Geographical networks of British hill forts using intervisibility graphs

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Summary

We present a range of exploratory methods at the intersection of geographical analysis and graph/network theory to investigate placement of Bronze age and Iron age hill forts in a landscape, utilising varying degrees of domain knowledge (expert/archaeologist). Techniques that we employ include: intervisibility/line-of-sight; visible area of hillforts; landcover and geomorphometrics; and network characteristics of intervisibility graphs. For the latter, we examine both local features (modularity, cliques, communities) and global features (clustering coefficients, statistical properties).

KEYWORDS: Intervisibility; Graph; Network; Optimisation; Landcover; Geomorphometrics; Archaeology;

1 Introduction

In recent years, network analysis has been proposed in conjunction with visibility tools to examine the relationship between cultural goods, human settlements, and the environment (De Montis & Caschili, 2012; Oatley, Crick, & Howell, 2015). GIS can be used in order to reconstruct and analyse likely networks of intervisibility between settlements, permitting social or complex network analyses (SNA or CNA) in order to characterise these networks using metrics such as centralization and cohesion (Mullins, 2016).

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In this paper, we propose a range of exploratory methods at the intersection of geographical analysis and graph/network theory to investigate placement of Bronze age and Iron age hill forts in a landscape, utilising varying degrees of domain knowledge (expert/archaeologist). We develop an empiricist approach to creating 'inductive' hypotheses about the data based upon patterns in intervisibility, visible area, landcover and geomorphometrics. A core aspect to this approach is the analysis of the network characteristics of intervisibility graphs, including measures of connectivity (degree, centrality), local features (modularity, cliques) and global features (clustering coefficients, statistical properties).

2 Hill Forts & Data

For this work, the authors have compiled a dataset comprising the locations of all known 913 bronze age hill forts throughout Wales, UK (a largely mountainous region, with an area of approximately 20,000km). Iron age tribes have been described as possessing a 'resilient and sophisticated clan based tribal confederation' (Howell, 2006) of the region and it seems reasonable to explore the extent to which spatial relationships and other landscape factors may help to shed light on the degree to which that description is appropriate. Although the location of each of these forts is known, other attributes, such as the height and extent are unknown as the majority of the structures are no longer intact. These attributes are therefore estimated using domain knowledge, and analyses are tested for sensitivity to these assumptions using monte carlo approaches. This work also presumes that all hill forts were active simultaneously, and once again the sensitivity of analyses to this assumption will be made.

3 Methods

We have found great value in developing tools for an archaeology expert to explore the data. Part of the initial analysis involves a visual inspection of the three dimensional landscape simply achieved using Google Earth. In this way, the domain expert is able to explore the fort locations in the context of the terrain.

The analysis of this unique dataset will be carried out in a number of ways. Landform features such as rivers, and morphometric classes (Bolongaro-Crevenna, Torres-Rodríguez, Sorani, Frame, & Ortiz, 2005) such as ridge, plane, channel, pit, peak, and pass are examined in relation to placement of the hill forts. We are interested in assigning labels to the forts, for instance valley versus ridge/high point, near water versus far from water. Subsequent graph analysis – social or complex network analysis (SNA or CAN) can then utilise such classifications for analysis of connections, employing a more sophisticated view of cliques and communities - for instance that they include at least one defensive fort, or one close to an arable area, or a flat area.

3.1 Intervisibility Graphs

In order to construct these intervisibility graphs, a bespoke visibility tool is used to assess the level of inter-visibility between each of these forts. This software library [1] was designed with the quick and efficient processing of large datasets in mind. For this reason, the software (written in C++) is available as a command line tool and as a set of Python bindings (generated using SWIG), as opposed to as a GUI or desktop GIS plugin. Though not as fast as some algorithms that utilise voxel-based pre-calculation (e.g. Carver and Washtell (2012)) or GPU acceleration (e.g. Osterman, Benedičič, and Ritoša (2014)), the benefits of this approach come from the simplicity of the algorithm, and the ease with which it may be used across multiple platforms (Windows, Mac and Linux).

Intervisibility graphs are constructed using a a Python script that uses an R-Tree spatial index and the above Viewshed software in order to rapidly establish which forts are intervisible. In order to support the rapid calculation intervisibility or viewsheds, the software calculates the required DEM data coverage for any given calculation and creates a virtual raster (*.vtm) from a directory of raster tiles. In the event that a requested data tile does not exist because it is too far offshore, it is replaced at runtime by a 'blank' of even 0m elevation (assumed mean sea level). Intervisible forts are then added to the graph as nodes joined by a single edge. One such graph can be seen in Figure 1, with nodes coloured by their network degree (the number of forts that are intervisible with it).

[1] https://github.com/jonnyhuck/Viewshed

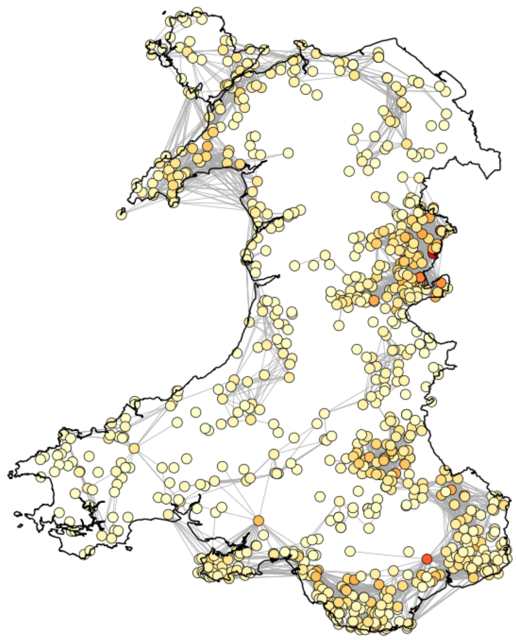

Figure 1: A simple example of an intervisibility graph network, calculated assuming a height of 2m for each fort and a maximum visibility distance of 30km.

Once the intervisibility graph has been constructed, it can be described using standard graph/network measures and coefficients. Networks with significant properties can be examined in more detail, suggesting, for instance, distances that support significant transitions in network structure which could have archaeological validity.We explore different ways of integrating GIS, SNA/CNA and domain knowledge. For instance Bunn, Urban, and Keitt (2000) built graphs using GIS coverages to define habitat patches and determined the functional distance between the patches with least-cost path modeling. Subsequently they analysed landscape connectivity within these graphs using edge and node removal.

3.2 Optimal coverage by hill forts

The calculation of viewsheds is a routine operation in GIS and is used in a wide range of applications. Many of these involve the siting of features - such as optimizing watch tower locations for forest fire monitoring (Bao, Xiao, Lai, Zhang, & Kim, 2015). The calculation of viewsheds will use the same bespoke software as described above [2]. The selection of a series of locations which collectively maximise the visual coverage of an area is a combinatorial problem and as such cannot be directly solved except for trivial cases. We utilise the viewshed algorithm in combination with a heuristic optimisation technique (for instance genetic algorithm) for these purposes. We employ optimisation techniques to select n viewpoints from among the v candidates, such that their combined viewsheds cover the maximum percentage of the land in the target environment. The v candidates include all existing hillfort locations plus additional high points spread across the DEM. n (viewpoints) is the total number of hillforts (913). Using these techniques we can determine which viewsheds subsume another, which could indicate a less important or different purpose. This can also link back to the land use classification and theories about the purpose of the hill fort or interesting combinations of viewsheds, for instance several peaks "governing" (covering) an area.

3.3 Identifying community structure

A key part of the analysis is concerned with identifying communities and community structure. While this is an important property of complex networks, an accurate definition of a community remains an open problem (Liu, Pellegrini, & Wang, 2014). In Orman, Labatut, and Cherifi (2011), a community roughly corresponds to a group of nodes more densely interconnected, relatively to the rest of the network. Generally a measure is used that estimates the quality of community structures such as modularity - which measures internal consistency of identified communities with reference to a randomised null model with the same degree distribution.

3.4 Network characterisation

Finally, we examine the statistical characteristics of the networks (small world, scale free), reviewing methods for geographical embedding of scale-free networks, see for instance: (Ben-Avraham, Rozenfeld, Cohen, & Havlin, 2003), and utilising exponential random graph modelling (ERGM) as a method for bridging static and dynamic approaches to interpreting visibility networks (Brughmans, Keay, & Earl, 2014). Using ERGM gives the possibility of exploring the dynamic processes that might have led to observed networks (Brughmans et al., 2014).

4 Conclusions

Despite being in the very early stages of analysis, this work has the potential to develop new insights into the relationship between bronze age and iron age hill forts, and even the possibility of proposing likely sites for yet undiscovered hill forts.

[2] https://github.com/jonnyhuck/Viewshed

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6 Biography

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