Thinking through time and space: the implications of GIS in archaeology

Jeremy Huggett
University of Glasgow
Scotland

Introduction

First of all, I should start by saying something about where I'm coming from. I'm not actually going to talk about a case study as such – instead what I want to do this morning is stand back and take a broader perspective of the application of GIS in archaeology. I should also emphasise that I'm not a GIS specialist as such – certainly not in comparison with some of the other speakers we've heard from this week. GIS is something I use, much as most of you here. And the widespread use of GIS is self-evident beyond the kinds of research we have seen this week, in many of the presentations, and in your own research projects. We can see that GIS have become embedded in the management of the archaeological resource, which suggests a degree of technological maturity has been achieved. But one question would be whether that technological maturity is matched by a methodological maturity. In most cases, applications barely scratch the surface of what is possible – the majority of archaeological GIS applications still fall into the basic mapping category, primarily making use of the basic connection between a spatial database and a map base. It's a generalisation that is beginning to hold less true today, as local government agencies in the UK for instance start to develop impact or threat maps using their GIS, and of course especially in North America, the Netherlands and elsewhere the use of predictive modelling tools in heritage management is a significant feature as we heard from Philip. But nevertheless, the basic categorization of GIS as a mapping tool holds true for the majority.

My interest is in the use of these technologies, and how they can help us do better archaeology. But my approach is rather different, in that it isn't so much a question of specifically developing new methodologies or new tools, but rather coming to understand what it is we do with computers, how we approach them, how we use them, and, most importantly, how the use of computers affects what we do as archaeologists. So in that sense, its more a question of turning the gaze in on ourselves as practicing archaeologists who are at the same time expert computer users. It's a focus on the social implications of these new technologies – whether they change us, how they change us, and why they change us.

So my first proposition is that Information Technologies – and therefore GIS too – are socially charged – there are issues of control, surveillance, power, politics, order, structure and so on associated with them. However, more often than not, these technologies, ideologies and philosophies are taken for granted. I want to question this.

My second proposition is that we should understand something about the relationships between archaeology, archaeological theory, and technological representations of archaeological knowledge – how that knowledge is created, manipulated, modelled, and understood. I'm certainly not the first and I won't be the last to point to the link between GIS technologies and archaeological theory and practice – Marcos spoke about this on Tuesday in relation to landscape archaeology, for example – but nevertheless it is important that we understand this connection and, furthermore, that those connections are actually borne out in reality – that the models we use really do represent the theories we started out with, for example bearing in mind the fact that, as we know, a GIS will always produce a picture but whether or not it has any meaning or value is an entirely different matter.

My third proposition is related in that it's as well to remind ourselves from time to time when we're surrounded by these technologies that the object of our study is ultimately the individual people who lived in the past – their settlements, burials, artefacts etc., yes, but in the end the task is to try and understand more about the people themselves. And these past individuals are knowledgeable people, aware of and working with their surroundings, not unthinking, mechanical clones who just react to circumstances and are simply victims of their environment – if we think about people in that way then we risk going back to 19thC ways associated with colonialism when groups other than ourselves were perceived as being fundamentally inferior, an untenable position to adopt.

These three propositions very much define where I'm coming from. Of course, you might well argue that all of this is unimportant – just so much hot air – that what's more important is understanding how best to implement the tools and technologies that are available to us. You could be right – but I would argue that the importance of standing back and taking this broader perspective is that, if the tools we use do change us, if they do affect what we do and how we do it, if they don't promote our understanding of past people, shouldn't we as archaeologists – especially us archaeologists! – be interested and concerned to know about this? After all, we're familiar with ideas and concepts behind culture change and the implication of new technologies – Mousterian tool technologies, the introduction of iron to bronze age communities, the impact of literacy, the development of the mouldboard plough, the internal combustion engine and so on – so why not consider the implications of new technologies on the practice of our subject? So the challenge is therefore to question whether we're immune to changes introduced by the tools we use, and, in a way, conduct a typical study of archaeological material culture, but making us as archaeologists and the IT tools we employ the focus of that study – turning the gaze inwards upon ourselves. Of course, this could quickly become an exercise in navel-gazing, but I think that these sorts of considerations can shed light upon our motivations and methodologies, which can be extremely valuable process.

I've used various ways of looking at this subject in the past – whether it's considering culture change and the implications of technological determinism (Huggett 2000), or thinking about issues surrounding information handling and processing (Huggett 2004a), the relationship between hypertext and archaeological writing (Huggett, in prep), or, of course, as you'll have gathered from the paper in your packs (Huggett 2004b), using the concept of fetishism as a medium for thinking through some of the technological implications of the tools we use.

Fetishising Technology

Some might be offended at the idea that what we do might be considered a fetish, but I should perhaps take a few minutes to explain the background to this approach, and perhaps indicate how it might relate to GIS.

There are various ways of considering fetishism. There is, for example the approach derived from anthropology, in which we can talk about fetish objects – items of worship and veneration. These are more traditionally associated with items associated with religion or magic, but it's not too hard to make the leap in associating computers or indeed the computer-based tools as fetish objects in their own right. In the paper you have, I talk about computers and their association with magic and mystery – the idea of the computer as a black box, serviced by initiates experienced in the ways of computing – whether we see ourselves as high priests or not is perhaps another matter. Be that as it may, I'm sure all of us have encountered people who believe they must use GIS because they should, rather than because there's a specific need and that can be verging on fetishising the tool.

Then there is the idea of fetish found in Marx – commodity fetishism. In Marx's eyes, fetishism is associated with the concealment of social orders and social relations – again, there are links with computing which I refer to in the paper. For example, the way in which computers have increasingly developed to separate us from their underlying workings – indeed, that's now seen as a good sign of a successful interface. But the implication of this is that, as we become further removed from the operations

of the machine, as more and more layers of opacity are inserted between us and the operations performed by the tools, the less and less we know about how they actually work – we come to the point where we push a button and our data changes but we do not know – or do not need to know – what has precisely happened. There's a sense in which viewshed analyses have become characterized by this kind of approach, for example As GIS have, thankfully, become more available and easier to use, it's correspondingly easier to employ them in an unthinking, unknowing manner.

Finally, there's the idea of fetishism based around Freud's concepts of sexual fetishism. While this may seem even less likely in our context, nevertheless it can be suggested – as for example, by Julian Thomas (2001, 169) – that the way that GIS and associated spatial technologies can be used to lay bare the landscape is a sexualized way of looking, a form of voyeurism as Kristof mentioned on Tuesday.

But as I said at the outset, I don't want to develop these ideas any further now, but they do serve to underline the change in emphasis that I am making in this presentation – moving away from the tools and technologies themselves to consider the broader context and implications of their use.

What I would emphasise is that I am not being critical, except perhaps in a self-critical way – I'm implicated in this too; I'm not standing on the outside and taking critical pot-shots at people. It's not my intention to raise major doubts or undermine approaches here. Instead, what I want to try and do is to lay down some challenges for us as archaeological users of GIS – to encourage us to be more knowledgeable, more self-aware about what we are doing and why. At the end of all this, you may not see them as challenges at all, and that's fair enough, though I'll have to disagree with you. Or you may see the challenges as impossible tasks which we can never hope to achieve, and that's OK too, but I think we should nevertheless strive to meet these challenges rather than continuing along the same old pathways. But the important thing is not so much whether or not you agree with what I am saying, but that you come on the journey with me and make your own minds up.

Challenge #1 : Subjectivity of the tools

Presentations that look at our overall approaches to using GIS have a strong tradition at meetings such as this. For example, there were two meetings on Archaeology and GIS at Ravello in 1993 and again in 2000 that were subsequently published. At the first Ravello meeting one of today's speakers, Vince Gaffney, was a co-author of a paper on the impact of GIS in archaeology which drew attention to the way in which GIS technology might mould archaeological thought and practice in a less than desirable manner, potentially leading to an environmentally or functionally deterministic viewpoint (Gaffney, Stančič and Watson 1995, 211). One aspect they highlighted was the way in which map presentations reduced place and space to location and distance, in the process losing cultural and cognitive perspectives, although they argued that GIS could overcome such difficulties by providing access to landscapes and manipulate that space according to variable imposed values (*op cit*, 212-13). As a result, they argued:

> "GIS is not … to be considered as a objective observer of pattern implicit within spatial data; rather it is a tool to create spatial relationships according to values we regard as important" (Gaffney, Stančič and Watson 1995, 213).

So the important point here is that the emphasis is on the subjective nature of the tools which are dependent on those things that we choose to see as important. There's therefore an essentially interpretative aspect to this, long before we ever reach the stage of actually having generated a map in response to some analytical query or investigation.

Challenge #2: Representing space

In their introduction to the publication of the second Ravello meeting in 2000, Gary Lock and Trevor Harris presented a socio-theoretic critique of GIS in which they particularly highlighted two aspects (Lock and Harris 2000). First, there was the nature and availability of data which tended to emphasise the

physical aspects of landscape above cultural process as a result of the inherent difficulty of generating cultural or social data. Secondly, there was the question of different representations of knowledge being potentially excluded:

> "GIS … is spatially deterministic, in that data that cannot be captured as a spatial primitive comprising point, line, polygon, or pixel, is essentially excluded from the database." (Lock and Harris 2000, xvii).

In their eyes, this led to a tendency for GIS to capture a view of reality that was heavily biased towards a scientific data-driven representation, leaving more qualitative interpretations out in the cold. As I mentioned in my introductory paper, this was the comment that really started me down this line of thought. Interestingly, they observed that the same fundamental issues of data availability and the nature of the data and the debates surrounding them remained much the same six years after the first Ravello meeting – I rather suspect the same could be said today, another seven years on.

It is impossible to deny that archaeology is spatially and temporally oriented. The significant patterns we observe arise through variations we identify within the spatial and temporal domains – the physical changes across landscapes and within sites that can be traced, mapped, manipulated, combined and interpreted according to a range of different theoretical constructs. But to what extent are those spatial and temporal domains affected by the ways in which we choose – or are required – to represent them? It is of course a fundamental question that cuts to the heart of the subject. It offers the possibility of a paradox in the application of present-day GIS in which the underlying organisational and representational structures limit at the same time as they enhance the kinds of models and interpretations we create of the past.

Some would not accept there is an issue at all – or at least not in certain respects. For example, in his study of time in archaeology, Gavin Lucas suggests that, in contrast to time, space has never been problematic – we have always been able to measure spatial parameters of shape, location, distance etc. using coordinate systems of one kind or another (Lucas 2005, 32). That's a reassuring perspective from the point of view of standard applications of GIS, leaving us free to concentrate on the more problematic nature of time. Of course, this isn't the case – space is a problem, not least because of the need to resolve problems of differential resolution of recorded data.

However, what this still fails to recognise is that this understood and commonplace approach to space is particular to a Western perception of the world dating back to the Enlightenment (e.g. Pickles 2004) and, despite its universality, is by no means uncontested. One very simple way of illustrating the contested nature of spatial representation is through the disputes surrounding different map projections (see Wood 1992, 56ff, for instance). The classic Mercator projection is the only projection on which lines of constant compass bearings are straight – a vital factor in pre-GPS navigation – but it distorts areas: for instance, Greenland and Africa are shown roughly the same size despite Africa actually being c14 times the size and arguably promoted a European perspective. The US National Geographic Society used the Van der Grinten projection until 1988 but again there were major distortions, with Greenland 554% and the USA 68% larger than actual size, for example. In 1988 they changed to the Robinson projection where the Greenland exaggeration is reduced to 60% but Africa is 15% smaller than it should be. The United Nations, World Council of Churches and other charity organisations used the (Gall-)Peters projection where areas of equal size on the globe are shown as equal size on the map, although distances are distorted, especially east-west distances towards the poles.

None of these are wrong as such – they are simply approximations of the world. My point is not so much that one projection is better than any other, since all of them distort reality in one way or another. It is to emphasise the fact that representation is not a simple matter, that it can be affected by political and social choices, and that those choices may be hidden or out of our control but they nevertheless affect the representation of our data and our perceptions of the world. This was underlined to me when I came across the phrase 'Mercator disease' coined by Robert Corell in a speech on climate change at the Fifth

International Symposium on Digital Earth this month, by which he apparently meant that people lacked an appreciation of the polar regions of the globe as a result of a lifetime spent staring at Mercator projections (Geens 2007).

Of course, much of what we work with are locations translated into a flat planar world of x and y coordinates. The GIS tools we work with are predicated upon this, the maps we use as the basis for our studies employ this, and this conception of space affects our approach to it, whether or not we have any say in the matter. It imposes an order on the world, partitions it, locates things within it and relative to each other in a way that is particularly characteristic of a Western, post-Enlightenment scientific viewpoint and which is not one that is necessarily held elsewhere. Some would argue that this reliance on Euclidean space is itself a problem – Julian Thomas, for example, points to the way in which space is conceived as rectilinear, isotropic [independent of direction], gridded and framed, and argues that this establishes conditions for distanced and dispassionate observation – the scientific gaze (Thomas 2004, 199).

We do record space in non-Euclidean ways – the various map projections available to us are evidence of this – but while we may collect data on geographic coordinate systems, these are generally transformed to a projected Euclidean system to make them useable. In other circumstances we are accustomed to maps which dispense with geographical accuracy entirely. We heard on Thursday Christian Grataloup talking about some of the different ways in which we can think about mapping information that don't incorporate a traditional map image. In the UK, probably the most familiar example is the London Underground map, designed by Harry Beck in 1931. Earlier geographic versions, such as the 1927 map by Fred Stingemore, showed the routes in relation to the streets above, but as the network grew the map became overly complicated. Today, the geographic representation of the Underground is totally unfamiliar because of the ubiquity of the Beck design. Indeed, artists like Simon Patterson deliberately take the iconic map and play with it – in Patterson's case, he replaced the names of stations with philosophers, actors, politicians and other famous people as a means of subverting our belief that maps provide a reliable source of information. Yesterday Jean-Yves talked about information visualization that went beyond the map or the 3D model. Indeed, he said that graphics should be seen in terms of alternatives, and should not be enforced by the tool, and this is perhaps where the problem lies with GIS.

From ethnographic and anthropological evidence, we also know that some aboriginal indigenous groups perceived the world and mapped it in a rather different way to the one we are accustomed to. Classic examples include the Pacific Marshall Islanders navigational charts made from palm ribs bound with coconut fibre, using shells to represent the islands and the palm ribs to represent the lines of swell at sea – each is made by an individual navigator and hence not thought of as generalisable (Pickles 2004, 14). Inuit have their own ways of representing space – for example, carved wooden maps representing the coastline and shores, which often closely relate to reality but which are distorted in those areas which are hunted more frequently or have better fishing (e.g. Piper 2002, 131ff). In fact, I doubt anyone would argue that people in other cultures and – especially – people in the past, saw their world differently to us.

Challenge #3: Changing perspective

The problem is, as Julian Thomas describes it:

> "GIS … may be irreducibly embedded in ways of looking and thinking that are distinctively modern, and that they hence are anachronistic when applied to the distant past." (Thomas 2004, 199).

Anachronistic may seem harsh, but it reflects the problem that we employ a modern geometric view of the world as a means of reconstructing and analysing past worlds that may have been constructed on quite different grounds. We are accustomed to technologically-derived views of the world which would be entirely unknown to anyone living in the mid-twentieth century, ranging from views of the world taken

from the Mars Rover, the classic view of the earth from the Apollo missions, constructed views of the world assembled from satellite imagery – all constitute what Donna Haraway has famously referred to as the 'God Trick'.

Even something as simple as reversing the orientation of a map demonstrates how relatively minor changes in representation can result in dramatic changes in perception – removing the north convention underlines how we have become accustomed to a world view that has the north – and the Western world – physically and metaphorically on top. How much more might this be true when thinking about past perceptions of past worlds? I'm not suggesting here that we can somehow realistically expect to get into the minds of past people – that's a whole different theoretical can of worms. What I am arguing is that the representations we use could at least attempt to move more in the direction of a world view which, although we may lack detailed knowledge about its nature, is nevertheless different in its emphasis on accuracy, reality, and detail. To use Julian Thomas's words again:

> "We have to consider whether, when we look at representations of the past on the computer screen, we are not merely reproducing a dominant scopic regime" (Thomas 2004, 199).

A concrete historical example of this kind of dislocation between classic Western and aboriginal conceptions of space is provided by Maria Zedeño's study of land use among the Hopi Indians of Arizona (Zedeño 1997). During the debates surrounding the Indian Land Claims Commission, Western 'common-sense' notions of homogenous, bounded, stable territorial units had to be set aside for aboriginal forms of territoriality in which the spatial unit consisted of aggregates of 'tenures' held at different times.

These tenures could be single places, portions of land (landmarks, fields), natural resources (wild herds, stands of trees, mineral outcrops), and the material record of human use of the land and its resources (burial grounds, villages, encampments, trails, shrines etc.) (Zedeño 1997, 71). Boundaries were broadly drawn, often associated with major geographic features in the landscape or migratory or trade routes, and these territories might be used by several groups of people – indeed a group's territory might consist of several non-contiguous areas or discrete places – but a history of land use by particular groups would persist. Crucially, as Zedeño emphasises, this concept of space and territoriality is in stark contrast to the kind of landscape in which space is contiguous and can be comprehended at a glance (Zedeño 1997, 73). Yet these are the kinds of territories we are more accustomed to dealing with, and to imposing on our past landscapes.

Instead, as this example suggests, we could potentially be dealing with multiple discontinuous spaces with different scales and different purposes and meanings. In the case of Hopi land use, Zedeño identifies four main categories, each with its own spatial correlates: living space (the construction of villages, access routes etc.); food production space (agricultural lands, farmsteads, field terraces, irrigation etc.); procurement space (hunting and resource collecting grounds, temporary camps, and resource location markings such as petroglyphs, cairns, and shrines); and ritual space (ceremonial structures, shrines, cemeteries, caches, ancestral sites etc.) (Zedeño 1997, 77-78).

This may seem impossible to achieve, but bear in mind that GIS models don't even represent our own spatial perceptions very well. For example, most of us probably conceive of the world in terms of our immediate surroundings, with a great deal of knowledge of space and relationships. Once we look beyond the direct world around us, things become more hazy and indistinct – scale becomes less precise, and proximity and distance become more a case of 'near', 'further away', 'a long way away', for example. This is not a characteristic of most GIS models, which again underlines their particularly scientific perspective, lacking in human scale.

Challenge #4: Beyond Euclid

This then leads to the question of representation of these kinds of spaces within GIS. Are the existing standard tools predicated on the Euclidean planar model sufficient for these purposes? Or is it the case that

> "'Cartesian perspectivalism' has limited the potential of GIS. A sterile geometry is associated with a simplified GIS that fails to fully represent some segments of society or complex geographic processes" (Miller and Wentz 2003, 575).

Miller and Wentz go on to argue that since data have become less scarce and computational power has increased, it ought to be possible to do things differently and better than in the early years of GIS applications. As they point out, some of the basic definitions of the Euclidean model raise distinct questions (*op cit* 578). For example:

- Is the distance between two points necessarily defined in terms of a straight line representing the shortest path?
- Is the distance between two locations the same in both directions? (Euclidean Symmetry)
- Is the direct distance between two locations always less than or equal to the indirect distance going through a third location? (Triangular inequality)

Some of these questions should give archaeologists pause for thought – after all, we know that human action will affect spatial interactions. For example, within the Hopi territory, it may well be that travelling between two locations might not involve a straight line – not only are there physical aspects of the landscape to consider but there are also the cultural constraints represented by areas within the landscape – the need to avoid the burial grounds of others, for example. Likewise distance between two points is not the same if a steep slope intervenes, or the familiarity of the route varies, or the purpose of the journey is different. I'm not saying that attempts to model these kinds of constraints are not made – they are, but in the main they are still the exception.

For example, Tyler Bell and Gary Lock (2000) created a model for their study of the Ridgeway hillforts in central southern England that reflected more realistic movement across slopes rather than directly up and down them, and at the same time recognised the importance of directionality, in that the cost of moving uphill is different to that moving downhill. But the process is complex compared to the ease of creating a standard cost-surface model that does not have these nuances built in at all. Furthermore, the model essentially focuses on the physical characteristics of the landscape, and does not incorporate cultural and cognitive elements. There are similar problems with visibility models which are well-known, and which I won't go into since Marcos covered them the other day.

Challenge #5: Representing cognition and culture

Can cognitive and cultural processes be modelled (after Gaffney, Stančič and Watson 1995 and Lock & Harris 2000)? Can an essentially processual tool represent post-processual concerns (after Thomas 2004)? We can attempt to incorporate some of these non-physical aspects into our models, but it's difficult. And if we tried to represent them, all we have to hand are the standard spatial tools which were derived for a different purpose altogether, and which are usually associated with the analysis of physical aspects of landscape in the first place.

For example, Thomas Witley (2004) has argued that it is possible to use standard spatial variables as proxies for cognitive processes. For example, he argues that visibility analysis stands as a direct proxy for visibility in the past. Distance and cost-distance is seen as an indirect proxy for spatial familiarity given that distance can be related to knowledge of surroundings. He demonstrates proxies in action in a study of the migration of the Nez Perce tribe through the Yellowstone National Park in 1877 and their avoidance of a known trail despite it being a convenient escape route. A combined viewshed and cost-distance model is

used as a proxy for community knowledge of the trail through hostile territory. This clearly provides a poor fit with the known route taken, so he applied a cost-distance model to represent where the tribe knew they were likely to encounter the US Army. Again, this did not seem to account for the route taken, so he employed another viewshed/cost-distance model to represent the knowledge of a captured settler. The final composite of all the knowledge and risk surfaces seems to provide a close match with the historically attested route taken through the area. Of course, an apparent match does not validate the model, but more problematic is the idea that somehow a viewshed can represent the 'knowledge' of an area that a group holds when at most it can be no more than a faint shadow of a very small aspect of that knowledge – visibility, with all its attendant problems, is a poor proxy in this regard.

A challenge to this relative poverty of representation can be seen in the recent bio-mapping projects of artists such as Christian Nold and Amanda Windle and their Greenwich Emotion Map project (Nold 2006). This was a six month project in which 37 participants wore biomapping devices measuring their Galvanic Skin Response which indicates their emotional arousal associated with their geographical location. The idea is that the maps derived represent the complex relationships between ourselves and our environment. My point is not that we should be emulating this because clearly this is an impossibility – instead what this highlights is the way in which perceptions about environment changes with location and by association with physical and cultural cues in the vicinity or further afield. Consequently, if we are to consider the way a world was perceived in the past, we have to take into account not just the relative attractiveness/unattractiveness of aspects of the environment, the location of natural, physical and human features within the landscape, but the way this may change in the light of other factors such as proximity, time, familiarity, nature, length and stage of journey, for example. For instance, near/far concepts of associated with distance and movement will clearly change as the position within the landscape changes.

The problem, of course, was illustrated by Predrag when he talked about the dynamism of nineteenth century Montenegran communities on Monday, and emphasized that the intra-community conflicts, raiding of livestock etc. were not expressed in terms that would be represented in the physical remains. It may be that the kind of actor-network model that Lena Sanders spoke about may help here if we are prepared to recognize that the actors themselves are always knowledgeable and act with intention. Their knowledge may not be perfect, and their actions may lead to unintended consequences, so we cannot assume that what we observe archaeologically was the outcome of deliberate intent – they may have had quite different goals in mind (Joyce 2004, 5).

Coupled with this might be a revisitation of Gibson's concept of affordances (Gibson 1977), which stresses the interaction between people and their environment – a form of ecological psychology. It's perhaps more to do with perception rather than cognition, but could help move us in the right general direction. It recognizes that the world around us doesn't just act as a stage on which we perform, but it offers us in various ways shelter, water, objects, resources, human elements etc. They aren't simply the property of the environment but they are determined by both the environment and the agent – but since more often than not it's the environment that is considered, there's a risk of environmental determinism here. Whether or not Gibson's model is appropriate (see, for example, Costall 2007), it does at least encourage the re-evaluation of the kinds of data we have access to, and may suggest ways in which we may unpick our data by evaluating the potentials of the landscape and in the process enhance our approach to understanding and representing human action in the past.

Challenge #6: Representing uncertainty

> "… the functionality of GIS needs to be enhanced to include ways of representing uncertainty in the outputs, not just the metadata" (Hope and Hunter 2007, 645)

Clearly any move to a 'richer' representation incorporating aspects of human cognition and perception as well as the physical nature of the environment will, by definition, involve uncertainty. So one of the things we need to develop are ways of representing uncertainty in our models. GIS are not alone in this – the

issue of how uncertainty and interpretation is represented in three-dimensional reconstruction models is a hot topic of debate, as Jean-Yves demonstrated elegantly on Friday, and Philip also discussed in relation to predictive modelling for example. But we aren't good at handling uncertainty in the context of GIS either. We're all aware, for example, of the deficiencies of our data in terms of quality, resolution etc. – if we're good, then we record these issues in the metadata accompanying our GIS models, but, as Hope and Hunter suggest, we need ways of actually representing uncertainty more explicitly within the models themselves. And of course, combining data that is more or less precisely located with data for which we only have a rough location is a recipe for problems.

There are perhaps three ways of thinking about this, not surprisingly linked to the three main categories of GIS data – points, polygons, and coverages.

Positional uncertainty arises when we are unsure of the actual location of something we are recording. For example, in the UK the location of sites in both the local and the national monuments records are often not precise – recorded to a mixture of resolutions from 1m to 100m or more for a variety of reasons. A common mistake that undergraduate students make is to plot all these sites in exactly the same way and then wonder why all these sites cluster in the bottom left hand corner of grid squares … One way of representing this positional uncertainty would be to create a buffer around the site that corresponds to the area within which that site could fall, given the resolution of its recorded location. This is commonly done with local sites and monuments data held by government agencies, for example. But as a representation, this is lacking since it assumes that the area is internally homogenous. Although we may not know where precisely the site *is*, we might at least know where it is *not* – for example, unless there's strong evidence to the contrary, it's unlikely to be in a river, or on a cliff face, for example. Consequently we could look at ways of determining the probability that a site is located in some areas rather than others, and rather than represent the buffers homogenously, perhaps using some kind of graduated shading to represent the probability distribution (see Hope and Hunter 2007, 646ff).

Borders present similar problems. People generally order their environment by creating conceptual divisions around areas, events, people, ideas, and this produces boundaries. For example, we regularly use vague concepts such as "the Alps", or talk about "ridges" or "valleys", but where do they start and end? In other contexts we talk about "the kingdom of the Visigoths", the "Celtic zone" – concepts that we cannot precisely delimit, which have indeterminate boundaries, and yet which we represent within our maps and models all too often with a firm, clear, bold line demarcating their limits. As we saw with the Hopi example, it isn't as simple as that, not least because a lot of what we study never had physical boundaries. Historically, for example, we know that in the medieval period, territories were often not clearly bounded – there was a fuzziness that meant that in effect there was a transitional space in which you were neither in one territory nor the other, but sometimes in one or the other, depending … Finding oneself in this transitional space in the wrong place at the wrong time could be extremely hazardous. Clearly, representing a boundary with a line in such circumstances is completely wrong. Again, we might represent this as some kind of buffer area instead but we need to be able to distinguish between the malleability of the boundary and its permeability (Kooyman 2006, 425) – malleability in the sense that the boundary shifts, expands, contracts depending on circumstances, and permeability in recognition that things may cross from one domain to the other to varying extents, again depending on circumstances.

Finally, there is thematic uncertainty – something that, for example, we have encountered with viewsheds where it is recognized that we do not have 20/20 vision, that we cannot see to infinity, that vision may be impaired by atmosphere and weather – and vegetation - etc.- all things which introduce uncertainty into the viewshed. It's still very rare to see this incorporated within a viewshed model – it's rarer still to see uncertainty represented in other kinds of coverage data – for instance, distance surfaces created from uncertain locations? Representing uncertainty is not a trivial matter – there are various ways in which it might be attempted – perhaps changing the spatial resolution relative to uncertainty, for example, or using a kind of 'fog' overlay that blurs areas where uncertainty exists (Hope and Hunter 2007, 647). It's not a problem that has been solved elsewhere either, but that doesn't mean it should be ignored in archaeology.

After all, maps have a tendency to power and authority so even though you may not have intended a map to be taken as the literal truth, it may come to be seen that way unless the levels of uncertainty are clearly indicated upon it.

Challenge #7: Representing time

> "Any enquiry into the past which does not reckon with the dimension of time is obviously nonsense" (Piggott 1959, 51).

Throughout, I have been arguing for a richer representation of past environments, and clearly the time dimension is critically associated with this, yet we have said very little about it this week. Gavin Lucas, for example, has commented that because time lies at the heart of archaeology, it often seems that we take it for granted, and don't fully consider the ways in which time, and our understanding of time, affects the way we do archaeology (Lucas 2005, 1). In GIS terms, we could usefully add the *representation* of time … Time is too big a subject to do justice to here, so I'll confine myself to one or two observations about the nature of time before looking at the representation of time within GIS as that's most relevant here.

First of all, it's as well to remember that we have different perceptions of time. We see time as a progression from the past to the present and into the future – essentially a linear process, though we often refer to alternative futures depending on different decisions or outcomes. We also deal with cyclical time – the motions of the sun and moon, the seasons, even the months and days of the week have a cyclical nature, although we number years in terms of a steady linear progression. But what we think of as objective time is culturally specific to the Western world, and especially associated with the widespread use of clocks as scientific instruments (Lucas 2005, 65). Others see time differently. Australian aborigines have a completely different perception of time – the past is very much in the present, in the here and now, and consequently they don't understand the Western obsession with heritage, for example. Other groups have different cyclical views of time based on the migration of animals, the agricultural cycle, and so on.

Donna Peuquet (2002) talks about the many different meanings of the terms "space" and "time" (for example, she points to around 29 different definitions of the meaning of time) and suggests that one of the problems is the way in which the two concepts are inter-related. For example, we talk of an event "taking place" at a particular time, or conversely we might say that "he's near to the end of his presentation". She suggests that this entanglement of time and space increases the difficulty of analysis (Peuquet 2002, 12). Archaeologically, however, we're accustomed to the definition of time in reference to space – for example, the spatial attributes of stratigraphy are associated with temporal sequence, and the same can be said for typology and seriation (Lucas 2005, 33).

GIS are of course well-equipped to represent space, but this is the point at which we hit the first problem – current GIS are not equipped to represent spatio-temporal data effectively. We can represent time as an attribute but that is a very limited form of representation.

For the most part, our incorporation of time into GIS falls into two categories:

1. Static GIS – where only a single state of time is represented in attribute form: "Show me all the sites from Period X". This is the current situation with most software, and hence the only method to exist in any accessible way at present (Worboys 2005, 3).

2. Temporal snapshots – where sequences of snapshots of frozen time are captured, essentially sampling a dynamic phenomenon at a sequence of temporal instants (Worboys 2005, 3). We saw this at work on Thursday in Lena Sanders presentation on agent-based modeling, for example. It's also the approach adopted by Ian Johnson in his TimeMap development, in which sequences of time slices are animated, illustrating for example the ebb and flow of an empire or region (Johnson 2002).

While these can undoubtedly be useful, neither are particularly effective or rich ways of representing time. They tend to assume that the features have clear-cut boundaries, that relationships between features can precisely defined, that it's possible to accurately measure their locations – all problems we've touched on already, and of course compounded by the problems associated with measuring time accurately and consistently archaeologically.

One way of visualizing time which might be useful is to conceptualise it in terms of what we already know about – space – even if some think that the connection between time and space is part of the problem. For instance, we could see time in terms of change and the measurement and representation of that change. This could be seen in three ways (after Pfoser, Tryfona and Jensen 2005):

1. Position changes over time – moving objects which are capable of continuously changing their location across time. You could see this in terms of a car, or alternatively you could visualize it as one of Marcos' individuals moving through the landscape guided by their directional view, zig-zagging up and down slopes, always with their desired destination in mind. Associated with this is the perception of time-space – the time taken to reach a particular location may be reflected in the perception of space and the structuring of that space, and that might well be something we would wish to represent.

2. Properties change over time – shape or features may change over time, but essentially the object does not move. A typical example would be a land parcel – its ownership will change over time, its name may change over time, its boundaries may be altered over time, but it does not physically move to a completely different location.

3. Position and properties both change over time – something that is a moving phenomenon that has characteristics which also change across time. Examples might include traffic volume, or depending on scale, the movement or migration of a population.

Categorising time is one thing – the problem, of course, remains the representation of these phenomena. Things are created or begin at certain points in time, they continue for a period, they may disappear and reappear at various stages, they may be transformed in a number of ways – evolving, merging with or splitting from other entities, for instance, and they die or otherwise leave the stage, to be succeeded by something else. The complexity of these change relationships, coupled with the complexity of recording archaeological time itself, means that representing these temporal dimensions in a standard relational or object-oriented database is extremely difficult – these kinds of data do not conform to a fixed schema. Even mapping apparently generic time categories such as Iron Age causes major problems of definition within the UK, let alone when you try to define it across Europe. We could, for example, consider the possibilities of time-space transformation as a means of representing change, but again, the tools at our disposal in GIS do not currently enable us to do this. Until then, we are largely limited to snapshots and animations that compress change into a single rather generic dimension.

Challenge #8: Accessing knowledge

A story about a mapmaker was told by Nicolas of Cusa in his *Compendium* (1464) as a metaphor for our access to knowledge (Morse 1998). According to Nicolas:

"A cosmographer has a city with five gates, which are the five senses. Through these gates, messengers enter from all over the world ... those who bring news of the world's light and colour enter through the Gate of Sight; those who bring news of sound and voice, through the Gate of Hearing; those who bring news of odours, by the Gate of Smell; those who bring news of flavours, through the Gate of Taste; and those who bring news of heat, cold and other tangible things, through the Gate of Touch. The cosmographer should sit and note down all things that are related to him in order to have a description of

the entire perceptible world represented in his own city. But if any gate of his city remains always closed – the Gate of Vision, for example – then there will be a defect in the description of the world because the messengers of the visible did not gain entrance. The description would not make mention of the sun, the stars, light, colours or the forms of men, animals, trees, cities, and the greater part of the world's beauties. And the same holds true for the other gates. The cosmographer therefore tries as hard as he can to keep all the gates open, to listen constantly for the reports of new messengers, and to bring his description ever closer to the truth. Finally, when he has made a complete representation of the perceptible world … he compiles it in a well-ordered and proportionally measured map lest it be lost ... And from the relationship of the map to the true world, he beholds in himself, insofar as he is the map maker, the creator of the world." (Morse 1998).

So the final challenge is for us as mapmakers, as modellers of past environments, to minimise the defects in our descriptions and representations, to strive for better, deeper and richer representations of the past, and not to be satisfied with the off-the-shelf solutions available.

Conclusions

- Think hard about representation:
    - the images/maps themselves
    - cultural and cognitive data
    - uncertainty
    - time
- Ensure theoretical rhetoric matches the models and vice versa …
- Remember the tools are not neutral – for example, "Tools emerge from a social and historical context to respond to changing needs, but also alter their users and their surroundings" (Chisman 1999, 182).
- Be a knowledgeable practitioner …

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