Viewshed and Cost Surface Analysis Using GIS (Cartographic Modelling in a Cell-Based GIS II)

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Introduction

Background

This paper reviews work in two related areas of GIS application – viewshed and cost surface analysis - that have received much attention in recent years because of their potential to escape from what has been termed 'environmentally determinist' reasoning in the worst New Archaeology vein. The latter has aroused widespread scepticism about the usefulness of GIS in archaeological research as, for instance, at the 1995 meeting of the UISPP (Bietti et al. 1996; Johnson and North 1997; reviewed by Bampton forthcoming). A balanced outsider view of the issue can be found in Taylor and Johnston (1995), who place current uses of GIS in the context of the 'quantitative revolution' and the 'New Geography' that took place in the 50s and 60s. These authors provide a useful and provoking discussion of the dangers of much current data-led GIS use but also stress the potential – mainly in pattern analysis (see also Gaffney and Van Leusen 1995).

The sub-title of this paper refers to an article I wrote in 1992 (Van Leusen 1993), in which I first speculated on the potential of viewshed and cost surface techniques and suggested several lines of further inquiry. The aim of the current paper is to provide a basis for GIS-using archaeologists to begin defining a 'best practice' as far as the technical application of viewshed and cost surface analyses is concerned. That done, we may be able to turn our attention to the more fruitful task of answering archaeological questions. But there is also a more serious reason for reviewing current archaeological applications of viewshed and cost surface analyses - archaeological arguments that are ultimately, if only partly, based on their outcome become invalid if they have been improperly applied or if the results have been wrongly interpreted.

In an attempt to make this review as complete and up-to-date as possible I have included materials that are currently unpublished (Dingwall et al. 1999) or only available on CD-ROM (Johnson and North 1997). The *Annotated GIS Bibliography*, by Petrie et al. (1995), was a source of much useful additional material.

Cost Surface and Viewshed Analyses, Related Techniques

What makes us think GIS can be used in reconstructing past landscapes? The landscape, both in the past and in the present, is structured by the fact that resources are distributed unequally over it. This applies to both natural and social resources - drinking water and infrastructure are only available in some places; good farming and stock rearing land is not available everywhere or is already occupied by others; centres of political power, civic administration, and ritual significance are few and far between. People's choices both structure this 'resource landscape' and are structured by it, and we therefore expect archaeological remains to exhibit structuring of this type. Viewshed and cost surface analysis are two ways to reveal such structuring.

Viewshed analysis uses the ability of most GIS to calculate the intervisibility of two given points on a given digital elevation model; cost surface analysis uses cost accumulation algorithms to calculate the cumulative cost of travelling over a digital cost landscape. Since about 1987 an increasing number of archaeological applications of these techniques have been presented at CAA conferences and elsewhere, and lately these are being hailed by some as examples of a 'cognitive' landscape analysis (cf. the debate in Gaffney and Van Leusen 1995). At the same time the basic techniques are being refined in ingenious ways such as multiple cumulative cost surfaces, least-cost paths, and multiple least cost paths or least cost networks.

Although they are superficially different, viewshed and cost surface analyses are intimately related techniques. Take, for example, territorial markers. These must be highly visible (though not indiscriminately so, as we shall see below) and also be located at the edge of some kind of 'territory'. The two cannot be separated. A more abstract way of looking at the relation between the two techniques would be to note that both incorporate the notions of *focus* (in the sense of a point-like location which might be the current or intended location of the protagonist, or might have a significant level of visibility or accessibility) and of *direction* (as in megalithic alignments pointing at midsummer sunrise points, or in the travel networks discussed below). And finally, viewshed and cost surface analyses are also related in a different sense by authors that combine both types of analysis in order to construct their archaeological argument – see, for example, the work of Gaffney et al. (1996a, 1996b:37-8), where cost surface derived catchments are compared with viewsheds of Iron Age hillforts on Dalmatian islands, and Madry and Rakos (1996:123), who use the visibility of Roman roads from hillforts in Burgundy as an input variable for cost surface analysis.

Post-processualism and GIS

Many authors have argued that the use of GIS inevitably leads to *environmental determinism*, an issue which has been discussed more fully elsewhere (Gaffney and Van Leusen 1995), and have advocated a post-processualist approach to using GIS. They trace the problem to the geographic approaches from which GIS were built, treating space in an abstract geographical sense (as in 'Cartesian space') – as Llobera (1996) put it, there is no observer, no perspective, and no history. Others think however that despite appearances, GIS can be used in various ways for the modelling of cognitive landscapes (Taylor and Johnston 1995) and that it is the individual researcher who is to blame if GIS techniques are not applied within a proper framework of archaeological problem solving, not the GIS *per se*. Attempts to address the perceived rigidity of current GIS applications include the incorporation of concepts of uncertainty (Gillings 1996, 1998, Loots et al. 1999, Nackaerts et al. 1999), the ideal organisation of space and society (Zubrow 1994), time and change, and of affordances (Llobera 1996). This is signalled as an important current development in the *GIS Guide to Good Practice* (Gillings and Wise 1998), but it is not yet clear what, if any, improvements these approaches will bring. This issue is discussed in more depth in section *3.3.

Cost Surface Analysis

Principles and Applications

'Cost surface analysis' is here used as the generic name for a series of GIS techniques based on the ability to assign a cost to each cell in a raster map, and to accumulate these costs by travelling over the map. Early examples were published by archaeologists working with the Arkansas Archaeological Survey and the US National Parks Service (Limp 1989, 1990). Cost surface analysis is rooted in traditional site catchment analysis, introduced to archaeology by Vita-Finzi and Higgs (1970), who wanted to study the economic basis of prehistoric life by looking at resources available within a *catchment area* or territory associated with a settlement.

The first step in site catchment analysis is to derive a territory (catchment) belonging to a given focus (site) by applying some geographical rule. In its simplest form this would be a distance rule, resulting in circular catchments with a typical radius of 5 or 10 km. The second step is to analyse the properties of the catchment area, usually to see what social (dominance over other sites) or economic (agricultural yields) benefits would accrue to the focus. The radius would be chosen by experimenting with actual travel times or using ethnographic data (Chisholm 1968). Deriving a circular catchment area within a GIS is a trivial operation, and reporting and tabulating the presence of variables within each catchment can be automated. Recent examples can be found in Saile (1997) and Lock and Harris (1996:234-8), who used such buffers to model areas of in- and outfield agriculture around Iron Age Danebury hillfort. A more sophisticated form of such analysis is the construction of distance buffers around the focus, allowing a statistical analysis to see if some archaeological correlate gravitates significantly toward or away from it. A well-known example of this is Hodder and Orton's (1976) calculation of the distance distribution between coins and Roman roads in southern Britain.

Closely related to catchments are *tessellations*, which have a more specific and theory-laden meaning. Whereas catchments are generally used to describe economic characteristics of the archaeological landscape, tessellations of archaeological landscapes are used to postulate a social (political, administrative, religious) structuring – for example, in Renfrew's (1986) peer polities. The most widely known traditional method for doing this is the calculation of Voronoi (Theissen, Dirichlet) polygons. These are based on a simple gravity model and result in a complete tessellation of space. Both traditional catchments and tessellations rely on the simplifying assumption that the landscape is a flat, two-dimensional space, and movement across it is isotropic (the same in all directions). They also result in choroplethe maps rather than mapping the continuous fall-off of variables such as accessibility and control. In a real landscape the size and shape of a catchment area or territory would be much more variable, depending on the nature of the terrain, the topography, and a host of other factors. In a real landscape, the economic use of, and social control over, an area becomes less with distance rather than suddenly switching from yes to no (1 to 0) as the boundary of the catchment or territory is crossed.

Cost surface analysis provides a way out of this by allowing the simple 'flat' geographical space to be supplanted by a set of complex cost surfaces incorporating many relevant properties of the terrain. It also allows for the distance- and gravity based rules for defining the catchment or territory boundaries to be replaced by a time- or energy expenditure based rule for accumulating costs. As the resulting cumulative cost surface is a continuous raster map, any number of values may subsequently be used to provide 'cut-off points' or boundaries to the catchment or territory. Alternatively, cost accumulation starting at multiple points may be allowed to run on until all available space has been used, in which case a tessellation of space similar to Voronoi tessellation has resulted. For example, Verhagen et al. (1999) calculate cumulative travel time in order to construct 'accessibility catchments' which are then used as input variable in a predictive settlement model. As we shall see in the next section, the possibilities offered by this technique have led to some confusion as to the best way of calculating costs.

Algorithmic Confusion

Employing a simple radius to define a catchment area is equivalent to travelling over a flat cost surface - accumulation is constant in all directions and the catchment is therefore solely defined by the maximum horizontal distance. If accumulation from a number of starting points is allowed to continue until all of the cost surface is covered, a Voronoi tessellation results. Just as the traditional method can be modified to employ travel time as a limiting factor, so cost surfaces can be modified to reflect the difficulty of travelling over various types of terrain. Accumulating such costs will result in irregularly shaped catchments for any particular total energy expenditure. This principle can be extended so that any combination of factors can be used to define costs, and any combination of criteria can be used to derive a cumulative cost surface from those costs. A further refinement of the technique, suggested by one of us (van Leusen 1993) but not yet implemented archaeologically, would result from assigning differential weights to the sites or *foci* of the catchments, so that accumulation proceeds with different degrees of ease over any particular cost surface. Exactly how all this should be implemented is a question that seems to have been answered differently by each individual author. In the published research there is a wide variety in the parameters used to calculate cost/energy surfaces and in the algorithms used to perform cost accumulation - a sure sign of the immaturity of the field.

Most studies have relied exclusively - and continue to do so - on slope as the factor determining cost (e.g., Gaffney et al. 1993, Massagrande 1996, 1999). This may work in areas where topography has an overriding effect on human behaviour; see, for instance, Huckerby's (1999) study of how well four rival foraging theories fit with the costs of accessing mammalian resources in Queensland, Australia. But more realistic calculations, based on physiological measurements of energy expenditure on different types of terrain, are now feasible and have been employed by us (see below). Some authors have attempted to derive costs inductively, from archaeological observations relating to actual territorial boundaries or actual distances travelled per time slice. One example of this is the work of Glass et al. (1999), deriving costs from observed dates of first occupation of South American sites and assuming that the 'delays' between occupation of successive sites are caused by the cost of travelling from one to the next. Apparently no universal set of absolute real world travel costs is to be found in the literature, but this need not be a problem so long as a universal set of relative costs can be found.

Travel cost surfaces can be isotropic (the same in all directions) or anisotropic[1]. The cost of traversing a particular location may differ depending on which direction it is being crossed in. Crossing cells representing a river is an obvious example of this - travelling down river in a boat incurs different costs from travelling up river, and different costs again when crossing the river. Surprisingly, until very recently raster GIS did not provide the functionality to introduce anisotropy; a closer merging with the functionality generally present in vector GIS seems needed. Examples of models based exclusively on isotropic cost surfaces can be found in Savage (1990); Rajala (this volume) maps territories in the Ager Faliscus using an isotropic cost surface derived from slope and based on empirical walking effort data. Verhagen et al. (1999) calculate the accessibility of settlements in the Vera Basin, Spain, on the basis of slope according to a formula provided by Gorenflo and Gale (1990). They specify the effect of slope on travelling speed by foot as:

$$v = 6\, e^{-3.5\, |\, s + 0.05\, |}$$

where v = walking speed in km/h, s = slope of terrain, calculated as vertical change divided by horizontal change, and e = the base for natural logarithms. Although this function is symmetric but slightly offset from a slope of zero so the estimated velocity will be greatest when walking down a slight incline, it is still isotropic. Finally, A. Diez at the University of California at Berkeley recommends the isotropic formula

Effort = (percent slope) / 10

However, most authors agree that travel cost has both an isotropic and an anisotropic component; the former exemplified by costs relating to the type of terrain (soil, vegetation, wetness), the latter by costs relating to slope and streams. For example, Bell (this volume) employs an anisotropic cost surface based on slope to generate a cumulative path network between Samnite sites in central Italy. Diez's formula (above) was modified by W. Hayden into an anisotropic cost formula by calculating full cost upslope, no cost cross-slope, and half cost downslope. Hayden then added an isotropic cost layer for different terrain types and terrain roughness (calculated as the change in slope). J. Steele suggested the following anisotropic function derived from backpacking (Ericson and Goldstein 1980):

Effort = (horizontal distance) + (3.168 * vertical distance up) + (1.2 * vertical distance down)

Adding insult to injury, Marble (1996) suggests that *the function relating physiological expenditure to slope is approximately symmetric*, and we can safely ignore the whole problem. He recommends a formula developed by Pandolf et al. (1977) which calculates the actual physiological expenditure M (metabolic rate in Watts) involved in moving over natural terrain and incorporates total weight (body plus load) moved, velocity V, a terrain factor N describing ease of movement, and percent slope G:

$$M = 1.5W + 2.0\,(W + L)\,(L / W)^2 + N\,(W + L)\,(1.5V^2 + 0.35VG)$$

Because the slope calculation used to obtain grade G is non-directional, no distinction can be made between downslopes and upslopes. This function is therefore isotropic. The terrain factor N is a cost surface constructed on the basis of terrain features known to influence movement - marshy areas, roads, and streams of various widths. Marble (1996:5) also supplies coefficients for most of these terrain features.

Further Work

Other than trying to agree among ourselves on the actual cost of travelling, are there any other immediate tasks before us? I can see two. The first is one of the improvements I suggested in 1992 (Van Leusen 1993), namely the differential weighting of the sites or foci used for cost surface calculations. The other is improving least cost path analysis.

One of the more promising areas of development in cost surface analysis is the least cost path. This operates by 'draining' a cumulative cost surface from a particular point, and finding the shortest (least cost) path from that point back to the original focus of the cumulative cost surface. Single least cost path calculation has been used by archaeologists on a few occasions, for instance to derive optimum routes between pairs of hillforts in Burgundy (Madry and Rakos 1996, 113-117). Compiling multiple least cost paths into one 'road network' was suggested by Dana Tomlin (1990) in an application searching for an optimum logging road network and was first archaeologically implemented by Gaffney (pers. comm.) in order to model approaches to Stonehenge. Bell, in his paper *Tracking the Samnites: topographically based anisotropic cost surfaces and cumulative pathway analysis* presented at the 1998 CAA conference, presents the first archaeological example of a least cost network. Gaffney

[1] Part of the following is reproduced from an e-mail sent by Mark Gillings to the GISARCH mailing list (Gillings, Fri. 10 Oct 1997).

and Van Leusen (in prep.), calculate similar least cost networks in the late Iron Age and Roman landscape around the town of Wroxeter (Shropshire, UK). However, some serious problems remain to be solved before this type of analysis can come into its own.

At a technical level, the accumulation and drainage algorithms are imperfect. Accumulation is performed using either a 4-neighbour or an 8-neighbour filter; even if the latter is used, the 'Knight's Jump' accumulation results in slightly incorrect accumulated costs for most cells. The drainage algorithm, in looking for the lowest neighbouring cell value, cannot produce the actual least cost path and in fact is quite likely to deviate significantly from it.

We should also carefully examine our model assumptions. Travel rarely if ever happens in a virgin landscape – the landscape has a history of use, which means it is riddled with animal tracks and the infrastructure left behind by the forebears of the current inhabitants. One could almost assume that, wherever one would wish to go, some sort of path already exists! On a less grand note, rather than climbing or descending very steep slopes, people will resort to hairpin bends in order to keep to a comfortable degree of slope. Usually there will be animal tracks to allow this. Thus, surmounting a steep slope (ridge) only requires travelling a greater horizontal distance at a lesser vertical angle.

Most fundamentally and worryingly, a real traveller uses his knowledge of the terrain, the expected length of the trip, the weather forecast, the final and intermediate goals, etc., to decide on the route - a decision that weighs the global costs of alternative routes. Current GIS, in contrast, can only make local decisions as to which neighbouring cell has the highest or lowest value - they incorporate no global knowledge of the landscape at all!

Line-of-Sight Analysis

Principles and Applications

Visibility has long been an acknowledged factor in the location and construction of archaeological monuments such as hillforts, henges, and barrows. One of the 'new' tools that GIS has offered to archaeologists is viewshed analysis. It not only enables researchers to quickly generate and test hypotheses about the (non-) visibility of salient sites and landscape features, but also breathes new life into the study of landscape perception or *cognitive archaeology*.

Single viewshed analysis is now a well-trodden area in archaeological landscape modelling. The basic technique operates on a digital terrain model (DEM) to determine which areas are visible from a given three-dimensional location. Single viewsheds indicate whether any two points are intervisible and which area is visible from a particular point; they may also include information about the angle of view. Applications in archaeology range from visual impact analysis for cultural resource management - minimising the visual impact of modern development upon an archaeological landscape (Katsaridis and Tsigouragos 1993, Knoerl and Chittenden 1990) - to reconstructions of Celtic road systems (Madry and Rakos 1996) and explorations of how prehistoric ritual landscapes might have been perceived by contemporary populations (Ruggles and Medyckyj-Scott 1996, Wheatley 1995, 1996b). In further GIS analysis, the basic viewshed can used to derive properties of the visible areas, relating to such activities as hunting (van Leusen 1993, Krist and Brown 1995), security (Madry and Rakos 1996), and the confirmation of cultural identity (discussed below). Ruggles et al. (1993, 1996) employed viewshed analysis in the study of bronze age monuments on the island of Mull, western Scotland, extending the idea of visibility to include prominent horizon features and astronomical events. Prehistoric stone rows add the idea of *directionality* to viewshed analysis, possibly aligning with landscape features to 'pinpoint' relevant astronomical locations such as points where the moon rises and sets.

For specific purposes, the concept of viewshed calculation has been refined in order to study *intervisibility* (whether two or more monuments are intervisible and might therefore be part of the same 'system'; Haas and Craemer 1993, Moscatelli this volume) and *visual alignment* (whether two points align in order to visually emphasise or frame a third point; Ruggles et al 1993). Single viewsheds have also been merged to yield multiple viewsheds (Jacobson et al 1994) and added to yield *cumulative* viewsheds (Gaffney et al. 1996b; Wheatley 1995, 1996b), both of which will be discussed in more detail below. Finally, the concept of viewshed analysis logically extends to the complement of visibility, the study of *non-visible* areas and monuments. Whereas one particular viewshed will show which areas are hidden from view from a particular vantage point, multiple viewsheds will highlight areas hidden from view from a *class* of monuments, with the potential of having a regional (ritual?) significance. Cumulative viewsheds refine this idea by giving a measure of how hidden particular locations are, enabling us to rank these locations by degree of seclusion. While viewshed exclusion has figured in archaeological studies, notably Tilley's *Phenomenology of Landscape* (1994), it has only been the subject of one GIS publication in recent years (Lock and Harris 1996:224).

Methodological Issues

In ascending order of complexity three groups of methodological problems can be distinguished with current viewshed applications – the problems of reality, of edge effects, and of significance.

Firstly, the problem of reality – is a calculated viewshed sufficiently congruent with the real viewshed? A fair amount of GIS literature already comments on the pertinent issues of data quality (especially of the DEM that underlies all viewshed analysis), operational assumptions (such as the viewing parameters and the use of palaeo-environmental reconstructions), theoretical considerations (such as the relative merits of employing an 'objective' Cartesian view of geographical space, or of using subjective notions that involve viewer and viewed in a more complex interaction), and the algorithm employed in the calculation of viewsheds (Loots et al. 1999; Nackaerts et al. 1999).

Secondly, the problem of edge effects – since viewsheds are generally large relative to the study region (especially if their radius is unconstrained), they tend to 'fall off the edge' of the region. Conversely, viewsheds of sites lying outside the region will fall partly within the region – but those sites are not part of the analysis so their viewsheds are never calculated! If not properly corrected for, this will lead to incorrect multiple and cumulative viewshed calculations and hence to incorrect archaeological interpretations. For example, in a 20 by 20 km study region, calculating viewsheds with a 7 km radius would leave only a 6 by 6 km area in the centre of the study region where the visibility index values are correct! The edge effect can manifest itself in unexpected ways. For example, Madry and Rakos' (1996) study of the Celtic road network in the Arroux valley in Burgundy suggests that there is a viewshed relation between these roads and the nearby hillforts, and that the intention was to keep the transportation network under constant visual control from these defensive sites. A cumulative hillfort viewshed is calculated and the roads are found to lie largely within the high visibility values. Statistical support for this is obtained by comparing the visibility index of the roads with those of the total study region. However, as no account was taken of the edge effect, the visibility values for the region are incorrect and the conclusion the roads have significantly high visibility is unsupported (though it may well be true).

Thirdly, the problem of significance – are the visibility characteristics of the archaeology *significantly* different from background values? Wheatley (1995) discusses one correction that should be standard in all cumulative viewshed operations - the 'view to itself' effect. In the examples discussed by him, this effect entails that the number of barrows observed to occur in a particular viewshed is always one higher than it should be, leading to misinterpretation of statistical results. Even more insidious is the 'viewshed radius effect'; I recently conducted some simulations (Gaffney and Van Leusen forthcoming) that show that the size of the viewshed radius has a profound effect on the distribution of visibility index values across the terrain. For *any* set of points (including archaeological objects), choosing a small radius will result in a 'preference' for the lower elevations (valley bottoms) occurring in the study area, whereas choosing a large radius will result in a 'preference' for the higher elevations (peaks and ridges). A good example of this effect at work can be found in Lock and Harris (1996: 224, fig 13.5). They note that viewsheds of Neolithic long barrows in the Danebury region are apparently selected so as to 'alert people crossing the surrounding ridgetops'; this 'rim effect' may be entirely due to the choice of viewshed radius.

It is no longer sufficient just to report on the properties of the viewsheds generated for groups of archaeological monuments - archaeological relevance depends on such viewsheds being sufficiently different from the background visibility properties of the study area. For example, viewsheds taken from high points in the landscape will tend to include relatively many other high points - ridges, peaks and such. A sample of viewpoints drawn from such locations (hillforts, barrows) will therefore preferentially 'see itself'. For example, Wheatley (1995, Plate 1) employs cumulative viewshed analysis to study the spatial relationship between barrows in the Stonehenge and Avebury areas. His analysis clearly shows the correlation between viewsheds and elevation, with ridges and peaks being preferentially seen. Wheatley rightly cautions (ibid., 180) against equating such statistical correlation with causation, but does conclude that being able to see other barrows is likely to have been a determining factor for barrow placement in the Stonehenge area.

It is all too easy to employ viewshed analysis simply to support one's preconceived ideas about the cultural and cognitive significance of archaeological monuments, especially if there is little or no methodological control on these quantitative models. Gaffney et al. (1996a:148ff), in their discussion of the viewsheds of monuments in the Kilmartin area of Scotland, fail to convince for this very reason. If the rock art and standing stones in this area are not visible from more than 100 meters and 3km away respectively, what is the use of calculating 15km viewsheds?

Visibility, Perception, and the Cognitive Landscape

It is becoming increasingly clear that archaeologists working with GIS want to be able to escape from the 'objective' geographical space enforced upon them by the design of the software. They want to be able to represent the subjective experience of past people - their perception of their physical and social environment, and their cognitive representation of their world. This is part and parcel of the general post-processual trend in recent theoretical work, a good overview of which can be found in Renfrew and Zubrow's *The Ancient Mind* (1994). Perception and cognition of the landscape are two different concepts, although our perception of the landscape is obviously steered and modified by our cognition (or lack thereof) of its history and constituents.

Perception, as the simple act of being aware of the landscape, has already been to some extent the subject of GIS-study among both geographers and archaeologists. Geographers intend to incorporate qualitative spatial reasoning into formal GIS models (see, for instance, Frank 1996, for a discussion of how reasoning with cardinal directions can be so formalised). Archaeologists have concentrated on less complicated visibility issues involving significant ritual and political landscape features (e.g., Boaz and Uleberg 1995, Nunez et al 1995, Gaffney et al. 1996a, Llobera 1996). Some thought but little action has so far gone into the generation of perceptual variables such as 'enclosedness' vs. openness of the landscape (Llobera pers. comm.); the potential of such approaches is therefore not yet clear.

Cognitive archaeology in the context of landscape archaeology is the archaeology that concerns itself with the cognitive aspects of past geographical and human landscapes, that is, the perception of significance. According to Zubrow (1994), 'one goal [of cognitive archaeology] is to show that people had preferences independent of economic necessity, and some decisions are independent of utility'. He continues 'as archaeologists, one of our ultimate goals is to extract the cultural ideals from the complicated reality in the complex patterns of prehistoric material remains'.

If we abandon our viewpoint as an external, even extra-spatial, observer of the archaeological landscape as represented by GIS-generated maps, we may instead adopt another role - that of the participant in a cognitive landscape. The link between visibility and cognition has been well made by Gaffney et al. (1996b):

> "A viewshed represents the area in which a location or monument may communicate visual information. Viewsheds may overlap, producing zones in which an observer might be aware of the presence of many such locations, all of which may carry information. The increased density of such information can in some circumstances be interpreted as a measure of the importance of a particular area. It provides a spatial index of perception, mapping the cognitive landscape within which the monuments operated."

Many authors have begun to explore the prehistoric cognitive landscape via visibility in recent years. For good reasons, such experimental GIS applications tend to concentrate on well-preserved and well-studied ritual landscapes such as the Stonehenge environs, that offer unusually complete data sets and a relatively high a priori degree of certainty that visibility was an important consideration when the monuments in these areas were constructed. These explorations, when visualised appropriately, have the potential of involving us much more closely with the past. Woodward and Yorston (1996) bring the study of landscape perception closer to dynamic Virtual Reality by interactively presenting changes in viewsheds as the viewer moves along the Stonehenge Avenue and different groups of barrows come into view.

Further Work

Further work in improving viewshed analysis will need to deal with two issues. The first concerns the technical application of viewsheds; the second, their theoretical justification.

Various technical improvements to viewshed analysis have already been proposed. For example, distance decay functions and 'fuzzy viewsheds' have been used in order to simulate the loss of visual resolution with distance (Fisher et al. 1996) and to (Nackaerts et al. 1999, Loots et al. 1999). Wheatley (1995: 181-2) includes a useful discussion of error and uncertainty in viewshed maps. Others (Ruggles and Medyckyj-Scott 1996) have applied a correction for earth curvature which is particularly relevant for astronomical observations[2]. Other improvements follow from the discussion of methodological problems above. The preliminary visibility significance tests I conducted indicate that statistical control of viewshed analysis needs to be much stronger before any archaeological interpretations can be built upon it. The tests will have to be generalised so that reproducible results can be obtained from them, and a proper way of incorporating background visibility data into viewshed analysis has been found. One way forward might be by resorting to *relative* visibility measures – for example, Lock and Harris (1996:232 and fig 13.15) note that early Iron Age hillforts in the Danebury area are positioned to maximise visual dominance over adjacent valleys and surrounding farmsteads *at the cost of* all-round defensive visibility. I am less happy with the tack taken by Gillings (1999) and Woodward and Yorston (1996). Gillings looks to Virtual Reality visualisations in order to explore the significance of archaeological viewsheds; Woodward and Yorston have implemented an application similar in spirit, that uses Java software to create interactive maps of the barrows in the Stonehenge area, where barrows visible from the current position of the mouse cursor light up. Although this type of work certainly comes closer to the post-processualist ideal of being participant in, rather than an observer of, the archaeological landscape, I am worried by what must be an increasing temptation to throw technical rigour to the wind.

Justifying viewshed analysis on a theoretical level is equally as important as its technically competent implementation. How important is it in fact to be able to see a particular site or monument, as opposed to knowing or being aware of its presence and location? Does the cognitive landscape not exist as much of such unseen but looming presences as it does of the more direct visual kind? And then there is the middle ground of things heard, smelled, seen only at night... Take barrows for instance – when were these supposed to be visible? When first constructed they would be highly visible, but their visibility must have dropped as they became overgrown with moss, lichen, and grass. Could it be that the less permanent features of a barrow cemetery were in fact the most visible (totem poles), audible (wind chimes), or smellable (decomposing offerings?). Inspiration will be found in the ethnographic literature, but there is also the danger of over-interpretation – *anything* in the landscape could have had cognitive significance. That does not mean to say that it had.

Conclusions

This paper critically examines the logic of assigning cognitive significance on the basis of multiple or cumulative visibility and accessibility indices, and finds that insufficient attention has been paid to some important methodological aspects of spatial analysis - notably the need to calculate 'background' or 'potential' indices against which an actual outcome may be judged. Recent work points to least cost path analysis as the most profitable avenue for further research in cost surface analysis. There are at least two avenues for further work here; firstly, analysis of historic infrastructural networks; and secondly, vector analysis of networks constructed through raster-based cost surface analysis. Recent viewshed applications seem to concentrate on studying the (inter-) visibility of ritual monuments, but as has been made clear here will need to apply a lot more rigour to their technical execution.

Rather than continuing a fruitless processual / post-processual debate, this paper shows current GIS implementations of 'cognitive' landscapes to be little more than a semantic change of clothes. The post-processualist argument has mostly taken the form of a bashing of supposedly 'data-led', 'environmentally determinist' applications copying the worst of New Archaeology practices. However, applications billing themselves as 'cognitive archaeology' seem to boil down to the same combinations of viewshed and cost surface analysis explored by others as well. It is also possible to argue that cost surface and viewshed calculations are themselves deterministic methods. Llobera's (1996) study of the visibility of late prehistoric ditches in the Wessex chalklands, although

[2] The correction for earth curvature applied to DEM data is: $d^2 / 1.273 * 10^7$, where d is the horizontal distance in meters to any point in the study area. A point at 10 km distance would thus be set nearly 8 metres lower, influencing the viewshed coverage.

couched in a theoretical context rather different from that of systems theory and processualism, still attempts to derive cognitive aspects of late Bronze Age society (the awareness of being inside a territory) in a deterministic manner - the location of the ditches is fixed, the calculation of their visibility is based purely on properties of the elevation model. So the difference with what has been termed environmental determinism is in the *environmental*, not the determinism, and we might as well speak of *cognitive determinism* when describing such work.

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