08 | IDENTIFYING SETTLEMENT PATTERNS AND TERRITORIES

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From Points to Areas: Constructing Territories from Archaeological Site Patterns Using an Enhanced Xtent Model

Abstract: Territorial reasoning is a basic topic of spatial archaeology. The ability to establish territorial extents of political, religious or economic zones allows us to move from point to area-based observations and hypotheses. We present a substantially enhanced, GIS-based version of Renfrew and Level's classic Xtent algorithm. Our version offers various advantages over the original. It respects terrain properties, a priori physical movement constraints and hierarchical relations between sites, maximum territory sizes are easy to control and a measure of uncertainty is provided. The software implementation used in this paper was done within the framework of the open source GRASS geographic information system.

Territorial Models in Archaeology

Territories, marking the spatial extent of an area of influence, are a basic concept of spatial reasoning in archaeology (e.g. Conolly / Lake 2006, ch. 10; Wheatley / Gillings 2002, ch. 7; Cunliffe 2003; Renfrew / Bahn 2000, 203–215; Stančič et al. 1994; Fletcher / Reilly 1987; 1988; Flannery 1972). The ability to establish territorial extents of political, religious or economic zones in a quantitative, formally correct way allows us to transfer hypotheses and knowledge from observations made at single archaeological sites to the landscape surrounding them – effectively moving from point to area-based descriptions. A typical archaeological site pattern consists of settlement locations encoded as two-dimensional coordinates and their attached attribute values such as size, age or function *(Fig. 1)*.

Archaeological settlement pattern analysis relies on fundamentals and methods developed by earlier researchers (von Thünen 1826; Weber 1909; Christaller 1933). In the 1960s, the advent of Quantitative Geography brought new approaches to settlement pattern analysis, culminating in the classic works of Haggett and his colleagues (Haggett 1965; 1977). The archaeological echo of these developments manifested itself in a book by Hodder and Orton (1976) that laid out a general archaeological agenda which today remains unsurpassed in its general relevance and methodical clearness. A few years earlier, Vita-Finzi and Higgs (1970) had introduced archaeological site catchment analysis. In the following decades, innovations ceased as the focus of attention shifted to the intrasite level of analysis and towards less formalized methods of research. For roughly the last decade, however, geographic information systems (GIS) have made ever more complex analyses of large spatial data sets broadly available. This has led to a revival of formal spatial approaches – a development for which the GIS implementation of the Xtent model discussed here may stand as an example.

Formal Concepts of Territoriality

Territorial reasoning comprises the elementary aspects of distance, hierarchy and network connectivity (*Fig. 1*; connectivity is a topic of network analysis

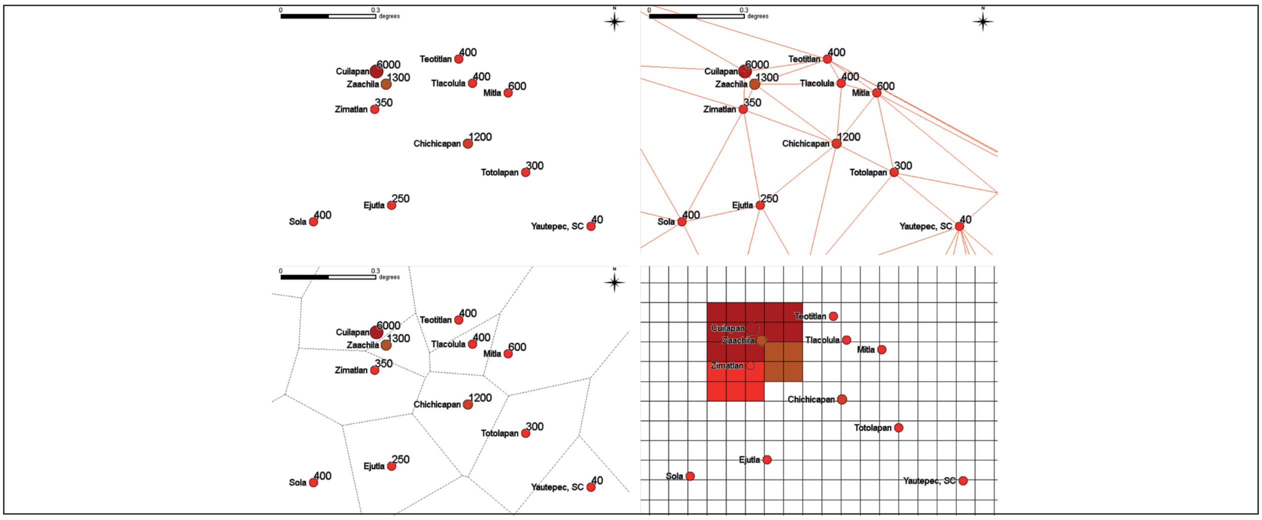

Fig. 1. Archaeological point patterns and territorial allocation. Top left to bottom right: a simple settlement pattern with sites of different population size (weight); a network of the same sites with full connectivity; a simple territorial division of the settlement area using a Voronoi diagram; unfinished state of a GIS algorithm in the process of allocating area units to the largest and nearest site in a raster-based model.

and will not be discussed further in this paper). Information about hierarchical relations is important for territorial assessments, as archaeological sites are typically embedded in a wider network (e.g. Hammond 1975) and it cannot always be assumed that they were autonomous. A series of archaeological case studies from different parts of the world made use of Christaller's (1933) basic model. Christaller claimed, based on empirical evidence from South and West Germany, that cities, towns and villages developed within a hierarchical network where each location would fit a certain functional niche that defined its size and character (Central Place Theory; see Hodder / Orton 1976, 55–73 for details). Although Christaller's study region was a 20th century settlement system, some of its implications could sensibly be thought to hold true for archaeological scenarios (Renfrew / Bahn 2000, 178–179; Clarke 1977, 23–24). Several case studies were able to show that hierarchical structures could be extracted from site patterns – albeit with varying degrees of success (Central Europe: Hennig / Lucianu 2000; Kunow 1988; Roman Britain: Hodder / Orton 1976; Middle East: Johnson 1972; Mesoamerica: Flannery 1972; Hammond 1975).

Concerning the aspect of distance, it seems reasonable to assume that territorial behavior is intrinsically linked to resource allocation (Hammond 1975). Ethnographic studies (Chisholm 1962; Lee 1968) suggest that resource usage is distance dependent. The basic idea behind site catchment analysis as introduced by Vita-Finzi and Higgs (1970) is to delineate the maximum area reachable from a site with limited costs of movement. The natural resources present within this movement radius would then be analyzed to infer the site's mode of subsistence (see Higgs 1972; 1975 for several case studies, Renfrew / Bahn 2000, 258–259). The method can also be reversed to define a site's territory by assigning as much area and resources as required to support a given subsistence mode (Flannery 1986). Foley (1977) substantially enhanced the method to show that it can gain greatly in plausibility if the concepts of distance and cost of movement are defined in a realistic way, including terrain properties and caloric movement efficiency. This detailed approach lends itself to a computational solution and Gaffney and Stančič (1991) provide an early GIS-based example.

However, the most common way to create a formally correct segmentation of space into territories is constructing the Voronoi diagram (*Fig. 1*; also known as Thiessen polygons; see Wheatley / Gillings 2002, 149–151 for details; also Renfrew / Bahn 2000, 204–205); a method taken from the toolset of classic point pattern analysis (Hodder / Orton 1976, ch. 3). The geometric simplicity of the Voronoi diagram has led to its early adoption in archaeology (e.g. Angell / Moore 1984; Danks 1977; Hodder / Orton 1976, Fig. 4.4; Cunliffe 1971) and constitutes at the same time its greatest strength and weakness. A territorial model based on a Voronoi diagram that e.g. criss-crosses hydrographic features or mountain ranges in disregard of their relevance as natural barriers has little plausibility. Extensions to the basic diagram have been made to remedy such shortcomings and to also reflect differences in site "weight", i.e. population size, importance, etc. (see Conolly / Lake 2006, 213 for a simple algorithm). Even in its improved form, however, the Voronoi diagram retains significant drawbacks for archaeological territorial analysis: the spatial partitioning is always complete; there is no room for the idea that some locations within the diagram should not be assigned to any territory at all; there is no measure of error or plausibility as the Voronoi algorithm always provides a perfect partitioning of space per definitionem and finally the diagram's shape is very sensitive to changes in the spatial configuration of sites.

The Xtent Model

The shapes of territories dominated by ancient polities were related to both the size of the capital centers and the distances between them. Based on this observation, Renfrew and Level (1979) developed a simple formula to predict the political influence of ancient centers from the distribution of archaeological settlement remains: the so-called Xtent model, a computational analytical tool that calculated hypothetical territories around a set of polities (called centers) and showed which of them fell into the territories of more influential neighbors. Following Renfrew and Level's assumptions, the Xtent model incorporates the settlements' sizes and distances between them as factors determining political dominance:

$$I = C^a - k \times d$$

In the formula above, I is the strength of influence that each center has at a given location in the study region. The basic idea is that each location will be allocated to the center that scores the highest I for that location *(Fig. 1)*. The magnitude of I at location x for each center is determined by two terms that "compete" against each other: center size (or weight) C and distance d. Obviously, a large center in close proximity will have the best chance to score the highest I (i.e. "dominate" a location). But a very large center can also be dominant, even if it is farther away. The two coefficients a and k determine the balance between center size and distance. The importance of distance increases in a linear manner while the importance of size increases exponentially. Thus, larger centers will compete stronger in relation to smaller ones, even at an increased distance.

The Xtent model rests on four basic assumptions: (1) territories belonging to a center are spatially uninterrupted and continuous, (2) a piece of land belongs to only one center, (3) the capitals of polities are larger (in area or population size) than lower-ranking centers within the polity and (4) the size of a capital center is positively correlated with the size of the territorial area it controls. Certainly, there are known exceptions to these assumed rules but as Renfrew and Level (1979, 146) argue, these can often be explained in their specific historical contexts.

The basic idea of territory allocation according to influence is not very different from the principle of a Voronoi diagram and indeed the two can be shown to converge under a=0.5, k=1.0 and constant C=1.0. Increasing a for C>1 gives results similar to a weighted Voronoi diagram.

An Open Source GIS Implementation of the Xtent Algorithm

The GIS implementation of the Xtent model presented here attempts to combine the strongest features of all the methods discussed above. It allows the incorporation of site hierarchies and weights, realistic models of distance and topographic features while still retaining a compact, formal framework *(Fig. 2)*. Common GIS packages will offer at least two basic tools useful in territorial modeling: geometric partitioning using Voronoi diagrams and the calculation of cost surfaces. These are the basic tools for creating territorial GIS models from the ground up. For this case study, we decided to go one step further and implement an enhanced version of Xtent that can be used to create variations of realistic territorial models in an automated manner. The software discussed here is freely available in open source form and can be downloaded from www.quantarch.org. It integrates into the free QGIS / GRASS GIS software package that can also be independently downloaded from www.gis.org and www.grass.itc.it. The Xtent formula is ideally suited for implementation in a raster-based GIS model. It is possible to use arbitrarily detailed GIS data models to parametrize it realistically. Center weights can be expressed as a function of e.g. population size, military strength, economic power or religious significance. Center proximity can be expressed as straight-line Cartesian or geodesic distance or cost of movement.

The physical properties of the landscape have a strong influence on the delineation of territories, par-

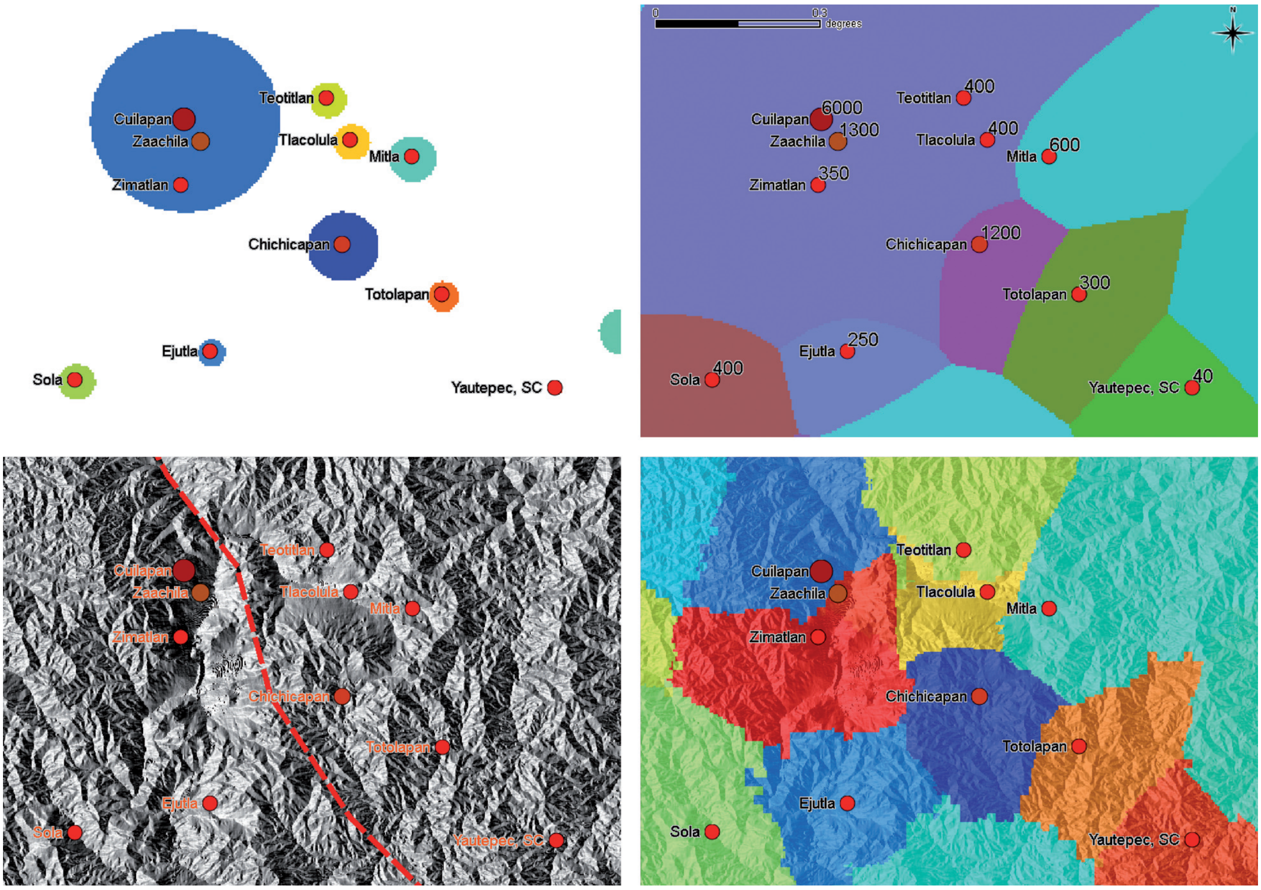

Fig. 2. Different versions of the (modified) Xtent model for a study region in the Maya lowlands. Top left to bottom right: basic model with territory sizes according to center weight; complete enforced partitioning without unallocated areas; inclusion of terrain properties (slope steepness) and barriers results in modified territory shapes.

ticularly in places where natural barriers or corridors impact human movement. In the original Xtent model, the varying nature of topography and its possible impact was recognized but not incorporated into the mathematical model (see Renfrew / Level 1979, 151; Grant 1986, 24–25). One straight-forward step towards more realism is to replace the straight line measure of distance d with a cost of movement measure that considers the actual, physical effort of moving on the ground from one location to another *(Fig. 2)*. All major GIS offer algorithms to create such cost surfaces with varying levels of detail and realism (see Conolly / Lake 2006, 215–225; Wheatley / Gillings 2002, 151–159 for details). It is possible to use arbitrarily complex combinations of GIS tools to create cost surface maps a priori and include them in the model, but simple cost maps can also be created ad hoc from a digital elevation model of the study area. Boundaries and pathways are topographic features (usually of linear geometry) that block or facilitate movement, respectively. Examples for boundaries may be broad rivers, mountain ridges or built walls; they may be absolute or permeable. Pathways could be natural passes or built roads. Exactly what qualifies as a boundary or pathway depends on the type of movement modeled in the territorial allocation process. Such features can easily be added to a cost surface map for enhanced realism if the archaeological record provides sufficient information.

There are few actual applications of the Xtent model in archaeology besides the original study (but see Soetens et al. 2002; Hare 2001; Grant 1986; Scarry / Payne 1986), although the method is discussed frequently in text books (e.g. Renfrew / Bahn 2000, 179–182; Conolly / Lake 2006, 213). The lack of case studies has been attributed to the fact that researchers are dissatisfied with the model's sensitivity to subtle changes in the a and k coefficients *(Fig. 3)* and the need to calibrate these subjectively for each individual study area while at the same time facing the problem that the actual value ranges that produce a good fit are hard to interpret as they do not correlate with meaningful weight or distance units (Conolly / Lake 2006, 213). Our GIS implementation offers alternative ways to constrain territorial outstretch by defining hierarchical relationships between centers and maximum

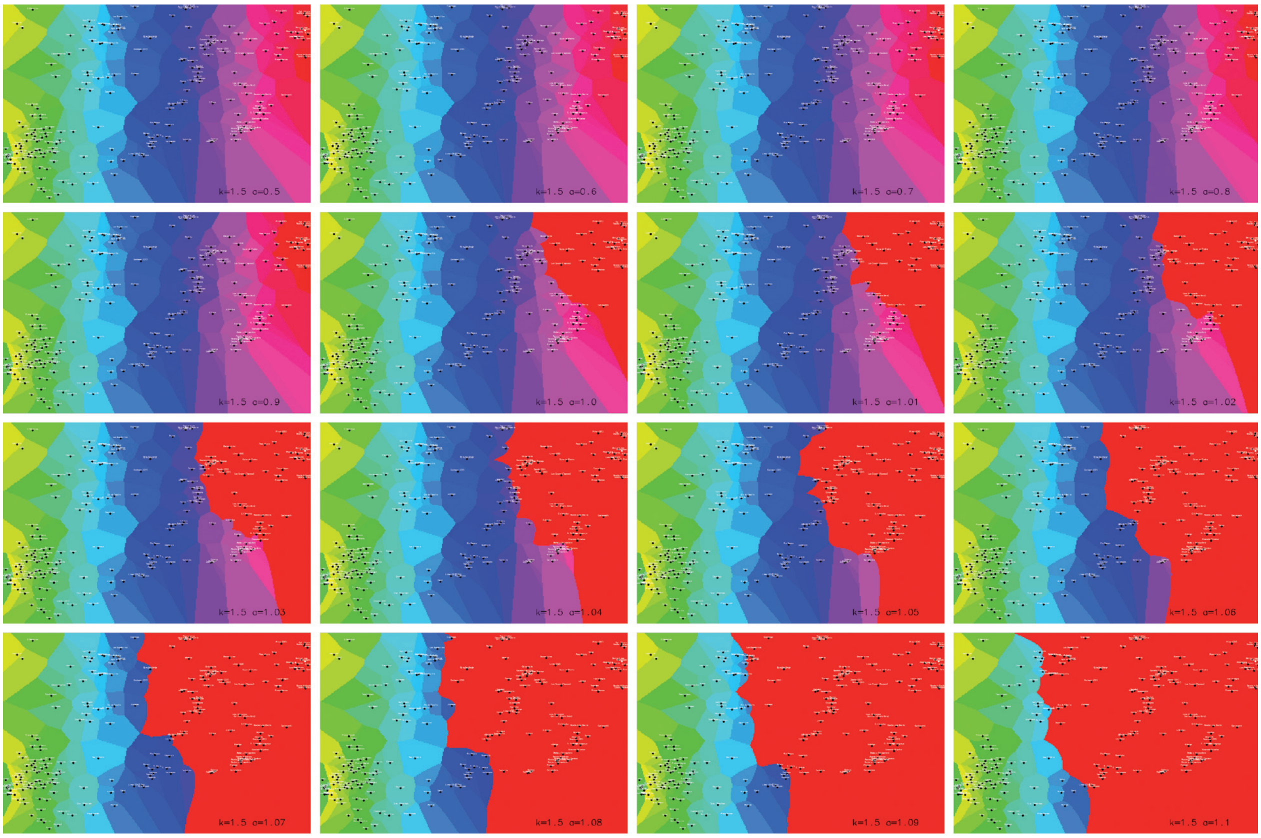

Fig. 3. Top left to bottom right: Experimental results for an Xtent model (with complete territory allocation) holding k constant and slowly increasing a from "0.5" to "1.1" in a large sample area. Note the growth of the largest center's territory in the east of the study area.

territorial reach a priori, making it easier to control the results and relating them to real-world scenarios. If a site is known to have been dominated by another center, no autonomous territory will be allocated to it. Modeling unallocated areas ("no-man's land") is made possible by the original definition of the Xtent formula which will leave any location for which I <= 0 unallocated. However, in the GIS implementation this constraint can be dropped and replaced with an a priori maximum territorial reach for each center. If the distance measure is taken from a cost surface map, territory shapes will be determined solely by hierarchical relations and terrain properties, making it easier to interpret and compare different models *(Fig. 2)*.

Territorial allocation is not always a clear-cut case and our GIS implementation caters for this by providing a spatial measure of uncertainty. Many different combinations of variables may lead to situations where a center A "wins" highest I only by a relatively small margin over another center B. In this context, we will refer to center B as the "competitor" and to the inverse of the margin between A and B as "competition strength". Thus, whenever there is reason to say that "center B is almost as influential as center A" at a location x, then the strength of competition will be high and B will be classified as the competitor for that location. Strength of competition is normalized to the range "0" to "1" for the entire region. Both the competitor's identification and the competition strength can be mapped and may form the basis for interpretations. Competition can also be interpreted as an error measure, with higher competition in locations where the territorial allocation may be erroneous due to flawed input data. It can only be assessed for models in which at least two territories overlap.

Conclusions and Outlook

We believe that the Xtent model is an exemplary case of a well-defined and useful formalism that could not live up to its full potential at the time of its inception owing to the limited computational resources available. The general availability of powerful GIS technology has enabled a successful revival of the Xtent model with increased realism and flexibility. The improved Xtent model also offers new exploratory and interpretative potential. An example is the competitor map which in combination with a threshold competition strength value could be used to map border regions from the perspective of any center. The extent of border zones could indicate potential "trouble zones" that are hard to control for the dominant center. The interpretative value of the results will be further enhanced if the distance measure employed is meaningful. More detailed cost maps could take into account vegetation, terrain roughness, etc. and represent actual physical movement costs. For example, Tobler's hiking function could be employed to express distance as actual travel time.

Xtent also combines ideally with site catchment analysis. It is a trivial operation to count the resources within a territory and use this information to check for either plausibility of the predicted territories or of the assumptions underlying a center's hypothetical resource needs. In any case, it is in archaeology's nature to produce incomplete data and any model derived from an archaeological settlement pattern should be checked for robustness against missing and false information. Such a sensitivity analysis can be carried out by systematically changing center locations and attributes within a reasonable range of variation. In this way, it will be possible to assess which information and assumptions have the greatest influence on the resulting territory shapes and should thus be treated with increased caution.

We believe that our enhanced GIS implementation of the Xtent model has a lot to offer for quantitative territorial analysis and would be delighted to see additional case studies that put our software's flexibility to the test. Feel free to contact us for questions regarding the use of our software.

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