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Images, databases and edge detection for archaeological object drawings

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23.1 Introduction

The aims of this paper are to present a brief overview of the GOAD (Graphically Oriented Archaeological Database Project) followed by a short discussion of two important issues for the development of sophisticated graphical databases, namely the automatic extraction of explicit shape information from raster images of line drawings and techniques for representing shape for effective shape retrieval and classification.

23.2 The GOAD project

The aim of the GOAD project was the development of an integrated text, graphical and image artefact database with particular emphasis on the storage, retrieval and dissemination strategies. It was initially funded by a two year grant from the Science Based Archaeology Committee of the SERC. Specific issues to be addressed in the project were:

- the development of techniques for the capture and storage of graphical and image data.
- the design of database structures and retrieval methods to provide rapid retrieval and effective display of text, graphics and image data.
- the implications for publication of such databases either electronically over networks or by more conventional paper-based methods.

The strategy adopted in the development of the database system involved integration of several important ingredients which are summarized as follows:

1. The Postscript page description language and interpreter. This was chosen to provide a versatile mechanism for communicating text, graphics and image information in a device independent way.
2. The NeWs network extensible window system which provides a WIMP interface based on modern bitmapped displays.
3. The Ingres relational database to provide the central information storage and retrieval capability.
4. Tools for capturing and processing raster images from scanners and vidicon cameras.
5. Extensive additional software written in-house in C and Postscript to complete and integrate the GOAD environment.

An example of a query session within the GOAD environment is shown in Fig. 23.2, illustrating the windowing facilities of the user interface where a variety of text and line drawing images may be displayed in separate windows. The close analogy with the desktop means that archaeologists can transfer easily from traditional modes of working to the use of more powerful computer based tools. Some of the current features which the GOAD environment provides via menus and buttons in the window based interface are as follows:

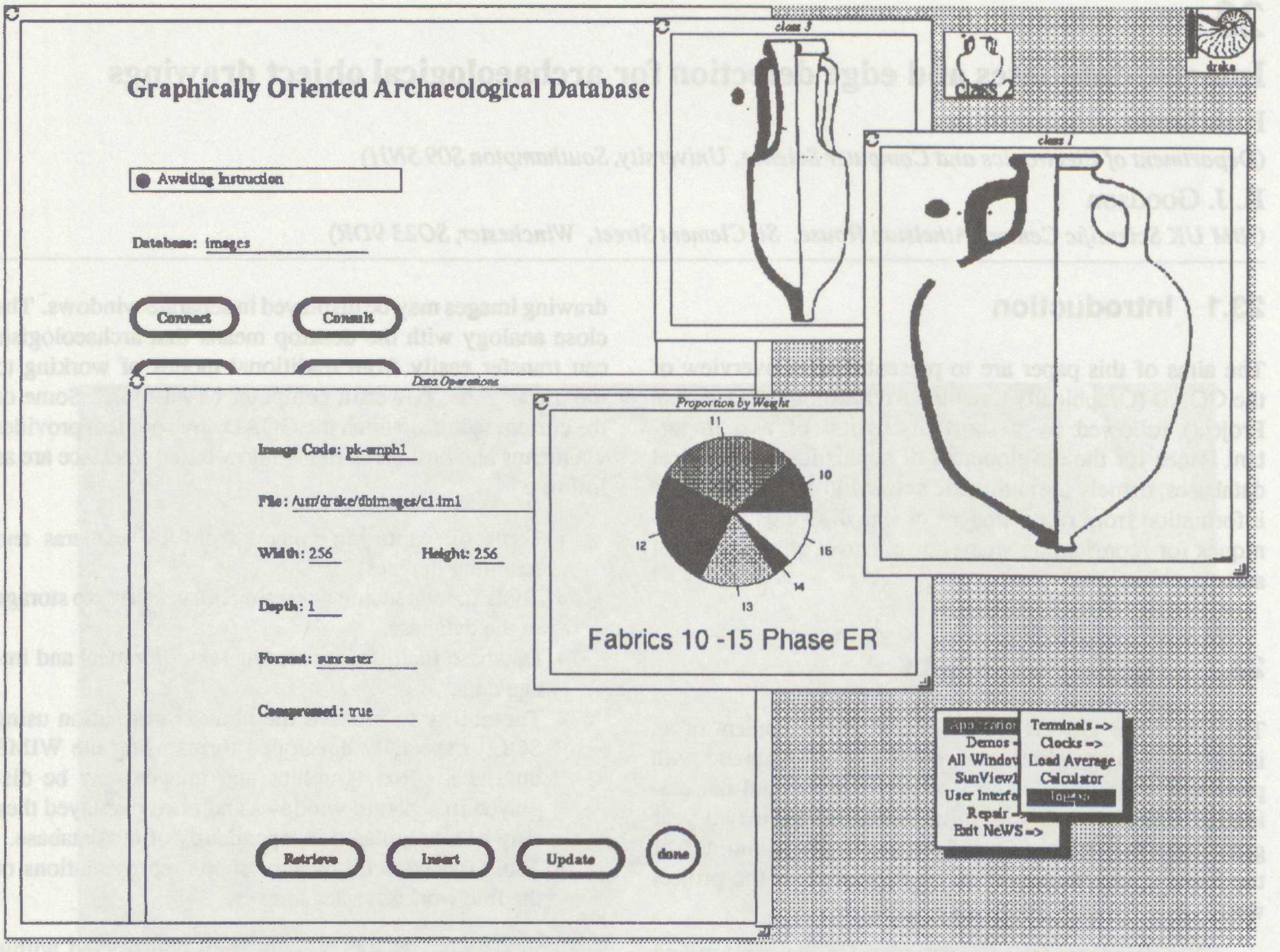
- Tools for capturing images from TV cameras and scanning devices.
- Tools for enhancing or editing images prior to storage in the database.
- Database facilities for storing text, graphical and image data.
- The ability to retrieve the above information using SQL or specially developed forms using the WIMP interface. Text, graphics and images may be displayed in separate windows and once displayed they may be manipulated independently of the database.
- Tools for extracting vector shape representations of the line work in raster images.

Two exemplar databases have been constructed within the GOAD environment. The first consists of the textural and image data relating to a corpus of Roman amphori (Peacock & Williams 1986) while the second is a representative corpus of forms of Roman pottery from the Oxford kiln sites collated with excavation and fabric data (materials supplied by the Oxford Archaeological Unit as part of a continuing project on the hospital site, after Young 1977).

The dissemination of the database is probably the area of the project that is most affected by technology changes. Our initial plan was to develop our own display routines and to port these to a microcomputer for distribution, but the rapid spread of Postscript as a standard for screen displays and not only printing devices means that we are now able to offer a single format for storage, display and printing although there are currently no suitable display Postscript implementations for micros. We are confident that this device independent approach is correct for publication purposes.

23.3 Automatic shape extraction

One of the major problems when building a useful graphical database is that of entering the graphical information itself. An abundance of line drawings of archaeological artefacts is available in paper form and scanning or frame-grabbing this into the computer as a bitmap or raster image is essentially straight forward. But if the drawing is to be used for anything other than for display purposes, for example if it is to be used for automatic shape retrieval or classification,



an explicit parameterised shape representation scheme must be adopted together with a similarity measure or matching algorithm for comparing shapes. The chosen representation may be either extracted from the raster image using image analysis software or obtained by direct manual digitisation from the original line drawings.

Raster to vector conversion techniques offer the possibility of at least semi-automatic extraction of the shape boundary information directly from a scanned image , and tools to assist with this process have been developed and incorporated into the GOAD environment. However, imperfections both in the original line drawings and in the image capture process can lead to problems with the raster to vector conversion and a set of tools for manually editing the binary or grey level raster images prior to automatic boundary extraction are provided. The initial vector boundary representation we have chosen is the simple Freeman chain code (Freeman 1974), and after using the editing tools, this can be extracted automatically from grey scale or binary images captured within the GOAD environment. The chain code representation is then stored in the database alongside other information relating to the artefact and is available for direct display or transformation to other shape representation schemes which may be more suited to specific applications.

More than one chain code may be associated with a single artefact, allowing, for example, inner and outer profiles or separate codes for pot and pot with handles to be accommodated.

Specific facilities in the bitmap editor include setting regions to black or white, drawing rectangles and lines and performing flood fills. Parts of the image may be examined in detail using a zoom option and a measuring tool is available to provide distance measures to be made between specified points on the image, identified using the mouse. This is useful if direct measures (for example, rim diameter and height) are required from the images.

23.4 Shape matching

23.4.1 The representation of shape for matching and retrieval

Shape information may be required for a variety of reasons. In the first instance, it may be required simply for retrieval and display alongside associated text in order that the archaeologist may examine the image. Text keys associated with the image could be used for the retrieval, thereby placing no additional demands on the shape representation scheme over and above those required for display. At another level, it may be attractive to store the shape boundary information together with explicit shape keys for 'manual' retrieval. For example, the diameter or height of an artefact may be used to retrieve subsets of the shape database. Finally, it may be required to store the shape in a database in a form suitable for retrieval by shape (pattern) matching software. The requirments for the shape representation strategy adopted may be different in each of these circumstances.

We are particularly concerned with the representation of shape for boundary retrieval and display using pattern matching to provide automatic retrieval tools within the GOAD environment. Various authors have published previous work in this area and there have been a number of papers presented on related topics over many years at CAA conferences.

Lengyel () reported the use of basic shape measures for pottery classification and in the same year Wilcock and Shennan (1975) reported the use of 'sliced' and 'mosaic' shape representation schemes, also for pottery classification. Richards (1982) described the use of principal component analysis applied to various shape measures for classifying Anglo-Saxon pottery and Hall and Laflin (1984) described the use of B-splines for shape representation, in this instance for compression prior to storage on computer for subsequent display.

Finally, Peter Main has presented a series of important papers (1978, 1979, 1986, 1988) on the use of tangential profiles and sampled tangential profiles for shape representation and storage in databases. He discusses many important issues for those considering the establishment of shape databases.

If we wish to provide a shape representation scheme in our database for shape retrieval by pattern matching, various types of retrieval mode should be considered. These are exemplified by the following tasks.

- Find the nearest shape(s) in the database to this complete shape.
- Find the nearest shape(s) in the database to this incomplete shape.
- Find the class to which this particular unclassified shape belongs?

Each of these tasks will place different demands on the pattern matching strategy adopted, but a general property which is clearly desirable for a single strategy to be adopted, is that it should be as robust as possible for incomplete as well as complete boundary data. Other attractive properties include invariance to translation, rotation and scale so that careful alignment and normalisation of the shapes becomes unnecessary.

We have examined a variety of representation schemes (Goodson 1989) including those referenced briefly above, but the scheme we are currently investigating is based on the generalised Hough transform due to Ballard (1981) which offers substantial promise particularly for coping with incomplete shape boundary information.

In the next section we describe the generalised Hough transform and its application to shape matching in the GOAD context.

23.4.2 The Generalised Hough Transform

Since its invention in 1962 the Hough transform has established itself as one of the most popular approaches to shape ananlysis, matching and recognition in the field of computer vision Hough 1962. Initially introduced as a technique for detecting simple geometric shapes such as circles and lines in images, it was generalised in 1981 by Ballard to provide a means of recognising arbitrary shapes in digital images with the potential for translation, rotation and scale invariance (Ballard 1981).

One of the major disadvantages of the generalised Hough transform (GHT) is the substantial storage requirement needed if more than two parameters are involved. However, as memory costs drop and available memory increases this becomes less of a problem. In any case a translation invariant version robust to missing information only requires two parameters as described below.

The basic Hough transform belongs to a class of transforms known as parametric transforms. Image features such as edge point data are used to predict parameters describing the shape being sought. It has been used widely for detecting straight lines, circles, ellipses and other shapes with a simple analytic form.

In the case of straight line detection, the parameters to be estimated may be the line gradient and intercept. The appropriate Hough space is a two dimensional accumulator of which the axes represent possible values of the parameters to be estimated. For each edge point in the image being analysed, Hough accumulator locations are incremented when they correspond to possible lines on which the edge point could lie. After processing all edge points, each significant peak in the Hough accumulator should indicate the gradient and intercept values of co-linear points in the image and the number of points in the peak cell indicates the actual number of co-linear points in the image.

Well known benefits of the Hough transform are its robustness to noise and its ability to respond to partially occluded shapes.

The generalised Hough transform was developed to detect arbitrary, but known, non-parametric shapes, i.e. shapes which do not possess a simple analytic form. In the translation invariant form of the generalised Hough transform, the X and Y coordinates of the shape centroid may be used as the parameters of the Hough accumulator. Suppose the image containing the 'template' shape to be recognised can be illustrated as shown in Fig. 23.4.2. For each boundary edge point i, the edge orientation ϕ_i (with respect to an arbitrary direction) and the vector, r_i, from i to an arbitrary reference point (usually the centroid of the shape) are calculated and ordered in a circular list according to edge orientation. This is referred to as the R-table. Then, for the unknown image in which we are trying to locate the shape, a 2-D accumulator array is set up with axes representing the X and Y values of possible centroid positions for the shape. For each boundary edge point, the orientation ϕ_i is calculated. The appropriate line in the R-Table is found and the r-values are used to identify possible centroids for the shape. The Hough accumulator is incremented accordingly. If we can assume zero rotation and no scaling, and if the edge orientation is known quite accurately, then only the R-table entries for template edge points with the same orientation need be used. If there is a possible error in the edge orientation estimations then an appropriate window around the observed edge orientation

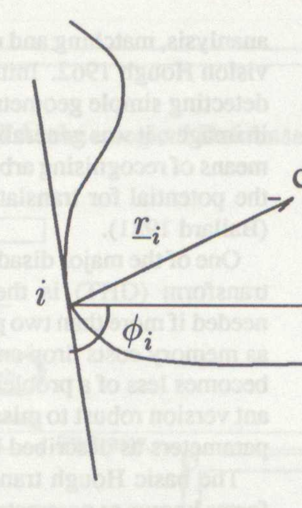


Figure 23.1: Shape Representation Using The GHT

is used to select R-table entries for updating the Hough accumulator.

After processing all edge points, the presence of a significant peak in the Hough accumulator indicates the occurrence of the template shape in the unknown image with a centroid value indicated by the peak position. The height and spread of the peak in the accumulator indicates the 'quality' of the match. A clean and accurate match should result in a peak cell with a count similar to the number of edge points in the shape.

If the shape in the 'unknown' image may be rotated from the original template position then an additional Hough parameter is introduced, namely the angle of rotation, and the Hough accumulator becomes a three dimensional matrix of cells. The incrementation process is also extended so that, for each edge point (orientation ϕ_i) in the 'unknown' image, all cells corresponding to rotation and centroid combinations compatible with ϕ_i are incremented.

If the shape in the 'unknown' image may occur at a different scale from that of the original template, the scaling factor may be introduced as yet another Hough space parameter. Again the incrementation process is extended so that for each edge point (orientation ϕ_i) all cells corresponding to rotation, centroid and scale combinations compatible with ϕ_i are incremented.

However, the size of the Hough accumulator immediately becomes a cause for concern. If the image is 512×512 there are effectively 512×512 possible centroid positions and if the angle of rotation is quantised to the nearest degree and twenty different scale factors are considered the size of the Hough accumulator will contain $512 \times 512 \times 360 \times 20$ cells and drastic action is necessary.

Various methods exist for reducing the memory problems with the Hough transform. The interested reader is referred to the review by (Princen *et al* 1989).

In order to use the GHT for pattern matching in the context of GOAD, the shape representation scheme to be derived from the chain code and stored with each known artefact in the database is the Hough R-table referred to above. Given the boundary of an unknown, the GHT is then calculated with each of the 'known' R-tables in turn and the height and spread of the most significant peak in each is recorded and is used as the discriminator in the pattern matching process. The shape giving the best match based on the height and spread of the largest peaks is then chosen as the nearest match to the unknown.

23.5 Conclusions

Our work on the development and application of appropriate techniques for shape representation and matching is still in progress, but the Generalised Hough Transform should provide a powerful shape matching tool in the context of GOAD and offer significant benefits over other matching methods particularly when only incomplete shape information is available.

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