

PREHISTORIC SPACE: AN ARCHAEOLOGICAL PERSPECTIVE

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Introduction:

Archaeology is concerned both with telling the story of the past and telling stories about the past. One does so using a recipe of adventure sautéed with descriptions of material artifacts and spiced with reconstructions and the use of numerous scientific techniques. For a long time these stories have used differing forms of spatial analysis measurement, and representation as well as differing concepts of space itself in their basic formulations. One of these stories is the story of cultural evolution. Many of archaeologists, including the author, believe in both the stories reality and its external validity.

As practitioners one tries to draw a coherent picture that encompasses both human meanings and general processes. This is not only a difficult task in today's world where one may interview the agents and directly measure the effects. At least the stories are first hand. It is difficult for archaeologists who try to derive these same stories and processes from the fragmentary detritus of material remains that have survived the vicissitudes of time.

There is a certain foreground and empowering quality about people in narratives for they are agents who do things out of love, fear, and desire. They empower us-but perhaps falsely. The space is the background and it is seldom the agent of change or empowering. More frequently, it is the phenomena upon which general processes act.

There are disjunctions between narrative and spatial analysis. They range from the commonplace –mistaking a correlation for a causal connection to the abstruse such as issues of

lack of independence and types of co-dependence. One mistakes anecdotes for statistical evidence, individual cases for averages, and the informal logic of context for formal logic.

In the case of space, one needs to distinguish clearly between spatial reality –that phenomena in which organisms, exist, move, and subsist - and the cultural construction of space. Even maps are not the disembodied view rather they are located in culture, space and time. Luckily, the common “mental map” has neatly publicized this distinction. Nearly everyone has seen the “urban centric” posters of New York with the region’s attractions in the foreground and the rest of the world vanishing into the distant background. The author’s favorite is the “Australian centric” map of world in which Ayers’ rock is located as the center of the cartographic universe and the familiar landmarks of Europe and North America are upside down and distorted by Mercator in a wonderful and almost unrecognizable way. These issues of cultural construction begin to be addressed by type of projection, projection point, and scale.

Schema:

This paper will focus on aspects of spatial analysis and cultural evolution. Three questions guide the discussion. They are 1) what are the relationships among types of spatial analysis and cultural evolution, 2) how prehistoric populations used spatial analysis to provide themselves with adaptive advantages, and 3) how has the use of spatial analysis evolved in the field of archaeology. The first, one might call the analytic, the second – the pre-emic, and the third the reflexive question.

What are the relationships among types of spatial analysis and cultural evolution?

Briefly, for Newton space and time are real (content neutral and independent of what is put in them). These are the fixed dimensional phenomena (independent of the phenomena that

move through them). For Kant, space and time are both empirically real (because all of our experience of things is in space and time) and transcendently ideal (because they are forms of intuition). Leibniz's view is as time is an order of successive events that are co-spatial; space is an order of spatially successive events that co-exist. Thus, the plurality of space and times creates numerous possible worlds (Leibniz 1968) Whitehead offered a relational, interactional theory of space and time. He suggested bodies do not exist in space and then interact with each other. Rather, that they interact and that their spatial reality is only an expression of this interaction. Thus, space and time are not independent realities but consequent relations derived from processes and events (Fitzgerald 1978) (Whitehead 1914). His re-conceptualization of spatio-temporality is contextual for his philosophy of organism and processual change. Einstein progressed from the concepts of 3-dimensional space –time with continuity, material bodies, and cause and effect to reorganizing measurements into a counterintuitive space, the four-dimensional space-time of the relativity theory of 1905 (Einstein 1961). Ultimately with quantum mechanics even materiality is rejected.

The modern archaeologist or anthropologist is left with a gap between what one believes exists quantum particles and fields and what is understood and observed every day regarding space, time, and causality in the field. One knows that time and space are absolutely inseparable from the intricacies of human behavior. They constrain individual activities, the environment, and the ability for individuals or populations to impact their environment. Both individuals and populations have limited spatial and temporal reaches. There is a physical limit that has been called a prism (Lenntorp 1978). It is a physicalist, concrete, observable realism and is not concerned with individual experiences or intentions.

This type of representation assumes a set of necessities. They are outlined below in Table 1.

Table 1. Table of Spatial Physical Realities

There is a spatial indivisibility of human beings and many other entities.

Movement uses space and time.

There is a limited life span of existence of all human and other physical entities.

There is a limited ability to participate in more than one task at a time.

All tasks are time and space demanding and are finite regarding both.

Every physical object has a space-time trajectory and thus has both a history and a biography.

Space has a limited capacity to accommodate events because no two physical objects can occupy the same place at the same time.

In modern spatial analysis a critical factor in representation are the concepts of the spatial and data layers. One, but not the only, heuristic is to imagine these phenomena are a set of layers similar to a birthday cake or an archaeological site. (See figure 1.)

Each layer contains either spatial or non-spatial data information. However, the information in the non-spatial levels is tagged spatially. The spatial information may be presented as a grid, which will then be transformed mathematically in the positions of a matrix. This is a very familiar representation for archaeologists. Or, it may be defined in terms of vectors

and nodes, which is equally informative spatially but is not as frequently used by either archaeologists or my anthropologists. The data layers may be partially collapsed if one is willing to use objects – i.e. predefined elements. Each system has mathematical advantages.

From a strictly methodological point of view, certain types of evolutionary problems lend themselves to these different philosophical positions and representations of space. Newton and Whitehead are far more applicable in the sense that Newtonian measurement and Whitehead's dynamic process/event oriented ontology are methodologically easier. Similarly, if one is concerned with finding out what would be or whether someone had a wide set of resources at a particular location, there is an advantage to using the grid representation. The rationale is one can apply all the power of matrix algebra. On these matrices, one may do discriminant, factor, and cluster analyses. One can find their eigenvalues. For the cultural evolutionist, one may do linear programming and determine standard optimization values. One may optimize across space and across the data layers. Of course, there is a large classic evolutionary literature about whether or not societies will optimize or suffice their foraging strategies; optimize or suffice other types of subsistence strategies such as agriculture or storage; and optimize or suffice other aspects of their lives such as reproduction, kinship, or migration.

Consider a general set of problems relevant to these theoretical and methodological issues. For example, archaeologists need to determine how patchy is both the cultural and the environmental resources. The degree of aggregation exhibited by a culture or by the resources in the environment is of obvious evolutionary importance. All other things being equal, the more "patchy" the environment, the greater the potential for successful "biological" or "cultural evolutionary" selection. Patchiness is a type of variability. Unlike the gradual differences of a cline, patchiness has abrupt changes that result from large differences in adjacent small areas.

Patchiness has both disadvantages and advantages. One may think of areas where precipitation is “patchy”. For example, in the Hay Hollow Valley, the rain comes over the mesa across the valley and falls on one small area leaving the rest to continue being a dry southwestern gully. Or, one might consider the snow belt just south of Buffalo where lake effect snows are twice the depth of areas a kilometer further north. One farmer has sufficient moisture, the next does not. One hunter is able to move through the forest, the next is mired in the snow. Modern precision agriculture (Zubrow 2000) and simple multi-cropping where farmers through shared knowledge developed through trial and error plant a variety of plants and use a variety of fertilizers or watering techniques. The variation optimizes the number and variety of plants to flourish on particular patchy locations (Zubrow 1974).

One needs to distinguish between “crowding” and “patchiness” in that “crowding” is density dependent¹ and thus being dependent on the total number present is experienced by the individual. On the other hand, “patchiness” is group phenomena only dependent on the spatial pattern. It is not dependent on the total number nor does the individual experience it. The two need not necessarily correspond with one another.²

¹ .A pattern may have two different aspects that are usually labeled “intensity” and “grain”. Intensity is a measure of the extent density varies from place to place -high intensity means large differences in density. Grain refers to the spacing of the clumps-i.e. large areas of high density widely spaced would be labeled coarse-grained and small areas of high density closely spaced would be fine grained

² For example, culture and environment each may be patchy, non patchy, crowded and non-crowded. The combinations are

Culture	Environment
Patchy	Patchy
Crowded	Patchy
Patchy	Crowded
Crowded	Crowded
Patchy	Not Patchy
Crowded	Not Patchy

Recently, a research group from Buffalo was concerned with developing new sets of mathematical tools³ to determine reconstructing cultural or environmental “hot spots” in an environment. Hot spots may be thought of as the “the ultimate in patchiness.” A decision was made to define the spatial philosophy in Whitehead’s interactional terms and the representation in a grid approach. The concepts of “hot”, “clustered”, “patchy” were not to be defined simply on the basis of a Newtonian space but in terms of a combination of the relationships among the objects themselves and their locational information.⁴ The concept was to examine the various data forms to determine significant clusters. A critical issue was the definition of what level of significant clustering passed the threshold that would make a cluster “hot”. Once this threshold was determined, the innovation was to define two types of clustering that could be calculated independently and that would interact with each other. The first type of clustering was a clustering using clustering techniques on the contents of the ‘data layers’ without locational information. In other words, one wished to see if there were clusters of attributes. Do small mobile mammals cluster with Guteriza grasses, cottonwoods, and juniper? Do household midden contents cluster with other midden contents and hunting debitage? In other words, does the data show that there are clusters of non-spatial variables? If not, then the research is finished.

Patchy	Not Crowded
Crowded	Not Crowded
Not Patchy	Patchy
Not Crowded	Patchy
Not Patchy	Crowded
Not Crowded	Crowded

³ It might be more accurate to state that it was the recombination of “old mathematical tools” in a new manner.

⁴ One may exchange different types of philosophy and different types of spatial representation- for example one may change from Newtonian to Kantian to a Whitehead approach or change from grid to node-vector representation. However, there is usually a cost in accuracy or resolution. Measuring dynamic processes as sequences of static events ultimately makes a smooth continuous process temporally discontinuous and similarly cuts continuous spatial phenomena into geographically separate regions with artificial boundaries determined by resolution issues.

But if there are clusters, the next step is to project where one might expect the clusters to be located given their content.

The second type of clustering is the inverse. It begins with clustering the spatial coordinates without concern to the attributes - in other words, clustering on the spatial layer. Do there exist spatial clusters of materials independent of what the material attributes were? If so, project them on the spatial layer and then determine what were their contents. In other words, one could examine spatial clusters for content and content clusters for spatial location.

In addition to the standard clustering techniques for both global and local relationships (including centroid, single and group linkage, group average, Ward's, and weighted group average), one may use neural networks, which frequently make fewer assumptions about the nature of the data.

An important example of the use of this philosophical interactive space and grid representation for cultural evolutionary studies was the Third Stage Project under the direction of Tjeerd H. van Andel of Cambridge University. One of the great advantages is that it has allowed an interactive standardization of data and a comparison of data from a variety of very disparate fields. The content variables may all differ but they are all tagged to a similar gridded space and set of matrices. This makes it possible for a variety of different types of scientists to use each other's data efficiently.

The Third Stage Project is the attempt to reconstruct the environment of Western Europe during the Upper Paleolithic. It examines the relationship among climate, topography, hydrology, fauna, flora, and human adaptation by *Homo sapiens sapiens*, *Homo Neanderthalensis*, and possibly *Homo erectus*. It is the classic case of cultural evolution. There are problems in climatic adaptation; problems in spread of populations; problems in changing

environments and topography; and problems in biological development. It is a cooperative project of more than 20 individuals and institutions in the New and Old World. One aspect is particularly relevant for the immediate discussion. The climatologists have now run the global climate model backwards with appropriate data for periods during the Upper Paleolithic. They thus provide daily temperature, rainfall, and wind-chill data for all of Western Europe with data points at a 100 km grid. Biologists can locate their palynological and osteological data while archaeologists locate their cultural data into similarly scaled data levels. Figure 2 represents the distribution of biomes based upon the January temperatures during the Stage 3 period at about 70,000 years ago. Several interesting conclusions have already been found. They include that by far the biggest environmental impact is that the summer temperatures were much colder than expected. Second, that people really had a relatively small window of places they could live permanently. These were primarily along the coasts. In fact, the only place the “Naked Neanderthal” would be happy would be where the “Naked European” is able to survive today—namely Cannes, Nice and similar areas around the Mediterranean. Finally, and perhaps most importantly, it would appear that the notion of the “more are less” continuous biome, the biome of the great primeval forest is not accurate. This was the biome originally suggested by the palynologists that supposedly covered non-glacial Europe. Rather, there are areas of continuous forest biome but it is punctuated with meadows, swamps and other biomes. It is far patchier than previous thought and this quilt of patches provided numerous refuges for earlier forms of fauna and flora. These refuges would not only be conservative biologically but conservative culturally.

For archaeologists, there are advantages to other philosophies and to other systems of representations. For example, the relativistic perspective with its ability to anchor perspective

from different loci in space and time has significant rewards for the archaeologist concerned with the broad set of issues around travel, migration, nomadism, and pastoralism. Similarly, for these archaeologists using the node and vector systems of representing space will be beneficial. The greatest advantage is that it allows one to create mathematical networks and use the networks more efficiently. One may solve common network problems on any theme containing lines that connect. The networks may be directed or non-directed⁵, isomorphic or non-isomorphic⁶, and connected or disconnected.⁷ (Chatrand 1977)

A standard cultural evolutionary problem is to determine whether or not a society is being adaptive by finding efficient routes. Some are fundamental to human evolution. For example, it may be a one-way trip (out of Africa hypothesis), multiple trips (out of Africa again and again), multiple trips from multiple destinations (out of Africa, Asia, and the Middle East) or a circular trip (out of Africa and back into Africa) or trips that must visit several locations on the route. Some of these are more popular to study than others. How many articles are about the “back to Africa hypothesis”? In particular, the issue of “return” has been under addressed in the literature. Some important other questions that should be asked are what proportion of the original migrating population reaches the destination; what proportion of the migrating population continues to migrate after the first migration, and how long does it take to reach the destination. For example, are there the “hyper migrants” (Zubrow 1977), people and situations in which numerous sequential migrations take place, that are discussed in more detail below? Does the migration take the form of “jump-dispersal” (i.e. the movement of individual organisms across

⁵ Directed networks are ones in which there is a non-reflexive relationship along one or more of the arcs...e.g. a one way street or water moving through an irrigation canal.

⁶ Isomorphic networks are ones where there are an equivalency relationship among the vertices and arcs of two networks.

great distances and then relatively static new colonies), “diffusion” (i.e. the gradual movement of a population through a hospitable environment over many generations), or “secular migration” (i.e. a diffusion that takes place so slowly that there is cultural or biological evolutionary change along the way) (Pielou 1979)? In any case, these “out of Africa”, “out of Asia”, etc. routings may be calculated in a variety of ways with different rates from a variety of anchored loci producing quite different temporal periods of migration. However, all are rather rapid and thus according to calculations there is no reason for “necessity diffusion” or “secular migration” for the “Out of Africa” hypothesis (Zubrow 2002).

A related question may concern a trip that takes place along a connected network that becomes disconnected at various times. This is a more formal approach to the entrance to the New World according to the Beringian hypothesis. The scale may be as already mentioned continental or far more local such as moving to and from local salt deposits. The locations may need to be reached in a particular order because one needs to obtain resources or enroll labor that is only available at a particular location before it makes any economic sense to move onto the next location. This is a variant of the “traveling salesman” problem or a “Hamiltonian network”⁸. One may solve these problems by asking what is the optimal visiting sequence given an individual’s constraints (Chartrand 1977).

Some other spatial network problems relevant for cultural evolution may be grouped into allocation and service area problems. These are the next step in the traditional archaeological sourcing studies. They take sourcing and add selection criteria. For allocation problems the

⁷ Connected networks are those in which every two vertices are connected, otherwise there will be disconnected segments. A circuit is a connected network that begins and ends at the same vertice while a cycle will be a circuit which does not repeat any vertices except the origin/end vertice.

⁸ Variants include the salesman must make a round trip and visit once each of a chosen set of cities; the salesman must make a round trip visiting each of a chosen set of cities in the most inexpensive manner; the salesman must

issues are to determine which resource or facility is closest in what quantities and to determine the best way to get to or bring that resource or facility given particular spatial or transport constraints to the production area. Given the optimal solution, one may compare actual prehistoric cultural solutions both to the optimal solution and to different cultures solving the same or similar structural problems. The service network defines a service area around a site and identifies the accessible routes within a specified travel time, distance or volume flow via the route network. Once one has a service network or service area, one may evaluate the true accessibility of the site. What may appear accessible need not be so and vice-versa. In other words, what routes and what distances will allow one to service a town or administrative capital such as Chichen Itza or Tula.

Up to this point, the emphasis has been spatial rather than temporal. There is a structural relationship between spatial representation and temporal representation. It may take many forms. Galton has suggested a spatial temporal field relationship for object-oriented mapping (See Figure 3). Just as one may represent space diversely, one may represent time in different formats. Frequently the results are changed depending upon the particular representation chosen. Does one wish to see time as continuous or discontinuous; infinitely divisible or only divisible up to a point; and are there points in time or only durations. Some archaeologists provide a beginning and an ending date for phenomena. For example, the Mogollon may be dated from 900AD to 1350AD with the Tularosa phase from 1125 AD to 1300 AD or the Magdalenian site of Verberie dates from 14000BC to 12000BC. There is an inherent assumption that the culture, the phase or the site continues throughout the period. In case of Verberie, it is erroneous for the site has 8 separate layers each representing no more than a brief occupation or reoccupation.

make a round trip visiting each of a chosen set of cities in the least amount of time; and the salesman must make two round trips to a chosen set of cities, one circuit selling the next circuit delivering, etc.

Others may provide a beginning date and duration. Even others may provide an average time or a mid-point time to represent phenomena. Each has its strengths and weaknesses and each will provide different results. (See figure 4)

Taking a more interactive approach to time such as endorsed by Whitehead, one uses a probability framework for examining the temporal aspects of spatial activity. Consider for a moment that movement to a specific activity location is related to the frequency and regularity with which an individual chooses to participate in a specific activity.

Look at the probability the individual (or for that matter a population) will make a given trip at a particular time. The possible forms such probabilities may take are illustrated in figure 5. If the person is traveling to regularly scheduled activities, such as attending a religious ceremony or going to a clan meeting the probability distribution would correspond to figure 5a. There is only a specific time that the activity is offered and it is quite limited. One either matches that time or there is no reason for going. Thus, the probability distribution corresponds to a regular set of spikes. There is high probability of going when the event occurs and very little or no probability of going when the event is not occurring. This is “event standardized” behavior” (Terenziani 2002).

The second distribution (figure 5b) expresses the type of trips necessary to obtain resources that are consumed regularly. The resources are always available. However, from the point of view of the individual, there is a gradual increase in probability for taking the trip prior to the trip. Immediately afterward there is very little reason to travel for the resources are now “in hand” and thus there is little incentive and only a very small probability to make the next trip. In fact, the probability will not start to grow until the resources are partially consumed. One may call this “event aversive” behavior.

The third type of distribution is shown in figure 5c. It shows that there is a sudden high probability for the trip. However, once the trip is undertaken there is a relatively high probability that the person or individual will take it again and even again. The probability slowly diminishes. Then after a period of low probability there is a sudden high probability for the trip. This type of activity is clustered in time. Demographers have shown this is frequently the case with migrants. In fact, they have defined what is called the “hyper migrant”. A migrant who migrates five times is very likely to migrate a sixth. This is “event contagious behavior (Lascock 1991).

Finally, one has trips to activities that occur randomly in time. Participation in such a trip or corresponding event does not affect the probability of participating again. One might call this “event neutral behavior” and it is illustrated in figure 5d.

These distributions have considerable cultural evolutionary significance depending on the particular type of phenomena one is considering. One may apply them to the classic economic models for the spread of population and the development of agriculture. For example from a Malthusian –Binfordian approach, one would expect the trips to follow either a regularized or event contagious distribution while from a Boserupian-intensification model either event aversive or random travel would be expected.

Temporal limitations of spatial analysis are apparent when the time of a change to any spatial object is unknown. An unusual type of spatiotemporal imprecision exists where an event occurs at a known location but at an unknown time. Aoristic analysis can provide a temporal weight and give an indication of the probability that the event occurred within a defined period. Visualization of temporal weights can be enhanced by modifications to existing surface generation algorithms and a temporal intensity surface can be created (Ratcliff 2000).

How prehistoric populations used spatial analysis to provide themselves with adaptive advantages?

Marvin Harris once said Levi Strauss found Durkheim standing on his anthropological head...and joined him. Similarly, this second question turns the issue of the role of spatial analysis on its head. It is not only archaeologists who are able to use these techniques successfully to help tease out the cultural evolution. In fact, it is far more important that prehistoric populations obtained adaptive advantages from the use of spatial analysis, mathematics and statistics.

Prehistoric and early archaeologically historic populations used spatial analysis in a variety of activities. This article touches on only a few of them -prehistoric map making, surveying, navigation, astronomy, architecture and prehistoric spatial mathematics.

It is well known that prehistoric populations used maps. Zubrow and Daly (1998) have created a large database of prehistoric maps and maps from ethnographic hunting, gathering, and fishing populations. Some of the findings are presented in table 2.

Table 2. Some characteristics of prehistoric maps

Map making is relatively rare.

Topography is important and societies with minimal topography do not use maps.

The greater the territory covered the greater the probability for maps.

Map making is not used for local ranges.

Maps tend to be dependent upon mode of transport-particularly use of boats.

Maps tend not to be originally secular but religious and show the relationship between

heaven and earth.

For some societies the process of making the map was more important than the information content of the map.

From a strictly mathematical point of view, there is no reason to necessarily assume that other societies needed to use Euclidean geometry for their maps. Euclid and the various projections that are presently used are a very limited view of geometry. Although it was not until the 19th century that Boole and Lobachevsky began formalizing non- Euclidean geometry, it is clear that prehistoric and ethnographic hunting, gathering, and fishing societies made use of different types of geometries. These include affine geometry (parallelism without other processes such as length or angle), grouping geometries (including only the processes of composition, inversion, identity, and association), haptic geometries (limited to touch thus minimizing distance), homeomorphic geometries (where one to one point correspondence is identity), proximity geometries (where there is only ‘nearness’) and syncretic geometries (where there are only directions).

A careful analysis from a culturally evolutionary point of view would make much of the fact that the distribution of prehistoric maps is worldwide and that they seem to occur at approximately the end of the Paleolithic and the beginning of the Neolithic. However, it is not clear that there is a clear correlation with the ownership of property.

By 5000 years ago, The Babylonians, Egyptians, and Sumerians were using sophisticated surveying techniques implying knowledge of spatial analysis. This can be inferred from both the material remains and from indirect references. Among the earliest known explicit records of

land surveying are those by the ancient Babylonians some 3,000 years ago. Nearly perfect “squareness”, north-south orientation, and boundary surveying using the groma and chain measurement were achieved in the fertile valleys and plains of the Tigris, Euphrates, and Nile rivers.

Similarly prehistoric navigation dates back prior to the first records. One knows of the predecessors of the classical Greeks used a form of log line for recording distances run from point to point along the coast. They also stored this information for repeated use by the same sailors and for others. Later they used the astrolabe and eventually the compass while making their slow voyages throughout the Mediterranean, the Persian Gulf, and the Indus. It implied not only the measurement of distance but also measurement along irregular curves. The latter is not a trivial problem and indeed it was a consideration of just such issues that resulted in Mandelbrot creating fractal geometry during the middle of the last century.

The study of astronomy resulted in the development of sighting and angle-reading devices. If one accepts Marshack's work, there was interest in astronomy in the Upper Paleolithic that has continued through today (Marshack 1971, Marshack 1985, Marshack and Movius 1970, Richards 1999).

The array of instruments ranges from simple alignments of structures to actual observatories such as the Caracol at Chichen Itza. Over the last 50 years the number of studies of prehistoric archaeoastronomy has grown prodigiously (Barlai 1980, Freeman and Elmore 1979, Nuttall 1932). If the literature is any indication, it was a widespread prehistoric activity. Prehistorically, it seems to have occurred geographically and temporally from a wide range of venues including Harrapan (Ashfaque ND), Levantine, (Aveni and Mizrachi 1998), British (Hawkins 1985, Hicks 1985, Morrison 1980), Spanish (Bausani 1982), American (Fletcher and

Cameron 1988, Fowler and Krupp 1996, Hively and Horn 1984, Malville, et al. 1991, Malville and Munson 1998, Mooney 1992), Mayan (Aveni and Hartung 1988, Bricker 1988) (Luxton 1991) and South American (Aveni and Silverman 1991). By the Seleucid period, the astronomers predicted future occurrences of lunar eclipses and critical points in planetary cycles (conjunctions, oppositions, stationary points, and first and last visibility). They used systems related to degrees of latitude and longitude, measured relative to the path of the Sun's apparent annual motion.

Early architecture shows indication of accurate spatial analysis mathematics. Examples include the scaling of the Egyptian pyramids or the Ziggurats as well as the proportional relationships of the Talud Tablero. The adjustment of height to fit standard elevations from building to building at places such as Uxmal or Tikal indicates that architecture is based upon concepts of mathematical proportion and spatial continuity.

Turning to prehistoric spatial mathematics itself, McDonald (1992) surveyed the relationships between early mathematics and geometry and their applied prehistoric applications. Numerous achievements were made in China, Sumeria, Akkadia, Egypt, Babylonia, Assyria, Ancient Persia, and Greece. Spatial mathematics used number theory in a form called "Pythagorean number triples" that was useful for the analysis of triangles and long distance measurement. Algorithmic approaches of sequential procedures were applied to geometric problems in Babylonia providing an operational solution to the Pythagorean Theorem more than one millennium prior to the Greek solution.

In Egypt, it was discovered what would later come to be called “pi” could be estimated knowing the area of a circle is proportional to the square of the diameter⁹ as well as the volume of a truncated pyramid.

The pre-Socratics and early Greeks held that “all things are number” until they found problems with this concept when they began to examine irrational numbers, infinity, and division by zero. Later the Greeks recognized the differences between discrete and continuous quantity and ascribed the latter to spatial analysis and geometry. Of course, from the perspective of this paper, the most pivotal study was Euclid’s of Alexandria’s *The Elements*, a relatively complete analysis of the spatial domain that made use of proofs. Although *The Elements* were a spatial tour de force, they were also static. This was not to last. For Archimedes soon added a degree of temporal dynamics to geometry. He was not only interested in the principle of buoyancy but used similar concepts in a form of spatial analysis. He tried to prove what were conditions of stability and instability for segments of paraboloids and sphere. In short, the ten millennia before Christ showed a wide use of spatial analysis throughout many societies. Even this brief introduction points to the more spatially sophisticated societies being those that survived or were major forces in the geopolitics of their times. Others, perhaps less erudite in spatial sophistication (particularly not only being able to use but not being able to record spatial phenomena) placed these societies at a distinct disadvantage in trade, navigation, warfare, and agriculture. Societies without these important economic, military, or political tools were marginalized. If they do not become extinct, they become part of the peripheral world of their era. Whether it was the Mayans, the Babylonians, the Sumerians, the Greeks or others –for those who used them the prehistoric and historic record shows there were considerable advantages.

⁹ This produced an estimate of pi that was only 1% too large.

How has spatial analysis evolved in the field of archaeology?

The third question is the most reflexive. This requires a warning. Being the most reflexive it is also the most biased by the author's knowledge and predilections. Frequently, archaeology is mono-vocal. It comes from the mouth of "white, middle-class males" in academic, governmental, "ngo" and private positions. Ideally, a reflexive archaeology should be multi-vocal representing various voices including more marginalized groups and even the "voice" of the past. If the construction of archaeological knowledge today is based upon rendering realities in terms of alternative modes of representation, then different traditions and different practices must be recognized. Some archaeologists have talked about "refleshing" the past, but as important is how we "re place" it. It seems clear that different present and past academic and traditions of practice have impacted upon the use of space in archaeology and in the archaeological approaches to cultural evolution. What follows is a construction about how the "field" developed, is developing and will develop that the author thinks is useful in understanding how spatial analysis is practiced by archaeologists.

Spatial analysis has moved through a series of stages of developments. They are the following:

Stage 1. Number at a location -namely the content of a location

Stage 2. Location- namely the numerical or statistical methods to provide location

Stage 3. Analysis and correction of location

Stage 4. Spatial simulation including predictive, non-predictive, and Bayesian modeling

Stage 5. Spatial systems

Stage 6. Spatial cognition

The simplest form of spatial analysis is the first stage. It is the linking of number to location. There are 225 Snowflake Black on White rim shards in room 21 at Carter Ranch. Similarly, in the Viru Valley, there are 24 archaic sites. These are spatial countings, in the sense that the number is linked to the location. They are found very early in the history of archaeology. Indeed, even such “ancestors of the field” and well-respected figures as Thomsen, Worsaae, Jefferson, and Winckleman described the number of items at a particular location.

Similarly, the fundamental concept of spatial variation (i.e. variation across spatial location at a particular time) is also fundamental to archaeology and quite early in the history of archaeology. The origins of the concept may be found in simple sentences that are making comparisons across areas. When the archaeologist states that at a particular site or within a particular region, the artifactual or site contains a number of items that are unusual, peculiar, strange, singular, original, extreme, special, unlike, unique, deviant, dissimilar, disparate, different, bizarre, too much and so on, the archaeologist is invoking a form comparison of spatial variation. The slang phrase “far out” even uses a spatial referent to emphasize the variation. Of course, sometimes these same phrases are used for temporal variation (i.e. variation across time at a particular location).

The second stage is the development of accurate methods of locating sites, artifacts, and cultures and even sometimes archaeologists. One might argue that this begins with the simple forms of latitude and longitude, develops through the numerous kinds of alternative measuring systems including utm’s (universal transverse metric coordinate system) and spcs (State Plane coordinate system), and then continues with the variety of spatial projections including Mercator (areal and distance distortion increases toward poles), Transverse Mercator (areal and distance distortion increase from Central Meridian), Alber’s Equal –Area Conic (area preservation at the

cost of distance and direction distortion), and Lambert Conformal Conic (shape preservation at the cost of direction and area distortion) to name a few. One of the most difficult problems for archaeologists has been the problem of measuring in three dimensions. There have been considerable discussions and techniques developed for measuring the depth of artifacts as well as surveying the layers of archaeological sites.

The third stage is the development of methods of correction for location and the analysis of location using a wide variety of mathematical and statistical techniques. How one location may impact the relationship of others is considered by such techniques as spatial autocorrelation. It is important. If ignored, then particular locations will overweigh the other data. As far back as the mid-60's, archaeologists were seriously doing locational analysis. One of the classic techniques was "nearest neighbor analysis". Numerous studies (Mudar 1999) (Ward 1983) (Zubrow 1975) (Hodder 1976) made use of Peter Hagget's (Hagget 1965) famous book 'Locational Analysis'. Whether the materials found at a location actually represented what should be there was also the issue of many studies. There is a long tradition in archaeology with regards to the concern for representativeness (Hodder 1979). Even in early archaeological vocabulary, sampling was an issue and is noted by such words as *instance*, *case*, *example*, while probability is described by *chance*, *likelihood*, *fate*, *luck*, and *happenstance*. These included a wide variety of sampling studies by Asch and Mueller (1975), Cherry *et. al.*(1978), Jermann (1981), Kristiansen (1985), and Orton (2000) ranging from simple random samples to systematic stratified semi-random samples. In addition there were explicit goal oriented prospecting studies by Zubrow and Harbaugh (1978). Finally, there continues to be an interest embodied by such recent studies on spatial interpolation and extrapolation studies by Robinson and Zubrow (1997).

The fourth stage would be spatial simulation and would include the wide variety of predictive analysis based upon spatial modeling (Hodder 1978b). It could be as simple as predictive modeling based upon locational analysis (Blain 1984, Carstens 1981, Dalla Bona 1993a, 1993b, 1994a, 1994b, 1995, Ebert 1988, Hasenstab 1990, Judge 1988, Kvamme 1990, Kvamme 1990, Kvamme 1992, Parker 1985, Stallings 1993, Thoms 1988) or upon content analysis (Hodder 1978a). Namely site location would be predicted on the basis of other site locations, environmental rules such as minimizing distance to water¹⁰, or even economic rules intrinsic in Loschian spaces and in Christaller analyses. Indeed, k3, k5, k7 models are draped over a wide variety of prehistoric landscapes. Thiessen polygons (maximizing the space around each site on a plane) are used to predict potential optimal strategies for resource consumption related to site location (Hunt 1990) and even the distribution prehistoric disease (Zubrow 1990).

One need not predict using standard predictive techniques assuming independence. One might believe that the one set of events will impact the probability of the next. Thus, there has been considerable interest in using Bayesian probability for archaeological studies and predicting prehistoric spatial phenomena (Buck *et. al.* 1996, Fan 2000). I have included a small example of it here. A woman discovers an archaeological site doing a survey in the far northern part of a valley along the Finnish Russian border. Previously, 85% of the sites already discovered in the valley belong to an ancestral Sámi culture located more than a hundred kilometers to the West in Western Finland along the Bothnia Bay. Fifteen percent of the sites belong to a Karelian culture located a long distance to the east along the shores of the White Sea. The archaeologist claims on the basis of surface evidence that the site was Karelian and claims that this indicates the

¹⁰ Numerous crm studies use this technique.

movement of people from East way to the north. Finally, we know she is correct in her cultural identifications 80% of the time.

What is the chance that she is right? Many scholars would suggest that she has an 80% chance of being right. However, the correct answer according to a Bayesian analysis would be 41%. Imagine that the woman has found 100 sites. The following table showing Bayesian probabilities will help.

<i>The site really is:</i>	<i>Karelian</i>	<i>White Russian</i>	<i>Subtotal</i>
<i>The archaeologist claims the site is Karelian</i>	12	17	29
<i>The archaeologist claims the site is White Russian</i>	3	68	71
<i>Sub total</i>	15	85	100

Of the 29 sites that she claims are Karelian (12+17) only 12 actually are and thus her probability of correctly identifying the site as Karelian is 12/29 or 41%.

The fifth stage is spatial systems. The most sophisticated of these today are the Geographic Information Systems that are being used in a wide variety of archaeological contexts and scales (Blain 1984, Brandon and Wescott 2000) 2000, Carmichael 1990, Groenewoudt 1990). Some are being used for surveys, other for site excavations, and some to maintain even microscopic information. They function for

administrative purposes including State Historical Preservation Office Files and analyses of a public prehistoric resources (Parker 1986, Hamilton 1994), for environmental studies at all levels of scale (Goodchild 1996), and even examining the spatial characteristic of prehistoric kinship and or cognitive categories.

The last topic mentioned is closely related the final stage- the use of spatial analysis to discover aspects modern, (Mennis 2000), ethnographic and prehistoric spatial cognition. This research is just underway now. Some researchers are concentrating on expert rule systems (Lagrange and Renaud 1985). Work is being done on experience and the conceptualization of space (Llobera 2001). For example, what is the image of the operational environment in which prehistoric populations existed? Whether space and the activities that occur within it such as “resilience” or “degradation” should be analyzed as functional phenomena, perceptual phenomena, an informational or encoding phenomena, or “a learned in the anthropological sense” phenomena are being debated. The role of archaeology in these big broad research issues (van der Leeuw S, Redman CL 2002) is being examined in a variety of research institutes in North America and Europe.

Conclusions:

This paper has examined the role of spatial analysis and cultural evolution. Three questions were asked? They are 1) what are the relationships among types of spatial analysis and cultural evolution, 2) how did prehistoric populations use spatial analysis to provide themselves with adaptive advantages, and 3) how has spatial analysis evolved in the field of archaeology. The brief answer to the first question is that how one represents space and time will clearly

impact on how one interprets cultural evolutionary processes in the past. Philosophical and methodological differences are explored and numerous spatial and temporal issues including the layer model; interactive clustering; patchiness; relativism; adaptation; networks; event standardized, aversive, contagious, and neutral behavior; and aoristic analysis are relevant.

The brief answer to the second question is that during the late Paleolithic and the Neolithic there were large innovations in prehistoric mapping, surveying, navigation, astronomy, architecture, and mathematics that made use of a variety of spatial analytic techniques. They provided a significant evolutionary advantage to the populations that obtained this information. Their development had clear economic, military, and social advantages.

The brief answer to the third question is that there has been a long continuing development of the use of spatial analysis in archaeology. One may distinguish six periods—number at a location, numerical location, analysis and correction, spatial simulation, spatial systems, and spatial cognition.

Finally, returning to the introduction, a word of warning. Archaeology may be similar to novels and be narrative or it may be quantitative and similar to science. In either case, it must consider representing of parts of the world spatially in order to help understand how people and cultures have changed evolutionarily. It may be more or less descriptive; more or less accurate; more or less suggestive. However, one must be careful if the narrative novels or the scientific models are built with “off the shelf” components from other fields that are only slightly customized. The novels won’t be very novel and the models won’t model very well.

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Illustrations:

Figure 1. The Spatial layer cake model

Figure 2. The distribution of biomes based upon the January temperatures during the Stage 3 period at about 70,000 years ago.

Figure 3. Common elements of the spatial and temporal field relationships for object-oriented mapping.

Figure 4. Three ways of representing time

Figure 5a and 5b. Event standardized and event aversive behavior

Figure 5c and 5d. Event contagious and event neutral behavior

Figure 1.

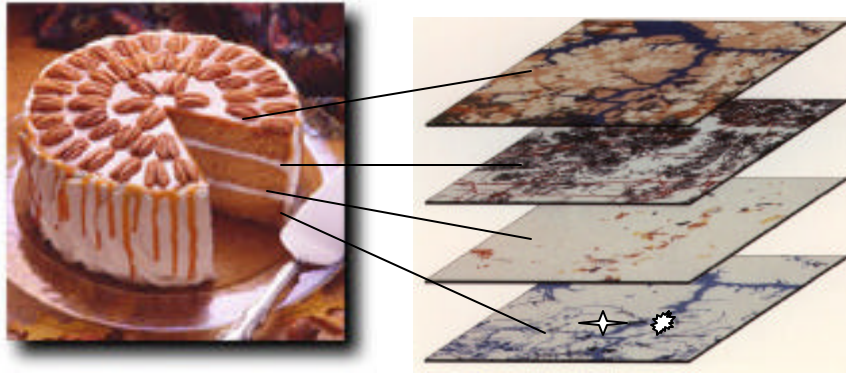
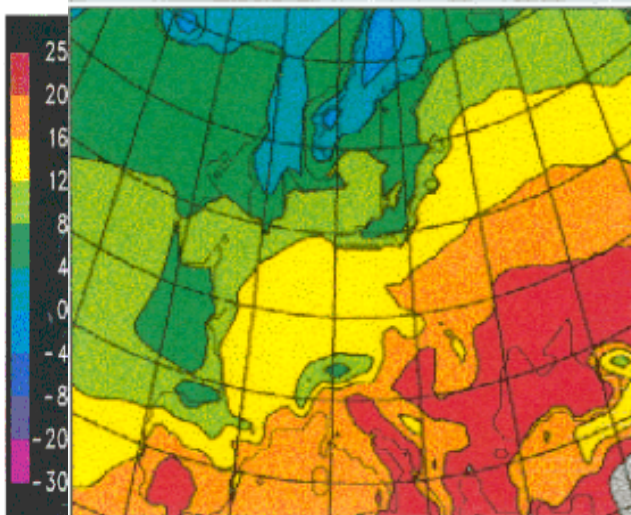


Figure 2a

Summer temperatures (°C)

Right: Warm event (c.40,000 yrs BP)



Predicted Land Surface Temperature minus 0°C
(Unperturbed System)

COLD (large) BIOME3.5



- Tropical evergreen forest
- Tropical semi-deciduous forest
- Tropical deciduous forest/woodland
- Temperate broadleaf evergreen forest
- Temperate deciduous forest
- Temperate conifer forest
- Warm mixed forest
- Cool mixed forest
- Cold mixed forest
- Evergreen taiga/montane forest
- Deciduous taiga/montane forest
- Tropical savanna
- Temperate sclerophyll woodland
- Temperate woodland
- Tropical grassland
- Temperate grassland
- Deserts shrubland and steppes
- Steppes tundra
- Shrub tundra
- Dwarf shrub tundra
- Prostrate shrub tundra
- Cushion forb tundra moss tundra
- Barren
- Land ice

Figure 2b

Figure 3.

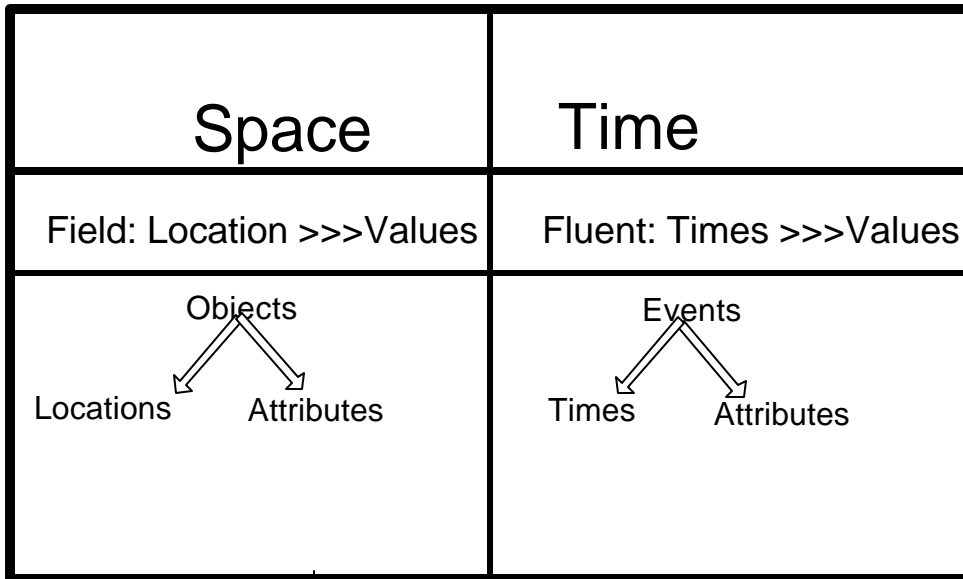


Figure 4

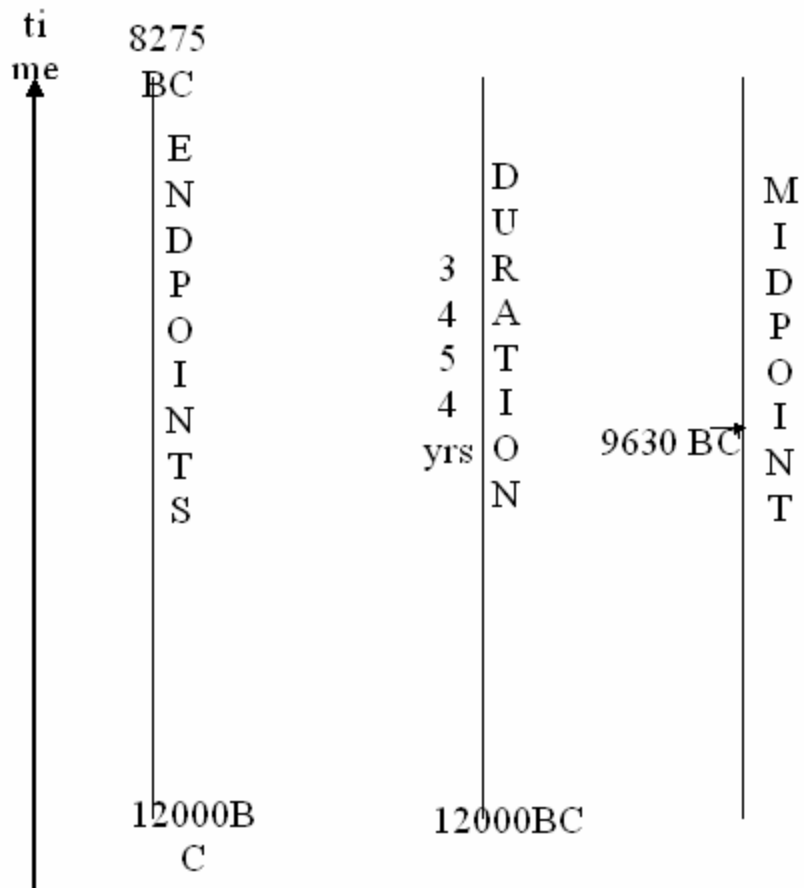


Figure 4.

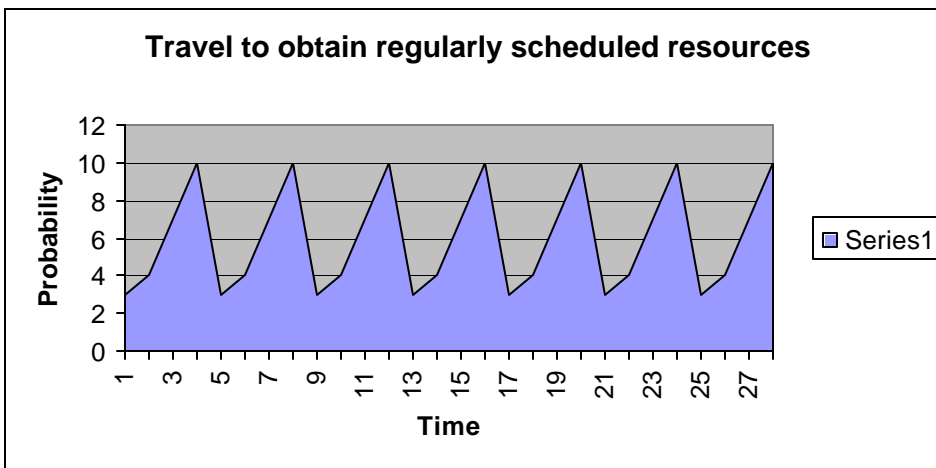
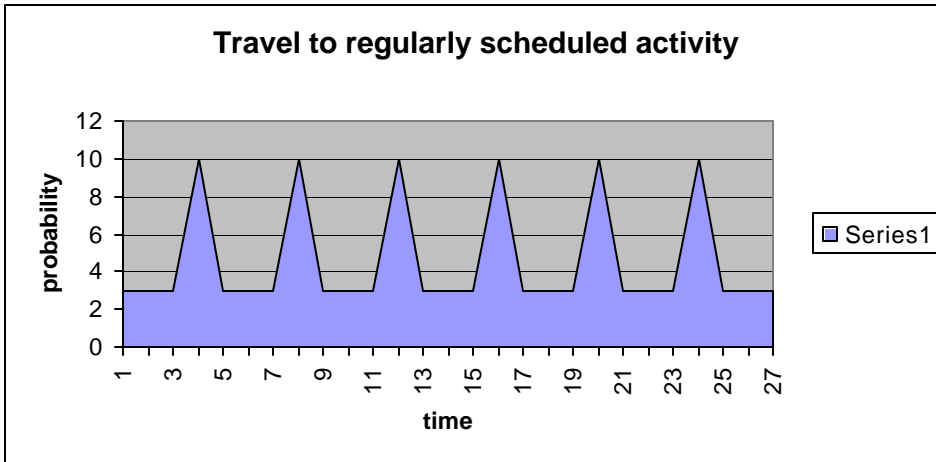


Figure 5

