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Models of settlement hierarchy based on partial evidence

Andrew Bevan[a,*], Alan Wilson[b]

[a] Institute of Archaeology, University College London, 31-34 Gordon Square, London WC1H 0PY, United Kingdom
[b] Centre for Advanced Spatial Analysis, University College London, United Kingdom

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ABSTRACT

The modelling of past settlement and landscape structure from incomplete evidence is a well-established archaeological agenda. This paper highlights a model of spatial interaction and settlement evolution that has long been popular in urban geography and which was first applied to model historical settlement hierarchies some twenty-five years ago, but whose use since then for archaeological purposes has been very limited. Via a case study from Bronze Age Crete, we extend the analytical range of this model by suggesting ways in which it can (a) remain effective in the presence of missing data, (b) be given a stronger grounding in the physical landscape, and/or (c) be used to consider the evolutionary trajectory of settlements and physical routes over time.

1. Introduction

This paper considers how we might construct useful understandings of past human settlement hierarchy in situations where our surviving evidence is patchy and incomplete. It builds on the continuing attractiveness of a family of spatial interaction and settlement evolution models that were first developed in the 1960s and 1970s in urban geography to capture, amongst other things, the growth of modern retail outlets (see Wilson, 2012a for a recent overview; Wilson, 1967, 1970; Harris and Wilson, 1978), and then first applied to archaeological settlement datasets by Rihll and Wilson in a series of papers some twenty-five years ago (1987a, 1987b, 1991; also Wilson, 2012b). Despite the promise of these earlier efforts, there has been little further work on these models, with only some exploratory consideration of how they might be recast as agent-based simulations (Graham and Steiner, 2006) or compared with alternative forms of dynamic network (Evans et al., 2012). These models have sometimes been dismissed as 'gravity models' but the approach here is fundamentally different. The spatial interaction elements are based on entropy-maximising methods and the settlement dynamics on a development of Lotka–Volterra equations first used in ecology (see Wilson, 2008, for a full account of these ideas which are also explored more fully in Section 2 below and in the Appendices). Here, we further extend their analytical scope (a) by demonstrating how the combination of point process models with spatial interaction models offers a viable approach in cases where there is only a very partial array of settlement evidence, (b) by grounding the model in more physically realistic routes of interaction, and (c) by considering whether it can also shed light on the co-evolution of path and place hierarchies. Bronze Age settlement and political geography on the Greek island of Crete provides a useful, well-known test case where all of these methodological developments can be explored.

We start by outlining a common research problem in archaeology, and one that has further relevance for historians as well. Given a partially observed pattern of human settlement from a particular period of the past, there are many different questions that we might wish to ask, with any eye to understanding the causal logics behind the settlement structure, exploring long-term dynamics of this structure or comparing it with a larger cross-cultural sample. One key goal is usually to reconstruct a wider political and economic hierarchy, as reflected in and promoted by a certain spatial configuration of settlement. We are typically also interested in related questions such as what aspects of this hierarchy are a consistent feature across most periods in a study region, and hence possibly induced by the local environment, and which ones are predicated on a particular cultural logic and/or a set of historical circumstances. Of further interest is also the role of formal trail or

* Corresponding author.
E-mail address: a.bevan@ucl.ac.uk (A. Bevan).

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road networks between settlements, the agricultural and political territories around them, and ultimately the manner in which whole landscapes become laden with cultural significance.

As David Clarke noted some time ago, archaeology is a discipline that seeks to understand "unobservable hominid behaviour patterns from indirect traces in bad samples" (1973: 17). In line with this maxim, most archaeological settlement distributions are incomplete and of uneven detail, often dramatically so. Even if we were happy, for example, only to consider the largest 100 settlements across a given study region and to ignore smaller hamlets and farmsteads as of minor consequence to the overall whole (itself a potentially problematic assumption), then in most cases, we would still only be able to identify some but not all of these settlements on the ground archaeologically, and would probably be able to assess other variables such as the settlements' relative importance only for a further subset of these. The reasons for missing data are various: in many parts of the world, archaeologists construct large-scale gazetteers of settlement from regional inventories that have often accumulated in a haphazard fashion over many years (e.g. most sites and monuments records) and as the result of many different types of investigation (rescue excavations, rare research-driven projects, chance finds, casual surface reconnaissance, literature searches, etc.). In some regions, more systematic archaeological surface surveys can claim greater data quality (e.g. Fish and Kowalewski, 1990; Banning, 2002; Alcock and Cherry, 2004; Peterson and Drennan, 2005), but such intensive reconnaissance techniques can usually only be implemented for comparatively small areas. Moreover, the vast majority of survey practitioners would agree that even these intensive methods still only provide an imperfect sample due to the fact that only certain kinds of evidence have survived into the present day in certain taphonomically-favourable places, and even where this evidence exists, settlements from different periods are often superimposed as awkward palimpsests (also Groube, 1981). Very occasionally, there are exceptions where larger scale, more complete coverage of one period is achievable for unusual reasons (for example, the 3rd millennium BC tell landscapes of north-eastern Syria: Menze and Ur, 2012), but it would be very undesirable to limit our analysis solely to this evidentially privileged minority of cases.

Even where we have a near complete record of the distribution of human settlement and a wealth of ancillary detail to draw upon, it is still important to construct models that allow us (a) to make sense of patterns in the data in a formal way, and (b) to use these insights comparatively and longitudinally. How we deploy existing knowledge about settlement patterns is also a strategic issue, as we might wish to withhold some of the evidence from the model-building exercise as a way of testing the plausibility of the results. There are thus several reasons for wishing to develop methods that are robust to missing information. Similarly, even if ultimately, we are left with several competing models that are underdetermined by existing archaeological observations (Hodder, 1977; van der Leeuw, 2004) the exercise still serves to formalise our thoughts, narrow down the range of possibilities and indicate where further research would be useful. The following discussion explores some ways in which this might be possible, building upon three existing modelling traditions in geography, spatial statistics and network science: (a) interaction models based on the principle of maximum entropy together with models of the dynamics of settlements (b) point process models that can capture both the first and second order properties of an observed point pattern, and (c) shortest path calculations and models of network evolution. The methods section below begins by outlining the potential of each of these in light of our research problem and thereafter, we consider how they might work together in an applied case from Bronze Age Crete.

2. Methods

2.1. Transport and settlement dynamics' models

In Appendix 1, we present the key ideas in the development of spatial interaction models – that have been used in a contemporary context, for example, to estimate flows of money from consumers to retail centres. These retail models have been extensively tested and can replicate the data representing a current situation very accurately. The method is based on entropy maximisation (Wilson, 1970, 2000) that, in part, is designed to make the best use of partial data and hence potentially lends itself well to archaeology. In urban retail analysis, the modelled flows can be summed at each centre and this revenue compared to the retailers' costs to provide an estimate of 'profit' at each location. This in turn drives the dynamics of the evolution of the system of centres (Harris and Wilson, 1978) and enables the 'most likely' structure of the system of centres to be articulated (what is sometimes referred to as its equilibrium structure). These methods can be transferred into archaeology if the 'centres' become 'settlements' and the 'flows' between settlements are understood as some composite of the relative intensity of trade along different routes, daily or seasonal journeys to work and/or the permanent migration of people. The model can then be used to estimate the spatial distribution of settlement sizes.

2.2. Inhomogeneous point process models

While the above framework provides a useful way to predict and explain the relative importance or size of different settlements without building in this information from the outset, by contrast, it still assumes fairly complete knowledge of settlement locations across a study area. As we argued above, such complete knowledge is rare in archaeology, even in situations where we are only interested in larger sites. We therefore need a method for proposing the position of possible missing settlements, based on the locational properties of the known sample, and then a way of exploring the sensitivity of model results in the presence of this hypothetical component. Recent approaches to inhomogeneous point process modelling provide just such a framework. We can think of a settlement distribution as one historical realisation of a settlement process played out over time and across a larger area, but observed for a particular time-slice within a particular study region. In many cases, we can make a simplifying assumption and represent the settlements by their centroids (i.e. ignore their spatial extent) and consider their configuration as a point pattern marked by a particular set of size attributes, as we do in this paper.

A useful general distinction to make from the outset is between the first- and second-order properties of a point pattern (O'Sullivan and Unwin, 2003: 51–75; Illian et al., 2008; Gelfand et al., 2010: 263–423). The first-order properties of a point pattern are those that describe the average intensity (per unit area) of points across a given study region, while its second-order properties are those that describe the influence of neighbouring points (i.e. the covariance structure). For example, we might think of the availability of better or worse farmland as a variable that prompts a first-order unevenness (inhomogeneity) in the intensity of human settlement. Beyond this however, there are also often second-order patterns in human settlement, for example regular-spacing due to competition over resources, or the reverse, clustering together of human habitation (for various reasons including protection, due to colonisation history etc.), or indeed some multi-scalar combination of these (for further useful ways to model the economics of these attractive and inhibitory factors, see Fujita et al., 1999). In archaeology, there is already an established tradition of exploring the first-order properties of archaeological site locations via logistic