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Introduction and theoretical issues in archaeological GIS

1.1 About this book

The study of geographical information systems (GIS) has now matured to the point where non-specialists can take advantage of relatively user-friendly software to help them solve real archaeological problems. No longer is it the preserve of experts who – in the eyes of cynics – chose their archaeological case studies solely to illustrate solutions to GIS problems. This is, of course, a good thing, because GIS has so much to offer archaeology. Nevertheless, the widespread adoption of GIS brings with it several attendant dangers. The most problematic is that modern GIS packages offer users a variety of powerful tools that are easily applied, without providing much guidance on their appropriateness for the data or questions at hand. For example, many current GIS software packages require just a few mouse clicks to create an elevation model from a set of contour lines, but none that we know of would warn that the application of this method to widely spaced contours is likely to produce highly unsatisfactory results that could lead to a host of interpretative errors further down the line. Conversely, there is a risk that researchers who become over-dependent on the data management abilities of GIS may shy away from tackling more analytical questions simply because it is not immediately obvious which buttons to push. It is our ambition that no archaeologist who keeps this manual near his or her computer will make such mistakes, nor be hesitant about tackling the sorts of questions that can only be answered with some of the more advanced tools that GIS packages offer.

We have adopted an approach that is both practical, because we recognise that many readers will be looking to get a particular job done with a minimum of fuss, and rigorous, because we are equally well aware that poorly described short cuts usually turn out to be the most tortuous routes of all. Practical means that we have focused on the kinds of problems that are routinely faced by archaeological users of GIS, in both cultural resource management and research. It also means that we have tried to give the reader sufficient guidance to achieve all but the most complex tasks without having to consult a raft of supporting literature, apart perhaps from manuals or help files specific to the chosen GIS software. The latter may be required because we simply cannot provide instructions for every GIS software package, although we have provided some package-specific examples to provide concrete illustration of certain operations. Our approach is rigorous in that we always try to explain *why* as well as *how*. In our several years' experience of teaching GIS to archaeology students, this is the best way of ensuring the appropriate application of methods,

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Table 1.1 *The main types of question that can be answered using GIS*

Question	Example	Chapter
Location	What artefacts have been found along the proposed route of the new road?	7 & 10
Condition	Where were Roman coins dating to the second century AD found?	7
Trend	How does the density of primary debitage change as one moves away from the prehistoric hearth?	6 & 8
Routing	Does the medieval trackway follow the most energetically efficient route?	11
Pattern	Are the burial cairns distributed uniformly across the landscape, or do they cluster on SE facing slopes?	7 & 9
Modelling	Where would one expect to find more Mesolithic campsites?	8

while also empowering users to develop new applications as the need arises. Indeed, we hope above all else that this manual will inspire a problem-solving attitude to the archaeological use of GIS.

Although we do not envisage many readers methodically working their way through this manual from start to finish, we have tried to maintain a logical progression such that topics are introduced in roughly the order that they might be encountered in the course of developing and using an archaeological GIS. This chapter considers some theoretical issues raised by the use of GIS. Readers who are new to GIS may find it helpful to return after reading Chapter 2, which introduces the basics, and Chapter 3, which illustrates the varied ways in which GIS can benefit archaeological projects. Chapters 4 and 5 are primarily concerned with the construction of a GIS and, in particular, the process of spatial data acquisition. Chapter 6 discusses a common next step in the construction of archaeological GIS, which is the generation of continuous surfaces from point data: for example, an elevation model from spot heights. Chapters 7–11 describe the use of GIS for analysis, that is, answering the types of question listed in Table 1.1. Readers who are using GIS for cultural resource management (CRM) will probably find Chapters 7 and 10 most immediately relevant to their needs, although CRM applications can be found for many of the techniques in the other chapters. Research-orientated readers will probably want to read Chapter 7 and a selection of Chapters 8–11, depending whether their interest is in spatial pattering (Chapter 8), derivatives of continuous surfaces such as slope and aspect (Chapter 9), the analysis of regions (Chapter 10), or the analysis of routes (Chapter 11). Chapter 12 describes methods for presenting the results of analyses for use by others, whether by traditional publication, or delivery via the Internet. Chapter 13 provides advice for the maintenance of spatial data. We suspect that some readers will be tempted to skip this last chapter, but metadata are of vital importance, as the investment in creating a GIS will soon be wasted without them. Finally, we have provided an extensive glossary to aid readers who pick their own path through the book.

1.2 Theoretical issues

As just explained, our primary motivation in writing this manual is to promote the appropriate and creative use of GIS to tackle archaeological problems. In essence, we treat GIS as just one tool – albeit a very powerful one – among the many that may be deployed for archaeological purposes. However, there has been considerable debate about whether GIS is just a tool, or whether it is a 'science' in its own right (Wright *et al*. 1997). It is argued that this matters because if GIS is just a tool then its use may be construed as largely theory-neutral, but if it is a science then its use automatically brings with it a particular theoretical perspective – one that may or may not be welcome. The remainder of this chapter provides an introduction to some of the key issues in this debate.

1.2.1 *The nature of space*

Geographical information systems require two descriptors to describe the real world: *attribute* records what is present while *location* records where it is (Worboys 1995). As will become clear in Chapter 2, the location descriptor is what sets GIS apart from other database systems. More importantly here, it requires a concept of what space is and a means of describing it.

What is space?

Any kind of spatial analysis, whether formal or informal, is ultimately predicated on a concept of space. Western thought has been dominated by two main philosophical ideas about the nature of space, one of which views it as a container and the other as a relation between things.

The **absolute concept** views space as a container of all material objects, which exists independently of any objects that might fill it. The origin of the absolute concept of space may lie with the Greek atomist philosophers (Harvey 1969, p. 195), but in any case it assumed a dominant position in Western thought during the Renaissance, particularly as a result of the success of Newton's laws of motion, which require a fixed frame of reference for the measurement of movement. Kant subsequently developed the absolute concept of space as 'a kind of framework for things and events: something like a system of pigeonholes, or a filing system for observations' (Popper 1963, p. 179). He categorised geography as the study of all phenomena organised according to this 'filing system'; this view remained central to geography until at least the mid 1950s (Harvey 1969, Chapter 14).

In contrast, the **relative concept** views space as a positional quality of the world of material objects or events (Harvey 1969, p. 195), from which it follows that, unlike in the absolute concept, it is impossible to envisage space in the absence of things. Philosophers of science, reacting against Newton's identification of absolute space as God or one of God's attributes, came to favour the relative concept during the nineteenth century. Physicists, however, remained wedded to the absolute concept until the early twentieth century, when the General Theory of Relativity reduced their dependence on Newtonian mechanics. Theoretically inclined geographers

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followed in the 1950s as they realised that many processes can only be understood if distance is measured in terms of cost, time or social interaction (Watson 1955), none of which can provide the invariant framework required for Kant's 'filing system'.

How can we describe space?

Just as spatial analysis is predicated on a concept of space, so it also requires a 'language' (Harvey 1969, p. 191) with which to describe the spatial distributions of objects and events in that space, and to discuss the processes responsible for such distributions. Formal spatial languages are known as **geometries**, and the two that are most immediately relevant to archaeological users of GIS are *topology* and *Euclidean geometry*. These and other geometries may be distinguished from one another because they are not equally capable of distinguishing the effects of particular transformations, such as stretching, enlarging or rotating.

Topology distinguishes spatial objects that should be considered different on account of the way in which they relate to their neighbours and, for that reason, it has a close affinity with the relative model of space. For example, suppose an excavation plan were drawn on a rubber sheet, then topology is concerned with those aspects of the recorded features that remain invariant when the sheet is stretched or knotted, but not cut or folded. These include stratigraphic relations such as 'contains' and 'abuts', but not the areas covered by different deposits. Indeed, one of the most notable features of topological geometries is that they do not allow one to measure distance or area. Nevertheless, the identification of explicit topological relations is often an important step in the construction of a GIS (Chapter 5), especially if it contains networks such as river or road systems (Chapter 11).

Euclidean geometry is the geometry that most of us are taught at school. Devised by Euclid around 300 BC, it is an example of a *metric* geometry, that is, one which includes the concept of distance between points such that the distance from point A to point B is the same as that from B to A. Euclidean geometry has long been associated with the absolute concept of space. Note also that the familiar Cartesian coordinate system (Chapter 2) is not actually an essential feature of Euclidean geometry – it is approximately 2000 years younger – but it is of course a very useful tool for analysing transformations in Euclidean space. Returning to the example of an excavation plan, Euclidean geometry allows one to measure the areas covered by different deposits as well as to state the stratigraphic relations between those deposits.

Since Euclidean geometry allows one to distinguish a larger number of transformations than topology it may be considered more 'specific' (Klein 1939). In GIS terms, a more specific geometry supports a larger number of meaningful questions about the spatial relations in a database.

Space in GIS

As already noted, GIS describe the world in terms of attributes and locations. The two principal data models used in GIS to describe how these should be linked to some extent mirror the two philosophical concepts of space.

The *continuous field* data model proposes a space over which some attribute varies, usually smoothly and continuously (Burrough and McDonnell 1998; Couclelis 1992). A concrete implementation, which provides a discrete

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approximation of a continuous field, is a raster digital elevation model (DEM). As will be discussed further in Chapter 2, a raster DEM records height above sea level for a set of cells arranged in a regular grid, but the important point to note here is that one can query any cell in the grid and expect to retrieve an elevation value (or a NULL value in the case of missing data), in other words, every location has an attribute value (at least in principle). Since the continuous field model organises information by a set of predetermined locations in space it can be considered to fit quite closely with the philosophical absolute concept of space.

The alternative *entity* data model proposes a set of entities which have a location and which are characterised by spatial and/or non-spatial attributes (Burrough and McDonnell 1998). A typical implementation of this model is a vector map of archaeological survey units, which records the extent of each unit as a closed polygon and associates with each a unique identifier and information such as the weight of potsherds recovered by surface collection (see Chapter 2). In contrast to the previous example, one would not expect to retrieve data about potsherds from locations other than those associated with survey units, in other words, some – possibly many – locations do not have attribute values. The entity model has some affinity to the philosophical relative concept of space, at least to the extent that it organises information by entity rather than by a set of predetermined locations in space. On the other hand, it is worth noting that in practice the locations of entities are given according to a fixed coordinate system that describes a space existing independently of those entities.

We have just suggested a close association between raster maps and the continuous field data model, and between vector maps and the entity data model. This association does indeed mirror standard practice in implementing the two data models. Nevertheless, it is important to be aware that raster and vector maps are themselves data structures rather than data models: it is in fact possible – although usually less convenient – to represent a continuous field as a vector map and a collection of entities as a raster map (e.g. see the discussion of triangulated irregular networks (TINs) in Chapter 6).

1.2.2 *Space in archaeological GIS*

Does it really matter much for archaeological purposes that there are different philosophies of space and that these are at least partially mirrored in the different models of space used in GIS? In our view it does, both for the use of GIS to record archaeological evidence and for its subsequent use to analyse that evidence in the hope of learning about the past. We consider each in turn.

Recording the evidence

Archaeologists routinely, although often implicitly, invoke particular concepts of space and particular geometries to record the spatial organisation of the evidence for past human activity. For instance, the single context recording system used on many deeply stratified urban excavations is essentially predicated on the relative concept of space and emphasises topological relations. Thus there may be few or no

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plans of a continuous surface showing the various stratigraphic units revealed at a particular stage in the excavation, since the primary concern is not to record what is present in each quadrat on the site grid, but rather the locations of and relationships between the individual stratigraphic units that provide evidence for past events. This, it may be argued, is better achieved by planning each unit separately and recording the relationships between units on a topological diagram – the Harris matrix (Harris 1979).

In contrast, a programme of field survey by surface collection is more likely to be predicated on the absolute concept of space and to emphasise relationships that require Euclidean geometry. For example, if the purpose is to locate settlements then the results might be recorded on a plan showing the number or weight of artefacts found in each quadrat of a survey grid, since the primary concern is to identify locations with particular attributes, in this case those with many artefacts. Furthermore, if for some reason it was not possible to lay down a regular survey grid then the results might be adjusted to take account of the area covered by each survey unit, something that clearly requires Euclidean geometry.

The requirements of the two different archaeological problems just outlined will best be met using different models of space: the entity model in the first case and the relative model in the second, which in turn suggests the creation of vector and raster maps, respectively (but note the earlier caveat). This illustrates that concepts of space and geometries are important for the very practical business of recording the spatial organisation of archaeological evidence.

Learning about the past

As noted at the outset of this discussion, there has been much debate in geography about whether GIS constitutes a ‘tool’ or a ‘science’ (Wright *et al*. 1997) and what theoretical, and indeed ethical, baggage might accompany its use (e.g. Curry 1998; Sui 1994). Archaeologists have engaged in a similar debate (e.g. Wheatley 1993; Gaffney and van Leusen 1995; Gaffney *et al*. 1996; Thomas 1993, 2004; Witcher 1999), albeit with less-explicit concern for ethics and for the feminist critique found in geography (see Kwan 2002). Roughly speaking, those who view GIS as a ‘tool’ take the view that it is potentially applicable to many kinds of learning, whether that is pursued through the inferential framework characteristic of the natural sciences or through other frameworks provided by, for example, humanist sociology. In contrast, those who view GIS as a ‘science’ tend to regard it as closely or even inextricably linked to the natural sciences model. Whatever the theoretical arguments about how GIS can and cannot be used, in practice it appears that the history of research-orientated[1] archaeological GIS recapitulates,

[1] In this discussion we use the term ‘research-orientated’ to refer to studies whose purpose is/was to make sense of present/past human spatial organisation. The very earliest archaeological applications of recognisably modern GIS mostly involved the construction of predictive models (e.g. papers in Judge and Sebastian 1988), but the primary purpose of these was often to predict the presence of archaeological evidence without necessarily seeking to explain or understand it (see Chapter 8 in this book).

over a greatly compressed timescale, the parent discipline's experimentation with different modes of learning and its changing emphasis on different facets of human behaviour (see Lake and Woodman 2003 for a more detailed treatment in the context of visibility studies).

'Common-sense' narrative Prior to the advent of the New Geography in the 1960s, most studies of the human use of space proceeded by descriptive synthesis, providing a narrative account of what happens where. The same reliance on description and narrative was broadly true of archaeology up until the late 1960s, especially in its treatment of space. Though both 'traditional' geography and 'traditional' archaeology had developed specific methodologies such as distribution mapping and, in the case of archaeology, seriation, neither were generally very explicit about their theoretical premises, nor about the inferential logic used to justify their claims.

Curiously, the earliest research-orientated archaeological GIS studies generally mirrored the 'common-sense' approach of 'traditional' archaeology (Aldenderfer 1996), even though they were undertaken as recently as the late 1980s/early 1990s. For example, Gaffney and Stančič (1991, 1992) used GIS to establish that Roman towers on the Adriatic island of Hvar are intervisible and then suggested that the location of these towers may have been determined by the need for intervisibility. While it is quite possible that this suggestion is correct, the authors did not attempt to support it by, for example, demonstrating that intervisibility is unlikely to have occurred by chance alone and was not a byproduct of some other favourable attribute.

Scientific explanation During the 1960s the New Geography (Holt-Jensen 1988), and subsequently the New Archaeology (Binford and Binford 1968; Clarke 1968; Binford 1989), adopted a positivist approach to their subject matter. It was hoped that the application of logical thought to observations of actual conditions could produce law-like statements about human behaviour. Even though the initial enthusiasm for Hempel's hypothetico-deductive method (as championed by Fritz and Plog 1970) soon waned as archaeologists struggled to apply it in the context of a historical science, much archaeological research conducted since the 1970s has been conducted in processual vein, that is, broadly predicated on the assumption that the methods of the natural sciences can be used to explain the subject matter of the social sciences. This is manifest in a more rigorous approach to inference and a greater use of quantitative and especially statistical methods.

A parallel development occurred in the early–mid 1990s as the use of GIS for archaeological research rapidly entered what one might term its post-pioneer phase. In 1993 Kvamme urged archaeologists to take an integrated approach to spatial statistics and GIS, having already noted how GIS might be combined with one-sample tests to examine association between site location and environmental parameters (Kvamme 1990c). In the same year van Leusen (1993, p. 120) performed a cluster analysis of the geomorphological properties of Palaeolithic/Mesolithic site viewsheds on the grounds that these would be expected to vary for sites that fulfilled different functions within the subsistence system. From then on there was a clear concern with increasing inferential rigour. Thus Wheatley (1995, 1996) used a one-sample Kolmogorov–Smirnov test to evaluate an explicit hypothesis about the intervisibility of sites. His work was subsequently further refined by Fisher *et al*. (1997), who emphasised that the mere existence of an association between human activity and one or more environmental variables does not in itself provide adequate evidence of a causal relationship. For example, they demonstrated how use of more-restricted control samples can help ascertain whether coastal sites with large viewsheds were deliberately located to have commanding views, or whether this was an unintended consequence of proximity to the sea.

Understanding, experience, symbolism and 'otherness' The antipositivist, or humanist, critique of positivist social science found its way into geography in the 1970s (e.g. Tuan 1974) and was taken up in the development of post-processual archaeology during the 1980s (e.g. Hodder 1982, 1986; Shanks and Tilley 1987a). Since the mid 1990s European archaeological GIS practitioners have been particularly concerned that the use of GIS has, whether intentionally (Wheatley 1993, p. 133) or otherwise (Gaffney *et al*. 1996, p. 132), encouraged the continuation or even re-introduction of a positivist approach that had otherwise been rejected by post-processual archaeology. The following introduction to the use of GIS within a post-processual framework is organised according to three strands of post-processual thought, although we concede that in reality these are not so readily separable.

One strand concerns how we learn about the past. This constitutes a rejection of the notion that the methods of the natural sciences are appropriate for the study of social life, and with it the goal of scientific explanation. Instead, drawing on Idealist thought, post-processual archaeologists often propose that human action can only be understood by taking the perspective of those involved (Hodder 1986). This has been augmented with a phenomenological approach that emphasises the creation of experience through bodily engagement with the physical world (e.g. Tilley 1994; Thomas 1996). Thus Chris Tilley argues in his *A Phenomenology of Landscape: Paths, Places and Monuments* (1994, p. 10) that 'space cannot exist apart from the events and activities within which it is implicated'. From this perspective one of the major problems with traditional GIS analysis has been its association with the absolute model of space and the way in which, as a result, it is claimed to perpetuate Haraway's (1991, p. 189) 'God trick': by making everything visible it not only presents 'a picture of past landscapes which the inhabitant would hardly recognise' but also facilitates 'a kind of intellectual appropriation' (Thomas 1993, p. 25). It is increasingly argued that the way forward is to combine GIS with virtual reality so as to provide some kind of localised experience of past material conditions (see Gillings and Goodrick 1996; Pollard and Gillings 1998; Earl and Wheatley 2002; also Gillings 2005 for a critique). This approach represents a significant break with positivist models of inference, eschewing expert explanation based on the results of statistical tests in favour of multiple understandings, each potentially unique to a particular participant.

A second strand of post-processual thought concerns what aspects of the past we choose to study. The tendency of processual archaeology to focus most attention on the ecological and economic dimensions of human existence has been replaced by an emphasis on meaning and symbolism. Thus, for example, the spread of agriculture across Europe is treated in terms of the replacement of one system of meaning by another rather than the replacement of one mode of subsistence by another (Hodder 1990; Thomas 1991b). Most attempts to move beyond the alleged environmental determinism of earlier GIS applications have treated symbolic landscapes as primarily a product of intervisibility (e.g. Gaffney *et al.* 1996). This, however, risks replacing a determinism based on one suite of environmental variables with a determinism based on another. In response there have been three developments in archaeological GIS. One replaces dependence on the simple presence or absence of a line-of-sight with an attempt to model more complex aspects of visual perception (e.g. Wheatley 1993; Witcher 1999; Wheatley and Gillings 2000). A second development combines Gibsonian psychology with the calculation of many or even all possible views in an attempt to map landscape 'affordances' (Llobera 1996, 2001, 2003). Finally, there have also been a few attempts to model senses other than vision (e.g. Tschan *et al.* 2000; Mlekuz 2004).

The third strand of post-processual thought that we consider here is concerned with the 'otherness' of the past. This involves a recognition that the past might have been very different, in particular that past people might have had very different ways of thinking (Shanks and Tilley 1987b; Thomas 1991a) and, even more profoundly, that the very experience of being an individual might have been quite different from that with which we are familiar (Thomas 1996). So far as the use of GIS is concerned, this perspective has contributed to the objection, already noted above, that GIS representations are built using models of space and spatial languages – such as the absolute model and Euclidean geometry – that are specific to Western thought. More fundamentally, Julian Thomas (2004, p. 201) argues that even if it is 'possible to develop a sensuous, experiential archaeology of place and landscape, which is sensitive to the relationality that renders things meaningful . . . it is questionable how far this process can be facilitated by a microprocessor'. At the root of his doubt is the well-known critique of computational theory of mind (Dreyfus 1972; Searle 1992), which argues that traditional artificial intelligence and computational methods simply do not capture the real nature of thinking and knowledge. Archaeological users of GIS have made suggestions that may go some way to addressing the first of these critiques. For example, Zubrow (1994) 'warped' Euclidean space to investigate the fit between the observed and ideal distributions of Iroquois longhouses. In addition it has been argued (e.g. Wheatley 1993) that cost-surfaces (see Chapter 10) provide another way of representing non-Euclidean experience of distance. It may also be that object-orientated GIS (Tschan 1999) will help us model space as inextricably bound up in events and activities. In contrast, the second critique initially appears less tractable, as it questions the very use of computer methods. However, artificial intelligence researchers, including many specialists in sociological simulation, are actively moving beyond traditional computational theory of mind and tackling issues such as the social construction of emotions (Cañamero and de Velde 2000) and the idea that cognition is not somehow separate from engagement with the world (Maris and te Boekhorst 1996). We suspect that these developments will filter through to GIS, perhaps initially in conjunction with the use of agent-based simulation models (Lake 2004).

1.3 Conclusion

GIS has been described as 'the most powerful technological tool to be applied to archaeology since the invention of radiocarbon dating' (Westcott and Brandon 2000, backcover), but also as a technology without intellectual vigour, overly dependent on simple presuppositions about the importance of spatial patterns in a dehumanised artificial space (cf. Pickles 1999, pp. 50–52). Although there are elements of truth in both these perspectives, we believe that one of the greatest strengths of the use of GIS in archaeology is its diversity. In some cases simply organising our data more efficiently is enough to prompt new ideas about the past. In others, new insights require careful use of spatial statistics. In yet others it is necessary to construct new methods within the framework of conventional GIS. And, finally, we will surely learn even more as a result of the integration of GIS with virtual reality, agent-based simulation and ongoing developments in artificial intelligence. Ultimately, the key to success is to use GIS appropriately, which means remaining cognisant of the theoretical encumbrances inherent within it and having adequate technical command of the powerful and diverse possibilities it offers.

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