

## Session / Séance 09-A

# Automated Relief Representation for Visualisation of Archaeological Monuments

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### Abstract

*The Royal Commission on Ancient and Historic Monuments for Scotland (RCAHMS) are obliged to record Historical Monuments and to make this information available to the public. The traditional method of relief representation within archaeology employs ‘hachures’ (a hachure being a hand drawn line along the line of steepest gradient of a slope and in the direction of that slope). With the development of GIS within RCAHMS this data has to be digitally accessible. This research reports on a method for automatic relief representation (archaeological features such as ramparts and mound) required in order to visualise archaeological monuments within a GIS. The need for automated relief representation arose because current methods for the representation of monument sites as points or lines is not adequate and an automated process was necessary in terms of time and economic efficiency. Furthermore alternatives to hachuring (such as contours, relief shading and DTMs) proved ineffective at showing the subtle morphological changes that typically define earth works and boundaries to ancient monuments. In this paper we report on an automated hachure process, developed in C, and embedded in the GenaMap GIS. The C program takes as input the isolines defining the top and bottom of the slope and ‘drops’ hachures between these contours. Results of implementation are presented and evaluated against hand drawn results.*

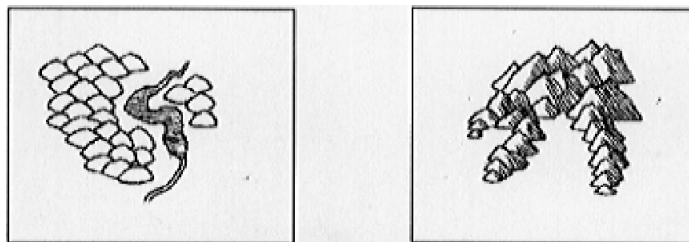
### Historical Development of Relief Representation

The paper focuses on methods for automated relief representation of archaeological features such as ramparts and mound. An automated process is necessary in terms of time and economic efficiency. The traditional method of relief representation within archaeology employs ‘hachures’. A hachure is a hand drawn line along the line of steepest gradient of a slope and in the direction of that slope. In the second half of this century hachures have been superseded by other cartographic relief representations. Within GIS this is typically through the use of Isolines (contours), relief shading and DTMs. Despite these developments, hachuring remains the convention used by RCAHMS to represent historic monuments. The problem with contours is that they are merely information about the elevation of a terrain and they do not directly symbolise the features they describe. Whereas a hachure drawing is a more direct symbolisation of the archaeological monument and this is more pertinent to the needs of the user i.e. RCAHMS. Where ‘contour’ lines are used in RCAHMS drawings, the contour is drawn in such a way that it represents the extent of the slope not the elevation and as such is misleading. Furthermore the resolution of contours in terms of spacing between them means that important detail may be lost. If the resolution of contours were so fine as to pick up every detail of a site the result would be too ‘noisy’ i.e. the important data about the morphology of a site would be lost within other data and the amount of effort involved in surveying a site in such a way would be inefficient. The potential public use of

RCAHMS via the Internet means that a conventional archaeological symbology such as hachures give the public a better understanding of sites.

The representation of relief has been an issue since the earliest days of map making. It is a challenging task, posing several complications not present with other map elements: the hachure represents a third dimension (height) that varies continuously over space and it has several mapable components such as height, slope, shape, and hence leads to multiple mapping techniques.

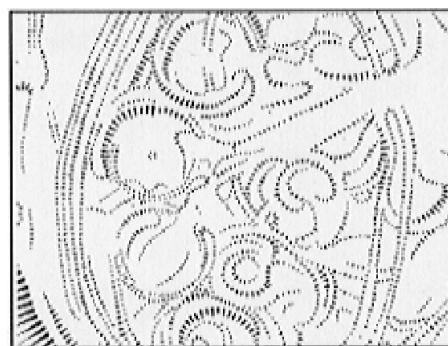
Early relief representations portrayed mountains as seen from the side. This type of representation was used in various incarnations such as sugar loaf mountains and fish scales until the Renaissance (Figure 1). Lack of scientific surveying techniques limited such representations to being merely symbols of mountainous areas without giving any real information about the topology of the slopes. Leonardo da Vinci's maps of Tuscany (1502-1503) were the first attempt to describe relief forms in a way that accurately represented the physical shape of the mountains and their topology as seen from an oblique bird's eye view. Slopes were further illustrated with the use of lines or hachures drawn down the line of steepest gradient. With the development of planimetric maps the problem of how best to represent relief became more complex. The hachuring technique previously used to illustrate slopes on the oblique views was now applied to planimetric maps. Hachures used lines of varying width and length to depict slope steepness.



**Figure 1:** 'Fish scales' and sugar loaf mountain symbols (after Imhof 1987).

Lehmann (1799) developed the theory of hachures in an attempt to express the slopes of relief by differences in light intensities. Because printing technology of the time did not allow shading, he developed hachures, many small lines as a surrogate for shading. The thickness of, and distance between, lines are varied so that variations in light and dark express variations in the slope of the terrain. Though popular it was generally time-consuming, obscured other information, was not very effective except in mountainous terrain and became at odds with surveying techniques that generated elevations, not slopes. As a result, hachures gave way to contours and hill shading in the nineteenth century, but are still used for very steep slopes such as cliffs, quarries, railway cuts, levees, where contour lines would merge (Imhof, 1987). In the broader world of cartography and general relief representation the automation of a technique such as hachuring is hard to justify. The general opinion is that hachures are a method of the past and cartography now only has two distinct methodologies from which to choose - contouring and hillshading. (Robinson et al., 1985). However within archaeology hachures have remain the most comprehensible and acceptable form of representation to the archaeologist (Clark, 1996) and allow a reader to identify relatively small scale features within that terrain. (Putnam, 1988). Figure 2 is an example of an archaeological site and shows the effectiveness of this approach in conveying the lines of defence and workings around the buildings.

At present there are no detailed images of monuments available on the OS Basic Scale map and it is one of the obligations of RCAHMS to provide monument information to the Ordnance Survey. What RCAHMS required was an efficient automated way of hachuring maps that avoided the time consuming process of drawing each individual hachure (as in Figure 2). Partial automated solutions have been achieved using AutoCad but these are time consuming, requiring the user to individually alter the

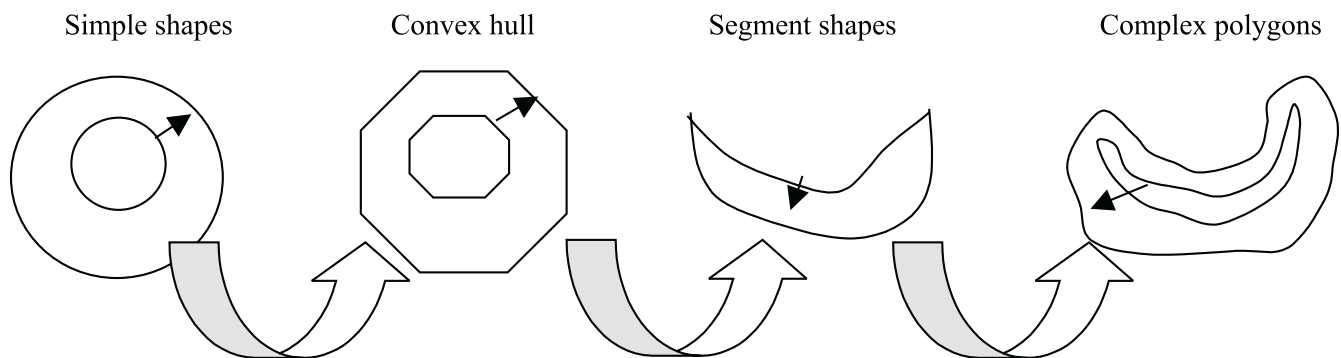


**Figure 2:** Complex hachure depiction of Gibbs Hill near Canonby. RCAHMS survey.

direction and extent of each hachure. The Ordnance Survey has automated the use of hachures in a clumsy way by drawing a line of triangles with an accompanying bottom of slope dotted line. Even if we ignore aesthetic issues, many small details could not be illustrated because the triangles are ‘clumsy’, especially when turning a sharp corner.

### Algorithm Development

Although the automation of hachures is a well defined problem, it is geometrically complex to model. Therefore the only way to approach the design of an algorithm was through stepwise refinement which involved breaking the process down into a series of geometric problems. (Figure 3) following the system life cycle proposed in Boehm’s Spiral model (Boehm 1988). This provides a series of prototypes that incrementally build in complexity as each problem is solved. The data used during the first step of the algorithm was two simple circles. It was important to start with simple data sets with predictable behaviour in order to make the first stages of development as simple as possible. From here the algorithm could be refined to cope with more complex shapes. For example the initial problem of radiating lines to an outer contour could be dealt with in isolation instead of solving the problem of interval points and direction of lines etc. Once the first functions had been developed, in isolation using circles, the rest of the development could developed, so that the algorithm could handle crescent shapes, and then complex polygons (Figure 3).



**Figure 3:** illustrating the progression of the algorithm development from simple to complex shapes

By the end of the project, the algorithm was composed of eight functions dealing with the various geometric and cartometric analysis and drawing (Table 1). For more details on all of the implementation see O’Loughlin (1998).

**Table 1:** Functions developed during development

Function name (In order of development)	Geometric issues
Meet	Finds where radiating lines meet outer contour
Interval	Divides upper contour into equal intervals
Radius	Find gradient of radiating line
Straight	As above
Radial point	Find a point to give line direction
Cross	Finds where lines cross
Hachure	Indicates direction of hachures
Correct	Corrects crossing lines

### Function Meet

The meet function radiates lines out from equal interval points on a circle and finds the meeting point with an outer circle. Finding the outer circle involved a simple line intersection algorithm.

### Function Interval

In the first part of the development the points of equal interval was easily found using the centre point of the inner circle in order to split the circle up into 'pieces of pie'. Since the data is rarely made of circles, it was then necessary to devise more robust solutions. This involved measuring equal intervals along the circumference of the outer line.

### Function Radius

Since all radiating lines must radiate perpendicular to the inner line, it was necessary to develop a circle fitting algorithm which took as input three consecutive (x,y) points along the boundary of the line. The point was radiated from the centre of the circle through the middle of the three points (Figure 5).

### Function Straight

Function Radius will only be effective in cases where 3 points are not on a straight line. In the case of a straight line Function Straight calculates the gradient of the line of 3 points and radiates a line perpendicular to the line.

### Function Radialpoint

Once the equation of a radiating line has been calculated the function radialpoint finds if the line crosses the inner contour at a point other than its point of origin. (Figure 6) If it does not then the radiating point can only cross the outer contour once and a radial point is not needed. If it does cross once this point can be used as a radial point. For more complex shapes the radiating line may cross the contour several times. In such cases the algorithm stores each point and determines which is the closest and uses this point.

### Function Cross

It is vital that hachure lines do not cross. Therefore this function performs a variation on line intersection to find if a line crosses any of its predecessors.

### Function Remove

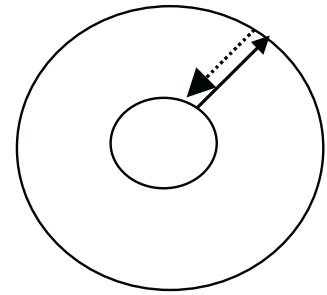
If lines cross this function removes them.

### Function Hachure

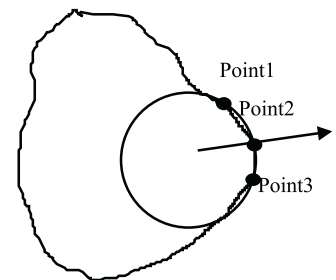
In order to represent the direction of slope every second line is shortened by a half.

### Function Correct

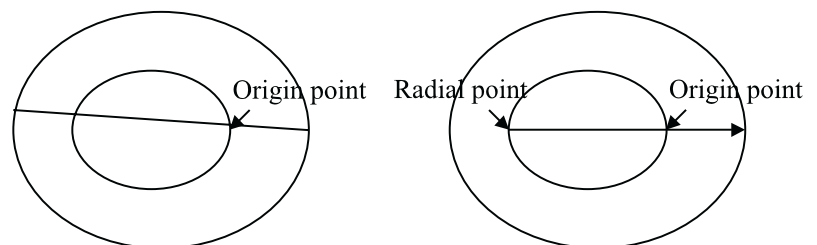
Function *cross* required refinement in order to fulfil successfully the user requirements.



**Figure 4:** Illustrating how lines can radiate in/out between two circles (depending on direction)



**Figure 5:** Fitting an imaginary circle in order to define the perpendicular.



**Figure 6:** Detection the number of intersections of a radiating line.

If each line that crosses is removed not enough lines are left to sufficiently describe the monument (This can be seen in Figure 7). This function attempts to add in more lines, by changing the gradient of the radiating lines generated using function radius. It does this by using the radius function, but replacing the before and after points by those one step further down the line (Figure 8). The above works in some cases but the line being corrected is not always the guilty one since it may be its predecessor. The function 'correct' can be applied to the preceding line and if an improvement is noted the line is checked to see if it still crosses the current line. If this does not work the current hachure can be improved and checked. In the case of neither attempt working the hachure is removed.

The removal of hachures is acceptable in tight corners where there may be too many hachures.

### Refinement of the Algorithm

#### *To reverse direction of slope*

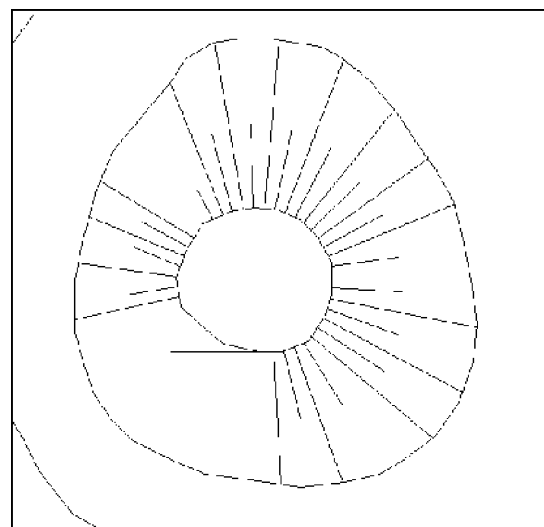
The simplest way to alter the algorithm to illustrate an opposite direction of slope was to radiate from the inner contour as before. Function hach was altered to draw the short lines from the outer contour.(Figure 9).

For complex shapes it is necessary to consider the number of times a line intersects the boundary of the outer contour. Where several intersections are encountered, the functions radilapoint and meet, the closest intersection was treated as the radial point.

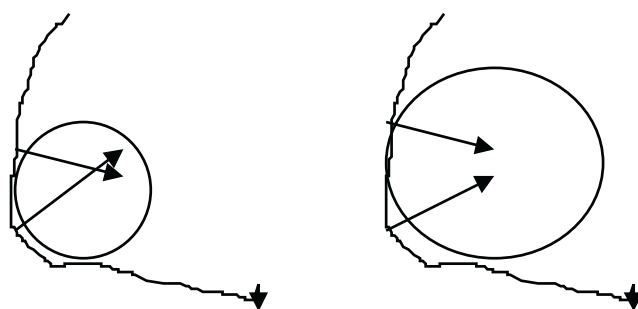
### Implementation

GenaMap is the current GIS used by RCAHMS. It has standard symbology functionality and a scripting language with good mathematical capabilities. Despite this the GenaMap script is not capable of performing the sort of mathematical manipulations described above. It was necessary to program the hachure algorithm in C, and to call the C code from within GenaMap.

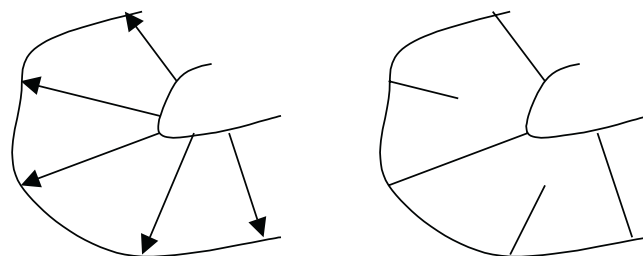
At present the line data representing sites is not good enough to support the automating process due to incomplete lines. For the purposes of the project it was therefore necessary to clean a subset of data to illustrate the idea, with the intention of ensuring that future data collection met the algorithm input requirements.



**Figure 7** Removing crossing lines does not leave enough hachures to describe monument



**Figure 8:** Function correct, changing the radius of the circle by choosing points further along the line.

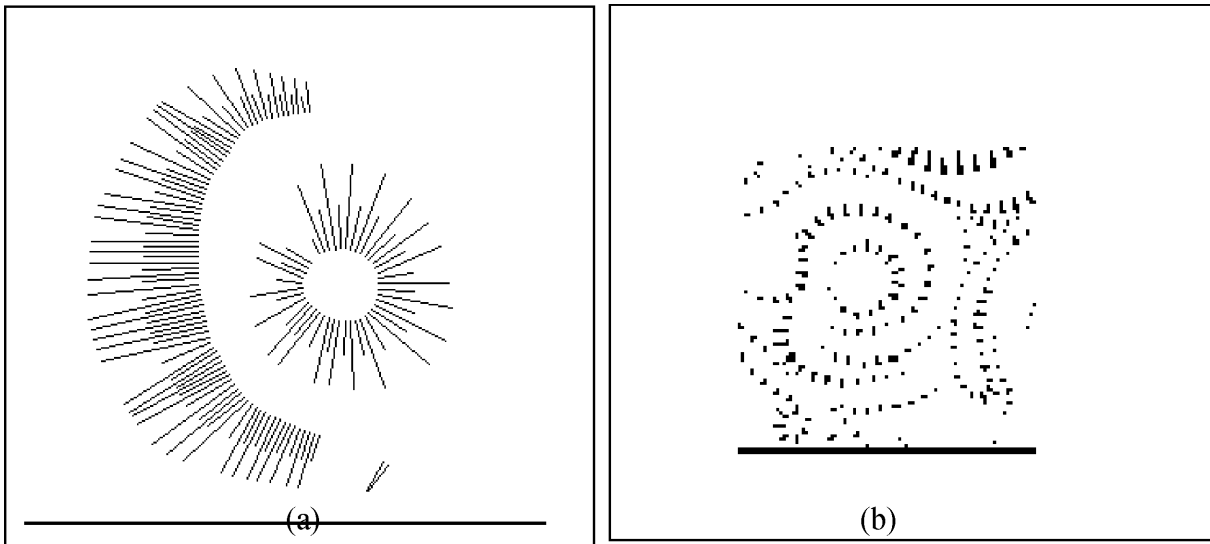


**Figure 9:** Reversing direction of slope.

## Evaluation

Though there is still room for improvement, the results compare favourably with hand drawn hachures.

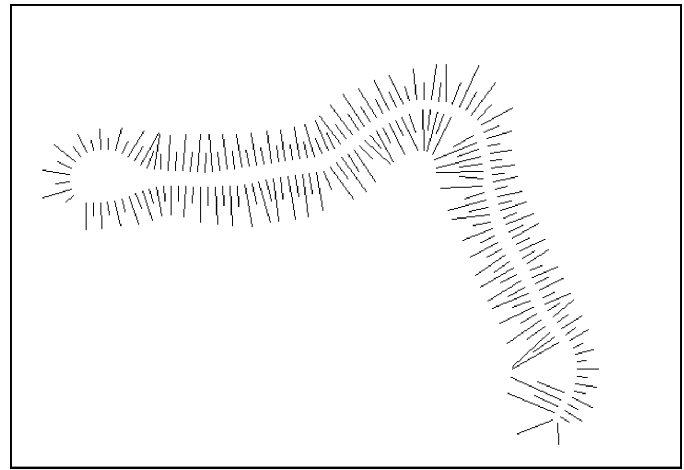
Figure 25, for simple shapes the automation certainly fulfils the brief of the project. The full extent of the monument is described as the hachure lines run to the bottom contour. Hachures radiate in a way similar to the hand drawn method using circles. Crossing hachure lines are picked up and where possible corrected. If correction is not possible the line is removed.



**Figure 10:** Comparison of samples (two different examples), a) automated and b) hand drawn.

More complex shapes work but due to time constrictions the program is not sufficiently debugged to cope with every scenario (Figure 11).

Figure 11 shows how for a complex shape is the algorithm a reasonable success though the bottom right hand corner has failed due to the difference between the width of the inner contour and the outer contour. Not enough hachures can be radiated from the inner contour to fully describe the outer contour. Figures 12 and 13 illustrate the use of hachure automation on part of a real site, the Hermitage Castle in Roxburgh. As can be seen the hachures describe the full extent of the slope, apart from the bottom right hand corner.



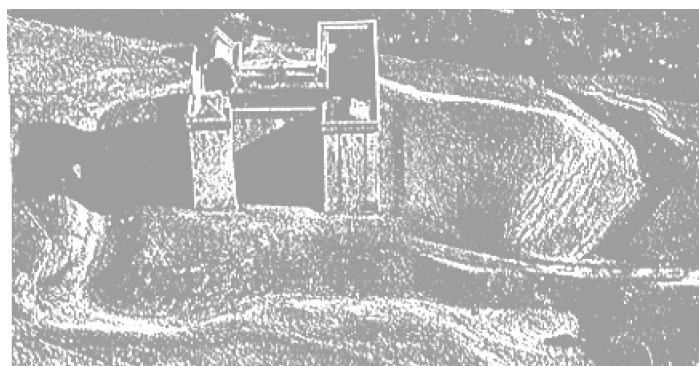
**Figure 11:** Results of hachure automation for complex shape (hachure radiating out from inner contour)

## Conclusions and further work

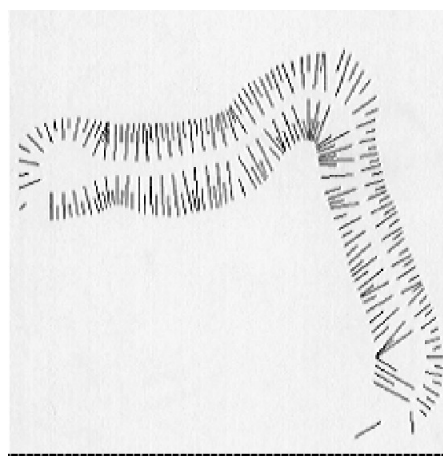
While it is important to realise what qualities are lost through automation in cartography it is equally important to realise what is gained, i.e. an efficient and comprehensible way to symbolise monuments digitally. In this sense the algorithm seeks not to mirror the skill and aesthetics of the hand, but to provide enough information

to convey reality (Nyerges, 1991).

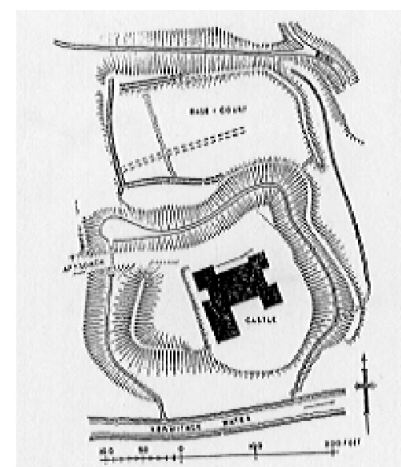
Investigation into the development of relief representation generally and within archaeology has proven that hachures still play a vital role in the visualisation of detailed relief for the work of the Royal Commission on Ancient and Historic Monuments of Scotland (RCAHMS). The automation of hachures was necessary due to the increasing use of GIS by RCAHMS. The sheer volume of data collected meant that the absence of automated hachures led to poor visualisation of monuments for the public. Other methods of creating digital relief representation for RCAHMS were time consuming and inefficient. An algorithm was developed and implemented in C and embedded in GenaMap. The algorithm can be judged a success for the simpler shapes, it definitely fulfils the requirements of the client in that it provides as much information as the hand drawn hachures. It can not reproduce the aesthetic properties of the former. This can be seen in places where lines wander in the wrong direction or where there could be a more even spread of hachures (figure 10). This is in part due to the quality of the digitised data.



**Figure 12:** Photograph of Hermitage Castle, Roxburgh (RCAHMS)



(a)



(b)

**Figure 13:** a) Result from hachure algorithm, b) Hand drawn version of hermitage castle (RCAHMS).

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