

Chapter 1

Introduction: Archaeological Inferences and Computational Spaces

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Spatial analysis in archaeology today encompasses a wide range of experiential, fieldwork-based, deterministic and/or stochastic approaches that vary considerably in their intended purpose and theoretical underpinnings. Although Hodder and Orton (1976) and Clarke (1977) both provided book-length treatment of the application of statistical and/or simulation approaches to spatial analysis in archaeology many years ago, the rapid uptake of computational methods such as Geographical Information Systems (GIS) and related methods in archaeology from the late 1980s and early 90s marks a disciplinary step change, for enthusiasts and critics alike, increasing by an order of magnitude the quantity of spatial data that could be managed and analysed, especially for those working at the scale of entire archaeological landscapes. The 1990s saw a string of methodologically focused edited volumes covering the development of archaeological GIS (Allen et al. 1990, Lock and Stancic 1995, Aldenderfer and Maschner 1996, Maschner 1996). The most recent in this vein is now over 10 years old (Lock 2000), perhaps partly reflecting the more mainstream adoption of 'standard' GIS techniques, as also evidenced by the appearance of textbooks on archaeological GIS (Wheatley and Gillings 2002, Conolly and Lake 2006, Chapman 2006) and recommendations for archaeological predictive modelling (Kamermans et al. 2009; Wescott and Brandon 2000, Mehrer and Wescott 2005). Since 2000 a major focus of methodological development in GIS has been integration with computer simulation, particularly agent-based modelling; the papers in Gimblett (2002) provide heritage management applications of this technology, while more research-oriented examples can be found in Kohler and Gummerman (2000). More generally, however, the last decade has seen something of a dichotomy in the presentation of new computational techniques as either forming part of something labelled "Digital Archaeology" (e.g. Evans

and Daly 2006; and more widely the “Digital Humanities”; Bodenhamer et al. 2010) or as the handmaiden of more explicitly model-based (Kohler and van der Leeuw 2007) or spatial analytical (Robertson et al 2006) approaches to archaeological inference (see also McCoy and Ladfoged 2009). Gary Lock (2003) convincingly argued that the development of computer applications in archaeology has always reflected the entanglement of both methodological and wider theoretical advances, as documented in detail by others for the specific examples of GIS-based visibility analysis (Lake and Woodman 2003) and computer simulation (several papers in Costopoulos and Lake 2010). We are thus very conscious that any collection of computational approaches to archaeology will likewise be ‘of the moment’, so it worth elaborating what makes this a particularly exciting moment at which to be presenting such a collection.

Two broad sets of developments in the computational and social sciences over the last few years have conspired to create something of a research watershed and topical point of departure for a volume of this kind. The first set combines (a) some practical thresholds now reached in an otherwise continuous trajectory of growth in modern computing, (b) the sharply increased amounts of digital data now available and (c) the wider climate of more open access to both data and software source code. A popular metric of the modern age has been the near exponential upward trend in computational power over the last six decades (so-called Moore’s Law). However, there are good reasons to point to the last ten years as unusually important, particularly with respect to the demands of research within the social sciences and humanities. On the one hand, laptop and desktop computers have reached a stage of development where they can be used for the vast bulk of programming, statistical analysis, modelling and

representational tasks in these disciplines. This is the hardware side of a wider democratisation process in computational archaeology. On the other, high-performance computing, often leveraging clusters of otherwise idle processors rather than dedicated super-computers, is enabling (a) far more intensive forms of Monte Carlo simulation with carefully constrained random samples and explicit hypothesis-testing, as well as (b) far higher fidelity renderings of visually-sophisticated spaces than has hitherto been possible (in this volume, see Bevan et al.; Lake and Ortega; Earl et al.).

Alongside this added capacity has also come a flood of digital information. Perhaps the most glamorous agents of this information revolution have been the automated or semi-automated collection routines enabled by Global Positioning Systems (GPS), mobile phones, social networking sites and space-borne remote sensing instruments. Such datasets are often referred to as 'big data' given that, at their most extreme, they can be large enough to demand innovative storage, retrieval and analysis practices (though rarely so daunting in archaeology), but in addition, there have also been major efforts at digitising archival or legacy datasets, as well as an steady trickle of manually inputted information (e.g. via citizen-lead projects such as Wikipedia, Google Earth community or in archaeology the UK Portable Antiquities Scheme: e.g. Bevan 2012a).

Within archaeology, some datasets offer richly structured formats and metadata in order to facilitate close semantic and technical interoperability with so-called Web 2.0 technologies, whilst others are archived in simple formats for direct download from institutional or national data repositories, and a third unknown, but most likely numerically dominant, group of datasets continues to float in a netherworld of eccentric

colleague-to-colleague gifting. Even so, archaeology is increasingly in step with a wider social, political and economic climate that emphasises 'open' approaches to both software development and data dissemination (Bevan 2012b; Lake 2012; Ducke this volume) that stress transparency, universal access and the promise of unanticipated onward use. Increasing instances of the tailoring of software applications to archaeological purposes is one outcome of this wider climate (for an early emphasis: Lake et al. 1998) and many of the papers in this volume reflect such efforts at customisation.

The second set of developments that arguably make a volume of this kind a timely venture relate to the increasing maturity with which researchers have, over the last ten years or so, been discussing some key trade-offs in analytical and interpretative approach: for example, with respect to the importance of realism versus abstraction, the primacy of bottom-up versus top-down processes or the relative heuristic value of lumping or splitting human behaviour. In this regard, and as Mark Lake and Damon Ortega argue in a later chapter, there has been a tendency for the sub-discipline of computational spatial approaches in archaeology to recapitulate broader disciplinary rifts. A good example is the dichotomy between 'space' and 'place' that pervades not only archaeology, but academic research more generally. Contrary to the traditional view of this as a confrontation between tribalised cultures and a few culture heroes (mirrored in the often stereotyped priorities of Processual versus Post-Processual archaeology), we would argue that many researchers now consider more quantitative and more experiential approaches, for instance, as valid alternatives that together generate a useful dialectic. Indeed, the strong overlaps between, for example, complexity science

and more avowedly humanistic approaches to space are visible in common interests with respect to historical contingency and path dependence or to behavioural emergence and structuration (see Portugali 2006). Where there is diversity of approach and opinion moreover, we would suggest that this should be thought of less as a set of generational pendulum swings or paradigms shifts, and increasingly as desirable to-and-fro to encourage within a research institution, over the course of an individual research career or indeed within the same edited volume.

It should be no surprise therefore that contemporary practicalities and cross-cutting methods are salient features of the chapters that follow in this volume but manifest themselves slightly differently depending on different researchers' analytical and interpretative agendas. Certain differences of intention persist and suggest a structuring framework for this volume that (a) begins with a focus on the continuing importance of spatial and spatio-temporal pattern recognition in the archaeological record, (b) continues by considering more wholly model-based approaches that fix ideas and build theory, and then (c) goes on to address those applications where situated human experience and perception are a core interest.

[Note to typesetter - the following headings are the titles of themes rather than section headings per se - see also below]

H1 Spatial Analysis

With these three emphases - loosely-speaking, spatial analysis, spatial modelling and spatial experience - in mind, the first three papers in this volume all have a common

interest in more inductive spatial approaches to archaeological inference. Together they take us across a sweep of different kinds of pattern recognition: moving from the spatial analysis of data recovered from primary fieldwork (e.g. via case studies spanning a major research excavation, a field survey, and joint assessment of records from rescue archaeology; Bevan et al.) to extraction of archaeological features from ground-based or airborne remote sensing imagery (Kvamme), to consideration of the collected records from museum archives and ethnographic observation (Clarke).

Bevan, Crema, Li and Palmisano return to long-cherished tool of empirical archaeology, the distribution map, and argue that a range of new methods and theoretical perspectives should encourage renewed efforts to characterise such spatial patterns and the underlying generative processes behind them, even if we will often still be left with multiple competing explanations at the end of this effort. Their discussion ranges from patterns exhibited by typological sub-groups of bronze weapons in the tomb complex of China's First Emperor, to early Iron Age settlements in the uplands of the West Bank to the pithouses of Japan's early complex hunter-gatherers. Throughout, they stress the importance of grappling with an archaeological record that is chronologically fuzzy and spatially uneven.

Kvamme offers a focus on two aspects of spatial and computational research that are common in archaeology but otherwise rare in this volume: the demands of cultural resource management (CRM) and the digital riches offered by remote sensing imagery. The challenge he articulates for the archaeological community is to come up with automated or semi-automated pattern recognition techniques that can leverage the vast

amounts of remote sensing data that are now available to provide cost-effective CRM solutions across the large swathes of the planet current under threat from development and destruction. The challenge is therefore one of seeking to upscale techniques that would otherwise provide nice vignettes at the site scale to ones that can be used routinely or can have a more global reach (see also Ducke et al. 2011; Menze and Ur 2012).

Clark argues for a more joined-up approach to multivariate analysis of large cross-cultural datasets. Drawing in particular upon analytical advances in ecology, he suggests that we can squeeze far more out of complex archaeological datasets (a) by collapsing such data into distance matrices expressing dissimilarities among different sample sites (e.g. taken from different settlements or different perceived culture groups) via one or more ordination techniques, (b) comparing it with patterns of geographic or social proximity, and (c) conducting careful outlier analysis. His case study using an ethnographic example from the Pacific coast of North America highlights how evidence as seemingly distinct as social structure, material technology, subsistence practices and ordinary distance can be brought together to offer useful analytical traction on one another.

The level of simplification and abstraction advocated in these three chapters is often considerable. Bevan et al. choose to ignore the complex 2D or 3D morphologies and alignments of their artefacts, houses and settlements in favour of pure point locations. Clark chooses to collapse the complex relationships that exist among a host of different cultural variables into a series of distance matrices. Both papers adopt relatively simple,

Euclidean representations of geographic distances and social proximities that are in reality far more complex . Kvamme argues for the use of similarly idealised geometric types, such as the circle, as benchmarks for comparison with the features that appear in the raster grids produced by remote sensing. In all three cases, these trade-offs are deliberate and ones that are only meant to be effective at certain spatial scales and not at others (see also Lock and Molyneaux 2006).

H1 Spatial Modelling

In partial contrast to these first three chapters, the four by Rivers et al., Premo, Barton and Herzog that follow can all be characterised as more deductive and 'model-based' in that they start with explicit theories or more informal understandings of human behaviour, and then seek to establish how these might play out under specific circumstances which did or could have obtained in the past. It is a measure of the diversity within this broad approach, however, that the conceptualisation of space in these four chapters ranges from the more abstract topological model favoured by Rivers, Knappett and Evans, to the geographically-referenced, continuous field, elevation models used by Barton and Herzog. Another axis on which these chapters vary is the extent to which they focus on individuals or groups as the unit of analysis.

Rivers, Evans and Knappett offer a graph theoretic model of the evolution of trade and exchange links in the Bronze Age Aegean. They formalise the spatial relationships assumed to be in operation between Bronze Age sites as an evolving set of weighted networks, and in so-doing provide important discussion of the sense in which network models can incorporate properties of the actual geographical space in which the network

is ultimately embedded. Their exploration of the different insights provided by looking at the most likely configuration of links and nodes, on the one hand, versus the most efficient one on the other, brings together ideas from statistical physics and network theory, as well as from the kinds of 'spatial interaction model' long popular in urban geography.

Premo conceptualises space as a continuous field sampled on a grid. This, of course, is the classic GIS raster map, but in his case the content of the map is artificial rather than a representation of any particular segment of the earth's surface. Premo's approach is congruent with the theory building ambition of his chapter, which is to understand whether geographically fragmented woodland resources could have provided a selective environment favouring the evolution of altruistic food sharing by early hominins. Premo attempts to answer this question using an agent-based computer simulation, a technique which he argues is particularly appropriate for exploring the interplay between individual decision-making and the interests of the group as a whole.

The question of what is an appropriate level of abstraction is currently the subject of lively debate among proponents of computer simulation modelling and Barton directly addresses this issue in his chapter. Whereas Premo's theory-building model maintains a comparatively high level of abstraction, Barton is more concerned to link agent-based simulation to real geographical spaces and some of the processes that occur in those spaces, not least because of his conviction that "the human past is essential to understanding human society today and planning for our long-term future". He explores this possibility through a discussion of four case studies drawn from both Europe and the

United States of America and covering archaeological interests ranging from the Upper Pleistocene through early agricultural societies to what he describes as "palimpsest of prehistoric artifactual residues".

If Barton's models typically require accurate representations of the earth's surface, the same is equally or even more true of the input to least cost path analysis, discussed in detail by Herzog. She presents the issues that arise when attempting to implement GIS-based models of the impact of terrain and land-cover on human - typically, but not exclusively, pedestrian - movement through landscapes. Quite apart from important technical issues that arise in the implementation of these models to imperfect and ultimately discontinuous models of reality, there are also wider issues concerning the necessary assumptions surrounding the principles governing path choice and indeed the scale of analysis at which they are applicable, with several coarser grained, less goal-directed options available as alternatives models of movement (e.g. McRae et al. 2008).

H1 Spatial Experience

In the mid 1990s some leading proponents of GIS (e.g. Wheatley 1993) expressed disquiet that the increasing uptake of the technology had revived a functionalist approach to archaeological explanation which had supposedly been discredited by the humanistic critique of Processual archaeology. While this may have been more of a concern in some parts of the world than others - notably in the UK - it certainly led to a spirited internal critique of the explanatory power of GIS models and, ultimately, a rash of studies focusing on the human sensory experience of landscape, particularly in terms of visibility. This interest in turn gave way

to a degree of disillusionment as many researchers realised that GIS-based analysis of visibility was often too coarse-grained to sustain the kinds of - often very particularistic - interpretation they sought and/or was excessively computationally demanding, although the work of Marcos Llobera (e.g. 2003, 2007) is a notable exception.

In their chapter, Lake and Ortega recount the vicissitudes of GIS-based visibility analysis in more detail before suggesting that contemporary computing power may now allow us to overcome some of the deficiencies of earlier visibility studies. They hazard to predict, on the one hand, a renewal of interest in large-scale comparative studies of the visual properties of archaeological sites, and on the other, the more frequent use of virtual and augmented reality to provide a means for understanding how these worked in terms of embodied experience. Lake and Ortega provide an example of the first approach and use the Monte Carlo simulation of nearly 30,000 viewsheds to investigate the extent to which the builders of prehistoric stone circles in England and Scotland deliberately chose topographical settings with particular properties.

Paliou's chapter provides a bridge between the work of Lake and Ortega on the one hand, and that of Earl et al. on the other. It does so in two ways which reflect important axes of variability in computational approaches to visual space. First, through a review of the concept of the 'visuallandscape' (see Llobera 2003), Paliou explicitly discusses the relationship between the kind of '2-dimensional' visibility analysis exemplified by Lake and Ortega's work and the possibilities offered outside conventional GIS for fully 3-dimensional study of visual space. Second, she describes recent work in geography and urban studies which could provide the basis for the analytical, as opposed to purely

experiential, use of 3-dimensional visual models. In particular, she introduces archaeologists to the *iso-visibility-matrix* and the existence of 3D visibility graph analysis.

The work of Earl and his colleagues exemplifies the 3-dimensional end of the spectrum discussed by Paliou. They describe the construction of a physically accurate 3-dimensional reconstruction of the Roman Basilica Portuense which is then used as the framework for an analysis of how people would have perceived the space in terms of the distribution of areas of light and dark. Perhaps the key thing which takes Earl et al. approach well beyond the sophisticated but ultimately inferentially naive production of an “attractive reconstruction” is their attempt to instill methodological rigour in virtual reality modelling. Thus, for example, they not only acknowledge the uncertainty inherent in reconstructing the upper part of the basilica (a quite different but equally important challenge to the temporal uncertainty discussed by Bevan et al.), but actually devise a method to address it: the use of procedural modelling to automatically generate alternative scenarios within the parameters set by surviving basilicas.

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Benjamin Ducke’s contribution brings this volume to a close by returning to some of the opportunities and challenges of contemporary computer science that we raised earlier in this introduction. In particular, he offers a persuasive argument in favour of ‘open source’ software (a.k.a. Free/Libre and Open Source Software, F/LOSS). It remains remarkable that archaeology has hitherto wedded itself so thoroughly to commercial solutions. While

there are archaeologists who use open source software for spatial modelling (of which there are many examples in this volume), the vast majority of teaching and research has so far been conducted with a limited number of (typically closed source and costly) packages. This is reinforced, for better or worse, by the institutional and infrastructural umbrellas within which archaeologists work, whether these be commercial archaeology units, provincial public sector organisations (e.g. UK county councils), museums or universities as many of these institutions. Hence archaeology exhibits an interesting combination of enthusiasm and resistance to these open source initiatives, even if the slow trend is arguably in their favour.

The above suite of chapters certainly cannot hope to capture the full range of computational spatial methods in use in archaeological research today, and we might further highlight important domains of enquiry such as mapping radiocarbon date distributions (Collard et al. 2010) or new spatial acquisition methods that are only beginning to be turned to research-driven agendas, such as large-scale geophysics, Structure-from-Motion and multi-temporal satellite datasets (Gaffney et al. 2012; Ducke et al. 2011; Menze and Ur 2012). Keeping such additional growth areas in mind, this volume nonetheless offers a representative snapshot of how historical built spaces, past cultural landscapes and archaeological distributions are currently being explored at a particularly compelling moment in the history of computational social science.

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