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Mathrafal: a case study in the application of computer graphics

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16.1 Introduction

A feature of papers on graphical applications in archaeology is that they often seem to be heavy on graphics but light on application. In this paper we present a summary of work carried out during the past year on a royal medieval site in Wales. We will discuss some of the research problems associated with the site, and the ways in which the application of a variety of computer graphics techniques have been used to assess different hypotheses concerning the site and to formulate an excavation design.

The Mathrafal Project has been in existence for four years with support from the IBM UK Scientific centre, the Society of Antiquaries, the Royal Archaeological Institute, the Board of Celtic Studies, and the Powysland Club.

16.2 The site

Mathrafal lies 15 miles west of Welshpool, Powys, on the bank of the River Banwy. The site has had a tradition of royal connections since the thirteenth century, when Welsh poets wrote in praise of the exploits of their leaders and named Mathrafal as their residence. This tradition has continued and when the antiquary John Leland visited the site in 1536–39 he recorded that Mathrafal 'as sum sai, was one of the principal palaces of Walis as for the Prince of Poisland'.

Mathrafal regularly switched between the Welsh and the English during the twelfth, thirteenth and fourteenth centuries. A motte and bailey castle built at Mathrafal by the Norman Robert Vieuxpont was destroyed after a siege by the Welsh prince Llywelyn ap Iorwerth Gwenwynwyn in 1211–12. Mathrafal reverted to Welsh ownership under the Welsh princes Llywelyn ap Gruffydd (d. 1282) and Owen ap Gruffydd. Edward de Charlton, Lord of Powys, signed deeds at Mathrafal relating to the capture of the Lollard leader Sir John Oldcastle and a Deed of Pardon was granted at Mathrafal to the Caerinian followers of Glyndwr (Arnold & Huggett 1986, p. 436–7).

The large motte remaining from Vieuxpont's castle is one of the most prominent features of the site, but there is also a substantial rampart and ditch enclosing a

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large, roughly rectangular area beside the river. The relationship between the motte and this rectangular earthwork is not clear, although it seems certain that they are not contemporary. Within the enclosure are a large number of visible and barely visible features, consisting of indeterminate mounds and hollows. There are two large 'quarries' in the south-west corner of the main enclosure, and a marked platform occupies the north corner with indications of a stone wall bounding it on the southern side, together with the circular depression of what may be a well shaft. This is likely to represent the remains of a farmhouse demolished in the late nineteenth century.

The possibility that Mathrafal was the pre-Norman residence of the lords of Powys has meant that the site has attracted the attention of archaeologists since the early nineteenth century. There are records of 'Roman relics' being found in about 1840 and in 1870 a small excavation revealed walls and evidence of burning. Roman coins had also been reported, but unfortunately few of the original records or artefacts have survived. In 1929–1930 a local doctor excavated along the river bank and discovered a substantial dry-stone wall. Three narrow trenches were also excavated within the enclosure. Little detail was reported except for the discovery of a clay floor from a burnt building situated adjacent to the motte (Davies 1932).

The nineteenth century discoveries led to Mathrafal being identified as Roman in origin, and the rectangular shape of the main enclosure was used to support this speculation. However, the excavations in the early twentieth century demonstrated that the 'Roman' tiles were in fact post-medieval domestic rubbish tipped down the river bank. Following the excavations in 1930, the excavator suggested that the enclosure might have been a copy of a Roman fort, built by a '6th century Celtic chieftain' (Davies 1932, p. 152). The only evidence for this was that the stone wall along the river bank was 'apparently Welsh work and certainly not Norman'. He believed that from the eleventh to the thirteenth century Mathrafal was the site of a motte and bailey castle which continued to be occupied on a lesser scale until the fifteenth century. The assumption has always been made that the motte and bailey castle used the rectangular enclosure as the bailey. This was because a second, 'typical' bailey enclosure could not be identified. However, it would be extremely unusual for a motte and bailey castle to have had such a large rectangular bailey. The early date for the rectangular enclosure has never been questioned.

16.3 The Mathrafal Project

Here then is a well-preserved site of potentially early medieval date, a rare commodity in mid-Wales, which has persistently defied attempts at interpretation. An obvious response would have been to excavate a large area within the enclosure but, before this could be justified, it seemed more appropriate to attempt to maximise the information which could be gained from the site before any further destruction took place. Non-destructive strategies have been applied, both to increase our knowledge about the site and to determine whether excavation could be justified both in terms of the archaeological yield and the preservation of the monument.

The first step was to re-open and record the trenches excavated by Davies in 1930 (Arnold & Huggett 1986). One of the trenches lay along the river bank and the stone wall it had revealed was still clearly visible. A second trench was reported to have been dug across the rampart on the western side, but its location could not be found. The remaining two trenches were clearly visible as they had not been backfilled. The one in the centre of the enclosure revealed part of a stone floor, the trench and spoilheap of an earlier excavation, and the edge of a ditch. The other, beside the motte, had cut through a scorched clay surface which had been dumped onto the original ground surface. This clay surface was separated from the motte by a ditch, the outer face of which was revetted by a substantial dry-stone wall similar that on

the river bank. A *terminus post quem* for the silting of the ditch was provided by a coin of Edward III (dated to 1351–3), although its context was not secure. At the bottom of the trench, lying on the old ground surface, was a deep deposit of burnt brushwood which gave a radio-carbon date of 700±60 BP.

All the evidence from the old excavation trenches appeared to point towards the Norman use of the site, and an initial interpretation was proposed (Arnold & Huggett 1986). It was argued that the motte appeared to have been imposed on one corner of the rectangular enclosure and that the enclosure was therefore earlier, and probably represented early medieval Welsh use of the site. The motte did not use the rectangular enclosure as its bailey, as previously suggested, but the dumping of clay in the area beside the motte represented levelling-up of the area to form a bailey in the south-eastern sector of the enclosure. The ditch found in one of the re-opened trenches appeared to be associated with the low remains of a bank which might represent the original line of the bailey on the northern side. On the motte side and along the river bank, the bailey was revetted by the stone wall.

16.4   The application of computer graphics

A great deal of information was obtained from the re-excavation of the old trenches, but there was little indication as to the use of the enclosure, or the relationship of the enclosure to the motte. The large number of earthworks within the enclosure suggested extensive activity, but the relationship of these to the prominent upstanding features was not clear, and consequently a reliable interpretation of the site was not possible.

Computer graphics had been applied in 1985 to an extremely limited survey of an area which included both of the re-excavated trenches. A wire-frame model was generated using the PICASO system (Lock 1980, Huggett 1985, p. 11) on an ICL 2966 mainframe and, although limited by both the software and the nature of the survey, the resulting images did lend support to the new theory that the bailey was contained within the ramparts. Subsequent experimentation with this limited data set (see Spicer 1985) suggested that computer processing of a full survey could be of immense value in understanding the nature of the site without the need to resort to excavation. The intention was to define an area of the site which offered the greatest archaeological potential with minimum destruction. Consequently, highly detailed topographic, resistivity, and magnetometer surveys were carried out during 1988.

16.5   Methodology

The size of the site meant that a full topographic survey by anything other than Electronic Distance Meters would have been extremely laborious and time-consuming. In the event, two Nikon Total Workstations equipped with data-loggers were used over a five day period. The work was slowed because of the need to download the data loggers twice a day onto a mains supply PC since a portable computer was not available.

Around 15000 readings were taken at approximately one-metre intervals along transects set about one metre apart. Additional readings were taken where minor details or rapidly changing gradients would otherwise have been missed. The intention was to saturate the site with readings and the generalised grid was used to ensure full coverage. In fact, this approach is a version of the Fletcher Spicer perturbed grid (Fletcher & Spicer 1988, p. 310–11).

The geophysical surveys were carried out by John Gater of Geophysical Surveys Ltd who was commissioned by the Mathrafal Project to carry out resistivity and magnetometer surveys of the interior of the main rectangular enclosure. Readings

were taken at one metre intervals within twenty by twenty metre boxes and held on data loggers. This resulted in a total of around 25000 readings for the geophysical surveys.

16.6 Computer analysis of the Mathrafal survey data

All the data generated has been ported over to the mainframe equipment used at the IBM UK Scientific Centre, Winchester, where several powerful graphics and image-processing systems have been employed to enable us to scrutinise and present these large data sets. The topographic data were first transformed into a computer-generated three-dimensional wire-frame surface, or digital terrain model. As is well known, such models can be extremely versatile and are susceptible to a variety of enhancement techniques which can often bring out details that might otherwise escape attention (inter alia, Harris 1988, Spicer 1988). Simply exaggerating the vertical readings can help to enhance less pronounced features and feature definition can be significantly improved by applying even the crudest pseudo-lighting techniques. A method we have found helpful in this respect is simply to apply a bright colour or shade to the model if it tips towards an imaginary light source, a darker shade when the slope represented tips away from the light source, and an intermediate value when the area is roughly level. It is possible, of course, to model optimum lighting conditions accurately, but this quick and easy method was found sufficiently effective for our purposes of preliminary data exploration.

Displayed in the form of a wire-frame surface, the Mathrafal topographic data were examined in detail on an IBM 5080 work station. Stripped of all unwanted vegetation, the relief of the virtual earthwork was accentuated by a factor of two and pseudo-illumination applied in order to define more closely a number of features which had been difficult to understand on the ground. Until more powerful systems become available, we prefer to continue to use wire-frame representations for the analysis of topographic data because even very large surveys can be displayed and manipulated dynamically with a suitable work station. However, current state-of-the-art systems will support shaded models with hidden surface removal that can be handled in real-time.

The same techniques were applied to the geophysical data, but it was found that this method of display was not entirely satisfactory. Typically, the signals recorded during the geophysical surveys contained a degree of spurious data or noise, which meant that the underlying shape of the data was grossly distorted by numerous spikes. Fortunately, it is possible to apply a range of well-known image-processing techniques to remove the characteristic noisy components of the recorded signals which tend to disguise the archaeologically interesting elements of the data.

The Mathrafal data were analysed using the IBM IAX Image-Processing System (IAX). Essentially, IAX is a kit of image-processing tools which has its own language with some 200 built-in commands and functions which allow complex image-processing operations to be specified concisely. New functions may be added by the user, and IAX statements may be entered directly from the terminal or in macro programs, which enables the creation of tailor-made tools. This combination of ready-to-hand tools, easy interaction and fast response times makes IAX an excellent data exploration facility.

Throughout the study, we attempted to compare and contrast the different features which emerge in the various data sets, thus several images needed to be viewed simultaneously so that the analyst could visually scan for complimentary and contradictory patterns. In Fig. 16.1 the resistivity data are displayed on the right-hand side, and the magnetometer data on the left-hand side. The top left-hand corner of both data sets corresponds to the same point on the ground and both data sets were

collected on the same grid system, although the resistivity data have one or two extra survey cells.

Initially the data are displayed as an image on the screen, each reading being represented by one pixel whose brightness represents the value of the reading. Two problems immediately arise. First, the range of values has to be rescaled to fit the 8-bit (0–255) pixels. Secondly, the resolution of the screen is quite high (1024 × 1024) so that if each reading is represented by only one pixel, the resulting image is rather small. Consequently the image has been expanded by pixel replication (ie. each data reading is represented by several adjacent pixels) in order to fill the available space for display purposes only. In the past, grey-scale or half-tone pictures have been found to be a useful display method, but in this case a false-colour palette based on pseudo-randomised lookup tables was used. The non-linear progression of colours achieved by applying a randomised sequence rather than a true spectral sequence proved more effective in emphasising boundaries and demarcations in the data.

By studying the distribution of rescaled survey values shown as histograms (using IAX's *thist* function) it became apparent that the truncation of a few outlying values would improve the overall contrast. These outliers were the cause of many of the confusing spikes in the original wire-frame model. The largest spikes were reduced by truncation, but the remainder of the high frequency component in the data was removed by median filtering. It was found by trial and error that a weighted median convolution gave the best results. The mask used was:

$$
\begin{matrix}
1 & 2 & 1 \\
2 & 4 & 2 \\
1 & 2 & 1
\end{matrix}
$$

Again, the contrast was improved by rescaling the values to fit the full 8-bit range.

A number of edge detectors were experimented with in order to try to define the strongest anomalies more clearly. Finally, two functions were selected as giving the sharpest and most interpretable form to the data. Roberts' gradient operator was applied to the magnetometer data, while the Sobel gradient operator was used with the resistivity data:

$$
\begin{matrix}
-1 & 0 & 0 \\
0 & 0 & 0 \\
0 & 0 & 0
\end{matrix}
\quad \& \quad
\begin{matrix}
0 & 0 & -1 \\
0 & 0 & 0 \\
0 & 0 & 0
\end{matrix}
= \text{Roberts}
$$

$$
\begin{matrix}
1 & 2 & 1 \\
0 & 0 & 0 \\
-1 & -2 & -1
\end{matrix}
\quad \& \quad
\begin{matrix}
1 & 0 & -1 \\
2 & 0 & -2 \\
1 & 0 & -1
\end{matrix}
= \text{Sobel}
$$

Experimentation with randomised lookup tables was useful in drawing attention to details which could be seen in some sets of colour combinations but not in others.

16.7 Visually linking the collected data and interpretations

A relatively recent development which helps investigators to form and convey their interpretations of what is quite abstract data is to combine several different types of data and interpretations in one interactive model. Thus, for example, the range and distribution of the geophysical data can be indicated as shaded contours on a terrain model of the site topography. It therefore becomes possible to determine visually whether or not the features suggested in the different data sets complement or contradict one another, which is of great assistance in forming preliminary interpretations.

For example, the edges of a large rectangular platform, thought to be the remains of a vegetable garden that existed on the site until comparatively modern times, were demarcated by strong linear anomalies in the resistivity data, and are interpreted as walls (Fig. 16.2). In other cases, partial correlations between anomalies in the different data sets enabled problematic gaps to be filled and helped resolve some problems of interpretation. A long linear anomaly traverses the breadth of the resistivity survey area, for instance, and when this was placed on the terrain model it was realised that this anomaly marked the continuation of a path that could be traced on the ground only along a short section by following a slight sunken feature on the surface (Fig. 16.3). Of course, some features detected in one data set cannot be correlated with any surface features (for example, the circular anomaly in the magnetometer data, which is interpreted as the remains of a burnt palisade, does not appear on the terrain model).

In the same way, attempts were also made to discover if there was any direct correlation between the resistivity and magnetometer data sets by mapping them over each other. No correlation has been observed so far.

16.8 Conclusions

A great deal has been learnt as a result of this exercise. There seem to be more features on the site than were originally apparent, with indications of what are tentatively interpreted as a rectangular building, an oval palisade, and two kilns in the central part of the site. Although the features revealed in the magnetometer data in particular are extremely interesting in themselves, they have profound consequences for the interpretation of the site. The oval enclosure, which has the motte at one of its focal points and appears to contain a building and associated kilns, may be interpreted as a 'typical' bailey—a feature which has been missing from Mathrafal. However, it would also completely contradict the original interpretation based on extremely limited evidence of a bailey in the south-eastern sector, beside the River Banwy (Arnold & Huggett 1986). The relative position of these features also implies that the rectangular enclosure may in fact post-date the motte and bailey castle, casting doubt upon the early medieval origins of Mathrafal.

Having arrived at an interpretation of the data it is sometimes useful to encapsulate these ideas in a reconstruction model, because such an exercise will often reveal any shortcomings in the original interpretation. Using the WINchester SOlid Modelling program, WINSOM, (Quarendon 1984, Quarendon 1987) it is now possible to integrate reconstructed detail with the recorded data, allowing the researcher to demonstrate how the interpretation relates to the collected data. In this instance, the reconstructions have been placed onto a solid model of the site topology (Fig. 16.4). In the process of highlighting those well-understood aspects of the data, the analyst is confronted again with the problem of accounting for all the unexplained features which remain as formless humps and hollows. In other words, the modelling process stimulates the researcher to look for further information, which may involve the application of additional analytical experiments on the existing data, or it may require the formulation of a completely new research design to answer the outstanding questions.

As a result of this work, an excavation strategy has been finalised which is designed to gain maximum information with minimum destruction of the monument. The excavation results may then be compared with the original predictions of the survey data and hence improve the way in which such data is processed.

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