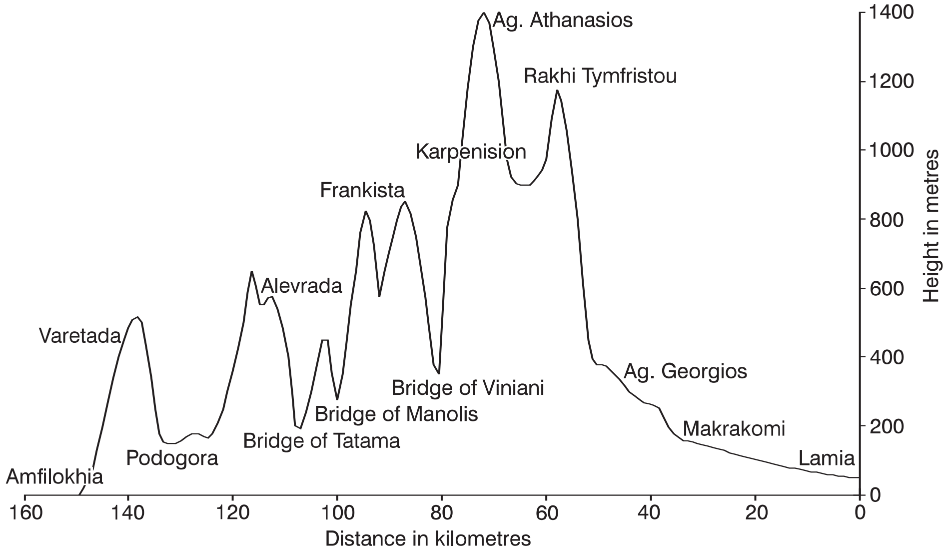

Figure 5. The E-W route connecting the Amvrakian and the Mallian Gulfs.

mentioned). We suggest that it is exactly the inhospitable character of this region which demanded the presence of so many inns.

A second concentration of inns is located around Lake Trikhónis. Under the presidency of Tríkoupis, a carriage road had been constructed around the lake by the end of the 19th century (Woodhouse 1897). On the northern shore of the lake, these *khans* served the connections from Agrinion to Thermon and from Agrinion to Karpenísi by Prousos. This last connection of the lake area with Evrytanía was also lined with *khans*, which indicates the importance of the connection.

4 River crossings

Rivers pose the most important barrier to communication. In a study of land routes it is therefore important to pay attention to the river system in the area of research and to study how and where they could be crossed. After *khans*, river crossings and bridges are important elements designating land routes in early modern Aetolia.

There are three main river systems in Aetolia. From west to east these are the Akhelóös, the Evinos and the Mórnos, each with its tributary streams. The Akhelóös or Aspropotamos is the largest of these (and indeed of Central Greece). In Antiquity it formed the border between Aetolia and Akarnania.

In the early-modern period, we encounter a great variety of types of river crossings in Aetolia. We distinguish fords, *karélia*, rafts or ferries, and bridges of various types. Over a hundred river crossings are recorded, and there are about 20 existing and former stone bridges dating from before 1900 (Manda 1984, 1987). Bridges in Aetolia vary from extremely crude (and feeble) constructions of wood and rope to elegantly curved packhorse bridges which have stood for centuries (fig. 4).

Little is known about the history of the bridges in Aetolia. The most interesting bridges form — or rather formed — a sequence which marks the route from the west coast to the east coast of Greece at the point where the mainland is at its narrowest. These are, respectively from west to east: the bridge of Tatarna (near a monastery of the same name), now submerged in the artificial lake of Kremasta on the river Akhelóös. Secondly, on the Agrafiotis, the bridge of Manolis, constructed in 1659 (Manda 1984: 40-1). Although it still stands, it can only be seen in summer, as in winter it is also submerged in the artificial lake. So far, attempts to save this monument have been unsuccessful. The third and most easterly, on a straight line with the former two, is the bridge of Viniani over the Megdova or Tavropos.

The W-E route, from Amfilokhia on the Amvrakian Gulf over Karpenisi to Lamia on the Mallian Gulf, can be reconstructed with the help of these bridges and the travel literature. A cross section of the route is presented in figure 5. The graph illustrates very well the difficulty of the terrain: there are two passes over 1000 m to be taken (the highest at 1400 m), whereas the valley bottoms are between 200 and 400 metres.

The total length of this route is 152 km. It is remarkable that 19th century travellers estimated it at 150 km. In time the travelling distance is calculated at 42 hours which means four to five days walking; the travellers of the last century recorded 38.5 hours for this journey (Route 48 in Murray's *Handbook of Greece*)

5 Conclusions

In conclusion, we have seen that our analysis of land routes in early-modern Aetolia, based on an approach of the minimization of distance, travel time and/or energy loss can offer an insight into alternative courses. Especially when combined with the literature and physical evidence in the form of *khans* and bridges we can say more on the importance of some routes than on others.

In principle, this method of landscape analysis can be applied to other periods as well, in order to evaluate the viability of alternative routes, provided that additional archaeological or source evidence is available.

Although it might be suggested that the 19th century routes outline the potential connectivity of earlier periods as well, we prefer to be cautious here, since the additional evidence is rather meagre. For instance, the research of the Ottoman archival material has only just begun, and the work on Byzantine routes through Aetolia is rather speculative (Koder/Hild 1976). The reconstruction of the 19th century communication system that has now almost totally disappeared, has a value in its own right. The few stone packhorse bridges in Aetolia that remain deserve preservation, just as some traditional country inns. It is probably a good thing that even the remotest villages in the Pindos can now be reached by car, but at least some aspects of the ways of travelling over the past centuries should be preserved.

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Application of GIS to images and their processing: the Chiribiquete Mountains Project

1 Introduction

The Department of Prehistory and Archaeology of the Universidad Autónoma of Madrid was invited to take part in the expedition to the Chiribiquete Mountains (Colombia) in 1993 in collaboration with the Royal Botanical Garden of Spain and the Inderena (Carlos Castaño) and the TROPEN-BOS (Thomas van der Hammen) of Colombia. The territories studied in the course of this expedition are located in the states of Guaviare-Caqueta in southern Colombia. The area lies at the confluence of the rivers Apaporis and Ajaju, in a mountain range comprising high plateaus of enormous biological and archaeological richness which break the monotony of the jungle landscape. The archaeological evidence consists primarily of the remains of dwellings and in particular, of over 34 caves with traces of paintings.

2 Documentation work

On this expedition in addition to surveying the mountain range as a whole, we started documenting the pictorial remains in a number of caves. This work was carried out under very severe conditions which meant that the study needed to include the most appropriate systems (photogrammetry, transparencies, etc.). The material we used for documentation had to be carried over long distances and sometimes to sites which were difficult to reach. For this reason we restricted ourselves to photographic and videographic materials. Mosaics of the panels were recorded photographically on slides and high definition paper, and several sweeps were made with a VHS video camera. The work covered a total of five caves.

In addition to the pictorial remains a number of test pits were cut in different caves in order to discover, as far as possible, the type of occupation and its chronology.

The evidence provided by these test pits indicated that the caves were occupied intensively over the course of time, but in no case for prolonged periods. Of the dates obtained by Professor Van der Hammen for the surface levels of the Abrigo del Arco cave, in which a sequence of datings was documented which included datings from 1375 BP at 10 cm from the surface, the most important one is of 5560 BP on a hearth structure and 23,650 BP at a depth of 35 cm, although these fire levels may relate to fortuitous fires.

Despite the data obtained, we share the opinion of various authors who are working in more southerly contexts, who do not put occupation of the area before 8-10,000 BP (Ms María Pinto Nolla and Mr Gonzalo Correal *pers. comm.*).

3 Description of the pattern of sites and the significance of the pictorial evidence

It would seem that the work aimed at documenting the possible areas of population will not be very fruitful, given the pattern of settlement adopted by these very nomadic groups with a hunting-gathering economy.

Furthermore, the areas in which the pictorial remains are found do not appear to present sufficient resources to support a population, even a small one, with a way of life that was at all sedentary. However, the documentation of a possible occupation of the located caves would seem to be a virtually essential task in that it might bring to light remains which would enable the paintings to be associated with particular remains or levels.

Let us analyse some of the characteristics of this art. The paintings usually appear in wide-mouthed caves that are not very deep but that are difficult to reach as they are high on the plateaus. Moreover, the motifs usually appear in groups, isolated images being very rare. Finally, and in the absence of subsequent analyses, the pictorial remains seem to point towards corridors or broad watercourses going through the mountain range.

As far as an analysis of the style and subject matter is concerned, the most significant features can be summarised in the following points:

1. The subject matter and scenes are very crowded together and superimposed on each other in some of the caves, as in the present case. The distribution of the pictorial motifs in each cave displays a degree of intensity related with height. The subjects become scarcer at a height of more than 2 m, and are much more abundant lower down. There are, however, caves in which the pictorial density is low.
2. In a first assessment of *style*, the existence of many different styles and qualities can be seen within similar

technical processes. So far the basic characteristics display the predominant use of flat monochrome colours, around which a line has normally been drawn with the figure coloured in (normally associated with paintings of jaguars). The motifs are painted in styles which range from the entirely naturalistic, through the semi-naturalistic, to more infrequently found abstract images or symbols.

3. The subject matter is of a very varied nature. The most notable subjects include:
   – Naturalistic/semi-naturalistic pictures of animals. Amongst these the following species are most frequently depicted: jaguars, deer, tapirs, snakes, birds, porcupines, monkeys, insects, etc. In some cases it is possible to see that scenes have been depicted.
   – Semi-naturalistic schematic depictions of anthropomorphic characters. In general these are not isolated figures but are depicted in very varied narrative associations. Prominent amongst the scenes created are hunting scenes and those which show collecting fruit of the palm tree, carrying food, dancing, fighting and motifs related to fertility.
   – Naturalistic and semi-naturalistic paintings of plants. Normally the paintings allude to the palm tree, either on its own or as the seed in germination, a clear reference to the idea of fruitfulness or fertility.
   – Symbolic images of different kinds. Dominant here is the appearance of hand prints, in some cases in clear association with examples of fauna (a number of hand prints around naturalistic figures of animals). Another type of element is a serpentine shape, drawn with a point technique, in this case very close to the idea of enclosures or nets.

4 Application of GIS to the study of evidence from the Chiribiquete Mountain range

As we said in the introduction, there are two fundamental problems in carrying out a study of the pictorial remains found in the Chiribiquete mountains. The first is the lack of cartographic information relating to the area which would enable a proper spatial study of the evidence found to be made. Our intention in this respect is to create a Geographic Information System in which we will integrate the altimetric restitution of the area on the basis of existing radar bands, or from satellite photographs. Once we have maps we can integrate the archaeological information into a system which would allow an analysis of the spatial relationships of the data to be made, including the subject matter, style, etc. of each cave.

This brings us to a second problem, and that is the enormous quantity of pictorial data in each of these caves. As we have said, there is a style common to all of them, which demonstrates a simplified technique that uses a single type of pigment existing in the surrounding area. With the passage of time an enormous variation of tones has been generated in the pictorial remains.

In this paper we shall describe the methodology currently being developed to try and analyse and order the registers obtained in each of the caves, concentrating on the specific example of the main panel in one of the caves: the Abrigo del Arco cave (fig. 1).

5 Work process

The work of integrating and processing the evidence was carried out within the ARC/INFO program (particularly its GRID module), because this was the program we were already using for integrating the spatial information relating to the sites. The work is being carried out on an IBM RISC 6000 workstation, an IBM 486DX2 and an HP ScanJet IIc scanner.

As we said earlier, the documentation at our disposal consisted of a photographic mosaic on slides and paper, which, including a size scale, took in most of the pictorial evidence in each cave. The work of recording began with the organization and assembly of a continuous image. To do this, all the photograms on paper were integrated using a scanner. At the same time the images were married up and distortions corrected. It was possible to carry out this task using the Geographic Information System itself.

These operations were carried out by assigning control points and defining ‘links’ that would enable them to be combined, and a single integrated image was obtained in the system. The next step consisted of producing vectorial information for each of the elements represented. To do this we initiated the process of digitalization from the screen.

We have opted for the process of manual digitalization (fig. 2), as the automatic processes, in our case, did not produce satisfactory results because of the crowded nature of the elements in particular areas of the panels and the state of the material on which they had been painted.

At the end of this process we had two data bases: a raster graphic data base in the form of separate integrated photograms, and a graphic data base of the same material in a vectorial format. The process of creating a topology using this latter base was carried out with the following fields:

1. subject – subject matter divided into options (animal, vegetable, human, symbolic or unknown).
2. style (naturalistic, semi-naturalistic, schematic).
3. green (component of green of the red-green-blue (RGB) of the image).
4. stgreen (standard deviation of the values relating to green).

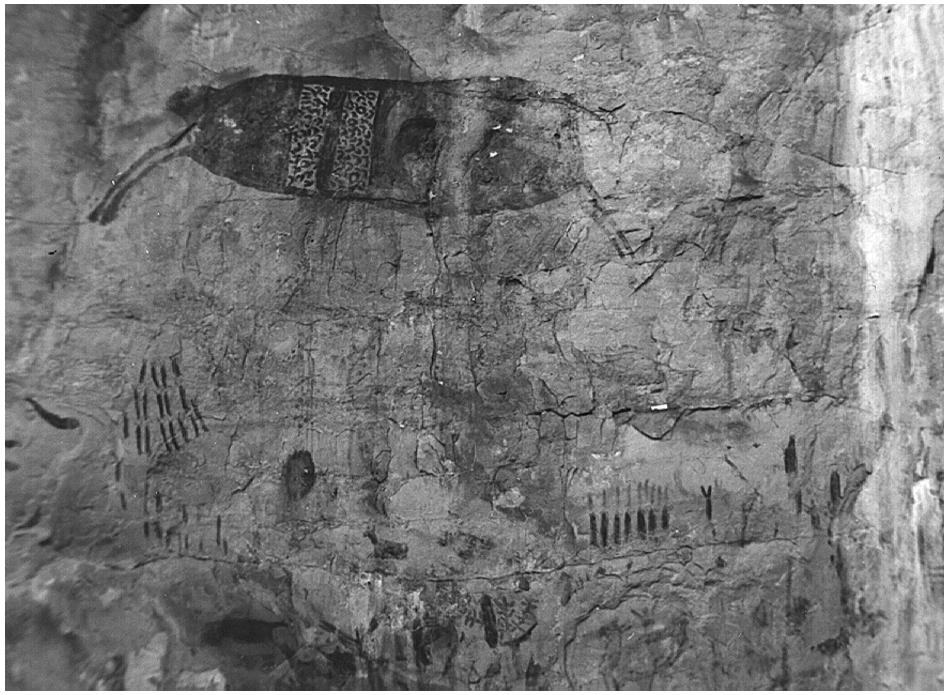

Figure 1. The main panel in the Abrigo del Arco cave.

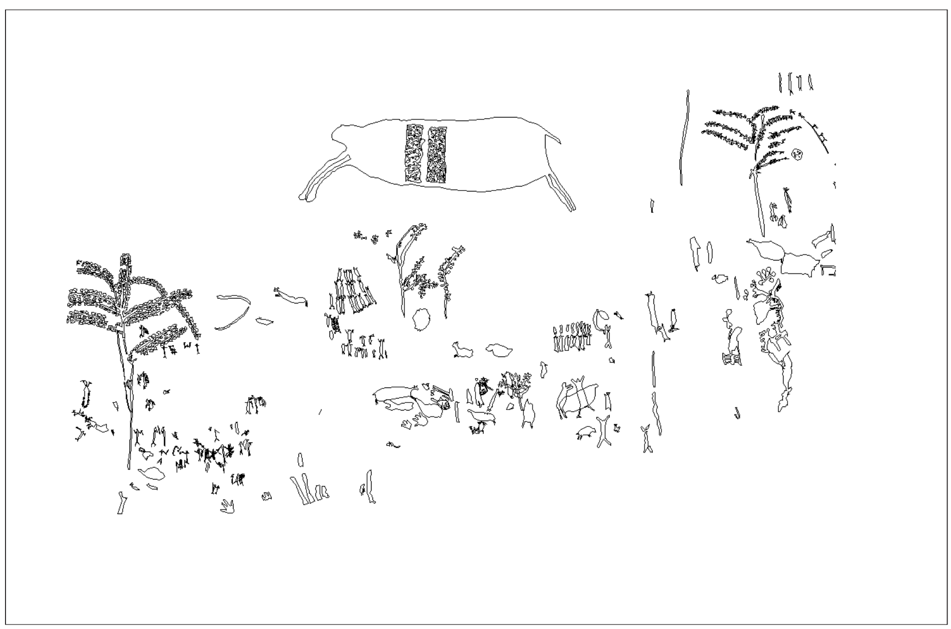

Figure 2. Manual digitalization of the main panel in the Abrigo del Arco cave.

5. red (component of red of the RGB of the image).
6. stred (standard deviation of the values relating to red).
7. blue (component of blue of the RGB of the image).
8. stblue (standard deviation of the values relating to blue).

Next we cut out the image (raster format) using each of the elements represented in the polygon overlay (vectorial format). To do this it is necessary to isolate each of the polygons present (fig. 3), convert it to raster, and cut it out using that grid, the one of the original panel. The use of AML language macros within ARC/INFO proved indispensable to us.

Having cut out the images, they were broken down into the basic colours present in each of the figures. To do this

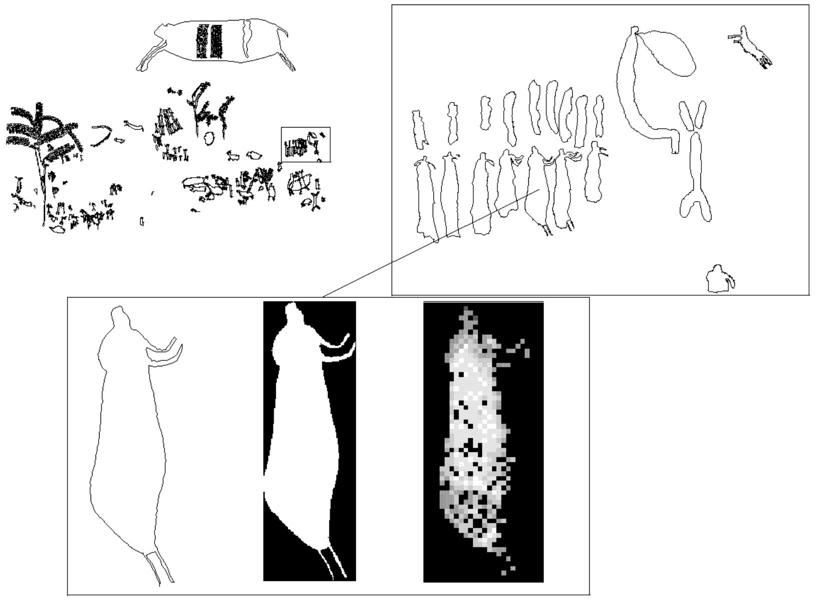

Figure 3. Cutting out the images (raster format).

Figure 4. The polygons resulting from the selection of different value intervals for three colours (red-green-blue).

the program averaged out the general values of the cut out whole element. The values taken apart are expressed in averages and deviations in each of the basic colours. These values are entered into the data base of the overlay with vectorial information.

Once this information has been recorded, analysis of the motifs represented begins. The choice of intervals and different statistical procedures will make it possible to establish distinctions between the figures depicted and the consistent nature or otherwise of some of the groups. The answers obtained can be defined as follows:

1. The system enables the existence or otherwise of stylistically and thematically homogeneous groups to be confirmed by statistical analysis, yet to be carried out, of the chromatic value. As an example we will show some

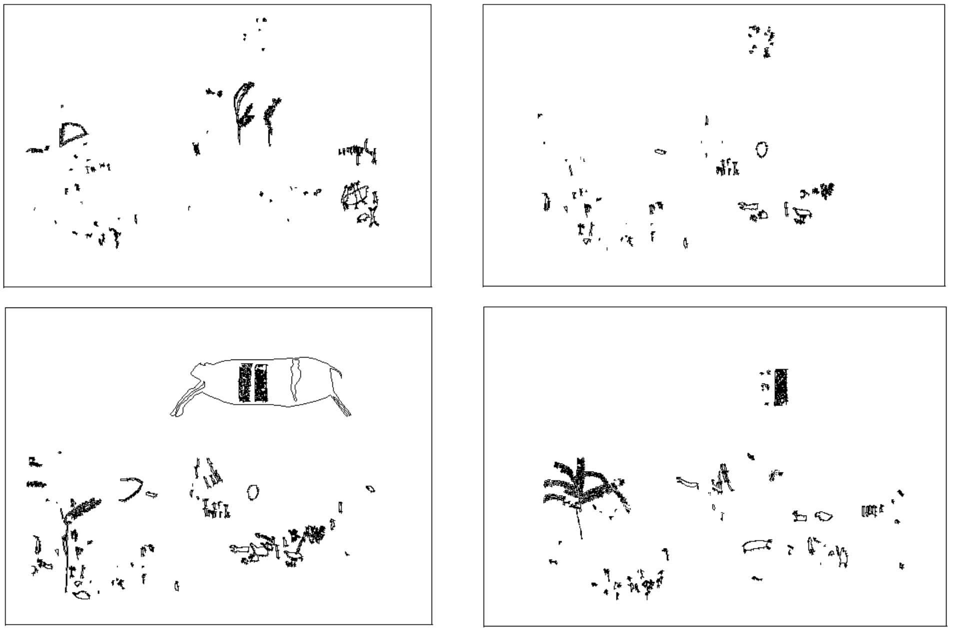

Figure 5. In addition to the complete group, selections can be seen corresponding to animal, human and vegetable figures respectively.

preliminary results. In figure 4 we show the polygons resulting from the selection of different value intervals for the three colours (red-green-blue). It can be seen how the thematic groups are broadly differentiated in each of the selections.

2. It also enables the existence of different phases in the analysed panels to be evaluated. A relative chronology can also be established (the parts painted earlier and the parts painted later) in the groups, although this ordering should be seen purely as a guide.
3. Because it is part of a GIS, the program facilitates the analysis of the spatial relationship between different groups or phases and the discrimination of the chromatic values in each of the subjects. In figure 5, in addition to the complete group, selections can be seen corresponding to animal, human and vegetable figures respectively.

6 Discussion

We cannot deny that the system used presents enormous difficulties, both of interpretation and of realisation. Firstly it is a system designed for the particular case we are dealing with, in which the pigments always seem to be obtained from nearby areas, and the painting is monochrome.

One of the most important aspects consists of the need for perfect control of the process by which the images are recorded, and their integration into the system. Differences in the incidence of light in each photogram, or in the resolution of recording, can distort the subsequent process of analysis.

Likewise we have to consider with the greatest care aspects such as superimposed subject matter, which produces changes in pigmentation in the polygons common to both images, or the existence of pigment which has been partially dissolved in certain areas of the panel.

However, despite these difficulties, the procedure described can be an extremely useful tool for analysing the pictorial evidence we have presented.

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Geographic Information Systems II: The York Applications

Julian D. Richards

From Site to Landscape: multi-level GIS applications in archaeology

In Old World Archaeology it is apparent that GIS have yet to live up to their promised potential, with many applications being content to put dots on a map. The aim of these papers is to show how GIS can be applied to archaeological research questions at a variety of scales, ranging from the individual graveyard, through city and rural landscape projects, to the region. Each of the four papers has three things in common:

1. Firstly, each of the papers is concerned with the archaeology of York and Yorkshire, where the Department of Archaeology at York University has a number of research projects (fig. 1).
2. Secondly, each of the papers features applications of a particular family of GIS. The first demonstrates an application of ARC/CAD running on a 486 PC; in this example ARC/CAD was felt to offer sufficient functionality to allow the extraction of layers from an AutoCAD drawing according to simple database queries. The following three papers all have need of more advanced GIS functions and make use of ARC/INFO version 7 running on a Unix compute server. Whilst the authors would agree that ARC/INFO has a very steep learning curve, and some charming idiosyncracies, we feel it provides the degree of power and potential for customisation that our applications demand. We believe there are advantages in archaeologists adopting industry standard software.
3. Thirdly, each of the papers starts with an archaeological problem and demonstrates an application of GIS to solve it, and that was our primary purpose in organising the session at the Leiden CAA Conference. We believe that each of our papers demonstrates that archaeological GIS have come of age and can now be used routinely in answering archaeological research questions.

We have chosen to illustrate the use of GIS at four very different research scales. We start with an individual site, a parish cemetery, and Harold Mytum looks at the use of ARC/CAD to study the chronological development of Kellington graveyard. From the rural churchyard we then move to a special class of site, the urban core of York,

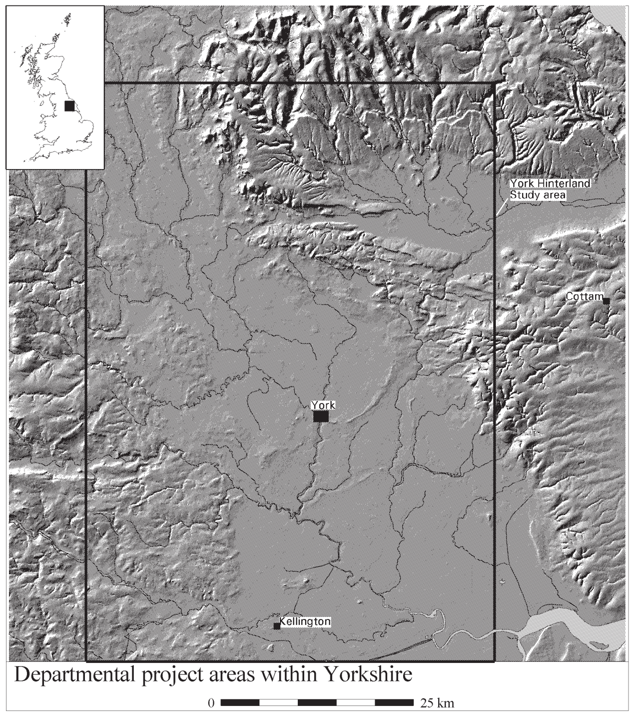

Figure 1. Departmental project areas within Yorkshire.

where Paul Miller has been using ARC/INFO to pose questions about the build-up of urban archaeological deposits. Then from town to country again, and Julian Richards describes the use of GIS in the study of the development of an early medieval rural settlement pattern in its setting in a local landscape project. Then finally, from the micro-landscape survey we shall move to the macro-landscape, and Jeff Chartrand discusses the application of GIS to the study of visibility of Roman archaeology within Greater Yorkshire.

However, whilst each of these papers represents an application in its own right, with its particular problems and solutions, it is the interface between them that is of particular interest. Rural churchyards and settlements, towns and landscapes, whilst they tend to be studied in isolation, are part of a seamless whole. Current archaeological research agendas need tools which allow the integration of data collected at different scales. It is the power of GIS that allows us to shift resolutions and move from site to landscape and back again.

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Harold Mytum

Intrasite Patterning and the Temporal Dimension using GIS: the example of Kellington Churchyard

1 Introduction

The popular image of English rural churchyards is one of quiet beauty, a timeless tranquillity in which the dead lie at peace, tended and remembered by the living. However, the reality is that churchyards are constantly changing to meet the needs of the community they serve. As archaeologists, we are interested in identifying and explaining change, and computer applications using Geographical Information Systems — GIS — are particularly useful in this regard.

The study reported here concerns one particular site, that of the churchyard at Kellington, near Pontefract in Yorkshire. Though not a particularly beautiful site, it has the advantage of having been intensively studied archaeologically in advance of mining beneath the site by British Coal. The whole of the interior of the church has been subject to excavation, as were those parts of the churchyard immediately around the church itself, in advance of major engineering work designed to underpin the building (Mytum 1993). As part of the project, the complete churchyard has been studied, and it is the analysis of graveyard monument distribution which forms the substance of this paper.

English rural graveyards are complex archaeological sites, usually with a historic core where many generations have been buried, and less favoured areas only used in times of population expansion. During the medieval period very few burials were identified by stone markers, and these were often subsequently removed, some being reused in alterations to the church fabric. As the location of burials was forgotten over the generations, areas were reused for burials in a cyclical manner, leading to complex intercutting sequences of burials, and a gradual rising of the ground level. Only with the increasing popularity of stone markers did the practice of reuse of burial spaces become inhibited. The external grave marker became common between the late 17th to late 18th centuries, depending on the region (Burgess 1963), but archaeologists anywhere in England have the benefit of at least two centuries of material culture change in a spatial context. At Kellington the earliest external memorial is of 1703, though there are relatively few monuments from the 18th century, so for the current analysis they have all been grouped together; subsequent memorials have been grouped by decade and the study ends with the 1980s.

Graveyard memorials are an important category of material culture for archaeological analysis because they are relatively well fixed both in time and space. Though there are exceptions, most stones were erected within a couple of years of the date of death of the first person commemorated on the stone. Moreover, the position of the stone in the graveyard is relatively permanent. Many churchyards have been subject to whole or partial clearance, but this is usually readily recognised. Ad hoc tidying up, straightening of rows, and rearrangement for aesthetic or other reasons can also occur, but is not a major problem. At Kellington some headstones have been removed, and chest tombs have been dismantled, some of the side and end panels being placed on the periphery of the churchyard and the flat tomb tops laid down over the graves as ledger stones. Most of the existing ledger slabs at Kellington were originally parts of larger, more visible monuments, but some were designed as ledgers from the first; however the vast bulk of memorials at the site are headstones.

2 Previous computer studies

Graveyards have been subject to computerised analysis in the past, but emphasis has been largely placed on the problems of classification and database management. The seminal work by Dethlefsen and Deetz (1966) in the north-east USA demonstrated changes in fashion of stones, and also the spread of ideas over space and time; this could be developed further if GIS were applied. Similar work has been rare in Europe, with more emphasis on typologies at individual sites such as at the Protestant Cemetery in Rome (Rahtz 1987). Spatial patterning within sites has not been greatly considered in Britain, Europe or America. I have been carrying out site-based and more regional studies in southwest Wales and Yorkshire, but so far published results have concentrated on language use in a bilingual area (Mytum 1994).

3 Spatial order in graveyards

A few small graveyards in both Wales and Yorkshire have been examined through manual sorting of records and marking up of graveyard plans to indicate patterns through

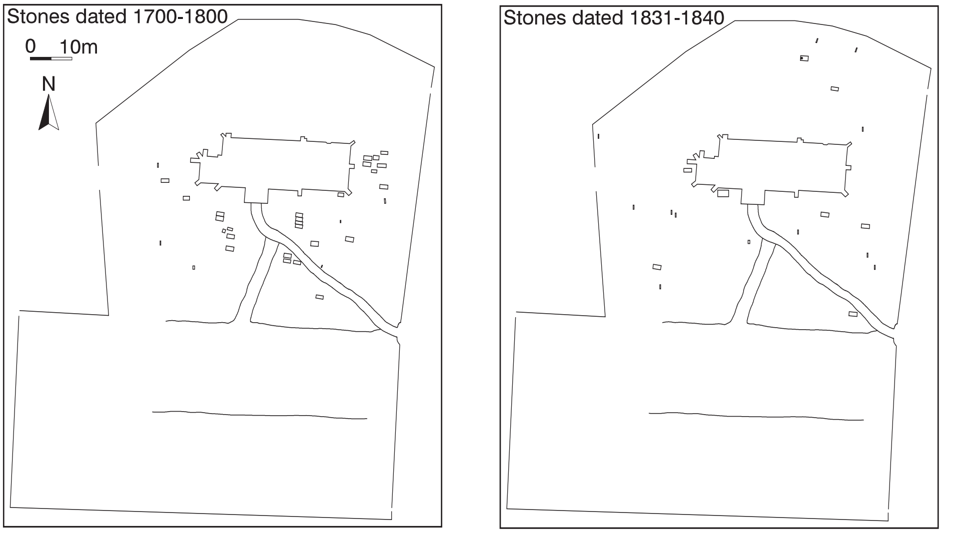

Figure 1. Left: 18th century monuments; Right: new monuments of the 1830s.

time, and these have shown definite trends in the way graveyards can develop spatially over time. Three elements can be discerned: dispersed clusters; cyclical reuse; and expansion into new areas, usually also involving ad hoc infilling of historic areas.

By using GIS at Kellington, a large graveyard could be examined, and these various elements considered. In conjunction with data sorting by Paradox and simple statistical analysis it has proved possible to identify first dispersed clusters, then cyclical reuse, and finally expansion. Interpretations of these patterns, and other trends in memorial and graveyard use can also be offered.

4 Data sources and collection

The gravestones were recorded using a standard recording form, with measurements for the size of the monument and coded data concerning shape, material, decoration. The inscription was also transcribed. There is also room on the form for a photograph (Mytum 1988). In addition, further forms were filled out, not on site, regarding the personal information of each individual commemorated on the memorials. A detailed plan of all memorials, structures, paths and trees, was produced with EDM equipment. This was then digitised and linked to the database for GIS analysis. In total there were 701 in situ stones. Of these, 651 were in good enough condition for the date to be deciphered, up to 1989.

5 Data problems

Some of the data problems relate to graveyard recording in general — the ease with which errors and omissions can be made, inconsistency, problems of legibility, and partial monuments as with the chest tombs.

Kellington was unusual for a graveyard in the number of gravestones with plain kerbs which defined the burial plots. Though occurring occasionally in most graveyards, these purely functional near-ground level kerbs are normally found in large numbers only in cemeteries. They considerably added to the survey work, and complicated both the digitising and linking to the database as we wished to be able to analyse the graveyard either including them or not. Eventually it proved possible to mark them separately, and call them up only if required. More elaborate kerbs, with inscriptions, are a very different phenomenon, and a common early to mid 20th century type of some significance.

6 Results

The GIS analysis has been most effective in displaying the process of dispersed clusters then cyclical graveyard infilling, eventually leading to first one graveyard extension and then a second.

Excavation has shown the greater density of medieval and later burials to be found on the southern side of parish churches, and at the eastern end. Fewer occur at the west, and least on the north side. The 18th century memorials display a similar bias, also supported by the excavated evidence at this site. The south has higher social value in that the main entrance to the church, via the porch, is on the south wall of the nave, and so the main path runs across the graveyard to this from the gate (fig. 1, left). There are also ideological reasons for avoiding the north, associated as it was with death and damnation rather than salvation; the north door was termed the 'Devil's door'. In contrast the eastern end is near to the altar and so a popular medieval burial location. Quite a cluster of 18th century memorials can be noted beyond the chancel. The areas of popularity

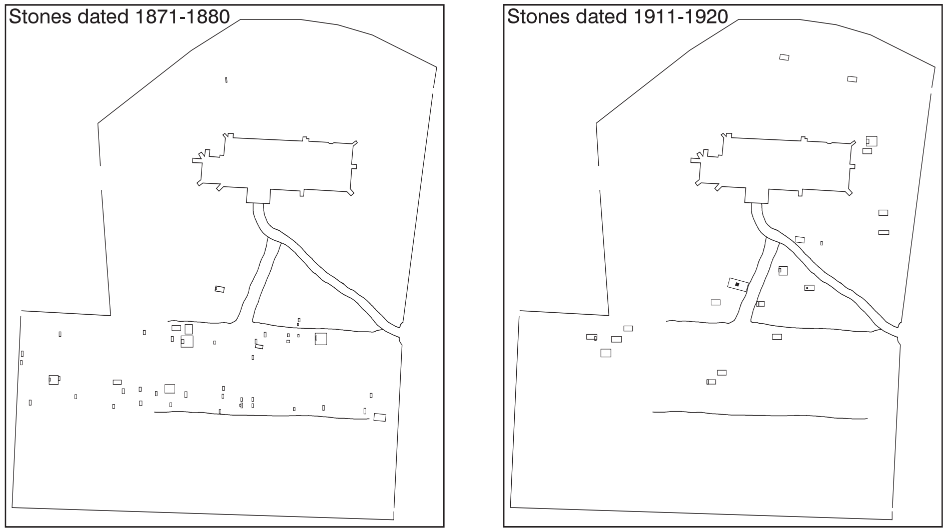

Figure 2. Left: new monuments of the 1870s; Right: new monuments of the 1910s.

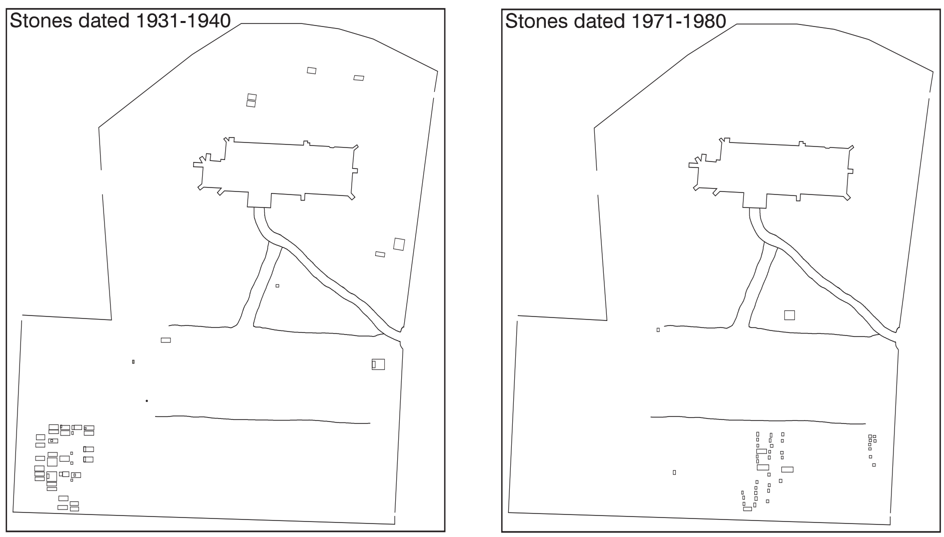

Figure 3. Left: new monuments of the 1930s; Right: new monuments of the 1970s.

remain similar through the 1820s, though there is a gradual expansion of the areas being used for memorials towards the gate and to the southwest. It may be of some significance that throughout this time headstones are only found on the periphery of the burial area marked by ledgers and tombs, suggesting that the lesser status families that could nevertheless afford some permanent markers were placed in slightly less favoured areas of the churchyard. Clearly only a small number of burials are being marked by memorials, but these are in dispersed clusters.

Up to the 1840s the ledger (or chest or table tomb) was the dominant burial monument, and this can be equated during the 18th century with the introductory phrase 'Here lies', emphasising the presence of the actual body, protected by the substantial monument overlying it. 'In memory of' and 'Sacred to the memory of' are more dominant in the 19th century, and on a wider range of monument forms.

From the 1830s the north is gradually utilised from the more desirable east end, with some infilling elsewhere (fig. 1, right). However, pressure on burial space was intensifying, reflected in the increasing popularity of kerbs to mark the full plots. The solution to perceived overcrowding in the old graveyard was expansion, with an extension opened to the south. From the 1870s the graveyard extension is extremely popular (fig. 2, left). The burials were laid out in much more organized rows, the whole area obviously having been laid out in advance.

This efficiency in the use of space is inspired by cemeteries, something also noted in the continued frequent use of kerbs to mark plots. The business of burial has become more commercialised, a mirror of Victorian interests and obsessions. This pattern continues through to the 1910s, when as the extension begins to become full, cyclical reuse comes into play (fig. 2, right). Some attempt is made at infilling in the old graveyard. This involves the reuse of burial spaces without memorials, and so considered suitable for use at this time. Once again, the southern and eastern areas are most desired, a process continued through the 1920s.

From the 1850s there is an increased diversification in the memorials. Though within a limited number of forms and supported by a far from imaginative repertoire of decorative motifs, variability increases dramatically. From this time to the present day 'In loving memory' is the most popular introductory term. With a combination of choices in form, decorative motifs, forms of introduction and lettering styles, as well as increased choice in material, every 19th century memorial could be an individual statement. Every family could express its identity within the range of choices made possible by industrialisation which improved transport, increased mass production of blank stones, and allowed for the support of professional masons within the elaborate funeral industry of the time.

The problem of limited available burial space in the graveyard was resolved in the 1930s once again by expansion further to the south (fig. 3, left). As kerbed monuments are popular at this time, and many more individuals desired and could afford memorials, the filling up here is even more obvious. Gradually the burials spread from west to east across the narrow strip of burial ground with the only change being the shift from kerbed monuments back to headstones in the 1960s, and at the same time the appearance of cremation plots. These are much smaller, and are marked only by a small slab. A separate area in the east was reserved for them, though the cremations and inhumations are now about to meet and a third graveyard extension will soon be needed (fig. 3, right). The impact of increased memorialisation is to prevent reuse of graveyard spaces, and at Kellington this has led to expansion into neighbouring agricultural land. If memorials were biodegradable, then the situation would be different! The memorials of this period, however, are sadly extremely resistant to decay. The marbles and granites almost completely replace the local sandstones; white marble reached its peak of popularity in the 1950s, with grey and black granite now being by far the most frequent choice for both headstones and cremation ledgers. However, the decorative motifs now have a predictability brought about by mechanised production of catalogue items (for a critique and alternatives, see Burman/Stapleton 1988).

The small size of the cremation ledgers precludes much use of decoration. Memorialisation has been reduced to a formulaic set of designs, though the language on the stones has moved away from the formal descriptions of the past. In the Blackburn diocese the use of familiar terms on gravestones is not generally allowed. However this is certainly tolerated at Kellington within the Wakefield diocese where terms such as Mam, Dad and Gransha occur on the recent memorials.

7 Conclusions

The use of GIS to interrogate the data spatially has allowed the development of Kellington churchyard to be understood in a fine-grained way. Further analysis is planned to examine the development of family plots, particularly in the 18th and 19th centuries. Analysis of material type and shape of memorials would also show clear distributional trends, but these are due to changes in popularity through time, and so will be found in those parts of the graveyard in use at a particular period. However, the differences in memorial choice between those in the normal burial area at a particular phase, and gravestones marking infilling in old areas, may be informative of the social strategies being employed through burial at Kellington in the 19th and early 20th centuries. Further analysis at Kellington will consider whether the decade is the most appropriate analytical unit, with implications for phasing and interpretation on other types of site. More contextual study of the graveyard itself will consider its development as a text — as each stone was added, it reinforced existing patterns or introduced new features. By considering overall burial activity, not just linked to the erection of the stone, but subsequent use of family plots, even more complex spatial patterns of graveyard use can be considered, in which the GIS applications will be the major tool for data ordering and preliminary analysis.

Although there are further analyses which can be undertaken, the study of the Kellington graveyard has already produced very significant results. The pattern of graveyard development has been discovered and displayed. Patterns of dispersed clustering, cyclical reuse and expansion have all been demonstrated. The apparently informal but in fact highly socially regulated earlier scattered groups of memorials, reflecting socially significant local families, can be contrasted with later developments where dense packing, high degree of organisation, and conformity of memorials are the norms. The celebration of death has become a less significant arena for social statements during the later 20th century. Control by the church has become stronger; familial loyalty is weaker and the average number of individuals recorded on a memorial declines during the 20th century.

Ideological, social and economic forces acted upon the graveyard, and in the 18th and 19th centuries at least, the monuments played an active social role. They reinforced group identity and class structures, and were active in their visible locations between the gate and the porch in reminding the living of the familial legacies. Old established families with their lines of tombs spoke of their legitimate and enduring position; the poor were consigned to oblivion. With the spread of wealth down the social scale it is no surprise to see more and more people obtaining monuments, even if the quality of designs leaves much to be desired. Whatever their aesthetic appeal, however, all the memorials at Kellington contribute to our understanding of social, economic and ideological developments over two centuries in this rural Yorkshire community.

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Digging deep: GIS in the city

1 Introduction

Over the past few years, CAA conferences have been bombarded by session after session on GIS applications. The conference proceedings for each year since the mid-eighties bear testament to the spreading adoption of GIS within the discipline, either through a rash of paper titles worded around 'GIS' or through allusions to a great new technology/awful new bandwagon within the text.

2 The evolution of GIS usage...

A cursory inspection of this literature is enough to suggest that the relationship between user and tool is a complex one, but it seems possible to simplify matters in order to describe an evolution in the way GIS is used and perceived by the profession. The simple analogy presented below serves to outline my view of the way in which we relate with this tool, and perhaps presents some timely warnings to those about to embark upon GIS-based research (or marriage!).

2.1 Stage One – Infatuation

The first stage would appear to be something approaching euphoria, as user and new toy court each other. The manual is incomprehensible, and the computer keeps insisting that it would really quite like 100Mb of RAM for the operating system, and with what you have given it you can forget running GIS too, but these problems are all surmountable. Given all that free time for research during the summer vacation, you can soon have a fully featured GIS that will solve all the problems ever faced by your subject.

I went through this phase. I even said 'In short, this project will answer questions of deposit creation and survival..., and will look at how these deposits reflect past human activity within the city' (Miller 1995: 153). The implication was that my GIS and I could 'solve' York.

2.2 Stage Two – True Love

After a while spent experimenting, the lucky GIS user gets a break, and courtship is replaced by love. Ideas of solving the problems of your specialism are soon replaced by megalomaniac tendencies — you and your GIS can solve *everything*. In my case, the lucky break was getting ARC/INFO's topology working well enough to select the city walls from a map of York, *and* colour them in.
A happy few days were spent painting the city walls using every colour in ARC/INFO's palette; no one else was impressed.

2.3 Stage Three – The threat of divorce...

Then the crash comes. In a fit of pique, your GIS starts *doing* things to your data. Previously closed polygon coverages spring leaks, and your nice database begins to look decidedly unwell. You seriously consider divorcing the GIS to run off with that nice drafting pen you met at a party. In conference presentations, this period expresses itself in the 'GIS is just a bandwagon. It cannot help archaeology' type of paper. These papers are as common — and as damaging — as the more positive papers advertising GIS as the answer to all problems.

2.4 Stage Four – Middle Aged contentment

For those stupid or stubborn enough to persevere past this threat of divorce, you then enter the last phase, where user has developed a healthy respect for GIS. Your use of the system is now tinged by a suspicion that it might be lying to you, which is probably a good thing. Your awareness of the limitations of system and data is now at its height, but you are also optimistic enough to recognise where potential does exist for useful research. In many cases, the presentations are less pretty and less impressive than in earlier stages, but they work, and your techniques are durable enough to withstand the battering of daily use.

I'm not sure what comes next in this analogy, as I can't really see me and my GIS staying in at night to drink cocoa in 40 years' time...

An advantage of having reached such maturity within your relationship is that a number of papers have been published (Chartrand/Miller 1994; Miller 1994, 1995; Miller/Oxley 1994) which cover the background to your work, meaning that little time needs to be spent introducing issues. Straining this analogy towards breaking point, you could say that all your friends have by this time met your new partner...

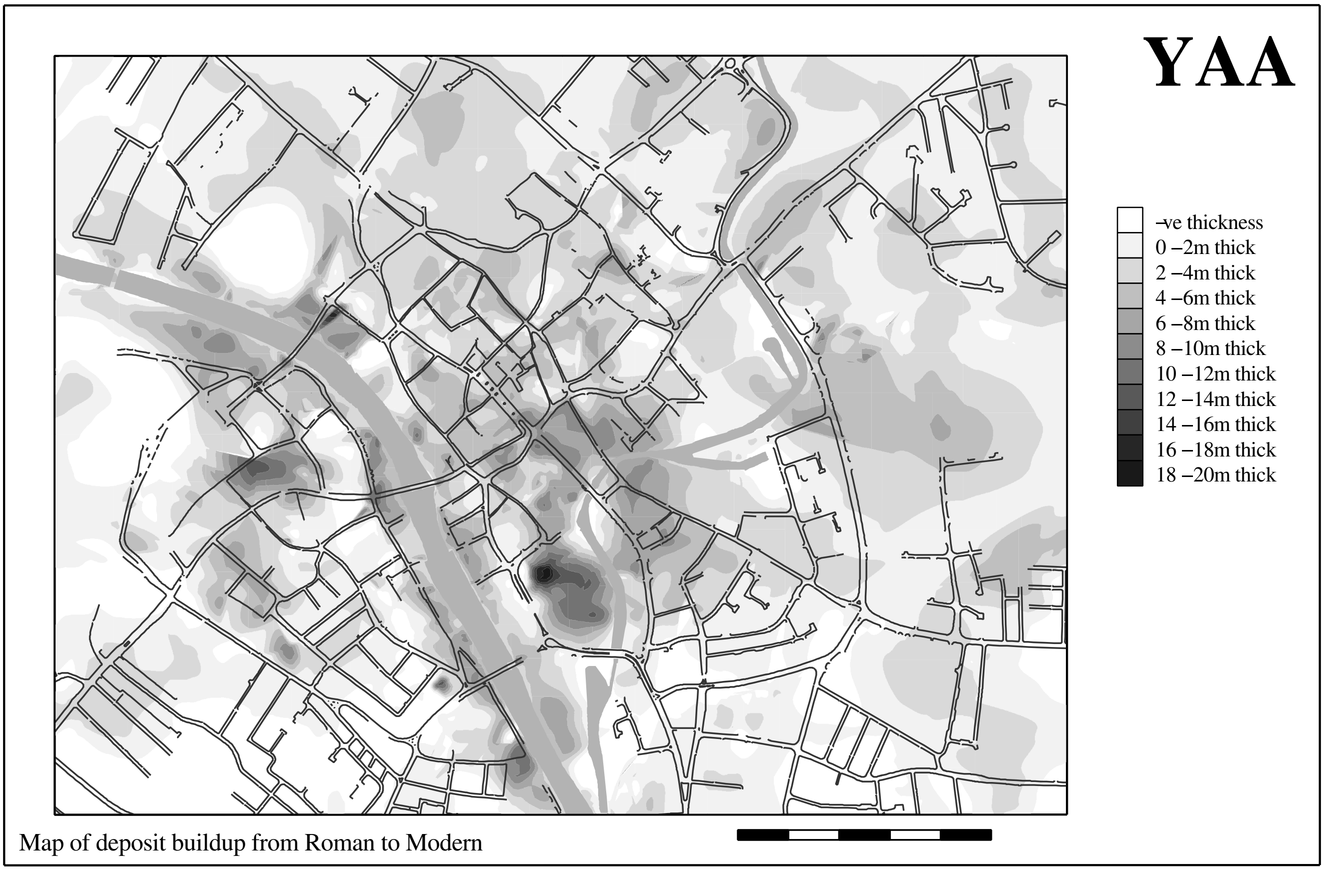

Figure 1. Deposit thickness across York city centre. Map shows computed thickness of deposition *c.* AD 70 - 1990.

3 Background

York has been an urban centre for some 2000 years (Addyman 1994), ranging from its apparent foundation as a Roman legionary fortress (Ottaway 1993) through Anglian *wic* and ecclesiastical centre to the famous Viking Jorvik (Hall 1994) and on into the Middle Ages as archdiocese and market centre.

Due to favourable conditions, deposits from this past have been well preserved across the city, and in some areas highly stratified anaerobic remains extend more than 10 metres below the modern street level. This research aims to examine the nature of deposits beneath York, and has been using them to answer questions about the city throughout its past.

Along with a group of others (Chartrand this volume; Mytum this volume; Richards this volume), this paper is part of a wider examination of the use of GIS at scales from the individual site (Mytum this volume; Richards this volume) through urban entity to the wider landscape (Richards this volume, Chartrand this volume). The urban assessment work in York described here fits in near the bottom end of the scale, examining everything from individual excavations through to a chunk of the urban entity some 3000 hectares in area. Even in this work, where the range of working scales from individual site to city core is relatively small, a variety of techniques need to be applied in any modelling of deposits. The research has shown the difficulty of applying standard techniques to problems at a variety of scales, and has illustrated the ways in which display and analysis techniques must be tailored towards specific problems.

4 Micro-scale applications

Although the examination of site-level dynamics within the city might appear less complex than the study of whole landscapes, added complexity is introduced by the significant deposition to be found in urban centres such as York, where ten metres or more of deposition are not unusual (fig. 1). Combined with the dense nature of settlement and the often anaerobic conditions, this makes York a vitally important archaeological resource, on a par with the Walbrook valley in London, the river front in Dublin and the centre of Ribe in Denmark.

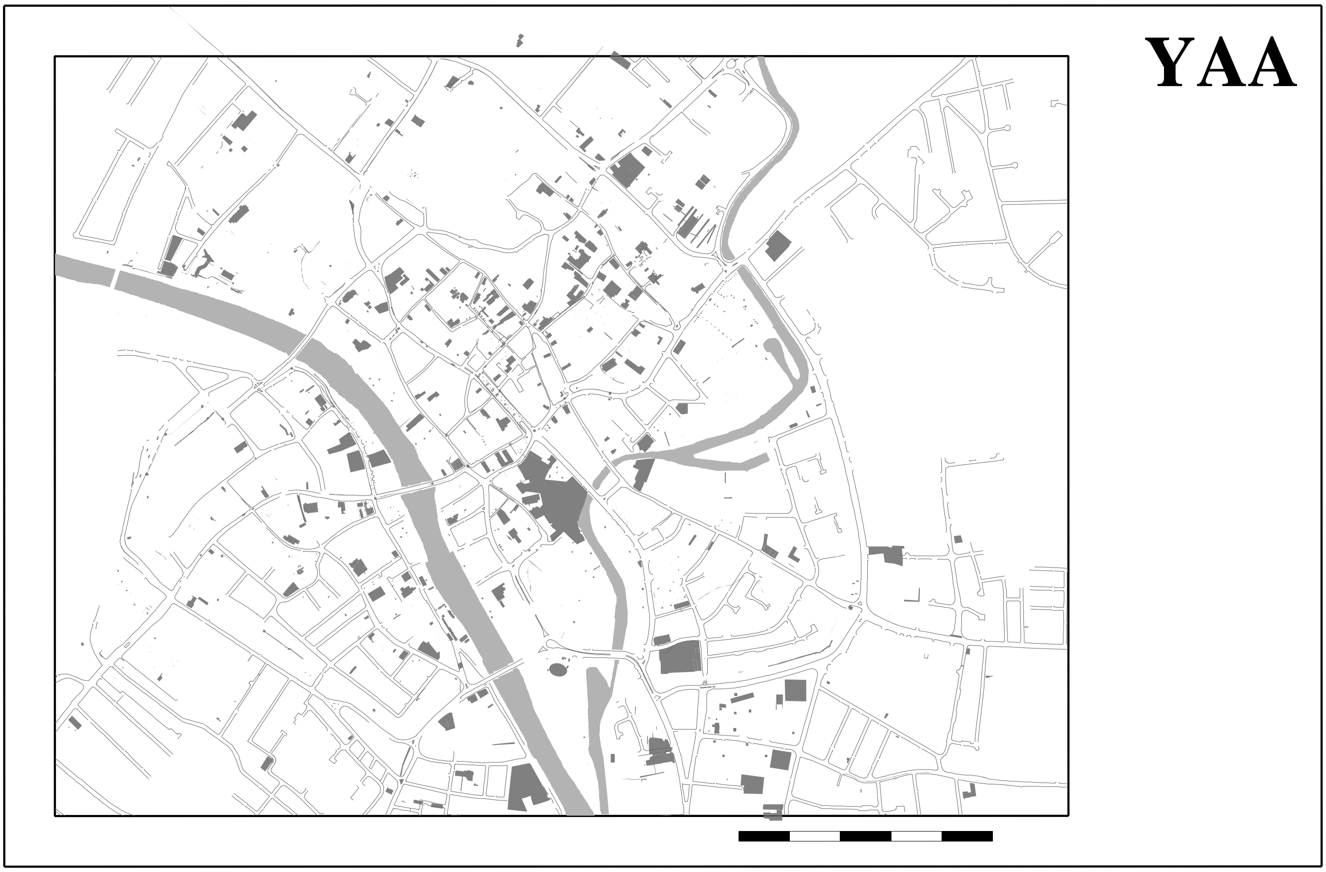

Figure 2. Excavations carried out by York Archaeological Trust, 1972-1992.

In a city such as York, there has been extensive archaeological work over the past few centuries which today provides a rich archive describing everything from antiquarian observations to state of the art excavations. A database of these contacts with the archaeology has been compiled (Miller 1994; Ove Arup 1991), ranging from observations of a Roman cemetery in 1681 through to York Archaeological Trust excavations at the end of 1992. The excavations of York Archaeological Trust over the past 20 years (fig. 2) have greatly enriched this archive, and two of their sites have been selected for examination in order to assess the usefulness of their archives to deposit related questions (fig. 3) at the micro level of the individual excavation.

4.1 City Garage, Blake Street

City Garage, 9 Blake Street, was excavated in 1975, and the extant archive reflects the age of this site. At the time, planning was by means of large composite plans, rather than today's single context system. The lack of a level III report and some apparent inconsistencies within the archive made the site difficult to study, and the final results were less than satisfactory for deposit modelling purposes.

Several hundred points were collected for six identified periods of occupation from the early first century AD through to the post-Medieval. Points were gathered in order to define the land surface at the beginning of each period, and were derived from all available site plans either as physically surveyed levels or as interpolated points manually generated in order to effectively render topography as described by hachures and breaks of slope on paper plans.

The distribution of points was far from even, and several points in one period even appear outside the accepted edge of excavation. Given the nature of the data, the available points produced very disappointing surfaces, and it is unlikely that any new information about the site may be gained from the exercise; the resulting elevation models would appear to bear no relation to the actual topography. In one case, only two points were available for the whole period across the site, rendering that particular phase unmodellable.

Figure 3. Locations of 9 Blake Street and 12-18 Swinegate, plus other YAT excavations.

4.2 12-18 Swinegate

The second site, 12-18 Swinegate, was excavated in 1989, by which time single context planning was in use. Helpfully, this site was one of those earmarked for experimentation with computer based techniques and, as such, all site plans were entered into Brian Alvey's Hindsite system (discussed at the 1989 CAA conference in York, but unpublished) during or soon after the excavation. Context information was also input into York Archaeological Trust's Context Recording System (CRS) database on site.

The nature of data storage made it a relatively simple task to identify those contexts on the 'bottom' of each period, and to extract them from the archive. These were then combined to create period surfaces, complete with breaklines defining the shape of cut features on the site. The resulting surfaces are far more realistic, contain far more data, and were constructed more rapidly than those for Blake Street.

Although only based on a sample of two sites, the results of this study would appear to highlight some of the dangers inherent in assumptions made about the value of data so painstakingly recorded. Without the presence of breaklines, even the increased density of points from Swinegate produces an unrecognisable and unsightly representation of the surface, and even the best results from Blake Street are dismally poor. Given the increased interest in building models such as these for excavations and larger areas, there is a need for greater care to be taken in recording, analysing and representing the data from which they are built. It seems that while prepared to accept some data without question, we are equally prepared to spend extended periods of time debating the smallest elements of other data sets in the name of academic integrity. A little more consistency might not be a bad thing.

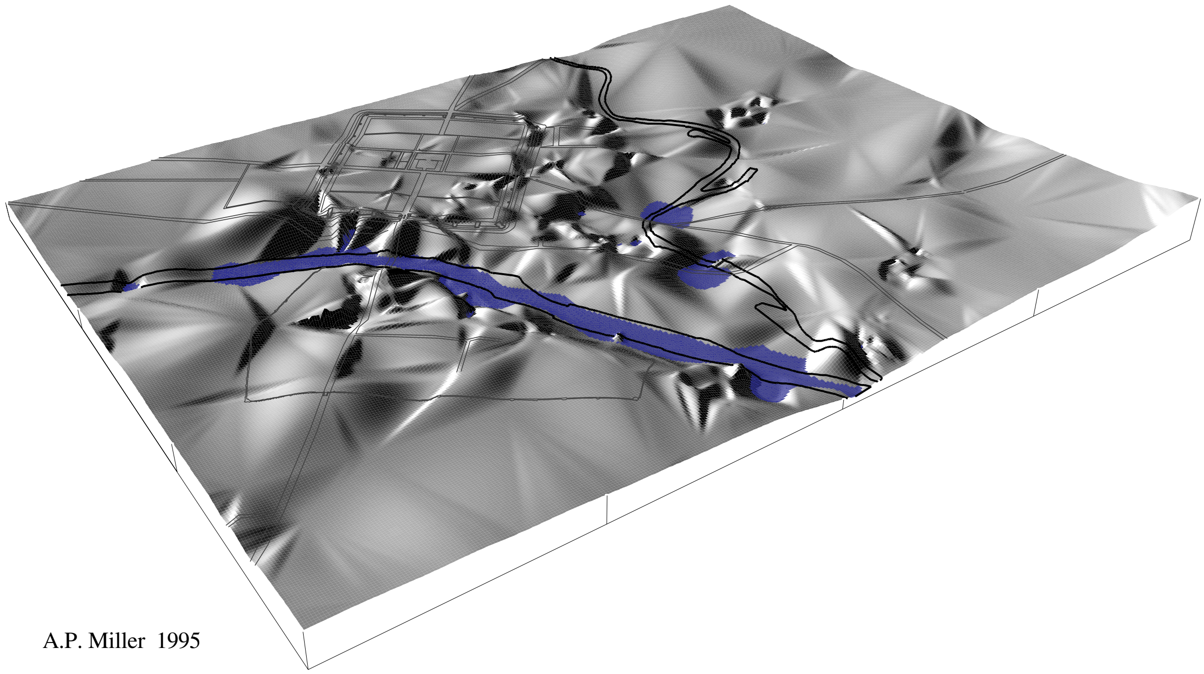

Figure 4. Digital Elevation Model (DEM) depicting the Roman topography of central York. Scale interval 500 m.

5 Macro-scale applications

Utilising a database of over 2,000 archaeological contacts, it becomes possible to produce surfaces depicting the topography across York at various periods in the past; and to examine the volumes represented by the boundaries of these surfaces. Due to the nature of the data, the best of these are the surfaces depicting the modern and Roman topographies, where alternative sources of elevation data add significantly to the distribution of data points from archaeology.

5.1 Topographic modelling

Modern topography has been constructed primarily from 1412 manhole cover heights provided by Yorkshire Water and York City Council. Other sources of data were investigated including stereo photogrammetry, the City Engineers and survey by Global Positioning System. Sadly, stereo photogrammetry of sufficient resolution proved prohibitively expensive, the City Engineers appear not to store height information over the long term, and cities such as York represent particular problems to GPS-based survey as it is really difficult to see enough sky for one satellite, let alone the three or more required for accurate locational information.

The Roman topography is derived from borehole logs and excavated evidence (fig. 4). Whilst the modern surface shape was refined through the use of breaklines defining the *known* course and elevation of the river system, the Roman surface is generated solely from a series of elevation values. As such, the depicted river course is based upon computer estimates of mean water level rather than excavated evidence for the whole length of the river bank. Despite this, the majority of the modelled river system appears remarkably plausible.

Given data on surfaces at different points in the past, it becomes simple to generate a map of accumulated deposition across the city (fig. 1).

Figure 1, constructed simply by subtracting the Roman from the modern surface, clearly indicates the areas of significant deposition within the city. As would be expected, they lie primarily within the Coppergate/Ousegate focus between the rivers Ouse and Foss.

Areas of negative deposition are also apparent. These white areas mark elements of the terrain model where the Roman surface was found to be higher than the modern. Whilst some of these may represent anomalies, many of the negative areas are accurate depictions of recent civil

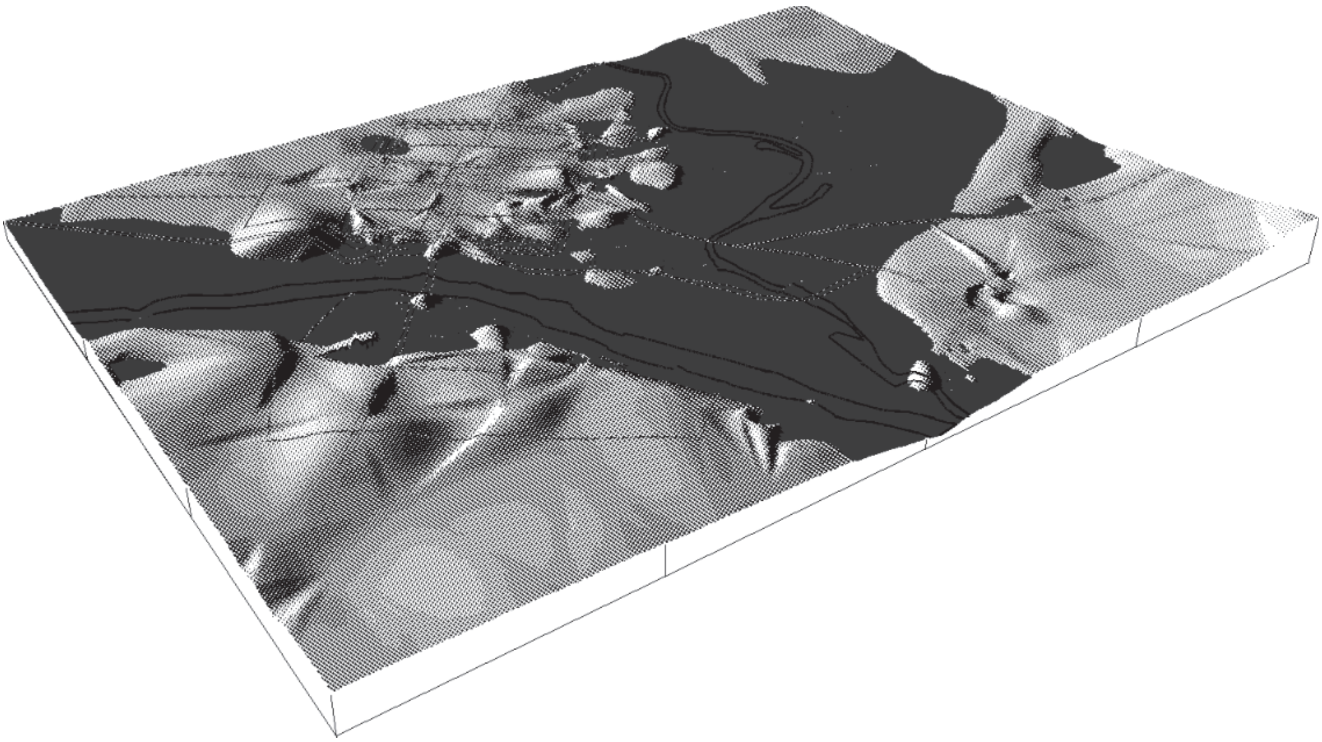

Figure 5. Result of flooding Roman elevation model to 10.66 m, as proposed by Herman Ramm. Scale interval 500 m.

engineering excesses, as with the British Rail headquarters complex, which today lies well below the surrounding ground in a readily apparent hole.

In any application of archaeological data, it is important to find ways in which the errors inherent within data collection, as well as analyses and displays, may be quantified and made explicit. The advent of tools such as GIS make it easier for users to produce impressive and visually stimulating results from often wholly inadequate data, and this trend increases the importance of developing error display techniques (Miller/Richards 1995). Within the York Archaeological Assessment, different ways of recording and representing error are being investigated, both in the form of metadata within the project database and in graphical displays of reliability.

5.2 Some basic archaeo-hydrological analyses

In the current debate raging over the possibility of preserving archaeology undamaged beneath modern buildings (Biddle 1994, 1995; Carver 1993, 1994; Ove Arup 1991), the most common suggestion has been that piles could be used to minimise disruption to the rich deposits beneath the ground (Ove Arup 1991: 49-52).

When deciding whether or not to employ piling it will be important to evaluate the effect groundwater has had on the preservation of any one site. Given that many of the most impressive sites in cities such as York are those sporting waterlogged deposits, it is likely that piling could have a disastrous impact upon preservation — the pile could act very efficiently to pierce the waterproof layer beneath the deposits, thus draining water from the site and potentially desiccating the deposits with disastrous consequences both for the archaeology and, possibly, for surface stability. Further work is required on the effects of piling, but it is unlikely that the technique will prove to be the perfect solution some expect it to be.

With information gathered from excavations and boreholes, it becomes possible to map the known extent of waterlogging, and to predict the unexplored areas also likely to contain waterlogged remains. It may well be that piling should be prohibited as a form of preservation in the mitigation strategies for those areas indicated as bearing waterlogged deposits.

A second area in which water has an effect upon York is the actions of the rivers during flood season. York still faces serious problems from flooding, despite the millions of pounds spent by the National Rivers Authority on flood alleviation. Given the effects of deforestation and dredging upon regional hydrology both now and in the past, it seems likely that the rivers were an important consideration throughout York's past.

In the early 1970's the late Herman Ramm (1971) proposed that 4th century Roman York was badly affected by the impact of rising river levels. He proposed that river levels rose to reach the 35' (10.66 m) contour, approximately 5 m above current mean water level and more than 7 m above computed mean Roman levels. This hypothesis was based upon limited evidence from a small number of excavations within the city, and was made in relation to the modern topography of the day.

For several reasons, the Ramm hypothesis was discredited, generating a backlash within York archaeology against the interpretation of alluvial deposits as being flood related. It is currently almost impossible to find serious references to flooding, despite evidence both of flooding today and of altering hydrology and sea levels in the past.

In figure 5 the Roman terrain model has been flooded to Ramm's 35' contour. The Roman fortress and the oldest parts of the *colonia* may both be clearly seen to sit above the flood zone. The lighter area is the computed area of the Roman river course when not flooding, which appears much narrower than has been suggested in the past (Ordnance Survey 1988). From this model, it is possible to plot the positions of known Roman excavations within the 'flood zone', and to investigate their archives in more detail in order to find means of refining the evidence for flooding. The current 10.66 m flood level proposed by Ramm may then be altered based upon this evidence in order to create more realistic views of river incursion in the late Fourth century.

6 Into the future ...?

When this project began, there was little existing expertise in the construction and interpretation of computer-generated deposit models for urban areas. Over the past couple of years, interest has grown and a number of organisations are now pursuing the possibilities offered by these techniques. Little work is being done, though, to judge the value or reality of the pictures produced. Hopefully, the research-driven nature of this particular project will allow it to produce both the pretty pictures and some guidelines for the ways in which they and others like them should be read.

Acknowledgements

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Putting the site in its setting: GIS and the search for Anglo-Saxon settlements in Northumbria

1 Introduction

The origins of the Anglo-Saxon kingdom of Northumbria are obscure, still shrouded in the Dark Ages (cf. Higham 1993). Despite a massive archaeological investment in excavation in the urban centre of York, where King Edwin built his Minster church and Northumbria's Viking rulers built their royal palace, we know little of early medieval settlement in York's hinterland, or of the relationship between the court and its region (Addyman 1984). This paper describes part of a larger research project whose aim is to investigate Anglo-Saxon and Viking rural settlement patterns in the historic Ridings of Yorkshire, and to look at town - hinterland relations between York and its region, from 700-1000 AD (Richards forthcoming).

A Geographical Information System (GIS), using ARC/INFO, is being used as a research tool at several scales within the project. In this paper I shall focus on its application to the study of a specific site, at Cottam, North Humberside (Richards in prep.). The site was discovered by metal detector users and the GIS is being used to integrate many different categories of data. These include:

a. the distribution of metal artefacts recorded by the metal detectorists;
b. the aerial photographic coverage;
c. data collected in two seasons of field walking;
d. magnetometer and resistivity survey data;
e. evidence from an evaluation excavation.

This data incorporates point, line and polygon information. The relationship between these categories is complex and would be difficult to observe using manual methods. The purpose of using the GIS is to place the site within its cultural landscape setting and to examine localised settlement shift through time. It is believed that this latter question is critical for our understanding of the development of early medieval settlement patterns in Northumbria. Comparisons are invited with neighbouring Anglo-Saxon settlements at West Heslerton (Powlesland 1986) and Wharram Percy (Milne/Richards 1992). I will also show how the GIS allows one to move beyond the single site, firstly to the regional landscape, and ultimately to the kingdom of Northumbria as a whole, applying models drawn from the individual site to the wider project area.

2 Anglo-Saxon and Anglo-Scandinavian settlements in Northumbria

It is widely believed that the commercial and trading centre of York must have been supported by an extensive hinterland of rural farmsteads (e.g., Hall 1994). However, whilst placename scholars have identified several categories of Anglo-Saxon and Viking Yorkshire placenames, we have virtually no archaeological evidence for these settlements (Richards 1991; Watkins 1983). It is assumed, indeed, that most lie hidden under present-day villages.

In fact, we probably know more about York's hinterland from what we can imply from finds within York than we do from the hinterland itself (e.g., O'Connor 1994). The main reason is that we have been unable to find Anglo-Saxon or Anglo-Scandinavian villages, and it is really the so-called *treasure hunters* who could provide us with a more accurate distribution map of settlement patterns of the period. In the last decade it has become apparent that metal detector enthusiasts have discovered a number of sites in the historic East Riding of Yorkshire with rich Middle Saxon and Viking Age metalwork, but which are of a hitherto unknown type.

3 The Anglian settlement at Cottam, North Humberside

This brings me to Cottam, which is the first of these sites within Northumbria to have been investigated by excavation. The site lies near Burrow House Farm, on arable land high on the Yorkshire Wolds some 10 miles from the coast, between the Yorkshire market towns of Driffield and Malton (NGR 49754667). One arm of a deep fluvio-glacial valley system lies adjacent to the site. It is also adjacent to the road which still runs along the Wolds' top today, parallel to a system of linear earthworks, or dykes. A number of neighbouring Deserted Medieval Villages (DMVs) are indicated by the surviving earthworks of peasant tofts and crofts. These are believed to represent the medieval settlements of Cottam and Cowlam which were established by the Domesday book of 1086, but which were abandoned during the Later Middle Ages. These features were all digitised under licence as separate layers within AutoCAD from the 1:10,000 Ordnance Survey map. They were then imported into ARC/INFO and a coverage was built to provide a local context map for the site-based project (fig. 1).

However, there is also a hidden landscape, visible only as crop marks observed by the aerial archaeologist. The aerial photographic coverage for the area has been recorded by RCHME as part of their Yorkshire Wolds project. A transcript was acquired from RCHME and was also digitised in AutoCAD and imported into ARC/INFO. This reveals an intensively and extensively cultivated landscape, made up of ditched enclosures, connected by networks of trackways (fig. 2). Such enclosures have often been assumed to be of Iron Age or Romano-British date, although this has rarely been tested by excavation. Whilst the ladder settlement enclosures, which appear to be associated with a distinctive pattern of small rectangular paddocks and droveways, do probably date from the Late Iron Age there are other categories of enclosure which have tended to be grouped together with them. The site known as Cottam B, on which I will focus in this paper, is an unusual sub-rectangular form which is not linked with an associated field system. Instead, it appears to sit astride a trackway which skirts a dry valley and then runs southeast to a second enclosure, Cottam A, where the metal detector users have recovered primarily Romano-British artefacts, and then to the Cottam DMV. In this single parish, therefore, we may be able to see the evolution of the settlement pattern from the Romano-British period to the present day. In particular, the relationship between the various archaeological nuclei, and their relationship with the DMVs at Cottam and Cowlam, offers the potential for a detailed case study of an evolving settlement hierarchy.

3.1 Metal detecting and field walking

The Anglo-Saxon site at Burrow House Farm was discovered by metal detector enthusiasts in 1987 and has subsequently been intensively worked, yielding a rich collection of predominantly Anglian metalwork, but also some Anglo-Scandinavian finds. From 1987-89 some 200 man-hours of searching yielded over 60 pieces of 8th and 9th century date. From 1990 the find rate has diminished to approximately one artefact per six hours of detecting. The find spots have been systematically recorded, and the objects have been published in the *Yorkshire Archaeological Journal* (Haldenby 1990, 1992, 1994). All the finds recovered to date have been found in plough-soil, close to the surface. The site has been regularly ploughed to a depth of *c.* 6" for cereal cultivation but, on at least one occasion, it has also been 'subsoil ploughed' for the planting of potatoes, resulting in disturbance of material to a depth of *c.* 15" (Robert Bannister *pers. comm.*). It has been noted that this led to the recovery of additional metal-work from the ploughsoil (David Haldenby *pers. comm*). In some areas broken chalk is visible on the surface, and the site may have suffered from topsoil erosion from raised areas; in other places it appears that topsoil survives to a depth of at least 12". Several of the metal items are quite corroded, having suffered from agricultural disturbance, whereas much appears to have only been ploughed up in recent years and is still in a good state of preservation. The finds are spread over a wide area and several appear to have been broken in antiquity.

To date the published finds include some forty simple pins, as well as disc-headed and racket-headed pins, a lead alloy brooch with close parallels in York, over thirty 9th century strap ends, a gilt mount, similar to the large book mounts from Whitby Abbey, a fragment of rolled gold sheeting, over twenty 9th century *stycas*, and numerous Roman coins. There is also evidence of domestic Anglo-Saxon activity, including eight lead spindle whorls, and some forty iron knife blades. The Anglo-Scandinavian style finds include two Jellinge-style brooches and two Norse style bells. The metal detector enthusiasts did not make any attempt to systematically recover the non-metal artefacts, although they have acknowledged that substantial quantities of both pottery and bone have been observable in the ploughsoil (David Haldenby *pers. comm.*).

A database of all the metal finds was created within Paradox for Windows, including grid references accurate to the nearest metre, as well as information about object type, material, date, publication details, and current location of finds. The database was then exported in dBASE format to permit use of the facility within ARC/INFO v.7 which allows automatic conversion of database records from dBASE to INFO format. A point coverage of all the metal detector finds was then built in ARC/INFO.

If the distribution of the metal detector finds is plotted there appear to be two main concentrations (fig. 3). There may also be further groupings but extensive metal detecting has only been carried out over the large arable fields which are subject to ploughing, and not within the smaller fields under grass and woodland which are adjacent to the modern farm.

If the positions of the metal artefacts are also super-imposed upon the plot of cropmarks it is clear that the southern concentration coincides with the ditched enclosure, whilst there is a second focus to the north which is less clearly associated with other features (fig. 4).

This suggests that the enclosure is itself probably Anglo-Saxon, rather than Iron Age or Romano-British, as might have been supposed. The GIS also allows one to query the

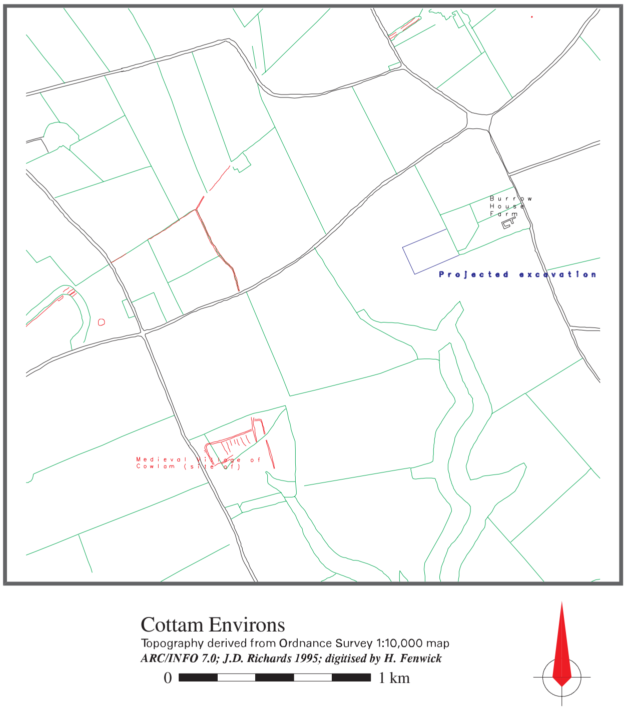

Figure 1. Cottam Environs, showing Burrow House Farm excavation, and site of Deserted Medieval Village of Cowlam.

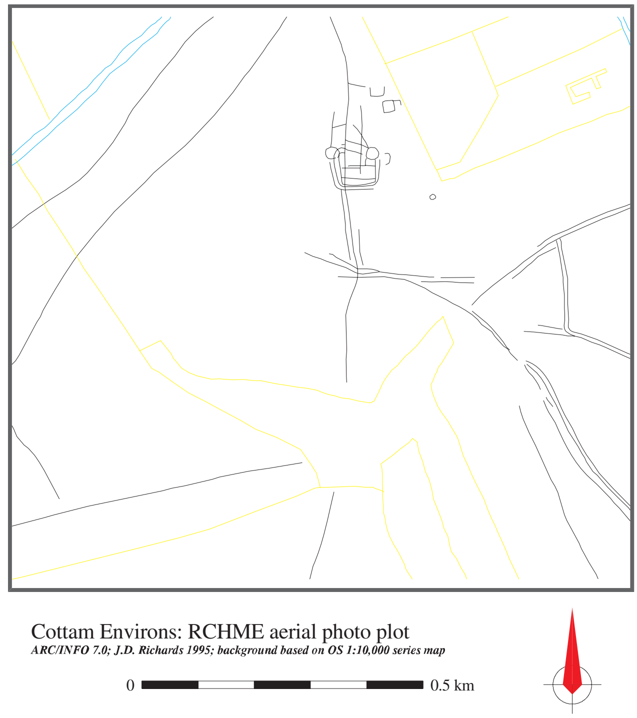

Figure 2. Cottam Environs, showing rectified aerial photographic plot, superimposed upon modern field systems.

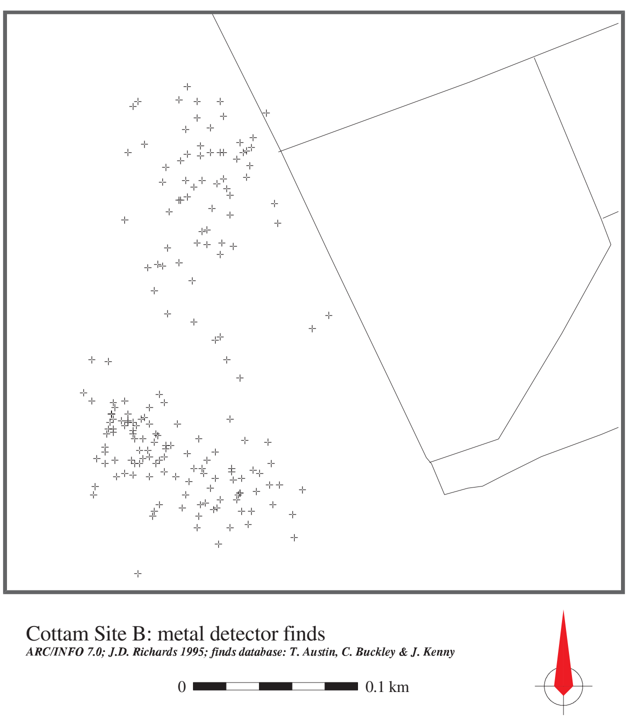

Figure 3. Cottam Site B, showing metal detector finds, superimposed upon modern field boundaries.

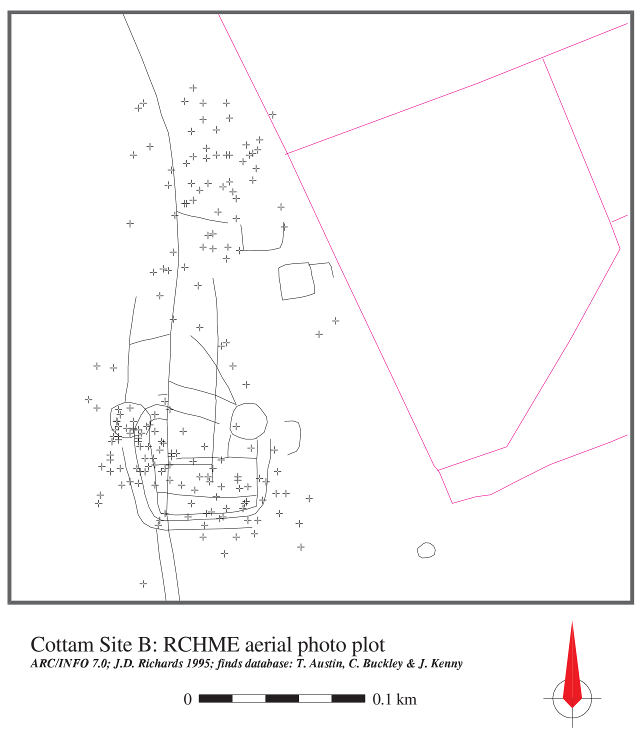

Figure 4. Cottam Site B, showing metal detector finds, superimposed upon aerial photographic plot and modern field boundaries.

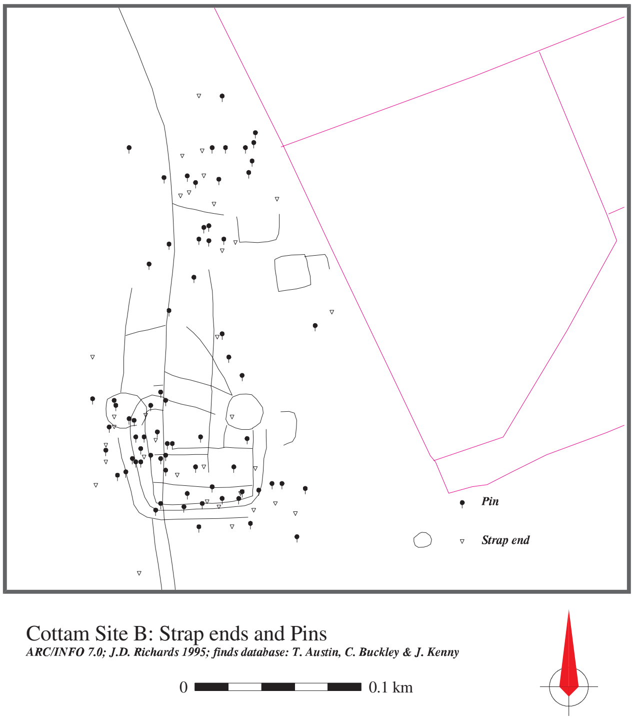

Figure 5. Cottam Site B, showing distribution of pins and strap ends, recovered by metal detector.

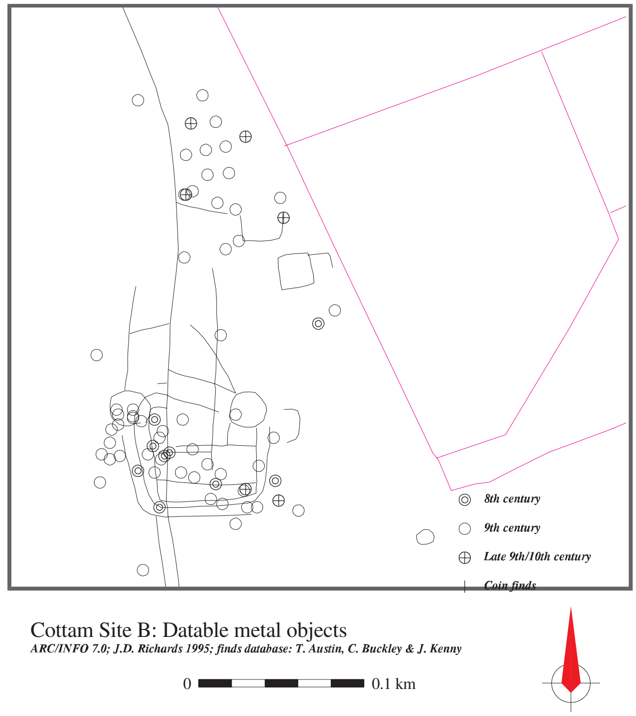

Figure 6. Cottam Site B, showing datable metal objects recovered by metal detector.

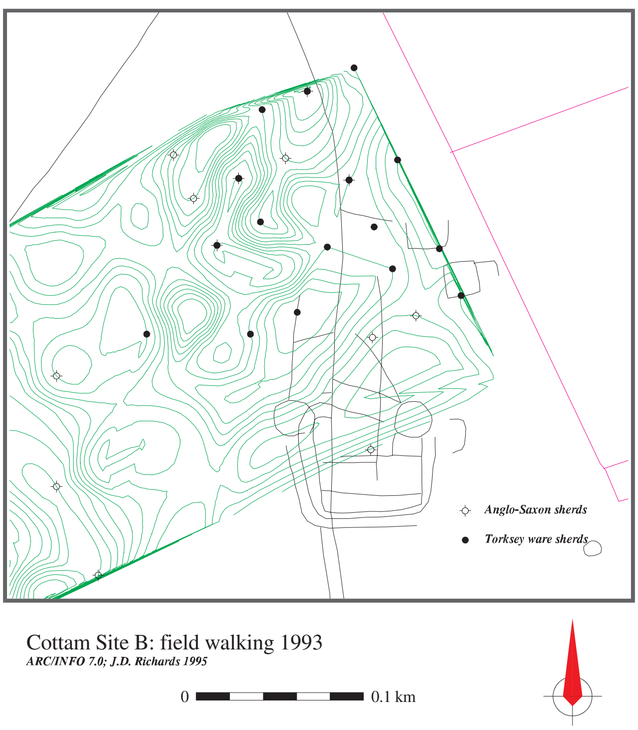

Figure 7. Cottam Site B, showing point coverage of Anglo-Saxon and Torksey-type ware sherds, and TIN model of density of number of Roman sherds, recovered by field walking in 1993.

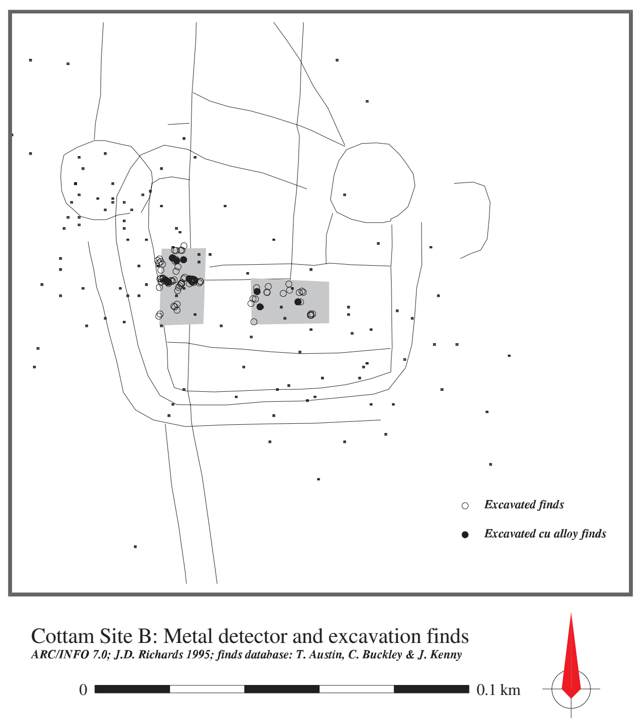

Figure 8. Cottam Site B, showing 1993 excavated finds, superimposed on distribution of finds recovered by metal detector.

distribution by type of object, although this reveals no clear patterning, with strap ends and pins, for example, apparently distributed randomly between the clusters (fig. 5).

However, if we use the GIS to plot datable metal objects the distribution suggests that there is a shift in date of the clusters, with most late 8th century finds towards the south, and late 9th and 10th century finds in the northern cluster (fig. 6). This work may, incidentally, allow us to refine the dating of strap ends which hitherto have been loosely dated to the 9th century. This is the only site where large numbers have been found stratified in at least two dimensions, highlighting the fact that metal detector users can make a valuable contribution to archaeology so long as the approximate location of finds is plotted.

Field walking has confirmed the picture derived from the distribution of metal detector finds. Field walking was carried out in 1989 on a 10 m grid and again in 1993 on a 30 m grid. Data was again recorded in Paradox and then converted into INFO tables. For classes of objects where there were only isolated find spots these were retained as point coverages. Where there were several occurrences of an object class per grid square these were converted into a lattice coverage and a TIN (Triangulated Irregular Network) model was then constructed.

Figure 7 shows a TIN model of the density of Roman pottery by number of sherds and point coverages for Anglo-Saxon and Torksey-type wares. This shows that there is a general background distribution of Roman potsherds across the field, whereas Anglo-Saxon sherds are concentrated towards the east. The Torksey-type ware sherds, which are not current before the 10th century AD, are particularly focused towards the northeast, which is where the 10th century metal finds were clustered.

By plotting these finds and superimposing the various coverages within ARC/INFO, therefore, we are drawn to the conclusion that at Cottam there were two concentrations of post-Roman activity, with an Anglian nucleus towards the centre of the field, and a subsequent shift to the north-east during the Viking Age.

3.2 Excavations at Cottam, 1993

But what was the site? It was clearly high status; and certainly a settlement; this is not just a periodic market site. What is the extent of preservation? What sort of features are the metal artefacts coming from, and has the site been completely ploughed out?

In 1993 we carried out a limited excavation to try to further determine the nature of the site and to evaluate its condition and potential for further research (Richards 1994). Two trenches were excavated across the enclosure, in order to investigate the 8th and 9th century focus. In both trenches occupation deposits had been ploughed-out, but truncated structural remains and the ditch fills of various ancient land boundary features survived. Finds were recovered from features cut into the chalk. The position of excavation finds was located in three dimensions, with metal detectors used to aid recovery. All finds were again recorded in Paradox, with NGR co-ordinates to the nearest centimetre, and were subsequently built as a point coverage in ARC/INFO.

By using the GIS to merge the coverage of metal detector finds with the excavated finds it was possible to assess the relative recovery levels, and graphically demonstrate that excavation can still add to the already rich metalwork assemblage from the site (fig. 8). This showed that metal finds continued to be recovered in proportion to the density revealed by the metal detector survey. It also revealed that the highest densities corresponded to areas with the highest numbers of cut features, as represented by the crop marks.

In the westernmost trench a major north-south ditch ran the full length of the excavation, representing one of the major features observable on aerial photographs of the site. The line of this feature, and the parallel ditch to the west, are observable in the plot of excavated finds in figure 8. This feature appeared to cut through the truncated remains of a rectangular post-hole building, presumed to be of Anglian date. To the east there was a circular pit, *c.* 1.5 m in diameter, in the base of which an adult female skull had been placed, which we have radiocarbon dated to the Anglian period (Richards in prep.).

3.3 The Geophysical Survey, 1994

In 1994 we followed up the excavation by resistivity and magnetometer survey of two blocks of land, corresponding to the two finds concentrations (fig. 9). It was only through the use of the GIS combined with the geophysical survey that we were able to locate exactly which features had been encountered by excavation. The raw data was exported from the GEOPLOT survey processing software as an ASCII file and set up as a grid coverage within ARC/INFO. By superimposing the outline of the excavation trenches with the processed survey results, within ARC/INFO, we were able to identify precisely which features we had excavated, and to provide a control for the geophysics (fig. 10). This revealed that the aerial photographic plot was misplaced by the order of 3-5m east-west, presumably as a product of rectification errors of oblique aerial photographs over an uneven landscape. Thus the major north-south ditch encountered in the excavation was demonstrated to be the major sunken trackway, rather than one of the enclosure ditches. Thus it was the trackway, rather than the enclosure boundary, that had been cut through the post-hole structure.

The combination of the survey results within the GIS also revealed that for the recovery of some types of information there was no need to carry out a large-scale excavation. Thus, for example, a recut of the north-south

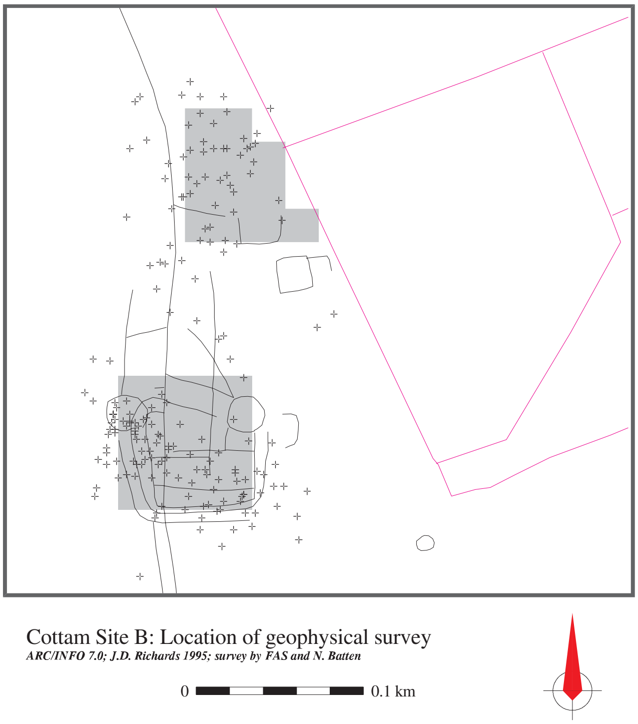

Figure 9. Cottam Site B, showing location of geophysical survey in relation to cropmarks and metal detector finds.

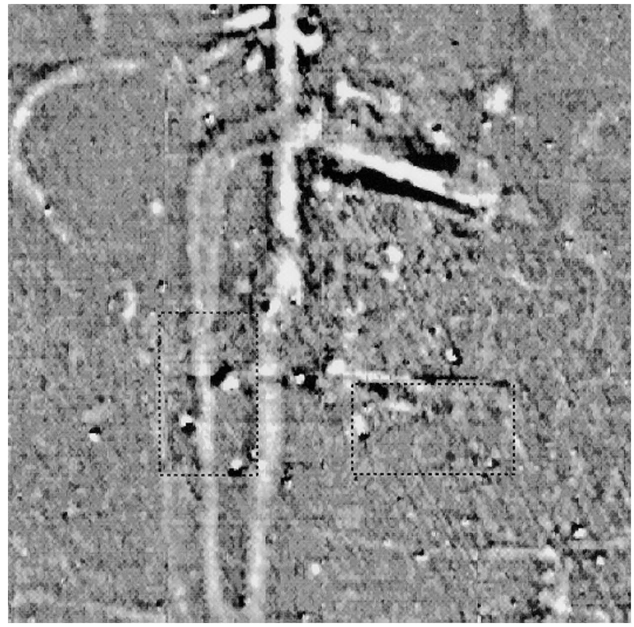

Figure 10. Cottam Site B, showing outline of 1993 excavation trenches, superimposed upon magnetometer survey of southern area.

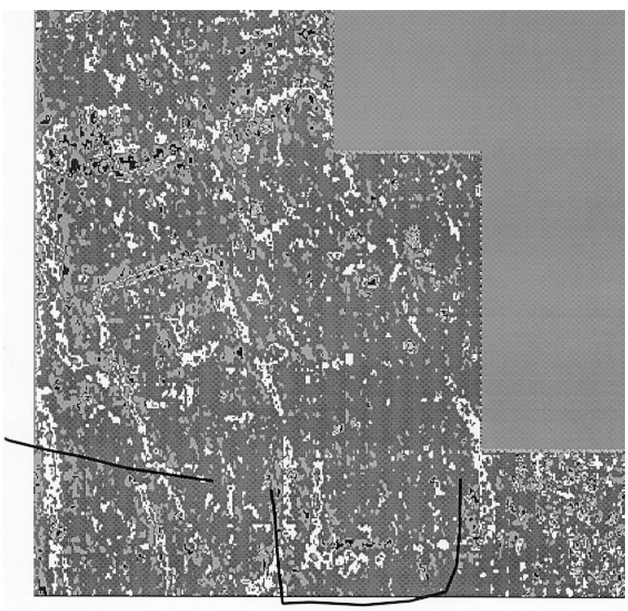

Figure 11. Cottam Site B, showing aerial photographic plot, superimposed upon magnetometer survey of northern area.

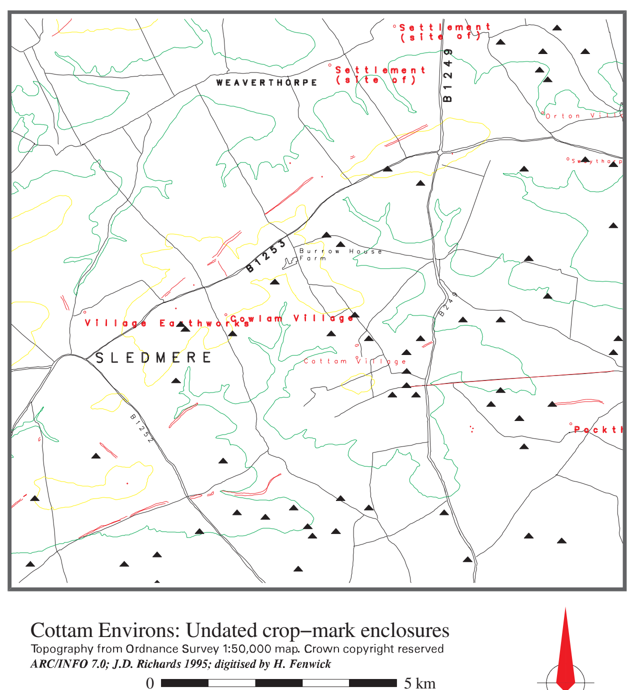

Figure 12. Cottam Environs, showing location of undated cropmark enclosures derived from Humberside SMR.

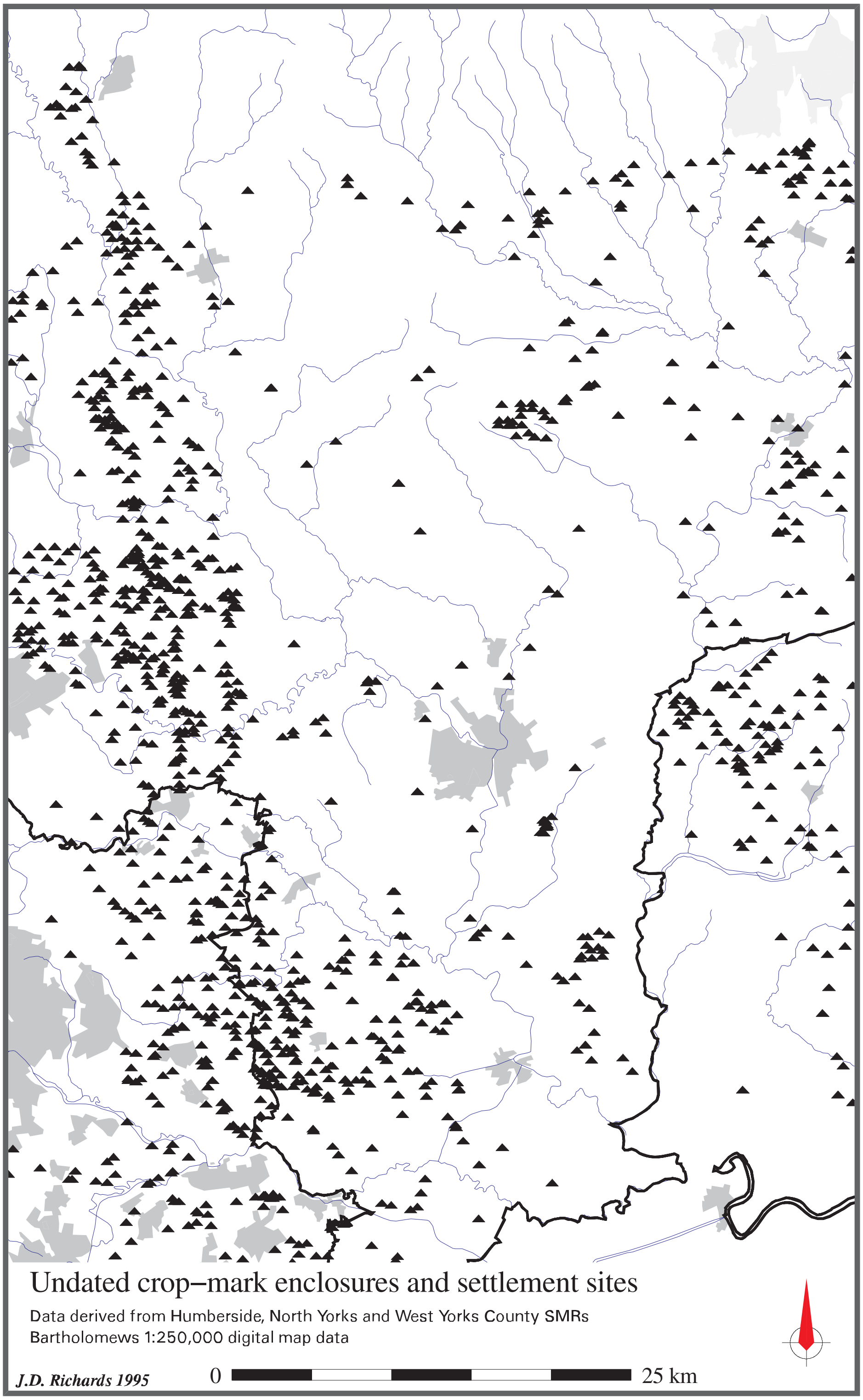

Figure 13. Vale of York, showing location of undated cropmark enclosures and settlement sites derived from Humberside, North and West Yorkshire SMRs.

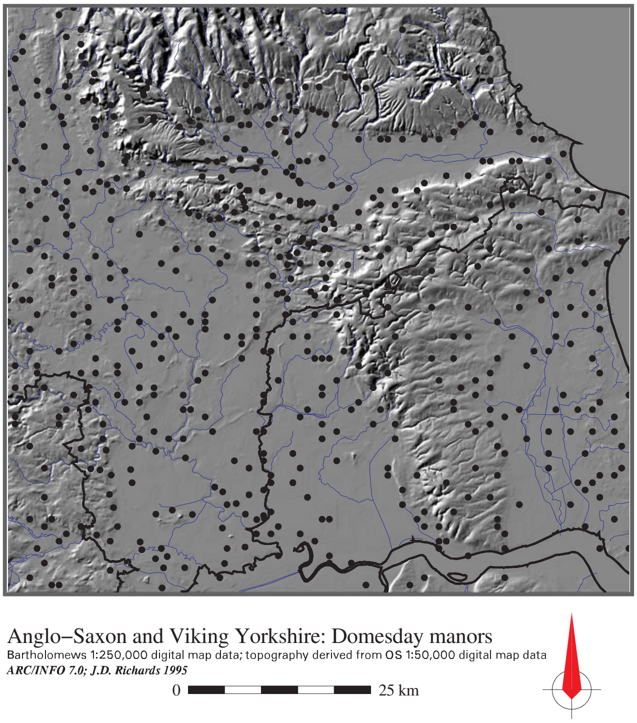

Figure 14. Southern Northumbria, showing location of manors referred to in the Domesday Book.

ditch which had been investigated by excavation was also visible in the magnetometer results. The resolution of the survey was also sufficient to allow us to pick out the effects of ploughing, and indeed, to identify the area of disturbed ground caused by our excavation and spoil heap. However, not surprisingly, the post-hole structures were not visible. By using ARC/INFO however, we have managed to coax more information out of the survey. One avenue being explored, for example, includes the combination of resistivity and magnetometer survey grids to produce a combined plot, with differential weightings.

A second magnetometer survey was conducted in the area of the northern concentration of finds, including Scandinavian style metalwork and Torksey-type ware pottery, with a 10th century emphasis. This revealed a number of sub-rectangular enclosures of a type not seen elsewhere, with an entranceway and internal features (fig. 11). These features are not visible as crop marks, possibly because they are more deeply buried. This area is to be excavated during 1995.

4 From site to landscape

In summary, the use of a GIS for managing the project results has allowed us to integrate a wide variety of evidence, which in combination means more than it does individually. This has included data collected at a wide variety of scales, from 10 m grid square for the field walking, a precision of about 1 m for the metal detector finds, and 0.01 m precision for the excavation finds. However, since the spatial context of all these categories of information was recorded with respect to the National Grid it has been possible to superimpose them within ARC/INFO, although the original resolution of recording has, of course, to be borne constantly in mind when interpreting the results.

Furthermore, within the context of the overall research project it is possible to move out from the individual site to the kingdom of Northumbria as a whole. Several characteristics of Cottam can be investigated on a regional scale, in the search for similar sites. I shall illustrate this facility with two examples: the crop mark evidence, and the fact that the manor of Cottam is referred to in the Domesday Book.

The GIS also incorporates records derived from the various county Sites and Monuments Records (SMRs). These records were downloaded from the respective SMRs for Humberside, North and West Yorkshire and, after extensive cleaning and conversion to the lowest common denominator in Paradox, were also set up as coverages within ARC/INFO using a standard database design (Chartrand/Miller 1994; Chartrand *et al.* 1993).

Cottam is just one of many undated crop mark enclosures in the local area. Figure 12 shows the distribution of all undated cropmark enclosures in the environs of Cottam, as recorded in the Humberside Sites and Monuments Record. Several of these may also be of Anglo-Saxon or Viking date and a comparison with the location of metal detector finds, also known to the project, may help to reveal which.

A step outwards again reveals the large number of undated crop mark enclosures, with a distinctive distribution, derived from Humberside, North Yorkshire and West Yorkshire SMRs (fig. 13). This distribution has to be assessed against various factors which affect the visibility of crop marks, including relief, soils, current land use, and controlled flying zones (Chartrand this volume). Figure 13 shows two such constraining factors: urban areas as dark stippling and forested areas (in the northeast) as light stippling, both derived from the 1:250,000 Bartholomews digital map data. The clear concentration which runs north-south along the western edge of the map represents sites found on the magnesian limestone ridge. The east-west line near the northern edge of the map represents a string of sites on the southern edge of the North Yorks Moors. It is amongst these sites that we should look for other possible Anglo-Saxon and Viking farmsteads.

These cropmark enclosures may represent the start of an evolving early medieval settlement hierarchy. They are the unnucleated farmsteads which develop into manor sites and nucleated villages during the 10th century (Richards 1991). The end of the process is represented by the snapshot of 11th century land-holding which we have recorded in the Domesday Book (fig. 14).

The recording of sites referred to in the Domesday Book was inconsistent between the local county SMRs. Therefore a project database of Domesday manors was created in Paradox and set up as a point coverage in ARC/INFO. The resulting distribution can again be analysed in relation to other variables. Figure 14 shows the distribution of manors plotted against a hillshade model calculated in ARC/INFO from the 1:50,000 Ordnance Survey digital terrain data, with the rivers and county boundaries from the Bartholomews 1:250,000 digital map data. We assume that the Cottam DMV corresponds to the manor of 9 *carucates* which the Domesday Book records as formerly held by Ulfr, but by 1086 had been taken over by York Minster (Faull/Stinson 1986).

By using GIS to look at these changing settlement distributions and land-holding patterns on a regional scale the project aims to model the process by which settlement nucleation and village formation took place, and by which the modern settlement pattern was established. By these means I hope to test the theory that it was during the 10th century, accelerated by the disruption to traditional land-holding patterns caused by the Viking colonisation, that most present-day villages were founded. For this story, the site at Cottam, with its evidence for settlement shift in the 10th century, is critical.

Acknowledgments

The results presented here form part of a larger project whose aim is to investigate Anglian and Anglo-Scandinavian settlement patterns in Yorkshire, supported by York University and the British Academy.

The 1993 Cottam evaluation was additionally supported by the Earthwatch Foundation USA. The excavation was co-directed by the author and Blaise Vyner. Thanks are due to the landowner, Mr Robert Bannister, and to David Haldenby and colleagues. The 1989 field walking was carried out under the auspices of Humberside Archaeological Unit by Peter Didsbury and members of East Riding Archaeological Society. The 1993 field walking was carried out by students of York University Archaeology Department. The geophysical survey was conducted by Field Archaeology Specialists Ltd, also of York University.

The project database was implemented by Tony Austin, Caroline Buckley and Jon Kenny. Aerial photographic plots were derived from Cathy Stoertz at the Air Photography Unit, RCHME. Additional digitising was conducted by Nigel Batten and Helen Fenwick. Other project data was extracted from the County Sites and Monuments Records of Humberside, North Yorkshire, and West Yorkshire. The project GIS was developed in ARC/INFO by the author, with assistance from Jeff Chartrand, Paul Miller, and Peter Halls.

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Archaeological Resource Visibility and GIS: A case study in Yorkshire

1 Introduction

This paper is an attempt to highlight some methodological issues for the examination of archaeological site visibility. It is based upon the concept of predictive visibility templates within the domain of Geographical Information Systems (GIS). The research presented here is an exploration of the potential for the application of recently appropriated methodological tools, specifically GIS, to extant archaeological data for the identification of visibility templates (Carver 1990) incorporating a synthesis of selected environmental and cultural factors.

2 GIS Past and Present

GIS are an example of a research toolkit and methodology which developed outside archaeological method and theory but which are seen by many to have potential in archaeological investigations. In archaeology, GIS are a fairly recent phenomena reflecting the diffusion of a technique from spatial geography to archaeological spatial issues. As with many techniques which are adopted rather than developed, GIS have suffered from dislocation. Our zeal for the GIS toolkit has resulted in the vast majority of archaeological GIS projects being driven by the tool rather than being part of a developing archaeological spatial information management system. The era of GIS being another tool simply to put crosses on maps is at last coming to an end. In recent GIS projects one can see the re-emergence of the research goals from the abyss of hardware potential (cf. Thoms 1988). The need for the development of archaeological spatial methodology to guide and direct the use of GIS in archaeological investigations allows us to re-examine key issues in archaeological spatial analysis.

3 Data Representivity

One of the primary conceptual concerns for archaeological resource visibility is the issue of the representivity of the data. In the past the development of archaeological predictive models depended primarily on broad regional projects which generally built upon existing research supplemented with extensive field truthing (cf. Hasenstab/ Resnick 1990; Kvamme 1988). Data collection in these projects provided primary data rather than depending upon secondary or even tertiary data. Because of the wealth of the archaeological record in the UK, regional analysis has not generally employed extensive field testing. Consequently we must choose to either ignore the extant record or incorporate these records into our research agendas and models. Data from the archaeological record is an incomplete, biased, non-random collection of information from which we are supposed to hypothesize about past activities and events. Although sounding bleak the situation is not as bad as it sounds. To use this biased data we are going to have to learn to apply *source criticism* to the archaeological record so that material collected by a great number of people over a long period of time can be incorporated into current research. As a result of the failure of many researchers to actively apply data validation, and the past emphasis on an environmentally deterministic approach, few models have progressed from their initial conception into general acceptance within the archaeological community.

It has therefore become apparent that the application of new spatial tools to archaeological data requires an examination of the limitations of the methodology of the spatial toolkit as well as the application of source criticism to data sources before meaningful attempts to create predictive visibility templates can be made.

To this end this paper will present a few of the approaches which may be directed to the resolution of a number of questions relating to the creation of visibility templates.

4 Data Mismatch

The work presented in this paper is one of a group of projects initiated by the Department of Archaeology, University of York, to look at the Roman, Anglian, Anglo-Scandinavian and Medieval town of York and its relationship with its hinterland. This paper deals specifically with the issue of Archaeological Resource Visibility with reference to the Iron Age/Roman interface. This period was chosen for a number of reasons, though the main one is that the arrival of the Romans is well established and represents a readably identifiable foreign material culture. As such it was felt that this cultural upheaval would be

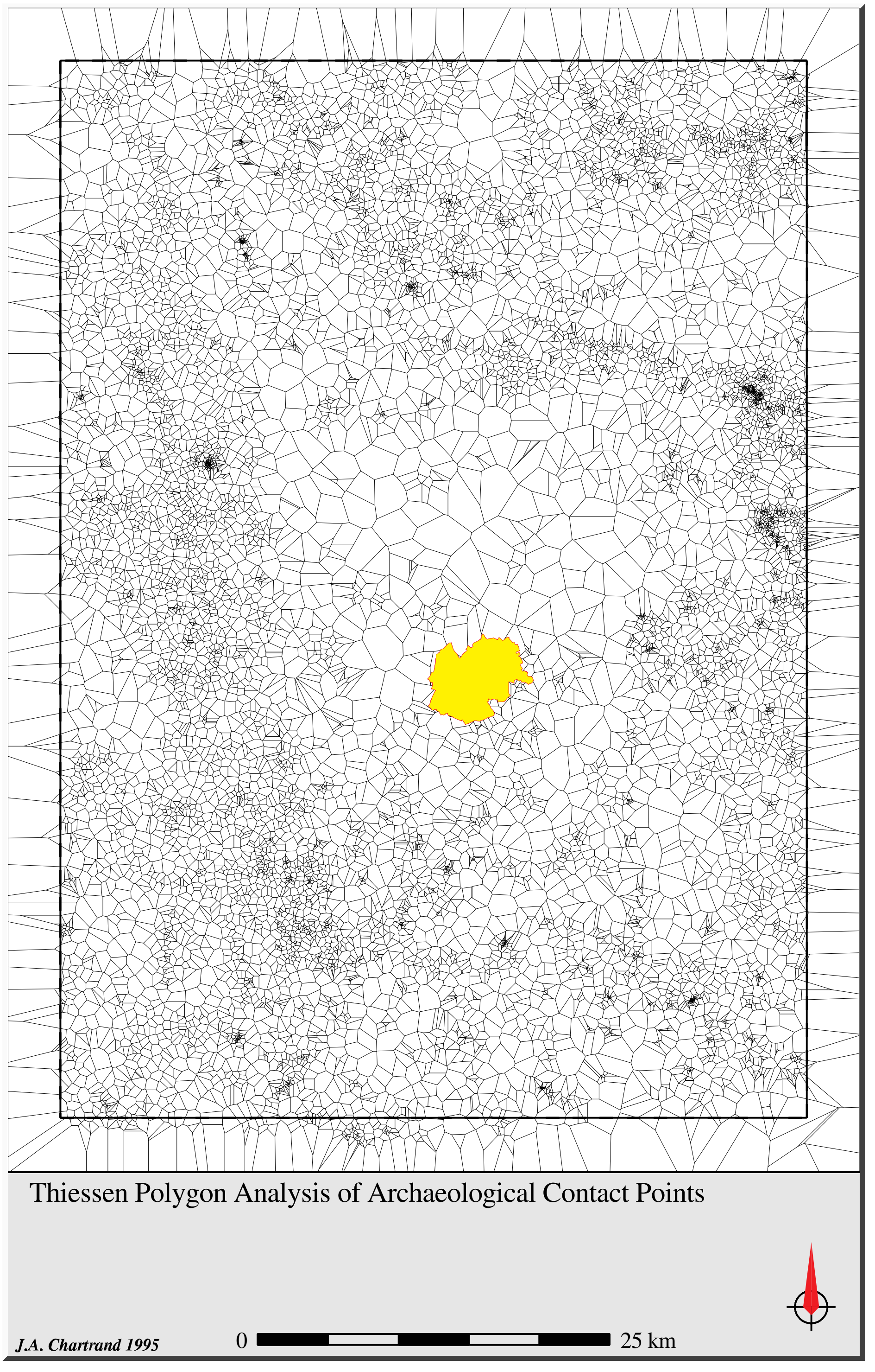

Figure 1. Multi Period Thiessen Polygons for Archaeological Contact Points.

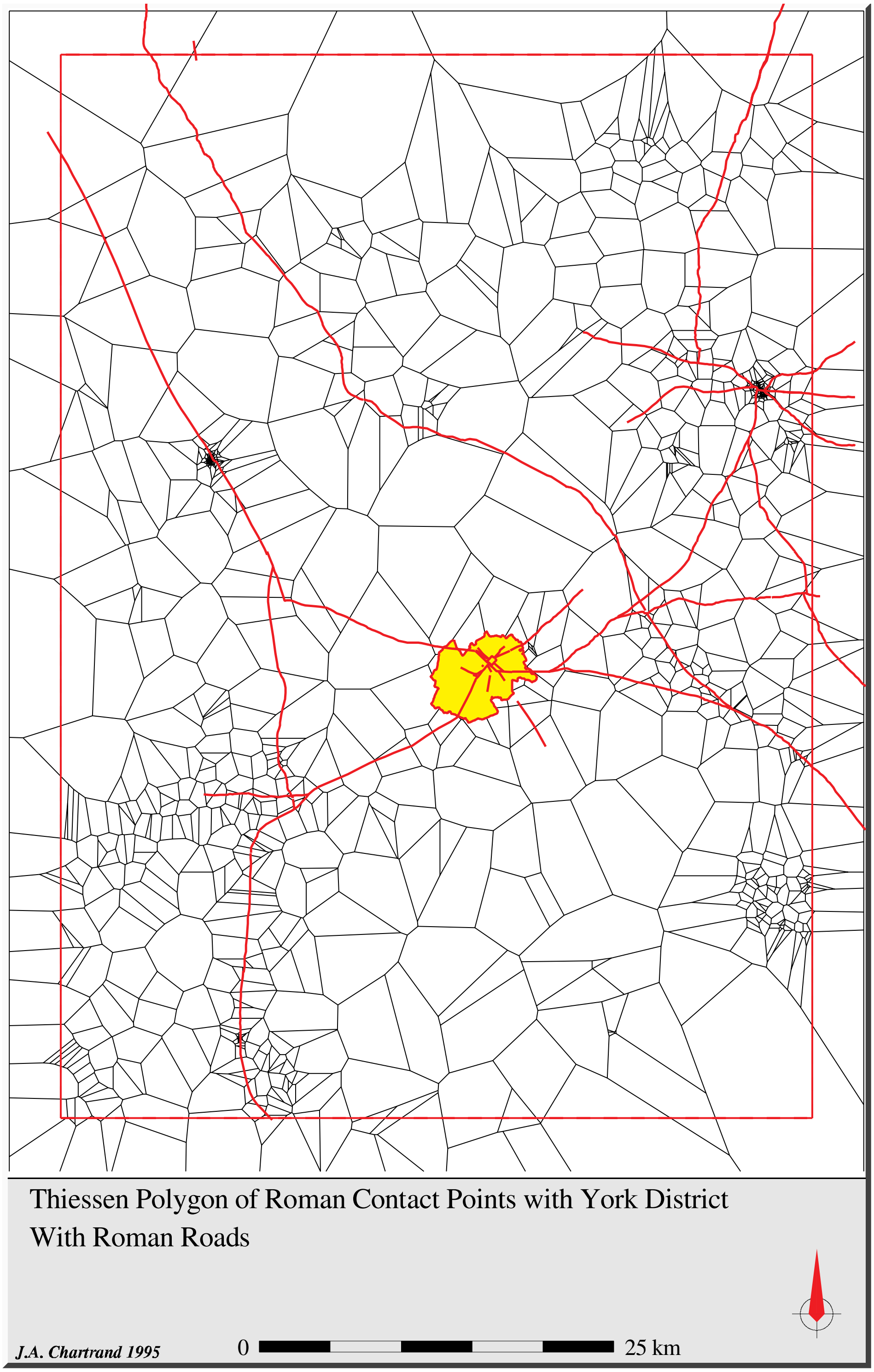

Figure 2. Roman Period Thiessen Polygons with Roman Roads.

visible in the archaeological record from material culture and land exploitation patterns. Considering this distinct cultural horizon we can identify both environmental and cultural variables which may bias the recovery of archaeological material. Archaeological Resource Visibility (ARV) factors include:

Environmental Factors
Physical
- Soil Type
- Geology
- Geomorphology (landforms)
- Aspect
- Slope

Vegetation
- Natural plant coverage
- Exploitive vegetation

Cultural Factors
Physical
- Land Use
- Proximity to modern foci
- Proximity to historic resources

Social
- Historic selection preferences
- Recognition
- Field techniques

The first step in the application of source criticism to archaeological data is to look at the basic nature of the archaeological record and identify the strengths and weaknesses of the potential archaeological resource.

Archaeological data has three key properties associated with resource visibility. The first of these properties is spatial location. It is this feature which makes reliable spatial tools essential to the future of archaeological analysis and interpretation.

The second essential property of archaeological data is placement in the temporal continuum, what we generally think of as the date. It is important to make the distinction between date and ethnicity. For example, material identified as part of 'Roman culture' is present within the study area as a result of trade prior to the Roman conquest. Conversely, archaeological evidence identified as 'Iron Age culture' will continue to be produced long after the Romans have arrived. Two distinct archaeological cultures may thus occur in a single temporal and spatial location.

The third property of archaeological data is our subjective classification of it. What have we identified and how? Our ability to interrogate data depends greatly upon the form and structure of the archive. Traditional recording has focused upon functional analysis, determined archaeologically, stored in text based format. Although this is changing with the inclusion of graphics and the use of alternative classification systems the effects of traditional data structure are still an important issue in data archive and retrieval. Documentation of the decisions of what information is stored and the form in which it is stored is important information for any subsequent use.

5 Geographic Information Systems

In essence the GIS function is to provide a method of filtering the large dataset and providing the basic spatial analysis tools with graphical output.

The digital data set which is being used comprises records from three very different county systems in very different formats. The study area encompasses three regional administrative bodies responsible for the recording and archiving of archaeological data. The bulk of the data is held by the North Yorkshire County Council in three independent mainframe (ICL) databases:

NYSMR (full citation record) 9426 records
NYSIN (selected citation record) 3719 records
NYAP (separate listing of aerial photography) 10906 records

The remaining data is held by Humberside County Council and West Yorkshire Archaeological Service on PC based systems:

Humberside (dBASE III+) 3333 records
West Yorkshire (Superfile) 1738 records

The primary difficulties encountered, once exportable data was extracted from the various systems, can be defined into two broad groups:

1. data structure differences:
   - different fields
   - different field types
   - different data formats
2. terminology differences:
   - lack of standard terms
   - differences in period starts and finishes
   - temporal period versus ethnic group

Another issue addressed by this project is the urban versus rural archaeological data mismatch, in terms of both data structure and data quantity. Landscape archaeologists have spent considerable time discussing how a 'site' should be defined, and have resolved that it simply represents an area of the landscape where there is a relative increase in the density of activity (Gaffney/Tingle 1985). In the case of a town, the complete urban core can be regarded as an arbitrarily defined site which has a number of components. The issue of viewing the archaeological resource in terms

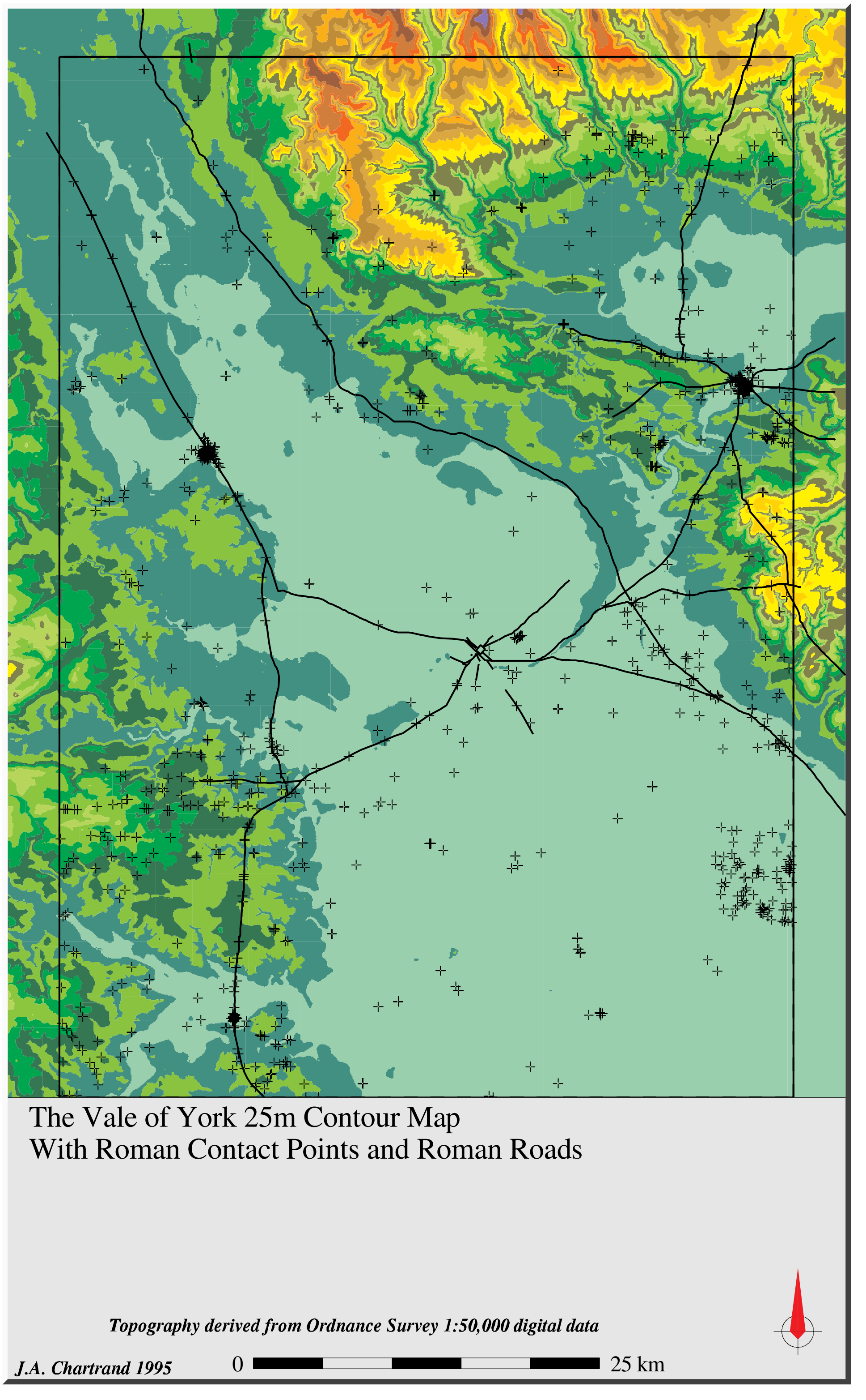

Figure 3. 25 m Shaded Contour Vale of York with Roman Contacts and Roman Roads.

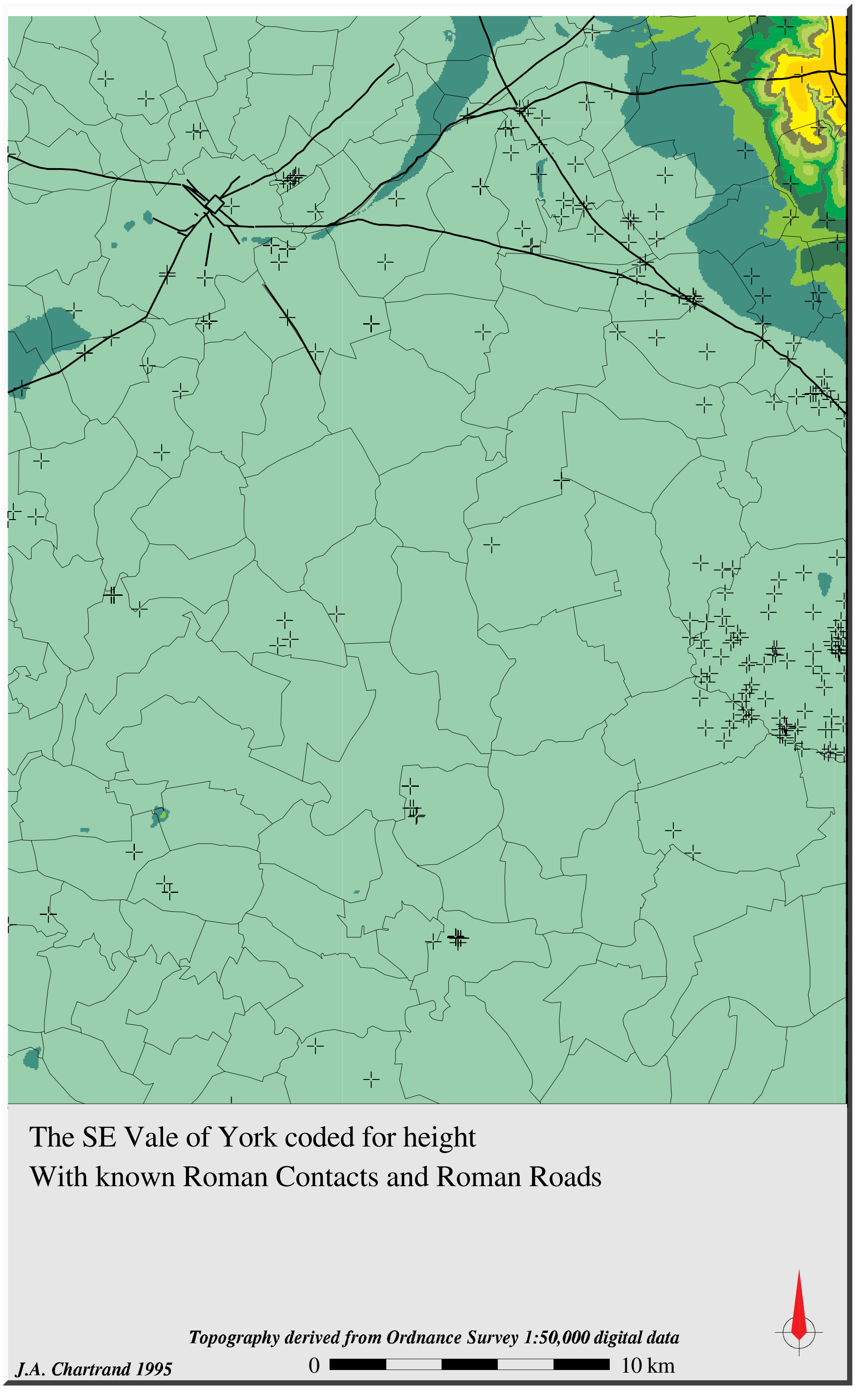

Figure 4. 25 m Shaded Contour SE Vale of York with Roman Contacts and Roman Roads.

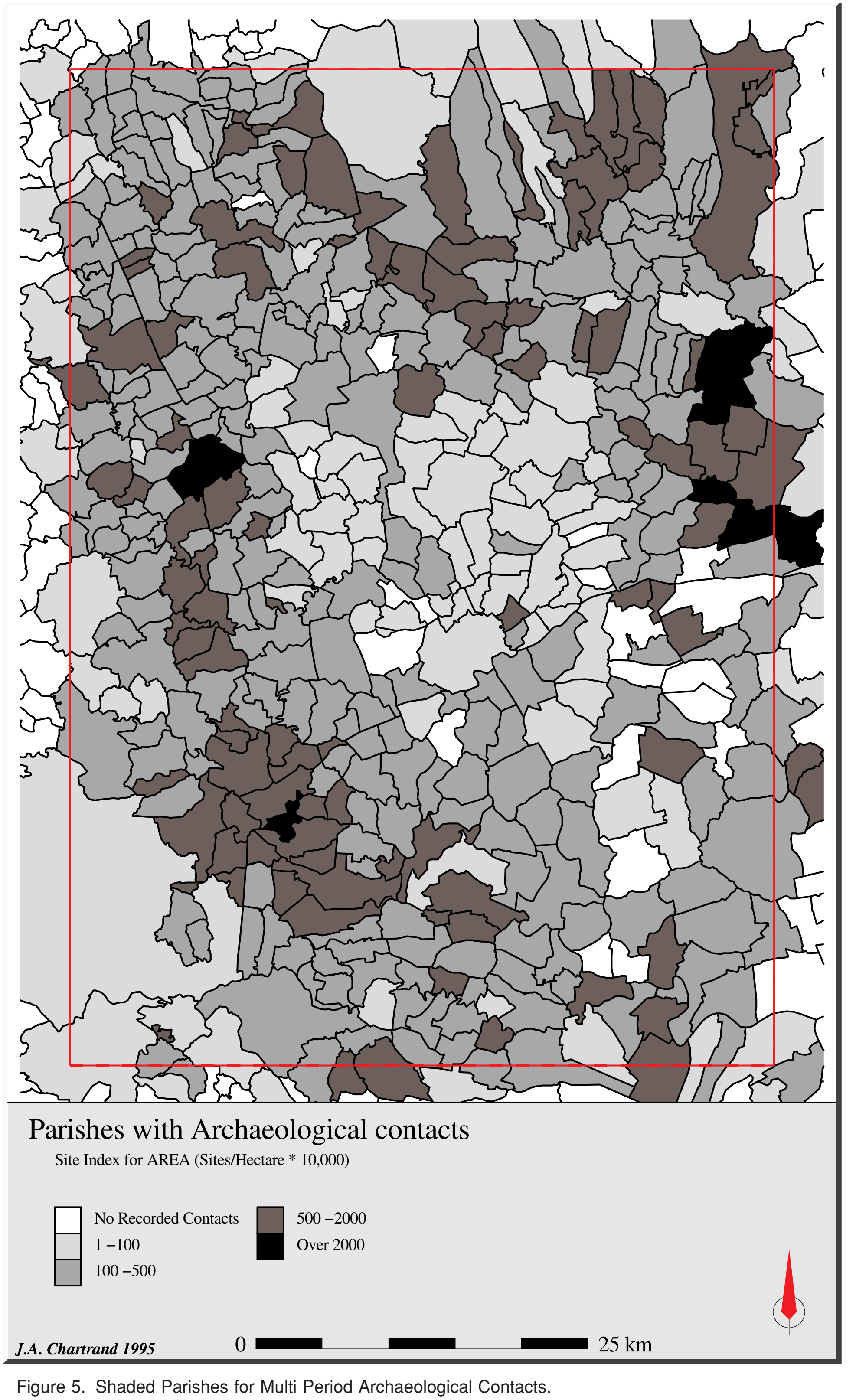

Figure 5. Shaded Parishes for Multi Period Archaeological Contacts.

of components is essential for this project. The component approach allows for the aggregation of data into spatial or temporal themes. Given the density of urban activity, and the vertical build-up of considerable thicknesses of deposits in urban areas, it is also more likely for the same horizontal spatial coordinates to be the location of a number of activities, separated in time. In fact this is just an extension of the problems which face those who try to provide a relational structure for a Sites and Monuments Record where sites often have remains representing several periods.

An essential point to remember in any archaeological study which includes well defined urban areas and substantial hinterlands is that both the town and country are part of the same landscape. It is the division in the way that archaeological data is collected and stored which generates a false distinction. In fact, it is rarely possible to draw a neat box around a town to define the point at which urban influences stop. In practice, there may be a number of boundaries, according to the aspect of urban life that is under consideration: craft activity, settlement, religious control, political control, landownership, artefact fall-off etc.

A discussion of the database approach and data structure utilized in this project has been previously presented by the author, including a fuller discussion of data fields, terminology and coding issues (Chartrand/Miller 1994).

6 The Results

The first step was to apply source criticism to the archaeological resource. In looking for tools to examine the issue of potential contact points[1] I have resurrected a tool from the past, Thiessen Polygons. Archaeological information as stored in the different databases varies widely within and between datasets. Some of the NYSMR includes full spatial records for each artifact where as others only have a single record for an entire excavation. Similarly, discrete temporal uses at a shared geographical location occur in many cases. To provide an indication of known archaeological contact we needed a system which would display contacts but which would not bias site location as a result of recording bias. Figure 1 is an example of the creation of Thiessen polygons based upon all known archaeological contacts. The smaller the polygon the more contacts in that area. This is a useful way of showing the overall distribution of the known archaeological contacts. The Vale of York north of the city of York has a low level of known contacts. This is also visible in the Vale of Pickering. The project border area also indicates something about the completeness of our data. Notice that for all of the boundary edges the polygons become large and elongated. This illustrates where the analysis is suffering from edge effects and demonstrates the need for project datasets to extend beyond the analytical boundary. The technique shows some interesting patterning and it provides some starting points for further investigation.

The same procedure can be applied to thematic questions. Figure 2 is a Thiessen polygon analysis based upon known Roman contacts. Even without any other data we begin to see some interesting patterns in the data. We can identify some known settlements and we can see some areas where there is very little known Roman material. As demonstrated in these two examples (figs 1, 2) the Thiessen polygon technique can be used to look at the spatial potential of the archaeological record.

Given that the distribution of archaeological material has been shown to be non-uniform we now need to examine specific ARV factors. One approach to the identification of landform significance is the use of the Ordinance Survey digital height data coded by 25 m groupings (fig. 3) using a standard topographical colour ranking. To this have been added Roman Roads and known Roman contact points. Notice that for the most part finds are associated with Roman Roads and known Roman settlement sites: i.e. York, Aldbrough, Malton, Castleford. Examination of the known Roman roads shows the truncation of the westward branch shortly after leaving the Vale. Roman contact points beyond this truncation strongly support the continuation of the road further into the upland area and may represent the major east-west travel route for the study area. One anomaly not associated with either the road or known settlement sites is the cluster of Roman contacts to the southeast edge of the project area. Upon further examination this proved to be the result of an intensive field programme by Durham University (Millett 1995). This anomaly (fig. 4) illustrates very clearly that the absence of known Roman contacts in the record in adjacent parishes is probably not related to potential resources but relates to the level of intensive field research illustrating the need for a detailed knowledge of historical archaeological projects.

The primary spatial recording unit for all three administrative bodies is the civil parish. The effect of the Durham survey on the point data has been shown in the previous figure. Identification of parish trends is an indicator of positive and negative bias in recording. Given the irregular size and shape of the parishes a system of indices has been employed. Figure 5 uses an index of site presence based upon sites per hectare for all archaeological contacts for each parish in the survey area. The results show a correlation between the geomorphology zones which border the Vale of York and point to a generally lower presence of material north of the city of York. The specific reasons for this are not clear at this time. This pattern may be a function of visibility due to environmental factors or related to modern activity.

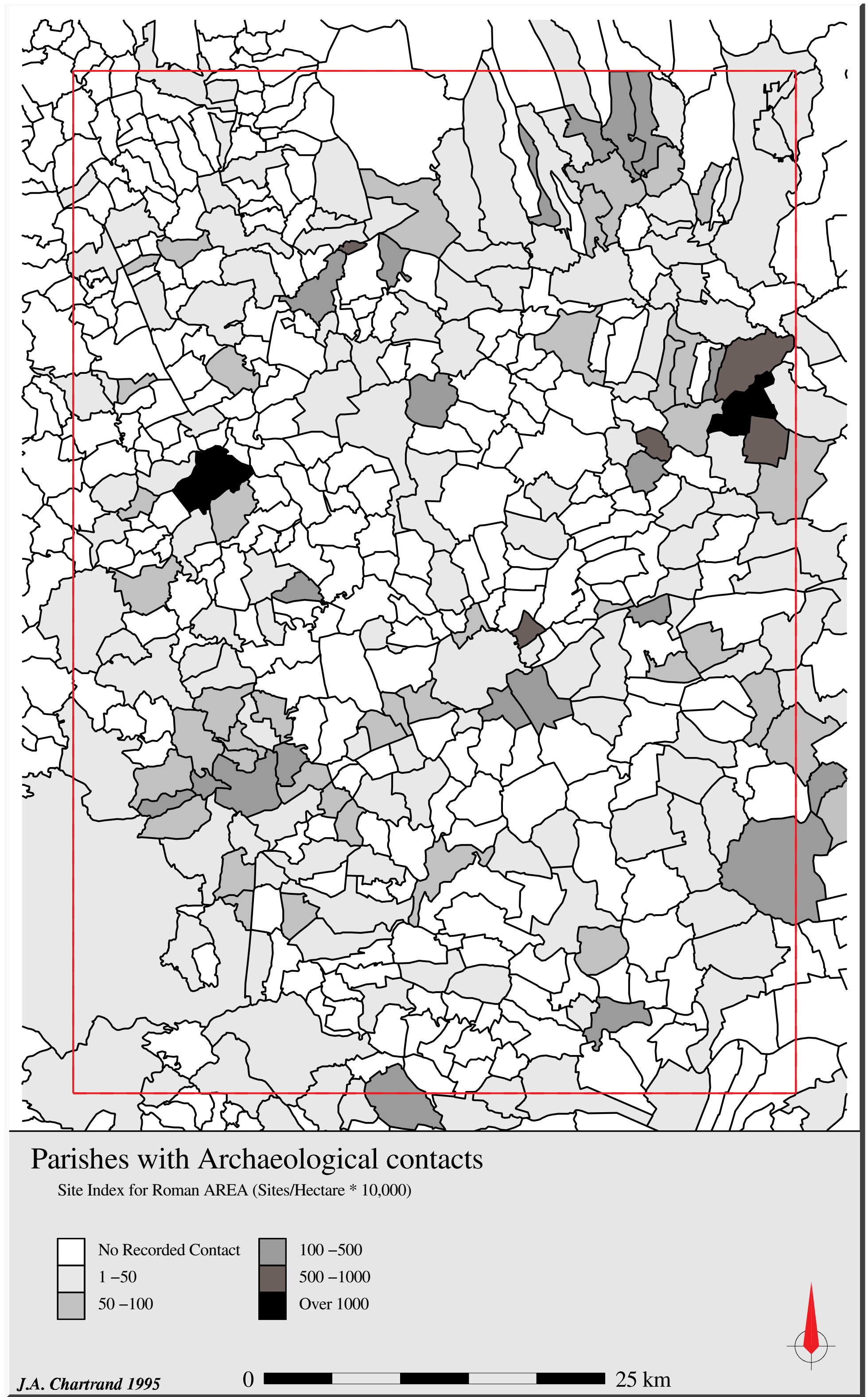

Figure 6. Shaded Parishes for Roman Period Archaeological Contacts.

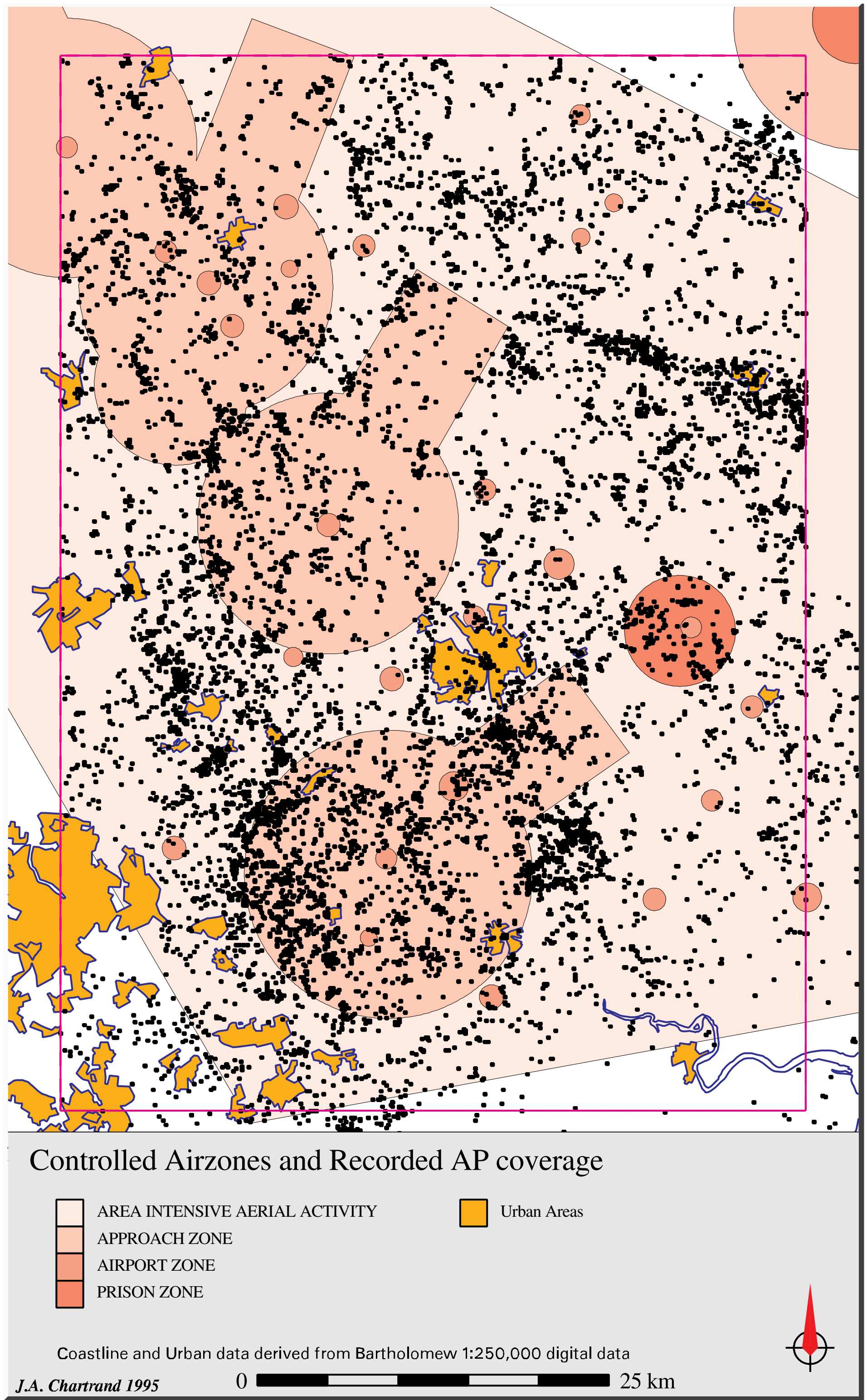

Figure 7. Controlled Airzones and Recorded Archaeological Aerial Photographs.

Using the same criteria the Roman Index (fig. 6) produces a pattern which is all too apparently related to recovery factors rather than being a product of Roman activity. Far too many parishes remain blank if we consider the Durham study as a guide to the Roman archaeological resource potential for the area. The distinction between parishes in the area, and specifically with the Durham Parish study, is a function of collection bias rather than Roman utilization.

The effect of modern land use and field recovery techniques is not limited to terrestrial approaches. The coverage of Aerial photography for the region has been plotted on a background map of the aerial control zones which affect flight patterns. It had been expected that the flight control areas associated with airports would have negatively affected coverage. In fact if we examine the result in figure 7 that does not appear to be the case. Several linear patterns can be seen to correspond to high occurrences seen on the Indices maps. The theory has been put forth that these may reflect the use of modern linear features, such as major road routes, for pilot navigation in addition to environmental factors of geomorphology and soils.

7 The future: Where to next?

The results presented in this paper are a reflection of work in progress but they show the potential for the use of the Archaeological Record. This project has demonstrated the use of the extensive machine readable data stored in the SMRs. For the work to progress we need to consider several issues. The volume of data in these datasets precludes being able to validate each piece of data, therefore we need to incorporate validation information into each record. The first step is to examine the records and see what the representation of the archaeology is at present and to try and find some explanations for its condition. The biggest obstacle that we face is convincing funding bodies and fellow archaeologists about the desirability of data enhancement, one of the most poorly resourced and least appreciated jobs in archaeology. Until we have a better understanding of the potentials and pitfalls of the archaeological record it will be impossible to progress from the environmentally deterministic modelling which can be seen to be so limiting. To this end I see the importance of including more information on the process of data collection and recording. Data validation information needs to be incorporated in the archaeological record for spatial, temporal and interpretational factors. For example, the incorporation of a precision field should be stored with every spatial location in order to indicate the accuracy of recorded spatial locations. Conversion of a 6 figure OS grid reference to a 12 figure location for GIS work will result in a 1000 m variation for actual location. We also need to record information on dating methodology. How are archaeological contacts dated — contextually, stratigrapically, by inference, scientifically or through a combination of techniques? This needs to incorporate a subjective evaluation of reliability. Researchers need to know, for example, if a contact: a) might be Roman, b) probably is Roman or c) definitely is Roman.

We need this information to examine the resource potential of both known and unknown landscapes for an evaluation of the 'archaeological value' — the matching of a deposit model or template with a research agenda.

It is essential that we change our approach to GIS so that we develop it into a tool that is part of our spatial methodology rather than our spatial methodology being the GIS. A tremendous amount of time and resources have been put into archaeological GIS but if it is to be anything more than a white elephant we must prevent the tool from dominating the craftsman. This project has shown that the vast amount of digital archaeological data collected for Archaeological Resource Management (ARM) can be used to examine archaeological research issues. It is now time to start putting our digital house in order so that new research tools can benefit archaeological research and management.

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note

1 Archaeological contact points are unique spatial locations where a recorded contact of an archaeological nature exist in fact or in record.

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Visualisation

John Wilcock

A description of the display software for Stafford Castle Visitor Centre, UK

1 Introduction

Stafford is a town of chiefly Saxon origins lying in the West Midlands of England. The name implies a landing place and a ford, emphasising that the original site was on an island of gravel almost surrounded by swamp and river. Although there are traces of activity from the Roman period, the first historical mention is as a 'burh' established in AD 913 by Ethelfleda, Lady of Mercia. It became the country and market town of the surrounding countryside, and at the time of the Norman Conquest in 1066 it is recorded as having about 200 households and a royal mint. One major change caused by the advent of King William I was the construction of a castle in the northwest corner of the town. This was the centre of the king's government of the county, but it was short-lived as a fortification, being totally destroyed and covered in modern times by a gas works.

The fortified motte and bailey of Robert de Toeni, on a nearby hill outside the borough in what became known as the district of Castle Church, was more or less contemporary with the royal castle, and it is this site with its Norman, Medieval and 19th Century phases which is today known as Stafford Castle. A huge timber fortress, with banks surmounted by timber stockades and deep dry ditches, had been built there by AD 1100, and excavations have found an extensive civil settlement outside the walls, which may be the village called 'Monetvile' (the settlement on the mountain) in the Domesday Book of 1086. In AD 1348 Earl Ralph reinforced the earthwork castle by a strong stone keep. During the Wars of the Roses the castle saw much activity by successive members of the Stafford family, who by then were Dukes of Buckingham. Edward Stafford, third Duke of Buckingham, was executed for high treason by Henry VIII in 1521, and the castle was forfeited to the Crown, but in 1531 it was restored to Henry Stafford. During the period of civil war between King Charles I and his Parliament 1642-1645 the castle was defended for the King by Isabel, Dowager Lady Stafford, but was captured by the Roundheads and partially demolished in 1643 — it became 'one of the ruins that Cromwell knocked about a bit'. Gothic Revival additions to the fabric in 1811-1812, including two prominent towers, were made by the Jerningham family of Norfolk, who succeeded to the Stafford barony, and the structure could be visited for tea until 1950. Afterwards there were no caretakers on site, and there was extensive damage by vandals, resulting in the death of a child from falling masonry. The site was given to Stafford Borough Council by Lord Stafford in 1961, and much of the crumbling masonry was then demolished. The whole site would have been in danger of being destroyed were it not for the activities of the Friends of Stafford Castle. In 1978 Stafford Borough Council employed an archaeologist, a series of archaeological excavations and reconstructions were undertaken, which were filmed for television, and annual lectures on the progress of the site became very popular. As a result, the site was officially opened to the public in 1988 and is now properly displayed. It has a Visitor Centre, which includes a small museum with models and a timber guardroom reconstruction of AD 1147, an informative trail around the site, and a reconstructed Medieval herb garden. A series of 'Living History' events have included Norman, Medieval, Civil War, and Napoleonic period costumed battles. Stafford is now billed by its publicists as 'the town that found its castle'. Stafford Castle is clearly an interesting archaeological site offering a palimpsest of some of the most important periods in English history, and it is an ideal testbed for hypermedia techniques.

2 General considerations of interactive package design

2.1 Multimedia, Hypertext and Hypermedia

2.1.1 Multimedia

Digital multimedia has developed as a powerful add-on to the personal microcomputer. The Graphical User Interface (GUI), with its Windows, Icons, Mouse and Pull-down menu (WIMP) concepts first appeared on the Apple Macintosh, using ideas which had originally been developed at the Xerox Palo Alto Research Centre. This interactive GUI idea is dominant in the Microsoft Windows 3.1 software which has popularised the integration of images and text in the What-You-See-Is-What-You-Get (WYSIWYG) form of output. Another important contribution of Apple was the Hypercard product, an early form of hypertext (see below). The Commodore Amiga was built primarily as a games machine, but had powerful image and sound capabilities, including concurrent analog (TV) image and digital computer graphics, four channels of digital sound, animation, video production facilities, and an authoring environment.

Interactive Video (IV) was developed in the 1970s (for example LaserVision), and has been used by commercial educators, particularly for the teaching of new software. The technique is to superimpose images from the disks with computer-generated text and graphics, using interactive devices such as the touch screen and the mouse. The disks are capable of holding text, images, music and sounds, speech, video clips and computer programs. The information is scored as small pits into the recording medium by a laser beam, and it can be read as a binary pattern by a low-power laser beam. However, IV has not lived up to its promise because it is expensive and there was no accepted standard in the early days. This lack of a global standard was linked to the incompatibility of USA and European television systems.

The High Sierra agreement (the ISO 9660 Red Book standard, the original definition for the standard audio CD, established in 1980) improved the situation, but this has not proved adequate, since different technologies have emerged to combine sound and video, with different methods of compression. Manufacturers have preferred to plough their own furrow, no doubt hoping that their technology will become the industry standard. Yellow Book is the addition of one layer of error correction, headers and synchronisation on top of Red Book recording, allowing recording of computer data.

A smaller optical disk, the Compact Disk-Digital Audio (CD-DA), became commonplace in the shops during the 1980s for digital recordings of music, and is much cheaper in multiple copies, because of the mass market. These have been adapted for use on computers as the CD-ROM, just as in the early generations of microcomputers the mass market audio tapes were used as a cheap form of backing memory with an adapted tape recorder.

Compact Disk-Video (CD-V) appeared in 1987, using LaserVision and a CD-DA track.

Lock and Dallas (1990) have described the Compact Disc-Interactive (CD-I) technology, to a specification agreed between Philips, Sony and Matsushita (Preston 1988). CD-I readers will also read CD-DA disks, output is compatible with all existing stereo and TV standards, and there is no need for a computer as in IV. Indeed the CD-I reader is a computer with its own Compact Disk-Real Time Operating System (CD-RTOS). Green Book is an extension of Yellow Book to link or synchronise a disk which contains both audio and data, the different data streams being interleaved during a presentation. The host environment is specified as OS/9, for use with CD-I.

CD-R is a Write-Once-Read-Many (WORM) technology which allows individually authored interactive packages to be written to a Gold Disk blank using interleaving. CD-R is not a sector-addressable media, but data must be written in a continuous stream. The computer that writes the data must guarantee to deliver data at a specific rate to the CD recorder. Failure to sustain the rate will lead to an unusable disk. Thus simultaneous video and audio digital data must be interleaved before writing it to the disk. Multisession recording leads to waste of space, since an index must be written on the disk at every session, and old indexes and multiply-recorded frames are then ignored. The Windows .avi extension stands for audio/video interleave. Orange Book is the physical specification for CD-media providing for different media types, including CD-R, which records complete tracks but allows multisession recording, and final conversion is to a Red, Yellow or Green Book disk.

CD-ROM XA (Extended Architecture) is a standard agreed between Philips, Sony and Microsoft which incorporates audio, text and graphics using established CD-I and personal computer standards, enabling multimedia CD-I disks to be produced in an MS-DOS environment. This of course requires the availability of a re-writable CD-ROM.

Digital Video Interactive (DVI), available from 1990, uses a hardware compression technique developed by Intel which stores only the differences between successive frames. It is being developed jointly between Intel and IBM.

Dual Mode, Mixed Mode format is a method of creating cross-platform CD-ROMs, with software for both pc and Mac on the same disk, the other format remaining transparent when used on either platform.

PhotoCD is a specification which allows cameras to record still images on CD.

White Book is the latest format standard for CD-ROMs.

Which of these technologies will succeed in the market is debatable, and the best technique may not be the winner, if previous battles in ciné film, video tapes, and operating systems are anything to go on. This is a re-run of the video tape saga, where there were many formats initially and Betamax, for example, provided a quality of image much superior to that of the eventually accepted industry standard VHS.

Various compression techniques have evolved. A CODEC is a COmpression/DEcompression Component, either a software compression/decompression scheme for video, or firmware on a chip which uses such an algorithm. Fractal compression is video compression using a fractal algorithm. Since fractals are not related to scale, enlargement of the image does not lead to larger blocks as in bitmap expansion, but new detail is created by the fractal algorithm. Frame differencing is a type of temporal compression that stores only differences in successive frames. Indeo is a CODEC marketed by Intel which is lossy (*i.e.* approximating the file, such that when expanded again the original file is not retained) and is optimised for analog video. High compression ratios lead to extreme lossiness where changes of shade, blockiness and artefacts can be produced on expansion. JPEG is the Joint Photographic Experts Group standard for compressing still frames, which is lossy. MPEG is an 8-bit digital method of video compression, involving I-frames (between 1 and 5 of these per second, which can be indexed by time), P-frames (which are predictive), and B-frames (which are bi-directional). Although the CD-ROM recording is linear, designed for TV playback rather than for computers, any I-frame can be accessed direct. MPEG is a 'bridge data format'. MPEG and video-CD may replace the laser vision disk. It requires XA specification, Mode 2, Form 2, and must have intelligence in the drive or on a decoder card. The standard was *not* written for computers, but for mass-market consumer TV, mostly linear, with no interaction. Quicktime is a CODEC marketed by Apple Computer for video compression. Video 1 is a CODEC by Microsoft which is lossy and optimised to analog video.

A set-top box is a box of electronics added to a TV set to enable satellite, cable or the information superhighway to be accessed in the home.

The use of this technology is already exhibiting a high degree of integration with other computing techniques. Authoring languages, digital audio and video production facilities, databases for binary large objects (digitised images and sounds), and database searching using languages such as SQL will all converge in the future.

The very high cost of producing the master disks, and high cost of the computer equipment needed to play the disks, has discouraged many potential users. Even so, many firms have used IV for staff training. In archaeology, interactive video-disks have provided a stimulating new method of providing information in museums, and there have been some examples of cooperative efforts to record archaeological information, such as the 1986 BBC Domesday Disc Set (Gove 1988; Hodgkinson 1993), the Project Emperor-I which has produced two videodisks on the tomb of Qin Shi Huang Di at Xian, which included the famous terracotta warriors and horses (Chen 1987), the Leicester Videodisk (Martlew 1988; 1990a; 1990b), the Perseus Project (1989) and the World of the Vikings Disk (York Archaeological Trust and the National Museum of Denmark).

An early complementary pair of IV disks authored in the UK by the BBC were the Domesday disks (Gove 1988). One of the disks consisted of demographic information on modern Britain compiled by schools for the nine hundredth anniversary of the Domesday Book. This was map-based, and the information was organised in 1 km squares, allowing logical search of statistics and map overlays, measurement of distances and areas, text search and retrieval of still images and text pages. The second disk was organised as a visit to a picture gallery, and allowed the exploration of many areas of contemporary British life and culture, including surrogate walks.

The story of the Leicester Videodisk with its archaeological images has been related by Martlew (1988, 1989, 1990a, 1990b, 1990c). The main subject for this disk was British stone circles, with some material on related sites. The aim was to include at least one picture and a plan of all known stone circles in Britain, in contrast to traditional publications where pictures are expensive to include, consequently few in number, and restricted to the most popular sites such as Stonehenge, Avebury, Callanish and Castlerigg. A notable inclusion is a video sequence of the winter solsticial sunrise at the Newgrange tomb. Only about half of one side of the disk was taken up with the Leicester archive, so space was sold to kindred organisations wishing to take the opportunity of testing out their material on the technology, including the Royal Commission on the Historical Monuments of England, the National Monuments Record of Scotland, and York Archaeological Trust.

Ruggles (1988) developed software for use with the Leicester Archaeology Disk. The Coppergate application from York allows surrogate walks through the excavation, with choice of route being selected interactively using a touch screen. A site map may be accessed to indicate the current position of the user, and the idea of 'digging deeper' is supported by organisation into modern, Medieval, Viking, Anglian and Roman periods.

The McGraw-Hill CD-ROM 'Multimedia Encyclopedia of Mammalian Biology' has some material on prehistoric humans. The Apple 'Shakespeare Disc' has simulations of the Globe, Rose and Swan Theatres.

The 'World of the Vikings Disk' is described by Maytom and Torevell (1993). This is an extension of the Coppergate project at the ARC in York, supplemented by material from Denmark, and organises groups of images into thematic chapters on transport, religion, weapons and warfare, settlement, subsistence, crafts, art, people, leisure, trade, and language and literature (including spoken sequences). Each chapter may have sub-chapters in a hierarchical fashion, e.g., transport is divided into land transport and water transport, while land transport is divided into carts, horses, skates and so on. Further there are regional chapters based on the major areas visited by the Vikings. There are also video sequences of Viking age methodologies performed by modern actors, and 3-D computer-generated animation for some sequences. Information may be accessed by theme, area, time, surrogate walk, and true hypermedia storyline.

The Microsoft 'Ancient Lands' disk (Microsoft 1994) is a very advanced presentation of the civilisations of Rome, Greece and Egypt, with text, graphics, eyewitness accounts, sound, video clips using Indeo (Intel Corporation) video compression technology, spoken commentaries and pronunciations, keyword search, map metaphor, time lines, hotwords, picture gallery, screen savers, overview movie, guides, and timed interactive tests.

In 1995 the National Museum of Antiquities, Leiden, exhibited hypermedia projects on the Goddess Nehalennia, and the Roman Army (Bulk).

2.1.2 Hypertext

'Hyper' means 'beyond' and signifies the existence of some navigational structure. The idea of hypertext was originated by Vannevar Bush (1945), but the term was coined in the 1960s by Ted Nelson (Nelson 1967; 1987). Nelson's concept has far-reaching implications for document storage and retrieval. Hypertext can be thought of as non-sequential text, and the system allows linkage between text documents in any sequence desired by the user, using hot words, reference, note and command buttons, navigation and backtracking. Some of the earliest hypertext software packages available were the OWL GUIDE system, and the Apple Hypercard system; for archaeological uses of Hypercard see Banning (1993), Farah *et al.* (1992), Orton/Grace (1989), Rahtz *et al.* (1989).

2.1.3 Hypermedia

Hypermedia is the extension of the hypertext navigational system to incorporate multimedia, including text, graphics, video and sound. The main problem seems to be the danger of 'getting lost in the hypermedia maze'. Maps, Home Screen with initial menu, other menus, contents lists and indexes are helpful in navigation. However, when users are unfamiliar with the subject matter they need to be prompted where to go, usually by means of a question, or a display of possible courses by means of buttons. Directed routes through the hypermedia network are one solution. Graphical browsers and use of the 'travel metaphor' are also helpful. Page-turning may be found to be tedious and boring by some users. Several authoring languages are now available for the construction of hypermedia links. There are essentially three levels of access which may be used: conventional database search; hypermedia links; and remedial tutorials drawn from the database.

The advantages of hypermedia are:

– It provides a richer learning environment than sequential text, and includes graphics, animation, video, speech and sound.
– Users can pursue their own particular line of interest: the intention is to allow the user to access information in the way that suits him best.
– On-line help manuals are ideally suited to hypermedia — a particular section of a manual, or the meaning of a word, or how to do a particular operation, may be investigated without having to read the whole.
– It readily lends itself to educational applications.
– Simulations or experiments may be run, or video clips viewed.

On the other hand, the chief problem of hypermedia seems to be 'getting lost in the hypermaze'. The feeling generally occurs when the size of the information exceeds 1000 nodes, and happens because the user does not know where he is, or is heading to, or how a desired location may be reached (Thalmann/Thalmann 1991). The following attempts have been made to solve the problem:

– Hierarchical tree: the nodes are organised in a strictly hierarchical tree structure, and it is always possible to exit to the next higher level, or to jump directly to the 'home' page (top-level menu).
– Index constantly on screen, with the current level indicated.
– Progress bar(s) to indicate how much of the package has been successfully completed.
– Use of a graphical browser. The idea of a graphical browser is that it is effectively a map of the nodes and the links between them. This may be possible for a small number of nodes: the user is able to select a node and display its information. But for a large number of nodes it is necessary to have several layers of help, and the user may end up getting lost in the help system which is supposed to prevent him from getting lost. Possible help for indicating the most relevant nodes to visit next may be provided by an updated 'surveillance system' which should have different types of icons to indicate the sort of information which could be accessed from the current node (e.g., graphic or picture gallery, eyewitness account, pronunciation or sound, spoken commentary, video clip, keyword search, map metaphor, time line, overview movie, timed interactive test, etc.).
– Icons constantly on screen, with links to HELP menu (help about the system, rather than the subject matter), NEXT screen (for pre-designated routes), BACK one screen, to current level menu, to superior menu for next higher level, to the HOME page for the top-level menu, SURVEILLANCE icon to survey possible links with the types of information available from them, LEXICON icon (to define a term), SOUND icon (to pronounce a term), EXIT icon (to exit from the package), etc.

- Use of the travel metaphor. The travel metaphor uses the familiar concept of map reading and travel to enable the user to move easily around a mental model of the system. Instead of a map a graphical model of the system, such as a building with rooms, could be presented. Since the information is presented in a more complex structure than the usually sequential method employed in text books, it is possible to miss out essential items of learning by taking routes which avoid them. This can lead to uncertainty in the user's mind because he can never be sure that all the relevant items of data have been accessed (this can be mitigated by the use of completion bars).
- Jump to any node possible.
- History list of previously visited nodes — may be accessed by BACK key, or any node selected from the list.
- Recommended route through the nodes (achieved by having a NEXT button, or a 'guide' — a simulated mentor, often a person from the historical period being described, or a cartoon character, who controls progression through a set of nodes in a logical sequence and gives a sound commentary for the guided tour). However, the use of guides goes against the main principle of hypermedia, which is the free random-access connection between nodes in any user-controlled sequence.
- Maps of local connection of nodes.
- Global map of the entire network of nodes (top level menu).

2.2 Presentation techniques

Some attention must be given to human-computer interaction and especially to interactive devices. The mouse, joystick, tracker ball, light pen, tablet, touch pad and touch screen must be considered as alternatives to the keyboard. The mouse is the most common modern device, and is probably the most familiar to the general public from its widespread use in personal computers, but it is easy to vandalise. Joysticks need more complex movements, tracker balls need additional selection buttons (both hands are needed), and the light pen is quick but causes fatigue. Touch pads and touch screens are fast, suitable for hostile environments and not prone to vandalism, and must be considered the most viable alternative to the mouse for a public environment.

The windows type of GUI must be actively considered. The advantages are:

i) The interface is easy to use, and intuitive, being based on a desk with files, etc. and a menu type of selection.
ii) Once the basic skills have been learnt, such as using the mouse, and icons, there is very little else to learn, and re-learning is not necessary after a period of non-use.
iii) The results of any actions can be seen immediately in a graphic manner.
iv) The user has control.
v) Very complex operations may be achieved with just a few actions.

The disadvantages are:

1. Slow screen updating may occur in complex operations, causing user frustration.
2. The graphics capabilities of the machine must be sufficient for display of complex images in enough detail.
3. A high cognitive strain may be placed on the user when there are several windows open with parallel processes running.
4. A lot of screen space is taken up by the windows system.
5. Windows programming is notoriously difficult, which has led to the appearance of programming aids such as Visual Basic and C++ compiler/windows interface routines.
6. A lot of memory and complex programming is necessary (the 300-line 'Hello, world' program is often quoted).

A windows presentation is, however, ideally suitable to the Visitor Centre type of presentation, provided that the layout is restricted to tiling (all windows present on the screen with no overlapping) or only temporary overlapping occurs, with no user requirement for selection, sizing or dragging of windows.

Graphics, animation and sound can be motivating, but what proves interesting on the first viewing may soon become tedious and boring — options must always be given to skip the special effects. The advantages of such techniques are that children learn without realising that they are doing any work (comments such as 'good fun to play with', or 'interesting' are very common).

Ideally, intelligent filtering of information should be carried out by the system, so that the system decides not only what information to present, but also the level, manner and vocabulary in which the information is to be presented, according to the established user characteristics and ability level (e.g., children will require simpler language and familiar concepts such as 'Today Mummy and Daddy are taking me to the castle' rather than 'We are going to investigate some features of the Norman Conquest of Britain'. Some attention must therefore be paid to the problem of users of widely differing capabilities:

- Naive users may never have touched a computer, especially older people, but these are becoming rarer, and most children will have operated a computer or at least a games console. These users may be accustomed with fast

graphics and animation and will not be content with boring screens of text. Naive users need tutorials in the handling of the computer hardware, e.g., use of the mouse. There may be problems with hand-eye coordination. The mouse is also an easy target for vandalism.
– Novice users have some computer experience, but are unfamiliar with the new system, e.g., the hypermedia. They will eventually become skilled users.
– Skilled users have a great deal of experience with computers, and will require a rapid interface which allows short-cuts.
– Expert users have knowledge of the computer and system structure, as well as the ability to modify it — some of these may even include children or students who might maliciously attempt to corrupt or crash the system, and there must be effective security measures against such people.

Graphics, animation and moving video with sound are useful for showing objects, creating impressions, and attracting attention, but are unable to convey precise ideas. Text, on the other hand, is best for conveying precise information and abstract ideas, but looks dull when used alone. It is clearly best to combine all the multimedia approaches whenever possible. Graphics, animation and moving video with sound are much more interesting than screens of text. Text and associated graphics should be displayed close together on the screen so that the user makes an association between them. Allowing a picture to build up on the screen, or displaying some type of % complete bar, is better than pausing a long time with a blank screen and then displaying the whole picture.

The number of colours used on screen must be kept to a minimum (two or three are suggested by Rivlin *et al.* 1990), good contrasts must be used (e.g., white on blue, yellow on black, black on white) and certain colours must be avoided (e.g. avoid red, which is generally taken to mean danger, and do not use it unless attention is meant to be drawn; and avoid combinations such as red on blue, since the eye cannot focus at both ends of the spectrum at once). If colour coding is used, this must be consistent, for example white on blue could always be used to convey information, yellow on black for specifying a question which has to be answered, or the 'traffic light' convention may be used (red for fatal error, yellow for non-fatal warning, green for normal information) and there should also be a consistent colour for hot words.

An interesting idea is that users should be able to choose which types of items or windows should be placed on the screen, and what their layout should be.

A display program, however well designed, will benefit from the provision of a help system (Dix *et al.* 1993). To cope with the different types of user from naive to expert, a help system is best layered in a hierarchical fashion with efficient menus, so that a naive user can obtain in-depth tutorials, while experts need to access only particular sections. Help on help may be required to guide the naive user. Help should be available at all times, by use of a perpetually available icon or menu. The presentation style and terminology should be consistent throughout. Help windows should not block out too much of the screen, so that help and normal work areas are visible at the same time. Context-sensitive help is also useful, where the position of the mouse cursor on the screen causes some helpful information (on what the window/icon/menu etc. represents or provides) to be supplied on a status bar or in a pop-up window or 'balloon'. Icons represent operations which could take a long text description, and they do this pictorially in a small area of the screen, but their meaning must be obvious — an icon with an obscure meaning only serves to confuse the user. Lodding (1983) suggests that humans find images more natural, and they can be easily learnt and recognised. Manes (1985) takes the opposing view that icons are confusing, wasteful of space, ineffective when dealing with similar commands, and not suited to complex operations. Animated icons have been suggested as a solution, but they are not very common. Ideally, icon meanings should be obvious to new and inexperienced users of the system, otherwise they are just a hindrance and a waste of system resources.

Usability must be addressed in the following regions:

– Predictability: Surprises should not be thrust upon the user — past interaction with the system should have given the user an idea of what to expect from certain features, and this predictability should not in general be violated.
– Consistency: This is also about predictability. Warning messages, use of colours, naming conventions, icon design and screen layout design should all be consistent throughout the presentation.
– Recoverability: Mistakes will be made by even the most experienced user. There must therefore always be some way of undoing the last action, such as quitting a long operation, undoing an editing operation, or just returning to the previous screen by means of a BACK button.
– Responsiveness: Ideally the system should provide a fairly instantaneous response. When the operation is going to take a long time, the user should be informed of progress, e.g., by use of a % complete bar.

There are a number of straightforward measures which can be employed to ensure that the operation is as effective as possible. Putting too much information on a screen causes information overload — research has shown that not more than about 30% of the screen should be filled. Messages must always be noticed by the user — they must therefore not be displayed momentarily but must remain on the screen until the user acknowledges them by pressing some key (the message 'Press any key to continue' may be found useful) or by use of an OK button. Most users will not be expert typists and will tend to look at the keyboard while typing, not at the screen. The locations of buttons of common function should be kept the same on different screens, so as not to confuse the user. A different colour, use of larger text, drawing a box around text, underlining and flashing can all be used to draw attention to an important item. Avoid the presence of a flashing cursor on screen — users do not tend to read anything on the screen which occurs after the cursor position.

2.3 Types of interaction

The following methods are commonly used for human computer interaction in educational packages:

- 'Hot Word': Text highlighted in a different colour, or in a box or underlined, is clicked by the mouse and then provides a navigational link to some other document.
- 'Note Button': A button which when clicked displays a pop-up window with additional information while the mouse button is held down, and disappears when the mouse button is released, returning to the original screen.
- 'Expansion Button': A button which zooms in on more detailed information (called 'unfolding'). This may be to a new screen, but return is always to the original screen.
- 'Reference Button': A button which enters a new screen, and there is no return to the original screen. This is equivalent to a jump.
- 'Command Button': A button which executes a hidden series of user-defined commands in the authoring language, which may perform any desired function, including controlling peripherals such as slide or video projectors, or entering external packages.
- Click area response template: A defined area on the screen must receive a click from the mouse.
- Drag one or more answers to correct/incorrect boxes: Correct and incorrect answers must be dragged and dropped by the mouse into boxes on the screen labelled CORRECT and INCORRECT (drag all answers is the extreme form of this).
- Drag one answer to box template: Only the one answer which is correct, of several possible answers, is selected.
- Multiple choice template: One or more answers may be selected.
- Pull-down menu template: One item is selected from a pull-down menu.
- Push button response template: A button is pressed.
- Text response template: A free-format text answer is supplied.
- Timed response: This method is frequently used in an educational interactive test or 'game' format where the user must supply all the correct answers within a given time limit, and finally receives a score. This is often accompanied by a ticking clock counting down to zero.

It is desirable that a mixture of these methods is used to provide variety of response, to keep the user interested.

3 Implementation of the pilot project

The project has been undertaken for the Archaeology Section of Stafford Borough Council, for use at its Visitor Centre at Stafford Castle. The project aim was to provide a simple interactive facility for the interrogation of multi-media files of text and images, for general public use. The package had to be used by visitors who could not be assumed to have any computer familiarity, and therefore extensive help facilities had to be included on the use of the computer, such as manipulation of the mouse. After undertaking the initial research, which is described above, into CAL, multimedia, hypermedia, HCI, graphics formats, animation, GUIs and authoring packages, the pilot package was written in C++. This has given good support for modular design, and it has proved relatively easy to create a GUI interface. The system has a background 'slide show' of castle images. When a visitor approaches and touches the mouse, however, a simple mouse tutor is entered, followed by the main viewer for the system, which has text, graphics, map and button areas. The system has purposely been kept as basic as possible. This pilot system is run from the hard disk under DOS.

3.1 The viewer

The main viewer for the pilot system consists of tiled windows for a still graphics picture, some text, and a map, plus a collection of buttons. The system uses the 'travel metaphor' to guide the visitor around a simulated tour of the castle site. Once a location is selected using the mouse, a picture relating to that location is displayed, accompanied by a passage of text. The buttons allow access to more in-depth information, and also provide direct links to associated areas of the castle.

Three types of buttons have been implemented:

- Note Button, which provides a pop-up window with additional information. This pop-up window is retained on screen as long as the mouse button is pressed, and then disappears when it is released.
- Expansion Button, which goes to another screen of information. The return from the second screen is to the original screen which called the expansion button

diversion, and this return is activated by pressing the BACK button on the second screen.
– Reference Button, which goes to another screen of information *without using the map*, but does not return to the original screen. This is equivalent to a jump.

3.2 The editor

A simple editor has been added for use by an archaeologist system administrator who has little computing experience, so that additional material may be added from time to time, as new excavation records and knowledge about the site become available. The editor allows the addition of pictures or text, and also allows the editing of the button functions attached to each screen. Areas of the castle map may also be activated or deactivated. Text may be prepared by using a word processor, while pictures may be scanned from photographs or printed material, or generated from scratch using a draw or paint package.

4 Developments

The pilot package was found to give adequate, if basic, performance. It was then decided to investigate the implementation of such a system without any coding, by use of available authoring systems, which organise assets (text, still graphics, video, audio) into a hypermedia package on hard disk or CD-ROM. Of course many such systems are available, for example:

– Apple/Claris Hypercard, an early text/graphics hypertext implementation.
– Video for Windows, a multimedia architecture and application suite launched by Microsoft in 1991. It includes audio, video and animation, and allows the pc to work as a multimedia authoring station using CODECs.
– Microsoft Visual Basic, which allows interactive features (buttons, dialog boxes) to be constructed under Windows 3.1.
– Media Maker.
– Macromedia Director.
– OWL Guide.
– Authorware Professional.
– Asymetrix Multimedia Toolbook, a tool for the creation of multimedia packages, using clips, graphics, animation, digital video, rich text format, hot words, Trutype fonts and databases.
– Adobe Photoshop, a package for the clipping and photomontage of images, such as those captured by still camera on Gold Disk using photoCD.
– Adobe Premiere, a package which allows premiere playback of videos constructed from text, still graphics, video and audio assets.

Any of these packages are capable of generating interactive hypermedia systems to varying degrees of complexity. Some (e.g., Hypercard) manipulate simple cards containing text and graphics. Others facilitate the implementation of a large number of button types, screen effects, animations, video sequences and sound.

Multimedia Windows 3.1 has access to CD-ROMs (using a driver to handle the CD-ROM effectively as a hard disk), facilities to play Musical Instrument Digital Interface (MIDI) files to a Sound Blaster board, and .wav files activated via Windows events. Then there is Microsoft Excel, part of the Microsoft Office suite of integrated software, which is predominantly a spreadsheet but which unusually is also capable of embodying hypermedia concepts with text, graphics, buttons, pop-up windows, etc. Excel allows the use of buttons, text boxes, information boxes, dialog boxes, charts, etc. which may be incorporated using the Macro Language or Visual Basic, and cell boundaries may be removed. These tricks make the user hardly realise that this is a spreadsheet package. Text appears in text boxes or information boxes. Graphics may be imported from a wide range of draw/paint packages by cutting and pasting via the clipboard. The effect of screens may be obtained by scrolling the spreadsheet. Even sounds may be generated via the Windows 3.1 .wav files.

Thus a second implementation of a Stafford Castle package was implemented using the spreadsheet MS Excel running under Windows 3.1, and this involved a minimum of actual coding.

5 Future considerations

The current packages having been prototyped and demonstrated on the currently-affordable and available hardware, considerations have been given to the future development of an advanced system:

5.1 Solid Modelling

Solid modelling to reconstruct archaeological monuments has been employed by many workers. Sites which have been so reconstructed include the bath building at Caerleon Roman fort in South Wales (the work of Woodwark/Zhang, reported by Smith 1985), the Saxon minster at Winchester (Colley/Todd 1985), Roman Bath (Lavender *et al.* 1990; Woodwark/Bowyer 1986), Japanese castles and palaces (Morimoto/Motonaka 1993; Ozawa 1986; 1993), Sutton Hoo (Reilly/Richards 1988), the unfinished pyramid at Abusir (Eisler *et al.* 1988), Mathrafal (Arnold *et al.* 1989), the Stabian Baths at Pompeii (Moscati 1989), Kirkstall Abbey (Dew *et al.* 1990), Furness Abbey (Delooze/Wood 1991), and a Hoffmann limekiln at Langcliffe near Settle, North Yorkshire (Chapman 1992). The initial work on the Bath project by Woodwark and Bowyer (1986) was commissioned to supply computer graphics for a television programme called ‘Bath waters: under the Pumproom’ shown as part of the 'Chronicle' series on BBC television. The view of the temple from the precinct was particularly dramatic, and gave an increased awareness of the site to the archaeologists. The later work by Lavender *et al*. enabled the roofing system for the East Baths to be worked out. The Pompeii project allowed the user to progress from plans to scanned photographs and hypertext panels. The Furness Abbey project allowed the user to 'get inside and walk around' the buildings. There have been several similar projects mounted, notably for Fishbourne, Cluny, the Acropolis at Athens, the 'Orion theory' simulation at Gizeh, Karnak, and the Dresden Frauenkirche.

It is unlikely that sufficient hardware resources would become available for real-time generation of solid models at the average Visitor Centre. Projection of a video generated from a series of computer graphics frames is cheap, but the generation of the original is hardly economic. Disadvantages of these approaches are that the archaeologist rarely has control, the software is seldom published, computer graphics is not subject to the same peer review as a paper, and the reconstruction, while popular with the general public, tends to be taken as gospel when in reality it is conjectural.

5.2 Virtual Reality

Virtual Reality involves interaction between the user and the computer generating the graphics. Simple systems (non-immersive) view 'through the window' of the computer screen, but advanced systems use a very expensive head-mounted display/headset to immerse the user within the graphics by stereoscopic vision. A simple headset was first designed by Ivan Sutherland in 1966, but the first immersive headset was built by Michael McGreevey in 1984 using small LCD television screens, and more modern helmets have used fibre optics. 3-D navigation devices are required such as the wand, 3-D mouse, space and force balls with tactile and force feedback, hand grip with multiple finger buttons, data glove or body suit. There is a need for a 3-D sound capability, and in the future there will be voice input. Motion tracking can be achieved by electromagnetic, ultrasonic, infrared, laser or gyroscopic means. For realistic graphics texture mapping is used, where a small piece of a real surface is digitised, then this pattern is extended and moulded onto the required surface. Examples of Virtual Reality applications which have been demonstrated in archaeology in the early 1990s are 'The Virtual Globe Theatre' (MacRae, Sun Microsystems), 'The Abbey of Cluny' (Queau, Institut National de l'Audovisuel), the 'City of Giotto' (entering a view of medieval Assisi derived from Giotto's frescos in the Basilica of St Francis) presented by ENEL. In 1995 there have appeared non-immersive virtual navigations in the archaeological landscape of Entella, Palermo, Italy and an Etruscan building using 3-D headset, data glove, and ultrasound tracking system with six degrees of freedom (Forte/Guidazzoli this volume); a system for stitching a series of still images of an artefact into a 3-D revolving image using Quicktime, an object-oriented database, compact disk and the World Wide Web (Lucy/Boast); virtual reality of the Adobe Pueblo site at Homol'ovi using Macromind Director for a touch-sensitive visitor centre display (Gann); virtual reconstruction of the Lascaux cave, with cave painting images moulded onto a wire frame of the cave (Britton); and virtual navigation around a Roman temple site near the River Meuse, using 3-D Studio and interpolation between images to create an impressive film sequence (Otte).

Virtual reality is unlikely to be affordable for the average Visitor Centre in the immersive mode. However, in the non-immersive mode it has some possibilities for simulation of reconstructions and animations in a manner which is familiar to children from video games. A typical use might be viewing 'through the window' into an environment where the animated user reacts by collision with objects, or pictures in a gallery, which then activate audio-visual presentations.

5.3 Case studies of archaeological examples

The following are examples of previous work for information points at archaeological sites, museums and heritage centres; and CD-ROMs developed for home use containing encyclopedias of text, data, images, sounds, video and film sequences, and computer programs:

- Hastings Museum, where a speaking exhibit was developed in connection with the nine hundredth anniversary of the Domesday Book.
- The Commission of the European Communities has produced a report (1988) which states that videodisks are in common use for archive purposes in several museums, and videodisks are being used in a number of projects to record standing buildings, works of art or cultural heritage artefacts.
- The SIRIS Project (1989) has used multimedia GIS using INFORMIX under X-Windows, for text, maps and images of historical settlements in the region of Emilia-Romagna, Italy.
- Italy: Surrogate walks through medieval Genoa (Commission of the European Communities 1988: 244).
- France: several examples of applications of videodisks to stained glass windows, mosaics and the collections of the Louvre.
- Denmark: applications in the National Museum in Copenhagen, overlaying the distribution of prehistoric sites on maps.

- 'The meaning of Stonehenge' (Addyman 1989) is a planned multimedia presentation using models, sound, film and video for the Stonehenge Visitor Centre. This will present the complex constructional sequence of Stonehenge, the legends associated with it, and the relationship of the monument to surrounding sites.
- Interactive gallery displays have been discussed by Moffett (1990) in connection with the public face of museums. Children are now familiar with keyboards, touch screens and mice, and the computerised display is becoming an expected feature of a museum gallery. They will be used not to replace the artefacts, but to complement them, replacing long and detailed captions, and providing background information in a more accessible form. The development of robot guides may not be completely fanciful.
- Avebury megalithic monument (Hall/Rahtz 1990), software for an interactive tour of the stones.
- The Archaeological Resource Centre (ARC) in York uses IV to explain archaeological methodology (Maytom/Torevell 1990). Visitors are able to use a finds recording database, a computer-aided design system, and interactive video using a collection of slides from the Coppergate excavation which had been placed on the Leicester Archaeology Disk.
- The Sacred Way project from Athens to Eleusis uses CD-I to document material about the Sacred Way, including archaeological method and theory; Classical Greek archaeology, history and society; and to perform a surrogate animated walk through the site of Eleusis reconstructed by computer graphics (Cornforth *et al.* 1992; Lock/Dallas 1990). This will allow true hypermedia navigation, allowing the walk to be interrupted for information about Greek civilisation, and simulated time travel.
- The Consorzio Neapolis exhibition of selected artefacts from Pompeii, which visited London in 1992, employed computerised presentation of archaeological information.

5.4 Are the techniques successful?

There is no doubt that the use of interactive multimedia, hypertext, hypermedia and virtual reality is more exciting than conventional captions, as is shown by the enthusiasm of children for the techniques. However, the equipment is still too expensive for routine use, and it must be proved that more can be learnt by the techniques than from normal text. Animation, film, video clips and sound of course provide additional dimensions.

6 Conclusions

It is concluded that the modern visitor to an archaeological site or museum expects more than dull text captions, and the use of computer-driven audio-visual presentations is now a required feature. The term 'multimedia' will disappear as quickly as it has arrived, since the techniques will become commonplace in the next generation of personal computers, and archaeologists must use them if they are to move with the times.

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Pictorial, Three-dimensional Acquisition of Archaeological Finds as Basis for an Automatic Classification

1 Introduction

A large number of sherds of archaeological pottery is found at excavation sites. These sherds are photographed, measured, drawn and catalogued. Up to now, all this has been done by hand, and means a lot of routine work for the archaeologist.

The aim of our project is to construct an acquisition system for archaeological finds that forms the basis for a subsequent automatic classification. Therefore we are constructing a system (prototype), that carries out an automated 3-D object acquisition with respect to the archaeological requirements. With the help of this system and the knowledge of an expert, an automated classification of archaeological finds should be achieved.

Whereas the results of the conventional acquisition by different archaeologists may differ, this system should serve the archaeologist as a powerful tool to reduce the amount of routine work and to get an objective, reproducible acquisition of the material. Figure 1 shows the drawing of a sherd found at the excavation site Petronell near Vienna. It was first measured with the help of a profile 'comb' to get the contour line (fig. 1a) and then a top view of the sherd was drawn (fig. 1b). Approximately 1½ hours were necessary to complete this drawing. The processes described above can be carried out by computerized methods in both a faster and a more accurate way. The process of drawing and archiving a sherd can be automated by computing the cross section from the three-dimensional model of the sherd and the topview with the help of the pictorial information of the surface of the sherd and the surface model.

In this paper an acquisition system is proposed consisting of a combination of the *shape from stereo method* (Menard 1991b) and the *shape from structured light method* (Sablatnig 1991) that could help the archaeologist in his work and automate the archivation process. First we present an overview of existing methods for archaeological image acquisition methods. These systems are half-automated, so the amount of work has not really been reduced. Next we focus on the two acquisition methods to minimize failures in the output, providing a 3-D surface representation of a sherd.

The results of the two methods are compared with each other and the fusion of these methods for an archaeological application is shown. Finally, the outlook is given for a

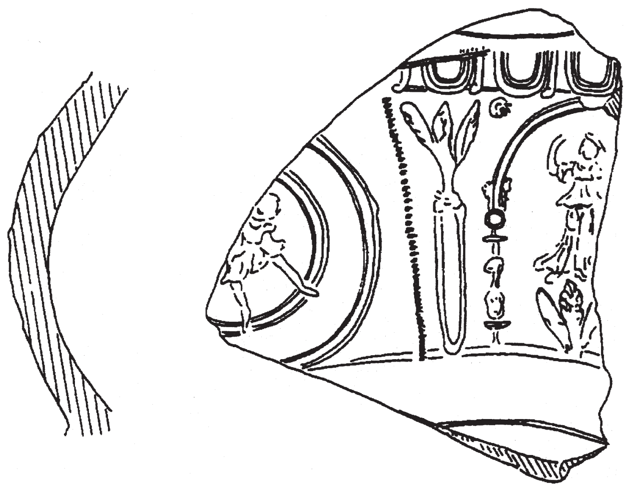

Figure 1. Sherd drawn by hand.

computer based automatic classification of archaeological finds. At the current stage of the project it is not possible to show final results, but we will test the new acquisition method with provincial Roman material from Austrian excavation sites and ceramic material from Velia in the future. In order to compare the new method with the traditional archaeological method, the material is tested and documented with both methods.

2 State of the art

Because conventional methods for pictorial acquisition are unsatisfactory, the search for possible automatic solutions began early. We show two systems, ARCOS and SAMOS, which are representative for many other methods of getting pictorial and 3-D information from a sherd, because the stage of development of these two systems is comparable to our system. Further tests in the field of macrophotogrammetry are discussed.

2.1 ARCOS (Kampffmayer/Karlsruhe)

ARCOS, the *AR*chaeological *CO*mputer *S*ystem, was developed in Karlsruhe and combines video- and computer-

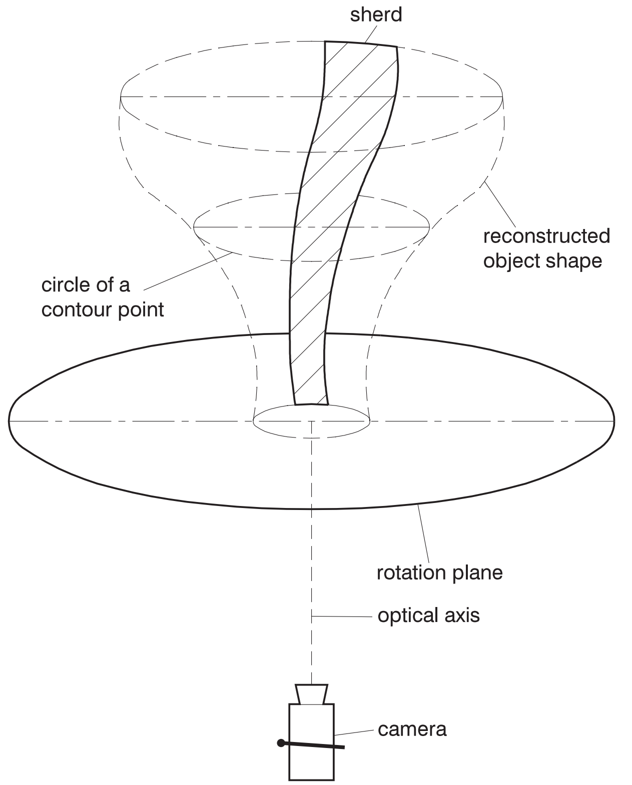

Figure 2. Acquisition system ARCOS.

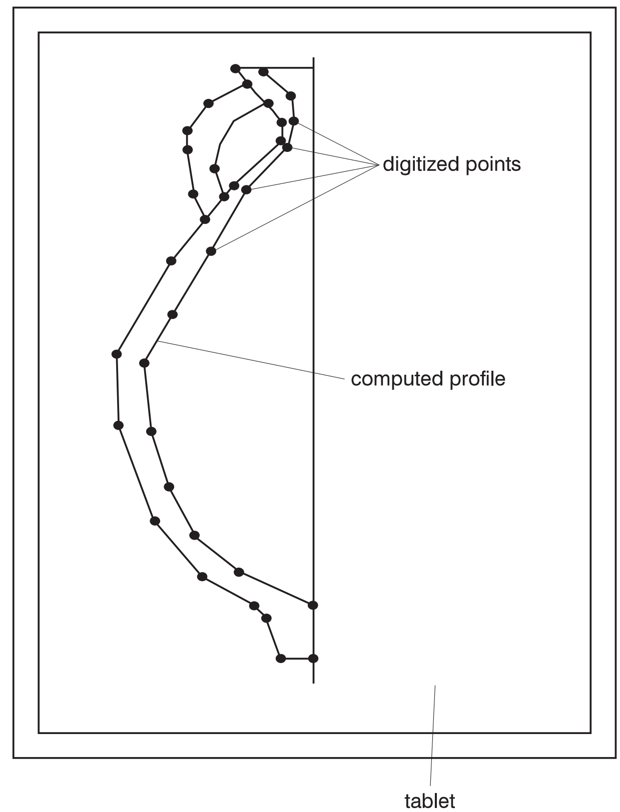

Figure 3. Tablet data acquisition: SAMOS.

techniques for the evaluation, analysis, and storage of archaeological data (Gathmann *et al.* 1984; Kampffmeyer 1985; Kampffmeyer/Teegen 1986; Kampffmeyer *et al.* 1986). Ceramic sherds are placed on a rotation plate, recorded by a video camera, then interactively processed and measured, and finally drawn automatically. In figure 2 the acquisition process is shown schematically: Ceramic sherds were oriented on a rotation plate according to their original position in the pot. The intensity images were taken with the help of one CCD-camera. The program extracts the contour of the sherd from the intensity image. The archaeologist can select the best cross section from several image acquisitions. Therefore, the reconstruction of the shape of a pot is based on the exact positioning of a sherd on the plate with the help of plasticine. The rotation of the sherd determined the shape of the original pot. Small inaccuracies in the positioning could therefore cause enormous mistakes in the reconstructed pot. Textures on the sherd were not recorded and had to be added manually. The archivated drawing was printed on a matrix printer creating steps in the contour line.

ARCOS was tested in June 1987 at an excavation site in Velia, southern Italy, where the following problems occurred: the parameters for the description of the ceramic were numerically coded, so that the possibility of making mistakes were rather high (Kampffmeyer *et al.* 1988; Luebbert/Kampffmeyer 1989). The program is installed in the computer as a chip and cannot be adjusted to suit the requirements of individual excavation sites. The necessity to add contour lines manually (the inner profile cannot be seen by the camera) on the monitor leads to inaccuracy and depends on the work method of the archaeologist (Sablatnig *et al.* 1993). Moreover, the resolution of the system was too low, so that very small cracks in the profile were not detected. Another considerable problem was the computation of the thickness of a pot, because small differences in the illumination cause great differences in the results (Krinzinger *et al.* 1990). Textures on the sherd were not recorded and had to be added manually. The development of ARCOS was stopped, because of the bad results of the prototype and the work for archaeologists not really having been reduced.

2.2 Samos (Steckner/Hamburg)

The second system is called SAMOS (*S*tatistical *A*nalysis of *M*athematical *O*bject *S*tructures). It provides the automatic drawing and reconstruction of profiles from pottery (Steckner 1988, 1989; Steckner/Steckner 1987, 1988). In order to get a contour line of a sherd or pot, this contour line is digitized with the help of a tablet by determining several points on this line (fig. 3). The missing points are interpolated by the computer-system. Although the accuracy of a tablet is very high, errors occur from inaccurate positioning of the pen and from interpolation. A small number of measure points may cause edges in the contour line (Menard/ Sablatnig 1991). After the half-automated input of the contour, several measurements — like volume, width, maximal perimeter etc. — are computed. These relevant measurements are computed automatically from the digitized profile. Reconstructions of pots from sherds are made by comparing the actual contour line with the contour lines already existing in the system. The most similar is taken for the complete reconstruction and classification. This system is also not able to record the texture of sherds, so it needs to be drawn separately or described.

Both systems are not able to record plastic decor or paintings on sherds, so it will be necessary to draw such details separately or to describe them.

2.3 Photogrammetry for archaeological finds

Tests concerning the recording and measuring of archaeological finds were also performed in the field of photogrammetry (Gruber/Schindler-Kaudela 1986; Kandler *et al*. 1985; Kladensky 1981; Waldhaeusl/Kraus 1985). These tests deal with the documentation of stamps in bricks and ceramics. The object is recorded photogrammetrically with the help of a camera and measured with an analytical stereo measurement system. With such a system the accuracy of the measurement of stamps on a brick can be increased, but the complete model of the object cannot be computed (fig. 4). The measurement process is not automated and the archaeologist is not able to make the image acquisition without knowledge about the configuration and illumination parameters. Moreover, a special stereo evaluation system will have to be provided. The evaluation on such a stereo system can only be made by a specialist and does not reduce the amount of work. The evaluation method could be simplified by methods of digital photogrammetry (softcopy photogrammetry). For this method it is necessary to scan the photos on a scanner. The two digital stereo images can be used as input for a digital stereo evaluation system. The development of these systems are not finished, yet costs computation time and requires an operator (Albertz *et al*. 1991; Leberl 1991a, 1991b).

It can be said that methods of digital photogrammetry for archaeological finds can only be used if a system can be constructed for the archaeologist, that reduces his work and

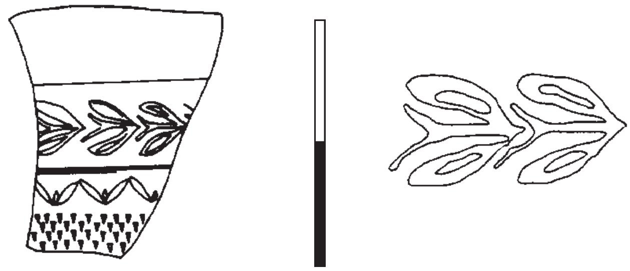

Figure 4. Result of a photogrammetrical measurement (Gruber *et al*. 1986).

does not require additional technical expense for archiving and evaluating the ceramic pieces. The acquisition process should be automated so that the archaeologist needs no knowledge of the measurement area, system parameters or digitizing photos. The expense of the acquisition procedure should only be the positioning of the sherd in the measurement area and the input of archaeological data. The system should be able to compute and display the object model on the monitor to see if the acquisition was successful. Direct control is very important at excavation sites, as it is not allowed to take the finds home. Analysis of the sherds (e.g., cross-section) can be done later.

2.4 Monocular acquisition systems for archaeological finds

In contrast to stereo methods, monocular methods work with only one camera and try to get the 3-D information with the help of a priori knowledge, such as illumination direction and surface texture. This class of algorithms is called ‘Shape from X’, where X stands for the type of evaluation. Two representatives are ‘Shape from Shading’ and ‘Shape from Texture’.

Shape from shading tries to compute depth out of the grey level variations of an intensity image if the position of the light source is known (Bichsel/ Pentland 1992; Horn 1990; Oliensis 1991; Pentland 1990; Woodham 1972). Shape from texture uses the surface texture of an object to compute the model (Ikeuchi 1984; Kender 1979; Ohta *et al*. 1981). The orientation and the distance surface elements can be computed with the help of the texture gradient. This texture gradient describes the modification of the density and the size of texture elements and so the surface orientation can be determined. From the distortion of the texture the angle to the image plane can be computed. If the texture is not distorted the image and object plane are parallel. None of these methods was used for the pictorial acquisition of archaeological sherds. Monocular acquisition methods have the disadvantage that a priori knowledge about surface and illumination is necessary.

3 Acquisition method

With the help of image processing methods it will be possible to make an automated acquisition of archaeological sherds. In order to get the 3-D information of a sherd, we tested two different representative methods, in particular shape from stereo (Cochran/Medioni 1992; Grimson 1981; Hoff/Ahuja 1989) and shape from structured light (Ishii/Nagata 1976; Jarvis 1983; Lin *et al.* 1989; Wust/Capson 1991).

3.1 Shape from stereo

The stereo analysis method is similar to the human visual system. Because of the way our eyes are positioned and controlled, our brains usually receive similar images of a scene taken from nearby points of the same horizontal level. Therefore the relative position of the images of an object will differ in the two eyes. Our brains are capable of measuring this disparity and thus estimating the depth (Marr/Poggio 1979). Stereo analysis tries to imitate this principle. Figure 5 shows the experimental configuration of the stereo system. The sherd to be recorded is placed in the measurement area. Two fixed CCD cameras are used to get intensity images from two different positions. The orientation parameters of the stereo configuration are given as follows:

$$B{=}65 \text{ mm},\ d{=}520 \text{ mm},\ f{=}16 \text{ mm},\ res{=}512 \times 480 \text{ Pixel}$$

where B is the distance between the two cameras, d the distance between object- and image plane, f is the focus of the lenses and *res* is the resolution of the CCD cameras. From these parameters an accuracy of 1.6 mm can be determined.

Consider the case of a single point in the scene. If this point can be located in both images its three-dimensional world coordinates may be computed, if the relative orientation between the cameras is known. The difference between one single point in the two images is called *disparity* between the two images, which is a function of depth and geometrical relationships between the imaging devices. By locating corresponding positions in two images a stereo system can recover the geometrical relationships and depth (Barnard/Thompson 1980; Eastman/Waxman 1987).

The search for the correct match of a point is called *correspondence problem* (Jenkin *et al.* 1991), the central and most difficult part of the stereo problem. Several algorithms were published to compute the disparity between images, such as the correlation method (Luo/Maitre 1990; Subrahmonia *et al.* 1990) the correspondence method (Grimson 1985) or the phase difference method (Jenkin *et al.* 1991). Our first attempt to solve the correspondence problem was to use the area-based stereo technique using image pyramids. This method finds corresponding points on the basis of the similarity of the corresponding areas in left and right images. The process consists of extracting feature points in the left image with the help of the *Horizontal Gradient Operator* (Shirai 1987) and finding the corresponding points in the other image. Given a feature point in the left image, the corresponding point is computed on the basis of the similarity of the neighbouring regions. In order to determine the similarity, we used the correlation of light intensity between the left and the right windows. The correlation $\boldsymbol{C}$ is defined as:

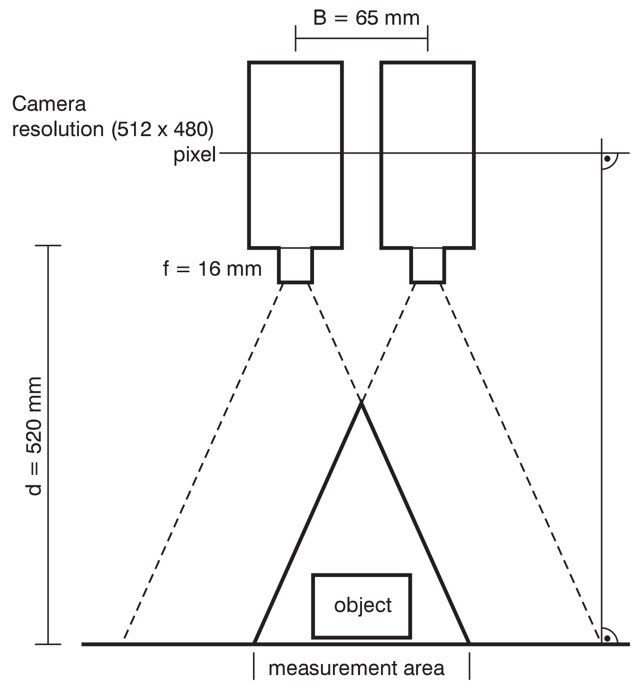

Figure 5. Configuration of the stereo system.

$$C = \frac{\sigma_{LR}^2}{\sqrt{\sigma_L^2 \sigma_R^2}}$$

where σ_L^2 and σ_R^2 represent the variance of the light intensity in the left and right windows and σ_{LR}^2 is the covariance of the light intensity.

To find the corresponding point in the right image for a given feature point in the left image, the correlation for all candidate points must be computed. The maximum of the computed correlation function is supposed to be the corresponding point. Figure 6 shows the principle of this algorithm. The image at the top shows the feature image of the sherd containing vertical edges, because the disparity can only be computed from these edges. The two images at the bottom are the stereo intensity images of the sherd. The horizontal dotted line is the epipolar line on which the

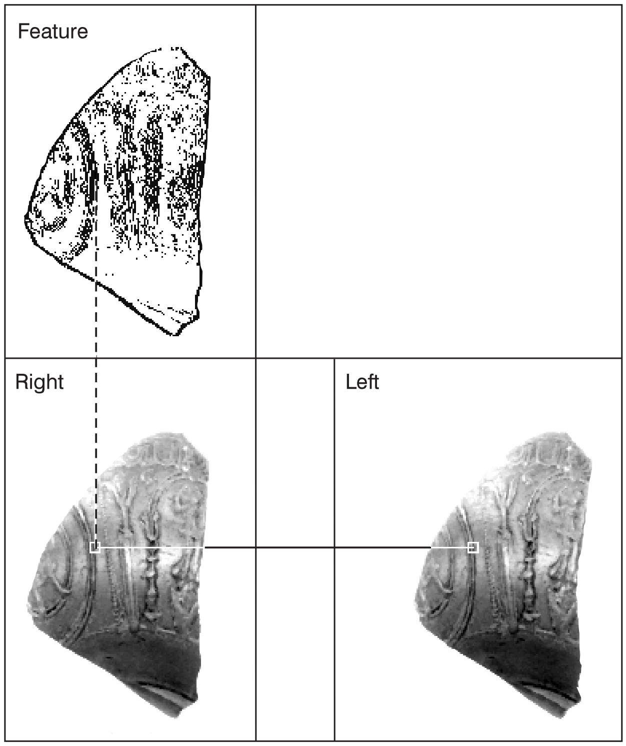

Figure 6. Principle of area-based stereo algorithm.

correlation function is computed. The maximum of this function defines the corresponding point. The depth information of the surface points of the sherd is only computed for the extracted feature points, thus the disparity map has large regions without information, especially in homogeneous regions of the intensity image. Image pyramids are used to fill these gaps in the disparity map. First the 5×5/4 Gaussian image pyramids (Haralick/Shapiro 1991; Kropatsch 1991) for the left and right intensity images are generated. Then the feature extraction is applied to each level of the left pyramid. These three pyramids are the new input for the stereo algorithm. It starts at the top level of the pyramids and uses the gained information as input for the pyramid level below. With this principle an average disparity can be determined for homogeneous regions in the stereo intensity images. Figure 7 shows the surface representation of the computed disparity map.

3.2 Shape from structured light

The second acquisition method for estimating the 3-D shape of a sherd is shape from structured light. A predefined light pattern is projected onto the surface of the object and then observed with a camera. The range information is computed from the distortions of the light pattern seen from the camera. Instead of a light pattern in our configuration, we

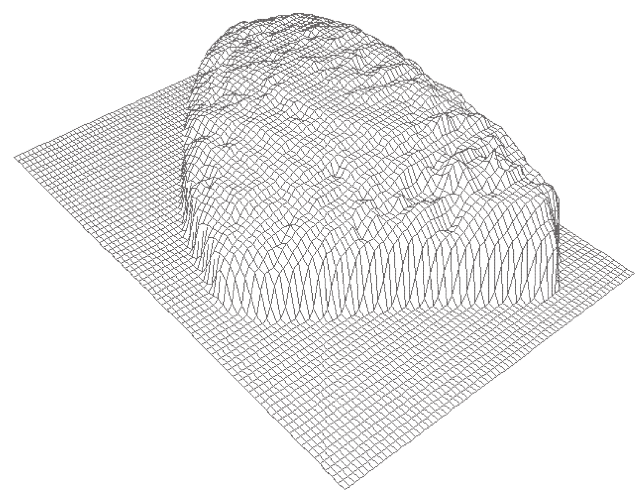

Figure 7. Surface representation of the disparity map.

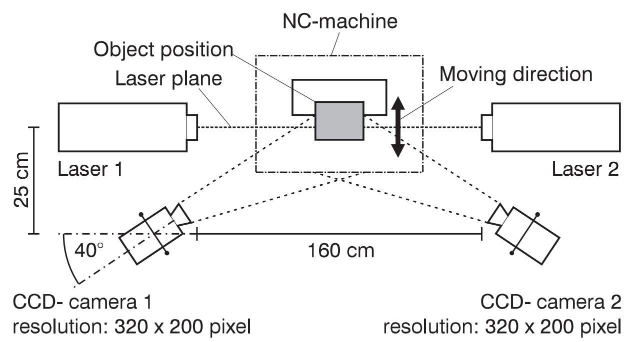

Figure 8. Structured-light acquisition principle.

used one laser light strip, projected onto the object. This light strip is recorded by a CCD camera. The image from the camera consists of a profile line that has the information about the position of the surface points observed, if the illumination and scene geometry is known (Kramer *et al*. 1990). With the help of the distance between the line observed and the calibrated line one can determine the position of the surface points in the 3-D space.

Two lasers and two CCD cameras were used in our test configuration. Figure 8 shows the configuration of the acquisition system with the orientation parameters. From these parameters a theoretical accuracy of 0.6 mm can be determined. This theoretical accuracy was confirmed with a calibration object. The two lasers are positioned in order to produce one lightplane. This lightplane intersects the sherd and the resulting light strip is observed by the two CCD cameras. In order to get the complete 3-D surface of the object, a NC machine is used to transport the object through

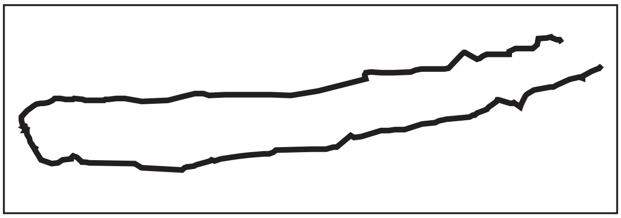

Figure 9. Cross section through the sherd.

the measurement region. The results are serial cross sections through the sherd. Figure 9 shows one of these profile sections. With the help of these serial cross sections, a 3-D model of the sherd can be generated. One way to construct this model is to stack up this serial cross section and to colour each cross section with different lightness. To get a real 3-D model of the sherd we used triangular surface patches (Lin *et al*. 1989; Shirai 1987). Figure 10a shows serial stacked up cross sections and figure 10b the model interpolated with triangular surface patches.

4 Combination of the two acquisition methods

The results of the two acquisition methods were not sufficient for archaeological requirements, because each of the methods presented has disadvantages (Menard/Sablatnig 1992). On the one hand it is necessary to get an accuracy of 0.5 mm especially in regions with textures and ornaments, on the other hand the pictorial acquisition is extremely important for archiving (fig. 1). The results of the stereo method are not accurate enough, because regions without texture are only approximated but the pictorial acquisition is available in high quality. The structured light method fulfils the accuracy requirement but there is no way to get the pictorial information (Sablatnig/Menard 1992). Furthermore reflections on the surface of the sherd caused by the laser can change the results of depth.

In order to reduce the disadvantages a combination (fusion) of the two presented acquisition methods is used. A fusion of two different data sources reduces the error probability dramatically (Wei 1989) because the result is computed from two data points for one object point. Furthermore the pictorial acquisition of the visual surface of the sherd is possible in true colour. The accuracy of the individual results of the two acquisition methods is improved through interdependencies of the two computation algorithms, the stereo method influences the structured light computation and vice versa. Pictorial information changes, for instance, the grid density because only areas of archaeological interest on the surface of the sherd, such as reliefs, are computed with high resolution in depth, whereas areas with low interest, like uniform areas with no texture, are computed with lower resolution. Textured areas are also computed by the stereo algorithm, thereby increasing the accuracy and reliability of the computed data.

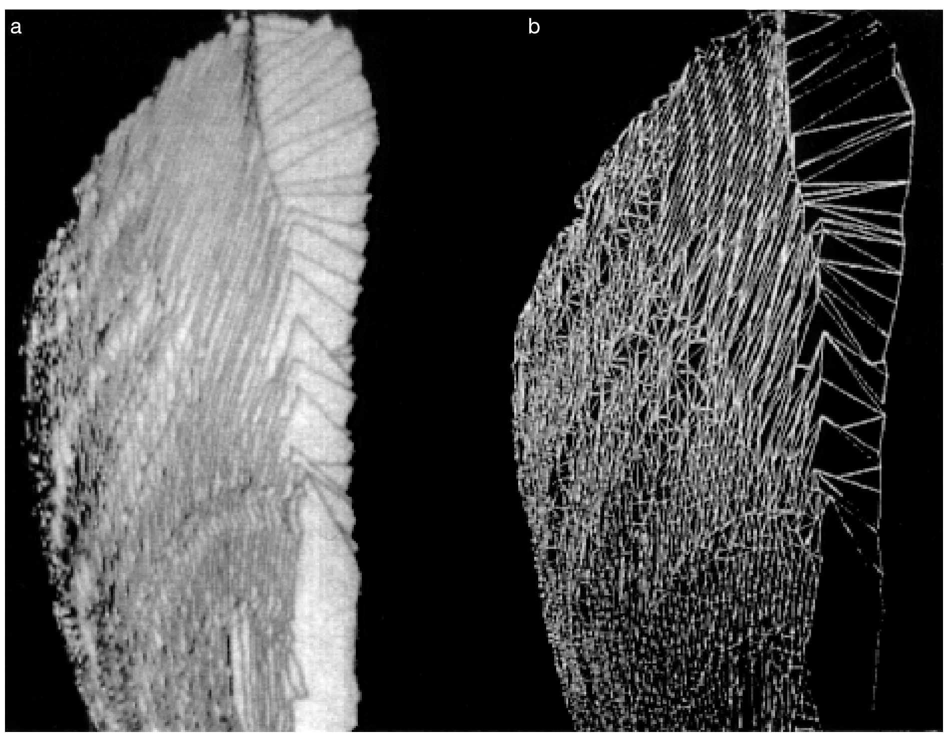

Figure 10. a. Cross sections.
b.Triangular surface patches.

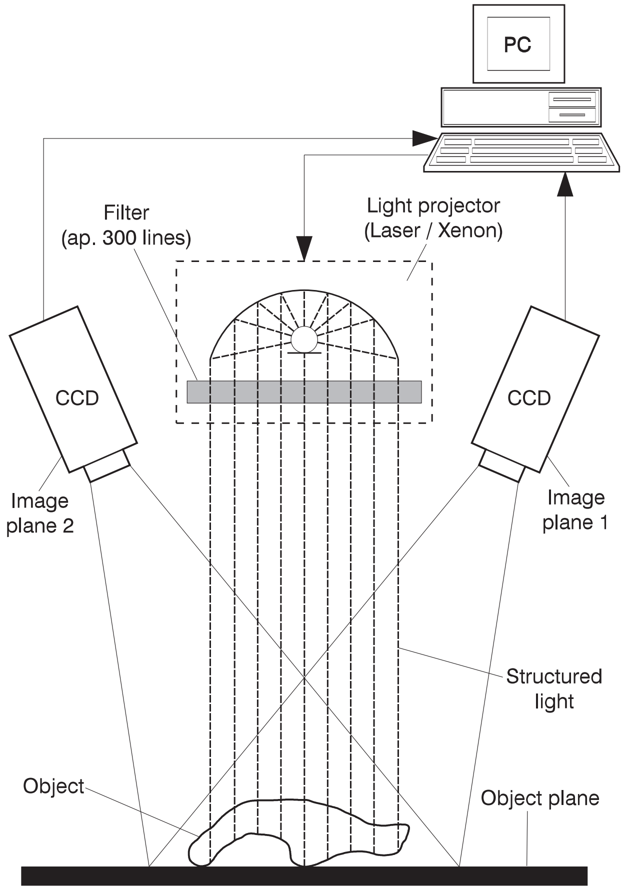

Figure 11. Fusion of stereo and structured light.

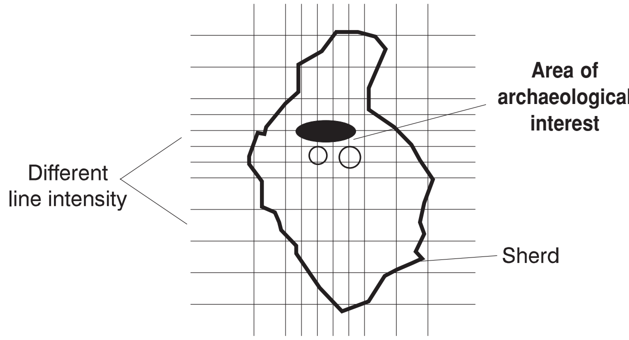

Figure 12. Influence of stereo.

In order to construct a robust and accurate acquisition system for the archaeologist that provides pictorial and 3-D acquisition, the system has to be portable to be usable in the field and should therefore be small and not too heavy.

4.1 Data acquisition

A possible system for the fusion of the stereo and structured light methods is shown in figure 11. The two CCD cameras are used by both acquisition methods.
In order to get parallel light strips onto the surface of the sherd, a special light projector is used which is able to project 600 horizontal and vertical lines onto a 30 cm × 30 cm measurement area. Therefore the resolution of the lightstrip method is 0.5 mm in x- and y-direction. With the help of these lightstrips no transportation through the measurement area is needed. First, the light projector illuminates the measurement area without lightstrips in order to get two intensity images. These two images are used to locate the object in the measurement area and to determine where areas of archaeological interest (reliefs, paintings, lines) are on the surface of the sherd. This information is used to drive the light projector, so that only those parts of the measurement area containing the object are illuminated and those parts of the surface which are of archaeological interest are computed with higher accuracy than other parts, as shown in figure 12. The intensity image therefore defines the density of the light-strips. The two cameras are used to take 4 different lightstrip images. The use of two cameras reduces the amount of occluded areas not seen by one of the cameras and increases the accuracy, because two different images of the same structure can be used to compute the depth information. Furthermore, vertical and horizontal lines are not projected at the same time to reduce errors in finding corresponding lines and to reduce fringe computation on line crossings.

4.2 Depth computation

Following image acquisition, four different structured light computations take place and lead to four range images produced by the structured light algorithm. These four range images are then combined into one range image, which is the first range approximation for the following stereo matching algorithm. Figure 13 shows one grid produced by the structured light method, where the dots indicate points with depth information. Depth computation with the help of the stereo matching can be obtained for all texture points on the surface of the sherd inside the grid. So the stereo algorithm fills the ‘gaps’ inside the grid. Because of the depth information along the grid lines, an approximation of the height inside the grid is possible. This reduces considerably the search space for the corresponding point in the two stereo images. Fusion of the data obtained by structured light with the information obtained by stereo will give more exact depth information.

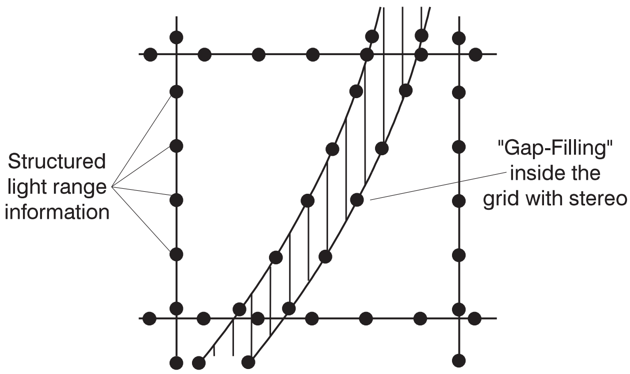

Figure 13. Higher accuracy due to stereo.

The range data computing process is shown in figure 14. The result of this working process — the object model of the sherd — is one element of the archaeological system which is able to provide the cross section and the top view of the sherd as shown in figure 1. Together with the colour image archive and the colour classification based on the colour image, this archaeological system provides multi data information about the archived sherd. The object model can be visualized on a computer monitor as well as on a laser printer in any desired viewing angle by interactively rotating and scaling based on geometric transformations. One possible way of visualization is a representation of the 3-D object model by a wire frame model which can be rotated in any direction interactively. In addition to the wire frame model, the corresponding intensity image can also be displayed. As a third feature, the cross section of the sherd is permanently displayed. So the archaeologist can orientate the sherd very precisely, in order to get the correct profile section for plotting. After defining the correct profile section it is plotted together with the additional parameters of the sherds, such as excavation site, excavation layer, material, and others.

5 Outlook

The 3-D information of the surface of a sherd is the basis for any further classification and therefore also the basis for an archaeological database. The exact orientation of the sherd is done manually by the archaeologist, correcting the orientation proposed by the system. The proposed orientation is based on the rotational symmetry which in the case of sherds is the curvature of the inner surface, since this curvature must be a circle in the direction of the rotation during manufacturing. Following the orientation, the profile section is stored together with the pictorial information and sherd relevant data for further classification. This classification is based on matching different profiles and classifying them due to the similarity of the profiles. Since the profiles are very accurate and independent of human measurement errors, the result is a classification based on objective, computable, and reproducible criteria, which would be very helpful in the work of archaeologists (Caselitz 1988; Furger-Gunti/ Thommen 1977; Schneider *et al.* 1989).

Furthermore, the optimal configuration of the system can be guaranteed by permanent collaboration between archaeologists and technologists. Further goals to be obtained can be summarized as follows:

- *Construction of a picture database:*
  The intensity images of the sherds are stored in a picture database. Together with each intensity image, the appropriate parameters such as excavation site, excavation layer, material, colour, archive number etc., are stored. It should be possible to search for text index keys (like excavation site or archive number), as well as for patterns in this database.
- *Proposals for pairwise sherd mosaicing:*
  Pairs of preselected, matching sherds are searched in the existing database and proposed for reassembling whether the surfaces of fracture correspond.
- *Assembling parts of pots from sherds:*
  The object model of the selected, matched sherds are assembled to parts of pots, in order to make the reconstruction easier and more accurate.
- *Reconstruction of pots with the help of existing part-assemblies:*
  The model of the complete pot is reconstructed from the existing part assemblies. This model can be transformed into a grey level image with the help of ray tracing methods.
- *Automatic computation of the dimension of a reconstructed pot:*
  The dimensions of the reconstructed pot such as diameter, height, thickness and the like can be computed.

All of the above mentioned goals can only be reached if the first and most important step, data acquisition works well. Therefore, we currently focus on the fusion of the two acquisition methods in order to have an optimal basis for all further goals. In the future this system could be used for various tasks, like information exchange via computer networks, support in teaching, presentations, publications and many others.

6 Conclusion

In this paper two acquisition methods were proposed for archaeological finds that could help the archaeologist in his work and automate the archivation process. First we presented an overview of existing methods for archaeological image acquisition methods. These systems are half-automated, so the amount of work has not really been

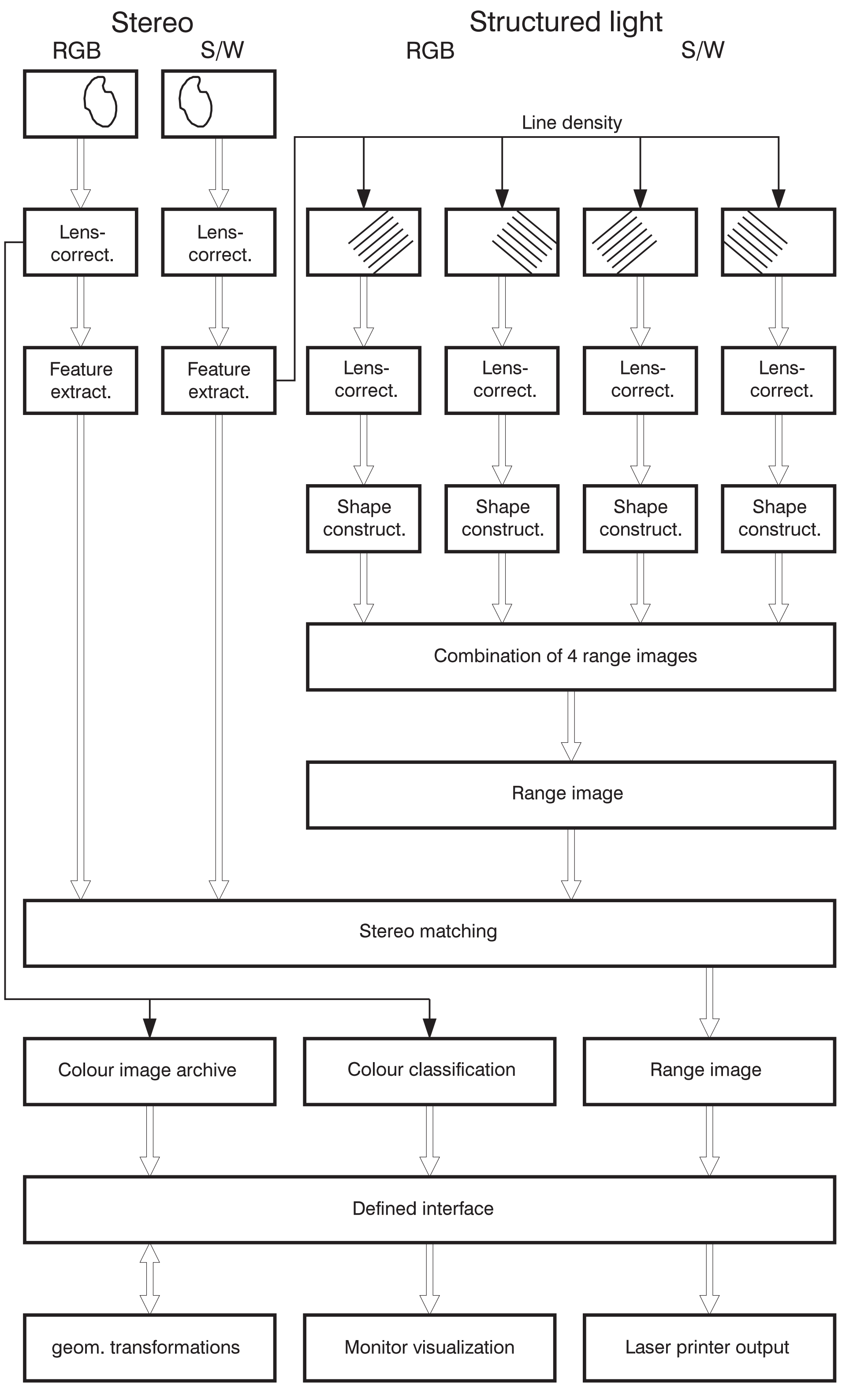

Figure 14. Schematic working process.

reduced. Next we focused on the acquisition methods to minimize errors in the output and to automate this process completely. In order to get the 3-D information of a sherd we tested two different and representative methods, in particular, *shape from stereo* and *shape from structured light* for providing a 3-D surface representation of a sherd. The results of these two acquisition methods were compared with each other and the fusion of these two methods for an archaeological application was shown. Finally, outlooks for a computer based automatic classification of archaeological finds were given.

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Simple fun – Interactive computer demonstration program on the exhibition of the Szentgál-Tűzköveshegy prehistoric industrial area

1 Introduction

This paper aims at reporting on an interactive computer demonstration program installed in an exhibition, the first of its kind in Hungary. The subject of the excavation was the prehistoric industrial area on and around the Tüzkö-veshegy ('Flintstone Mountain' at Szentgál, West-Central Hungary (fig. 1). Red radiolarite from the environs of Szentgál was first mentioned in archaeological technical literature in 1876 (Lipp 1876); thereafter, however, the site was neglected and only the investigations of the past few years could prove its actual significance amongst Hungarian prehistoric sites.

The archaeological rediscovery of the exploitation area took place in 1982, in the frame of systematic fieldwork for the exploration of potential sources of prehistoric lithic raw materials (Biró 1986a, 1986b). The workshop character of the site was immediately recognised. Excavations started there in 1983 and are still in progress. The first mining pits were found in 1993; sofar, 5 individual mining pits have been separated.

For the determination of the period of mining, parallel excavations were started by J. Regenye (Regenye 1994). Systematic fieldwork and a survey of museum material on the distribution of the raw material was also done (Biró/ Regenye 1991). By 1995, the gathered information formed the basis for the setting up of an exhibition devoted to the problems and results of the Szentgál industrial complex. The exhibition was opened on 15th March 1995 in the Veszprém Laczkó Dezső Museum and is reported to be fairly popular. It will be open till 31st March 1996 and there are plans for a permanent exhibition in a different museum after that date.

Both the excavations and the exhibitions had a very low budget. We had the support of volunteers for the excavation and lots of friends to help with the installation of the exhibits, as well as the compilation of the computer program.

The idea of setting up an interactive computer demonstration program within the exhibition was already considered in 1993 (Biró 1993). The discovery of evidence of mining in the exploitation area gave a last impetus in the realisation of this exhibition, because unlike with other flint mines (e.g.,Tata, Sümeg; Fülöp 1973, Bácskay 1986), there seemed to be no chance of preserving the shafts and pits and arrange a presentation to the public.

2 The exhibition

The exhibition of the Szentgál-Tűzköveshegy prehistoric industrial complex is unusual in many ways. It is devoted to joint studies of two archaeologists on a range of related problems: formation, exploitation, access, distribution, prehistoric and modern use of 'Szentgál flint'[1]. The focus of interest is not on 'objects' but on context. We therefore used a model based presentation and tried to place the individual finds in a realistic context. Formation of the radiolarite was modelled and map information was collected in a tangible, relief form. There are 3-D 'in situ' models of the mine, the source area and the location of the prehistoric industrial settlements, the excavation and the reconstruction of the prehistoric settlement features. Visitors have a chance to handle some of the exhibits and the interactive computer demonstration program, which is the subject of this paper, is also offered for manipulation.

3 The computer program in the exhibition

3.1 Technical solutions

From the start, we were aware that in installing an inter-active computer demonstration program we would have to keep everything very simple. This was partly necessary because of the very limited funds but also because of the novelty of our enterprise. We aimed at the knowledge and interest of the young 'computer generation', but the whole program had to be constructed in a way that does not require sophisticated means nor any substantial knowledge of computers. Thus the basis of our exhibition program had to be very easy to handle and not very demanding as far as hardware was concerned. Also, we had to base our presentation on legal software. To meet all these require-ments, the public domain hypertext program, HYPLUS, by Neil Larson was selected. We had tested the potential of this program in the construction of textbooks and lectures previously, both as users (students; Bakonyi *et al.* 1994) and as authors and lecturers (Biró *et al.* 1994, as well as different conferences and symposia).

This program runs on a minimal configuration effectively (AT 286 with min. MS-DOS 5.0, Hercules and/or mono VGA monitor). The generous support of the SZÜV (a local computer dealer) and the Ministry of Education finally made it possible to run the exhibition program on a 486 SX computer with SVGA monitor, which is certainly much better for speed and aesthetical quality. The manipulation of the program can be realised by the cursor keys alone. To filter out possible sources of errors, the exhibition program is started by the autoexec.bat file with all necessary settings. The computer is placed in a closed box for protection and the keyboard is partly covered. The museum attendants have no special duty but to switch it on and off like the light in a room. The motherboard is 'green', so that it can be operated during all exhibition hours. Switch-off time is set to 5 minutes.

3.2 Contents

The contents of the program was constructed to cover basic fields of the exhibition with a detailed explanation and many illustrations. The complete structure of the hypertext is outlined in figure 2.

The deeper layers of the program contain specialists' information, i.e., archive data and text of available publications. The full text of the exhibition guide is also included, in a Hungarian, English and German version. For the foreign visitors, a simplified version of the hypertext with full illustration list is given in English and German. There is a special part for youngsters who have as yet no school experience in prehistory, geology and related problems. The program had two short slide shows on the production and refitting of a core. The elements of the slide show were registered step by step on an experimental series.

The most demanding part of the construction of our application was the compilation and proper quality of illustrations. There are currently 144 images included in the program (with the slide shows, 191). The origin of these images is very varied. Some were constructed in the computer by drawing programs (CorelDraw, Paintbrush etc.). Other elements, like spatial statistical data and 3-D models of the environs of the site, were made with GIS packages. Part of the images were scanned and manipulated to fit in the exhibition demo. Video scanning and digitalization of microscopic images was also utilised. For part of the images, particulary the slide shows, a digital camera was used. For all the facilities we used, I have to thank a number of good friends.[2] Inserting the images into the program required a lot of patient work, conversion between forms and formats, hardware platforms and resolution. The more demanding pictures (photos) were finally inserted in the form of self-extracting images (.exe form) because the viewer of the hypertext could not handle high quality images in acceptable quality.

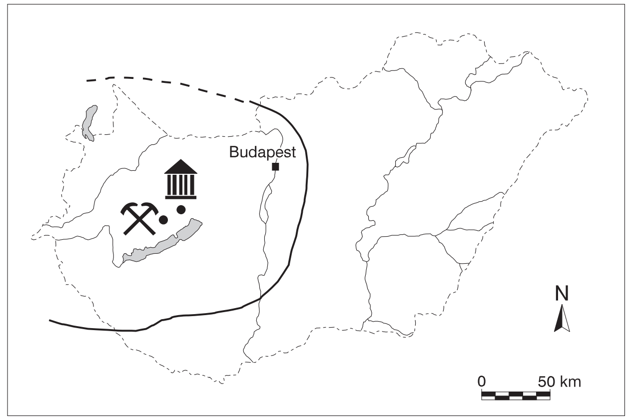

Figure 1. Location of the site and its environs.

4 Current experiences

To the best of our knowledge, the program has been very well received. It was certainly a challenge to the museum staff; as they had to master not only the handling of the program (which is really very simple) but also had to have a different attitude towards visitors. In contrast with the former duties ('don't touch the exhibits!'), the visitors have to be encouraged to touch, to try and manipulate the program. Many teachers with schoolchildren have discovered the possibilities offered by this different exhibition approach. Excavators of the past 10 years have shown much interest in the parts relating to their own work: chronicle, excavation reports, documentative photos. We are following comments in the guestbook and intend to complete the illustration material, especially in some fields which were not fully documented.

5 Documentation, availability

The full text of the program (1.0, test version and 1.1, first exhibition version) was compiled into a text file and printed as reference material for museum educational purposes. The latter text version is available through the INTERNET from the Museum shelf of the Hungarian Electronic Library (currently at the gopher service of the University of Economics, ursus.bke.hu). The possibility of producing a CD on the basis of the exhibition material is also considered[3].

notes

1 More exactly, radiolarite.

2 Especially, F. Gyulai (National Science Foundation Archaeological Instruments' Centre), Gy. Munkácsy (Photographic Collection of the National Pedagogical Museum) and Á. Burkus (Museum of Fine Arts).

3 The CD was published for the 18th of May 1995, the International Museum's Day, and can be obtained from the author.

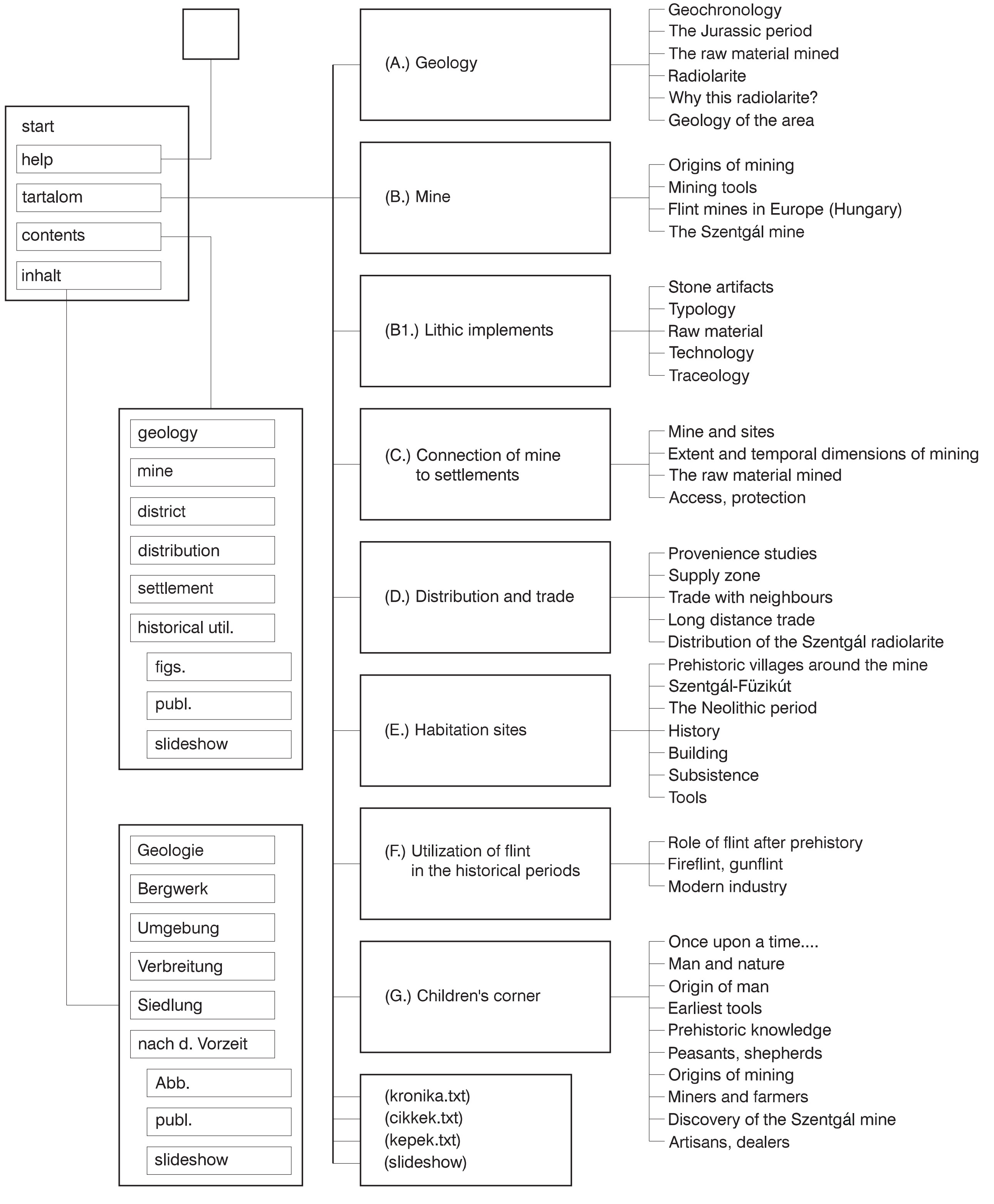

Figure 2. Structure of the hypertext exhibition guide.

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Documentation and modelling of a Roman imperial villa in Central Italy

1 Introduction

Of the possible archaeological adaptations of computer techniques, this paper is devoted to documentation.

1.1. About the documentation

The importance of archaeological documentation cannot be overestimated. Field archaeologists are aware of the fact that their activity, in most cases, leads to the complete destruction of archaeological sites. Theoretically, the various layers of a stratified settlement are peeled off one after the other until the earliest level is reached. Finally, even the last stratum is shaved off to make sure that nothing is left underneath. It may be stated therefore that when the archaeologist's work is accomplished nothing is left and subsequent visitors can admire only the natural environment of important prehistoric sites trying to imagine the original landscape and its inhabitants. Being a Roman Period archaeologist (FR), I am specialized in a period which is characterized by a better than average preservation of archaeological features. It is not necessary to remove stone walls since nothing can be expected below them. Floor levels, however, with the exception of occasionally occurring mosaic floors of great aesthetic value, have to be systematically removed. In this rare case, one may add, non-scientific considerations are given priority: deposits under the floor are not studied for the sake of presenting a beautiful design. This type of presentation means that a moment of history is arbitrarily emphasized, although earlier and later finds must be investigated as well.

It is common archaeological experience that any surface is in the best condition at the time of recovery. That is the time when it must be documented using the broadest range of methods possible including drawing, photographing, film and video recording, verbal description as well as digital procedures. Computerized data gathering and analysis has created an opportunity for introducing new methods in this work opening perspectives that cannot even be fully appraised at this point.

1.2 About the site

Excavations at the Piano dei Santi baulk near the village of San Potito di Ovindoli in Italy have been carried out within the framework of a cooperation between the Archaeological Institute of the Hungarian Academy of Sciences, the Soprintendenza dell'Archeologia degli Abruzzi and the Comune di Ovindoli (Gabler/Redő 1986, 1988, 1991, 1994a, 1994b). This archaeological site, a villa from the Roman Imperial Period, is a fortunate case in which the most characteristic level could be pinpointed relatively easily. Most of the stratigraphy is horizontal, vertical components mean that previous features were damaged already by Roman Period construction activity. Layers within the periodization correspond to variations in the size of the habitation area.

Three elements in the documentation of this site will be presented here. Some details of this work were already presented to a professional audience in Ravello in 1993 (Csáki *et al.* 1995). Since that meeting, however, major developments have taken place both in the quantity of documented detail and the scope of methods applied.

2 Documentation of the environment

A digitalized map was prepared showing the site's broader environment. Data of the topographic contour lines in this map were used in preparing a surface model. Constructing this type of surface models often requires the introduction of artificial distortions. Eroded elevations and silted river beds sometimes changed only by centimetres; however, even such small differences may be of significance and must therefore be shown. Fortunately, such a distortion was not required in the case of San Potito since modelling the narrow valleys in the Abruzzo mountains could be carried out using contour lines indicating 10 m elevation, which resulted in a copious pattern.

Our model makes the exclusive selection of coeval topographic data both in a geographical and a historical sense, thereby showing Roman Period relationships between settlements, roads and water surfaces (Grossi 1991). Constructing the model itself will not be discussed in detail. One practical experience, however, is worth mentioning here: a high resolution model showing the excavation's immediate surroundings is equally necessary.

The model that perfectly represents the broader hilly environment shows the site itself within one level, since no

Figure 1. A digitized part of the geometric decoration of a pavement.

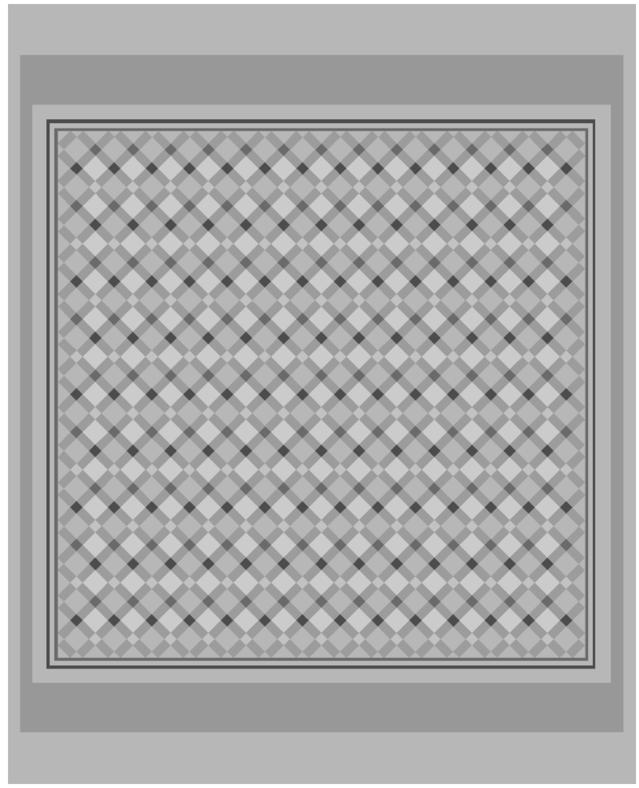

Figure 2. The fully reconstructed geometric pavement.

differences in elevation exceeded 10 m at the settlement (Csáki *et al*. 1995). At the same time we know that there were major differences in the levels of various features within the villa as is evidenced by the presence of stairs between the inner courtyards. Our measurements are indicative of more than three metres of vertical difference between the lowest and highest points of the Roman Period floor levels. The orientation of the villa's drainage system was also carefully laid out. It is for this reason that a stepwise surface model is required that will bridge contradictions in the data and will make the satisfactory documentation of excavation results possible.

3 Documentation of mosaic pavements

The size and luxurious character of the villa under discussion here was well above even the Italian average. On the basis of data available to date, one may say that the residential section, made up by rooms around an approximately 50 by 70 m inner courtyard, was built with care and reflects wealth. It was equipped with glass windows and decorated with wall paintings as well as mosaic floors.

The documentation of mosaic floors was an interesting task. Theoretically, data could be recorded in two different ways. Photographs and drawings of the floor could be either scanned, or digitalized drawings could be used.

3.1 Different methods of documentation

My experience is that computerized data recording does not save the tedious work of making precise drawings. The poor state of mosaic floors in the field circumstances of recovery usually does not make 'objective', that is non-commented, documentation possible. Fragmented surfaces cannot be cleaned to the degree that is required for the taking of informative photographs. Field drawings, on the other hand, also have their limitations set by scaling, the thickness of pencil points and our eyesight. These may be modified by the beneficial influence of additional information gathered on the object. It is not an accident therefore that this type of hand-drawn field documentation also contains quantities of written, that is, non-visual information. It is at this point that the tremendous advantage offered by digitalization can be exploited. This computerized technique makes the recording of features in natural size possible. The amount of

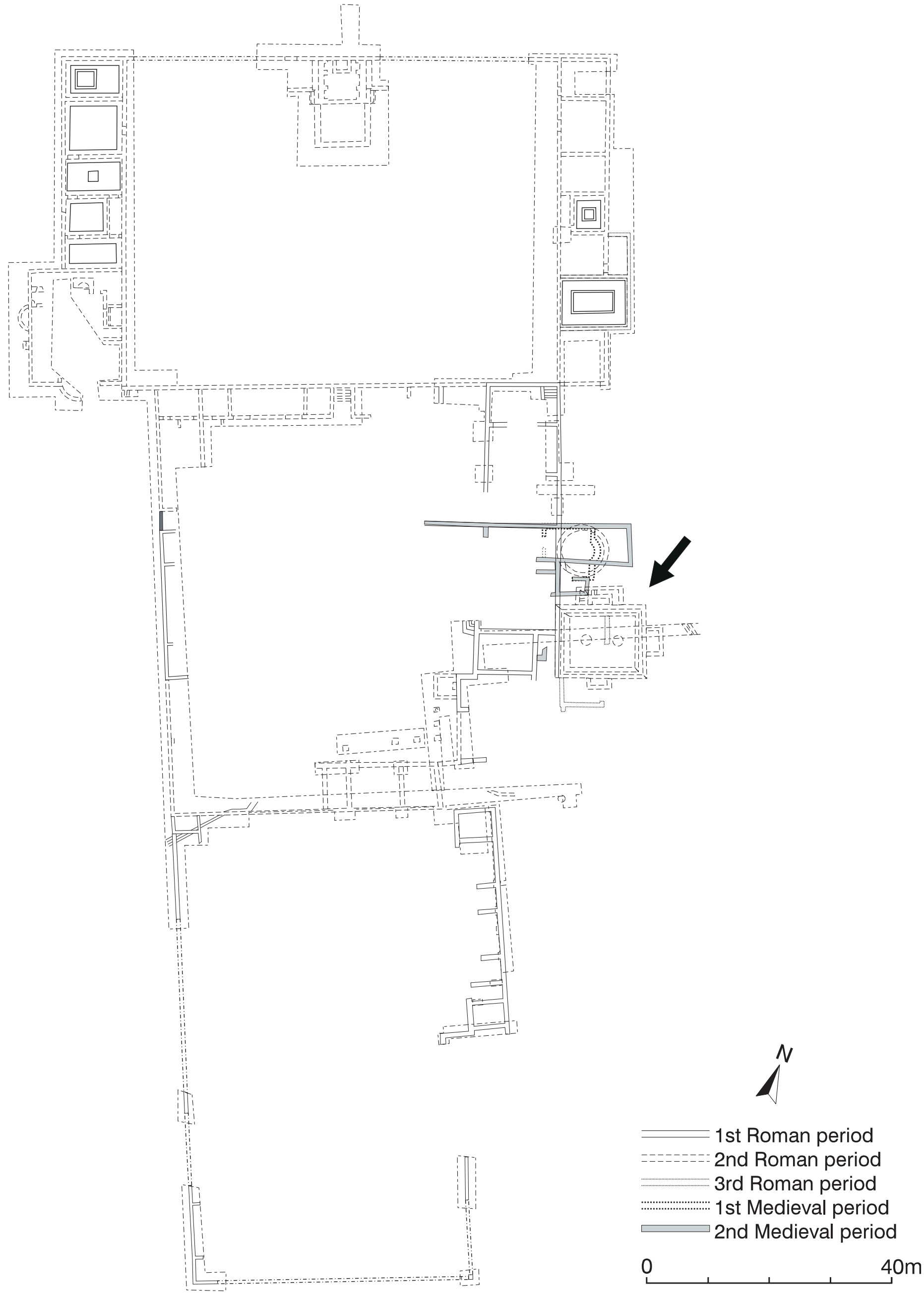

Figure 3. Ground plan of the villa, with the double walled construction.

detail and precision in such records, however, is far beyond physical visibility, falling within the realm of knowledge. Consequently, the possibly most complete data set may be compiled (fig. 1).

Naturally, not every detail in such a data set is utilized simultaneously and constantly. On the other hand we have a data base at our disposal that is as complete as possible and can be exploited to the degree required.

3.2 Reconstruction and publication

Of the examples discussed here, the completion of mosaic floor surfaces may be considered the most exciting. The

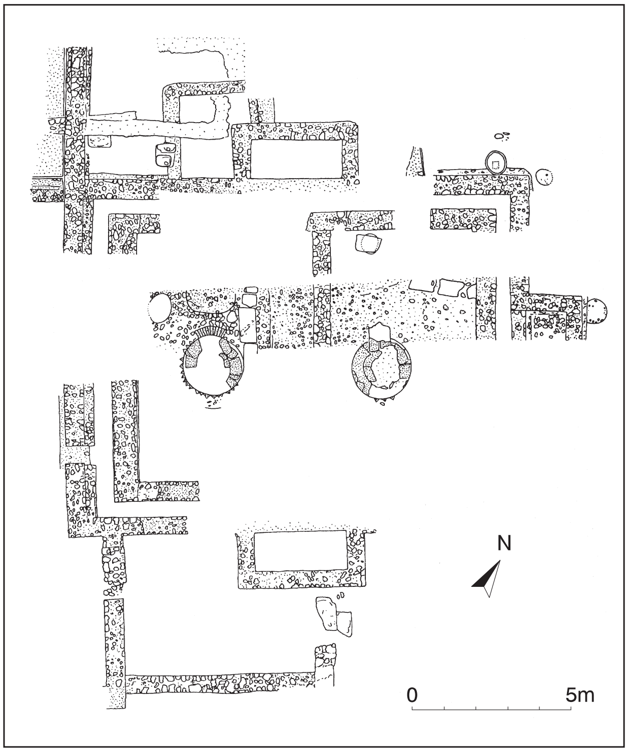

Figure 4. Compiled drawing of the double walled construction.

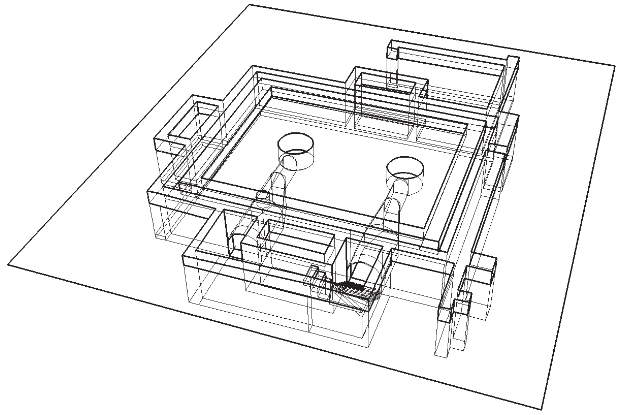

Figure 5. A transparent perspective view of the feature.

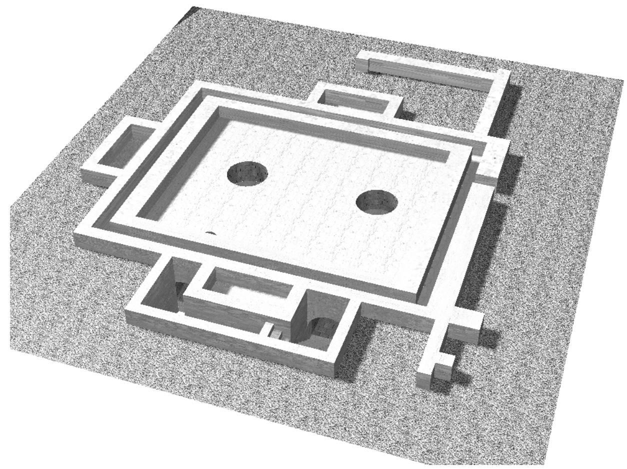

Figure 6. The double walled feature viewed from the north.

examples presented here include floors with geometric patterns that could be completely reconstructed (fig. 2), and floors with figural decoration that could only be partially reconstructed.

A special advantage of digitalized drawings is that the material becomes accessible for computerized image processing for the purposes of publication (Gabler/Redő 1994). Colour pictures as well as black and white half tone reproductions can be equally created: the excess information included is an excellent means for mediating our expertise.

4 Three-dimensional modelling of different features

The third area of use is a novelty both in the analysis of this site and in our personal experience. This is the topic of 3-D modelling.

It has been a challenge for a long time, that following the reconstruction of hills and valleys including the roads and water surfaces, the villa itself should be 'built' within this landscape. This would be a formidable task, however, at this point it has to be abandoned in the absence of additional data. First, further details of the site plan must be recovered. Even full knowledge of the building's plan, however, would not shed light on the structure of vertical walls which therefore remain unknown. Reconstructing these, as well as the roof and windows of the villa would introduce a speculative element in the reconstruction that could not be controlled by the archaeologist alone.

Possibilities of 3-D modelling were therefore tentatively used in solving a specific problem. There is a section within the villa that could not be identified (fig. 3). Specialists neither in Italy nor in Hungary could even comment on this detail. Aside from the rarity of the feature in question, its mysterious character is partly due to the fact that it has never been fully visible and it could therefore not be appropriately presented for the purpose of consultations. The site's location at an altitude of 1000 m as well as the frost that may last for five months every year make the annual re-burial of each excavated and documented feature necessary. As a result, the feature under discussion here was excavated in three consecutive seasons and could never

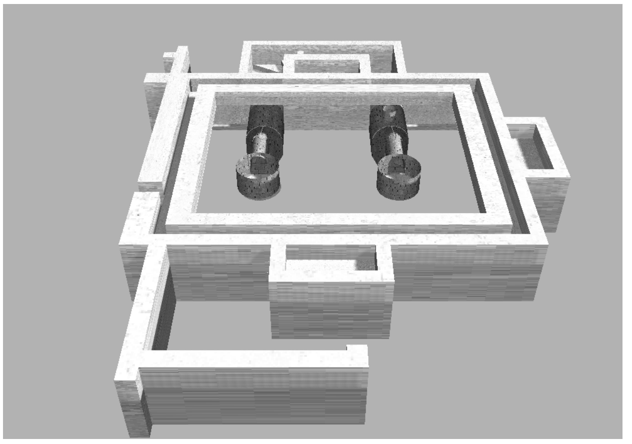
Figure 7. The double walled feature viewed from the sorth (without the surface).


Figure 8. An inner view of the western tunnel of the double walled feature.

be entirely seen. In addition, some of its sections still lay unexcavated (fig. 4).

This feature is particularly suited for the purpose of 3-D documentation, since it extends 2.8 m below the surface and is interrupted by tunnels and shafts. In other words, it is an unusually complex structure whose 3-D reconstruction can be carried out without unnecessary speculation. All sections and aspects of this feature were digitalized providing data for the construction of its computerized model. The result of our work can be viewed and measured from any angle (fig. 5). Its data points, edges and surfaces can be made visible or removed from the picture as requested.

It must be mentioned here that the working process itself, the unambiguity required by the technical solution, helped clarify our thoughts and refine the relevant hypotheses. Real results, however, will facilitate the selection of the most characteristic aspects, help 'walking around' the feature's subterranean sections and offer an inside look at the construction (figs 6, 7, 8). This high quality information will permit the presentation of the identification problem in a way that can be appreciated and discussed by an international audience of experts.

Acknowledgements
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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.

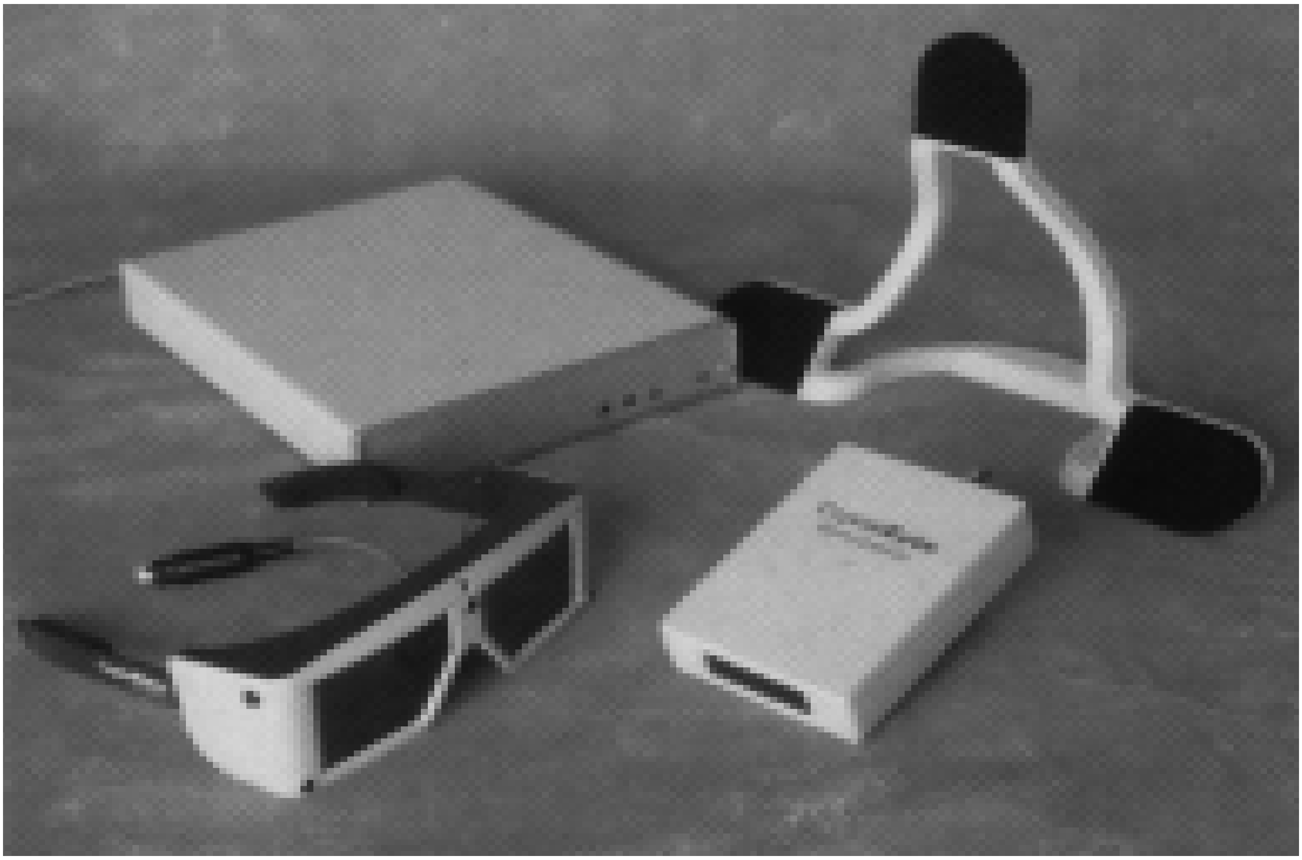


Figure 1. Crystal Eyes System.

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

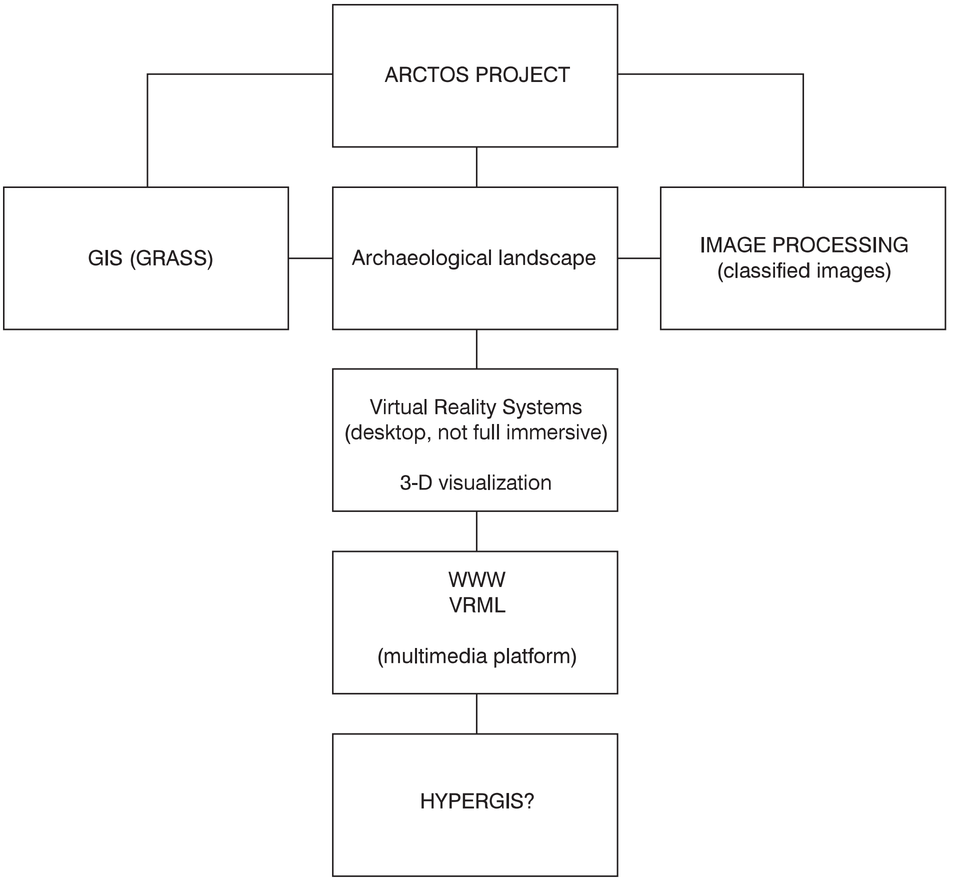


Figure 2. ARCTOS Project development.

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

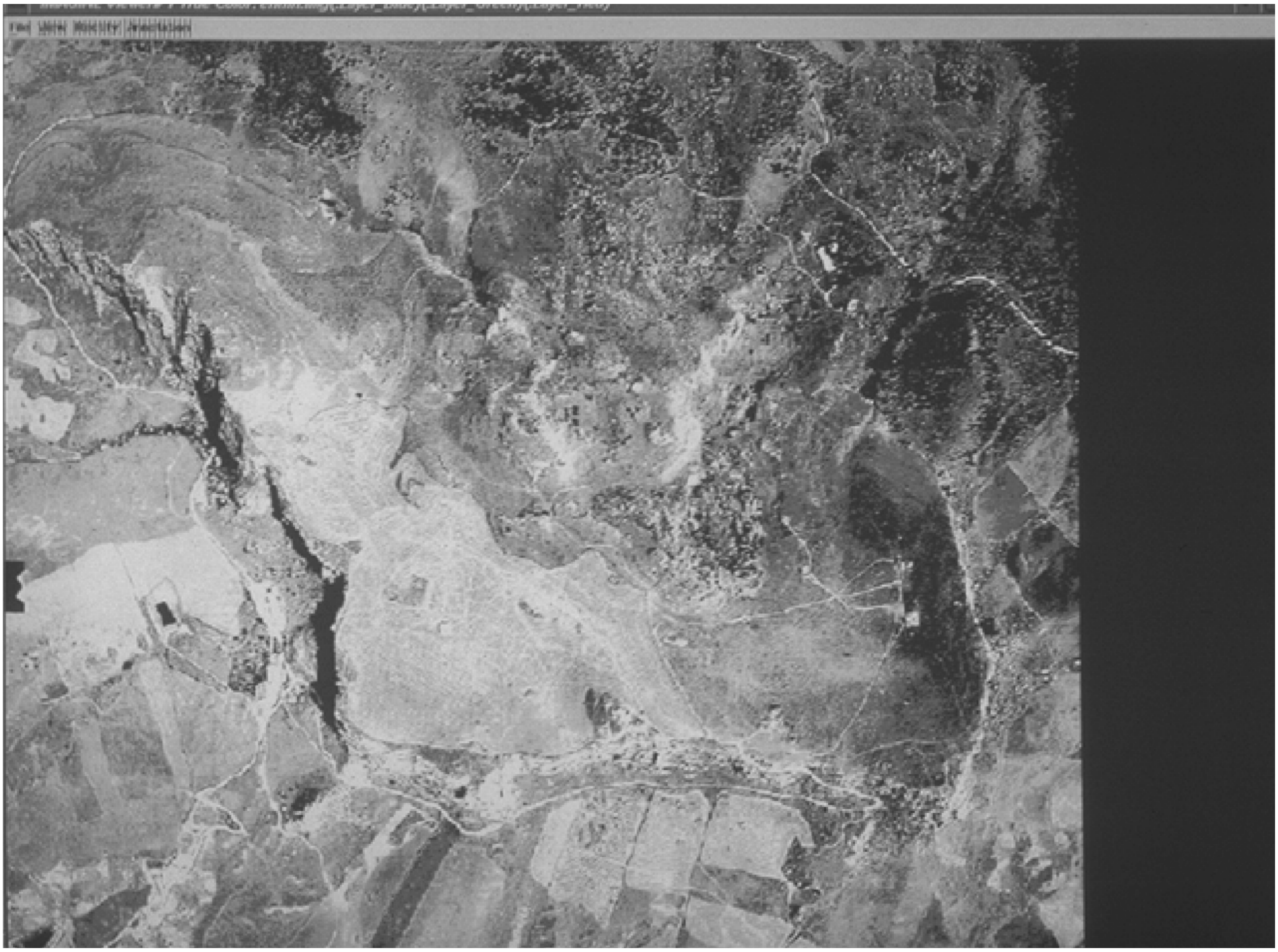


Figure 3. Rectified aerial photograph.

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

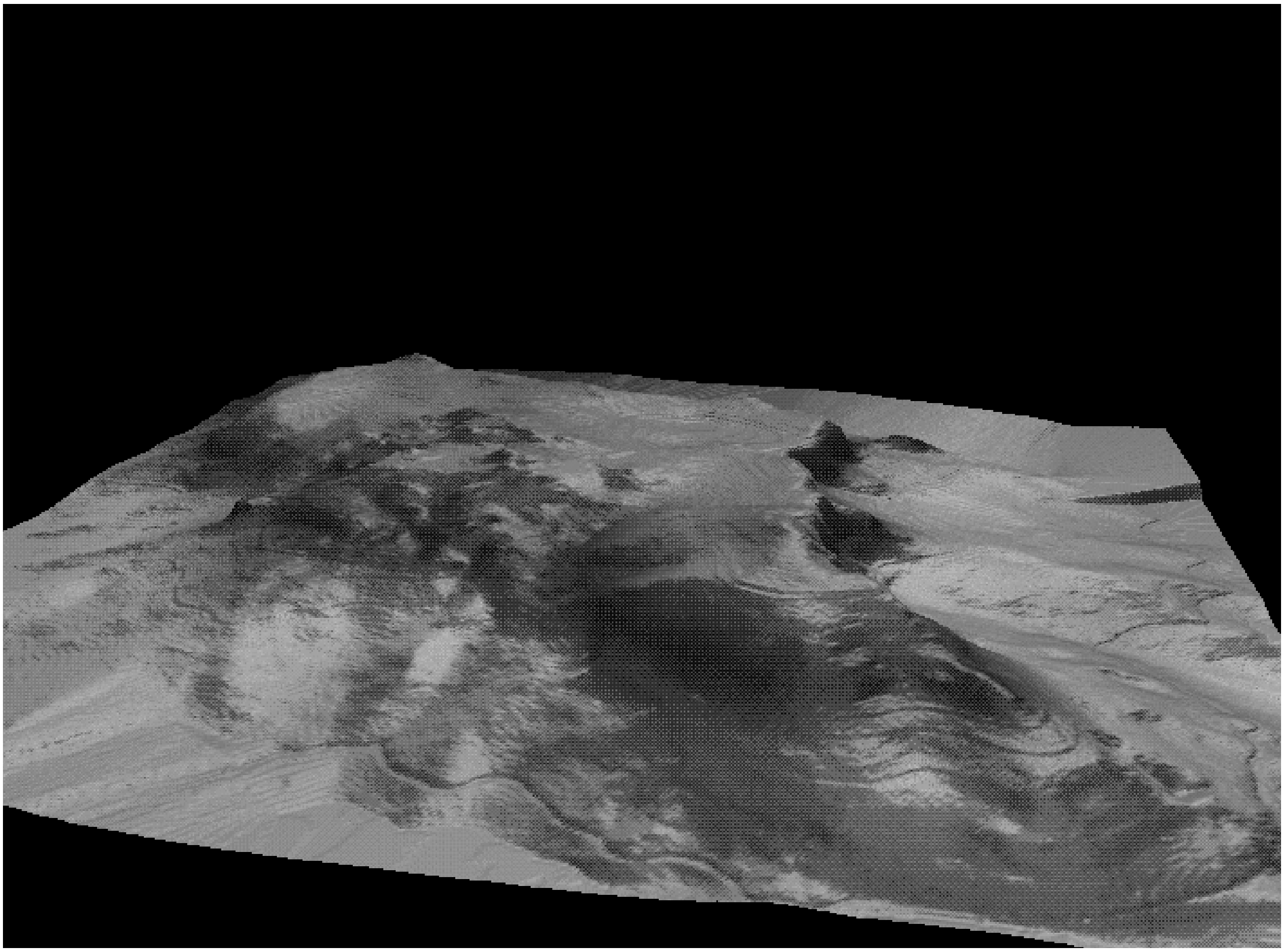


Figure 4. (Digital Terrain Model) in 3-D interpolated by cartographic contour levels (GRASS): dark colours correspond to the highest areas.

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);

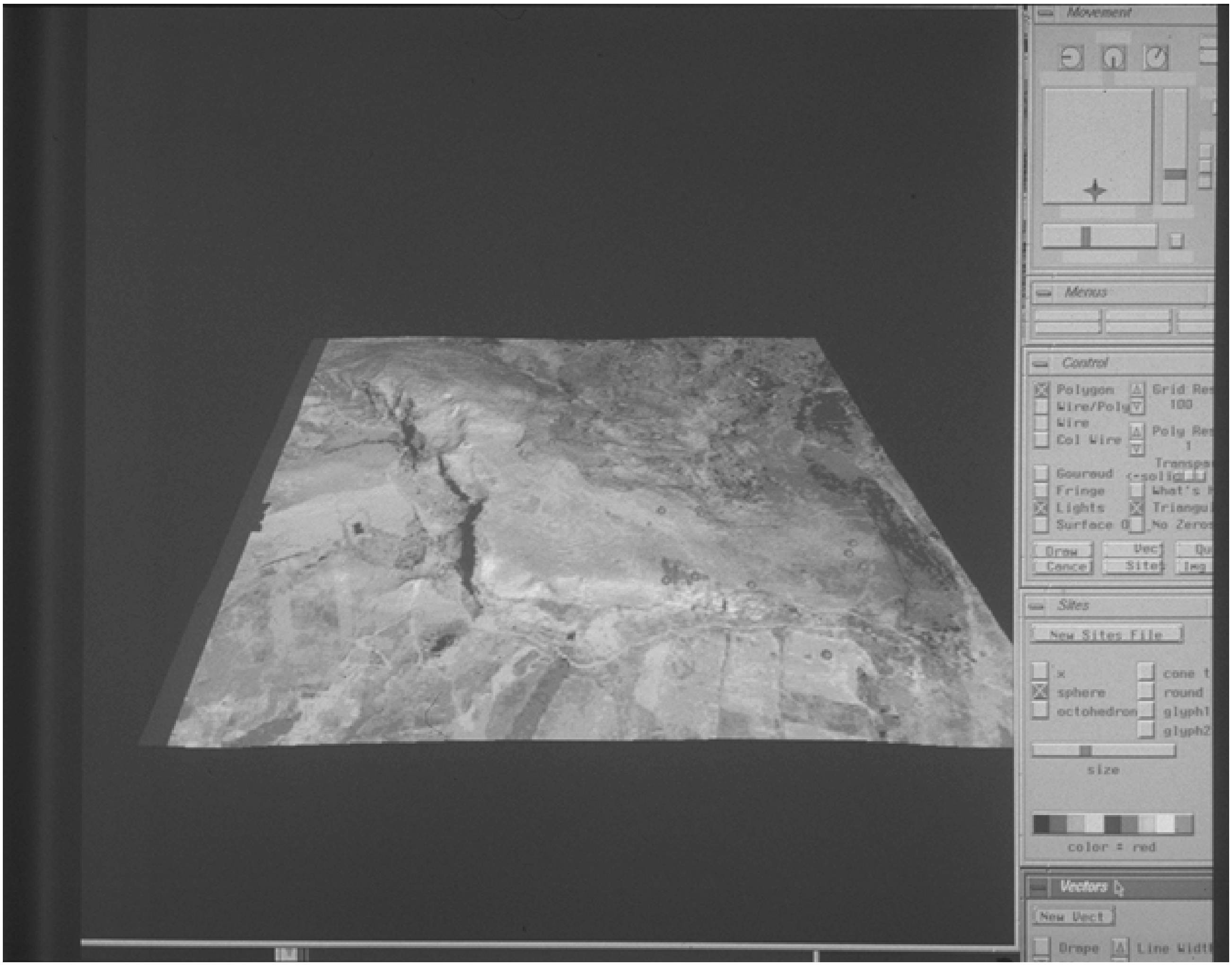


Figure 5. Texture mapping of the aerial photograph on the D.T.M. (GRASS).

– 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);

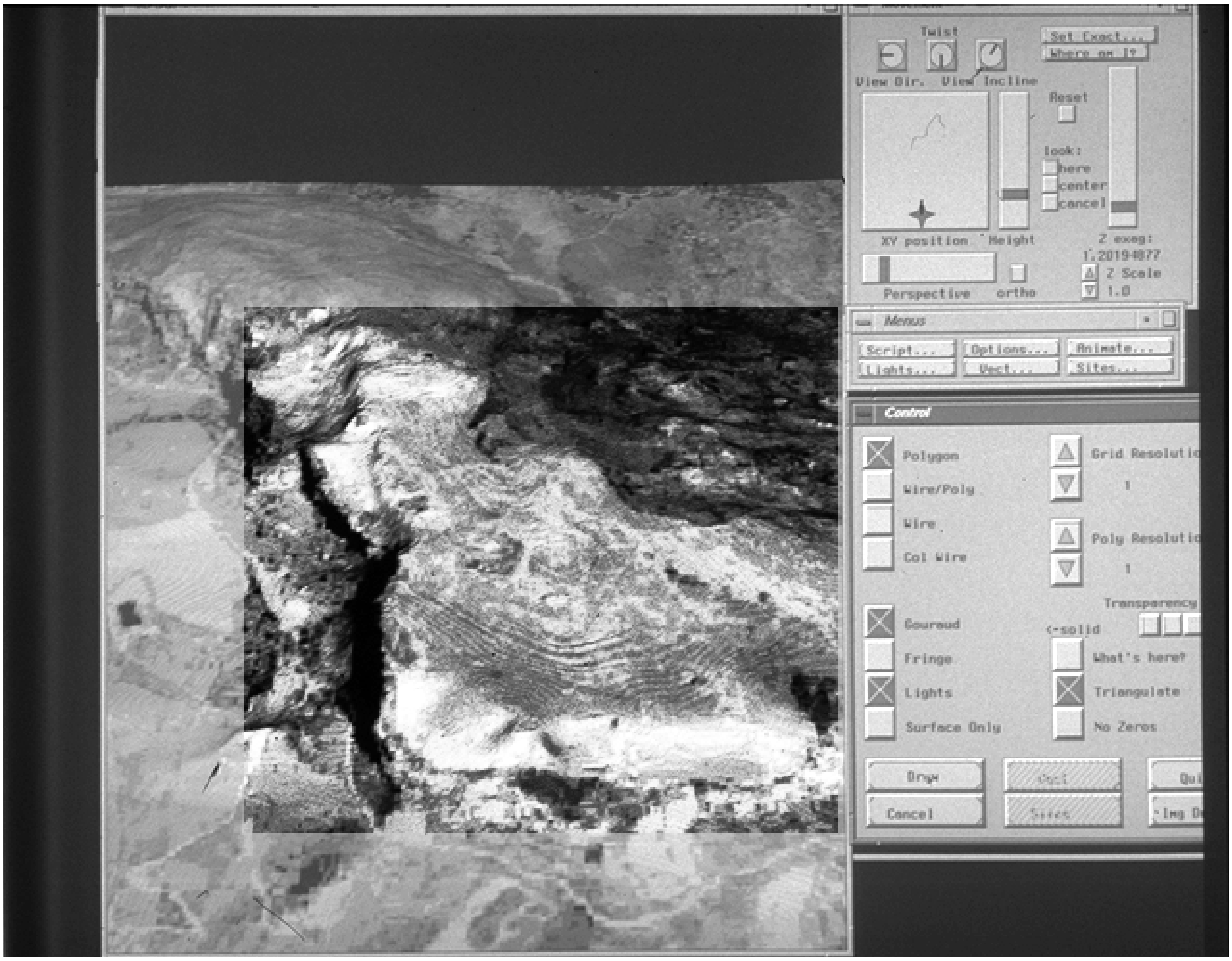


Figure 6. 3-D Digital classification of the aerial photograph: histogram equalisation and density slicing (ERDAS + GRASS).

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.

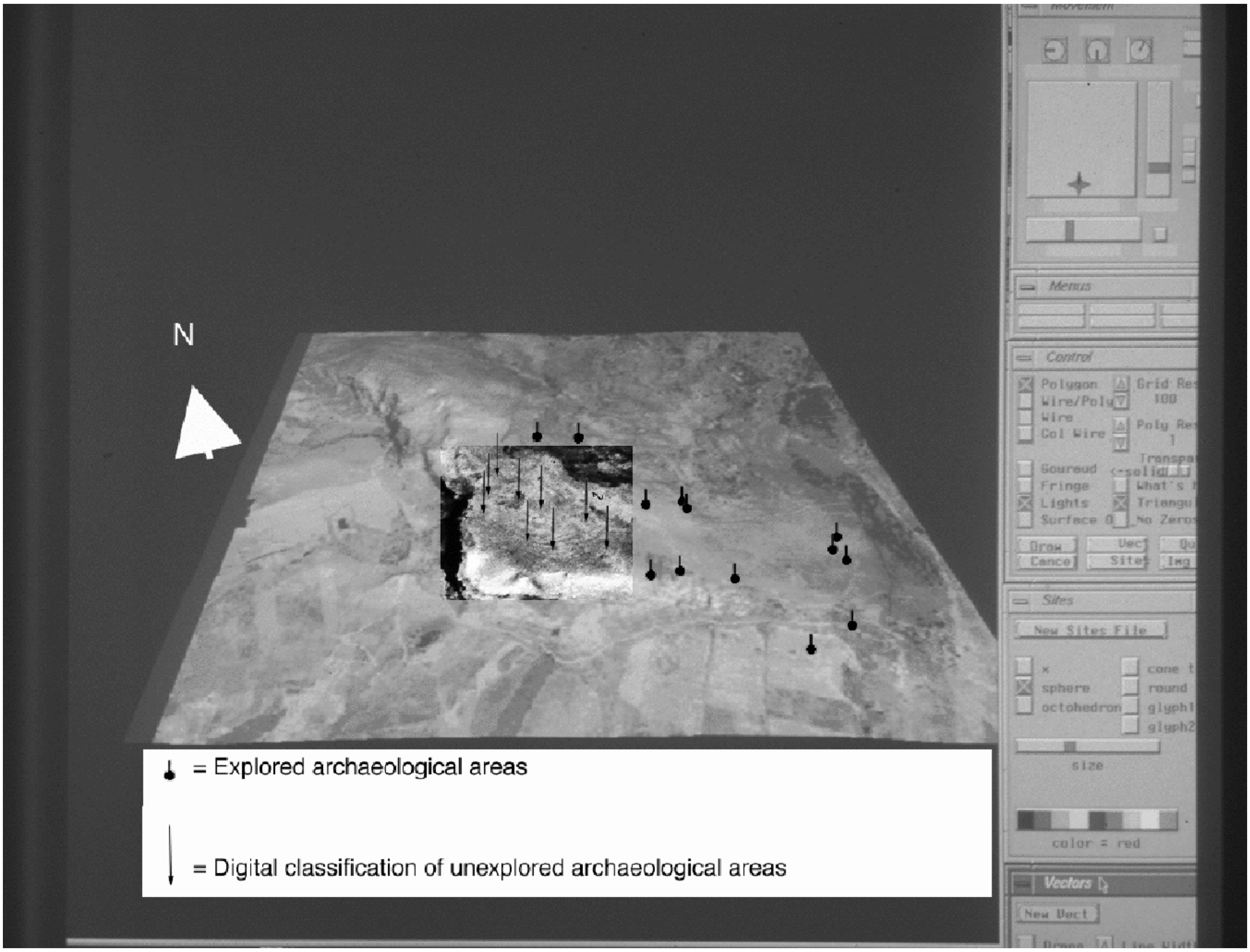


Figure 7. 3-D Digital classification: known archaeological areas (vectorial data) and unexplored archaeological areas (digital predictive information, ERDAS + GRASS).

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.

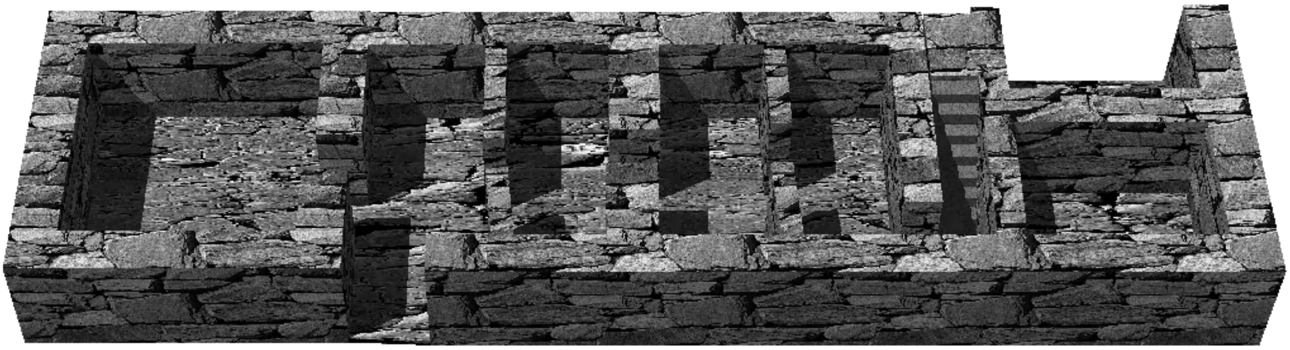


Figure 9. Rocca di Entella (Palermo): computer graphic reconstruction of a Hellenistic building.

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.

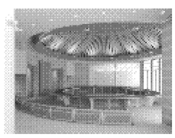
Take a Virtual Walk through Lightscape Models!

Next page
Go to top

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
© Copyright 1995 Lightscape Technologies, Inc.
9 MB



Jerusalem City Hall model
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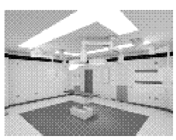
12.5 MB



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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Dissecting the palimpsest: an easy computer-graphic approach to the stratigraphic sequence of Túnel VII site (Tierra del Fuego, Argentina)

1 Introduction

The broad spread of quantitative methods in archaeological research is, without any doubt, one of the most outstanding facts in recent years. Nevertheless, the impact of technological development is seldom properly controlled due to the immaturity of our discipline. This means that the relation between archaeology and quantification is not as simple as hoped by its advocates. On several occasions, a weak theoretical methodological frame has gone from the initial fascination for the unknown to the adoration of the incomprehensible. In the advance of social sciences this process is not alien to the quest for 'science' by means of uncontrolled technical sophistication. It does not surprise us then, that some professionals see in statistics and applied computer science the solution to their explanatory incapacity. They could not find anything better to conceal the theoretical weakness than the needless sophistication in the description and analyses of the empirical information.

Archaeologists cannot be excluded from the technological trend. They, too, feel the need to generate complex descriptions of apparently simple phenomena. The availability of statistical packages and scientific software was the starting point for the frantic run in quest of 'science'. In this awkward situation, most of the time the demarcation criterion has not been the perfection of the selected instrument, but the degree of 'technological/psychological impact' among the colleagues. The fascination for these available new 'toys' has caused, on numerous occasions, for the validity and relevance of the results to be relegated to second place. Once again, the professionals forget the aims, and seem to take delight in the objects.

It is clear that the defense of the basics is still essential, and, thus, we wish to insist on the need to perfect the techniques to the real dimension of the problems that are raised. This work, then, becomes another contribution to the following motto: '*the easier, the better*' (Barceló *et al.* 1994). We put up a defense of the potential of quantification and the need to use it as an objective instrument for the description of the empirical reality. Nonetheless, quantification is not a synonym for sophistication, but for accuracy, standardization and agility of data processing. It is not enough to assume a careful attitude towards the correct application of computer-based tools or statistical tests. It is also important to choose the proper tools ensuring that they are user-friendly.

2 An easy computer answer to a simple archaeological problem

Our proposal can be summarized as follows: the selection and application of the easiest computer solution to archaeological problems which are usually fairly simple. The aim is to gain greater control over the operative procedure of analysis which will, probably, make it possible to achieve more useful results. Do not forget that the unnecessary use of complex computer-based tools hides behind its apparent versatility and potential of trouble in its handling. It is not surprising, then, that the archaeologist, as well as the less experienced user, incurs a wide range of errors and inaccuracies. The tool exerts close control over the patient user who regardless of the confusion becomes the 'wizard of data' to those who are not computer users. The interest and reliability of the results often remain unquestioned because the other professionals cannot understand the cryptic language of the so-called experts.

The statistical data processing is the most illustrative example of the 'numerical magic' in service of 'science'. Nobody seems to understand anything but everybody wants to apply a statistical test. However, this is not a unique case in the archaeologists' technological fascination. Recently, graphic data processing has become one of the archaeological research lines which has profusely implemented the new technologies. In a short period of time, the freehand plots have been replaced by the application of powerful drawing software. In our discipline, the possibilities of these tools are almost infinite and, hence, it does not surprise us that they involve a total 'physical dependence' on its users. We believe, though, that it is dangerous to lose the balance that should exist between the dimension of the problem and the quickest, easiest and most profitable solution. From our point of view, the search for this balanced relation between the problem and the solution has to be made within the frame established by the sentence: '*the easier, the better*'.

In order to illustrate our approach, we have selected a concrete problem. This approach consists of the computer processing of drawings which makes the reconstruction of the stratigraphic sequence of the Túnel VII site (Tierra del Fuego, Argentina) more efficient. Furthermore, it will enable the testing of the observational stratigraphic sequence. The aim of this task is to separate the palimpsest into relevant occupational levels for a socioeconomic explanation.

2.1 The Túnel VII site (Tierra del Fuego, Argentina)

The excavation of the Túnel VII site is part of an ethnoarchaeological research project about Magellan-Fuegian groups of the Beagle Channel, carried out in Tierra del Fuego (Argentina). The project is built on a Spanish-Argentinian cooperation proposal (Piana 1988; Piana *et al.* 1992) aimed to test, archaeologically, the available ethnographic image of these groups. To make this test, we work in recent chronology sites (19th century) with evidence of European contact.

The most salient feature of the Túnel VII site (dated to 100 ± 45 BP) is its intensive reoccupation, for short periods of time, which generates a palimpsest that can be delimited for each hut. Moreover, we should mention the taphonomic specificity of these marine coast sites, because they are anthropogenic shell middens formed by food refuse from mollusc consumption and by remains of the working processes carried out there. The taphonomic specificity complicates the excavation methodology (Orquera/Piana 1989-90, 1992) and, consequently, the reconstruction of the stratigraphic sequence.

2.2 From the palimpsest to the stratigraphic sequence

During the excavation we attempt to dissect the palimpsest of the shell midden by delimiting the extraction subunits which are called ‘sub-shell middens’. This procedure should enable us to obtain an approximate image of the depositional sequence and of the taphonomic dynamics of the site. The main problem is to correlate the different subunits, which are overlapping in the configuration of the shell midden, in order to obtain an approximation of the social activity that they represent. The explanation of the site dynamics lies in the building of an ‘ideal’ stratigraphic sequence that can be tested against the photographic record and the refitting between the lithic or bone remains. To do so, it is very important to count on graphic representations of the subunits delimitation.

At first, the drawings were made from the coordinates record of several points which delimit the shape of the extracted subunits. Our proposal is simply to facilitate the obtaining of these plots by using simple computer-based tools. By doing this we wish to make its handling more efficient for testing the hypotheses about the stratigraphic sequence.

3 The computer-graphic approach

Since the problem is simple, the computer solution should be simple too. It is not necessary to turn to complex tools of graphic design to obtain simple two-dimensional representations. From the first moment, the computer design is based on the combination of conventional software tools which enable the transfer of numerical information to graphic image. However, the adjustment to the data set has already imposed certain restrictions on the first implemented design. These restrictions minimize some agility in its management. The operational scheme in the Apple Macintosh platform consists of the following steps:

a. Building an ASCII file with the coordinates of the points that form the delimitation of every subunit. The coordinates can be obtained from a data base or can be introduced from a text editor.
b. Obtaining a graphic image of the delimitation by means of a simple program in BASIC language. This will allow the generation of hard copies (printed or plotted) or files in PICT format.
c. Recovering the graphic files from an adequate software for the management of drawings. We have mainly used MacDraw, because it is user-friendly. However, it is preferable to work with Canvas because it enables you to combine, in an easy way, many drawings and to generate overlapping or sequentially enchained layers.

All in all, the procedure always includes three main steps:
a) to generate the initial subunit delimitation,
b) to import this drawing from a graphic software, and
c) to handle the obtained drawings.

In a second stage, we have tried to improve the chaining between the different types of selected software. The ideal operational scheme implies the following steps:

1. Capturing the subunits’ delimitation in the excavation by recording points, an automated process if done with the help of a total station. Having carried out this first step, it is easy to create files in ASCII format. Another possibility is to digitize or scan the image and save it in PICT format.
2. Recovering the coordinates files from the software Surface, in order to obtain the delimitation plots (outlines). The drawing should be saved in PICT format (fig. 1).
3. Importing the PICT drawings from a software such as Canvas. Canvas facilitates its correction and, henceforth,

the handling of the different subunits' delimitation can be carried out. This implies the use of graphic software as an adequate platform for the efficient management of data. With this software package we are able to create new graphic representations by simple cut & paste operations. And so, Canvas becomes a very flexible visual tool that enables us to study the overlapping or isolation of the subunits.

It is also feasible to combine the delimitation plots with distribution plots of the material remains. With the processing of the different delimitations we can make hypotheses about the stratigraphic sequence, testing, that way, the field observations (fig. 2).

4 Summary and conclusions

The aim of this work was to provide a brief example of the controlled application of a design for graphic data processing. Since the problem is very simple, we have tried to provide a simple solution based on the combination of commercial software. With the graphic processing we tried to facilitate the determination of observational criteria for the delimitation and location of the subunits which form the studied shell midden. In order to carry out the testing work of the draw hypotheses on the excavated area stratigraphy, it was necessary to rebuild the sequence but in an inverted way, that is, beginning from the successive subunits overlapping along the different occupational stages.

The making of the subunits' delimitation plots and their combination in a computer-based platform has been an easy and adequate solution to the assessment of stratigraphical or spatial hypotheses. Moreover, it is possible to generate in a second stage of the analysis a dynamic vision of the stratigraphic sequence by chaining the layers or by QuickTime 'animations'. In any case, the most important idea lies in the control of the selected tool, in order to achieve relevant results which agree with the features of the posed problems.

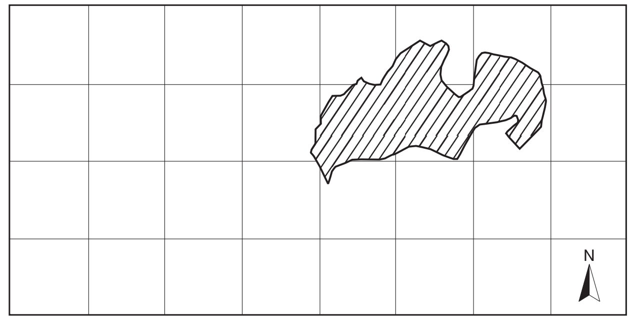

Figure 1. An example of a PICT file. The drawing shows an excavation grid and a subunit delimitation from the Túnel VII site (Tierra del Fuego).

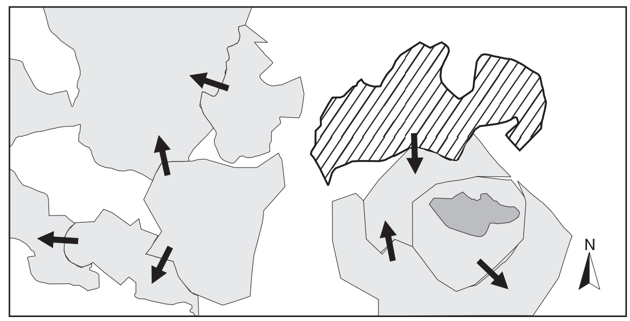

Figure 2. Example of a stratigraphic sequence of the Túnel VII site. We show the overlapping of subunits that belong to the same occupational stage. The arrows illustrate the hypothesis of depositional dynamics.

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Remote Sensing and GIS in the Study of Roman Centuriation in the Corinthia, Greece

1 Introduction

During the last eight years a computerized architectural and topographical survey, the Corinth Computer Project, has been underway at the site of Ancient Corinth. The work is being carried out by a research team from the Mediterranean Section of The University of Pennsylvania Museum under the auspices of the Corinth Excavations of the American School of Classical Studies at Athens, Dr Charles K. Williams II, Director.[1] A brief summary of elements of this long-term and multifaceted project was presented last year at CAA94 as a part of the consideration of the overall methodology and techniques of the work (Romano/Tolba 1995). The overall project is under the direction of the senior author and was initiated in 1988. Since 1992 O. Tolba as a Research Intern has been working with remote sensing and GIS applications especially with respect to centuriation studies of the Corinthia.

One of the primary objectives of the project has been the definition of the plan of the urban Roman colony of 44 BC, *Colonia Laus Iulia Corinthiensis*. A separate element of the work is presented here, an aspect of the study of Roman agricultural land planning, centuriation, which has been documented in and around the colony, specifically the area between Corinth and the ancient city of Sikyon, 17 km to the northwest.[2] The area under present study, approximately 150 square kilometres, is roughly that found between the Helisson river to the north and west of Sikyon and the Xerias river to the east of Corinth, a stretch of mostly flat coastal land which, judging from its modern day fertility and intensive use, must have been highly prized and greatly utilized in antiquity.

The centuriation of agricultural land was a well-known aspect of Roman land planning and is documented from many parts of the Roman world (see, for instance, Dilke 1971; Clavel-Leveque 1983). In recent years a number of examples of Roman centuriation has been described in mainland Greece.[3] For the past few years we have been aware that the land between Sikyon and Corinth was centuriated and that much of the organization fits around the south side of the Corinthian Gulf so as to respect this natural topographic feature. To date, a number of systems of organization have been defined in this area, at least one of which appears to be linked in a series of grids. It has been our interest to define each of these systems, examining the size and relationship of the systems internally and in relation to each other.

2 Project Result Summary

The following is a preliminary summary of the results of the study to date. One system (Land Division System A) is characterized by a series of linked grids of 16 × 24 *actus* units (1 *actus* = 120 Roman feet).[4] This system is set out with respect to the topographical location of the Corinthian Gulf to the north and the plateau that borders the plain to the south (figs 1, 2). Some centuriation extends as far as seven kilometres to the south of the Gulf. Remains of other schemes of centuriation have been defined in the same areas, although the internal relationship between these grids is not as clear. There is reason to believe that these are successive systems in the same area of land.

2.1 Land Division System A

Five linked grids (A1-A5) composed of 16 × 24 *actus* units are identified between Ancient Sikyon and Ancient Corinth (fig. 1). Each grid is characterized by the fact that it meets its neighbouring grid at an angle of slightly more than 14 degrees (fig. 3). Outlines of the overall grid are present in the 1:5000 topographical maps, from the evidence of the field and property lines and roadways, as well as from the SPOT satellite image (see discussion below, Methodology). A principal element of this land division system A is found in grid A3 where there is a dominant line in the landscape, a *limes* of the 16 × 24 grid, found in a northwest-southeast direction. This dominant line extends *c.* 3400 m along the line of the land organization of grid A3 and then continues in a straight line, although at an oblique angle to the land organization system, across the neighbouring grid A2 for an additional *c.* 3500 m (fig. 1). Two corners of the 16 × 24 *actus* units of A2 are the end-points of the oblique line. A field examination of this line shows that it is a modern paved roadway for much of its approximately 9 kilometres of length although a 1.4 km section of the road remains unpaved as a dirt road. The road extends an additional 1200 m further where it crosses the

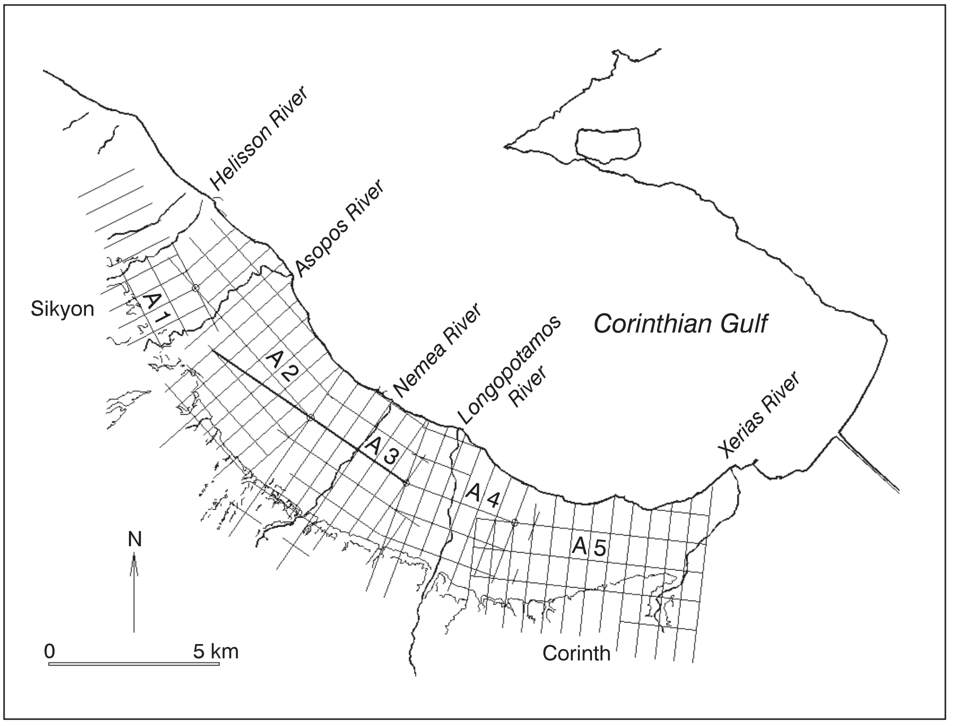

Figure 1. Region of the study between the ancient cities of Corinth and Sikyon illustrating Land System A.

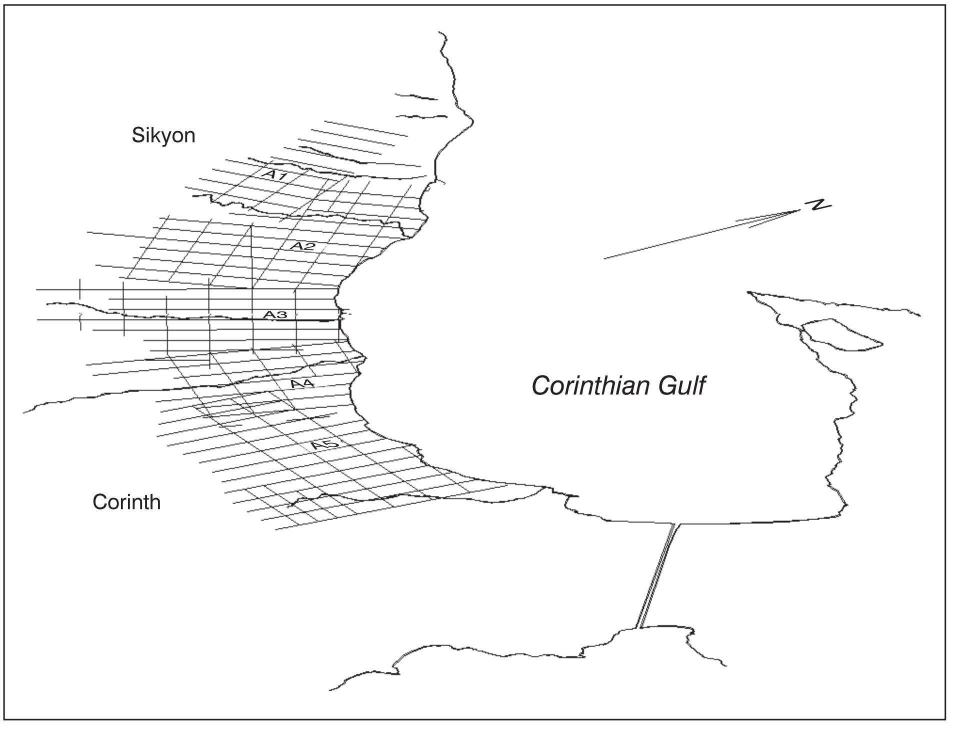

Figure 2. Simulated aerial view of the region of study from the southeast illustrating Land System A conforming to the south coast of the Corinthian Gulf.

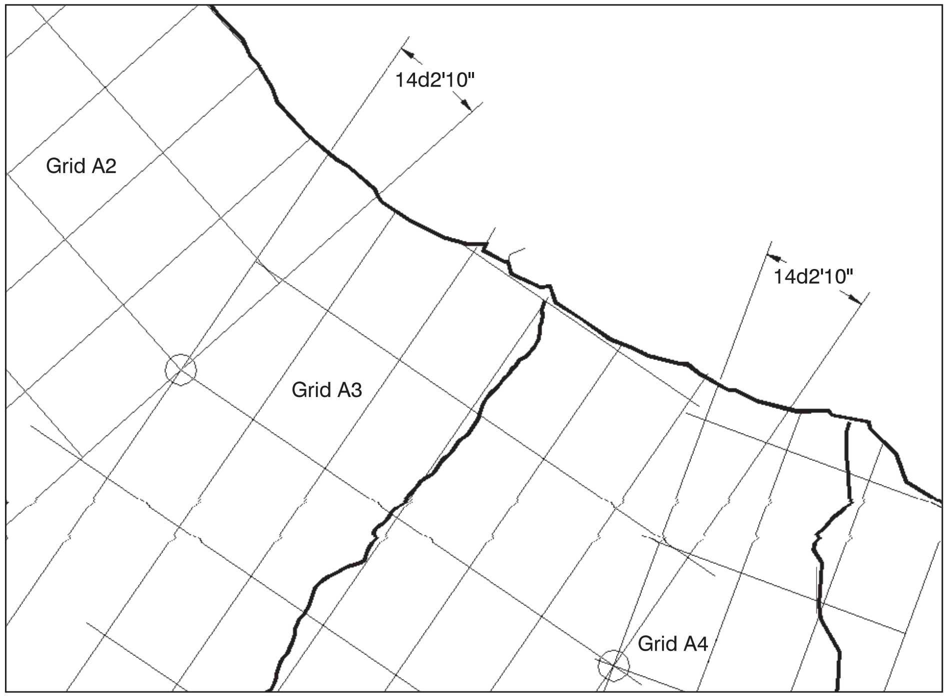

Figure 3. Detail of Land System A illustrating the linking of grids A2 with A3 and A3 with A4 showing, in each case, the joining angle of 14 degrees, 2 minutes and 10 seconds.

Asopos river, to the southeast of the ancient city of Sikyon. It is known in the modern day as the ODOS SIKYONOS, the Sikyonian Road. Besides its clear association with the Roman land division, two other facts suggest that this portion of the road is ancient. Firstly, there is a short section of the roadway that is no longer a thoroughfare of any kind since a church has been built in the line of the road. Secondly, it points in a direct line, in a generally southeast direction at the ancient city of Corinth (fig. 4).[5]

The area of meeting of grid A2 and A3 demonstrates the angle created by the joining grids (fig. 3). The angle of the intersection has been recorded from the modern property lines and roads of the topographical maps and the satellite image, in a number of instances, between 13 degrees 57 minutes to 14 degrees 20 minutes. The same angle of intersection is found in the joining of A4 with A3 as well as A5 with A4. The fact that the oblique line crossing grid A2 intersects two of the corners of the 16 × 24 *actus* grid suggests a trigonometric relationship between the oblique line and the centuriated rectangles. The relationship of the oblique line to the rectangles is 24:96 or 1:4.[6] This fits very well with our observations and indicates that the Roman surveyors used 1/4 relationships in laying out the grids.

The grid A5 which is found in the area of ancient Corinth has the same organization that has been identified and described previously (see discussion below) although some modification may need to be made with respect to the size of the centuriation module[7] (Romano 1993: 23-26).

The pattern of the modern fields and roadways that still retain the orientation of the Land Division System A are shown in figure 5. It seems clear that the Sikyonian Road, which is the oblique roadway of grid A2, is an important element of the linking of grids A2 and A3. In fact, the orientation of a certain portion of the fields to the south of the Sikyonian Road in grid A2 show that they continue to be oriented with the alignment of grid A3. From a preliminary analysis of the remaining land to the east of Corinth as far as Cenchreai it appears that the system of linking grids may continue to the Saronic Gulf.

2.2 Land Division System B

A second series of five grids (B1-B5) are being defined between Ancient Sikyon and Ancient Corinth, roughly the same area as that described above for Land System A. The study and analysis of this land division system is currently in progress.

3 Historical and Chronological Considerations

Although it is very difficult to accurately date the systems of centuriation defined in this study, it may be possible to eventually date the systems in relative terms. It would seem as a good possibility that system A was conceived of and layed out at a single time. The Sikyonian Road is an important element of the A system. It forms part of the A3 grid and it may be argued that the entire land organization system is dependent on its orientation. It is possible,

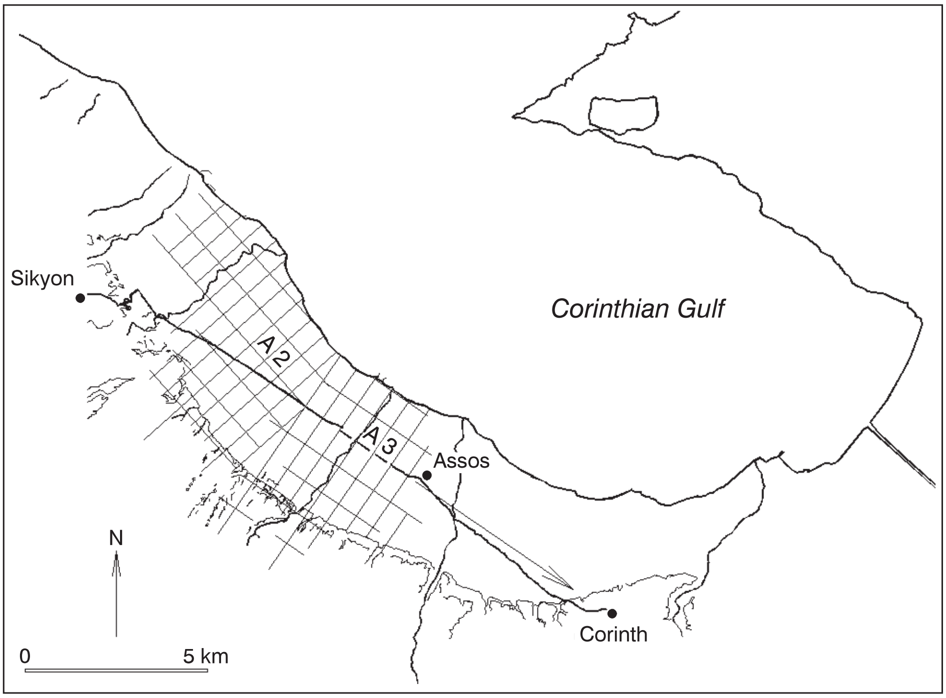

Figure 4. Grids A2 and A3, illustrating the line of the modern road from the location of Ancient Sikyon to near the modern town of Assos. The dashed line represents the portion of the ancient roadway that is no longer a thoroughfare. The arrow indicates the extended line of the roadway towards Ancient Corinth.

however, that when the oblique line, the Sikyonian Road, was layed out the grid was already in place. It is also possible that there existed a Greek road between Corinth and Sikyon that may have in part or in whole taken this orientation, and that the oblique road may have been a straightening out of this road. On balance it seems most likely that the A system and the oblique roadway, now known as the Sikyonian Road, were set out as a part of the same project.

It has been suggested previously that the portion of the A system that is found to the north of the city of Corinth, grid A5, is a portion of the land that was measured out in 111 B.C. as a part of the work described in the Lex Agraria (Romano 1993: 23-26). System A is related to the Sikyonian Road as reflected in the field lines found both to the north and south of the road. This would still seem to be a good likelihood based on the fact that the system seems to have been layed out all at the same time and that it may predate the B Land System.

4 Roman Surveyor's Techniques

The linking of the grids as suggested above conforms to a system of mathematics which may be inferred from observation of similar links in other centuriation systems. Although we have almost no evidence from any other source such as ancient documents, it seems to have been a standard practice of Roman surveyors[8] (Peterson 1992). The system involves the use of the ratio of small integers as a primary means of creating alignment of roadways between neighbouring and related grids. This appears to have been the system employed in the plain at Corinth. The ratio that is documented between grids A2 and A3, both 16 × 24 *actus* grids, is the ratio of 24:96 or 1:4. In a practical sense this would have meant that the *agrimensores* could have used whole multiples of one *actus* units, already employed to lay out the grid system, to determine the alignment of the straight road by measuring out one *actus* in a generally NE direction and 4 *actus* in a generally SE direction. Furthermore, the fact that the ends of the straight road segment intersect the corners of the grid suggests that this was a feature of organization that was an integral part of the centuriation system (fig. 1).

5 Methodology

The project's data set is composed primarily of AutoCAD drawing files. These include digitized 1:2000 and 1:5000 topographical maps, actual state plans, survey coordinates downloaded from the electronic total station, and all the analytical studies.[9] The results discussed in this paper have been achieved through the study of satellite imagery and topographical maps.

5.1 Satellite Imagery

It has been noted that SPOT satellite imagery has proven helpful in the identification of uniform grids of field sys-

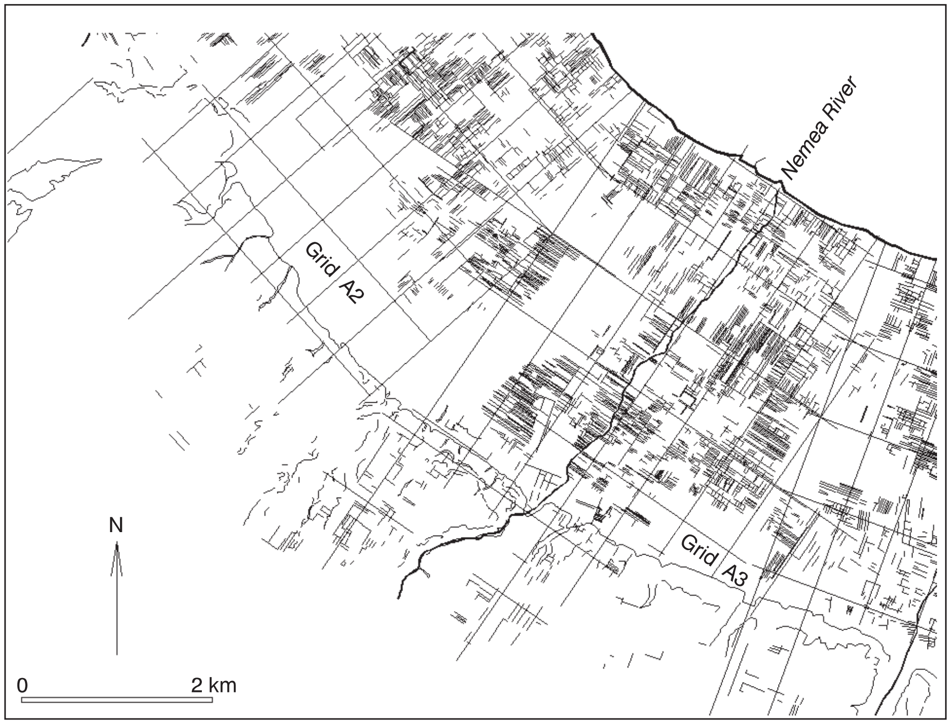

Figure 5. Detail of Land System A showing the digitized individual property lines, field lines, paths and roadways from the areas of grids A2 and A3. The oblique road of Grid A2 is visible where the field lines of Grid A2 are in keeping with the field system of grid A3.

tems possibly of Roman origin. The reason for acquiring these images was to expand on the study of the Roman colony and its territory begun by the main author in 1988, which showed evidence for centuriation in the area to the north of Corinth. It was crucial, therefore, that this new data set would be acquired in a format that matches the existing data sets. SPOT company rectified the images and delivered them in UTM projection as requested. UTM map projection is suitable for this study since the work requires accurate measurement of azimuth and distances. Additional image processing techniques, available in IDRISI, Clark University, were employed to enhance the visual clarity of the images. IDRISI's edge enhancement filter and contrast stretch functions were quite satisfactory.

5.2 Topographical Maps

Although the main roads and general pattern of agricultural fields are visible in the satellite images, it is not possible to distinguish the individual field boundaries and the minor paths. It was necessary, therefore, to verify and augment the initial results found by studying the satellite images with detailed maps of the study area. Since maps at 1:2000 scale were not available for the entire area extending from Corinth towards Sikyon, the project acquired more than thirty 1:5000 maps from the Greek Army Mapping Service extending west towards Sikyon and east towards Cenchreai on the Saronic Gulf. The entire area covered by these maps (26 × 22 kilometres) encompasses much of northern Corinthia.

The topographical maps were scanned using an 8.5 × 14 inches flatbed scanner in order to avoid the time needed to trace all the lines on a digitizer tablet. Each map was scanned in several smaller pieces at the resolution of 100 dpi, then the pieces were matched and merged into one larger TIFF file using CAD Overlay GSX. The calibration of the maps was possible since the coordinates are given for the corners of each map and marks are drawn at 500-metre intervals. It was also possible to print the maps and the satellite imagery on letter size paper to aid in field examination and navigation. The order of accuracy of these maps is approximately 5 metres, while the resolution of the satellite images is 10 metres.

5.3 Analysis and Model Testing

The study began by tracing over parallel roads, as seen in the satellite image, and measuring their azimuth and spacings. These lines were stored in AutoCAD drawings with the aid of CAD Overlay GSX, Image Systems Technology, which facilitates the display of images within AutoCAD. By comparing the spacings of the roads to multiples of the Roman *actus* it became evident that many of these measurements correspond to 16 and 24 *actus*. A hypothetical model of Roman centuriation was constructed as a grid of 16 × 24 *actus*. It was possible to rotate this grid and move it across the AutoCAD drawing in order to achieve the best match with the recorded evidence. In some areas it was easy to find the match; in others it seems that overlapping uses of the land have produced a very complex pattern. Therefore, it was necessary to compile a drawing of the field boundaries and paths that correspond with the alignment of the hypothetical grids (fig. 5). This drawing was useful in the identification of the spacings of the grids as well as their exact locations.

By constructing many of these grids, it was noticed that the field systems changed their orientation as they wrapped around the south coast of the Corinthian Gulf (fig. 1). The consistency with which their azimuth was changing alerted the project team to study the possible schemes the Roman surveyors would have used to lay out these rotating grids. At first, it was thought that the surveyors may have rotated the grids using fractions of the circle, for example 15 degrees. However, when a fifteen-degree rotation was imposed on the grids the accumulated error was unacceptable. An angle closer to 14 degrees was more favourable but could not be constructed using fractions of the circle. Therefore, an investigation of possible oblique surveying techniques started with comparing the measured angle with whole ratios. The closest ratio was determined to be the tangent of 1:4. Most of the gathered evidence fitted this hypothesis within one degree. This relationship did not only seem to be consistent with the grid dimensions, which are multiples of four *actus*, but also a simpler technique for the ancient surveyors than the division of circles.[10]

6 Future Directions

The study of the centuriation systems in the immediate area of Corinth is continuing towards the Corinthian port of Cenchreai on the Saronic Gulf. With the use of 1:5000 topographical maps and SPOT satellite images the areas shall be considered in the same way in which the area between Corinth and Sikyon has been presented.

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notes

1 During each summer of the survey project, the work has been carried out as a part of the architectural aspect of the Spring Training Seasons of the Corinth Excavations. The annual reports of the excavations appear in Hesperia, the Journal of the American School of Classical Studies at Athens.

2 The authors thank Mr Jeremy Hartnett of the Department of Classics, Wabash College, Crawfordsville, Indiana for assistance during the summer of 1994 concerning the definition and interpretation of the trigonometric relationship of the land systems described below.

3 Early notice of centuriation in Greece was made by R. Chevallier (1958). More recent articles include P. Doukellis (1988); P. Doukellis and E. Fouache (1992); A. Rizakis (1990).

4 The dimensions of the grid were determined from the computerized mapping process, specifically the measurement between significant roadways, field and property lines in the landscape. The result where 16 × 24 *actus* units is 566.4 × 849.6 m, gives a (local) Roman foot of 0.295 m.

5 The centuriation of a similar area of the Corinthian coastal plain has been recently studied and published by P. Doukellis (1994). Doukellis describes two schemes of centuriation, one of which he associates with the Lex Agraria of 111 BC (his fig. 9) and the other of which he associates with the colony of 44 BC (his fig. 3). Doukellis' grid of 111 BC roughly corresponds with the orientation of land system, A3, and his colonial grid roughly corresponds with the orientation of the Roman colony as previously published in Romano (1993).

6 This type of relationship is discussed in Peterson (1992), 185-196.

7 Above note 5.

8 See above note 6.

9 For a complete description of the project hardware, software, and data set see Romano and Tolba (1995).

10 This conclusion, on the most likely surveying technique, was reached independently of the suggestions made by Peterson, note 6.

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An application of GIS intra-site analysis to Museum Display

1 Introduction

At CAA94 we showed a research oriented ARC/INFO application of GIS to intra-site spatial analysis (Quesada *et al*. 1995). A topographical map of the 500-plus cremation graves was matched with a complete database including type of grave, area and volume of the tumuli, chronology, sex, different categories of grave goods, two different criteria for assessing wealth (wealth units and number of objects) and other data.

This application provided a quick and easy screen or printed output of different maps according to varying criteria: distribution of graves according to sex, wealth, date and all combinations of these and many other data. Many hypotheses were put forward and tested using these results. It was soon clear that only the use of a computerised GIS database allowed the formulation of many tests, which would otherwise have been very tedious and time consuming, or simply unaffordable in terms of time and the cost of manually producing dozens of different distribution maps. Some preliminary results of this research, involving the initial layout of the cemetery and some spatial analysis based on grave distribution were shown at CAA94. In the near future, the digitized area will be integrated into the wider topographical and archaeological framework of the area, including the settlement situated a few metres away to the east, and the sanctuary, built onto a ridge to the south.

From the very beginning this project was also designed to allow a completely different and complementary approach, using the same set of data and software, and thus maximizing the results of the original digitization and input of data.

The ‘El Cigarralejo’ site has been excavated for nearly forty years, yielding thousands of objects, so much so that a small but complete monographic Museum was opened two years ago in a small palace near the site, in the neighbouring town of Mula (Murcia). The Museum was specifically designed to house the finds from that site, being intended both as a research and tourist centre. It was then decided that a public access, Museum display oriented application should be designed, for use only in this Museum, taking our research database and maps as a starting point, and thus optimizing our efforts. This is the application we are presenting now: it is intended in the first place as tool for the small Museum staff and visiting researchers, not conversant with the intricacies of AML programming, and, secondly, for gallery display. In the latter case, some features shall be simplified, some options blocked to avoid a too complicated interaction with visitors, and, if possible, a touch-screen will substitute the mouse.

The application has been designed using our main research tool, ARC/INFO, as its information is originally intended for complex use including 3-D data, but it will be soon adapted into AVENUE for use in a PC environment, which any small museum can afford.

2 The site

El Cigarralejo (Mula, Murcia) is one of the best known Iberian cemeteries. More than 500 graves have been excavated, accounting for almost all the space in the cemetery. Only 350 of these have been published so far (Cuadrado 1987), but our work takes all the graves in the site into account. The site was used between the first quarter of the 4th century BC and the end of the 2nd century BC, although most of the graves can be dated to the 4th century BC.

The funerary rite used was the usual in the Iberian culture: cremation of the body — outside the grave enclosure — moving of the ashes to the grave; and deposition of the cremated remains in an urn or directly in a grave or pit, together with a fairly large number of grave goods. The graves can be divided into two basic types: simple burials in an uncovered shallow pit, and burials in a pit covered by a quadrangular or rectangular tumulus of stones and mudbricks with a small mudbrick tower on top, or even with a stone monument (a tower-like *stele* or pillar), decorated with anthropomorphic or zoomorphic stone sculptures.

Because of the shortage of available space, or for social, religious or other reasons, the graves were literally heaped together in a very confined space, and as many as eight levels of tumuli overlap each other. These overlapping levels (an average of four in the cemetery as a whole) considerably hamper excavation and interpretation, but are of great assistance in establishing the relative and absolute

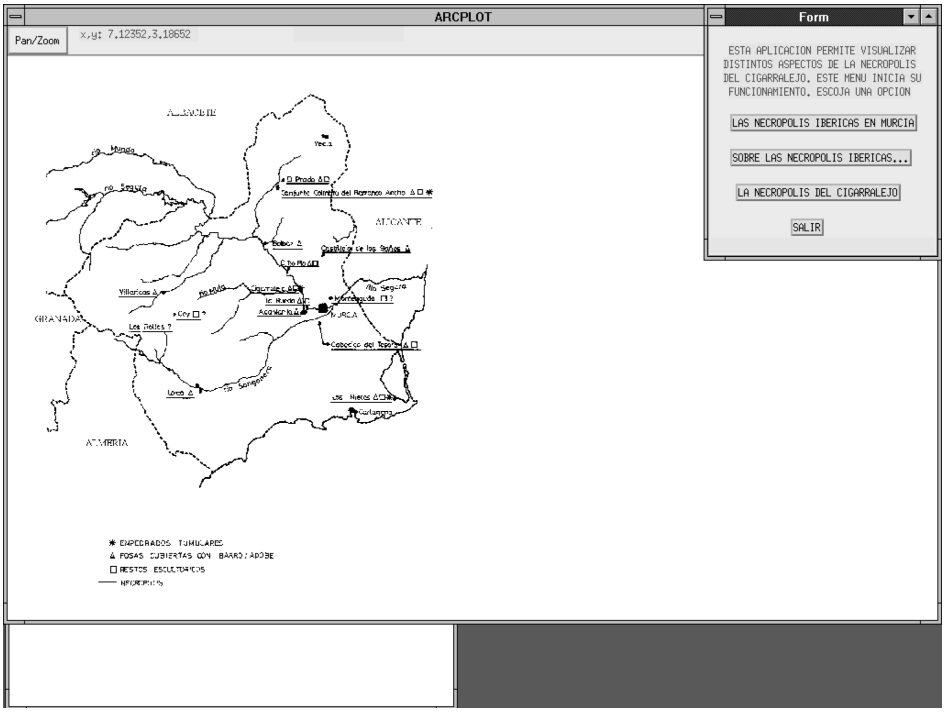

Figure 1. The Main Menu.

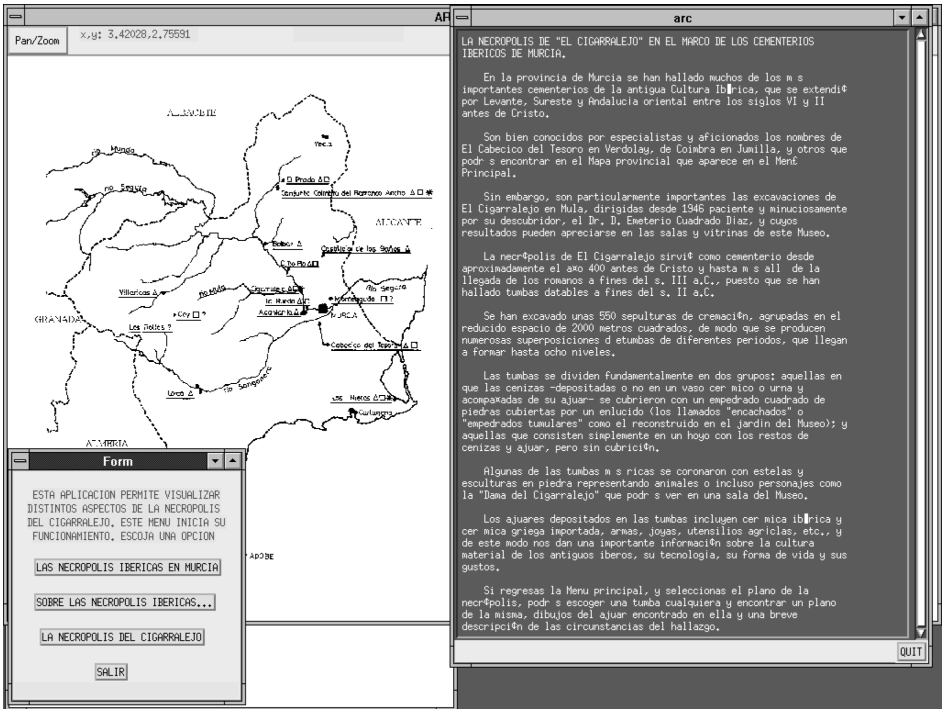

Figure 2. A short description of the 'El Cigarralejo' site in its regional context.

Figure 3. A map of the 'El Cigarralejo' site.

Figure 4. Zoomed in on the map of the 'El Cigarralejo' site.

dating of the various burials. By combining the stratigraphic sequence of the superimposed graves with the dates provided by the abundant black glaze imported pottery that appears in a large proportion of the grave goods, it has been possible to propose a fairly precise chronology for most of the graves, with margins of error of as low as 25 years.

The concentration of many graves within such a small space produces a great deal of archaeological 'noise', because the graves of different periods and characteristics have become intermixed. Any attempt to carry out a social analysis of the cemetery (horizontal stratigraphy, family clusters, hierarchical stratification of the community, sexual distinctions, etc.) had to start with the production of a great many thematic maps.

3 A museum-oriented application

This application has been built using the AML programming language, used by the ARC/INFO package used by our team in the different GIS studies within our general research Project 'GIS and Spatial Archaeology', funded by the DGYCIT and carried out in the Dept. of Prehistory and Archaeology, Universidad Autónoma de Madrid, together with the Cartographic service of this University.

The structure of the application, built on the abovementioned databases (ARC/INFO digitization modules and dBASE III+ character and numeric fields), has been kept deliberately simple and straightforward to allow its use by non-trained staff and visiting scholars to the Museum, although a further simplification will probably be necessary to eliminate any possible 'bugs' which can hinder the smooth running of the program in the hands of non-experts.

The Main Menu (fig. 1) offers three options and a fourth, 'Exit' option:

A This option shows a general map of the Murcia province, and the distribution of known Iberian Iron-Age cemeteries. For the moment, this is a simple PCX-format scanned and modified published map (using HP Scanjet Scanner and Photostyler software); but in the future it will be feasible to introduce it as a coverage, using ARC/INFO modules, to allow further development (pointing to different sites in the region and obtaining more information on them).

B This option displays as a new window a short ASCII format textfile. It includes a short description of the 'El Cigarralejo' site in its regional context (fig. 2). The last paragraph invites the reader to quit and return to the Main Menu to display a detailed map of 'El Cigarralejo'.

C This option, 'La necrópolis de El Cigarralejo', initializes the main module, and the user starts a detailed session on the site. There are several options which allow simple and more complex queries.

The available options are as follows:

1/2 'DIBUJO' draws a map of the site (fig. 3). It may be combined with the 'IDENTIFIERS' option to visualize on screen the number of the actual graves, and it can also be combined with the 'zoom' options (fig. 4) which produces redraws of the selected areas in greater detail. As the structure of superimposed tumuli made it difficult to use polygons, each grave has been drawn using arcs.

3 SELECTION. The next option, 'selection', is more complex. By pressing it, a new pull down menu appears (fig. 5). It contains a help window to navigate first-time users, and a series of sub-menus to make selections, which will then appear, highlighted, on the site plan below. For example, it is possible just to write a grave identifier, and the particular tomb will be highlighted in red (using the option 'selection by tomb number'). Much more complex selections can be made by using the next buttons (field, logical condition, value selection) (see fig. 6). It is thus possible to produce partial on-screen maps of the site according to different criteria, such as for instance chronology, sex, wealth, size or any combination of these. The procedure is as follows: first, 'selección del total' starts from the whole database; then, field (sex, size...) and logical and value conditions for them (e.g., whole site/wealth/greater than/66 wealth units). The 'results' button on this pull down menu redraws the screen and plots the tombs fulfilling the desired requirements. This selection process is probably too complex for visitors to the Museum, and should be blocked in a Gallery display.

4 'COLOURS' option: A pull down menu allows the user to change colours or adopt dotted or dashed lines for tombs with a view to printing.

5 'CLEAR SCREEN': A CLS option allows to clean the screen and start again.

6/7 'ZOOM' options are meant to be used in combination with 'draw' and 'selection'. The process of selecting and zooming into a small area of the site by drawing a window with the mouse is explained by a 'help' window. As the layout of the site is complex, this is a very useful option.

8 'IMAGENES'. This option, which has its own on-screen help window, works as follows: The user selects a particular tomb by using the mouse (fig. 7) or by touching the screen. A pair of windows in the shape of a book then appears showing different 'pages' (fig. 8) which can be opened pressing an icon. These pages contain images of the tomb plan and sections, drawings of the grave goods, and a short explanation of its contents, date and other characteristics. For more advanced users, it is possible to access to a new pull

Figure 5. The "selection" option.

Figure 6. More complex selection options.

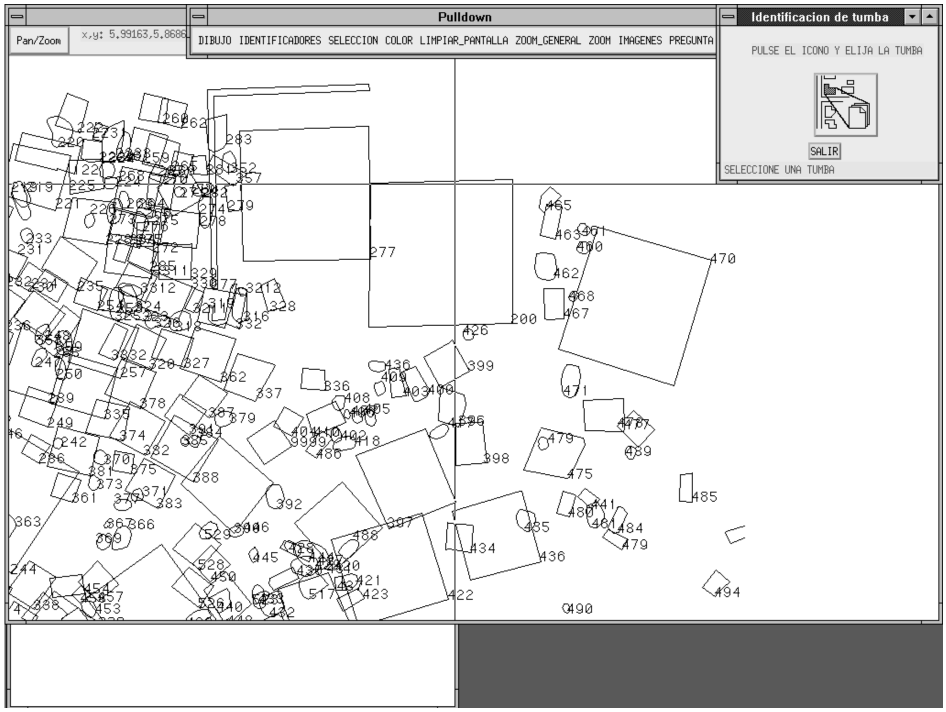

Figure 7. Selection of a particular tomb.

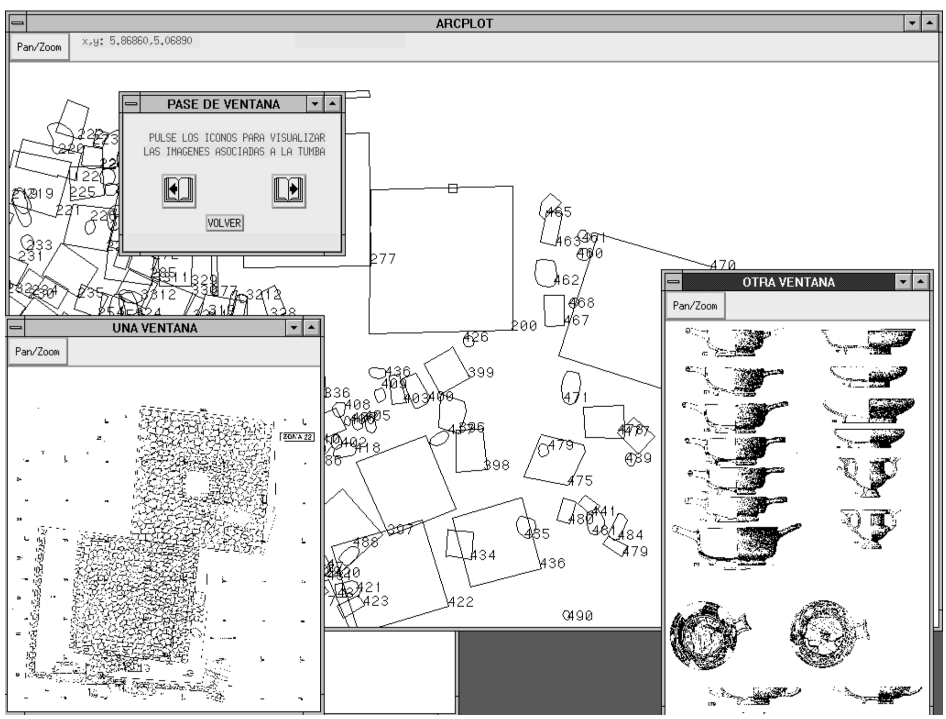

Figure 8. Information about a particular tomb.

down menu (Pan/Zoom) with more complex options, such as Zoom in/out, Scale 1:1, etc., which can be useful for visiting scholars.
Not all the grave goods have yet been scanned and introduced into the database, but it is has been calculated that the whole documentation in PCX format will occupy about 1.8 Gbytes of memory.

9 ‘PREGUNTA’. The query option allows Museum staff and/or visitors a direct access to the alphanumeric database, by an interactive selection with any tomb chosen from the on-screen map. All data on the particular tomb (size, grave goods, chronology, etc.) can then be visualized or printed, as well as other data such as the room/case/magazine in which the grave goods are displayed/stored, and, if necessary, inventory numbers and photographic records.

10 ‘SALIR’. Finally, the ‘quit’ option returns to the Main Menu.

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Education and publication

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Teaching with objects

1 Introduction

Archaeologists know, of course, that objects are not just objects. A layperson with no archaeological knowledge, faced with, say, an Anglo-Saxon cremation urn, would be unable to identify it. There is nothing inherent about that object which could place it in its context of use, or in its place in time. It does not have its country of origin, or its date of manufacture, inscribed on it for all to see. We, as archaeologists, however, know precisely what it is; in what contexts similar objects have been found, and in which areas such urns are thought to originate. This is because we are inculcated with that mass of ideas and information that is archaeological expertise. In our role as teachers, it is our aim to transmit some part of this expertise to our students — to inculcate our students in that mass of information that places objects in context.

Undergraduate teaching is not just about transmitting facts, however. As well as teaching students what to think, we also attempt to teach them how to think. Every discipline revolves around the use of appropriate practices and analytical skills. In archaeology we try to teach the ways in which data can be analysed and evidence interpreted, and to show students how to construct logical and coherent arguments. This paper will describe a computing application under development, the Virtual Teaching Collection, which hopes to support these educational goals.

2 What are Objects and How are they used in Teaching?

If objects do not speak for themselves, what gives them their meaning? In archaeological contexts, the answer to this would arise from a combination of factors:

- In what country or area was it found?
- What was the archaeological context in which it was deposited? (i.e. a cemetery, a settlement?)
- Where, and in what contexts, have similar objects been found?
- What other objects was it associated with?
- Where, and in what contexts, have these associated objects been found?
- What are the academic debates surrounding these objects?
- What consensus has been reached on the nature and dating of these objects?

and so on.

We make sense of an object by placing it in the framework of knowledge which we all create in our careers as archaeologists. An object's positioning in such a framework is reliant on the contextual information available. Through our lectures, practicals, seminars and assigned reading, our students build up a coherent picture of the past. The student increasingly associates a series of initially unrelated objects to information about their use, manufacture, significance and their roles in archaeological debates.

Subsets of these frameworks can be represented as narratives, or stories, in which the objects play a starring role. Teaching is about enabling our students to construct their own frameworks of reference. We do this by creating narratives which our students can grasp; narratives that convey the current issues and significant relationships surrounding those objects. Once they have adequate frameworks constructed out of these narratives, in terms both of facts, and of theories about those facts, then they (hopefully) will be able to critically analyse and interpret further information. These narratives are to some extent personal to the lecturers and students concerned, for they arise out of each individual's own framework of knowledge. Different lecturers will draw on different objects and their related contexts in varying ways in the construction of different (and sometimes contradictory) narratives. The aim of the Virtual Teaching Collection is to provide software tools which offer the flexibility to do this quickly and easily.

3 How is archaeology taught?

The tools which lecturers employ to these ends can be summarised simply as words and pictures. Archaeologists have always used visual representations to talk about their subject. From the time of the earliest antiquarians, their maps, illustrations and later photographs and film have been central modes of presenting information about the past. In the archaeological lecture the backbone of information is provided by the slide illustrations, while the lecturer constructs verbal narratives around these images. The students (those that are still awake) attempt in the darkened room to take notes on what the lecturer is saying, usually mis-spelling site names and object types in the process.

The seminar is more intellectually stimulating, as there is greater interaction between teacher and student. The teacher can, through his or her questioning, and assessment of course-work, determine how much information the student has gained, and can partially reconstruct the frameworks which he or she has constructed around it. This instruction does, however, largely take place without the aid of any illustrations, for the use of slide illustrations is difficult in the more flexible and informal atmosphere of the seminar. Students too, are limited to what can be described in words in the essays which are the standard form in which work is submitted.

An alternative form of instruction which has arisen over the past few years has become known as 'course-ware', fixed packages of information, usually in the form of tutorials, which the student can work through at his or her own pace (Laurillard 1993: 149-162). Such course-ware constitutes a form of publication; it is like a text-book, presenting mediated, and often seemingly authoritative, texts which cannot be changed or adapted by the user, whether that user be student or teacher. We would argue that such packages are of little use in areas which deal with material culture. Objects can be employed in narratives in a multitude of ways, and with the development of new theories and frameworks, those narratives are, and should be, highly changeable. Most archaeological teaching at university level draws on information that is constantly changing. The work of the university lecturer is as much to keep the student abreast of changing information and interpretation as teaching the 'facts' of archaeology. The relatively inflexible nature of course-ware, with programming skills needed to make alterations, necessarily makes it inappropriate for use in such teaching contexts. What is needed instead is a resource base, of images, other representations such as video, sound, 3-D photos and models, and associated contextual data and related texts, which lecturers can draw upon (and add to) in the construction of their narratives, using appropriate software tools in their presentation (Laurillard 1993: 211).

4 The Virtual Teaching Collection

The Virtual Teaching Collection is comprised of two separate entities, the CabiNET software, which provides searching, presentation and narrative tools, and the Archaeology and History of Science Collections which are examples of what can be achieved using CabiNET. CabiNET is perhaps best seen as a computer application like a word-processing or spreadsheet package. By using the software, the user creates, not text documents or spreadsheets, but collections. In the same way that the format of a novel does not determine its contents, CabiNET is merely a tool in the hands of users.

The Collections for archaeology and history of science do not explore the limits of what can be created; they merely give some indication of the possibilities.

4.1 The archaeology and history of science collections

The two Collections that are being initially developed each consist of over 2000 images and other representations of objects, along with the related contextual information for each object or artefact illustrated. Within the Archaeology Collection, these objects span the Neolithic to the Medieval period in Britain. As well as directly related information, such as descriptions of each object and details of its excavation or discovery, the Archaeology Collection will also include text resources, with longer narratives on topics such as typology, chronology and the archaeology of gender, as well as bibliographies, glossaries and pointers to other resources.

These collections will provide a broad resource which can be used to support a variety of different teaching requirements. Though several narratives will be included, these are seen, much as any work, as the view of that author. The resources in the collection can easily be modified, added to and reorganised by the users who will want to create their own narratives for their own teaching needs.

4.2 CabiNET

CabiNET is an easy to use and well presented suite of software tools, engineered in C++. Using these tools, the user can create his or her own collection, and can search, retrieve, display and browse the existing collections. The presentation tools will allow the user to compare different objects, to identify and display significant details, to create links to related images, video and text, and to embed representations in their own authored texts, whether these be straightforward documents, or more complex hyper-textual formats.

The tools have been designed for ease of use. Many of the standard Macintosh features, such as drag and drop, have been adopted, and much thought, including the use of a professional designer, has been given to the graphic design involved in the user interface. It is our intention that users should be able to learn to use CabiNET in a very short period of time, usually less than a day, and to this end the workings of the software are designed to be extremely intuitive.

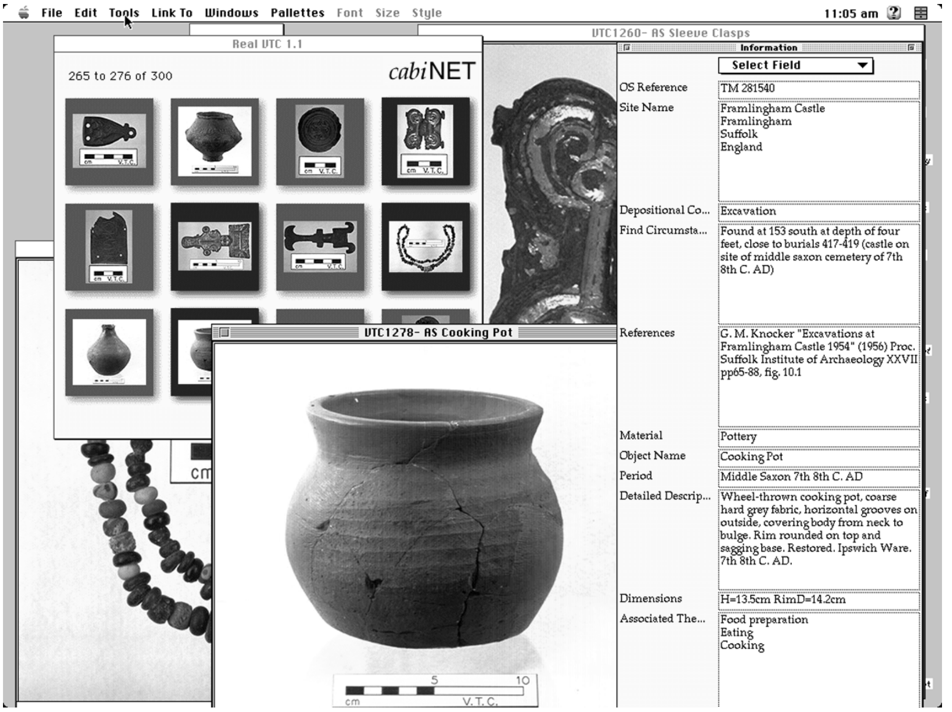

Figure 1. The CabiNET tools.

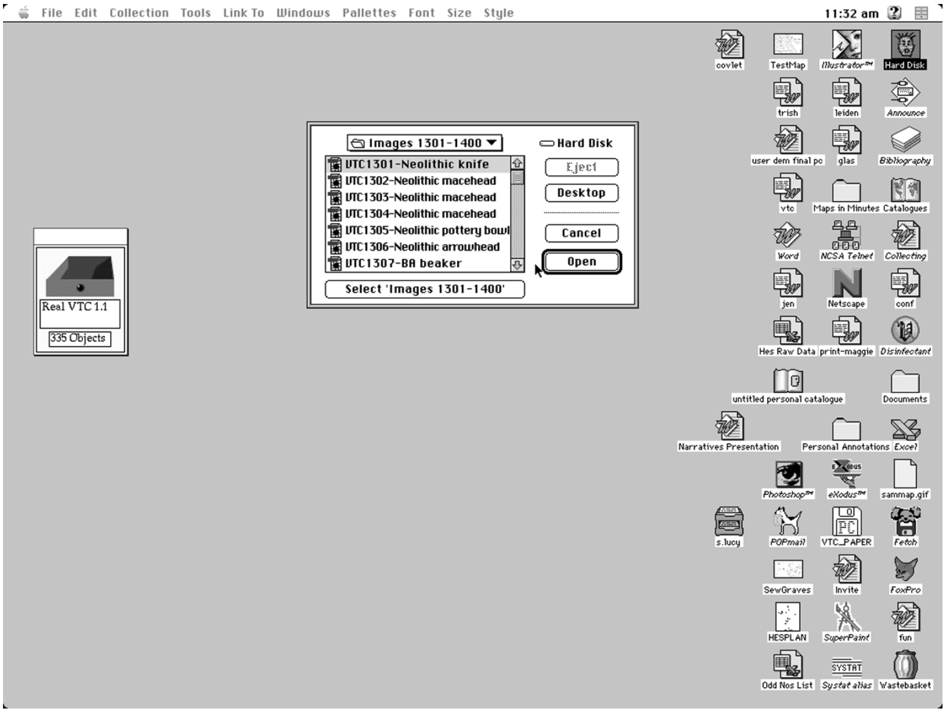

Figure 2. Importing an image into a Collection.

CabiNET is centred around the images and representations of the Collections, whether these collections are those provided or the user's own. It is very simple to import images, texts, video and 3-D representations from the packages which created them into a new or existing collection.

Each object-image is associated with its own database form, containing as much information as possible in fields

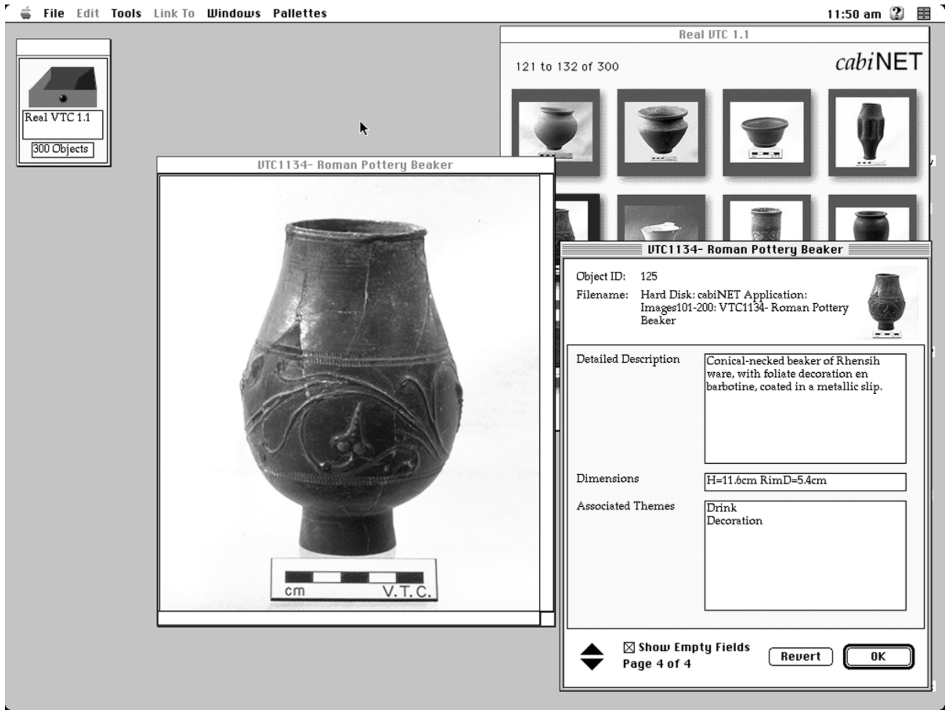

Figure 3. Using the Database form.

specifically designed by the creator of each individual collection. Thus in the Archaeology Collection, these fields relate, among other things, to contexts of discovery and to information about the dating and identification of objects. However, the database form is completely editable so the user can add, edit or delete data as needed. New fields can also be added, old ones deleted, and existing ones altered.

The user can choose to examine the form related to a particular object at any moment, or s/he can choose to have an information window permanently open, displaying selected fields whenever an object window is active. Object-images are thus bundled together with the database forms. They can also be bundled directly with other relevant information, such as descriptions or other texts relating specifically to that object or to other representations of the object. At any time, the user can easily add in similar links.

There are many ways of linking objects together. Images can be directly linked, by the simple gesture of dragging the small icon of one over the large representation of the other, and naming the link.

With the ‘links’ palette open, the user can immediately identify which other objects or texts an image-object is linked to, as soon as that window is clicked on. Images, other representations and texts can all be related to each other in a sort of ‘web’.

Another, more indirect way of linking objects is to include them in a linear, or hyper, text. A user, reading through a written text, can click on a picon (picture icon) to bring up an image of the object under discussion, or on highlighted words to bring up other related information, such as glossary terms, bibliographies, or other related texts. In CabiNET, hypertext links can be made at any time and linked images can simply be dragged and dropped into the text. To forestall the problems of incoherence and navigation in this medium, we have chosen to adopt the standard Mac environment, whereby all windows stay open until explicitly closed by the user. This should help the user locate themselves more readily than in other formats, where only a single window is open at once, or navigation is achieved by the use of directional arrows, or other mapping systems.

As well as linear and hypertextual documents, we are also developing other methods of presentation. One of these is the slideshow. At the moment, this is done by sweeping a selection of objects onto a palette, arranging them in order, then displaying them, using the mouse as the next slide button.

Although some would argue that this is an inefficient way of teaching, considerable improvements can be made by using modern computing technology. It will eventually be possible, using future versions of our slideshow, to show more than one image on the screen at once; to display text alongside these images (thus hopefully preventing comical spelling of names and places); to allow drop-down notations

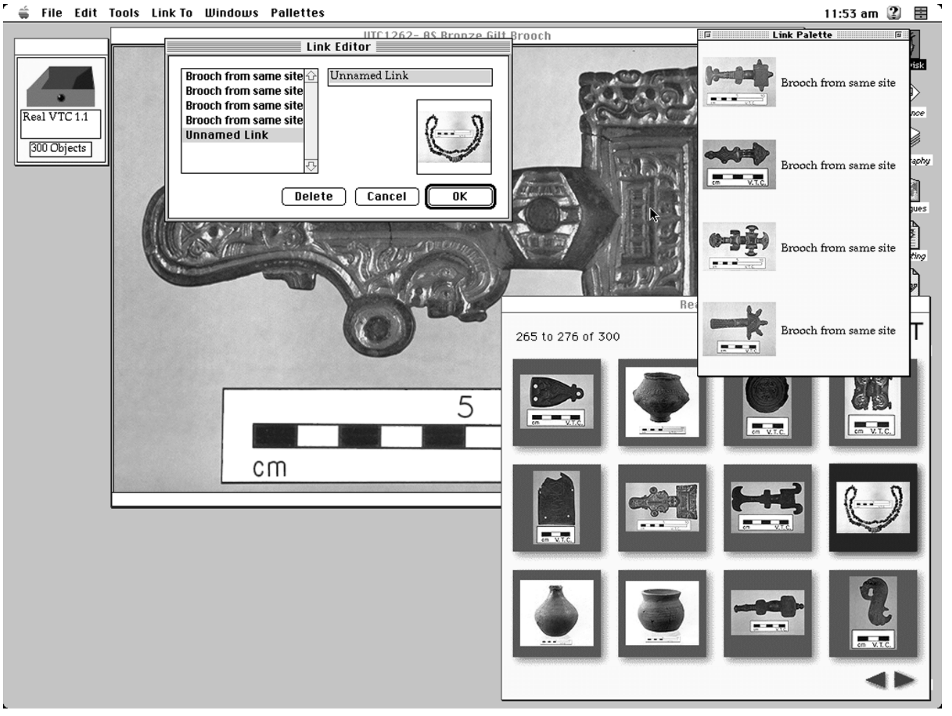

Figure 4. Linking an image to another image.

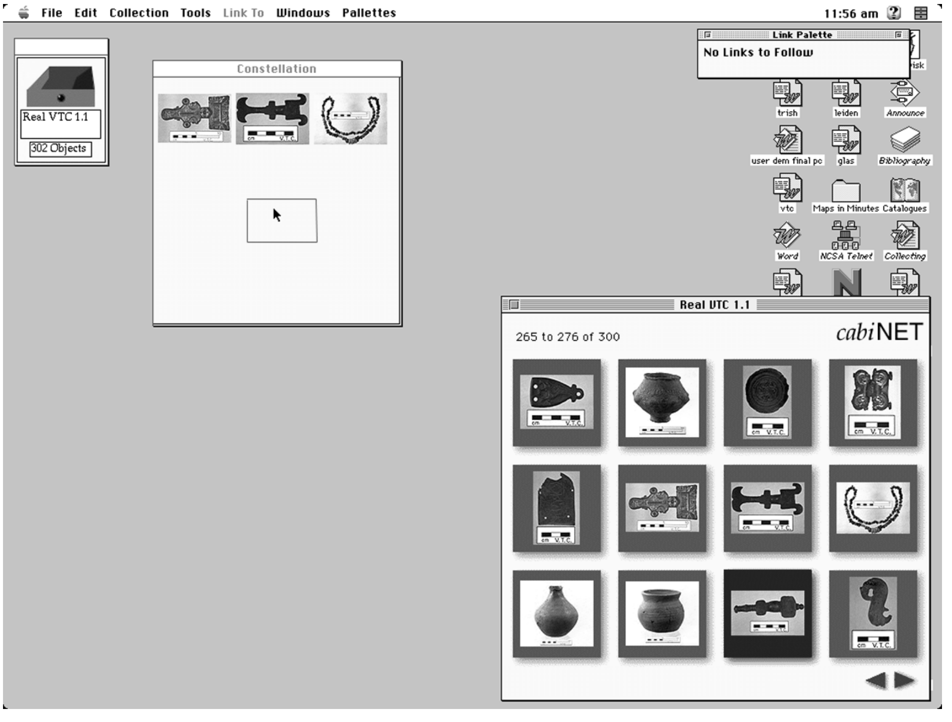

Figure 5. Constructing a Constellation.

to aid description; and to provide more flexibility in display, allowing the user to jump to any point in the sequence at will. Hopefully these innovations will serve to make lecturing more dynamic and informative for the students.

The Virtual Teaching Collection is a very flexible package, and therefore we hope that it will be used in a number of ways. There will of course be those, assuming they can be persuaded to use it in the first place, who will

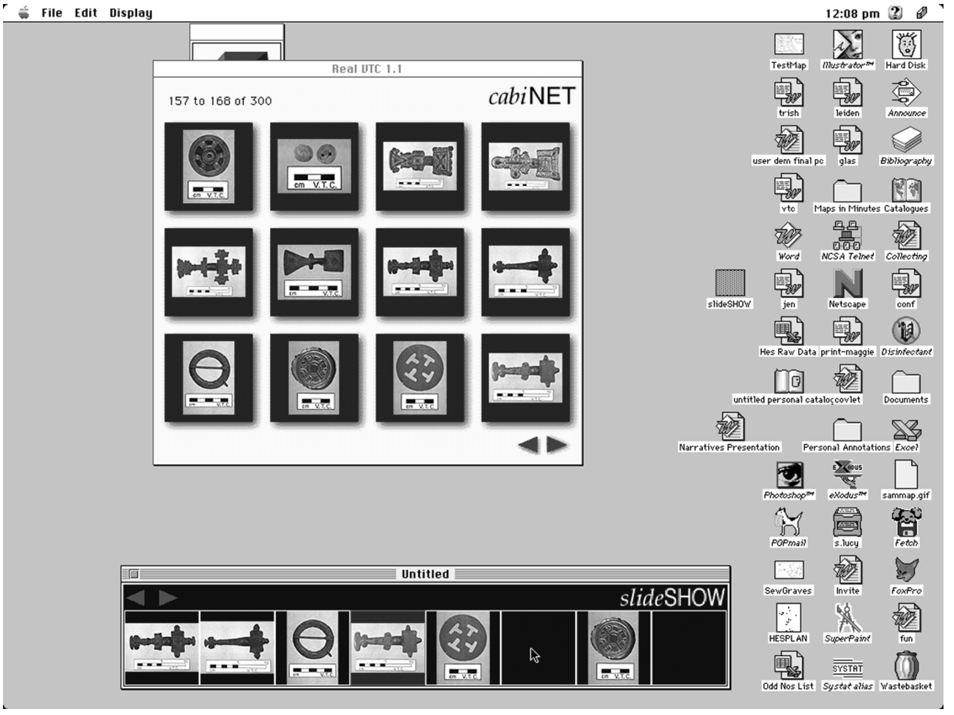

Figure 6. Producing a slideshow.

just use it as a glorified slide collection. We hope, however, that there will be others more willing to explore its potential. We see it being used in the traditional lecture situation, but perhaps with a lecture remaining on open access afterwards for students to work through at their own pace. We see it, perhaps, replacing the lecture to a certain extent, allowing the lecturer more time for the individual tuition which can transform a student's understanding. We would also like to see students themselves using the software to create their own presentations, perhaps as seminar work, perhaps even as a replacement for the traditional essay. Given the highly visual nature of archaeology, it does seem a little strange that the vast majority of our students' work goes unillustrated.

5 Conclusions

The Virtual Teaching Collection aims to combat problems of access in archaeology and history of science teaching collections, and, in the course of this, explore how we can better use objects in teaching. For those departments without their own teaching collection, the Archaeology Collection represents a valuable resource which can be drawn upon at all levels of teaching. Even for those departments with such collections, the Virtual Teaching Collection, uniquely, offers easy access to the related contextual information about artefacts which is so often confined to museum accession registers. It also represents an expanded resource which students can draw upon in their own work.

The flexibility of the presentation tools frees the lecturer from the rigidity of the slide presentation and brings the full potential of related information to their presentations. There is increased freedom of movement between images, and these can be placed in more than one narrative at a time. Objects can also be freely associated with each other and with explanatory texts. It also provides a more interactive resource than a lecturer's slide collection, or the objects in a teaching collection. Students can easily access information about objects, and can examine links which the lecturer has already created within the Collection.

Obviously, the images within a Collection cannot replace the actual objects. There can be no substitute for the actual look and feel of an object. However, to restate the point made in the introduction, objects gain their meanings from context. The use of CabiNET can make access to such contexts simpler and easier, facilitating the creation of narratives which draw upon a rich visual and textual resource.

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Teaching the Visualisation of Landscapes – Approaches in Computer based learning for Archaeologists

The Visualisation of Landscapes project is a University of Bristol funded teaching initiative. This project is an inter-disciplinary exercise into the interpretation of archaeological data with the aid of computer technology, in order to visualise landscapes: from those that exist in the broad physical geographic sense, to those that make up the internal features of an individual archaeological site. The eventual results will be packaged so that they can be used in first and second year undergraduate teaching.

This paper will describe the details of the project and the implications that multi-disciplinary collaboration have for the future of archaeological education.

1 Introduction

1.1 The Visualisation of Landscapes Project

The Visualisation of Landscapes Project (VLP) is a University of Bristol (UK) funded teaching initiative. It is an interdisciplinary exercise in the development of computer aided interpretation of primary archaeological data. Essentially, the visualisation of landscapes in the full spectrum of scales, from that on the largest scale of physical geographic data to the smallest of the more specific internal features of an individual archaeological site. The impetus behind the initiation of the VLP was the desire to amalgamate the expertise available in several interdisciplinary research projects currently underway within the Departments of Archaeology, Computer Science and Geography. As much of the data of these projects is of a spatial nature it can be thought of as representing a variety of levels of landscape; from the highest level in the 'traditional' geographic based regional landscape, to the medium level, represented by an archaeological feature or site, right down to the smallest level, that of individual finds within an archaeological excavation.

1.2 Aims and objectives

To maximise the potential of these projects the VLP was initiated with the long-term objectives involving the development of the following:

- Computer aided visualisation of landscapes.
- Teaching initiative for first and second year archaeology students.
- Increased computer literacy of archaeology students.
- Greater understanding of archaeological implications and technical parameters for Geography and Computer Science students.

2 The VLP package as Computer Based Learning

2.1 PC based tutorials

The VLP package is being developed as a series of PC based multimedia, interactive tutorials (CBL – Computer Based Learning). Time and development costs permitting, the package will consist of three separate modules covering the concepts and techniques available to archaeologists when interpreting and visualising archaeological landscapes. These tutorials are to be used in conjunction with, and as a supplement to, more 'traditional' practical teaching sessions. Although produced as stand-alone packages, each tutorial will be accompanied by a printed workbook that will put the computer based information into context and act as a source of background reading.

2.2 Integration into current curriculum

The introduction and usage of the tutorials will be fully integrated into the established curriculum and will introduce students to the concepts and ideas behind the visualisation of landscapes and different levels of archaeological data. The inbuilt experimental interaction within the tutorials will allow a 'hands on' approach to the techniques available in the interpretation of archaeological landscapes; enabling staff to create a need to know amongst students, ensuring greater retention and more student responsibility for learning.

2.3 Multimedia ToolBook 3.0

The tutorials are being developed in Asymetrix Multimedia ToolBook 3.0; a relatively simple and easy to learn multimedia authoring package. This particular software has been adopted in many such CBL projects and has been used in Bristol before within the bounds of the TLTP (Archaeology Consortium) central government funded initiative. Issues of screen design and functionality have largely been tackled before and are not the subject for

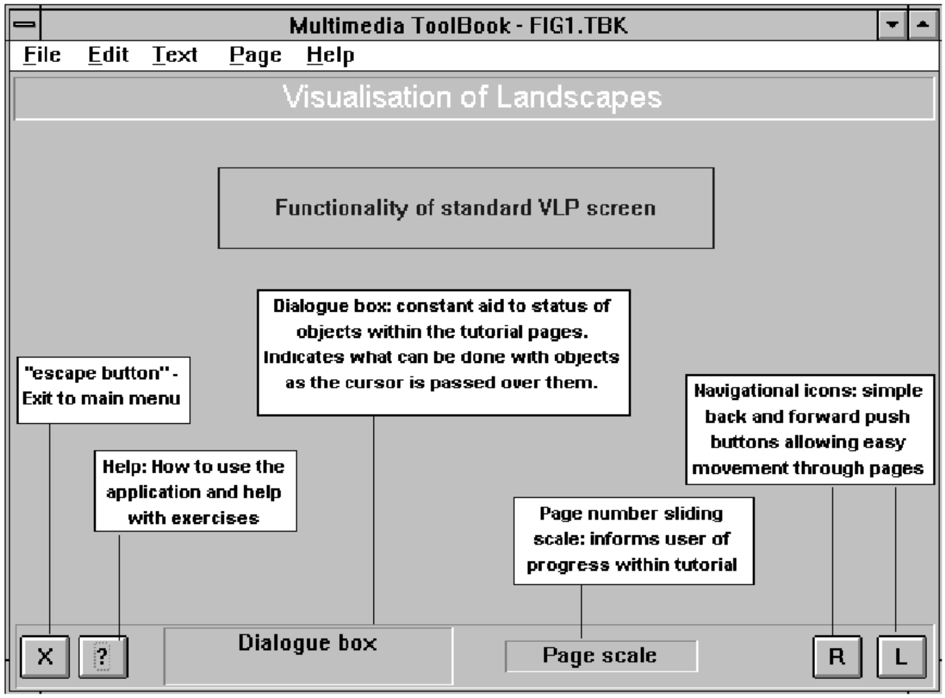

Figure 1. VLP standard page layout and functionality in ToolBook.

discussion here. However, a sample screen is shown as an indication as to the basic presentation and working medium.

2.4 EXPERIMENTAL INTERACTION

Because of the nature of the material, a degree of interaction can be built into the VLP tutorials that is often detrimentally missing from CBL. This interaction will consist of problem solving and 'original' experimental visualisation by each user. Examples of such experimental visualisation might be in the visualisation of, say, Maltese temple structures by a variety of different techniques, or some simple GIS analysis new for each user, as they select which sets of data to use in the visualisation. Because of technical parameters, the number of test landscapes that can be viewed by a user will be limited, as each computer graphic landscape will have to be rendered before inclusion in the tutorial. Hence the experimental landscape viewing will be from a limited data set, although how each student uses this data will appear original. The final result is to produce interaction that genuinely keeps the users' interest and stimulates further investigation into more detailed applications of visualisation.

3 The visualisation of landscapes

3.1 APPROACHES

One of the primary aims of the VLP is to integrate and present the techniques already being utilised by several research projects currently underway within the university. These projects draw heavily on the interpretative value of visualising archaeological data: the INSITE project (Archaeology and Computer Science) looks at reconstruction of archaeological structures as an aid to interpreting ritual (although it also has much wider implications), while the GIS based interpretation of archaeological data (Archaeology and Geography) in central Italy has a large visual content. One of the aims of the VLP is to introduce archaeology students, particularly first and second year undergraduates, to these techniques and concepts. These areas of visualisation are to be supplemented by more traditional methods, as well as some further computer based physical and natural environment visualisation. A series of subject landscapes (in the widest geographical sense) will be used as case studies to show the suite of techniques available to archaeologists that can help them visualise the variety of different scales of landscape, as well as acting as an aid to interpretation of archaeological data.

3.2 Areas involved in the VLP

3.2.1 Gozo, Malta

The temple structures on the islands of Malta form the central thrust of the research within the INSITE project (Chalmers/Stoddart 1995; Chalmers *et al.* 1994). Their computer based reconstruction and analysis will be one of the central parts of the visualisation tutorial for this region. A developing environmental and regional study for the location of the excavated sites will form a further aspect of

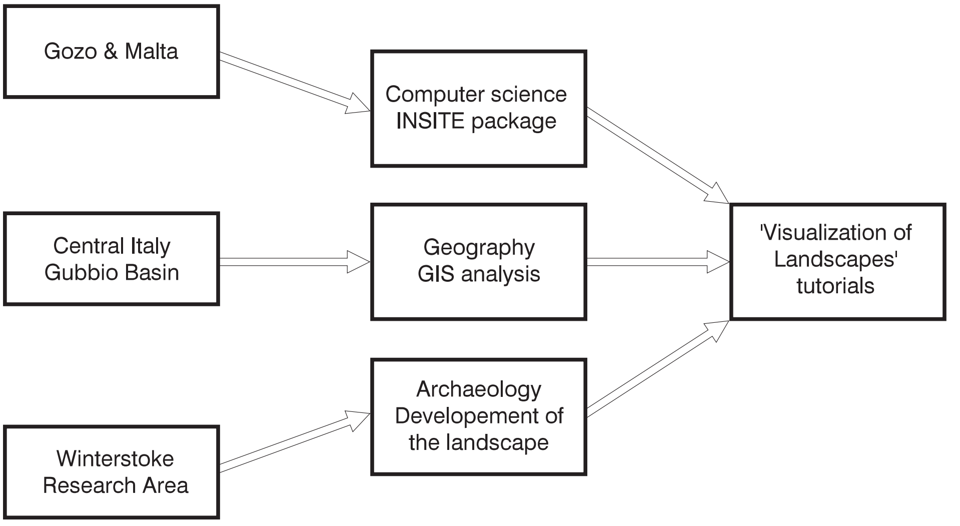

Figure 2. Interdisciplinary links and the visualisations project.

the visualisation, placing the centres of in-depth archaeological research within their wider context of a landscape setting.

3.2.2 South Etruria, Central Italy

The emphasis on visualisation in this area will be on introducing students to GIS and supplementing many of the GIS based analytical images with descriptive and interpretative text and complimentary images. Three-dimensional landscapes will also be modelled (with the data obtained by palaeo-environmental and geomorphological research projects currently underway), producing different landscape and vegetation models for different periods.

3.2.3 Winterstoke research area, Avon and Somerset, UK

The techniques and ideas developed in the previous two projects are to be utilised and built upon in this long term local research project (University of Bristol 1995), resulting in a fully integrated local landscape visualisation methodology. As in the preceding projects a large body of archaeological survey and excavation data is available for setting within its landscape.

4 Inter-disciplinary approaches

4.1 Inter-disciplinary links

The landscape visualisation project makes use of the most up to date analytical tools from a range of disciplines, and thus requires a high degree of inter-disciplinary collaboration (fig. 2). Through the use of the teaching package, students will be introduced to and become familiar with the dynamic inter-disciplinary interaction necessary in order to maximise the information gleaned from the primary archaeological data. Each tutorial will be centred on a geographic area of university research and will utilise a specific set of analytical tools to aid in the interpretation of the associated data. As the projects and VLP proceed a full set of analytical tools will become available for each area. Ultimately each area will contribute a varied approach using the same visualisation techniques which, when incorporated into the computer based tutorials, will facilitate a better understanding of the concepts behind the techniques being employed.

4.2 Input and Benefits

4.2.1 Computer Science

Recent developments in computer graphics have made it possible to construct virtual environments on a computer and view images of these scenes. 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. Photorealism enhances the quality of computer generated images and thus greatly improves their visualisation value.

Computer graphics is taught to final year undergraduate and Msc students within the Department of Computer Science. As well as covering the fundamentals of computer graphics, the course also examines the photo-realistic techniques of: ray tracing; radiosity; and, particle tracing. The value of any computer graphics course is not, however, merely the understanding of the mechanics of the underlying graphic models. To appreciate truly the benefit of photo-realistic computer images, the students need to see the techniques applied to real problems. The visualisation of archaeological sites is one such problem. The VLP tutorials will enhance the learning experience of Computer Science students. They will be able to investigate the computational complexity and subsequent effect of different graphic techniques in the interpretation of archaeological sites. This will enable them to understand better the applicability of each method, and see for themselves how photo-realistic visualisation may help in the interpretation of computer modelled virtual environments.

4.2.2 Geography
Landscapes are of particular concern of Geography, and Geographic Information Systems (GIS) are a particular specialisation of the department. The department of Geography and the department of Classics and Archaeology have already been involved in the implementation of a TLTP project concerning GIS (Blake *et al*. 1995). The VLP is building upon this experience, and extending the use of the existing tutorial to first and second year undergraduate teaching in Geography. Here, in particular, it will enhance existing computer-based practical teaching in GIS and spatial analysis by providing a dynamic application of landscape analysis and visualisation. The addition of an archaeological dimension to geography teaching in this way will add important material which illustrates the principles of planning, cultural resource management and regional analysis.

4.2.3 Archaeology
It is around primary archaeological data that the other research projects are built. It is with this data analysis that the archaeologist is chiefly concerned. By introducing archaeology students to the full suite of visualisation techniques available it will facilitate a better understanding of landscape visualisation and analysis. The VLP also serves the purpose of introducing archaeology students to a dynamic inter-disciplinary environment.

5 Discussion and conclusion

5.1 Discussion
The idea behind students using the VLP tutorials is not to produce archaeology graduates who can produce 3-D models of landscapes and sites, or who are experts in GIS. Neither is it the aim to produce archaeologists from Computer Science and Geography students. Rather, it is to introduce the students to the concepts and techniques behind such visualisation by showing them some of the tools and facilities that are available. If they wish to take this further they are then familiar with the tools available. This will enable archaeologically based visualisation projects to be undertaken by third year students for their final year dissertations.

The benefits for both Computer Science and Geography students are based primarily on an introduction to a dynamic application to what otherwise are often predominantly theory based areas of their study as well as on introducing users to a variety of different applications of specialisms within their field.

These tutorials will also have the complimentary benefit in that they facilitate the development in users of transferable skills for careers outside archaeology. The familiarity of computer use, database management, use and manipulation of data will be skills acquired by users of the VLP, producing archaeology graduates confident with computer applications, something all too often lacking in Arts based graduates.

5.2 Conclusion
The Visualisation of Landscapes Project has several important contributions to make towards education in archaeology. It presents a suite of integrated technologically explicit techniques in visualising landscapes and archaeological data, within an interactive PC based environment, for use in undergraduate teaching. It also demonstrates a simple and effective inter-disciplinary project in terms of both education and research.

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A Tool for Multimedia Excavation Reports – a prototype

1 Introduction

This paper presents the results of the first stage of work on developing a new tool for multimedia excavation reports, using the Hypermedia system Microcosm.

2 Hypermedia in Archaeology

Archaeology is having to find ways in which to deal with the information explosion that is a result of the development of analytical techniques. The computer revolution means that a large amount of the data generated by these specialised analyses is now stored on computer. The resulting problems of publication in archaeology are well known: the sheer quantity of excavation data makes complete publication virtually impossible, and the trend is now towards summary publication with an accessible archive.

The idea of using multimedia for archaeological applications is not new. It has long been understood that archaeology is a discipline which relies heavily on data from a diversity of sources in a number of shapes and formats. It is now recognised and accepted that archaeology should take advantage of the possibilities offered by multimedia. There have been attempts at resolving some of the data management problems using novel technologies, especially electronic storage, computer and multimedia technology, for the publication of the more 'unwieldy' records generated by excavation: line drawings, photographs, catalogues and tables (Rahtz *et al.* 1989).

The points in favour of using multimedia are summarised and adopted here from Rahtz, Hall and Allen (1992: 360-361):

- Much of the information in archaeology is very specialised and full publication is not economically viable, nevertheless data must remain accessible. Even if it is not economically viable to publish material in a conventional book which will only be read by a few hundred people, some means of disseminating it is required.
- Archaeology is a very data intensive discipline, both in the field and also in the post-excavation process. Computers can help with storage and access.
- The graphical representations already included in conventional publications frequently present some problems. Oversize drawings either have to be reduced, with consequent loss of detail, or are included as fold-out plans which are unwieldy and increase the cost of the publication. There is already considerable use made of graphical representations of the data (plans, drawings, photographs, stratigraphic diagrams), none of which are reproduced easily in a traditional book format.
- Whilst colour plays an important role as part of the archaeological record for discrimination, it is hardly ever used in publication. Ceramic thin-sectioning would be an obvious example where the discipline would vastly benefit from the ability to publish in colour.
- An important point is that the proportion of data held on and generated by the computer in archaeology is growing steadily. Virtually all but the very smallest excavations now use databases to organise some aspect of their archive. Many archaeologists already have large quantities of machine readable data, and considerable experience of formalising information.
- Finally, the results generated by new computer techniques, such as GIS, now frequently used in archaeological research, are not suitable for publication on paper and thus require new methods of publication. Multimedia also provides an opportunity to publish data from the excavation archive that has so far never been published, such as colour photos or moving pictures.

Hypermedia should not be aiming to replace the book. The basic assumptions by Rahtz *et al.* (1989: 20) in their evaluation of the technology for archaeology state that we will not be able to dismiss conventional books, as linear narrative and argument have been the basis of scholarship for millennia. The book has been the repository for past knowledge, so any new form of representation must have some kind of continuity with existing methods. Nevertheless, there is an opportunity to supplement the book in certain areas of knowledge representation — especially where arguments are supposedly backed up by reference to the original data, this data should be freely accessible to allow the assessment of the statement.

A system is needed that can be added onto existing practices, which is easily understood and does not require complex mark-up languages or programming skills. The current unpublished archives are artefacts of inadequate technologies for disseminating archaeological information — the time has come now to remove this stepping stone and make the archives accessible. We are aiming to provide an electronic archive with good access, which is directly referenced back to the written report.

There have been attempts to use Hypermedia to provide a new kind of excavation report, by producing hypermedia publications of electronic books or archives. The problem with most attempts so far is that they were developed using monolithic packages and closed systems (such a Hyper-Card). In a closed system the user is constrained to finding and following the links made by an author. These usually appear as highlighted text or graphics such as buttons. These links frequently have to be explicitly defined one by one by the author, thus making the authoring effort needed for the compilation of such an application very labour-intensive. Closed systems import the data and make it their own, import or especially export facilities are relatively unusual. Link definitions are frequently 'hard-wired' into the data files; there is then no possibility to communicate with other programs, or query the information in a way that the author had not anticipated, as the data cannot be read by other programs.

2.1 Open Hypermedia and Microcosm

Microcosm has attempted to overcome the problems of closed systems. Since 1989 the Microcosm team has been working on it and the third version has been released (Davis *et al*. 1992c; Fountain *et al*. 1990; Hall *et al*. 1992; Hill *et al*. 1992a). Microcosm is not just an authoring or presentation system, it should be seen as an extension of an operating system (Hall *et al*. 1992: 14), organising the access to the documents. It consists of a message passing system, which allows a number of autonomous processes to communicate with each other. The information about the links is held in a database separated from the document files. This separation of links from the actual data files is an advantage (Davis *et al*. 1992a), as it allows for far greater flexibility. Files can be updated and accessed from applications that are not part of the hypermedia application itself.

A Microcosm (MCM) application comprises a set of documents (individual files in the file system) that the program knows about, together with a set of relationships defined for those documents. MCM allows relationships to be defined between objects and ideas in a variety of document types such as text or graphics. The user is provided with a core set of viewers; these are programs which allow the viewing but not the editing of any files of supported formats. These documents are prepared in various software packages and viewed through the MCM viewers. MCM also comes with a core set of filters. These are programs which provide it with its information processing and retrieval functionality. As it consists of a set of independent programs which communicate with each other, the functionality of these can be altered according to the user's requirements.

A minimum definition of an open system as used by Microcosm is (Davis *et al*. 1992c: 6):

- A system which does not impose any mark-up on the data which prevents it from being accessible to other processes that do not belong to the system.
- A system which can integrate with any tool that runs under the host operating system. Data produced by tools that are not part of the hypermedia system may be used within it without adding any special value to that data and without compromising the continued use of the data outside the system.
- A system in which data and processes may be distributed across a network, and across hardware platforms.
- A system in which there is no artificial distinction between readers and authors.
- A system in which it is easy to add new functionality, i.e. new program modules may simply be inserted.

An important way of accessing the documents inside Microcosm is by following links. The system allows a number of different actions to be taken on any selected item of interest; links are specified either as buttons or invisible links. A button simply binds two items of information whereas the links can be of four different types:

Specific Links: specific links are similar to buttons, however the link anchor is not highlighted.

Local Links: if a destination for a local link has been defined in a document, the user can select the anchor anywhere in the current document to follow the link.

Generic Links: The user can follow the link after selecting the anchor in any document in the current application.

Dynamic Links (Compute links): This allows the user to follow links not explicitly defined by the author. The available links will be calculated based on the anchor selection anywhere in the application.

With the design of Microcosm the developers have also tried to address the question of what users expect from a hypermedia system (summarised in Davis *et al*. 1992b: 182), which is also applicable to the archaeological environment:

- Users want a computer environment which is adaptable for the integration of data, tools and services as required. Users remain free to use whichever text editor or drawing package they prefer, without being bound to the one provided for the particular hypermedia system. By separating the links from the documents, this independence has been maintained.

– To maximise exchange with other persons active in the field, a system that is platform independent and allows distribution across different platforms would be an advantage. UNIX and Macintosh versions of Microcosm are under development.
– A system that comes with powerful navigational aids to allow the user (both the author and the reader) to find and update the information without having to wade through large amounts of irrelevant data. Text may be pre-indexed (Li *et al.* 1992) to allow a general search of text files. Other kinds of links also help to reduce the authoring effort. A differentiation between public and personal workspace and links is achieved by using personal linkbases.
– Finally, a system in which all data types are treated in a similar manner. If making links to data of one type of package differs widely from the next package, the learning will be more difficult and familiarity with the more advanced features will progress more slowly.

3 A tool for Archaeology

It has to be accepted that nobody actually reads a complete excavation report; they are clearly not designed to be read from cover to cover. They are expected to give an overview of the excavation and allow a fairly detailed view of the data which the conclusions are derived from. However, with the increasing trend towards summary publication all that detail will be lost to the average reader by being kept in the archives. These archives require extra effort for access and in some respects are even worse than microfiche. Excavation reports were supposed to be written with specific reference to the data like a good index to the site. If it is easier to access the data maybe people will change their attitudes and consult and work with it more.

What is needed in archaeological publication is a tool which will give access to the material in the excavation archive for research. The computer can improve on access and versatility and is a much more flexible tool than microfiche. For example, images can be manipulated, their brightness and contrast or colour maps can be altered interactively to enhance special features of the image. We have to stress here that this program will not be aiming at the ‘public’ level of archaeology, but at research, which will be able to make sense of the mass of fairly unrefined data we propose to disseminate.

Initially we will be aiming at the excavators who have to write up the paper report text. The new system will allow them to organise their data and establish links between the text and the supporting data. It is then possible to release this electronic archive, probably on CD-ROM, on request. This would be in addition to the conventional printed volume, allowing researcher and readers access to the levels of archive not usually accessible at all unless the archive is visited. There are cases where archives can be split over several locations, making access even more difficult. We are not denying that there are instances where a visit is essential, but generally it can help to disseminate more archival information about a site.

One aim of the prototype is to remove from the user the need to recognise the functions of each Microcosm 3.0 icon by uniting them all into a toolbar. The toolbar is a relatively simple program; it simply calls up individual Microcosm 3.0 components which can also be accessed directly from their icons. The toolbar should reduce the user’s confusion about the 10 icons along the bottom of the screen. Obvious components to be called are ‘show links’ or ‘open a document’. Furthermore the archaeology toolbar will allow users to integrate into Microcosm the other types of tools now routinely used by many archaeologists such a Harris matrix program, databases and spreadsheets. If all these could be linked on a common identification such as the context number, the data would become more useful.

4 Key study: the excavation at St Veit Klinglberg

The excavation selected was carried out at St Veit Klinglberg (SVK) in Austria by Shennan in the summer seasons of 1985-89. The site is situated in western Austria about 60 km south of the city of Salzburg. It lies between the small towns of Schwarzach and St Johann im Pongau (Shennan 1995).

The excavation archive is relatively small (approx. 1350 contexts), and only slightly stratified. A large part had already been entered onto computer. The context, pottery and botanical record were readily available as database files. Finally all single context plans had been digitized with AutoCAD (approx. 1360 files). Larger phase plans and site plans were then compiled by amalgamating these plans.

The archive at the moment represents the excavation report as submitted for publication, with the addition of the complete database and illustrations archives.

4.1 Preparation of the archive

As AutoCAD is a program that requires large resources of computer memory and speed, and can behave sluggish at the best of times, an alternative had to be found to present the digitized plans and sections. It was decided to convert them into DXF (data exchange format) files, as there is a viewer for Microcosm under development that can access

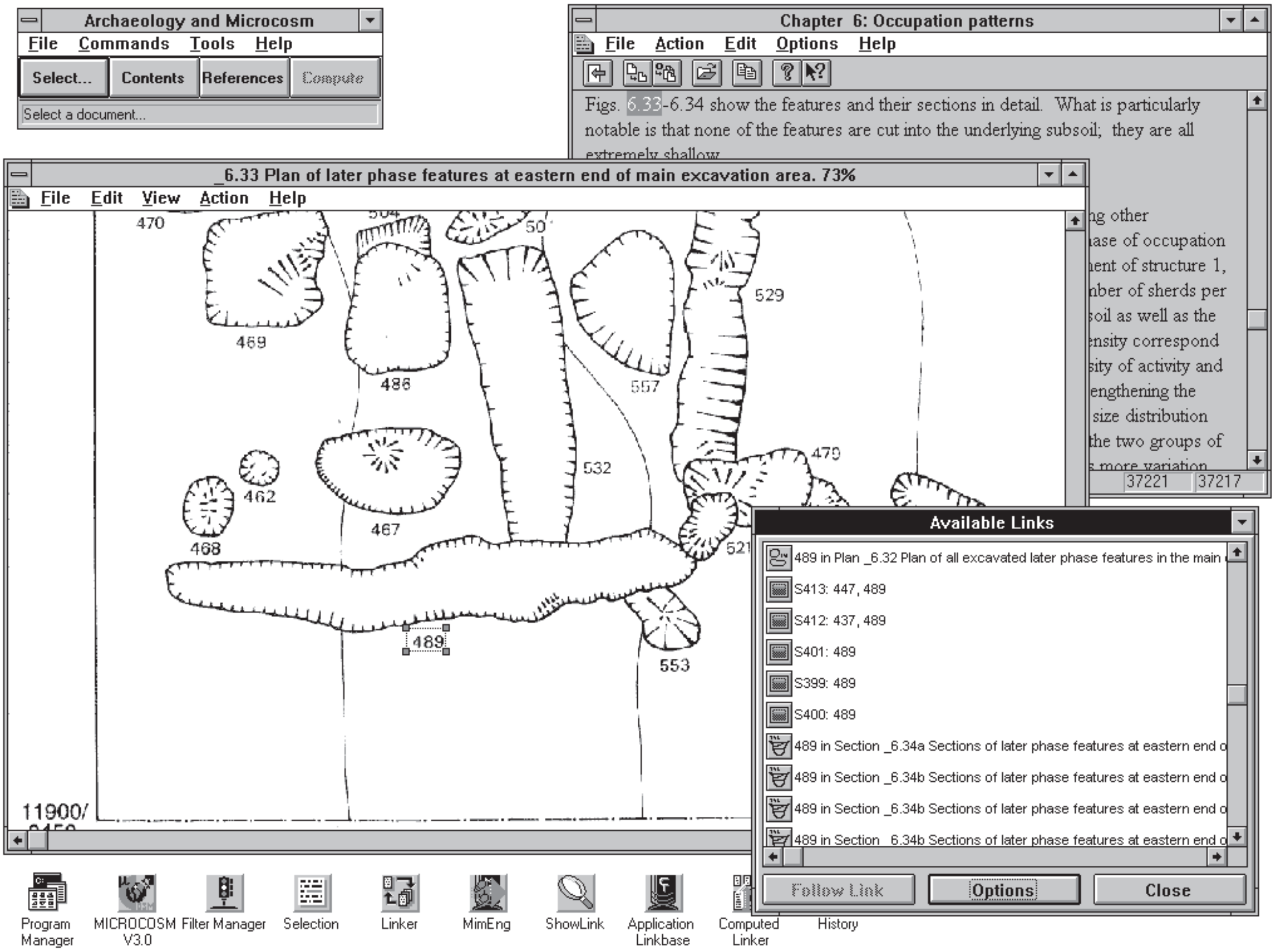

Figure 1. An example screen of Microcosm running with the sample data, showing a rich text document, a bitmap plan and the available links that exist with regard to the selection made from the plan. Along the bottom the icons can be seen which represent the individual Microcosm components. The Archaeology Toolbar is in the top left hand corner.

these files and block attributes if they are defined. The multiple context plans have at the moment been scanned from the publication drawings on a flatbed scanner due to time constraints. Once the visualisation tool has been developed all plans and sections are expected to be available as DXF or AutoCAD files to build up a three-dimensional visualisation of the excavation records.

The report text has been preserved in chapters and appendices as written for the published report. As the current objective of compiling this electronic archive is to make available the existing archive, no attempt has been made to make new arrangements for the text by splitting it into smaller sections. The files were saved in rich text format (RTF), which preserves their formatting and is used to exchange word processor files between different programs. As Microcosm 3.0 is supplied with a RTF viewer, the formatting of the text could be maintained and all footnotes were preserved as pop-up boxes. Tables and Excel Charts were originally supplied as large Word for Windows files; the chapter files contained both tables and figures (Excel charts) grouped by chapter; these were separated into individual files, named with the figure numbers. This allowed the establishment of direct links and the multiple display of tables or graphs for comparison and made their management and labelling more straightforward.

The photographic excavation record and the smallfind photos were digitised from slides and negatives using a Nikon slide scanner. The resolution chosen was 635 dpi, which will enlarge the slides to a size of 800*600; this proved a satisfactory resolution for displaying them on colour monitors. Further editing involved the sharpening of the image and conversion from 24 bit (true colour) to 8 bit colour (256 colours) to reduce storage requirements. The editing carried out involved some adjustment of brightness, but essentially the aim was to preserve the details including brightness of the slides as it was first captured in the field. This means the multiple photographs of contexts were all scanned, so that comparisons between different brightness settings are possible. All files were converted to JPG's which allowed a compression of 75 percent with minimal loss of detail. The increase in display times is a necessary and acceptable drawback, given the fact that the files are now considerably smaller than the other format (Windows BMP) that can be viewed with Microcosm 3.0.

4.2 Arrangement of archive within Microcosm 3.0

An example of running Microcosm with the digitized data can be seen in figure 1, which shows a screen shot of the Microcosm SVK application in action, showing multiple windows of different document types.

To enter the files into the Microcosm application they were dragged into the *Select a document* window. To facilitate the organising of types, the following logical types were defined:

– *Report* to include all textual material included in the excavation report
– *Figures* to include all figures as referenced in the report, including plans, sections and charts
– *Sections* to include all referenced sections, of which most so far have been scanned rather than digitized
– *Plans* to include all referenced plans, of which most so far have been scanned rather than digitized
– *Finds* to include all smallfind photos
– *Slides* to include all excavation slides

These classes will allow users to locate the material by type at a glance. Some items will inevitably appear in more than one class, as figures include sections and plans, as well as tables and charts. The advantage of logical types is that the files will not have to be duplicated on the hard disk and can nevertheless be listed in more than one place.

4.3 Establishing links and descriptions

The main way of organizing the cross-referencing of the documents was defined by context number; searches on context numbers will reveal links to every reference to a particular context number, in both text and image files. For all bitmaps, named selections were defined on each context number listed on these, with generic links anchored on each of them. Sections and plans were treated in the same way. Slides also have generic links ending on them according to the context numbers represented on them. A list of such links as displayed by Microcosm can be seen in figure 1.

For the report text the computed links filter provided a good mechanism for searching across all text files for the occurrences of the relevant word. The user can select any word and search in the created index for any matching passages. However, this is only possible for text files and may not be adequate for some kinds of searches. All author names in the references were defined as generic links, as were all figure numbers as mentioned in the text. Figures were given descriptions containing both their original numbers as used in the report and their descriptions as copied from the captions.

5 Presenting it to the user – the toolbar

In our view Microcosm suffers from a slightly confusing interface, presented by the 10 icons along the bottom which all have different functions. As this is meant to be a system for the casual and one-off user, it is important to make it usable in moments rather than hours. Therefore the toolbar unites the access to the icons in a group of menus and buttons — to make it all more manageable and understandable.

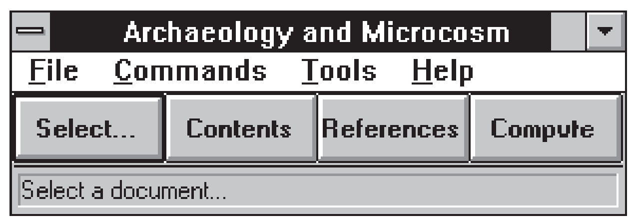

Figure 2. The Archaeology Toolbar prototype.

The tool bar (fig. 2) gives the user a more straightforward interface of MCM. Rather than having to understand the functions of the icons along the bottom of the screen and having to double click on MCM to open the *Select a Document Window*, it was decided to write a simple toolbar front end which gives a button and menu interface that will stay the same throughout. Direct access to certain core documents which are pre-defined by the author is provided as an entry point. Another key element to the usability is the ease of preparation of the archive and therefore it is desirable that the excavator should not have to specify links by hand.

Microcosm is composed of many communicating processes or components, allowing for different features or services depending on which components are currently active. This feature exists in keeping with the open hypermedia philosophy. The communication between the outside world and Microcosm is effected using Application Programming Interface (API) used by Windows. Messages are passed to Microcosm components to initiate actions. The Visual Basic application uses API to communicate with

Microcosm, to interrogate settings in the Registry, a central file where all Microcosm settings and details of imported documents are defined. In this way details about existing documents can be accessed and specific documents can be opened. Similarly individual components such as the *Select a Document* window or the *About* box can be called up.

5.1 Tool Bar functions (fig. 2)

In keeping with other Windows programs, the *File* menu gives access to functions such as *Open* and *Exit*. It also gives the option to open specific documents which the user might want to access with ease. These were previously specified in the registry. In this case the Contents and References were defined as such fixed documents.

The *Commands* menu includes all Microcosm functions such as compute links, show history and show links, which connect to the functions of the Microcosm filters which perform *Compute Links*, *History* and *Show Available Links*.

The *Tools* menu so far gives access to one simple function called *Change Titles* which will organise the re-naming of a list of documents contained within the same directory. After the user has specified a directory, and selected whether to change titles or types, the following window will appear, giving the option to either skip the current document, if no change is intended, or to type in a new title or type and to change the document's record in the Registry.

The *Help* menu currently points straight to the Microcosm 3.0 help file which is executed using the windows help program (winhelp.exe) as there should be very little explanation necessary for the tool bar itself. The second help option allows users to seek help for any specific key word. The standard *About* box for Microcosm is also included.

Finally, the buttons repeat selected menu functions, adding ease of use and a visible reminder of available commands.

6 Future options

The current version of the toolbar program provides a simplified entry point to Microcosm for the user; it does not provide any specifically archaeological tools such as stratigraphic visualisation or data analysis modules, which are the main aims of this project.

The setting up of applications should become far more automated, so that the user only has to specify which files to include, and possibly one additional text file which contains the appropriate file descriptions. The program would be able to complete the set-up and renaming of documents by itself. The current facility for easing file renaming after import is still very limited as it will only examine a list of files contained in a directory, when it might be advantageous to examine all documents imported under a certain logical type.

Another important aspect that should be added is the automatic linking. Currently it is possible to search for a specific word using the 'Compute Links' filter to search text files. These automatic links will probably be defined on file names or the file descriptions, which will then need to contain the context number represented in the specific image file for example.

Stratigraphic relationships are used extensively by the excavator to understand the excavated site and material. Stratigraphic relationships are identified which influence the final interpretation of a site. It is thus crucial to allow the user to centre the organization of the dataset around the stratigraphic relationships rather than the report text as the example application currently does. Possible approaches would be to provide an extension of the program so that an existing stratigraphic program can be used. Other data visualisation tools that will allow users to examine site reconstructions generated from the plans are the elements which are needed to make the program uniquely archaeological. Possibilities include interactive find distribution plotting from selected finds, projected directly onto a plan.

7 Conclusion

We hope that it has been shown that the use of open hypermedia is the way forward for archaeology. It will allow archaeology to deal with its data dissemination problems.

The first experiments with Microcosm and the excavation archive under consideration have shown that the proposed tool is possible with existing technology. The materials present in the excavation archive could be digitized satisfactorily and proved to be suitable for electronic representation. Microcosm provides a useful and flexible framework for grouping the data within the excavation report lay-out. Windows API with Visual Basic means that most programs can be adapted to add the archaeological functionality that distinguishes it as an archaeological tool. It will now be necessary to add the specifically archaeological analysis tools to the toolbar under development.

The tools which make the compilation of an electronic excavation archive easier will also make it easier to reassess the excavator's conclusions. These days it is very hard to do anything but take the excavator's report on trust. In order to really examine an excavation report in depth takes too much time and effort. Hypermedia excavation report tools can make the excavator's argument much more open to criticism and reassessment as specific details can be found and examined more quickly. This may be uncomfortable for the excavators but is certainly important for the discipline.

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Exploring Archaeological Information through an Open Hypermedia System

This paper presents the principles which guide the authors' research in creating an open learning environment in archaeology. The environment can serve as a flexible book (and notebook) where the user can systematically include personal extensions (text, images, sound) to the initially provided archaeological multimedia database.

The presented representation scheme is a specialisation of a more general knowledge representation form, guided by archaeological goals and priorities. It supports mapping from the world of archaeological objects onto the programmed microworld.

The environment is programmable; classes containing definitions of structure and behaviour act as conceptual templates which allow the definition and interconnection of all objects-instances in the implementation. The initial library of classes included in the system can be extended by the users, who can create their own worlds, to cover specific needs. Links with content and condition enforcement support the implementation of composite objects, while they preclude fundamentally unacceptable associations. Information can be explored either at the knowledge level (i.e. the conceptual definitions of the classes) or at the specific object level (i.e. information about specific instances – persons, places, artefacts, etc.).

Navigation within the representation scheme is supported by 'intelligent' viewing and accessing mechanisms within user-defined contexts. Furthermore, the structure of the system allows interfacing with programs for specialised evaluation tasks, hypotheses testing, etc.

1 Introduction

This paper presents the principles which guide the authors' research in creating an open learning environment in archaeology. The dual objective is to support free and creative exploration of information and to contribute to computer literacy, by introducing concepts of the object-oriented paradigm for the non-expert user. The focus is on supporting the exploration of information across non-predefined paths. The user can thus formulate his own conceptual model of the presented data, identify semantic relationships among information pieces, materialise the respective interconnections, extend the original environment and gain familiarity with the programming aspects of its structure.

The description in this paper covers technical issues; this infrastructure is needed to support domain specific knowledge of various archaeological areas.

1.1 Motivation

An intelligent repository of archaeological information can serve at many levels: It can help the teacher organise and present a lecture, the student compose and document an assignment, the researcher combine information of the system with personal notes, and the generally interested individual explore the historical space through an unconstrained promenade in a virtual museum. Although there are large-scale systems in that domain, such as KLEIO (Dionysiadou 1994), there is a need for software suitable for smaller domains as in school courses, tourist information or for a rapid search, i.e. for less demanding use by non-specialists, while maintaining the openness of the environment. The courses intended for archaeology students require special attention, as the objective is not solely the presentation of the course material, but the usage of the material representation as a mechanism to improve the expertise of the student on computer science principles, as the importance of computer technology in archaeological research and archiving becomes paramount.

The fundamental representational problem in this domain is to adequately reflect the actual world in a collection of data, so that someone exploring those data can re-construct, as easily as possible, a mental model of the represented actual world, suitable for his needs. We assume here that the user has the necessary background and common sense for the interpretation of such data. The problem is both a modelling and a communication issue. A representation scheme is sought, to accommodate a good part of the data handled by archaeologists, in a structured and manageable way. Information processing tools are needed to access and manipulate this data, as well as to support the user's navigation within the environment.

The representation draws on ideas from Geographic Information Systems, CAD models, object-oriented programming, databases, computer graphics and multimedia. The value of such constituents for archaeology has been recognised, from their relatively early stages (Eiteljorg 1988; Guimier-Sorbets 1990; Kvamme 1986; Reily 1991).

Hundreds of publications (Ryan 1988) prove the keen interest for computer applications in archaeology. Between the studies on the guiding principles for the construction of such environments, the most relevant for this work are those examining the conceptual modelling under principles that permit a 'hyper' exploitation of the implemented semantics (Burnard 1991).

Despite the huge work presented sofar, the everyday's technological advancement as well as the immensity of the conceptual space of archaeology, keep open the question of 'the appropriate computer environment for representing archaeological data'. A computer environment for storage and manipulation of the complex, hyperlinked and multimedia information required in an interdisciplinary approach, and easy to use in an ordinary computer such as an MPC, is now much more feasible than a few years ago.

Archaeological information management requires linking of information which exceeds the capacity of Hypercard-like environments, where a small number of 'buttons' links the presentation of related entities, but there is no semantic content of the linkage within the link. So it is not possible for the user to examine deeper relationships, to make hypotheses and to test them. The necessity of links with explicit conceptual meaning is examined here, mainly from a technical point of view, but also from the point of view of the conceptual space (Rigopoulos 1991).

For that purpose, the design principles are conceived at two levels: the first level aims to help the 'author' implement a specific conceptual space, as a universe; the second level aims to help the end user concretise the context of his work, i.e. explore the contained information, formulate personal ideas, express them as an integral part of the program and test them.

1.2 Objectives for the environment

The hypermedia environment under development, adheres to the object-oriented paradigm, with the dual aim of:

a. providing a fundamental template for the organisation of archaeological courses' material, virtual museum visits, navigation through archaeological sites etc.;
b. introducing non-computer experts to object-oriented data modelling, because they will increasingly face the need for advanced computing applications in their careers.

The environment will undergo two major development phases:

a. an initial phase performed by the author(s) who will provide the archaeological information and organise it with the assistance of an application designer;
b. a 'tailoring' phase undertaken by the teacher/tutor/museum guide, who will customise the material according to the envisaged interests and expertise of the end user.

The process of authoring and tailoring are described in Kibby *et al.* (1989).

The following fundamental requirements are taken into account in the design of this environment:

Interactivity, allowing the user to communicate with the system at the level of Predicate Calculus objects, (i.e. to obtain or to implement simple or composite objects, patterns, rules and methods of manipulation). Obviously, the existence of a graphical user interface allowing the user to exploit interactivity is taken for granted.

Concept management tools, allowing the user (researcher, tourist, learner, teacher, etc.) to include in the system any additional information or ideas, and interconnect them. Consistency and redundancy checking are also required.

Context definition tools, supporting the user's navigation over the retained information. Contexts are established with specification of constraints that result in subsets of the database material. Contexts are established dynamically and evolve with the user's interests and understanding.

Schema management tools, allowing restructuring of information with reformulation of any part of the hierarchical structure, and the redefinition of functions. Although most users are expected to be satisfied by the initial information templates (as organised by the author and tailor), some may want to modify the environment. Schema management requires an efficient monitoring mechanism to prevent the user from destroying the structure of the already existing material and to disallow conceptual discrepancies in the formulation of new abstract object and relationship templates.

2 Technical approach

2.1 Principles

The model combines principles of the hypermedia and the object-oriented paradigm, with the objective to create a flexible archaeological hypermedia environment with a rich underlying database, that can serve as an electronic book and notebook. The user should be allowed to systematically extend the initially provided environment with personal annotations (not necessarily limited to text) as well as with hyperlinks. The extensions of the original environment should be incorporated in a seamless way, enabling the user to consistently exploit them for the exploration of the new environment.

The general idea of almost any hypermedia environment, i.e. of applying a 1-to-1 mapping from the actual world onto the programmed microworld to reflect thinking has been thoroughly examined (Beeman *et al.* 1987; Jonassen

1986; Kibby *et al.* 1989). This idea is treated here within the frame of the above considerations and of archaeological goals and priorities. Archaeological concepts (more or less concrete) are implemented as computational objects, under the following directives:

a. the observed relationships among concepts in the actual world are represented as links between entities;
b. the nature of the information process applied by the program must be analogous to the one applied by the archaeologist in the actual world;
c. the actual world is always in change and thus there is a need for continuous adaptation of the program to the actual demands;
d. the user can extend the environment by adding computational objects and relationships, and lessen the environment by imposing rules restricting the space.

Essential points in that process are:

– the creation of conceptual objects as information clusters (of any type and kind of media carrying them) and their nomination;
– the interconnection of any objects with links bearing semantic information;
– the classification of objects and the possibility to reorganise that classification;
– the analysis of any object into components, which can be examined as self-standing entities.

2.2 The object-oriented data model and the fundamental schema

The object-oriented paradigm was selected as a basis for the model, because it supports encapsulated structure and behaviour of conceptual entities in their type definitions; it is therefore particularly suitable for information modelling and the understanding of its principles even for the non-expert computer user.

Classes are generative templates of instances which contain definitions of structure and behaviour; they determine the potential interconnections of all instances in the implementation. The initial library of classes provided by the model can be extended by the user.

Within the object-oriented environment, the actual world of archaeology is reflected in a semantic network, where the nodes represent specific objects (mapping more or less abstract objects or conceptions in the actual world) and their connections represent their relationships (as they are considered in the actual world). The objects may be considered as instances of some fundamental types, defined according to the semantics and considerations of archaeology. For example, the node types can be:

Person, Idea, Place, Event, Artefact, Animal, and Group,

and of their subtypes, as for example, for ‘artefact’ are ‘building’, ‘statue’, ‘container’, ‘tool’ etc. These subtypes can be further subtyped, as for example for ‘building’ are ‘temple’, ‘house’, ‘theatre’, etc. This semantic organisation of the network is the basis on which the functions and rules are defined. But it should be viewed as an example for organising these semantics and not as a rigid form to which the construction and any usage must conform.

A separate class hierarchy reflects the representation and handling of information through different media (i.e. types as ‘image’, ‘text’, ‘sound’, ‘video’, etc.).

An initial set of fundamental object types holds the basic (archaeological) type definitions. All other types are described as specialisation (subtypes) of the fundamental types and their subtypes. Of course, the openness of the environment combined with the inherent extensibility of the object-oriented data model, allows the addition of more fundamental types and/or properties when necessary.

Properties are inherited through subtyping. The selection or definition of the appropriate types is a fundamental task, recommended only for experienced users. The network organisation can change, when additional types and sub-types are defined or when the hierarchy is restructured, to more accurately reflect the user’s mental model of the domain. Extensibility of the base model is addressed in the next subsection.

The network nodes are interconnected by directed links with semantic content. The links are objects in their own right instantiated from a relatively large number of link types (human relationships, ownership, part-of, logical relationships as implication and contradiction, etc.). The content of a link is expressed as a series of properties with corresponding value (context sensitive or non context sensitive).

No knowledge of the network structure is needed for its exploration; on the contrary thorough knowledge of the class hierarchy and the network of instances is needed for successful interventions to its structure.

2.3 Using and extending the fundamental environment

The user is allowed to attach personal annotations to the fundamental environment, and to add links materialising relationships that he observes. New classes are defined when the object types originally provided to express the semantics of entities (nodes) and relationships (links) do not suffice to express the user’s concepts.

From the aspect of computer programming, it should be mentioned that most computer languages are not yet easily accessed by non expert users. However, there are many indications that programming languages will be a common expression mean in the future; nowadays children can handle deep programming meanings from very early ages, by using Logo and Logo-like environments. In addition, visual editions of programming languages make their usage much simpler and more efficient; Hypercard-like environments can be easily handled by non-experienced users.

From the modelling principles viewpoint, it should be noted that the archaeology student (as the student of any discipline) follows modelling principles that do not necessarily (nor usually) coincide with the principles of database data models. The object-oriented data model permits more free modelling. The student who wishes to reflect his mental model to the fundamental environment should consult the existing scheme and identify analogies. This understanding of the environment will allow the student to extend it, and also will gradually make him familiar with the principles of its computerised organisation.

2.4 Preserving the consistency of the extended environment

The hypermedia environment in which the user is working is not a passive repository of information. Rather, the user's extensions are integrated with the already existing information: new information pieces and annotations must be connected with already existing ones to depict the relationship of new and old information; new links will reveal relationships among existing objects.

In this evolving environment, the incorporation of incompatible associations can destroy the semantics of the network; the incorporation of logically compatible but redundant or trivial associations can rapidly make the environment intractable for any practical purpose. Hence, the extension of the environment with information provided by the user must be subject to an internal control mechanism that detects and prohibits contradictory associations and redundant information. For that purpose, the partial ordering of link types is utilised by a mechanism that compares the semantics of the new link with those of existing ones among the connected nodes, identifies links that contradict or are semantically subsumed by already existing ones and undertakes prohibiting/repairing actions. This mechanism is analysed in Gyftodimos/Spiliopoulou (1994).

The annexation of new link types can be supported by a mechanism that asks the user to place each new type inside the partially ordered set of link types and to describe its relationships to the other link types; the user thus is expected to identify the types subsumed and those subsuming the new type, as well as types that are logically incompatible with the new one.

3 Exploring the hypermedia network

3.1 Navigation, creation of new elements and exploration

Navigation within the representation scheme is the action of visiting nodes by following links (not necessarily in their direction) (Nielsen 1990). It is supported by 'intelligent' viewing and accessing mechanisms within user-defined contexts.

The software under development aims to be an open exploratory environment for the end user. Exploration can be performed by traversing links and by issuing queries; during exploration, the user may add links and nodes as necessary, being subject to the monitoring mechanism that preserves correctness.

Query processing of information organised in a database is a well-known technique from database theory. We hereafter focus on the navigational paradigm of information retrieval, as it is more widespread in hypermedia applications. We mention though that the expressiveness of a query language permitting non-procedural associative access cannot be matched by a simple navigational mechanism, so that both paradigms are necessary, especially as the user becomes more experienced and is interested in sophisticated data associations.

3.2 Navigation and disorientation

A hypermedia system can assist the learning process significantly, by keeping parts of the work which the learner would like to temporarily leave aside and recapture later. It can also assist him when he gets lost.

A problem occurring when hypermedia systems are used in an exploratory manner, is disorientation; the user does not know how and why he reached the currently visited node, or has a wrong impression about that. In a learning environment, the problem is even more acute, because the learner has not yet created in his mind all semantic relationships among the visited information pieces (Gyftodimos/Spiliopoulou 1991).

Many commercial systems assist the user in getting oriented again, by storing the traversed path; examples are the 'history of cards' in Hypercard™ and the 'footprints on maps' of the hypermedia network used in NoteCards™. However, most of those systems do not use multiple types of links and therefore do not face the possibility of many links connecting two nodes under different contexts, which is frequent in learning. Furthermore, they overlook that 'history' grows fast, thus becoming practically unusable.

The learner constructs a route in the non-sequential hypermedia network. Disorientation occurs when the learner forgets parts of this route or even the reason for visiting some nodes across it. An 'intelligent' tool is designed, which assists the user in exploring the hypermedia network,

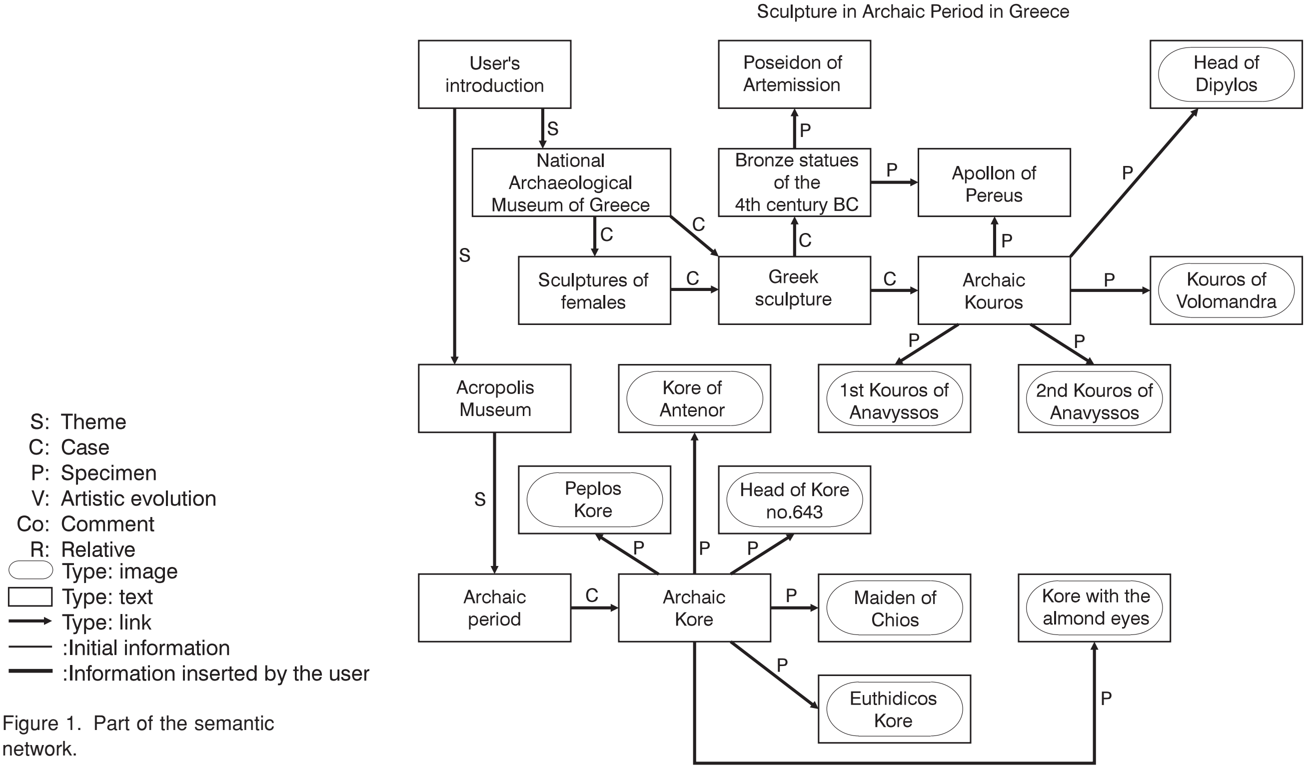

Figure 1. Part of the semantic network.

by maintaining and processing the route (nodes visited and links traversed sofar). This tool creates two lists, namely the 'history of traversed links' and the 'list of landmarks' which are visited, nodes having a particular importance for the learner.

The user explicitly declares important nodes, thus including them in the 'list of landmarks'; the computer also recognises landmarks by observing the user's moves. It must be noted, that the usage of landmarks has a direct impact on the learning process: a good selection of nodes to be characterised as landmarks by the learner both assists the learner in recapturing previously visited information and allows him to integrate the information explored sofar with already existing knowledge.

For the efficient maintenance of these lists, it is essential that their components (nodes and/or links) are periodically filtered, so that unnecessary or disrupting information is eliminated. However, the remaining objects should be adequate to help the learner recapture the route he followed during exploration of the hypermedia network and to connect new information with old knowledge. Filtering concerns the elimination of nodes or links that are no longer important for the learner's mental process. Although only the learner knows what is important for him, the tool may take the liberty to filter out information that apparently is redundant, such as the parts of the route (traversed links) which form cycles or build excursions around a landmark node. For more sophisticated filtering, both the co-operation with the user and the usage of artificial intelligence techniques is necessary. These manipulation tools are described in Gyftodimos/Spiliopoulou (1991).

'History of traversed links' and 'list of landmarks' may assist the user to:

– retrieve objects previously examined; the tool serves as an intelligent notepad, more flexible than a simple inspection of the walk;
– become reoriented whenever he gets lost; the tool maintains return tracks from long excursions;
– inspect walks of other users; this may serve the educational use of the network, by informing the teacher briefly on the progress of the pupils, or other members of the working group in the case of a collaborative study.

They can also be used by the teacher, who can predetermine important routes, indicating relationships which he wants to emphasise.

3.3 An example of exploring the network

As an example, a part of such a semantic network (a view) and the interventions of the teacher and learner are presented here. The following schema represents a part of the semantic network, linking information concerning

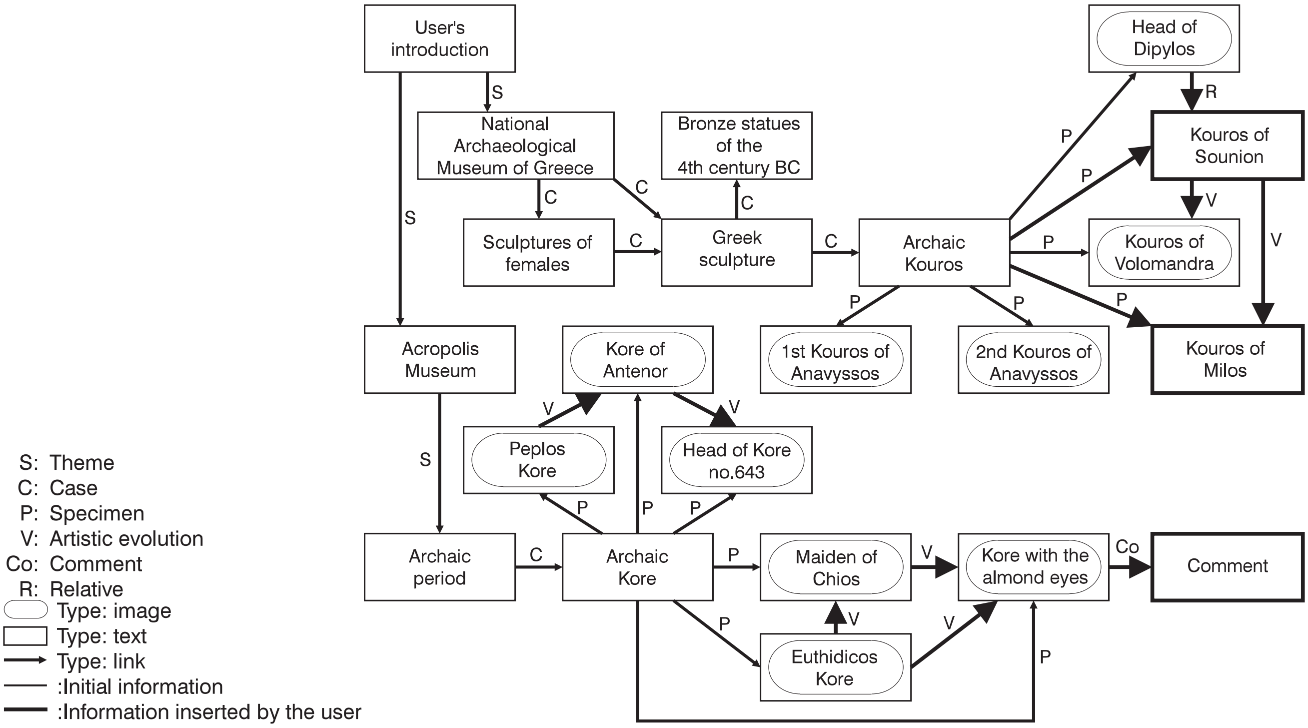

Figure 2. The tailored network.

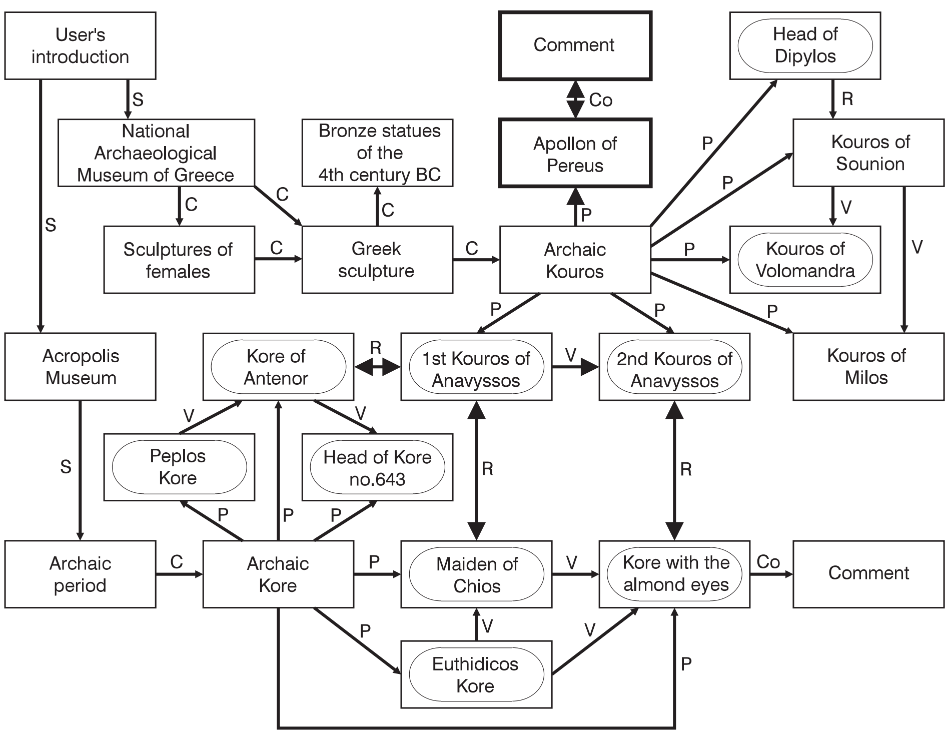

Figure 3. The network in the learning phase.

exhibits from different Greek museums (Andronikos *et al.* 1975). The user may observe analogies on the studied objects, and introduce his conclusions in the network for further study.

4 Conclusions

Completely fulfilling these specifications in a real scale environment is a rather ambitious task, because of the complexity of the domain and the consequently extended labour demands, high cost and heavy computational requirements. Currently one can realistically expect that related research can result in a prototype desk accessory for teachers, students and researchers. Such a prototype permits experimentation and evaluation of representation and manipulation issues, so that extension to real scale becomes easier when the technological advancement will allow it. The progress in the fields of object-oriented programming, databases and multimedia, and the drastic price reduction in hardware and software, set the frame for current and future research directions.

The study of historical facts, based on findings, demands the examination of a large number of relationships. In such a study, objective information is mixed with personal considerations. The computerised environment must be designed in a way allowing the expression of both, yet maintaining their distinction. The proposed hypermedia system permits this expression and it offers a number of tools evaluating the interventions and helping the navigation.

Such an environment is expected to serve as:

- A hypertext-type book, easy to use for independent study, flexible and adjustable; it may be used for tourist information. The search at this level is supposed to be performed by ‘clicking’ on predefined ‘buttons’, for observing museum exhibits or specimens in an archaeological place and reaching relative information.
- A hypertext-type book for a more advanced study, based on information from different museums, interesting for students; the search at this level may be improved by allowing the user to apply programming ideas. Programming is considered here as an expressive medium, permitting the formulation of composite meanings; thus it must be supported at least in the advanced levels of use. Of course, it requires that the user has an Computer Science background, which we may assume for all students in the near future.
- A flexible notebook, equipped with some ‘intelligence’ in order to collaborate effectively with the user for a comparative study, based on hypothetical reasoning; this requires *querying* capabilities within the knowledge space. This feature is useful for obtaining global information which can be further used as a new search space.
- A teaching book, equipped with facilities allowing the teacher to adjust the subject matter to the needs of the course, yet not obliging the student to limit his efforts in the proposed domain or to follow predefined paths. For that purpose, this environment may be essentially useful for inductive learning.

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Toward a European Archaeological Heritage Web[1]

1 Introduction

The study of archaeology, like the cultures we attempt to describe, is evolutionary in nature. As new data are collected, methods, techniques, theories, and interpretations undergo change. Archaeologists are increasing in number, their research interests are diverse, and their study areas overlap both in a geographical and a chronological sense. Traditional techniques of data sharing and communication between archaeologists, such as print media and organised conferences, can no longer keep up with the quickening pace of this evolution. They are slow, prohibitively expensive, and often do not allow for the presentation of complete data sets which would be useful for research purposes.

As the discipline of archaeology continues to expand and evolve, we should exploit new technologies which allow for a cost-effective means of pooling information, and foster international collaboration in a timely manner. Scholars in a variety of disciplines have found that resources offered by the Internet provide a means of sharing and distributing information of many different kinds (sound, video, graphics, and text) in many different ways. In this paper we outline some of the shortcomings of traditional techniques for the sharing and presentation of data and ideas, describe current Internet resources being developed by archaeologists, and conclude with a proposal for the establishment of a European network of archaeological information services accessible via the Internet.

1.1 Evolving communications channels

In view of the delays and costs inherent in traditional communications (phone, fax, letters, meetings, conferences, books, journals, exhibitions), it is perhaps surprising that archaeologists have not been faster to take up the possibilities offered by the world wide computer communication structure called the *Internet*. Many, especially in northern and western Europe, Australia, Japan and North America already have this facility at their disposal. The Internet allows for both communication and reference services to take place, using a variety of techniques and protocols of which the user (luckily) need not be aware.

Communication via the computer, using facilities ranging from e-mail via news and discussion lists to video conferencing and electronic publications, enables researchers and archaeological resource managers to profit from the knowledge and experience of others, without incurring the costs of traditional conferences or the delays of traditional publication. Many archaeologists already communicate by e-mail on a regular basis, and their messages arrive at their destinations all over the world within the hour. Recipients are warned of the arrival of electronic mail on login and a reply function facilitates prompt answering of questions. Mailing lists act as electronic bulletin boards in that correspondence is directed to a central list address which redirects mail to a group of ‘subscribers’. This is the easiest way to make contact with a world wide audience and peer group, to discuss research and debate current topics. Newsgroups are similar to list servers, but the correspondence is held at a central archive which is accessed by the subscribers.

Reference services by computer are also being used by many archaeologists who, if they are connected to the Internet, may regularly use a file transfer protocol (FTP) to swap documents, software and images. Instead of asking around in their office or going down to the library when they need a bibliographic reference, they telnet to the on-line searchable library catalogue and get full details immediately. Archive materials from field surveys, excavations, and museum collections to legal documents on heritage management are being made available through FTP and related services such as the Gopher browser developed at the University of Minnesota. On-line searches of world wide bibliographic databases, including grey literature and journals, radiocarbon dating archives, and national archaeological databases have been made possible through the use of telnet and related services.

1.2 Integrating Internet services

Although list servers, FTP, and Gopher have been available for years, they require a certain amount of technical skill and knowledge of the structure of the different protocols used. This has tended to scare off many potential users. In addition, the absence of specialist guides for the

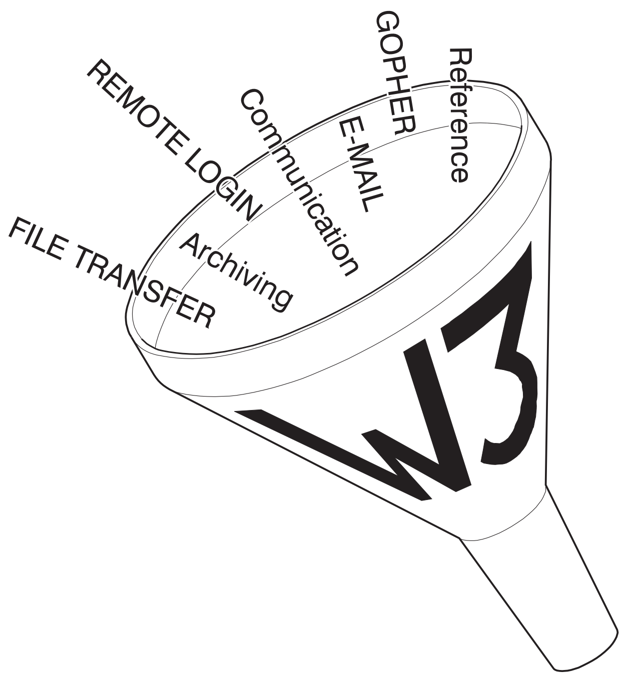


Figure 1. World Wide Web architecture serves as a funnel, integrating a plethora of network services and protocols. It presents the user with an easy-to-use 'browsing' interface to a wide range of multimedia information resources on the Internet.

inexperienced user has meant that a lot of persistence was required to find one's way to contacts or information. Several ways of dealing with these technical problems, all now rapidly converging on the World Wide Web (WWW or W3) architecture developed by the European Centre for Nuclear Research (CERN) in the late 80s, have emerged (fig. 1).[2]

Browsers and search engines are two methods for navigating the Internet that present the user with a) an easy-to-understand interface to the technical side of Internet, and b) a keyword-based way of automatically finding resources of potential interest. Browsers such as Gopher, providing a text menu based interface to Internet resources, have evolved into the current generation of WWW hypermedia browsers, which use hyperlinks to access material *from all older Internet protocols* and in addition allow for the viewing of multiple media documents. These now have become the global standard for navigating the Internet. The development of search engines has shown a similar evolution from relatively simple engines such as *Veronica* (searching titles in Gopher space) and *Archie* (searching FTP archives) through *WAIS* to the *WWW Worm* (key word search of indexed Web space) and the *Web Crawler* (document search). These are all based on string searches and conform to the WWW standard.

Internet Resource Guides are documents produced by professionals working in the field, that locate and summarise the available resources. Guides such as Peter Stott's (1994) *Internet Resources for Heritage Conservation, Historic Preservation, and Archaeology*, Allen H. Lutins' (1994) *Network Resources of Interest to Anthropologists*, Simon Holledge's (1994) *Archaeology on the Net*, and Sara Champion's (1995) *Internet Resources for Archaeologists* have generally become available either in print or as Internet documents only since early 1994, and they provide guidance and links to Internet resources of interest to archaeologists.

What if it were possible to combine browser, search engine, and resource guide into one application? The WWW protocol can do this, and is therefore radically changing the way people use the Internet as data providers and consumers. Search engines, because they follow the WWW protocol, can be accessed through Web browser interfaces such as Mosaic and Netscape. Resource guides written in hypertext format and accessed through these Web browsers allow readers to 'jump' instantly to information of particular interest. *ArchNet*, maintained by Thomas Plunkett and Jonathan Lizee at the University of Connecticut Department of Anthropology, sets out to do exactly that and has been available on the Internet since November 1993.[3] One of its goals is to facilitate international data exchange — it 'provides a road map to the information superhighway' (Plunkett/Lizee 1995). ArchNet is a collaborative effort which provides links to all known archaeological data on the Internet and serves as the World Wide Web *Virtual Library* (resources list) address for archaeology. Since its inception, ArchNet has been accessed over one million times by users in 50 countries. Research and teaching archaeologists, cultural resource managers and museum staff are all now starting to see the potential of the Web to provide attractive means of communication, data exchange, and presentation.

Is there enough useful information available on Internet? With user-friendly access insured by World Wide Web technology, we quickly arrive at an information bottleneck: the limited number of information providers that serve the fast growing legion of information consumers. Current archaeological communication services often restrict themselves to providing basic (names, addresses) and/or general information (exhibits, 'tours', brief project descriptions) aimed at a large rather than a professional public. Current reference services are largely restricted to bibliographic catalogues and a limited number of survey and site reports. Archaeologists might well be justified in not bothering to explore the Internet if the available resources are few and of low quality. In order for the Internet to fulfil its potential in both of these areas, a lot of

Figure 2a. *ArchWEB-NL.* (downloaded 23.2.96)

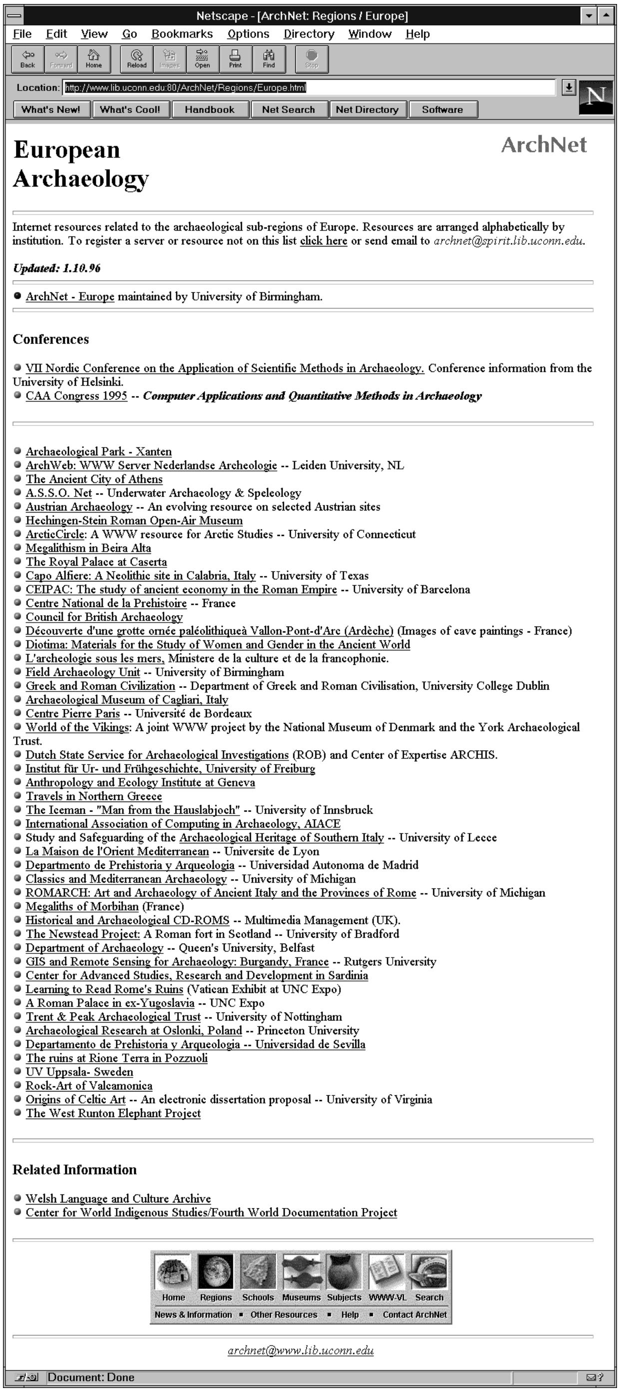
Figure 2b. WWW 'Home pages' of *ArchNet*. (downloaded 23.2.96)

effort must be put into opening up the many resources that are as yet only available through traditional means of communication and reference (fig. 2).

So what IS available in the way of resources for European archaeology? Overviews, admittedly skewed heavily in favour of hypermedia resources, are being maintained in the *Europe* page of ArchNet[4] and in a page especially compiled by the authors for the 1995 CAA conference (*ArchNet - Europe*).[5] The latter page provides some idea of how a European Archaeological Heritage Web might look. It contains links to all the archaeological resources relating to or originating in Europe, that the authors have been able to locate so far. The majority of resources consists of academic departmental information, museum exhibits, and project descriptions. These are all localised initiatives, and little attempt seems to have been made to construct nationwide or international access to archaeological resources. Examples of such localised Web services are the University of Southampton's Archaeology server[6], the Cagliari National Archaeological Museum exhibit[7], and the French Ministry of Culture archaeology pages.[8]

The only example of a nationally organised archaeology server at present appears to be *ArchWEB Netherlands*.[9] Set up in late 1994, this server for Dutch archaeology, involving most of the professional and amateur archaeological community, museum and heritage management staff, etc., has received funding for an initial period of 1.5 years by the company that maintains the Dutch academic network infrastructure, after which responsibility for its upkeep reverts to the ArchWEB-NL members. No transnational archaeological information services other than ArchNet, the global discussion lists, newsgroups, and some electronic journals could be identified.

Yet interest in such services appears to be large and growing rapidly. For example, in 1992 an attempt was made


Netscape - [ArchNet: Regions / Europe]
File Edit View Go Bookmarks Options Directory Window Help
Back Forward Home Reload Images Open Print Find Stop
Location: http://www.lib.uconn.edu:80/ArchNet/Regions/Europe.html
What's New! What's Cool! Handbook Net Search Net Directory Software

European Archaeology

ArchNet

Internet resources related to the archaeological sub-regions of Europe. Resources are arranged alphabetically by institution. To register a server or resource not on this list click here or send email to *archnet@spirit.lib.uconn.edu*.

Updated: 1.10.96

- ArchNet - Europe maintained by University of Birmingham.

Conferences

- VII Nordic Conference on the Application of Scientific Methods in Archaeology. Conference information from the University of Helsinki.
- CAA Congress 1995 -- ***Computer Applications and Quantitative Methods in Archaeology***

- Archaeological Park - Xanten
- ArchWeb: WWW Server Nederlandse Archeologie -- Leiden University, NL
- The Ancient City of Athens
- A.S.S.O. Net -- Underwater Archaeology & Speleology
- Austrian Archaeology -- An evolving resource on selected Austrian sites
- Hechingen-Stein Roman Open-Air Museum
- ArcticCircle: A WWW resource for Arctic Studies -- University of Connecticut
- Megalithism in Beira Alta
- The Royal Palace at Caserta
- Capo Alfiere: A Neolithic site in Calabria, Italy -- University of Texas
- CEIPAC: The study of ancient economy in the Roman Empire -- University of Barcelona
- Centre National de la Prehistoire -- France
- Council for British Archaeology
- Découverte d'une grotte ornée paléolithiqueà Vallon-Pont-d'Arc (Ardèche) (Images of cave paintings - France)
- Diotima: Materials for the Study of Women and Gender in the Ancient World
- L'archeologie sous les mers, Ministere de la culture et de la francophonie.
- Field Archaeology Unit -- University of Birmingham
- Greek and Roman Civilization -- Department of Greek and Roman Civilisation, University College Dublin
- Archaeological Museum of Cagliari, Italy
- Centre Pierre Paris -- Université de Bordeaux
- World of the Vikings: A joint WWW project by the National Museum of Denmark and the York Archaeological Trust.
- Dutch State Service for Archaeological Investigations (ROB) and Center of Expertise ARCHIS.
- Institut für Ur- und Frühgeschichte, University of Freiburg
- Anthropology and Ecology Institute at Geneva
- Travels in Northern Greece
- The Iceman - "Man from the Hauslabjoch" -- University of Innsbruck
- International Association of Computing in Archaeology, AIACE
- Study and Safeguarding of the Archaeological Heritage of Southern Italy -- University of Lecce
- La Maison de l'Orient Mediterranean -- Universite de Lyon
- Departmento de Prehistoria y Arqueologia -- Universidad Autonoma de Madrid
- Classics and Mediterranean Archaeology -- University of Michigan
- ROMARCH: Art and Archaeology of Ancient Italy and the Provinces of Rome -- University of Michigan
- Megaliths of Morbihan (France)
- Historical and Archaeological CD-ROMS -- Multimedia Management (UK).
- The Newstead Project: A Roman fort in Scotland -- University of Bradford
- Department of Archaeology -- Queen's University, Belfast
- GIS and Remote Sensing for Archaeology: Burgandy, France -- Rutgers University
- Center for Advanced Studies, Research and Development in Sardinia
- Learning to Read Rome's Ruins (Vatican Exhibit at UNC Expo)
- A Roman Palace in ex-Yugoslavia -- UNC Expo
- Trent & Peak Archaeological Trust -- University of Nottingham
- Archaeological Research at Oslonki, Poland -- Princeton University
- Departamento de Prehistoria y Arqueologia -- Universidad de Sevilla
- The ruins at Rione Terra in Pozzuoli
- UV Uppsala- Sweden
- Rock-Art of Valcamonica
- Origins of Celtic Art -- An electronic dissertation proposal -- University of Virginia
- The West Runton Elephant Project

Related Information

- Welsh Language and Culture Archive
- Center for World Indigenous Studies/Fourth World Documentation Project

Home Regions Schools Museums Subjects WWW-VL Search
News & Information ■ Other Resources ■ Help ■ Contact ArchNet

archnet@www.lib.uconn.edu

Document: Done

Figure 2c. ArchNet 'European resources' page. (downloaded 23.2.96)

to start the process of setting up a European Archaeological Database (EUARCH). The initiative for this was taken in late 1991 by Uwe Schoenfelder (Essen, DE); it was discussed at the 1992 CAA conference in Aarhus (DK), and a preliminary plan was produced by Anne Vikkula (Department of Archaeology, University of Helsinki, FI) and mailed to the ARCH-L discussion list in July 1992 (Hansen 1993). Two of EUARCH's aims were to:

– preserve the common European Archaeological Heritage;
– facilitate the access and exchange of archaeological data within Europe.

Again in 1992, the European Association of Archaeologists (EAA) was formed, which aims to:

– promote the development of archaeological research and the exchange of archaeological information;
– promote the management and interpretation of the European archaeological heritage;
– promote proper ethical and scientific standards for archaeological work;
– promote the interests of professional archaeologists in Europe;
– promote co-operation with other organisations with similar aims.

Clearly both EUARCH and EAA aims would be well served by the establishment of an appropriate internationally networked communication structure, which would also tie in well with the 1992 Convention of Malta (Council of Europe 1992), which aims to:

– form inventories and databanks for cultural resource managers to use in preparation for development projects;
– educate the public in the value of the archaeological heritage as a major element of the European cultural identity.

The latter point introduces yet another important area of traditional interest for archaeologists which should be pursued using Web technology, that of public outreach and education.

2 Toward a European Archaeological Heritage Web

We propose that access to, and use of, archaeological information resources in Europe be facilitated through the establishment of a *European Archaeological Heritage Web* (fig. 3) service building on and extending the ways archaeological information is accessed by ArchNet and ArchWEB-NL. This service should cater to both providers and consumers of archaeological information at all levels. It should provide a forum for professional discussion and publication, promote public interest in and access to European Archaeological Heritage resources, and actively extend itself into regions and sectors that are currently poorly connected.

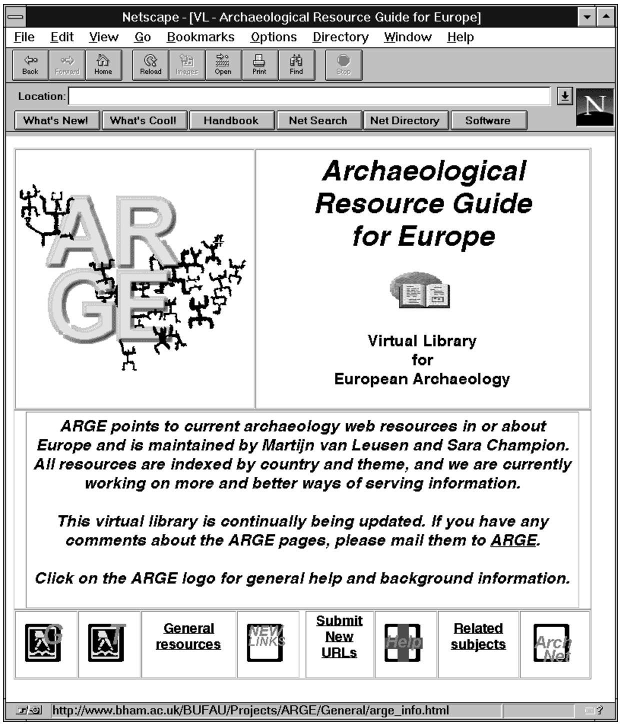


Figure 3. WWW home page of the Archaeological Resource Guide for Europe (ARGE), which the authors hope will become the nucleus for a European Archaeological Heritage Web.

Although this proposed service could be set up using minimal resources (just pointing to locations on other servers), that would not be satisfactory in view of the fact that many sites do not have server capacity. We therefore envisage establishing one or more Web servers either dedicated entirely to archaeology or piggybacking on existing servers.

We are fully aware that many aspects of our proposal will need to be more fully explored, and our discussion of its problems and potential in the next two sections accordingly is not meant to be exhaustive.

3 Problems to overcome

The establishment of the proposed service will to some extent have to overcome a range of problems. These relate to access (connectivity to the Internet and legal access to information), costs (of establishing and maintaining the service), and the language barrier, and will be discussed in some detail below.

3.1 Access

The main technological problem will be to ensure that a high-capacity infrastructure to support large data streams (the Information Superhighway) is in place. Obviously archaeologists will need to have access to this infrastructure both in the sense of being connected and of knowing how to use it. At present practical access to the Internet is largely restricted to academic networks in western Europe. E-mail connectivity exists over most of the remainder of Europe, but has not been discovered yet by many archaeologists there. Luckily, we need not worry about such technological hurdles. Given the speed of current developments, within a few years access to the Internet will have been extended to many more archaeologists all over Europe. For the moment, institutional connections by modem are quite affordable, the cost being comparable to that of an ordinary telephone connection. Public Domain software is available for both client and server sites and for most computer platforms.

One of the major benefits provided by the establishment of a European Archaeological Heritage Web would be to enable access to filespace by European countries, institutions and individuals whose IT infrastructure is not currently able to support the development and maintenance of on-line information services for archaeology. Museum catalogues, Sites and Monuments Records, excavation records, special exhibitions, research papers etc. could be stored on or linked with the European server and be available for consultation and use as the owners/generators of those data wished. It would thus be possible for 'owners' to restrict access to certain data sets, such as sensitive information on the exact location of sites, by the use of a password only given out to suitable people who wished to register with the 'owner' of that data set. We would see this as an enabling device, allowing excavation units, local authority planning departments, museums and individual researchers to deposit and share their work.

It should be remembered that copyright issues currently play an important role in restricting the types of information that may be distributed over the Internet; the question of 'ownership' of information and knowledge is one which will have to be the subject of considerable debate, and may require radical new attitudes in the context of the wider potential access to material.

3.2 Costs

In addition to the costs involved in the purchase of a server or in the rental of space on an existing server, the work of setting up and maintaining information services will take a certain amount of technician's and specialist's time. However, the benefits, compared with traditional print media, outweigh such costs. Exhibits can be mounted or 'published' by their authors and submitted electronically. High resolution colour images can be made available at little or no cost, which would enhance archaeological research and education.

The development of archaeological Internet resources, and the provision of access to these, have up till now been the work of dedicated individuals, who have neither been told nor paid to do this. Some have managed to acquire grants from various sources. It is to a large extent one of the strengths of the Internet that it allows and encourages this kind of initiative, and we think most of the work on European Archaeological resources should be done this way in future. It is only where the purchase of hardware and technical maintenance is concerned, that more permanent facilities should be set up. The cheapest alternative is to piggyback on an existing WWW server; costs might then be restricted to buying or renting filespace and a certain level of maintenance. Any work on the design and upkeep of the information access structure could be done by a small group of interested archaeologists and librarians.

3.3 Language

The language barrier, which is effectively keeping, for instance, the large anglophone archaeological research community apart from other language communities on the Web, is surely the most important problem that any truly European resource must deal with. There are three main areas where an appreciable language barrier would be fatal: a) in the Web navigation structure or 'road map'; b) in the documents themselves (e.g. papers); and c) in discussion lists.

Any inability or difficulty in understanding the first of these will effectively bar one from using the Internet; the second, bars one from following news and developments in one's field; the third, bars one from understanding and taking part in discussions with colleagues in other language communities. Although it is the user's own responsibility to learn any language that she may need, the EAHW should in no way add to her problems. The Web navigation structure, with its main function of providing pointers to archaeological resources elsewhere on the Net, could be made multilingual with a relatively minor effort by volunteer translators. Texts and e-mail would be much more resistant to such translation because of the effort involved. Here perhaps the path taken by traditional publications — abstracts in other languages — points the way forward.

Any translations must also deal with the restrictions inherent in the standard ASCII character set -ISO-Latin is the current standard for Web documents, but this will not provide for Greek or Cyrillic character sets, a problem currently under research.[10]

4 Potential for new developments

Problems apart, we see in the WWW a way to change radically the way in which archaeologists communicate the results of their work, both for the benefit of their fellow professionals and for the wider public. Although it will not replace traditional means of communication, it will certainly enhance communication itself by removing many traditional obstacles to inter-institutional and international information sharing and collaboration.

4.1 Research

For ongoing fieldwork projects, the annual or interim report has become a standard method of publication, with its associated time and financial burdens. In many cases such interim reports take up considerable space in august journals, take more than a year to appear, and are required to conform to standards more suitable for a final report — indeed, often the material thus published has to be repeated in the final report anyway. In other cases, an archaeological organisation may produce a more popular document of its own, which can cost a considerable amount to print in any numbers.

In both cases, we see the WWW and a European server as an obvious way to present ongoing fieldwork, as the examples on the Southampton server demonstrate. Here a normal descriptive text is illustrated by plans, coloured contour plots and colour photographs, the last two of which would be difficult to justify on cost grounds in a standard interim report and which would be expensive to produce in a self-published format. Access to both types of publication is limited, while any number of people, both professional and members of the public, can access the material on the WWW. The amount of material included is quite enough and of a perfectly acceptable standard for an interim report.

Similarly, the interim results of ongoing research work, and the presentation of kite-flying new ideas, find an obvious home on the WWW, where they can be commented on and discussed, and replaced with further versions as they develop. Again, examples can be found on the Southampton server; it seems to us that this is an economic and accessible way in which to try out new ideas and to keep new research under review. Moderated electronic journals, with articles subject to peer review and simultaneous comment, are already beginning to appear (e.g. *On-line Archaeology*[11] and *Electronic Antiquity*[12]). Such journals have been developed in other scientific disciplines since 1990 (Harnad 1990, 1995; see also Harnad's Web pages[13]).

Until now, many in Europe would be prevented from taking part in such contact except when they could get to conferences. Even if they themselves do not have access to the WWW, they could file things on the European server, reach a much wider audience, and receive e-mailed or 'snail-mailed' comments. While some of these research ideas might find their home in moderated electronic journals, others could quite happily be presented as individual contributions — the WWW is infinitely more flexible than hard copy.

Another development with a considerable research potential concerns the creation of Web browser interfaces to existing softwares. Current work includes research into interactive access to visual databases and catalogues (Jakobs/Kleefeld 1995) and to major software packages (GIS, RDBMS).

4.2 Education

We also see great possibilities in the area of public education, and in the presentation of the heritage. Quite apart from public access to the above, the graphic and interactive potential of the WWW will allow the development of a wide range of resources associated with particular sites, localities and countries which can be linked to or placed on the server for the purpose of information and education. Already a small number of such resources exist, both in the form of museum exhibits, and as 'virtual tours' round sites of interest (e.g. a 'field trip to Salisbury Plain'[14] or a 'tour of the Pompeii Forum'[15]).

A further way to engage the European public would be the development of distance learning materials, which could be located on the server and whose introductory levels could be made available for public browsing. Access to more detailed course materials could be by password after registration with whichever institution had developed the course, and credit could presumably be obtained on completing assignments and the payment of assessment and other fees. At a more junior level, the opportunity to develop an interest in and an understanding of the European heritage in children could perhaps be provided by the setting up of a European Archaeology Club, where not only basic educational materials could be produced by the Education Officers related to national heritage bodies, but where communication between children along the lines of the global *Kidlink* project[16] could be facilitated. Clearly, problems of language may be involved (see section 3.3), but these have not prevented tremendous success in this particular project.

Finally, all the above resources have the potential to also draw in people who would otherwise have difficulty in experiencing the European heritage at first hand — the disabled, elderly, sick, housebound and geographically isolated.

5 Conclusions

The intention of our proposal as outlined above is to use the power, speed and trans-national attributes of the World Wide Web to facilitate increased and more productive communication between archaeologists; and to allow improved access to the results of archaeological research by the development of on-line publication, and the creation of electronic links between researchers and computerised databases, whether these be excavation records, sites and monuments records, or museum, heritage and conservation resources.

In addition, the intention is to improve access to such resources and information by non-specialists, through the construction of user-friendly interfaces to the data in order to enhance leisure-based experiences, and through the development of more formal educational packages for both children and adult learners.

The decentralised and co-operative structure of the Web (a network of networks) contrasts with the centralised and often hierarchical structure of professional archaeology, and in seeking these improvements in communication, we are aware that we tread a potentially difficult middle path. We do not wish to exercise any central control over sources of archaeological information, nor their content; but we would like to encourage specialists to provide more open access to their material by assisting with the construction of links from such resources to the European Archaeological Heritage Web.

We also wish to encourage the use of such a central distribution point by thousands of potential users, many of them currently unfamiliar with modern information technology, or navigation procedures on the World Wide Web, by constructing attractive and easily negotiable pathways to the information available.

We thus see the role of the European Archaeological Heritage Web as a facilitator for communication between archaeologists and heritage professionals, the archaeological data which they generate, and the wider community of Europe.

An informal glossary

FTP	File Transfer Protocol, a set of rules that all software used to transport files over the Internet should adhere to.
Gopher	The predecessor of today's Internet browsers, this software allowed full browsing of the Internet but had no hypermedia capability. Gophers, being burrowing animals, represented the software's role of digging for information, besides punning on the word 'gofer' and on the fact that this animal symbolises the state of Minnesota, the home of the software developers.
HTML	HyperText Mark-up Language, the protocol for writing hypermedia documents.
HTTP	HyperText Transfer Protocol
Hypermedia	Software that accesses multimedia information through hypertext links in the documents themselves.

Hypertext	Text that contains 'active sites' — words or images — which, when clicked upon with the mouse, link the user to a new document. The actual process by which such documents, which may be located anywhere on the Internet, are accessed is hidden from the user.
Internet	The network of networks consisting of computers linked all over the world. Also known as the Web. Originally grown from the US Defence ArpaNet, it now consists of many publicly and some privately owned networks in most of the world's countries. It has no 'centre' and no hierarchy.
Multimedia	Software that allows presentation of more than one type of medium. Commonly taken to include at a minimum text and images, this may also include sound, movies, and interactive access to various services.
TCP/IP	Transfer Control Protocol / Internet Protocol, a set of rules to govern the movement of data over the Internet.
Telnet	Software that gives users login access to remote computers. A common application of Telnet is accessing library catalogues.
URL	Universal Resource Locator, the protocol for defining both the document type (plain text, image, hypertext), the location (server name, path and filename) and the server type (FTP, gopher, http, file, news) for a resource.
WAIS	Wide Area Information Server. Searches the indexed contents of Internet documents.
WWW	World Wide Web, a protocol developed at CERN to access the Internet.
WWW browser	Any of a range of programs that provides a hypermedia interface to the Internet (e.g. Lynx, Mosaic, Netscape).

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notes

1 As this paper is published in traditional manner in the CAA proceedings, and will not be available until April 1996, most if not all of our description of the current state of Internet resources for archaeology will be out of date by then. We feel that this will not affect the thrust of the paper, and may add a note of historic interest to it.

2 The World Wide Web protocol allows for the transmission of large data sets of multiple media which include images, text, sound, and video in a seamless presentation. Hypermedia presentations, constructed using the HyperText Mark-up Language (HTML), also allow for the construction of collaborative data sets using interactive forms for data input and querying.

3 http://spirit.lib.uconn.edu/ArchNet

4 http://spirit.lib.uconn.edu/ArchNet/Regions/Europe.html

5 http://www.bham.ac.uk/BUFAU/Projects/EAW/

6 http://avebury.arch.soton.ac.uk/index/

7 http://www.crs4.it/HTML/RUGGIERO/MUSEO/mus_ind.html

8 http://www.culture.fr/gvpda.html

9 http://prehist.leidenuniv.nl/archweb_nl.html

10 http://www.free.net/Docs/cyrillic/notes.en.html

11 http://avebury.arch.soton.ac.uk/Journal/journal.html

12 gopher://info.utas.edu.au/70/11/Publications/Electronic%20Antiquity%20%3A%20Communicating%20The%20Classics

13 http://cogsci.ecs.soton.ac.uk/~harnad/

14 http://avebury.arch.soton.ac.uk/LocalStuff/Stonehenge/salisburymap.html

15 http://jefferson.village.virginia.edu/pompeii/page-1.html

16 http://www.kidlink.org/

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Internet archaeology: an international electronic journal for archaeology

1 Background

In 1993 the Higher Education Funding Councils (HEFCs) published a review of libraries and related provisions in higher education in the UK, chaired by Sir Brian Follett (Follett Report 1993). The review group devoted much attention to how information technology can help to meet the needs of library users and library management over the next decade. It proposed that the funding councils should jointly invest some £20 million over three years in support of a range of activities to further the development of the electronic library. It was subsequently announced that the Higher Education Funding Councils for England, Scotland and Wales, and the Department of Education for Northern Ireland had agreed to allocate £4.75m during the 1994/95 academic year to proceed with the Information Technology (IT) recommendations set out in the report.

The Follett Implementation Group on Information Technology (FIGIT) was established to manage the implementation of many of these recommendations (see JISC Circular 4/94, *Follett Implementation Group on Information Technology: Framework for Progressing the Initiative*). FIGIT works closely with the Joint Information Systems Committee (JISC) of the HEFCs. Instead of inviting competitive institutional bids for projects in each category FIGIT invited higher education institutions and other interested parties to submit expressions of interest in programme areas. Some of the institutions which expressed interest were invited to make a presentation to the appropriate FIGIT working party, and subsequently an even smaller number was requested to submit formal proposals for funding. One of the programme areas was electronic journals, where FIGIT agreed to fund a number of initiatives to improve the status and acceptability of electronic journals, and the promotion of new forms of electronic journals and opportunities for parallel publishing.

We initially expressed an interest in establishing an electronic journal for archaeology and following an apparently successful presentation on 23 February 1995 to the Electronic Journals Working Group we were invited to submit a formal proposal for funding. Our proposal to establish an international electronic journal for archaeology received funding. The intention is that the production and dissemination of the journal will be network-based, ultimately available to all via the Internet.

The journal will publish the results of archaeological research, including excavation reports (text, photographs, data, drawings, reconstructions, diagrams, interpretations), analyses of large data sets along with the data itself, visualisations, programs used to analyse data, and applications of information technology in archaeology: for example, geographical information systems and computer modelling.

Conventional publication via the printed page cannot do justice to the rich diversity of archaeological information. Electronic publication, by contrast, offers opportunities to overcome these difficulties. The journal will be fully refereed. It will set a high academic standard. Contributions will be provided by archaeologists throughout the world, and the journal will be aimed at an international audience.

2 Consortium membership

The bid was led by the Council for British Archaeology (CBA) in close collaboration with the British Academy and the University of York as well as several other Universities. The University of York will act as the host for the project. The project's Managing Editor will be based in the University's Department of Archaeology and the journal will be made available via a network server linked to the University campus computer network.

The CBA will act as the publisher of the journal. The Council was founded in 1944 and is both an educational charity and a company limited by guarantee. It is primarily a liaison body made up of over 400 archaeological organisations and 2800 individual members. It works to advance the study and care of Britain's historic environment, and to improve public awareness of Britain's past. Three of its focal areas of activity are education, information and publication. It has extensive experience of journal management and will act as the subscriptions manager. Guidance will be provided through its Publications Committee and the staff of its Publications department. The CBA will also assist in the marketing of the project and the generation of project publicity.

The British Academy, founded in 1901, is a learned society, which has responsibility by Royal Charter for promoting advanced work in all the humane disciplines. Among these is archaeology. It has supported much archaeological fieldwork, publications of archaeological research including study of archaeological collections and excavation reports, and supports Schools and Institutes abroad. The Academy will provide editorial guidance from among its fellowship, technical assistance through its IT department, and will make available the expertise of its Publications Committee and department.

The other consortium members are all UK universities with major archaeology departments (Durham, Glasgow, Oxford and Southampton). Together with the University of York, they will contribute the specific expertise of individuals from within their archaeology departments to both the editorial board and technical panel.

3 Why archaeology?

Archaeology is a particularly appropriate subject to promote the use of electronic media as it is multidisciplinary, with a wide variety of data types. Much archaeological work is by its very nature destructive — it is only possible to excavate a site once — and archaeologists therefore need access to primary data in order to repeat and test conclusions, and reanalyse data to apply alternative hypotheses. New computer tools are being developed to allow archaeologists to make statements about the data they collect which were not previously possible. Traditional methods of publication cannot provide the functionality that these new methods and data types require.

The electronic journal will allow archaeologists to distribute full excavation data, in addition to their interpretations, allowing other researchers to reanalyse the material to confirm conclusions or to draw new conclusions. It will also be possible to distribute photographs, drawings, and dynamic reconstruction images, together with the computer programs that were used to analyse the data; and this is particularly important where the analytic programs hide hypotheses that might have influenced the analysis of the data (Ross 1995).

4 Why an electronic journal?

Electronic publication offers new possibilities for the display and interpretation of archaeological data that is not possible through conventional publication. However, there is some need for culture change if electronic journals are to become common (RS/BL/ALPSP 1993; Vickers/Martyn 1994). Difficulties include: problems with refereeing and guaranteeing quality; lack of standards governing the citation of electronic publications; the fact that electronic documents appear to have an ephemeral character; difficulties of access; fundamental questions in the minds of academics on what constitutes a publication and what it means to be published; and that electronic publications cannot be accessed without other hardware and software (BLRDD/BA 1993: 30).

This electronic journal will gradually help to break down barriers to these new approaches. Three factors will cause this change. The first will come about naturally and results from the general availability of computing equipment, software, and wider access to electronic resources. The concomitant collapse of psychological barriers to digitised information will take place as more people realise that, with electronic resources, it is possible to do things with the sources that could never be done with their printed counterparts. The second factor has to do with guaranteeing quality. Journals with poor quality content have no financial viability, whether stored in print or available via the networks. An academic refereeing process is required to make certain that digitally distributed scholarly articles achieve the same standards of excellence found in their printed counterparts. Third, many objections to electronic publication are disappearing as publishing houses add electronic imprints and series to their lists. There is a fear, and one that probably has a great deal of justification, that publishing electronic material will lead to the scholarship being marginalised by colleagues. This journal will aim to make certain that this does not happen because it will be both refereed and sponsored by the UK's premier learned society for the humanities and social sciences, the British Academy. We aim to ensure that electronic imprints are accorded the same scholarly recognition as any print journal.

5 Journal content

The journal will present its material in four sections:

1. general articles on archaeological issues whether theoretical, methodological or analytical studies;
2. excavation reports and finds studies;
3. the application of new techniques, such as software tools or the application of visual methods to archaeological analysis;
4. reviews of technological applications such as databases and other services available on the network.

5.1 Software

By defining the needs of archaeological publications as multimedia based, and the goal of the journal to deliver multimedia information, it is clear that the delivery tools must be both capable of displaying this kind of material and of running in a client-server environment. Several other characteristics are also essential: the interface model must be reusable and tools widely applicable; where possible based on currently available network access and retrieval software (such as WWW browsers); be capable of accessing and running other software packages, of displaying still and moving images, data, and text and its use must put minimal financial and training overheads onto the journal reader; no substantial development and deployment costs must be borne by the journal.

The interface required shapes our approach to the rest of the software. Four categories of software are involved:

1. the software the user will run to access the journal (described above);
2. the software to create the HTML marked-up journal (e.g., query forms, links between data, charts, etc.);
3. the application programs for interfacing between the Web forms or reports and the databases or other information services which lie behind them;
4. the Web server program.

Users should use WWW client software: either public domain versions such as Mosaic or a commercial version such as Netscape. The users will also need to use viewers for images, charts and graphical representations. Once again these will be public domain tools wherever possible. This constrains the server technology to a Web application — CERN Web server software will be adequate for this. However, for the development of the journal articles it will be helpful if the Managing Editor has access to layout and design software that will ease the production of multimedia networked applications. The project will use Silicon Graphics WebForce software for the development of the journal front-end. Although we are generally avoiding using bespoke or commercially developed software, WebForce has a rich set of tools to aid the implementation of Web-based articles such as those required for HTML mark-up.

Between the Web server technology and the application databases, spreadsheets, information, or software, we will need programs which take input from the reader and translate it into a query or request which can be used by the appropriate software as the basis of queries. When the result is returned from the program it will need to be formatted before it is passed to the Web client who made the request. These programs will be written on an 'as-needed' basis (that is in designing an article the software will be produced if data in the article requires access to the programs). The objective will be to keep bespoke programming to a minimum.

It will be necessary to produce access control software. This may need to be a special development, although we do not believe that the software itself will be unduly complicated. What will be needed is a way to verify that readers have a legitimate right to access the journal. We are currently investigating how this might best be achieved.

All this has the caveat that we do not feel that locking the journal into a single delivery technology would be wise. For this reason we are proposing that the delivery strategy should be reviewed on a regular basis. For instance it may turn out that the use of Portable Document Formats (PDF) will supplant the use of HTML marked-up files in the future and we would want to be in a position to migrate the journal forward.

5.2 Hardware

The journal will require three kinds of hardware: development, delivery and reader. The development hardware will be used by the Managing Editor to produce and test the journal. The complexity of integrating text, images, data, programmes and other digital sources requires access to a Unix workstation class machine which has excellent visual representation tools. The work will be time consuming and heavily screen based. To improve productivity the development machine must be capable of running authoring tools for Web production.

The project also requires a delivery machine which can host the journal and provide processing power to manipulate the data which forms the foundation of each of the articles. This machine must be capable of running a Web Server and a full range of database and visual representation tools. It must be connected to JANET/Super JANET by a high bandwidth (minimum 4Mb) line. Articles and software will be worked up on the development machine and periodically archived to the delivery machine. We believe that a separate project server for journal delivery is essential to provide independence from the future technical developments of the host site, and will also make access control significantly easier to manage.

The reader machines will be a definition of standard hardware that a subscriber must have access to if he/she is to read the journal. Current thinking is that the machine must be capable of running Mosaic or Netscape and other public domain visual display tools. This suggests that a minimum of a 486 DX33-based machine with 8Mb of RAM and 20Mb of free disk space, a 24-bit graphics card with 1Mb of video memory onboard would be required to read a single article in any issue. In the short term the journal will be designed to be delivered at one of two levels, users with faster connections will be able to take the high-level version whereas those with low speed modems will only be able to take the low-level version. (A critical element in the design of the journal will be 'delivery time to the user's desk' of the articles.)

5.3 Standards

The key to the long term viability of the journal will be the choice of portable standards which will make the data and information accessible from a wide variety of hardware platforms and software packages over a long period of time. In practice this means that while each issue of the journal must appear to the reader as a coherent piece which could be read or browsed from beginning to end, it must be capable of being broken up into its constituent parts for archiving. By doing this it will be possible to store the components in standard and widely used file types whether these are images, text, data, or CAD files. No files will be stored in proprietary data formats except as a last resort or where the standard has been commonly adopted. This will make it possible for AutoCAD file formats and Kodak's Photo-CD image definitions to be used for reconstructions or site records.

Each journal will therefore consist of its Web definition, which will be accessible only as long as the current generation of HTML-based Web software is being used; the files which the user front-end accesses; and documentation which details the interrelationship between the components so that the article could be reconstructed if necessary from its parts. Where for instance an article depends upon its visual sources to make its argument, details of these will need to be preserved along with a description of the hardware that is required to view the material.

We do not wish at this time to list all the standards that we will use, since to do so would pre-empt work which will be done by the Arts and Humanities Data Service when it is established (Burnard/Short 1994). One of the main objectives of the Data Service will be to outline data standards that can be applied to the creation of data if it is to be stored for long periods. But for the record it may be worth mentioning just a few standards which will be applied. Text will be stored as HTML marked-up files, images as either Graphical Interchange Format (GIF) — assuming the current copyright problems are resolved — or Photo-CD files, where possible dbf for PC-based databases, or ASCII comma-delimited files, and dxf formats for CAD renderings. Surprisingly, the most commonly used kind of data has the least widely established data standard. This is tabular data and the problem is particularly acute where multi-valued fields are used or the data is stored in Unix-based database packages. This issue will need to be addressed by requiring all data to be converted into a standard SQL package which will be running on our server and special hooks will need to be written to access this material. In all cases documentation on the data formats and coding used will be included within all articles.

The question of data compression for both storage and delivery is important. For still image compression the journal will rely on JPEG and for moving images it will use MPEG because these are the industry standard. Whether we will be able to use this for material that is being delivered to the end user is doubtful because to uncompress files at the reader's machine would be both time-consuming and require substantial amounts of processing power.

The focus will be on data standards that are widely accessible and do not pose significant long term storage problems.

5.4 Project management

A major problem which faces consortium-based journals or projects is that they are basically a loose confederation of members without any firm foundation beyond the agreement of the participants to take part. This problem may be less important for some projects, but it is a pressing issue for an archaeological journal which must plan for the long-term accessibility of the information which it publishes. In an attempt to provide a bond between the consortium members and to ensure that the journal has a foundation which will guarantee the preservation of the material it publishes, we plan to establish a charitable trust to own the journal. This is common practice for ongoing non-commercial projects, such as journal publications. For example, *Antiquity* the main international print journal for archaeology is owned by the Antiquity Trust, a registered charity founded in 1927.

The trustees will be the members of the Steering Committee, who would be responsible for overseeing the entire project on behalf of the Trust. This has the advantage that no single organisation within the consortium has significant control of the journal, and that the journal is seen to be independent. No single organisation can unduly influence the project and the project is not dependent on the continuing existence of any one organisation. The constitution of the trust will ensure that it can only use the project income to develop the journal.

5.5 Refereeing

One of the main tasks of both the editorial board and the technical panel will be to oversee the refereeing process which is essential for quality control and academic credibility. We envisage a two-stage refereeing process, all undertaken electronically via the network, based on concept refereeing and product refereeing. Initial concept refereeing will be undertaken by the editorial board, together with external referees where appropriate, who will firstly assess the academic quality of the proposal, followed by the potential of a contribution for its suitability to be published in the journal and the validation of the underlying resources that will be required. Contributions will be selected on their merits for electronic dissemination and their potential to make full use of the new media, as well as on traditional scholarly factors. The editorial board will also need to ensure that each issue of the journal is balanced, particularly in view of the varying quantity of production work to be undertaken by the Managing Editor that will be required for the different articles. Once a contribution has been provisionally accepted for publication then contact will be established between the Project Managing Editor and the contributor to work together to produce the final electronic article. It is assumed that in the early stages of the journal there will need to be significant input from the Managing Editor to prepare material for publication; however, as archaeologists become more familiar with electronic publication and the advantages it offers we assume that less work will be required to rework submitted material. The product refereeing will be managed by the Managing Editor, and must be undertaken over the network to allow referees to evaluate the contribution as it will be viewed by users, to ensure quality in content and delivery effectiveness. Refereeing will take place via the development server which is only accessible by the editorial board and technical panel members and a select group of referees. The whole refereeing system for the journal will therefore be an iterative process, undertaken entirely electronically, managed by the Managing Editor.

5.6 Dissemination

Protecting the copyright of electronic journals poses major obstacles to the widespread dissemination of information through computer networks. The journal will require contributors to grant it a non-exclusive licence to publish their material (including photographs and data) in electronic form. It will protect its own copyright and the intellectual property rights of its contributors by requiring users to accept licensing terms to access and use the journal. The licence will govern accepted usage as well as stipulating that readers follow defined rules of citation (including author and article titles, etc.).

A method of accepting the licensing terms will be provided online. The intention is to restrict the redistribution of the articles or the data included in them, but we will encourage secondary analyses of the data itself. We will encourage users to publish reinterpretations of the data disseminated with articles in the journal, and stimulate debate on interpretations both in the journal and through the associated listserver mailing list.

Copyright and intellectual property rights in the articles and data will be vigilantly protected to assure the journal a continued revenue stream from its collection of core materials. We will keep under review the possibility of using a variety of information fingerprinting techniques to make it possible for the journal to protect its material.

As mentioned previously, we are looking into ways of taking advantage of the Internet functionality to verify the rights of access of subscribers. This will be supplemented by a password protection system which is made simpler by the use of a separate network server for the journal.

5.7 Subscriptions

The main source of income for the journal will come from ‘subscriptions’ and other access charges. The focus will be on revenue stream diversity to ensure the maximum flexibility in charging for users and to provide a sustainable long-term revenue stream for the journal.

The majority of users of the journal will pay a straightforward subscription charge to access the journal issues for a particular calendar year. There will be individual and institutional charges, with the institutional subscription based on access availability for all members of the institution and the subscription being proportional to the size of the potential user-base. It is hoped to keep subscription charges low to maximise the subscriber base and to reduce library subscription costs. From studies of subscriber numbers to international print journals in archaeology we believe that it will be possible, within three years, to gain sufficient income to make the journal self-supporting.

Subscribers to the electronic journal would only have access to the issues for the year in which they subscribe, though in due course they could also purchase the rights to access issues from previous years. We plan to implement a scheme to allow free content searching of issues of the published journal. This will allow users to check whether there is any material of direct relevance to their research interests in the journal before they subscribe. We will then charge for retrieval of individual articles for a variable fee depending upon the type of article, whether access to a particular set of material requires processing on our host server, the quantity of data, and the currency of the material.

5.8 User and community feedback

The network server which hosts the journal will also run a listserver program which will allow the journal to have a dynamic discussion list based on the journal’s contents. The listserver will encourage discussion on the academic contents of the articles, as well as providing feedback to the Steering Committee on the quality and applicability of the journal issues. We will also investigate the possibility of including a WWW-based letters section linked to the journal which would be dynamically updated and available on open access.

6 Conclusion

In conclusion, the objectives of the project are as follows:

a. a regular electronic journal
b. a detailed description of the process of establishing and managing an electronic journal
c. definition of a suite of access and navigation tools that will allow the readers to use the journal
d. a contribution to cultural change through the increased use of electronic media.

It is the intention that the first issue of the journal will be available within a year of the start of the project.

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A Survey of the Development of Computer Applications in Romanian Archaeology

1 Introduction

Situated in southeast Europe, Romania has been from the oldest times a region favourable to man's life, as well as to cultural contacts and influences. As a result of this, archaeological remains are extremely rich and diverse. Before the Second World War, Romanian archaeological research followed the general development of the discipline elsewhere in Europe. After the Second World War, when the communist system was created in Romania, this natural development stopped. First of all, the relationship with the West was broken, and later, after Ceauşescu's National Socialist regime took power, contacts with other socialist countries were cut to a minimum. Although the progress of human thought can be hindered by such obstructions, it cannot be irrevocably stopped. Inevitable technical progress, although slow, and the permanent searching process which is a general feature of the human mind, led to Romanian researchers becoming interested in computer applications and quantitative methods in archaeology.

2 The beginnings

The first studies concerning the application of quantitative methods in archaeology and related sciences were spontaneous and disorganised. The use of mathematical models was necessary in those fields of research where large numbers of similar objects existed. This is why the first applications of statistical methods was in numismatics (Mihăilescu-Bîrliba 1969).

At the same time, the end of the 1960s, at the Mathematics Institute of the Romanian Academy, Professor Grigore Moisil started a course in mathematical methods for archaeologists and numismatists from Bucharest. Some joint projects between mathematicians and archaeologists were completed and it seemed that a period of favourable co-operation was beginning.

On the initiative of the same great Romanian mathematician, the Romanian Academy and the Royal Society of London organised the Anglo-Romanian Conference on Mathematics in the Archaeological and Historical Sciences, which took place in 1970 at Mamaia (near Constanţa, ancient Tomis). Numerous well-known researchers, both from Europe and other continents, took part. The proceedings were published in the following year (Hodson *et al.* 1971). The papers included dealt with cluster analysis, seriation, and the identification of tree structures. The editors wrote:

> 'the first point made by the contributors to this volume is that statistical methods, quantification and computer processing of data do not suddenly transform history from a subjective to an objective study... [because] such mathematical analyses... [are] capable only of reducing the level of uncertainty'.
>
> (Edinburgh University Press, 1971: dust-jacket).

Nine Romanian archaeological papers by twelve authors were published. The themes presented at this conference included: 'Some mathematical aspects of taxonomy and diagnosis in archaeology' (Manolescu/Bordenache 1971), 'Discrimination and classification of certain types of pottery' (Savu 1971), 'Applications of mathematical methods to epigraphy' (Ştefan 1971a), 'Some possibilities for using the volume of information in archaeology and history' (Oprescu 1971) and so on. Some of these studies moved beyond mathematical methodological considerations and dealt with real archaeological problems. Examples included how one could infer the cultural origin of the group of artefacts from the Middle Bronze Age when this origin is uncertain, through their assimilation with 'inference problems' or 'Federal problem' and solve this using Bayes' theorem (Iosifescu/Tăutu 1971); and the chronological seriation of Greek inscriptions using the methods elaborated by Hole and Shaw (1967) for archaeological sites, adapted for epigraphy (Kivu-Sculy 1971; Ştefan 1971a, 1971b).

3 Stagnation

Naturally, after the Mamaia conference, the application of mathematical methods in archaeology should have grown rapidly. Unfortunately, this did not happen because politics interfered again. Immediately after Professor Moisil's death in 1973, the Mathematics Institute of Bucharest was dissolved, the buildings and computers were given to other institutions and the researchers were sent to work in other towns or factories. What had happened? Ceauşescu's daughter, who was working at the Institute, had a 'strange adventure' which annoyed her father. After visiting the Institute he decided to close it down. During this period, a 'mini-cultural revolution' was underway. Any possible opponent had to be eliminated and intellectuals were particularly targeted. Everybody had to know that there was only one omnipotent master.

A period of stagnation, which lasted for more than a decade, followed. However, progress could not be stopped entirely and there were individual efforts during those years. Thus, at the Institute of Archaeology in Iaşi, Cătălina Bloşiu proposed a general system model of archaeological data computer processing. The proposed system relied upon standardised descriptions which then may be used as a basis for information retrieval, and with the advantage of automatic generation of catalogues (Bloşiu 1972-1973). Alexandra Ştefan also continued to work on a method of chronological seriation of Greek inscriptions (unpublished). Unfortunately, their emigration from Romania put an end to these projects. In 1979, a 'Round Table' was held in Paris on the theme 'Statistics and Numismatics' (Carcassonne/ Hackens 1981) and papers were presented by Mihăilescu-Bîrliba (1981, 1981-1982) and Poenaru Bordea (1981). Both papers examined statistical methods for numismatics.

4 A new beginning

From the start of the 1980s, computer applications in archaeology again began to expand and some research teams were founded. A strong team was instituted at the *Information Centre for Culture and Heritage* (CIMEC). CIMEC, led by Dan Matei and Irina Oberländer-Târnoveanu, is responsible for the development and administration of the National Cultural Information System (Oberländer-Târnoveanu this volume). SI-PCN was designed and tested from 1978 to 1981[1] and implemented over several years, beginning in 1982.

Another research centre was founded at Cluj-Napoca where archaeologists such as Gh. Lazarovici and Z. Kalmar, from the Museum of the History of Transylvania, started co-operating closely with mathematicians and physicists from the Institute of Isotopic and Molecular Technology, Cluj; the Faculty of Mathematics and Physics, Cluj and the Institute of Nuclear Engineering, Bucureşti-Măgurele. As a result of this close co-operation two national conferences on the application of physics and mathematics in archaeology were organised, both in Cluj-Napoca, in 1987 and 1989. The papers have been published in two volumes of proceedings (Frangopol/Morariu 1988, 1990).

These two conferences in Cluj give a clear picture of the stage of Romanian research in this field before the revolution of 1989. We shall quickly mention some of the themes covered in those volumes. For example, Frenţiu and Lazarovici (1988, 1990, 1993) used cluster analysis, factor analysis with VARIMAX rotation, and seriation methods in the classification of archaeological materials; Stănescu (1990) examined the possible astronomical significance of the sacred precinct at the late Iron Age site of Sarmizegetusa Regia;[2] Blăjan, Oproiu and Popa (1990) investigated the orientation of graves in the early medieval cemetery at Alba Iulia; Dumitrescu and Lazarovici (1990) proposed a new fuzzy clustering procedure for archaeological data; Mărgineanu-Cârstoiu, Harhoiu and Cârstoiu (1990) undertook a comparison of various multivariate data reduction methods including principal components analysis, correspondence analysis, and classic and non-metric multidimensional scaling; Morariu, Salvanu and Frangopol (1990) undertook a dimensional analysis of pottery and Rişcuţia *et al.* (1990) performed an archaeometric investigation of human groups and produced cladogram projections on time co-ordinates. An information system for archaeology called BAZARH was presented for the first time. This project was established at the History Department of the Museum of History of Transylvania. The BAZARH system had three components: a database, a knowledge base, and an expert system for analysing the information in the knowledge and databases. Data processing varies from statistics and simple classification to complex mathematical analyses (Kalmar/Corbu 1990).

There were other projects developing computer applications in this period, but they were not satisfactorily developed, or were abandoned due to a lack of hardware and software (e.g., Cârstoiu 1990; Dumistrăcel/Mantu 1987; Harhoiu 1990; Mărgineanu-Cârstoiu 1990).

5 The Present Day

The revolution of 1989 has brought some major benefits. One of them is the free circulation of people, information and technology, and a freedom of initiative. Consequently, in 1992, CIMEC organised the *Eastern and Central European Regional Conference on Museum and Cultural Heritage* in Sinaia (RECOMDOC 1992). On this occasion CIMEC's computer based projects were presented. These are large! About 28 experts work at CIMEC. The National Cultural Information System (SI-PCN) is the largest in southeast Europe and the fourth largest in the world. The database has 740,000 entities recorded in machine readable form and about 740,000 data entry cards await processing. It also includes a museums reference database with 1,500 items of information about museum services; museums activities data collections; museum professionals' reference databases (for about 2,000 Romanian specialists); and a Romanian theatre history database. Recently, a historical monuments and archaeological sites database has been added with about 17,000 items. The 'National Database' includes an archaeological database (ARH) with more than

120,000 items and a numismatic database (NUM) with more than 140,000 items. The National Database is based on *thesauri* which standardise object and specimen description and thus enable data retrieval. These *thesauri* contain about 28,000 terms. Since 1989, CIMEC has used IBM compatible computers; software includes PARADOX, AXES, and for numismatic materials CHI-WRITER (Geber 1992; Matei 1992; Oberländer-Târnoveanu 1992; Oberländer-Târnoveanu/Geber 1992; Scorpan 1992).

Besides CIMEC there are other *nuclei* of researchers in Bucharest. The Institute of Archaeology 'Vasile Pârvan' has a group of researchers interested in computer applications. They use IBM PCs running PARADOX, SYSTAT, GIS and CAD programs for databases, seriation, clustering and classification, graphics and so on. In the Romanian National History Museum in Bucharest, there is another team of five analysts using PCs to construct databases of archaeological material, topography etc. The numismatic department is developing a database for a catalogue of coins from Roman Dacia and of the Byzantine collections. Lastly from Bucharest, at the Romanian Institute of Thracology, another team is creating a database of archaeological and anthropological materials.

The National Conferences on Archaeometry continue to be held in Cluj-Napoca; six have been held so far. The co-operation between archaeologists from Cluj and the experts from the Institute of Nuclear Physics (Bucureşti-Măgurele) and the Institute of Isotopic and Molecular Technology (Cluj-Napoca) also continues.

Other projects in Romania include a database at the Museum at Constanţa, and the analysis of the cemeteries from Cerneachov-Sântana de Mureş by Ion Ioniţă from the Institute of Archaeology in Iaşi. The final example comes from outside Romania, from the Republic of Moldova.

In the Institute of Archaeology, Chişinău, researchers were working on databases of archaeological evidence and monuments, as well as applying quantitative methods to the study of neolithic and Middle Age settlements (Dergaciov 1980; Postică 1994). Unfortunately, their only computer is currently broken.

6 Conclusions

In Romania, computer applications and quantitative methods have developed unevenly — periods of progress were followed by periods of stagnation. However, development could not be stopped. At present the main areas of research are the development of archaeological databases and the application of statistical methods. Graphical methods are less developed and GIS is impossible due to a lack of access to map data. The following problems face us:

1. computers are uncommon and often old;
2. as a result of 1. few archaeologists can use them in their work;
3. available software is not always suitable.

We hope that as the number of computers increases, and closer contacts with the rest of Europe improve, so research in this field will advance rapidly.

notes

1 The system was developed using MISTRAL 2 on a FELIX 256 mainframe, the only hardware and software available in Romania at that time.

2 See Daicoviciu, Ferenczi and Glodariu (1989) for a description of the site.

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Computer-aided publication in practice

1 Introduction

A version of this paper was presented at the 1995 meeting of CAA under the light-hearted title *I just don't believe it (typesetting can seriously damage your health).* At that time there was no intention to publish but comments from the (small) audience suggested that there was a need for the points made there to be more widely available and hence this paper. It has no particular originality, but aims to give advice to potential authors, editors and typesetters based on the experiences of one who has been involved in the process of computer-aided publication over the last six years. I also take the opportunity to air some thoughts concerning the future of publication in archaeology and academic publishing generally, especially in regard to electronic publication.

Before proceeding to the main aims of the paper, I wish to put the subject in context. Up until the end of the 1960s, the majority of publications in archaeology and other disciplines, was undertaken by professional publishing houses who either typeset the volumes in-house or sub-contracted to specialised firms. Generally, the result was high quality publications such as the *Society of Antiquaries Research Reports* (e.g., Wheeler/Richardson 1957). By the end of the 1960s the huge expansion of archaeology, both in the field and academia, created a need for a cheap and rapid form of publication, and it was this need which prompted the foundation of *British Archaeological Reports*, as well as other series. These reports were often little more than bound typescripts — either from the famous BAR typewriter (e.g., Casey/Reece 1974), or occasionally as submitted by the author. These publications filled a need. Another example of this form of publication is, of course, the early volumes of *Computer Applications in Archaeology* (e.g., Laflin 1986).

At the same time, computer technology was advancing rapidly. As cheaper PCs, functional word-processors and dot-matrix or daisy-wheel printers became more easily available, the roles of author and typist became conflated. All but a handful of technophobes now take for granted the process of writing one's own papers on a word-processor. This is a relatively new state of affairs.[1] Unfortunately, the wide variety of word-processing packages available often resulted in the computer files not being re-usable and publishing houses having to re-key papers. This situation still exists — I know of at least one numismatic journal, and at least one recent book published by a major academic publisher, where the text was re-keyed. The majority of scientific journals re-key submissions. This is despite attempts at standardisation and development of exchange formats (e.g., Wilcock/Spicer 1986).

During the early to mid-eighties the increasing availability of reasonable quality laser printers and the popularity of typesetting packages such as TeX (Knuth 1984) and LaTeX (Lamport 1986), or DTP packages such as PageMaker, led to a further conflation of roles — this time the role of editor and typesetter. Rahtz (1986) summarises the situation in the mid-eighties. From 1987 onwards the CAA proceedings ceased to be produced as little typescript booklets and reasonably well-typeset volumes were published in a recognised series. These volumes, and all those subsequently, have been typeset by one of the editors using a variety of systems.

It is the conflation of the four roles into two: typist and author, editor and typesetter, along with the continuing pressure to publish quickly, which creates tensions in the whole process. In some cases, all four roles are combined into one: the most obvious example being the writing of dissertations and theses. Unfortunately, authors attempting to typeset texts which are for submission to a journal or edited volume often create extra work for the editor/typesetter. Hopefully, this paper will promote a little mutual understanding and thus help to ease these tensions.

A second facet of these developments is that the editor/typesetter is often now an individual who has no training, and possibly little interest, in typography or typographic design. Few of the available typesetting systems, or word-processors, actually offer any advice in these matters to the user, either in the manuals or on-line help, if available.[2] One is told *how* to do things, but not *when,* or *why.* This has resulted in the highly variable quality of publications. I do not claim any great merit for my own work; for example some pages in Lockyear and Rahtz (1991) are truly awful. Some self-typeset publications are of great merit; a good example is Dixon (1994) which was superbly typeset by the author using PageMaker 5. The second aim of this paper is to provide potential editor/typesetters with a few basic typographic rules and tips.

2 Never mind the quality, feel the width...

The phrase which best illustrates why quality of production matters is 'don't worry about it, it's only a BAR...'. Whether we like it or not, first impressions do matter and the quality of production is often used as an indication of the quality and *credibility* of the contents. Of course, this equation is not necessarily true: some fundamental papers have been published in BAR volumes using the infamous wobbly typewriter, whereas the elegant and stylish *Cambridge New Directions* volumes include papers which are of far less value. To a lesser extent, the opposite can also be true: extremely well typeset and luxurious volumes with many colour photographs, such as *Symbols of Power at the Time of Stonehenge* (Clarke *et al.* 1985) can be dismissed as 'coffee table books' without the reader actually reading any of the text![3]

Another aspect of design, which is important to publishing companies, is the creation and maintenance of a 'house style.' This allows readers to identify, perhaps subconsciously, a particular style with a particular publisher, and by association with certain topics, or even certain levels of quality and credibility. A good example of this is again the distinctive *Cambridge New Directions* volumes such as *Ranking, Resource and Exchange* (Renfrew/Shennan 1982). Given the title page of any article in this series most British archaeologists instantly recognise the source, and associate the paper with cloth-bound, thin volumes with a high theoretical content. CAA is trying to maintain a general house-style with volumes being in an A4 format, two columns, red cover and so on, although at a more detailed level there are many differences.

A more important aspect of quality and good typographic design is functional. Typography and book design is the result of a long process of development over many centuries. Many parts of a book allow it to be *used:* tables of contents, lists of figures and tables, page numbers, running headers and footers and the index can all be seen as navigation tools. Having found the piece of text one wishes to consult, the next stage is to *read* it. Typographic design, especially in academic publication, is primarily aimed at presenting the author's words in a manner which allows them to be easily read; just as grammar and punctuation is primarily aimed at helping one to understand the meaning. If the text is badly typeset, it becomes difficult to read: lines are lost, punctuation missed, emphasis is not apparent and the meaning becomes obscured. Tukey's superb *Exploratory Data Analysis* was typeset in an adventurous and unusual style (Tukey 1977). Unfortunately, the style makes reading and using the book difficult which is ironic given that the techniques described therein are designed to make patterns in data clear.

It is also true that production of a well-typeset book is an aesthetic pursuit and the process of turning text into type is one which can afford great personal satisfaction. Some typographic rules are more concerned with appearance rather than function. Within the rules there is much scope for personal expression and experimentation, but the fundamental question should always be *is the book readable?* Many people regard books as objects both of value, and potentially of beauty. I will freely admit that seeing my work transformed from 300dpi laser print into 1300dpi type on high quality paper with a stitched cloth binding (e.g. Duncan 1993) is highly satisfying. Section 6 presents some tips for the novice typesetter.

3 The editor/typesetter's problems

What are the problems which face an editor who is also acting as the typesetter? These fall into two categories: those which arise from the authors themselves and problems with the software.

3.1 The authors

Today, most books and papers are received on disk. The biggest task of the whole process is editing these files. Often, text is poorly input by the author. One of the main reasons is that usually the authors do not use the full functionality of their word-processors, or use ingenious but wrong methods to achieve the effects they require.
A common error is to force a new page with hard-returns. For submission to a publication the authors should forget about pagination — the pagination during writing will have no relation to the pagination of the typeset article. If the text is to remain no more than a word-processed document, page-breaks should be forced using the correct command. The worst error, however, is the use of spaces to centre text, line-up columns and so on, rather than using the centre command or tabs. DOS word-processors, such as WordPerfect 5.1, have to use a fixed space font on screen, i.e. every character takes up the same amount of horizontal space. Some printer fonts, such as Courier, are also fixed space, but in a typeset publication these are only used in special circumstances such as quoting an e-mail address, as in the *Archaeological Computing Newsletter* (ACN). The main font in a typeset publication will be a proportionally spaced font where the letter i, for example, will take up much less horizontal space than the letter m. If columns are lined up on screen using spaces, they will be ragged when printed in a proportional font (fig. 1). In typesetting Duncan (1993) I had to remove the spaces from 113 tables and replace them with tabs and this task formed the major part

```
 12   456   axe      LEC592
 75    67   cup      LEC189
 13   432   beaker   LEC592
101  2400   sword    LEC593
102  1200   dagger   LEQ67J
```

12	456	axe	LEC592
75	67	cup	LEC189
13	432	beaker	LEC592
101	2400	sword	LEC593
102	1200	dagger	LEQ67J

Figure 1. Lining columns with spaces on the left hand side (top) results in ragged columns when a proportionally spaced font is used (bottom).

of the job. That volume, input by a professional typing firm, also used an ingenious method of getting subscripts such as x_1. The '1' was put on the next line, positioned using spaces, and then the line height set to 0.5!

Most journals and conference proceedings issue guidelines for authors. It is astonishing how often these are ignored. The instructions could be unclear but when I have issued these to contributors, I have never been directly asked for clarification. This is, however, no excuse for inconsistency — even if the authors have not understood the instructions given, it is easier to change the files using macros if they have been consistent.

Two problems which always occur are horrible graphics and references. I have aired my thoughts on graphics, and what is known in statistics as chart junk, elsewhere (Lockyear 1994). Graphics should be clear, uncluttered and simple. I have often returned graphics to the authors as unpublishable and the following three reactions are common:

1. the graphic is dropped (ideal — saves space)
2. the graphic is reduced on a photocopier (this does *not* improve the quality of the graphic)
3. the author pleads 'this figure is really important and I haven't got time to have it re-drawn as...
   ... the drafts-person is away
   ... I don't have the data any more
   ... my computer is broken... [insert as appropriate]
   ... Could you include it anyway – I've seen worse published in...' (I re-draw the figure myself).

Given that the graphics are the most obvious part of a paper, *why* does anyone want to ruin their otherwise carefully crafted *magnum opus* with a figure that looks like the scrawls of a five-year old with a felt pen?

References are a continuing problem not unique to the current situation. References are a fundamental part of an academic paper and distinguish them from popular publications. To check that everyone's references are correct is very time-consuming. As a minimum, the editor will check that all the parts of the reference are present: volume number, pages, journal title, etc., and in any case it is the author's *duty* to ensure that the bibliography is complete. Despite this, approximately 60% of papers I have typeset have had incomplete references.[4]

A common failing with authors, and one which I am as guilty of as most, is late submission of texts. One advantage of computer-aided publication is that it is sometimes possible to include papers that have been submitted late, especially if the submitted text is well written and well input. It is when a late text contains the errors noted above that the editor/typesetter's job becomes even more fraught.

3.2 Software

I shall not waste space here with detailed criticisms of software but simply wish to warn budding typesetters that they will have to cope with:

1. incompatible formats and poor import filters
2. poor manuals
3. undocumented features (bugs).

The last problem will appear the day before you want to submit your camera ready copy and will never have happened to anyone else until you solve the problem, at which point everyone else will say it was obvious.

4 Authors' problems

The authors' biggest headache is, of course... the editors. All authors have a horror story of how the editor changed the meaning of a piece of text, left out a graphic, inserted something they don't agree with or refused to publish a table of data crucial to the argument. My favourite is where the editors moved the data lines from one graph and combined them with the axes from another. Other cases include the editor changing the grand totals in a table by adding the phase 1 totals to the correct totals, or helpfully correcting the spelling of the name of a site, but in fact changing the name to that of an entirely different site.
In defence, I would say that editor/typesetters are often under great pressure to complete the task quickly, and have to cope with the problems outlined above. One way to help prevent these problems is to follow Lockyear's Golden Rules.

5 Lockyear's Golden Rules

If you want a high quality publication, quickly produced, *take responsibility for your own work.*
Firstly:

- follow the instructions; if they are unclear ask for clarification;

- do not waste time typesetting the text yourself – it usually creates more work for the typesetter who has to undo your work first.

Then, submit:

- well input text using the full facilities of your word-processor;
- high quality, i.e. well drawn, graphics;
- complete bibliographies;
- files in a variety of formats. For the text submit the file from your word-processor and an ASCII text. For graphics, submit several popular graphics formats such as POSTSCRIPT, or DXF format, as well as good quality hard-copy so that the typesetter knows what *you* expect. If at all possible avoid bitmap formats as they often scale badly.

The logic is simple. If each paper in a 40 paper volume requires 5 hours work for the editor, this results in 200 hours work, roughly 5–6 weeks full-time. If each author takes more responsibility for their paper and reduces the editor's input to 1–2 hours work, this results in 40–80 hours work, or 1–2.5 weeks and given that most editor/typesetters have a real job as well, this is a significant time saving. The size of the figures quoted may seem surprisingly large but in reality they are quite conservative.

One final comment on style: try to use headings and subheadings sparingly. There is a trend to use endless headings — sometimes for every paragraph — and this is unnecessary: it breaks the text up too much making it more difficult to follow, it is very ugly and it uses excessive paper.

6 Typographic basics – some hints for the novice typesetter

This section contains a few basic guidelines for novice typesetters. For more detailed advice one should consult the large number of books on this subject; for example two old, but excellent texts are Oliver (1945) and Williamson (1956); more up-to-date books including advice on DTP methods include Felici and Nace (1987) and Sassoon (1993). *The* comprehensive manual on style, which also includes advice on all aspects of publication, is the *Chicago Manual of Style* (University of Chicago 1993). Zapf and Dreyfus (1991) contains some interesting essays on classical typography in a modern environment. (Hermann Zapf is a well-known typographer and font designer — for example *Zapf Chancery Italic* is one of his fonts.)

6.1 FONTS

'Typefaces can do for words, and through words for ideas and information, what clothes can do for people; they can attract or repel, enhance or detract, emphasise or neutralise; making a piece of text memorable or forgettable.'

Grosvenor *et al.* 1992.

Two choices need to be made: the font(s) to be used and the size of the font.

As regards size, it has been clearly shown that the human eye can only follow lines with a limited number of characters per line; if the line is too long it is difficult for the eye to back-track to the start of the next line and the reader tends to either miss lines or to re-read the line twice. The usual rule of thumb for English is 66 characters, or about twelve words per line. Therefore, the best font size[5] for the main body of the text depends on the size of the paper being used. A4 paper, the most common size in the UK due to its ubiquitous use with laser printers and photocopiers, is less than ideal. Either the text has to be in a large point size (at least 12 point) and possibly with large margins (e.g., the journal *Archaeologia*) or the text has to be in a two column format (e.g., *Journal of Roman Pottery Studies*). Fitzpatrick and Morris (1994) has been typeset in a relatively small point size in a single column in an A4 format with up to 97 characters a line, resulting in an almost unreadable text. The first few CAA volumes published with BAR had large margins to keep the line length down but this resulted in the expensive two-volume proceedings for 1988 (Rahtz 1988). From 1990 the proceedings have been in a two-column format in 10 point despite the attendant increase in typesetting problems. The frequency with which this basic and fundamental rule is broken is partly due to software; for example, the default text size in the Word for Windows 'normal' template is 10 point — far too small for A4 paper in a single column. I would strongly advise anyone undertaking the typesetting of a book to investigate the possibilities of *not* using A4 — just because your desk-top printer uses A4 does not mean you have to fill the page, or that your printing company will have to use that size. There are many other smaller standard paper sizes which are more convenient for typesetting and reading.

The choice of font is also extremely important. Originally, the limited range of fonts packaged with laser printers resulted in non-professional typeset publications using a small range of fonts. The advent of TrueType fonts for use with Windows applications has increased the number of easily available fonts for the casual user; these can be purchased in most software outlets, usually on a CD-ROM. Many of these fonts are, however, fancy display fonts, suitable for posters and fliers but not for body text in book length publications. There are also many very poor quality TrueType fonts on the market. Most professional type-setting houses use POSTSCRIPT fonts which are more expensive. Chivers (1994) discusses some aspects of

`Courier — fixed spaced font`	`Hello World!`
Helvetica — sans serif font	Hello World!
Times-Roman — common font, quite dark	Hello World!
Times-Roman Italic	*Hello World!*
Palatino — lighter than Times-Roman	Hello World!
Palatino Italic	*Hello World!*
New Century Schoolbook	Hello World!
Zapf Chancery Italic — beautiful Italic font	*Hello World!*
Avant Garde Gothic Book — avoid	Hello World!

Figure 2. Some common fonts.

TrueType fonts in relation to PostScript. If funds are available, I recommend investigating fonts other than the standard set supplied with laser printers. See Lawson (1990) for a discussion of typefaces.

For body text a Roman font with serifs, such as Times-Roman, Palatino, Bembo, Lucida Bright or Garamond, is preferable. The serifs, the little feet or bars on the top and bottom of the verticals of the letters, reinforce the horizontal line and help the eye to follow it. These fonts have other characteristics of their own. Garamond is quite thin in places and should only be used if the final production is to be on a high-resolution device (300dpi is *not* high resolution!). Times-Roman is a quite compact font compared to, for example, Palatino. A document in Times-Roman will be physically smaller than one in Palatino, but will also be 'darker.' Italic fonts, used for emphasis, are not just slanted versions of the Roman font, but are a separate font designed to complement it. Sans-serif fonts such as Helvetica or Arial, are unattractive for body text and are often difficult to read when used in large blocks. They can be used to good effect in headings, helping to differentiate them from the main text (e.g., Beck/Shennan 1991). Again, if funds are available, purchase a sans-serif font designed to blend well with the main font. Helvetica, which is supplied with most PostScript laser printers, does not blend well with the Roman fonts supplied and mixing them in the text is ugly (Duggan 1994). Figure 2 presents a few common fonts and illustrates their characteristics.

One aspect of fonts which is not often appreciated is that, with good quality fonts, a letter in 12 point is not simply a scaled version of the 5 point character or vice versa; Small Capitals fonts are not a simple mixture of point sizes and so on.[6] Few computer-fonts attempt to implement these design characteristics although they do make a large difference to the appearance and legibility of text. The font creation program MetaFont takes a base font design, and then a series of parameters, to produce bitmapped fonts for each point size. To design a complete font from scratch is not an easy task and Computer Modern Roman remains the most common MetaFont font. Adobe's Multiple Master fonts also implements these design aspects, but using these fonts with many systems is, again, not a trivial task (Goossens/Rahtz 1995).[7]

A final problem is special characters. Few fonts have the wide variety of characters and symbols required to typeset mathematics such as often appears in the proceedings of CAA. Often the solution is to mix fonts but this is usually ugly. There are some fonts which contain a wide variety of maths symbols — Computer Modern Roman (mainly for use with [La]TeX) and Lucida Bright for example. Foreign accents are also a problem. Most systems, especially Windows applications using TrueType fonts, do not easily allow for many accented characters such as the Romanian character 'ă', although it is sometimes possible to create the required character by combining a floating accent with a letter. It is an anglophone conceit that accents are relatively unimportant.[8] Part of the problem is that even the extended ASCII character set is simply not big enough to contain all characters. The advent of Unicode may help the problem (Fairbairns 1995). Meanwhile, the typesetter can either use systems which will create the accented characters on the fly such as WordPerfect or (La)TeX; or has to buy special fonts that contain the accented letters. Programs also exist which allow one to create accented or extra characters and encode them into a font but this, yet again, is not a trivial task.

6.2 White space

As important as the black ink on a page, is the white space. White space serves both functional and aesthetic purposes but I shall concentrate on the former. Within the body text, white space is obviously used to separate words — thisdoesnotmakemuchsensedoesit? It also helps to differentiate sentences; in English typography an inter-sentence space is larger than an inter-word space. When I was at school I remember the chant 'full-stop space shift...' echoing out of the business studies classroom. In the conflation of the role of typist and author, this rule has been generally lost. In a WYSIWYG system such as a word-processor, the inter-sentence space has to be inserted manually and the typesetter has to insert the extra space if the author has omitted it. Systems such as (La)TeX interpret the sequence 'full-stop space(s) capital-letter' as the command for an inter-sentence space. Spacing is also language specific. It is usual practice in English typography to have no space between a letter and an exclamation mark (e.g., hello!) but in French typography a space is inserted (e.g., Mon Dieu !). Lastly, a recent trend has been to omit full-stops and spaces in initials, e.g., SPQ Rahtz. With recognised acronyms, especially those pronounced as one word (e.g. CAD), this is acceptable. With personal names, mainly in bibliographies, I prefer to stick to the old-fashioned but elegant form: S. P. Q. Rahtz.

White space around headings also serves a functional purpose. The amount of white space is style specific but it is usual to have more white space above a heading than below it. This reinforces the fact that the heading belongs to the following text. A problem occurs in many systems such as Word for Windows or PageMaker when a subheading follows a heading immediately, resulting in too much white space, which is ugly. In the case of those two packages the typesetter either has to define a style 'subhead after heading', or manually adjust the spacing.

Sufficient white space should also be left to differentiate tables, figures, headers and footers from the main text, and to separate multiple columns. The last is known as the *gutter space*. The space can be reduced if a thin line or *rule* is used to enforce the separation.

6.3 Typographic symbols

Use of correct symbols also helps improve the quality, and the legibility of text. Modern computer keyboards have three keys for quotation marks: the single opening quote (top-left of the main key pad on an English keyboard), a single closing quote (the usual quote key used) and the double-quote (shift-2 on an English keyboard). The use of the double-quote results in a typewriter-style double quotation mark —". Avoid it as it is ugly. Use the correct opening and closing quotation marks, either single or double, from the base font, even if they have to be accessed in a special manner. In Word for Windows 2 they are not automatically used and have to be input using ALT-145, 146, 147 and 148 or the 'insert symbol' menu. Word for Windows 6 tries to use the correct quotation marks automatically, even if one only uses the closing or double-quote key. It usually succeeds but can be fooled. WordPerfect 5.1 will use the correct single quotes but not the correct double quotes. Do not confuse the single and double quotation marks with the symbols for feet and inches, or minutes and seconds which are somewhat different, i.e. 5' 7".

Use the correct types of dash:

- hyphens in words, e.g., co-ordinate
- en-dash in ranges e.g., AD 43–410
- em-dashes as phrase markers — like this

These dashes occur in most fonts. In WordPerfect 5.1 use control-V n- for an en-dash and control-V m- for an em-dash. In Windows systems use the 'insert symbol' menus. These dashes are important because they help to differentiate between different meanings. For example, if an ordinary small dash ends a line, is it a hyphen, or a phrase marker, or a range? One should also note that the mathematical minus symbol is also a separate character.

Ligatures improve the appearance and readability of a text. Few systems allow for ligatures and many professional publishing houses do not now use them which is a pity. In words such as 'official' the fs and the i, especially the dot of the i, usually clash and look ugly. Ligatures are characters where the fs and the i are joined together, the i usually using the bulb on the descender of the f as its dot. Ligatures include the sequences fl, ff, fi and ffi. LaTeX will use any of these letter sequences as the command to insert the correct ligature. The German double-s character 'ß' is, in fact, a ligature of a sharp s[9] and a regular s.

6.4 Tables

Tables are a matter of design and personal preference. However, many non-professional typesetters over-use rules (i.e. lines) in tables. For example, the default table style in WordPerfect 5.1, as used in CAA91 (Lock/Moffett 1992), is extremely heavy and ugly and should be avoided at all costs. Originally, I used vertical rules in tables (e.g., Beck/Shennan 1991; Lockyear/Rahtz 1991) but quickly decided these were extremely ugly. I now avoid vertical rules if at all possible using a style derived from the Cambridge University Press (e.g., Duncan 1993). The columns in a table can be easily separated using white space, and groups of columns using varying sizes of white space. Kroonenberg (1994) and Allan Reese (1994) discuss various aspects of table design.

6.5 Underlining

Don't. Use *italics* for emphasis in Roman fonts like this, *or use* Roman *in pieces of italic text like this.* For headings, use combinations of font size, bold face and italics.

6.6 Consistency

Above all, whatever design choices are made, use them consistently. For example, use of AD, A.D., AD or A.D.[10] is up to the designer, but they should be the same throughout the document.

7 Types of system

There are four main types of system for typesetting and all have their advantages and disadvantages. These systems are:

- generic markup (e.g., LaTeX)
- advanced use of word-processors (e.g., WordPerfect 5.1)
- desk-top publication systems (e.g., PageMaker)
- professional typesetting systems (XYvision, Miles 33)

I have *not* conducted a comprehensive survey of different packages and have no experience of the professional systems or Quark Xpress, Ventura Publisher, WordPerfect for Windows, troff, etc. I have, however, used one of each of the first three types of system in the production of book-length publications: Lockyear and Rahtz (1991) and Beck and Shennan (1991) were typeset using LaTeX; Duncan (1993), and others using WordPerfect 5.1; *Diatribe* volume **4** and Wilcock and Lockyear (1995) using PageMaker 5. Each has advantages and disadvantages. The output of these systems can be examined easily as the proceedings of CAA since 1987 have been created by all three types of system: CAA87–90 were typeset using LaTeX; CAA91 in WordPerfect; CAA92 and 93 in PageMaker 5 and CAA94 (Hugget/Ryan 1995) in Word for Windows 6. This volume of CAA will be the first to be professionally typeset.

PageMaker and LaTeX have vastly superior hyphenation, kerning[11] and justification routines compared to, e.g., Word for Windows 6. If one compares the text from CAA94 with CAA93 one can quickly see PageMaker's superiority. Conversely, editing text in PageMaker is painful and the process of adjusting the text after editing is quite slow. A good combination, if one wishes to follow the Windows/WYSIWYG route with all its attendant advantages and disadvantages, is to edit files in a word-processor such as Word for Windows, then complete the typesetting in a program like PageMaker. Unfortunately, PageMaker has some severe problems, the worst of which is its table editor. The table editor only allows one font in one size in a cell of a table and thus constructions such as σ^2 are impossible. It is also extremely memory-hungry and 8MB of RAM is barely sufficient and occasionally causes crashes. These were less frequent when a new hard disk allowed for a larger virtual memory file. Also, the program needs to know exactly which PostScript printer you will be using, and changing printers can create some unpredictable results.

WordPerfect 5.1 as a word-processor has some excellent advantages. It is one of the few packages to be able to create many accents easily including a full range of Greek characters with breathings and accents. It uses a sensible default font size. Its 'reveal codes' facility, which enables one to explicitly examine the control codes in the text and thus edit them, is invaluable when 'typesetting' texts.[12] There are other features I have not found easy to copy in other word-processing packages. Many, however, hate the package because its opening screen, which is almost empty, is unfriendly; its use of function keys, possibly with shift, alt or control, seems difficult to learn; tables have to have a line spacing of 1.5 and the default rules are *extremely* ugly; the style-sheet system is not obvious and rather counter-intuitive. Many of these issues are solved by using WordPerfect for Windows 6.

Most modern word-processors use some system of style sheets. Style sheets define the visual characteristics of sections of text with a specific function. For example, a heading can be defined as being in 12 point bold Helvetica with a 1.5 line space before the heading and a 0.5 line space after the heading. Each heading is then tagged as such, and will inherit those visual characteristics. Changing the definition of the style, or using a different style sheet, will result in the visual format of all headings being altered without the user having to manually change the settings for every heading. These systems are not perfect but are improving rapidly. For example, it is usual in a numbered list for there to be some extra space above and below the list. To achieve this in many systems requires the definition of three styles: first numbered item, numbered item and last numbered item. In a complex document this can lead to a proliferation of styles. Authors are, however, strongly advised to make full use of the style sheet system of their word-processor.

LaTeX does not meet with much enthusiasm from many people. This is because it has an old-fashioned interface: processing a LaTeX document is analogous to compiling a program rather than word-processing, and obviously the programming language has to be learned. The text input to LaTeX is in ASCII but they are full of commands such as:

```
\documentstyle[11pt,a4]{article}
```

which makes reading the text on-screen difficult. Figure and table placement in LaTeX is automatic which should be an advantage, but in a paper with large numbers of figures and tables in relation to the quantity of text, the results are poor and have to be manually adjusted. Installation of the system can be difficult with large numbers of font files, style files and so on. It is also a 'guru'-based system reflecting its origins on UNIX work-stations. The advice 'consult your local TeX guru' is not useful when working on a DOS machine from home, for example. However, many of these problems have solutions. The new LaTeX, LaTeX2ε, addresses and solves many programming problems. Use of the Eddi4TeX editor on DOS machines[13] helps reduce typing, and on-screen colour-coding of parts of the screen helps with writing. The GnuEmacs editor from the Free Software Foundation has excellent capabilities for editing TeX files and is available in Unix (and X-Windows) and DOS (and Windows) formats. Installation of TeX for PCs is automatic if one uses the 4AllTeX workbench, available on CD-ROM from the Dutch or UK TeX Users Groups, or less conveniently by down-loading the package from the *Comprehensive TeX Archive Network*.[14] The various TeX User Groups and electronic discussion lists (such as TeXhax) can give you access to a world of TeX gurus, even if it does take time (most gurus seem to take TeXhax in digest form).

Despite its age, LaTeX remains an extremely powerful typesetting system. The best recommendation I can give it is that having started using LaTeX2.09 in 1988, I then tried various word-processors and typesetting systems, but returned to LaTeX (although I used the new LaTeX2ε) to write Lockyear (1996). The main reasons for this choice were:

- it is free
- it uses the BibTeX bibliography package (also free)
- document portability (i.e. the ASCII text files can be processed by LaTeX on PCs, UNIX machines, VAXs, Macs and so on).
- there is easy access to all accents[15]
- input text as ASCII files (the whole of Lockyear 1996 fits on one floppy disk and thus it is portable in more than one sense)
- easy generation of typeset tables from a database
- poorly structured PostScript graphics (generated from Canodraw, or written by myself) can be included without problems

Other advantages (although not all are unique to LaTeX) are:

- consistency of style enforced by style files
- excellent hyphenation, kerning and line spacing/justification routines
- cross references automatically created
- extremely powerful mathematics typesetting capability
- conversion between HTML[16] and LaTeX is fairly easy with latex2html and html2latex
- conversion to SGML is not too difficult (see below)
- it is possible to create PDF files with rich mark-up (see below).

In the hard sciences TeX is used widely. Compiling a volume of papers ought to be relatively easy. In archaeology, where most contributors use a word-processor, conversion to LaTeX is dull and time-consuming. Writing a large book (such as a thesis) from scratch is less painful and many LaTeX features make life relatively easy and I would recommend it highly. Conversely, few archaeological journals, or editors of proceedings, are able to process LaTeX documents, although the ACN is an exception. For papers to be submitted on disk, I either have to convert the paper to another format, or use a word-processor.

8 'Electronic publication' and archaeology

To conclude this paper I would like to make a few comments about 'electronic publication', especially publication over the World Wide Web (WWW). For other interesting comments see the recent debate in ACN (Holledge 1995; Kilbride 1995; Rahtz 1994, 1995). Despite the current burst of interest in the topic, and the immanent formation of electronic journals (see Heyworth/Ross/Richards, this volume), the concept has been around for some time (e.g., Rahtz 1986). However, the rapid expansion of the Net, and the recommendations of the Follett report (JFCLRG 1993), seem destined to make this style of publication a reality. Some predict that electronic publication will cause the death of traditional academic journals (Odlyzko 1995).

Current electronic journals take a variety of formats. For example, *Psycoloquy* publishes as simple ASCII files; others maintain articles as PostScript or TeX files (e.g., *The Journal of Artificial Intelligence Research*) and more recently journals are being published as HTML WWW publications, or using *Portable Document Files* (PDF). The latter is an extension of PostScript with 'rich markup' which allows the document to contain hypertext style links and buttons. PDF files are read with Adobe Acrobat which is available free. The current debate around electronic journals tends to contrast *paper* publication with *electronic* publication. I feel this is an artificial and unhelpful division as each medium has inherent advantages. Firstly, it is an oft-quoted truism that most people cannot read large quantities of text off a computer screen. This is most clearly seen when people edit an article they are writing — most still print it out, mark corrections and then edit the file. Multimedia teaching packages also prove the point — if the screen contains too much text the student scrolls by until the next link or graphic is reached. Any electronic journal either has to:

1. create a new style of writing in word-bites
2. provide the journal in a form that allows large pieces of text to be printed out in a high quality format

The first option seems unlikely for academic work. If the second route is taken, the points made about typography in section 6 must be taken into account. Unfortunately, HTML is, as yet, not capable of producing well typeset text.

Conversely, paper publication is not feasible for large collections of plans, photographs, data etc., much of which ends up as an archive or 'grey literature' (i.e. limited production, privately printed material). Microfiche, silver-jacketed or not, is a data cemetery, not a data archive. As Rahtz (1986) notes, electronic publication is ideal for this sort of material. I recently conducted a straw-poll of non-computing archaeologists on the value of electronic publication which revealed that the greatest enthusiasm for electronic publication was the possibility of access to data archives that lie behind traditional publications. The much-vaunted non-linear nature of multimedia publications was met with apathy, although hypertext-style links to other documents and data resources was seen as an advantage. The technology exists to produce electronic publications which include such links, high-quality typesetting and printing possibilities and thus to combine the advantages of both styles of publication. The largest hurdle, however, is the fact that most people *like* books and as stated above they are regarded as objects of value and beauty; many still prefer a well bound volume to stapled laser-print. This psychological hurdle is one which will have to be met by electronic publications, and is not a problem that I feel will go away quickly. After all, it is still more convenient to read a bound book on the train rather than a pile of loose sheets of paper.

Another problem that these publications will have to meet is that they are now conflating a further two roles: that of publisher and that of library; they need to consider problems of the long-term archive. A recent debate on the mailing list ARCH-L centred around the viability of CD-ROM for archaeological publication, and concerns were raised about its long-term potential. This debate missed the point. Provided that the publisher/library is willing to move its publications from one machine/medium to the next at every upgrade, the problem is not the *medium* for data storage, but the *format*. For text, this must mean the use of *Standard Generalised Markup Language* (SGML; ISO 1986; Van Herwijnen 1994). It is to the shame of computing in archaeology, at least in the UK, that we have yet to develop an SGML document type description (DTD) for archaeology, specifically for excavation reports. In Norway, large quantities of text based information including that from archaeology, is being marked-up in SGML and the resultant files parsed to create relational databases of the document's contents (Holmen/Uleberg, this volume). The potential for searching documents is immense. The time has come when we should seriously examine the potential for the use of SGML in archaeology.[17]

9 Conclusion

This paper has quickly reviewed the past, present and future of computer aided and electronic publication in archaeology. It has shown that computers have conflated a number of roles: typist and author, editor and typesetter and now publisher and library. At each stage, past problems have been solved but new problems have arisen and some suggestions and advice have been offered.
In particular, it was argued that centuries of development in typography, in terms of its aesthetic and functional role, should not be ignored, but on the contrary provides many valuable lessons for publication irrespective of the manner of that publication. The challenge for electronic publication is to learn the lessons of the past, and combine them with the technologies of today, to provide us with a resource for the future.

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notes

1 For example, in 1987 I was one of the first undergraduates in the archaeology department at Durham to word-process their dissertation (on a mainframe!). Most other students wrote their dissertations by hand and then had them typed, with consequent delays for corrections etc.

2 For example PageMaker 5. The LaTeX manuals (Lamport 1994; Goossens/Mittelbach/Samarin 1994) are an honourable exception.

3 I tested this theory during a class on typography, and this was precisely the result when they were asked to comment on this book.

4 It is often quicker to look them up in the library, or now, over the InterNet, than to ask the author.

5 Fonts for typesetting are measured in points: a point is 1/72nd of an inch. Some basic printer fonts are measured in cpi, *characters per inch.*

6 Goossens *et al.* (1994: Chapter 7) contains an excellent discussion about these matters.

7 I have been informed that Multiple Master fonts are easy to use with Macintosh computers.

8 In Romanian, the letter 'ă' is regarded as a separate letter, not just an accented 'a' and comes after the latter in the alphabet. This letter can change the meaning of a word, and thus the sentence. For example 'fată' is best translated as 'a girl' whereas 'fata' is 'the girl.'

9 A 'sharp s' is the older form of 's' that looks like an f with no cross-bar. It can be seen regularly in, for example, 18th century English texts such as the earliest volumes of *Archaeologia.*

10 Note that AD should always precede the date and BC should always follow it, i.e. Britain was invaded in AD 43; the battle of Actium was fought in 31 BC.

11 Kerning is the adjustment of space between letters. For example, the letter o can be placed closer to the letter K than to the letter H because of their shapes. If inter-letter spaces are of a fixed size they will appear variable, a kind of optical illusion.

12 Typesetting is here in quotation marks as purists would deny that a document could be typeset in a word-processor such as WordPerfect.

13 Contact Ulrich Jahnz, ulrich_jahnz@pe.maus.de, for details. A registered version of the Eddi4TeX editor is available to all UK TeX Users Group members.

14 FTP to ftp.tex.ac.uk in the UK, or to one of its mirror sites at ftp.dante.de or ftp.shsu.edu. The CTAN archives contain huge quantities of software and information relating to TeX and TeX related software including mailings to discussion lists etc. and complete TeX installations such as the emTeX package for MS-DOS machines. The archives run an enhanced version of FTP and have other useful site-defined commands. Down-load the files README.archive-features and README.archive-commands for an overview. For queries regarding the UKTeX Users Group contact them on uk-tug@tex.ac.uk.

15 I investigated the possibility of using WP5.1 with the Endnote bibliographic package. Although WP5.1 would create the accents I required, Endnote would not.

16 *Hypertext Markup Language*, used for documents that can be read over the World Wide Web using programs such as NetScape or Mosaic.

17 This argument in not new; Sebastian Rahtz has been arguing along these lines for many years. HTML can be seen as a SGML DTD, but it has a loose structure and recent developments, more concerned with document appearance rather than structure, are making it hard to justify HTML as a SGML DTD.

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