Archeologia e Calcolatori
7, 1996, 313-326

A CRITIQUE OF G.I.S. IN ARCHAEOLOGY. FROM VISUAL SEDUCTION TO SPATIAL ANALYSIS

1. Spatial analysis in archaeology and GIS software

Most archaeological information is *spatial* in nature, because it deals with the placement of archaeological finds, contiguity and neighbourhood relationships between archaeological entities.

Since archaeologists realised the potential benefits of studying relationships between behaviour and the *spatial* distribution of material culture, new ways of representing, visualise and analyse archaeological findings have been proposed. Mapping, or the map-based approach has represented the earliest phase of spatial analysis in archaeology insofar as it has been for centuries an extremely efficient storage medium for condensing a large amount of spatial data and associated attribute variables into a single sheet of information. In this respect, until the earlier 70s archaeological spatial analysis had relied on descriptive informal methods based upon map inspection and almost intuitive impressionistic interpretation. This visual analysis benefited from the dissolution of composite maps into overlay plans showing selected features and categories, to examine their degree of correspondence and to make some subjective judgements about the strengths of the relationships between them. Although in the initial and exploratory stages of many types of archaeological spatial analysis such methods are still valuable, the human eye-brain system is not always a very precise instrument to assess the strengths of spatial relationships.

This fact lead to the adoption of formal quantitative methods borrowed from other disciplines such as plant ecology and geography in order to get more objectivity in data recording and analysis. This quantitative movement got off on the wrong direction because it made too often the straightforward assumption that archaeological problems were easy to solve and that statistics and archaeology shared the same problem solving logic. This thoughts yielded a mechanical non-reflective application of mathematical techniques to solve badly defined archaeological problems, without considering the analogy between mathematical models and real problems. For more criticisms of quantitative spatial analysis approach see, among others Aldenderfer 1987; Lock 1992; Ammerman 1992; Barceló *et al.* 1994.

In such an atmosphere of disappointment about the performance of formal techniques as they have been applied over the last two decades one may understand the rapid growth and expansion of Geographical Information Systems during the 80s. Currently, GIS software has been proposed as the best solution for nearly all archaeological problems, because it has the ability to store not only the locational and attribute data for each archaeological entity but also the *spatial relationships* between them. Nevertheless, despite widespread recognition that spatial analysis is central to the purpose of GIS, most applications to date have only shown their power to input, storage and manipulate spatial data, in order to elaborate computer mapping. In fact many of the current archaeological GIS projects are only a database containing a discrete representation of archaeological data in a static two-dimensional space, with a functionality largely limited to primitive geometrical operations to compute simple relationships between points in the space, and to simple query and summary descriptions (GOODCHILD *et al.* 1992). It seems as if the only goal was to insert the maximum quantity of information into a map. This indiscriminate map production is related with a lack of prior theory or hypotheses about the kind of problems archaeologists want to solve or about the expected relationships between spatial data, believing that mapping equals spatial analysis (GAFFNEY, VAN LAUSEN 1995). This tendency can explain why many recent applications of GIS, particularly in regional settlement location studies, reflect an environmentally deterministic approach to archaeological explanation (as have been pointed out by GAFFNEY, VAN LAUSEN 1995, VERHAGEN *et al.* 1995; HARRIS, LOCK 1995). Archaeologists are mainly working with environmental variables that are amenable to cartography describing the topography, lithology and hydrology of an area and that are relatively simple to map, forgetting the importance of social interaction in the analysis.

The research challenge lies in building on these principles a new theory of spatial relationships and using a new set of spatial analytical tools. There has been some work in that direction (BIRKIN *et al.* 1987; GOODCHILD 1987; BATTY 1988; CLARKE 1990; OPENSHAW 1990; FISHER, NIJKAMP 1992; FOTHERINGHAM, ROGERSON 1993; ANSELIN, GETIS 1992), but most of these references have not found their way into archaeology.

2. The need of a socio-spatial theory

2.1 *The concept of social space*

Even nowadays most archaeologist still do not recognise that space is a very general concept used in many different contexts to denote different things. There are abstract mathematical spaces (structures made up of arbitrary elements according to a set of axioms), psychological spaces, economical spaces, physical spaces or the "real" space in which human activity evolves, etc. (HERNANDEZ 1994).

The word "Space" seems to denote a "set" of entities to which may be attached associated attributes or properties, together with a relation or relationships, defined on that set (GATRELL 1983, 1991; PEUQUET 1988). *Space* is then the network of all underlying *spatial* relationships between different entities. A *spatial variable* is, consequently, any quantitative or qualitative property of data varying *spatially*, and which contribute to explain the dependency relationships between the locations of those entities (CRESSIE 1991). Given these features, we can define *social space* as any network of spatial relationships linking any set of *social units*.

2.2 *Social activity areas*

These social units are not always sets of people (families, local groups, villages, tribes, political territories, etc.), but any set of *social actions* (productive, reproductive) that have been performed in a single location. We may call these units *Social Activity Areas*. Given the fact that there are many different possible associations between social actions performed at a single location, there are many different ways to describe those social units, and thus many levels of representations. In this respect some isolated finds may define a low-level social activity area, whereas the spatial relationships among those low-level units may contribute to the definition of higher-level units. Here, *low* or *high* level refers not to any measure of relevance, but to the degree of structural complexity.

Some examples of social activity areas may be:

- an empty area, for instance, a ceremonial area after ritual cleaning
- an isolated grindstone
- a hearth
- a garbage pit or dumping area
- a storage pit
- any activity area within the settlement (butchering area, tool manufacturing area, food preparing area, metallurgical or artesanal activity area, etc.)
- a house
- a village (a set of houses, storage and garbage pits, activity areas, etc.)
- a grave (the set of rituals and ceremonies performed in that location, not the people buried there)
- a burial area (a set of graves and ritual structures)
- a territory (for instance all its village components and the set of social interaction networks among them)

Social activity areas are spheres of social interaction without any fixed boundaries; they are characteristically 'fuzzy' (GOODCHILD 1987; BURROUGH 1990; CASTLEFORD 1992; USERY 1993). Moreover, their features and topological characteristics change/vary according to time (LANGRAN 1989), because the units of social space are not only multidimensional, but *dynamic*. Consequently, not any single partition method of geographical space results in a model of the social space in use.

Archaeologists used to mechanically define social activity areas from discovered artefact concentrations. However, there is not a direct correspondence between the observed properties of archaeological contexts and social activities because of the enormous variety of transformational processes with different dimensions and temporal rhythms that can have acted upon the archaeological record. Consequently, in order to divide physical space in spatial areas where some social actions were performed, we have to discover *temporally dynamic, multi-dimensional* and *fuzzy* sets of spatial associations among archaeological finds, not only tool-kits, but also any kind of elements or features useful to diagnose a social activity.

In the same way, as it was shown by early etnoarchaeological studies, activity areas do not need to be spatially dispersed but there are different alternative models which embrace:

- Dispersed or segregated activity areas that assumes that different objects and features are partitioned into spatially distinct units, each corresponding to a single activity or group or related activities.
- Agglomerated or multifuncional activity areas, characterised by the overlapping of different social activities.

Given the effects due to *time*, we have to distinguish between more or less stable (fixed) areas and dynamic (temporally modified) ones. This temporal distance may be present in a single continuous episodic occupation but it is stronger as a product of different processes of reoccupation and reuse. Insofar as the archaeological record is the product of repeated depositional events over different periods of time, we must also take into account this change through time.

2.3 *Relationships between social activity areas*

Social activity areas are not spatially undifferentiated or isolated. They are in a intrinsically better or worse location for some purpose because of their position relative to some other meaningful unit: social groups build their own space because they appropriate some biophysical spatial areas and are able to defend them against the members from other groups (Tricot, Raffestein 1979). Consequently, *space* is not a property of distinct areas existing outside and prior to society, but it is socially constructed (Lefebvre 1974; Soja 1980, 1985; Coucelis 1988; Verhagen *et al.* 1995; Pallarés 1993; Barceló 1995).

The fundamental premise of the socio-spatial dialectic, already pointed out by Lefebvre is that social and spatial relationships are dialectically interreactive, interdependent; that social relations of production are both space-forming and space-contingent (Soja 1980). In this respect, as spatiality is simultaneously the medium and outcome of social action and relationship, it is not only a product but also a producer and reproducer of the relations of production and reproduction (Lefebvre 1974).

As a result, in order to study *social* spaces we should discover the *spa-*

tial properties of all relationships linking those areas defined by the set of associated social actions performed there. Social Space is not only a partition of geographical space into "social" areas, but a network of interactions between those units. These interactions are built upon difference/similarity relationships between social activity areas, and configure a complex structure of *social* and *physical distances.* For instance:

- distance produced by the spatial proximity between each area
- distance produced by the diversity on resources in each area
- distance produced by the diversity of production activities in each area
- distance produced by the differences in volume of production in each area
- distance produced by the diversity of consumption activities in each area
- distance produced by the differences in volume of consumption in each area
- distance produced by the differences on quantity (density) of social agents in each area
- distance produced by the differences on the nature of social agents in each area
- distance produced by the differences on quantity of social interactions (contact) in each area
- distance produced by the diversity of interactions (contact) in each area

If we arrive to integrate in a GIS environment different layers showing fuzzy social activity areas at different levels of complexity and temporal modification, and we extract similarity relationships between any kind of units to define a multi-dimensional distance metric, we will be in the position to describe the structure of a social space.

However, current commercially GISs do not allow the representation and analysis of social space models, because they are still generally designed around basic raster and vector models which place primary importance on locations of geographic phenomena, sacrificing the rich analysis capabilities provided by structuring entities on the basis of classification attribution and interrelationships (Goodchild 1987; Usery 1993). This inappropriate language of representation is a consequence of the very fact that GIS systems lack a coherent body of theory and organising principles by which real-world archaeological entities can be represented in a *social* space.

New models must be developed to fully support spatial analysis and to relate particular social processes to particular spatial associations of objects, elements and relationships.

3. Integrating social space theory and spatial analysis techniques in GIS projects

Some basic features of social spaces can be determined automatically through a combination of analytical and statistical processing, using set theory. For example, several social activity areas are defined by the presence/absence of specific archaeological finds. In those cases we can build a production rule associating the presence of archaeological data with their interpretation as a distinct social activity area. An expert system may be programmed to do this job, provided we have the right knowledge-base with ethnoarchaeological and experimental information (BARCELÓ 1996).

Nevertheless, understanding the complexity of spatial processes and therefore how relational patterns are produced, controlled, and reproduced is not an easy task. Most social space categories are fuzzy, because it is not possible to specify a rule that identifies all of its members and only its members. The solution comes from a multi-dimensional approach that accepts the existence of social activity areas at different resolution levels. The goal of the analysis is to assess how low-level areas are organised in higher-level units, and how relationships between low-level areas contribute to explain the multi-dimensional structure of social space.

In the following sections we introduce a multi-dimensional approach which may be easily integrated into a GIS project. The framework can be summarised as follows:

- Geostatistical analysis of archaeological data (artefact concentrations, waste, ecofacts, architectonic remains, etc.) to discover discrete units ("partitions") in the geographical space that can be classified as distinct social activity areas.
- Ordering of social activity areas according to their complexity level (in terms of associations between different kinds of archaeological evidence). Social activity areas of the same level are included in a single layer. Different layers contain social activity areas at different complexity levels.
- Comparison of social activity areas through Boolean analysis between layers.
- Analysis of neighbourhood relations (spatial *dependence* model) between social activity areas, both within the same layer and between layers of different complexity level.
- Analysis of similarity relationships (*distance* model) between social activity areas, both in the same layer or between layers of different complexity level.

The result of all these techniques is not a "visualisation" of social space, but a *model* of social interactions between social units. We obtain not only a list and a description of social activities performed at different locations, but also the *dependence* between those locations produced by the similarities and differences between social actions. Given that *social interaction* is the formation process of social spaces, we describe "archaeological space" as a structure defined by the network of dependencies between social activity areas. In this way *social space* appears as something constituted, reproduced and changed by social relations, and in turn constraining the unfolding of such relations (COUCELIS 1988).

3.1 *From artefact distribution to social activity areas*

Because artefact concentrations do not correspond necessarily with social spaces, we defend the use of several methods in a complementary fashion in order to define social activity areas using archaeological evidence as an indicator of their presence. All these methods are related with the partition of continuous physical space in discrete social units. To translate physical features into social structures, we should select material evidence of social actions, and the spatial distribution of those data. But the most important aspect of social partitioning is their multi-dimensional nature, that is, the need of associating disparate kinds of evidences (human manufactured with nature produced, foods with tools, luxury items with rubbish, etc.).

There is a fertile literature concerned with different techniques to identifying spatial patterning isolating discrete areas. This task may be performed by means of different clustering methods, that try to partition objects and features into groups based on observed similarities or differences. The methods of pattern recognition that at present seem to have a better performance are *Pure Locational Clustering, Unconstrained Clustering, Presab* (presence/absence method) and *Correspondence Analysis* (Kintigh, Ammermann 1982; Kintigh 1991; Whallon 1984; Blankholm 1991; Gregg *et al.* 1991; Pallarés 1993).

Image processing techniques provide an alternative approach to clustering. *Image segmentation* is the process of dividing an image into regions or parts of uniform appearance that have a strong correlation with objects or areas of the real world contained in the image (Sonka *et al.* 1993). In archaeology this can be used to locate areas where archaeological sites are likely to be found. Edge detection and image enhancement are techniques used to identify specific cultural features. Current applications in archaeology have focused mainly on field survey data, and regional intersite analysis, in order to locate sites and features, define physiographic regions, soil zones, etc. Nevertheless, most of these techniques can also be applied with any spatially distributed data in two or three dimensions at the intrasite scale, to investigate spatial organisation and thus establish social activity areas (Vorion Canicio 1993; Lang 1992). The purpose of image processing is not to see images, but to analyse information contained in an image, searching for unknown structure by removing the effects of noise or blurring, or to find a relation between an input image and an archaeological model.

Another possibility implies the use of unsupervised learning neural networks based on algorithms which implement some kind of "competitive" learning rules allowing clustering of input data solely on the basis of the intrinsic statistical properties of the set of inputs (Caudill, Butler 1992). Given a raster model of physical space in a GIS layer, the neural network allows the *classification* of different *discrete* input into a model of *continuous* space. For instance, let us imagine we have discovered two hearths and several postholes in a site. We know that each hearth constitutes a social activity area, but we are interested also in knowing if there are some activity areas at a higher complexity level associating the hearths with the postholes (for instance, one or two dwellings each centred around each hearth). An unsupervised neural network can be trained to calculate the degree by which the input activation from the postholes is assigned to each one of the hearths.

It is beyond the scope of this paper to detail technical questions or to make a comparative evaluation of the shortcomings and resolution power of each method and technique. The only thing we have to keep in mind is that in order to classify discrete partitions of physical (archaeological) space as social activity areas, we should include as many social data as possible, in the form of different kind of evidences (productive process evidences, consumption remains, residential structures, natural resources, etc.). This is the principal restriction of some statistical methods that are specially sensitive to differences in scale or that impose metric constraints on raw data. We simple advocate the use of those methods which have been developed to solve archaeological problems and operate under as few constraints as possible. If we use them in a complementary fashion, working both with continuous/binary data, and coordinate/gridded data, thus they may be useful to isolate discrete activity areas.

3.2 *Comparing social activity areas at different complexity levels*

Once we have defined some discrete units by means of different complementary methods, the next stage of the analysis consist of comparing these social activity areas at different complexity levels. The objective is to integrate in a GIS environment several layers with different information concerning location, morphology, size, archaeological content and contextual information of every discrete unit in order to build similarity relationships between social activity areas at different structural levels.

This process must be done by means of a formal GIS language with a defined syntax and vocabulary specific to map analysis which can define any model of spatial interrelationships. In this respect, it is needed a map algebra that defines not a simple arithmetic combination of map layers but integrates some more complex spatial operators.

Specially relevant for us are the possibilities to compute mathematical and Boolean operators with points and clusters of points. This paradigm is based on the formalised system for expressing GIS functions developed by C. Dana Tomlin (TOMLIN 1990; MILLS 1994). The representation language MapAlgebra, described by Mills (MILLS 1994), seems one of the most powerful modelling paradigms because it works with different operations that seem able to induce any kind of associative principles, connections and relationships between the variables of interest to describe social spaces.

3.3 *Geographical distance between social activity areas*

Our next task is to measure the degree of *spatial* variation in each layer of social activity areas, that is, variation in social space due to neighbourhood distances. What we are looking is if what happens in one social activity area is related (depends on) with what happens in the mean of neighbour social activity areas. If the observed spatial variability between social areas has not any known source (time, function, ethnicity, culture, economy, society, etc.), then we shall not expect any spatial association. Spatial heterogeneity occurs when there is a lack of spatial uniformity in relationships between the variables under study. When the variation is not wholly erratic, and there is some regularity, we say that there is a certain degree of *spatial dependence* between spatial units (OLIVER, WEBSTER 1990). The analysis then pretends to examine if the characteristics in one location have anything to do with characteristics in a neighbour location through the definition of a general model of the space. There are many different techniques to compute if there is some degree of spatial dependence (CRESSIE 1991; GETIS, ORD 1992; TRICOT 1987).

It may also be useful to calculate a *model* of the dependency structure discovered. Surface interpolation is the most usual technique to perform this task. Polynomial surfaces of various orders may be fitted to the maps containing social activity areas. The goal is to obtain a geometrical surface generalising the observed distribution of data to portray their overall patterns of location (SCHIEPATTI 1985; OLIVER, WEBSTER 1990; CRESSIE 1991; VOIRON CANICIO 1993).

Once we know whether neighbouring social space units are similar or not, we have to explain why the location of social activity areas shows that level of spatial homogeneity or heterogeneity. This can be done using contextual classification methods, that is, the assignation of conceptual labels (explanations) to our social space dependence model, relating different social actions (manufacture, cooking, residence, ritual, etc.) with the discontinuities measured on our model of social space. The problem is that most actual GIS projects confound geographical variables (soil productivity, soil erosion, vegetation, etc.) with contextual data, ignoring the specific nature of contextual information. Contextual data can be defined as those that are relevant to identifying some archaeological observation or pattern, or to interpreting some facts, excluding the data that are used by the one model to make the identification/ interpretation (CARR 1991).

3.4 *Other distance measures between social activity areas*

There is not any single method to analyse the effects of non geographical distance on the variability between social activity areas. One of the most common approaches in recent archaeological studies consist of applying multidimensional scaling, or correspondence analysis, in order to *classify* archaeological data in different social activity areas.

We can also use unsupervised learning Neural-Network to "translate" feature input vectors into neighbourhood functions using similarity relationships between input vectors (KOHONEN 1988). The purpose of the system is to evolve localised response patterns to input vectors. When two input vectors are similar, they evoke similar localised response patterns. Consequently patterns of high dimension (distinctive features of social activity areas) are transformed into a two-dimensional pattern, preserving the ordering of the input patterns. Distances between points will not be preserved but their topology will -that is, input vectors that were adjacent to each other will still be adjacent to each other. Given that distance metric is not preserved on the output layer, the result is not a representation of physical space, but of social space *excluding* distance between social activity areas. The location of areas in the Kohonen layer has not any sense, but the degree of social partitioning measured can serve as an evidence for the *complexity* and *differentiation* level of social space.

Another way to study non-geographical distance models on social space would be through graph theory (HERNANDEZ 1994). Mathematically speaking we can translate the locations of social activity areas into vertices which are connected by edges to points with the same value on a spatial variable (similarity). We call it the *neighbourhood structure*, because we suppose that the closer the points, the closer the measures of spatial space.

The analysis of similarities and differences between social activity areas does not end here. We can use many other methods derived from Classification Theory and Machine Learning (BARCELÓ 1996). Some of these methods can be integrated into a GIS framework (specially induction methods and genetic algorithms), but some other (fuzzy cognitive maps, for instance) are difficult to integrate. Much more work is needed in this area of spatial analysis.

3.5 *From spatial analysis to visualisation*

In our view current approaches to GIS applications in Archaeology are based on the wrong assumption that inference proceeds from *visualisation* to spatial analysis, as if visualisation was a tool for spatial analysis. To us, the best procedure is to use visualisation tools to support results from spatial analysis.

Visualisation is a way of explanation: it transforms the symbolic into the geometric, enabling researchers to observe their simulations and computations. Data visualisation is a means whereby much more multi-dimensional data can be brought within the range of human experience and cognition. It should be stressed that the graphical aspect of solid modelling systems is not necessarily their prime function. Realism in solid modelling is achieved not only by modelling natural lighting effects, but by trying to embody some element of the social context and function of the subject in the visualisation and thereby bring the visualisation to life.

Geographic visualisation will be defined here as the use of concrete visual representations-whether on paper or through computer displays or other media- to make spatial contexts and problems visible. Visualisation in a GIS environment then has to be a part in the process of scientific discovery, helping archaeologists to detect regularities in the patterns of spatial relationships among social contexts. It may be integrated into a GIS platform as a means of presenting a series of hypothetical scenarios which are relevant to our understanding of human/environmental relationships. This can be done principally through the construction of a 'territorial' model designed to articulate a set of semi-autonomous activity spheres which are said to be implicated in the reproduction and organisation of a specific archaeological locus, or settlement (FLETCHER, SPICER 1992; LOCK 1992; HARRIS, LOCK 1995; REILLY 1992; VERHAGEN *et al.* 1995).

4. CONCLUSIONS

In recent years GIS has emerged as the best solution for nearly all archaeological problems due to its ability to manage large amounts of georeferenced data and integrate different kinds of spatial relationships. Here it has been argueed that one of GISs major restrictions as they have been commonly applied is their lack of analytic capacities. The wrong assumption that visualisation equates Spatial Analyis has led archaeologists to reduce problem solving to the making of pretty but sometimes meaningless pictures.

In our view GIS software can be of great utility in Spatial Analysis but only if we use it in the frame of a well reasoned theory, posing the appropiate questions to explain historical phenomena. The purpose of these essay has been to introduce some elements for a *theory of spatial relationships* needed to study *social spaces*. To this end we have proposed an operational *multidimensional approach* to discover social activity areas, which can be easily integrated into a GIS framework. This proposal involves the use of some already existing analytical tools in a complementary fashion (geostatistics, intrasite spatial tests, digital image processing, artificial intelligence, etc) in such a way that allows the model building of social interaction between different social units and therefore a better approximation to historical explanation.

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Acknowledgements

In this paper we discuss some theoretical assumptions and some methods we are using in our research on hunter-gatherer archaeology (M. Pallarés) and early iron age research (J.A. Barceló). We acknowledge fundings from the Spanish Ministry of Science and Education (Project PB93-0397 and Project PB93-0867) and a FI grant from the Catalan Comission for Research and Technology.

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ABSTRACT

The purpose of this paper is to critically explore the role of Geographical Information Systems in the archaeological research. Currently some archaeologists seem largely captivated by new computing technologies believing that the sophistication of powerful software outputs will lend respectability by itself. In our opinion GIS is merely a set of techniques to visualise and manage large amounts of georeferenced data. Thus there must be other tools to move from *visualisation* to *explanation*, which fall within the domain of *Spatial Analysis*.

The ultimate aim of this paper is to show how we can integrate these already existing tools (geostatistics, intra-site statistical tests, digital image processing, artificial intelligence, etc.) in a GIS framework, in order to move from beautiful images to hard analysis. Finally we criticise the lack of theoretical background in archaeological uses of GIS technology arguing that GIS is the only software and may benefit our research only if we use well defined *archaeological* problems on a well-based theory.