WORKSHOP 2 / ATELIER 2

SPATIO-TEMPORAL MODELLING IN ARCHAEOLOGY

MODÉLISER LES SYSTÈMES DANS L'ESPACE ET LE TEMPS EN ARCHÉOLOGIE

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INTRODUCTION

This session has been planned to emphasise the importance of spatial and temporal data in the establishment of mathematical models to be applied to archaeology. Space and Time are in fact fundamental dimensions of change and dynamics, which can provide profound insights into human historical and social processes.

In his paper J.A. Barceló stresses the importance of data "location" to describe the archaeological record. This relevant observable feature can only be understood in functional terms, in other words, in terms of what is done in each place (space) at each moment (time). The Author sets out to analyse spatially-related social actions through time and verify where, when and why they vary from one spatio-temporal location to another. Mathematical techniques are used as a representation language for studying the concepts of accumulation and attraction, and therefore for analysing social space in dynamic terms.

In the framework of the current wave of interest in, and enthusiasm for, agents in the computer science and artificial intelligence research community, A. Costopoulos presents a simulation model based on free-form "impulses", individually controlled by agents, as an alternative to the traditional linear and phase-based models used in Anthropology. This alternative approach to the study and understanding of social processes opens up new prospects for agent-based modelling in archaeology in general, and facilitates the emergence of social-like processes in a computer agent population in particular.

D. Snow presents a new dynamic spatio-temporal model of North American prehistory and protohistory, to visualise the ebb and flow of culture change and demographic processes. This model – based on the use of a GIS for recording and maintaining site-specific data which can be displayed as animations of spatial changes over time or as environmental changes over time and space – raises some theoretical and methodological questions about how archaeological data can be recorded and disseminated.

Finally, the article of B. Bosselin and F. Djindjian has been added to this session. The Authors propose a method of palaeoenvironmental reconstitution which, by building a palaeotemperature and a palaeohumidity curve, makes it possible to separate and correlate these two climatic components. The method, applied to three main European peat bog pollen sequences: La grande Pile, (Vosges, France); Tenaghi-Philippon (Macedonia, Greece); Banyoles (Catalonia, Spain), and compared to more recent results of ice cores (Summit, Greenland), permits a global reconstitution of the climate between 40.000 and 10.000 BP, with a precise definition of the main climatic events of the period in terms of temperature and humidity.

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ARCHAEOLOGICAL THINKING: BETWEEN SPACE AND TIME

1. The social nature of archaeological data

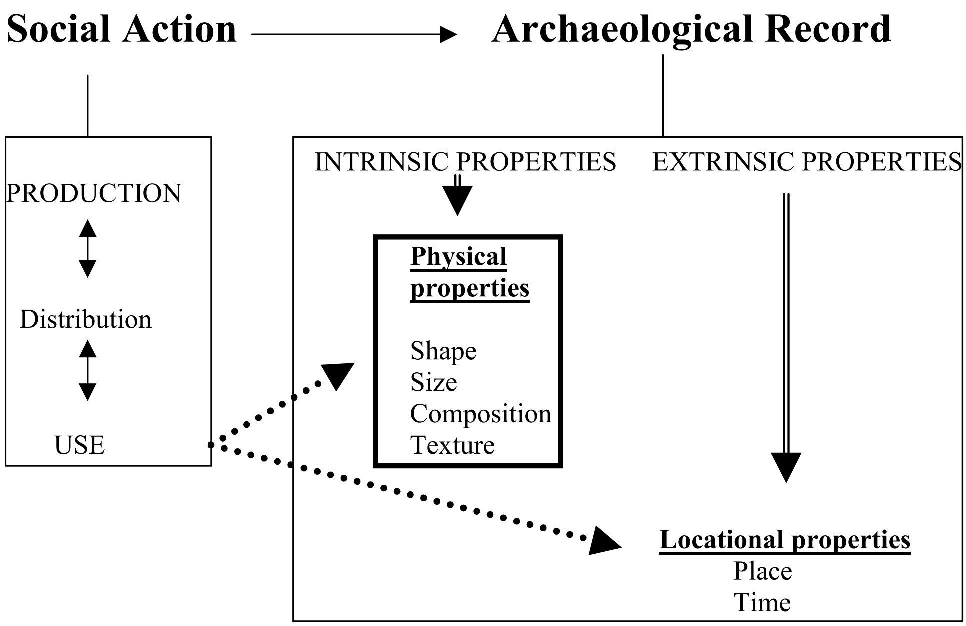
Archaeological artefacts have different shapes, different sizes, different compositions, and different textures. We should describe differences in those features and explain the sources or causes of that variability. Why stone axes have different shapes and sizes? Why graves have different contents? Why pottery sherds have different textures? In general, production, use and distribution are the social processes, which in some way have produced (*cause*) observed differences and variability (*effect*). For instance, some tools have different use-wear texture, because they have been used to cut different materials; some vases have different shapes because they have been produced in different ways; graves have different compositions, because social objects circulated unequally between members of a society and were accumulated differentially by elites…

The archaeological record can also be described using another observable feature: location. Shape, size, content, composition and texture values vary from one location to another, and some times this variation has some appearance of continuity, which should be understood as variation between social actions due to neighbourhood relationships. Why have stone axes in a specific location in space and time different shapes and sizes? It is impossible to answer why "stone axes" have different shapes and sizes, because there is no scientific law that applies to all stone axes in the world. But we can ask why stone axes from this location have shapes, sizes, compositions and textures, as compared to stone axes from another location.

The word "location" has not only a spatial meaning. It is also a way of describing any moment in time. Time and space are not different ways of considering the nature of archaeological data. There is space only, when the observer does not consider dynamics, that is "movement". And we can speak of time as a generalisation of changes and modifications in place. A pattern existing at one moment of time is the result of the operation of processes that have differential spatial impacts. In the simplest sense, patterns answer the question "where", processes answer the question "why" (Scheme 1).

Therefore, to speak about "location" necessarily implies to consider both space and time, because things happen *here* and *now*.

"Location" can only be understood in functional terms, that is, according to what is performed at each place and at each moment. What we require for both understanding and explanation is insight into why things are where they are. This is a consequence of the fact that social actions are (or have



Scheme 1 – A general framework for archaeological problems.

been) performed in an intrinsically better or worse spatial/temporal location for some purpose because of their position relative to some other location for another action or the reproduction of the same action. That is, events are defined by the spatial extent of the thing over all time periods. The space-time study of any spatial organization will remain incomplete if not coupled with an explanation based on the nature of the object or the event (KELLERMAN 1989).

Temporal relationships influence the spatial position of social acts, in the same way the spatial relationships of actions influence the temporal location (reproduction) of the same actions. Our objective is then to analyse where, when and why a social action "varies from one location (temporal-spatial) to another". In other words, the main objective should be the correlation of different social actions:

– how the spatial distribution of an action has an influence over the spatial distribution of (an)other action(s);

– how the temporal displacement of an action has an influence over the spatial distribution of (an)other action(s);

– how the temporal displacement of an action has an influence over the temporal displacement of (an)other action(s);

– how the spatial distribution of an action has an influence over the temporal displacement of (an)other action(s).

Given that *social interaction* is the formation process of social dynamics, we should correlate social actions, and translate the resulting correlation matrix in terms of a network space, called "social space" (Barceló, Pallarés 1996, 1998). I am using here the word "space" in the mathematical sense of the word, and not as a synonym for "place", that is, as a "network".

Social interaction involves the nature and function of connections among locations. These connections may be viewed as a layout of routes, or represented by information on the volume of movement, or flow, among places and times. The basic question is which places and times are connected to which others, at what level of intensity, and why? Which of these *connections* can be described as *causal relationships*?

2. Causality

What is "cause"? The most common answer is "the way an entity becomes what it is" (Bunge 1972); in our case, the "cause" of the society is the way this society has been formed, organised and determined, that is, how social actions produce social organisation. We can also say that a cause is the set of conditions, which determine the existence of any entity or the values of any property.

Our primary objective is not the cause of the archaeological record, but the formation process of society. To speak about the cause of society is to speak about the processes, which determine and generate social organisation. Consequently, we should study how social interaction produces social organisation, and not mere associations between objects. This is impossible if we do not use the archaeological record to infer the past performance of social actions. This means that we are studying a double causality chain. We do not have direct evidence, for social actions performed in the past, however, through time social actions have produced as a consequence some observable modifications on natural things, and some of these modifications have been preserved until today. Although we do not know what actions have produced what material consequences, we can relate the variability of observable features (shape, size, content, composition, and texture) with the variability of social actions through time and space. Consequently, we can infer the variability of social action from the variability of the archaeological record, and we can infer social organisation from the variability of inferred social actions.

All this means that in archaeology we should deal with events and not with objects. An event is an expression of the fact that any entity has some feature *f*, that this entity is in a state *s* and that the features defining state *s* of that entity are changing or not. The fact that a vessel has shape *x*, and the fact that a lithic tool has texture *t* are events, because a social action has been performed at this spatial and temporal location (event), resulting in an artefact with, among other things some specific shape and texture properties. Nevertheless, there is not any direct, mechanic or necessary connection between cause and effect (ANSCOME 1971; BUNGE 1972, 1985; TOOLEY 1987; KARPINSKI 1990; EELLS 1991; KELLERT 1992; MELLOR 1995). Some times, the social action is performed in one location, but the expected effect is not observable here and then, because the same action may not produce always the same archaeological features at the same location. Events are never produced isolated from other events. It is the spatial and temporal location of a nearly infinite quantity and diversity of related or unrelated events, which modifies the expectable consequences and effects of causal actions. Therefore, space and time influence the actual realization of effects once the social action has been performed. This apparent ambiguity between social cause and material effect should not be confounded with *indeterminism*.

All elements of the archaeological record, including spatial and temporal location, have been caused by social actions. There are many actions and processes, both social and natural that have acted during and after a primary cause, and also primary causes act with different intensities and in different contexts, in such a way that effects may *seem* unrelated with causes. In most real cases, we should speak of multiple causes and complex causal relationships, rather than of indeterminism or intrinsic randomness. The fact that we cannot *predict* the material outcome (*shape, size, content, composition, texture*) of a single action, does not mean, that an archaeological feature cannot be analysed as caused by a series of social actions and altered by other series (or the same).

The practical solution to this paradox is to consider that a social action or sequence of social actions will be causally related with a *state change* if and only if the probability for the new state is higher in presence of that action that in its absence. Causal significance of a factor *C* for a factor *E* corresponds to the *difference* that the presence of *C* makes on *E*. That is, changes in shape, size, composition, and texture are not determined univocally by production, distribution and use. But there is some probability that in some productive, distributive or use contexts, some values are more probable than others (SUPPES 1984; SALMON 1984; CARTWRIGHT 1989; EELLS 1991).

There are 4 main causal mechanisms:

– **Single Action**: P1 determines P2. Therefore, changes in P1 *cause* changes in P2, and P1, P2 are temporally ordered.
– **Stochastic Action**: P1 determines P2 *probability* of existence. Therefore, changes in P1 *cause* modifications in the probability value of P2 existence, and P1, P2 are temporally ordered.

– **Single Interaction**: P1 and P2 are reciprocally determined. Therefore, changes in P1 cause changes in P2, and changes in P2 cause changes in P1.
– **Stochastic Interaction**: The probability of existence for P1 and P2 are determined reciprocally. Therefore, changes in P1 probability of existence determine changes in P2 probability value of existence and changes in P2 probability of existence determine changes in P1 probability value of existence.

In archaeological terms, *cause* or *determination* can be defined as a probability function between social action (*production, distribution, use*) and material appearance (*shape, size, content, composition, texture*). However, we should not explain why different objects have the same or different shape, but we should explain why objects with the same shape appear at the same place, and at the same moment. Causal research will be wrong or even impossible if we do not introduce locational information.

It is important to realize that "location" is a property of social acts, but it is not a *cause* in itself. The spatial and temporal location of social acts is a consequence of other social acts, which limit, constrain, and, in some cases, determine future actions. Therefore, the real cause should be explained in terms of the "influence" an action performed at a location has over all locations in the proximity, and this "influence" can be described in terms of probability.

According to this idea, the degree of influence between neighbouring social actions depends on the knowledge each agent has of neighbouring agents, the spatial or temporal distance between social agents at different locations and the frequency and nature of interactions between agents at different locations. *Distance* is defined as the difference between the values of any property at two (or more) spatial/temporal locations (Gattrell 1983). The concept of *distance* is seen as a causal mechanism, because we usually assume that "everything is related to everything else, but near things are more related than distant things" (Tobler's law). This assumption is based on the Neighbourhood Principle (Boyce *et al*. 1967, 1971; Fix 1975), which relates the intensity of influences converging to a single location from the neighbouring locations. We should calculate the action performed on a location from the sum of probabilities of actions performed in a given area around it, or, instead, whether this sum of probabilities explains why an action was not performed in that place and at that time.

An action can generate the reproduction of similar actions around it, or it can prevent any other similar action in the same vicinity. Some of the actions performed in the vicinity of the location increase the probability of one type of action and decrease the probability of others. For instance, traditional conceptions about hunter gathering defend the axiom that *space* determines *settlement*. That is, that settlement is a consequence of the environ-

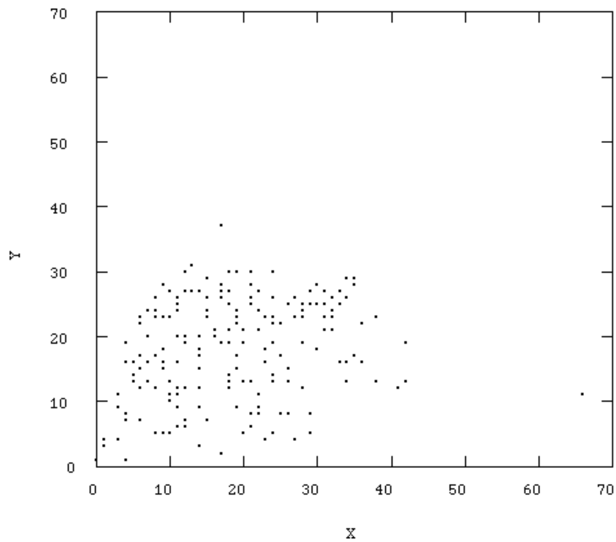


Fig. 1 – The Iron Age cemetery of Carmona. A distribution map of burials.

mental features or spatial properties of resources. I think that this is a too simple generalization. "Space" is not a *cause*, because social actions are not *adapted* to the environment, but productive actions (hunting, fishing, and gathering) determine the location of residential actions (settlement). What I am suggesting is that a social action can generate the reproduction of similar actions around it, or it can prevent any other similar action in the same vicinity. A settlement is not *adapted* to environmental conditions or resources, but it is the place where social agents perform actions like gathering, hunting, and/or fishing. The spatial and temporal location of those activities increases the probability of settlement in the vicinity and decreases the probability of other social actions (Barceló, Piana, Martinioni in press).

Therefore, when there is some regularity in the observable effects of social action across locations, we say that there is a certain degree of *dependence* between locations. What we are looking for is whether what happens (and *happened*) in one location is the cause of what happens (or *will* happen) in neighbouring locations. The analysis then pretends to examine if the characteristics in one location have anything to do with characteristics in a neighbouring location, through the definition of a general model of spatial dependencies. Once we know whether social actions at neighbouring locations are similar or not, we should explain why the location of social actions is homogeneous or heterogeneous in the area defined by the performance of those actions. The characteristics of space as a dimension, rather than the properties of phenomena, which are located in space, are of central and overriding concern (CLARK 1982). The overriding aim is to develop an understanding of the general principles which determine the spatial and temporal location of those observable properties of material effects *caused* by social actions.

3. SPATIAL LOCATION PATTERNS

A *social activity area* is not the place where a series of related social actions has been performed, nor the region where archaeologists find materials, but the *spatial consequence* of a social action or a series of social actions.

In archaeological research, we never know where the action was performed (in the past), but only the location (in the present) of some of its material consequences. Calculating the spatial density of those consequences, and assuming that a measure of density is a function of the probability an action was performed at that point, we can say that the area where the spatial density is highest, is the attraction point for all material consequences. Therefore, a social activity area can be described in terms of the probability of an unobserved action, which has caused the spatial distribution of observable material effects. The underlying idea is that changes in the probability of the input (performance of social action) determine changes in the probability value of the output (spatial variability of material effects). The probability that a social action occurs at a specific location is related to the occurrence of its material effects (the archaeological record) at nearby locations. In other words, the more frequent the material evidence of a social action (archaeological artefacts) at a specific place (location), the higher the probability that a social action was performed in the vicinity of that place.

We know that the location of archaeological artefacts is the joint result of a series of actions, and processes, both social and natural. Therefore social *activity areas* can only be calculated *probabilistically*. Given the Principle of Stochastic Interaction, if and only if there is some probability of causal relationship between input and output, then there should exist also some correlation between the output and the input. In this way, changes in the density probability function of artefact locations are related with changes in the probability value of a social action being performed at a specific location.

To compute the probabilistic map of a social activity we do not need to introduce a qualitative partition of the archaeological space. That is, no division into areas or regions will give us a model of the spatial probability for social actions. The approach here relies on a prior hypothesis of spatial smoothness (see also BARCELÓ, PALLARÉS 1996, 1998), which considers that two neighbouring observations are supposed to have been more likely originated from the same group than two observations lying far apart. This can be computed

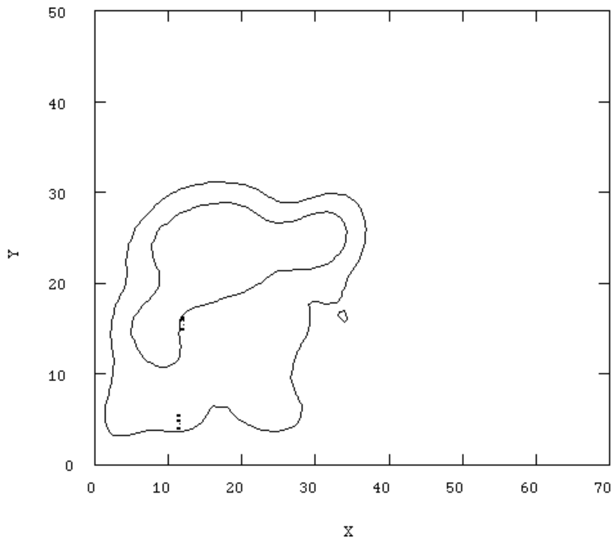


Fig. 2 – The Iron Age cemetery of Carmona. Kernel Density Mapping showing different concentrations of graves.

easily by estimating the spatial probability density function associated with each location. Given that locations are defined bidimensionally, we can calculate an interpolated surface representing the form of a probability density distribution for two continuous random variables, the Cartesian co-ordinates x and y. The idea is to estimate this bi-dimensional density function, given a sample of known locations. Kernel estimation techniques may be used for this task (Silverman 1986; Baxter, Beardah 1997; Beardah 1999; Beardah, Baxter 1996,1999; Delicado1999).

Let us look at some examples. Fig. 1 shows a distribution map of burials[1]. A cemetery is a spatial consequence of ritual performance. We can calculate a map representing the probability that some ritual action has been performed at specific locations (Fig. 2).

This is a standard contour graph, showing a relatively homogeneous spatial distribution of probability values. Where graves (points) are more dense, the spatial probability values are higher. In the case displayed in Figs. 1 and 2, their spatial distribution of graves is so dense that no distinct areas of higher probability seem to appear.

[1] The Iron Age cemetery of Carmona, South of Spain, with special thanks to Antonio Fernandez Cantos for these data. The co-occurrence of graves at some locations is not shown in this figure. Consequently, in some areas the density is much higher than is shown in the plot.

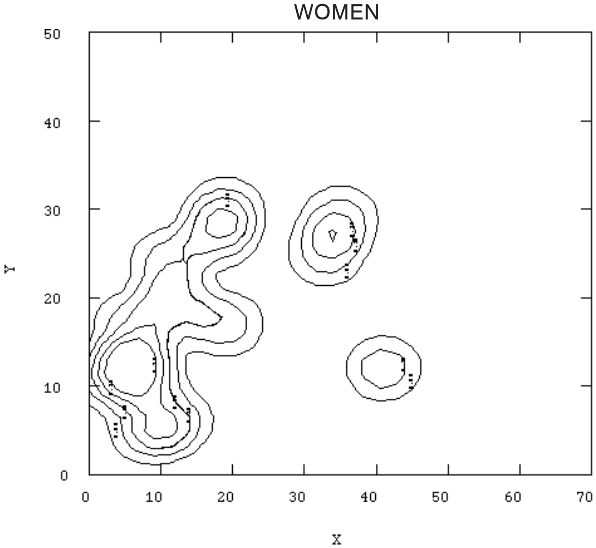


Fig. 3 – The Iron Age cemetery of Carmona. Kernel Density map for women burials. It shows their spatial concentration.

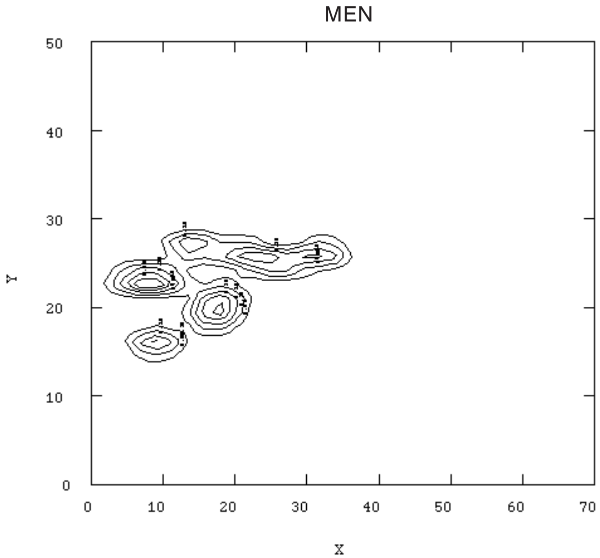


Fig. 4 – The Iron Age cemetery of Carmona. Kernel Density Map for male burials. It shows their spatial concentration.

We can use this model of spatial probabilities to understand social distance. Figs. 3 and 4 show the probability maps for women and men, and Figs. 5 and 6 the contour maps for symbolic ornaments and weapons. Figs. 7 and

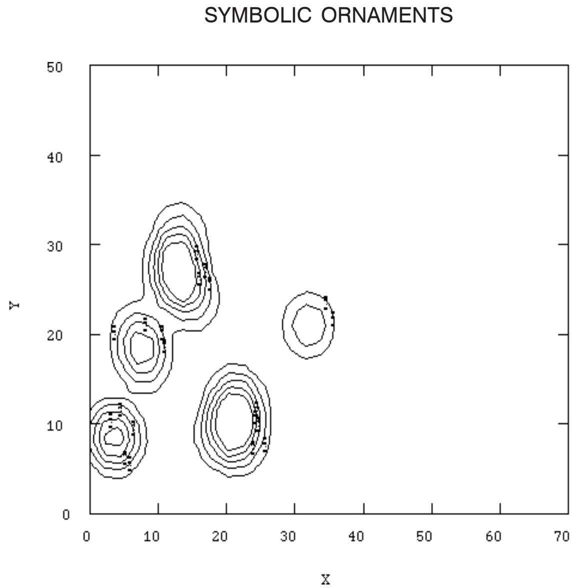


Fig. 5 – The Iron Age cemetery of Carmona. Kernel Density Map for burials with symbolic ornaments as grave goods. It shows their spatial concentration.

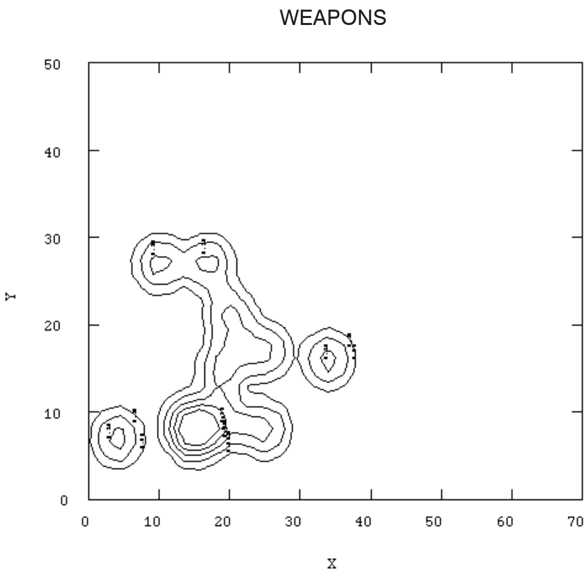


Fig. 6 – The Iron Age cemetery of Carmona. Kernel Density Map for burials with weapons as grave goods. It shows their spatial concentration.

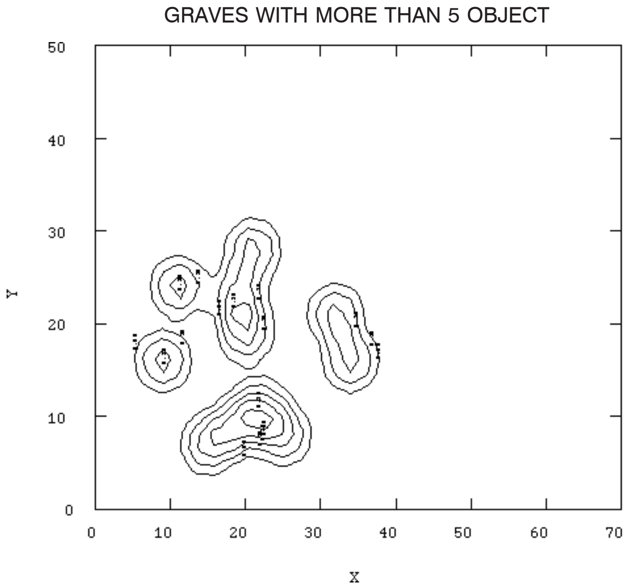


Fig. 7 – The Iron Age cemetery of Carmona. Kernel Density Map for burials with more than 5 objects as grave goods. It shows their spatial concentration.

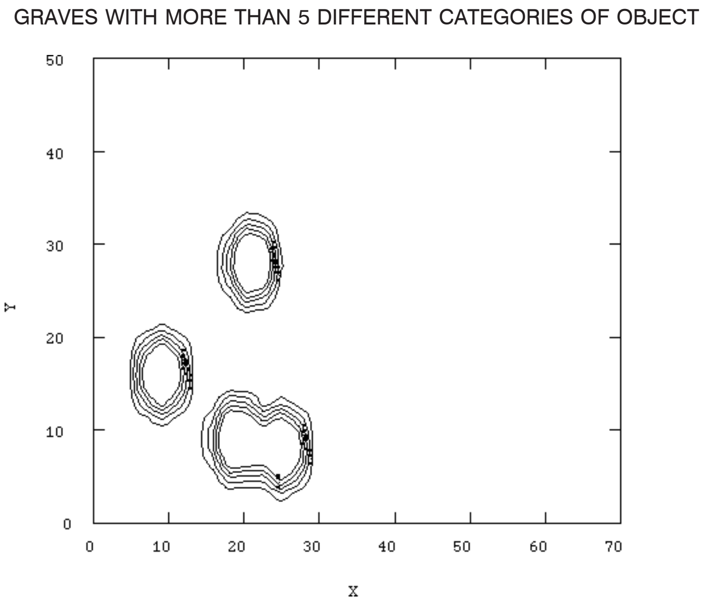


Fig. 8 – The Iron Age cemetery of Carmona. Kernel Density Map for burials with more than 5 different kinds of objects as grave goods. It shows their spatial concentration.

8 are an interpretation of rich graves, based on the quantity and diversity of grave-goods. It is easy to see that these specific ritual activities have different probabilities of being performed at different spatial locations. The funerary ritual for rich women is performed at specific places and the ritual for poor men is located in other places.

Probability maps should be considered a visual model of location features, and not an explanation of spatial causality. Contour maps as those presented here are a graphical convention for showing changes in the probability of a specific social action we suppose was performed there as a function of the location of some of its material consequences. In the case above, we know there is a causal relationship between social hierarchy and the spatial variability of graves with many grave goods ("rich" burials). Given the specific nature of that causality relationship we also know that the action was not performed in all places where a "rich" grave has been found. The spatial variability of graves is a consequence of the way in which burying a very important person has generated these specific material effects. Through probability maps we visualise how social order imposes a specific structure upon ritual locations.

4. Timing space

Let us now consider the relationship between time and space. Fig. 9 shows the probability map for ancient graves (7th century BC), and Fig. 10 shows the probability map for modern graves (6th-5th century BC).

It is easy to see that where the probability of performing a ritual action during 7th century is high, the probability of continuing that actions during the 6th and 5th centuries decreases. In some way, the spatial variability of graves from the 6th and 5th centuries is conditioned by the ritual activities performed there before.

Let us consider a different example. We have designed a series of controlled observations in order to be able to calculate the probability relationship between the disturbance effect and the composition and spatial pattern of archaeozoological remains. We have studied 30 carcases of "guanaco" (*Lama guanicoe*, a south American middle sized herbivore), scavenged by foxes in Tierra del Fuego (Argentina). During three years we have measured the density and locations of remains of animal carcasses that were produced by a catastrophic natural death in 1995 (Estevez, Mameli 2000; Mameli, Barceló, Estevez 2002). We have calculated a single probability map for each year of observation.

As time moves on, spatial disturbance increases, and the density of bones diminishes. Specially interesting is the second year, where the density in the centre goes up. Probably this is a "side-effect" caused by gnawing the

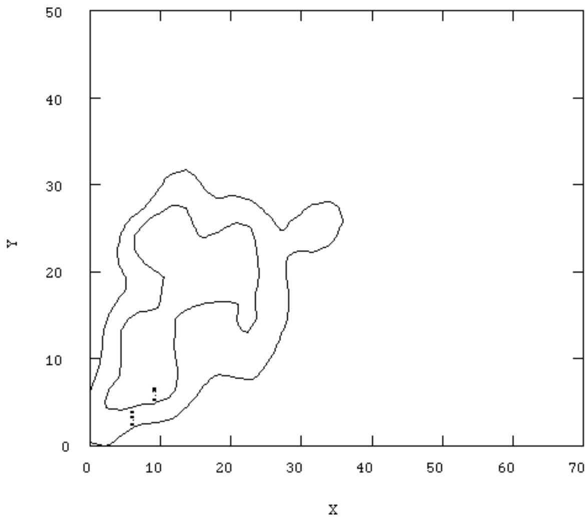


Fig. 9 – The Iron Age cemetery of Carmona. Kernel Density Map for ancient burials (7th century BC). It shows their spatial concentration.

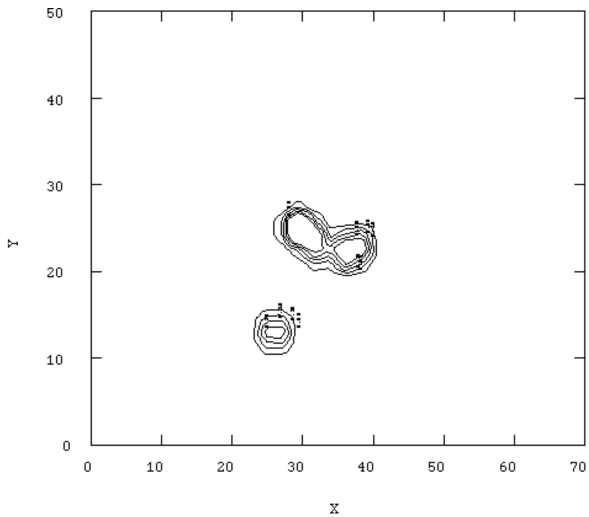


Fig. 10 – The Iron Age cemetery of Carmona. Kernel Density Map for recent burials (6th to 5th. centuries BC). It shows their spatial concentration.

bones into smaller pieces there. Fig. 11c shows the global density of bone placement after three years of continuing scavenging. There remains a core area of more dense findings, corresponding to the precise location of the original action (animal death). Now we can affirm that the higher the density

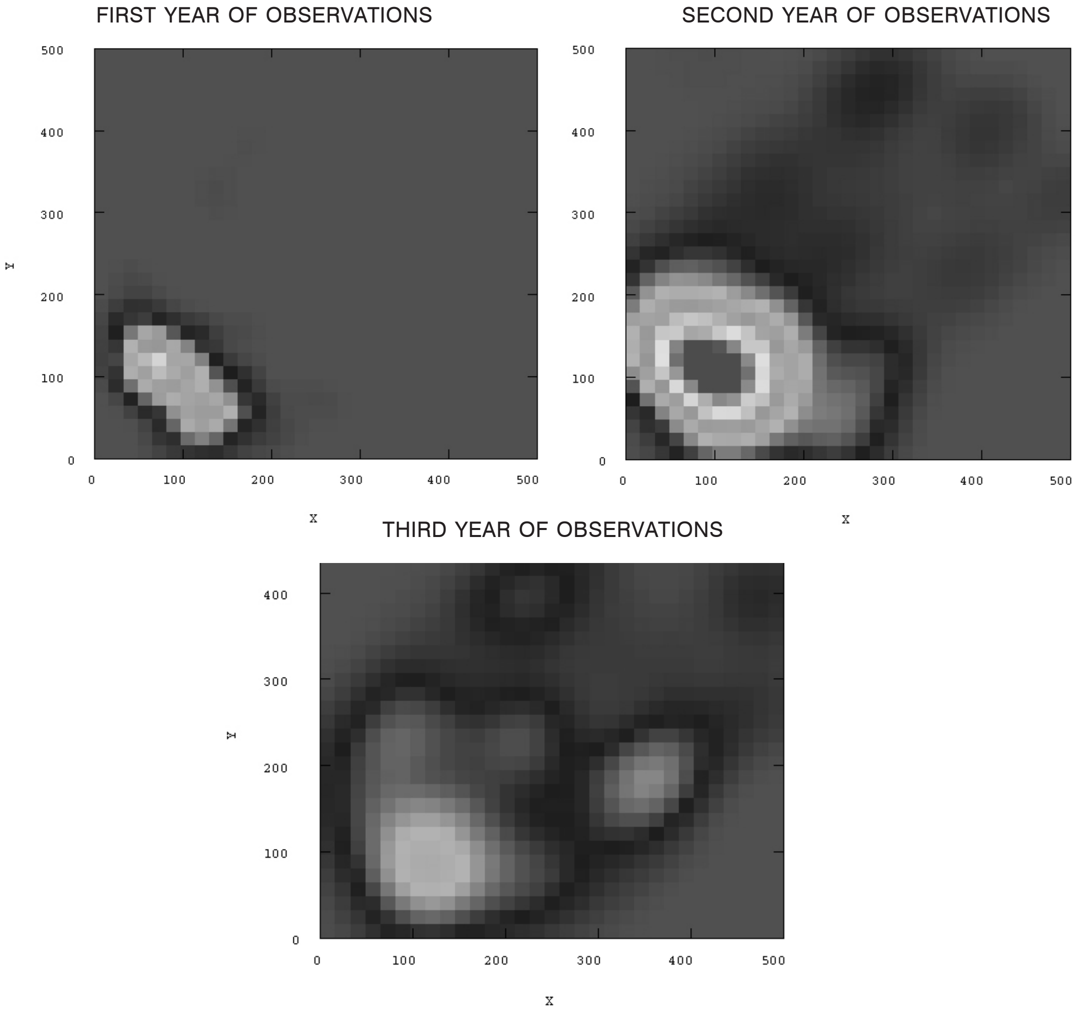


Fig. 11a-b-c – Spatial distribution of bones. a. Original location of bones during 1st year of observations; b. Location of bones during 2nd year of observations, after post-depositional disturbance; c. Location of bones during 3rd year of observations, when animal carcases enter the archaeological record (trampling).

of findings is at the end of the process, the higher the probability of this being the location of the original action. We are not calculating the probability of scavenging, but evaluating the possibilities to infer the original action in the palimpsest generated by scavenging as a post-depositional process.

These examples show how space is timed by the *duration* of activities which occur in a given space and indirectly by the location of an activity *X* within the sequence of activities (*a, b, c,…x…, z*). Space is timed in terms of the number of activities that occur over some time period t_0-t_1 (PARKES, THRIFT 1980; KELLERMAN 1989). Thus, different spatial locations may be used as resources in several ways, and these spaces may shrink or expand during, or as a result of changing, uses. Activities move in space and cause an extensive spacing of time. But time is passive only in the sense that spatial changes occur in it; but it is also an active resource that determines the *pace* and *dynamics* of these changes.

5. SPATIO-TEMPORAL DYNAMICS

The most typical spatial feature of processes acting though time is *accumulation.* When studying accumulative processes, it can be useful to use 3D analogies (mounds and relief patterns) for understanding spatial probabilities. In our archaeozoological example (Fig. 12) temporal dynamics of scavenging are not characterised by a simple accumulative process from low entropy sets (death animals) to higher entropy patterns (scavenged carcasses). It should be defined as a non-linear aggregate of quantitative changes, which, beyond a threshold, produce a qualitative transformation (an archaeological deposit).

Alternatively, if we invert the 3D representation of a probability map, we obtain an idea of *basins* or pits (Fig. 13), which are very useful to represent the dynamic aspect of social activity areas.

For instance, in this graph of the spatial probabilities for all burials from the Carmona cemetery, ritual activity area is viewed as a deep and narrow *attraction basin* where all burial locations are concentrated.

The higher the concentration of material consequences of an action, the more concentrated in space was the social action. That is, if the representation of the basin is deep and narrow, the action was concentrated. The opposite pattern corresponds to a smooth and wide basin, when the response surface is associated with actions which have strong spatial influence.

Thus, we have two main features of spatial dynamics: concentrated and disperse patterns of material consequences of social actions, and they are related to two different classes of processes: *accumulation* and *attraction.* What we are really studying is the directionality of social action, and this can be done by means of the analyses of *locations* as *places of attraction or accumulation*. The basin analogy is very appropriate for studying the formation and consequences of *attraction*; as it is the analogy of the gravitation law for studying spatial interaction (HAYNES, FOTHERINGHAM 1984). «A state cycle is an attractor, when all possible actions will settle into the same state cycle, and the collection of trajectories that flow into it is called the basin of attraction» (KAUFMANN 1995, 78). In this way, Social Activity areas should be considered as *spatial attractors*.

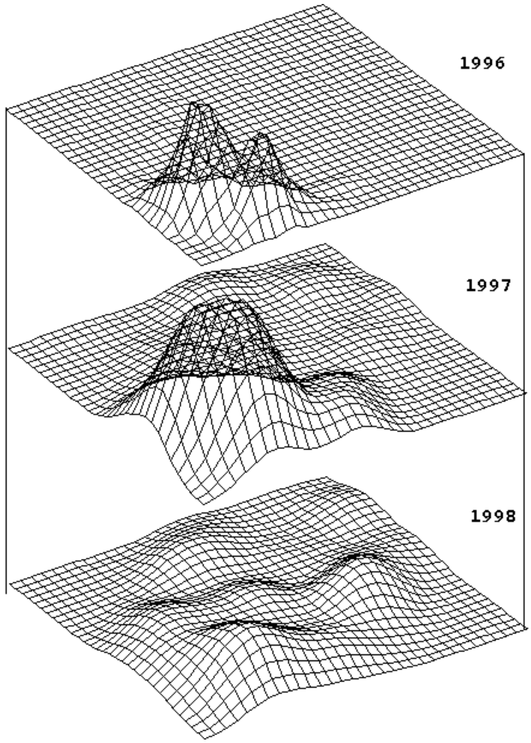


Fig. 12 – Spatial distribution of bones. A 3D view of Kernel Density Mappings depicted in Fig. 11.

It is important to take into account that *social activity areas*, and therefore, response surfaces, are not maps of social actions, but representations of the spatial density of the material consequences of those actions. Assuming that a measure of density is a function of the probability an action was performed at that location, we can say that the area where spatial density is the highest, is the attractor for its material consequences. Furthermore, if we observe inside the attraction basin for a social action the material effects of other actions, we can conclude, that some social actions *attract* other social actions.

The question is how the locational differences among the effects of cause *C* have determined or conditioned the locational differences among the effects of cause *B*. This property has also been called *locational inertia*: it is a time-lag effect that activities experience in the adjustment to new locational influences (Wheeler *et al.* 1998).

For instance, we could ask «is the probability for the location of poor graves – without grave goods – low in the area where the probability for rich

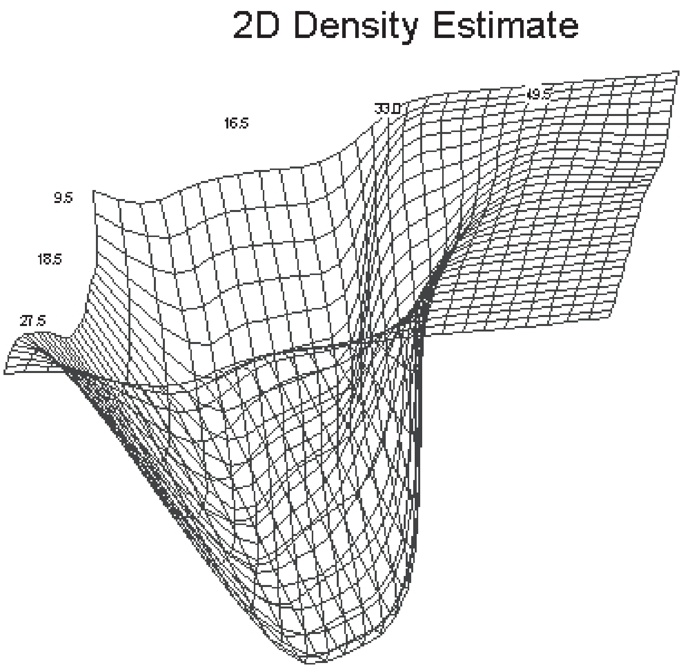


Fig. 13 – The Iron Age cemetery of Carmona. Attraction basin for all graves.

graves – with more than 5 grave goods – is high?». We thus would be suggesting a causal hypothetical model: the performance of a social action at a location – burying a very important person – prevents the performance of a related action – burying a poor person – in the vicinity of the *social activity area* defined by the first action.

Although the response surface for rich burials is much more concentrated than the smoothed surface for poor graves, it is easy to see that rich graves does not impose any spatial influence. That is, the spatial variation of poor graves is not determined by the spatial variation of rich graves. The action of burying a very important individual does not prevent the performance of the action "burying a poor individual" in its proximity. On the opposite, the probability density function of burials with weapons is similar to the one of the rich graves, evidencing a spatial association between them, and the possibility of spatial causality between burying a warrior and burying a rich individual. The differences between the probabilistic map of weapons and rich burials suggest that not all warriors are very important individuals. However, most warrior graves tend to be near rich burials or they are rich burials.

6. Conclusions

If the range of possible locations may be so wide, why do spatial trajectories of social action seem to be almost always regular? Why is so usual to find spatial dependence structures, if spatial consequences can be so diverse? Social Interaction is not a free flow of exchanges, because any social action is performed *in* space, and as a consequence it produces a social activity area, that is, an area which *attracts* other social action, and/or where social actions *accumulate* their joint effects.

The concepts of *attraction* and *accumulation* allow the study of social space in dynamic terms, that is, taking into account the time dimension. Each localized event in space and time, be it an individual, a collective action, or a series of actions, develops together with its environment as a complex network of bi-directional relationships at multiple levels, conditioning the performance of the action and successive actions performed in the neighbourhood. On the one side, it materializes a complex field of attraction, radiation, repulsion, and cooperation around this activity, producing the necessary energy for the functioning and even the existence of the social system. On the other side, activities localized around this activity influence it through different interaction channels (Camagni 1992).

Time and Space are used by social agents, but they are also produced by them (Kellerman 1989). Time and Space do not exist by themselves, waiting to be used or waiting to contain social actions. Location, as a material product of a social process, acts back on social processes, limiting, constraining, and, in some cases, determining future actions. Both the action in space and the action of space *cause* a society's unique environment and its temporal changes. From such an approach, space and time cannot be seen as abstract qualities providing the medium of social action, but rather as dimensions created through the concrete operation of social actions. In this way, the continuum of social actions in time and space constantly have an effect on temporally previous spatial arrangements, conditioning other social actions and constituting the dynamic nature of any social relationship. Therefore, social space should not be restricted to the mere socialisation of physical space, but it is social action, which creates its own social space.

In general, social relations of production are both space forming and space-contingent. Social space is something constituted, reproduced and changed by social relations, and in turn constrains the unfolding of such relationships. In this respect, as spatiality is simultaneously the medium and the 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. The social and the spatial are inseparable; the spatial form of the social has its effects on in subsequent social actions (Lefebvre 1974;

SOJA 1980, 1989; GREGORY, URRY 1985; GOTTDIENER 1994; SIMONSEN 1996; SANTOS 1997).

The basic idea is that space forms an integrated part of social practices and/or social processes; such practices and processes are all situated in space (and time) and all inherently involve a spatial dimension. Consequently, spatial causality is a very complex relation. The spatial structure of social activities is not constant, neither static, but it is dynamic because it is socially *caused* and simultaneously *determines* society. Social space is not absolute, but relational. It depends on the underlying network of social actions, that is the interrelationships between objects, objects and individuals, individuals and individuals, and individuals and activities.

The spatial social system should be viewed as it exists at the present, as well as a kind of artefact, created largely in the past and only slowly responding to more current influences. The present spatial pattern at any particular place for any specific social action, through a feedback mechanism, helps to shape the unfolding of the next stage of the process. The task of explanation is to unravel the various spatial processes that acted in the past and continue to act in the present.

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ABSTRACT

The archaeological record can be described using a relevant observable feature: location. Shape, size and other properties vary from one location to another, and sometimes this variation has some appearance of continuity, which should be understood as variation between social actions due to neighbourhood relationships.

Time and space are not different ways of considering the nature of archaeological locations. Consequently, "locations" can only be understood in functional terms, that is, according to what is performed at each place at each moment. In this paper, the objective is to analyse where, when and why a social action varies from one location (temporal-spatial) to another. Some mathematical techniques are presented to calculate the probability of social actions at specific locations, based on the spatial properties of archaeological data. These techniques are used as a representation language for studying the concepts of accumulation and attraction, which allow the study of social space in dynamic terms.