Conceptual data modelling in an archaeological GIS

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Abstract

Recent discussion of archaeological GIS method and theory has centred around a debate concerning the use of the technology. This paper argues that key problems in this debate can be overcome by looking at how data are defined and structured with regards to the overall project. It specifically deals with two points. First, that an appropriate theoretical framework needs to be developed and that this should occur at the level of the data. Second, recent debate has overlooked the importance of database design and data structure at the conceptual level. Conceptual data models provide a link between reality as it is perceived by humans and the way in which reality will be represented in the database. A spatially extended entity relationship (SEER) conceptual data model is developed for an archaeological GIS which will make explicit any relationships (both spatial and non-spatial). A hermeneutic methodology is outlined that will ensure that the conceptual model developed will accurately reflect the dynamic nature of the data. The data itself comes from a case study on the distribution of archaeological sites in Northeast Thailand.

1. Introduction

Although geographical information systems (GIS) can no longer be regarded as a new technology, within much of the archaeological literature attempts are still being made to 'show the usefulness of GIS in archaeology'. These studies repeat things that have been said many times in the past. It can now be stated with some confidence that we know that GIS are useful - the time has come to develop an appropriate theoretical basis for the use of the technology within archaeology. This is an area that has not been addressed and there is an ongoing concern about "the general lack of an underlying theoretical basis for understanding spatial and temporal data within the context of a given discipline" (Burrough and Frank 1995:102).

This suggestion that GIS are *discipline-independent* has important implications for archaeology. No longer should we wait for developments in associated disciplines, it has become critical that we develop an appropriate theoretical framework from which to utilise GIS. Discussions regarding this point have been intimated in the archaeological literature, but they lean towards more general discussions concerning the future directions of the technology (e.g. see Limp 1996). In many cases, there appears to be a kind of 'technological determinism' involved with the technology itself directing the nature of the research rather than the research being the primary focus and the technology as the tool.

This paper argues that theoretical developments should occur at the level of the data, not at the level of the technology. Technological advancements can only lead us so far; although there are many areas which need redressing, it is stressed here that for the development of appropriate method and theory we must turn to the fundamental level of a GIS - the database. The database is essentially the foundation from which the system is built and without this there would be no GIS. Data modelling and database structure are issues that have not been addressed in the archaeological literature which is worrying as it is here that data and their various relationships are defined. The following sections discuss the current use of GIS in archaeology; from this, several problems and limitations are identified in the use of GIS and it is argued that these problems can be traced back to the fact that there is no consistent theoretical framework from which to utilise GIS. A hermeneutic methodology is outlined that will ensure explicit data definition for the maintenance of data structure and data integrity. This methodology is discussed with an archaeological example from Northeast Thailand.

2. GIS in archaeology

This section shows the need for the development of a consistent theoretical base for the utilisation of GIS within archaeology. It discusses the previous uses of the technology and outlines the need for a substantive geographical information theory.

Harris and Lock (1990, 1995) and Kvamme (1989, 1995) have discussed the history of GIS in Europe and North America respectively and they note a fundamental difference in the use of GIS between the two. This is most evident when applications are compared between these two areas (for Europe see Lock and Stancic 1995 and Bietti *et al.* 1996; for North America see Allen *et al.* 1990 and Aldenderfer and Maschner 1996). First, and generally within a North American context, emphasis is placed on a functionalist, or processual, approach to explanation. It is argued that human behaviour is non-random and that general patterns can be seen in the archaeological record. These patterns are created by people interacting with the natural environment and can be identified in a statistically meaningful way. This allows for mathematical formulations to be developed that allow for the prediction of sites and simulation modelling. This approach treats space in a Cartesian manner largely devoid of social meaning. Second, other writers, predominantly from Europe, argue that space is socially produced and its manifestation on the landscape depends on its particular context and cannot be generalised. They argue that human behaviour is unpredictable and that patterns seen in the archaeological record can be misleading (Hodder 1982). They are interested in what they call the 'social landscape' and include attempts at 'rehumanising' GIS.

2.1 The environmental modelling approach

The use of GIS in the first instance developed from archaeologists interested in examining the relationship between archaeological sites and various environmental conditions. These associations were statistically defined and this facilitates the development of models from which to predict site location within a given area. For such purposes GIS is an excellent tool, but it must be acknowledged that there is no explanatory power in this method (Voorrips 1996). In fact, the use of GIS in this manner can lead to the exposition of an outdated environmentally deterministic argument. For example, Brandt *et al.* (1992) develop a model for the prediction of site location in the Netherlands. Due to harsh vegetation and alluvium deposits surface surveys are difficult to undertake; therefore, the development of a predictive model would facilitate site recovery. They note that environmental data are being used as they are "easy to obtain for a region" (Brandt *et al.* 1992:269) and since social variables must be reconstructed for each period, which is "a task often beyond our data retrieval possibilities" (Brandt *et al.* 1992:269), they do not incorporate such data into the analysis. They further restrict their study by limiting themselves to "simple associations between sites and modern map categories" (Brandt *et al.* 1992:272). Such restrictions mean that they cannot say anything useful about prehistoric behaviour, and although behaviour could be inferred from such relationships, their lack of interest in social variables rules out inferences of this type. In a more explanatory approach, Hunt (1992) undertook the analysis of site catchments in the Late Woodland Period (A.D.1000-1600) in Western New York State. The catchment area is "the zone of resources, both wild and domestic, that occur within reasonable walking distance of a given village" (Flannery 1976:91). The GIS was used to determine soil productivity in each of the site catchments and it was concluded that villages were established in areas suitable for the production of maize. Again this study is concerned solely with environmental and not cultural data. Although it is not necessarily an environmentally deterministic approach, the relationships that are developed are obvious and one does not need a GIS for their confirmation.

2.2 The 'social landscape' approach

Strong criticisms of the situation of GIS within such an explanatory framework came from various researchers whose theoretical orientations are sympathetic to the second group. Wheatley (1993:133) stresses the need to move away from such functional interpretations as they are "an extremely restrictive approach to archaeological explanation." Furthermore, Gaffney *et al.* (1995:211) note that:

> "there are good reasons to suggest that the application of GIS techniques in such a way could ultimately prove to be restrictive to the general development of archaeological thought. In its least harmful form, the indiscriminant use of GIS solely in conjunction with mapped physical data may result in the slick, but repetitious, confirmation of otherwise obvious relationships. In the worst case, it might involve the unwitting exposition of an environmentally or functionally determinist analytical viewpoint of a type which has largely been rejected by the archaeological community."

What these and other authors suggest is the need for the incorporation into a GIS of theory laden data representative of a culture. This type of argument is firmly linked to the 'post-processual' tradition of thought stemming from England where there has been an increasing interest in the social production of space and its physical and temporal manifestation across a landscape (Bender 1993; Thomas 1993; Tilley 1994). This theoretical awareness has been alluded to in many GIS studies and this has been a necessary development to move away from the limited explanation under a processual approach.

The main approach so far used for 'rehumanising' GIS has been viewshed analysis (Wheatley 1995). It is argued that this method provides a means for incorporating human perception into a GIS analysis. For example, viewshed analysis has been applied for the determination of visibility between monuments over a landscape. Wheatley (1995) provides an analysis of the intervisibility of long barrows in two separate areas of Neolithic Britain and shows that between these areas there is a difference in visibility. From this a post-processual interpretation is offered concerning the control of the monuments enabling the legitimacy and perpetuation of ones own status and authority through the historic importance of the extant monuments. This analysis has several limitations. First, it uses limited data sets; for example, only topography and the location of the monuments are used. No consideration is given to any other variables, be they other sites or even other basic environmental variables. Second, the actual study uses the ground surface as the basis for inferring line of sight; this does not necessarily suggest intervisibility as it was noted that the prehistoric vegetation was considerably greater than at present. Finally, such studies "critically confuse the concept of 'vision' with that of 'perception'" (Gillings 1996:79). Just because two monuments are intervisible, or visible from various parts of the landscape, does not necessarily imply a relationship of importance to the prehistoric individual. Here they distinguish between perception as sensation and perception as cognition (Rodaway 1994). There is a continual dialogical relationship between simple acts of vision (sensation) and mental process (cognition) which enable the individual to create a geographical understanding - a sense of the world. In the archaeological studies using GIS in the realms of 'perception', they have situated the analysis firmly with regard to perception as vision, and have disregarded cognitive aspects which underlie phenomenological approaches to the environment (Tilley 1994).

What these studies show is a supposed change in focus from environmental to cultural concerns. Whereas the former studies are explicit in the use of the environment as a major factor in their analyses, the latter try to downplay the importance of such variables. Although they appear to incorporate cultural variables, in actual fact they provide nothing more than studies based solely on environmental data - and in this regard, in many instances, there is a reduction of data. The cultural variables stated as part of the analyses are never explicitly defined and regard is only given to them in interpretation.

2.3 Towards a substantive archaeological geographic information theory

The need for the development of a theoretical basis for GIS in archaeology has come after similar discussions of this type in geography and information science. There have been arguments for the development of a geographic information theory dealing with the representation of knowledge (Molenaar 1989), a geographical information science[1] which sees the need to develop generic questions to create a 'core discipline' (Goodchild 1992) and a more holistic 'discipline-independent' theoretically informed post-modern 'theory of spatial relationships' which is both mathematically elegant and in tune with concepts developed in the minds of humans (Burrough and Frank 1995; Mark and Frank 1996). Although these are opposing ideas for the development of a GIS epistemology, they all make the same general point concerning the lack of an underlying theoretical framework - be this as a discipline in itself or as something that must be created for each discipline in its own right. Although each subject area utilising GIS has some inherent spatial component, there are fundamental differences regarding the nature of space; because of this "problems that are specific to the application of GIS in a particular field clearly need to be addressed in the context of that field, and with the benefit of its expertise" (Goodchild 1992:41).

The area of concern in this paper from an archaeological viewpoint is the modelling of data at the conceptual level (Batini *et al.* 1992). There are generally considered to be three levels of abstraction relevant to geographical databases (conceptual model Ë logical model Ë physical model). Conceptual data modelling is the first of these levels. It formalises human concepts of space and is necessary because computer systems work through sets of formal rules. Furthermore, conceptual models are an abstraction of the real world and incorporate only relevant data (Maguire and Dangermond 1991). The other two levels (logical and physical) are to do with implementation issues and storage requirements respectively. For the present purposes, the conceptual model can stand on its own without regard for implementation since, at this stage, we are concerned with explicit data definition rather than the implementation of a database. This will be achieved through the use of hermeneutics (see below); although hermeneutics has been previously used in GIS design (Gould 1994), the concern was with the interaction between the designer and the user. In the case here, hermeneutics is concerned with the interaction and interpretation of data.

The development of appropriate conceptual schemas help to, first, incorporate non-environmental data in order to augment the more common environmental variables within a data model and second, to extend the data model to incorporate abstract semantic mechanisms for the definition of spatial and topological relationships. In the past, the conceptual design of standard relational databases have not accommodated semantics that explicitly define such relationships. Recently, several models have been developed to extend the capabilities of the conceptual schemas in this direction (Fernández and Rusinkiewicz 1993; Firns 1994). Archaeologists have not used traditional entity-relationship (ER) data modelling techniques for the establishment of GIS databases and it seems appropriate, in the light of the preceding discussion that such techniques be employed for due consideration of the data.

The critique above concerning the uses of GIS highlight several basic problems. Concerns regarding the functionalist use of GIS led to the expounding of approaches within the realm of a humanist archaeology. This rehumanising has merely shifted the environmental emphasis to a more subtle position which has narrowed the scope of GIS through the use of limited data sets. The following section

[1] This has been seen in the name change of the International Journal of Geographical Information *Systems* to the International Journal of Geographical Information *Science* (Fisher 1997).

outlines a methodological approach and example for the development of conceptual database schemas essential for the incorporation of explicit information concerning the nature of the data.

3. Using hermeneutics to design an archaeological database

3.1 Hermeneutics

Hermeneutics grew out of attempts to develop a theory of interpretation. Initially it set out to equate social sciences with natural sciences thereby seeing both as following an objective approach to understanding. Gadamer (1975[1960]) reacted against the use of hermeneutics in this manner; rather, he developed the notion of 'prejudice' from Heideggers' 'pre-understanding'. He argues that prejudice and understanding are thoroughly conditioned by the past, a past he calls 'effective history' (Gadamer 1975[1960]:267). Furthermore, the "really central question of hermeneutics" is that of separating "the true prejudices, by which we understand, from the false ones by which we misunderstand" (Gadamer 1975[1960]:266). Although this notion has been critiqued by Habermas (Warnke 1987) and Ricoeur (1981) it is believed to be a useful concept and is used here. Prejudice in the case of data structure for an archaeological GIS is likewise determined by our 'effective history', in this case 'effective knowledge'. Determining the data to be incorporated within the GIS database necessarily involves questioning the assumptions of the analysis and the assumptions the researcher has concerning the study.

Figure 1 outlines the hermeneutic procedure for this study; it identifies prejudice, problem definition and data definition as being major components. However, these three components are not mutually exclusive, rather, there is a continuing dynamism between them. Although it appears an iterative approach, the dynamics involved preclude the definition of a step by step procedure. Interpretation proceeds differently for each individual as it is part of their 'effective knowledge'. Past experience determines the prejudiced notions an individual has; from an individuals' knowledge base, the identification of problems occurring in our understanding of a discipline takes place, and in turn data are defined in order to consider these problems. Such data comes from a variety of sources, and its definition

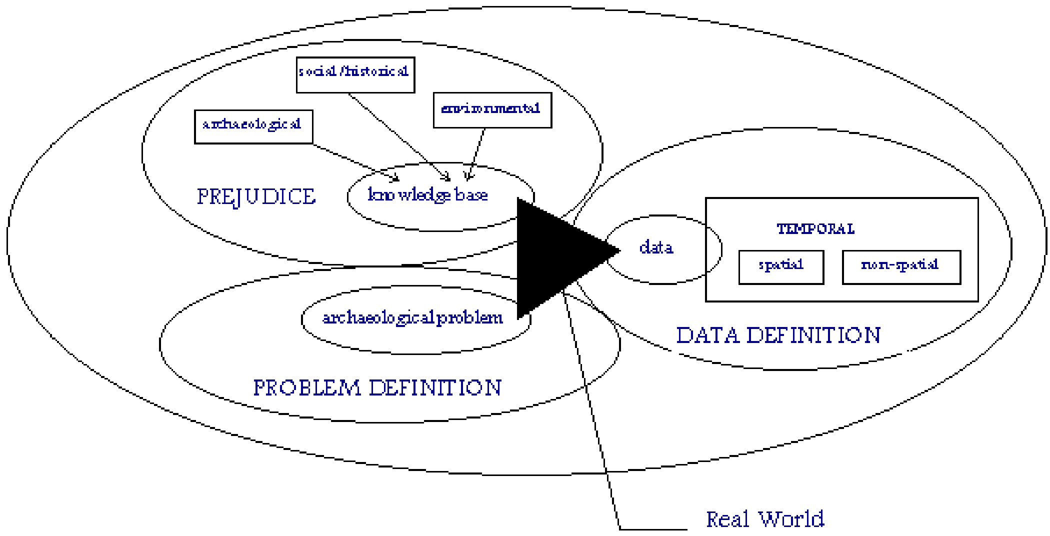

Figure 1: Hermeneutic method for conceptual data modelling for an archaeological GIS

necessitates change in our knowledge base as there is an extension of knowledge and the potential for new problems and different ideas to be developed as a result of data definition. In turn, this information is augmented by input from the 'real world' which is accumulated knowledge not specific to the problem but which more or less alters an individuals' perspective; in a sense, random knowledge. Data come in two forms, spatial (e.g. the distribution of settlements) and non-spatial (data based on ethnographical, anthropological and archaeological sources). These are accumulated and evaluated within the terms of the research and are embedded within an overall temporal framework. At no time do these data have any fixed meaning; this is because "Data do not just 'exist', they have to be created, and who does the creating, for whom, and for what purposes, is vital" (Taylor and Overton 1991:1088).

How then does this translate into a method for generating suitable schema for design of a database? In the preceding discussion we have noted the fact that explicit incorporation of data into an archaeological database does not currently occur at a satisfactory level. The hermeneutic method outlined here necessitates the elaboration of necessary data and does so in an explicit manner.

3.2 The archaeological problem

There have been numerous settlement pattern studies undertaken in Thailand and they are generally concerned with site distribution on a regional level, specifically, the relationship between the distribution of sites and the environment (Higham *et al* 1982; Ho 1992; Moore 1988a; Mudah 1995; Welch and McNeill 1991; Wilen 1987). Previous studies of settlement patterns of a particular type of site in this area, the moated site, has seen the explication of models concerning their development and distribution (Moore 1988a; Welch 1985). The basic model is: settlements were first established on the alluvial plain of the Upper Mun Valley during the Tamyae phase (1000-600B.C.). Intensive forms of agriculture were adopted during the Prasat phase (600-200B.C.) which made possible the expansion of settlement from the alluvial plain to the terrace and upland zones. Expansion to these areas saw the exploitation of salt, iron and timber resources which became important trade items. Welch (1985) was interested in documenting the role of centralisation, urbanisation and agricultural intensification with regard to these sites and their roles in long distance exchange. Moore (1988a) was interested in the moated sites as a technological group and attempted to document their overall structure and distribution. She studied them in isolation from an overall settlement pattern that included the larger moated sites, as well as smaller unmoated sites and rectangular water storage reservoirs (*barays*).

These models overlook a large body of data regarding human societies. Specific community level behaviour cannot be enlightened by such regional analyses. A major assumption in this analysis is that there is some kind of community structure based on the individual site (Trigger 1978). It is not that this structure has so far proven to be elusive to researchers in this area, it is just that it has not been an area in which major research has been undertaken. In order to locate these communities, relationships need to be identified between various factors considered useful for their identification. If the community concept can be identified, a fundamental aspect is the change in such organisation from prehistoric times into the historic Khmer period; a temporal shift of approximately 2500 years. This period saw fundamental changes in religion, symbolism, ideology, technology and social organisation which reached its peak during the time of the Angkorian *mandala* (8-14th centuries A.D.). Although these developments are manifested in monumental structures such as the Khmer temples of Cambodia and Northeastern Thailand, changes in basic community structuring are still largely unknown. We will undoubtedly have to wait until a larger proportion of sites has been excavated, but we can begin by examining spatial relationships of community structure. The archaeological problem is, therefore, to identify these communities both spatially and temporally; this is a problem that GIS can help solve.

3.3 The GIS solution

The archaeological problem identified above is just one part of the hermeneutic procedure (problem definition). The data contained in the spatially extended entity relationship (SEER) (see Firns 1994) diagram in Figure 2 is the other part (data definition). The critique above questioned the level to which data are defined; the following discussion concerns the SEER model and what it means in terms of this study. The data can be placed into several categories, or locational reference points: soil, hydrology, prehistoric vegetation, sites and temporal period. It will be seen that the first four of the categories are contingent upon temporal period. Each locational reference point is related back to a location which has a specific x, y coordinate value (see figure 2). At this stage we are not concerned with implementation of a database, so such abstraction is useful. These locational references are discussed below.

3.3.1 Hydrology

This category holds information concerning rivers, reservoirs (*barays*) and moats. Since prehistoric times, rivers have moved across the landscape, either naturally as they become flooded or due to human diversion (Welch 1985:292-3). From this, determining the contemporaneity between sites and rivers is very important and although river channels can be dated (Bishop *et al.* 1994), there is no information from this part of Thailand. Instead, we must work by association and relative chronology. The existence of the moated sites and *barays* help in this situation. The function of the moats surrounding these sites are not yet known, but most writers agree on them being used for some kind of water reticulation necessitated by the extremely arid conditions. It is assumed that the moated sites had a water source, and as can be seen on aerial photographs, rivers provide this source. Site abandonment is often linked to the movement of this water source, so as the river moves, so does the site, and the latter can be dated. Furthermore, the *barays*, which are large rectangular storage structures constructed by the Khmer between the 7-14th century AD for domestic, agricultural and religious purposes, were supplied by river and stream diversion (Moore 1988b). So it can be seen that the rivers did not just exist as a natural phenomenon, they played a large part in society. In fact it can be seen that "in no small sense, South East Asia is a region where water - not land - is the defining element and where human-water relationships, not human-land relationships are determining" (Rigg

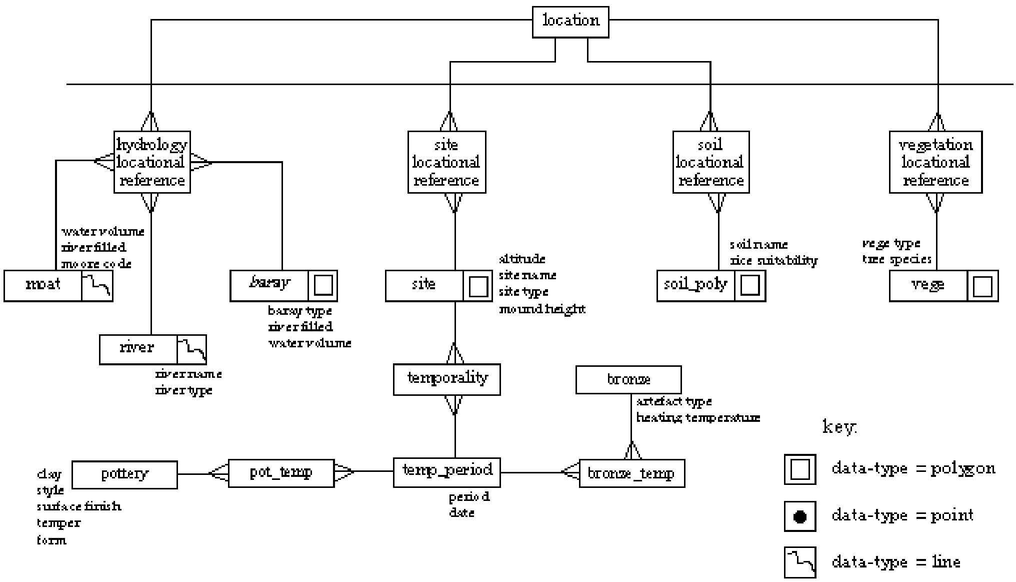

Figure 2: SEER diagram of the archaeological database

1992b:1; also, see papers in Rigg 1992a). An important example for this is the *bun bang fai*, the skyrocket festival of Northeast Thailand where a rocket representing a giant phallus is erected and shot into the sky to fertilise the heavens and to supply rain serving "to remind the male rain god to pour out his semen onto mother earth" (Demaine 1978:52).

3.3.2 Prehistoric Vegetation

This section of the database holds information concerning the prehistoric vegetation of the area. Stott (1978b:7) quotes the 17th century French naturalist and explorer, Nicolas Gervaise, who said that the forests are "so great that they take up more than half of the land...so thick that it is almost impossible to pass through." The vegetation cover of today in no way reflects that of prehistory or indeed of the time of Gervaise. In 1942, 42% of Northeast Thailand was covered in forest, there is now less than 10% (Moore 1992). However, we can recreate the past environment with a good degree of accuracy (van Liere 1980). Deforestation occurred in prehistory although not at a level which seriously altered the nature of the vegetation. Due to the methods of rice cultivation where areas were cleared to increase productivity, soil generally deterioratef and became incapable of supporting any form of plant life other than coarse grass and scrub (Ng 1978). Indeed, over time as more land was cleared such problems undoubtedly increased.

3.3.3 Soil

Basic characteristics regarding soil types are held in this section of the database. Most importantly is the definition of soil suitable for rice cultivation. However, Bayard (1992) has noted several limitations in using soil type as a factor in determining site location and the suitability for rice cultivation. Undoubtedly soil type was important, but it has been exaggerated as a factor in prehistory.

3.3.4 Site

Data regarding the site are important as it is assumed that this is where community structure is to be located. This part of the database holds information concerning basic data on the site; including mound height, size of the mound and the site type (e.g. moated, unmoated, rectangular, territorial and salt making [Moore 1988a]). Each of these types had different functions and can be dated to different periods. Therefore, it is important to define explicitly each type chronologically and once this is done, relationships between the various types can be discerned. Of these types, the salt-making sites are the most ambiguous. Although there are hundreds of mounds scattered throughout Northeast Thailand very few have been excavated (Higham 1977; Nitta 1992). These were important manufacturing sites as salt became a powerful trade item and was used for the preservation of food for consumption during the dry season (Nitta 1992). Salt-making was a dry season activity (Higham 1996a:315) and undoubtedly played a large part in community life. Thus these salt-making sites are essential components in the identification of the community.

As many sites were continuously occupied over long periods and fit into different settlement systems throughout the term of their occupation, there needs to be strict temporal control over their distribution at certain times in prehistory. This entity is linked to temporal period for this purpose.

3.3.5 Temporal Period

This aspect of the database is the most important as it is here where non-environmental variables are defined. Variables such as language (Higham 1996a, 1996b), religion (Tambiah 1970), burial practices (Higham *et al.* 1992), trade (Glover *et al.* 1992), along with information regarding bronze (Pigott *et al.* 1992), iron (Pornchai 1992) and pottery (Bayard 1977) technologies allow communities to be located at a given temporal period. Possibly the most useful indicator of temporal period is pottery which is an artefact type that has huge diversity in form, uses and style. These aspects along with rim-form, surface finish, surface-texture, colour, and temper help to differentiate between pottery types of different periods, but it is the general attributes of particular styles that are important rather than specific aspects. Therefore, incorporation of such variables could be considered useful for a regional/nationwide database, but for the present study they are not deemed necessary; strict associations between pottery types and temporal period will suffice.

The most important relationship is between this entity and the site entity. The site entity holds only that information for the physical nature of the site whereas the temporal period entity holds data that defines the activities at a site at a particular time. It is these activities that allow temporal relationships between the various entity sets to be defined. Furthermore, it is important to note that although the locational references discussed are environmental, they are embedded within a social context making it extremely difficult to make general conclusions regarding human activity - this social context is explicable at the level of the community.

To date, the problem has been defined and the process of data definition is currently underway. Thus I am still involved in the hermeneutic process; the so-called hermeneutic circle is in full swing. The GIS analysis will proceed once data have been defined to a satisfactory level which will lead to the discussion of community patterning.

4. Conclusion

Several problems in the use of GIS in archaeology have been noted. These problems have been related back to the lack of a general underlying theoretical framework from which to utilise the technology. One area in particular has been highlighted as a necessary beginning for the development of such a theory. This area is that of conceptual data modelling for the explicit definition of data to be incorporated into the analysis. A hermeneutic procedure has been outlined for this definition, and an archaeological dataset has been discussed.

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