TIME to look for a Temporal GIS

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ABSTRACT

Research to develop temporal GIS databases that facilitate spatiotemporal analysis commenced in the mid 1980s. The majority of research concentrated on how time could be incorporated as an attribute instead of as a dimension. Langran (1992) was one of the earliest researchers to provide an excellent foundation for future developments that could incorporate time as a dimension in a GIS. Amongst recent research projects in this area is the Chorochronos project that aimed at coordinating European researchers working on spatial and temporal GIS databases. The ultimate goal is to create a comprehensive Spatiotemporal Database Management System (STDBMS). An increasing requirement for GIS, especially in the field of archaeology, is that they be capable of tracing and analysing changes in spatial information. An a-temporal GIS obscures the process that causes states to change from one to the next, making dynamics of the modeled world difficult to analyse or understand. Until a truly integrated spatiotemporal database becomes available the additional temporal or t-coordinate can be included in the attribute database in order to account for time, and hence allow for data to be queried for temporally related issues.

1. INTRODUCTION

This paper presents information about the ongoing search for ways of integrating the aspect of time within GIS databases and its interaction with archaeological research. An important issue for designing and implementing an appropriate temporal GIS relates not only to the way in which time is recorded but also how the passage of historical time is viewed (Hunter, *et al.*, 1990). This area of research could perhaps be termed as cognitive views of past timescapes. As archaeologists we are confronted with the remains of past time as it has been encapsulated by three-dimensional objects that belong to a timescape other than our own. For archaeological research the concept of time as the fourth dimension is vital in order to better analyse and comprehend the process of change that is evident in the material culture. But for the time being, just how time can and should be incorporated into current spatial databases such as GIS still remains a topic of research. However it is important to contribute to the ongoing discussion about temporal GIS, especially by archaeologists whose research is essentially based on investigating spatial changes over time. This paper presents some relevant ideas and a prototype application that attempts at incorporating time into GIS. Originally GIS were designed to manage only spatial data in digital maps. Consequently GIS have made considerably more progress in analysing spatial rather than temporal data. Database technology for dynamic temporal maps still requires to be developed. So far no current commercial GIS can provide efficient support for the temporal analysis of spatial data (Ott *et al.*, 2001).

Amongst recent research in the area of spatio-temporal databases is the Chorochronos project that aimed at coordinating European researchers working on spatial and temporal GIS databases (Sellis, *et al.*, 2003). Links to current research can be found at the Chorochronos website (http://www.dbnet.ece.ntua.gr/~choros/). The ultimate goal was to create a comprehensive Spatiotemporal Database Management System (STDBMS). To achieve this goal, research covered the following 6 areas. 1: The definition of an *Ontology, Structure and Representation for Space and Time.* And 2: *Models and Query Languages for STDBMS* that are based on relational and object-oriented models. Another area was 3: To develop *Graphical User Interfaces for Spatiotemporal Information.* And 4: To enhance *Storage Structures and Indexing Techniques Query for Processing in Spatiotemporal Databases.* Finally it is necessary to 5: Define *STDBMS Architecture.* And to 6: *Apply a STDBMS to a realistic problem.* These are considered to be the major research areas necessary for the implementation of a true temporal GIS (Sellis, *et al.*, 2003, p. 3). In the future a spatio-temporal GIS could facilitate a number of possible data configurations and queries. These can be conceptualised by mapping spatial 3D data with the added dimension of time. However Temporal modeling commenced with the integration or inclusion of time in relational and then object-orientated databases. For the integration of time in GIS a number of temporal models have been proposed. Time can be modeled by what are usually referred to as Time slices or snapshot layers of data or by using Time stamps that provide a basic method for dealing with the temporal element (Armstrong, 1988). Time stamped data include a temporal value as an attribute of the data. Another model that has been suggested is that of Phase space which is derived from Physics (Langran, 1992).

2. HOW CAN TIME BE RECORDED FOR ARCHAEOLOGICAL DATA?

It is necessary to understand how archaeologists go about dating or assigning a date to data they uncover. Time is essential to archaeology. Were it not for time, archaeological data would not exist. Therefore the storage and analysis of time is integral to archaeological research. Archaeological research is unique because time is analysed in relation to changes in space that occurred in the past. Archaeology does not trace recent changes which are occurring and probably will occur in the future as is necessary for land resource management systems based on GIS (Burrough, 1986). Instead archaeological research seeks to reconstruct past time references based on data that have been collected. There is a requirement for further research to develop appropriate spatio-temporal databases specifically for archaeological stratigraphic analyses. When appropriate spatio-temporal databases become available it is envisaged that the application of GIS technology to archaeology will help answer questions about how cultures developed over time.

Applying GIS to archaeological research with specific reference to stratigraphic analysis, in other words the analysis of changes over time has not been fully exhausted. This is due in part to the necessity of ongoing research in archaeological methodology that deals with attributing dates to the finds. Furthermore the current modelling capabilities and the ability to provide appropriate data structures for spatio-temporal analysis, hamper efforts to provide a GIS appropriate for this specific area of research (Hazelton, 1991). Archaeological sites are analogous to mines containing a wealth of information concerning cultural changes just waiting to be quarried. Currently multitudes of raw data that have been collected over the years wait to be processed and refined even further. Ultimately spatio-temporal GIS will allow for analyses of for example changes that occurred in the environment within which humans interacted. Consequently mapping cultural changes over time by using a spatio-temporal GIS can significantly contribute to our understanding of for instance environmental processes that have been affected by humans and their resulting impact on the growth or demise of past societies. In a practical sense such analyses may be used to shed light for the planning of future urban landscapes to assist in minimising any foreseen negative environmental impacts and one way that archaeology can contribute and may be of benefit to future generations.

Spatial data in GIS databases can be recorded with time stamps as either instances or points in space or longer time intervals. Time slices or layers lead onto event or process-based modeling over long periods of time. Visualising changes over time on a map is an integral way of analysing changes. However these models lead to a redundancy of data in the database and ineffective methods of analysing the temporal aspect of change. In TimeSlices each image is disjoint from every other image so there is the problem of matching objects of interest between different Time Slices for analysis. So for now spatial data can be digitised and stored relatively effectively but the problem remains as to how time can also be recorded efficiently? Another possible temporal data model has been proposed by Langran (1992) who uses the term "phase space" which physicists use to describe a hypothetical space that is constructed by as many dimensions as is necessary to define the state of any given system (in this case the x, y, z, and t coordinates are necessary). Within spatio-temporal phase space three scenarios of temporal data representations are possible: 1. Horizontal planes of data that represent snapshot sequences as defined by a single date stamp. 2. Vertical columns of data resulting from start-end date stamps. And 3. A mixture of 1. and 2. where data in the phase space have both vertical and horizontal directions. Mapping spatio-temporal data in this way results in the following corresponding scenarios: (a) A snapshot time sequence that occupies horizontal planes in phase space. (b) Object histories that occupy columns of phase space, and (c) Spatial data with incremental changes that combine both horizontal and vertical phases. Based on these Langran presents potential queries that a spatio-temporal GIS could answer. The major queries are: 1. Examine a feature's lifespan. 2. Examine a single time slice. 3. Examine a feature's lifespan; when the feature meets some criteria, examine its time slice. 4. Examine a single time slice; examine the life spans of features meeting some criteria. 5. Examine the life spans of all features. 6. Examine all time slices. These representations and resulting queries of spatio-temporal analysis are analogous to the way archaeologists query the data. For instance archaeologists often examine material found in one horizontal plane to determine whether they all belong to the same era. Questions such as does the depth of the strata reflect a certain time span? Or how long does one culture type last? may be effectively answered with true spatio-temporal GIS databasesStatic databases provide either snapshots of one period of time or can include multiple layers of changes that occur in a certain area over time. On the other hand the visualisation or representation of temporal data or changes that result to 3D objects over short time periods are recorded in dynamic databases that have constantly changing states. Archaeological data represent static or "frozen" periods of time that are unlike dynamic temporal databases that have to be designed for constantly changing events in the present. In the case of archaeology there are techniques, such as data animation, that can be used to provide a visual perspective of how changes occurred over time. However functions are lacking that can enable querying and analysis of such changes. Archaeological data can provide a unique contribution to the field of spatiotemporal GIS research because they yield an abundant source of temporally referenced data. Archaeological sites and landscapes encapsulate a series of changes that occurred due to human activity but it's important to understand how archaeologists fix time that is represented by these changes. Temporal changes in archaeology are predominantly reflected with reference to their spatial x, y, and z coordinates. The stratigraphy or layering at a site is usually used to determine a chronological sequence. Stratigraphy provides a relative chronology for the majority of the finds. It is possible to assign either a relative or absolute date to each of the uncovered features and objects. Once objects or features are dated the extent of an occupation layer for any given era can then be determined. Absolute dates within a certain range of accuracy can only be attributed to features and objects that can be dated. Any feature or object found in relation to those objects that have been assigned an absolute date are dated according to a relative chronological scale. The recording of temporal sequences in GIS databases has been neglected due to the fact that GIS technology currently lacks the capability of fully integrating the temporal or t-coordinate. So how can time, as recorded by archaeologists, be incorporated into a spatio-temporal database for the time being? As static snapshots in space or as a mosaic of instances, which could be a reflection of traditional recording techniques? It is therefore important for the development of any future temporal models to consider the Harris Matrix system.

3. CURRENT ON-FIELD PRACTICES

It is beneficial to relate how archaeological data are currently attributed the element of time. Most archaeological excavations uncover features from the soil in a series of layers. The process and manner in which they are recorded forms layers of excavated data. These excavated layers are distinct from actual occupational layers that indicate the transition of changes due to time over vertical space. The stratigraphy of a site is determined by the analysis of the change in material culture across vertical space and can then be recorded with the Harris Matrix system. A true "spatiotemporal" GIS may assist archaeologists to reconstruct more accurate chronologies, from the recorded stratigraphy. So far archaeological time is usually recorded within the construct of the Harris Matrix (Harris, 1989). The stratigraphy of a site can be determined by analysing changes in the material culture across vertical space, and time is viewed as an attribute associated with features or artefacts that are found within the stratigraphy. Archaeological research is unique because time is analysed in relation to changes in space that occurred in the past. Archaeology does not trace recent changes that are occurring and probably will occur in the future as is necessary for land resource management systems based on GIS. Instead archaeological research seeks to reconstruct past temporal sequences. There is a requirement for further research to develop appropriate spatio-temporal databases specifically for archaeological stratigraphic analyses. The main principle of stratigraphy is that the excavation process reveals data that appear in a reversed time scale, except in cases where data have been disturbed. In some cases a jumbled mixture of layers complicates the tracing of archaeological data that are used in order to establish a temporal sequence or chronology. The extrapolation of an archaeological temporal sequence that is back-to-front in relation to the present (except in the case of a disturbed sequence) can be established by sorting out the data based on what their expected order of appearance is, as best understood by the archaeologist. The reasoning processes behind this complicated unraveling of time may one day be assisted by computerised expert systems (or Artificial Intelligence) that include similar rules archaeologists use to reveal the temporal sequence.

Until a truly integrated spatio-temporal database becomes available the additional temporal or t-coordinate can be included in the attribute database in order to account for time, and hence allow for data to be queried for temporally related issues. The way the element of time is stored, and the granularity of the temporal coordinate has to be determined for an archaeological spatio-temporal database. Whether time intervals are recorded in terms of years, centuries or millennia, depends on the ability and extent to which the available data have been dated. A GIS database should fully incorporate the temporal coordinate. Once a truly spatio-temporal GIS is developed the resulting benefits and analyses that it could provide may assist archaeologists to reconstruct more accurate chronologies. The Temporal or T coordinate can be considered to be a time stamp for every feature found at a site that can be related to each other by the distance in both space and time. A spatio-temporal database that includes an "era-stamp" for archaeological objects and features can be used to determine whether or not any disturbance has occurred in the stratigraphy. For instance a search can be made for all objects of a given chronological era, in relation to their elevation points or z coordinates. As such it can be concluded that the depth of each object is directly connected to its time of existence, except for those instances of disturbance in the occupational sequence, which can only be determined retrospectively. Figure 1 symbolises the relational interaction of the four coordinates (*x, y, z,* and *t*) that constitute the recording of all archaeological data over time.

4. POSSIBLE SOLUTIONS FOR ARCHAEOLOGICAL STRATIGRAPHIC ANALYSIS

Either a whole era or a snapshot in time can be provided for each object. Time as an attribute can be recorded either as Absolute chronology (T_A) if it is known, or as relative chronology (T_{RC}). The granularity or resolution of the date stamp can vary with the end-start dates for each object or feature. A reasonable goal for GIS is that they be capable of tracing and analysing changes in spatial information. An a-temporal GIS describes only one state of data. This means that historical states are essentially forgotten and the anticipated or forecast future cannot be treated (McDonald, 1989). Because of this, an a-temporal GIS obscures the processes that cause states to change from one to the next, making dynamics of the modeled world difficult to analyse or understand. In contrast, a spatio-temporal GIS would trace the changing state of a study area, storing historic and anticipated geographic states. By storing temporal or historic information a spatio-temporal GIS could respond to the following queries: Where and when did change occur? What types of change occurred? What is the rate of change? What is the periodicity of change? These questions are often considered in archaeological research. Given access to these types of data, "temporal" software might assess: Whether temporal patterns exist. What trends are apparent? What processes underlie the change? How fast changes took place. Such assessments could form the basis for understanding the causes of change leading to a better understanding of either the human or environmental processes at work in a region. The assessment of these issues is fundamental for the establishment of stratigraphic sequences and determining cultural patterns over space and time.

The requirement of spatio-temporal analysis is integral for the development of a GIS that can offer the capability of modelling landscapes affected by human activity. A spatio-temporal GIS could map cultural changes that could then be studied to determine what role these had on their immediate and wider environment. Currently time can be incorporated as an attribute. It is proposed that both Absolute dates (T_A) and Relative Chronology (T_{RC}) be recorded for each object found in the field (see Figure 2.). Ongoing research expects to facilitate a more comprehensive integration of time into GIS database structures. Given access to temporal data, questions regarding whether temporal patterns exist, what trends are apparent, what processes underlie any changes, and how fast changes took place could be assessed. In order to answer such questions the relational interaction of the four coordinates (*x, y, z,* and *t*) of archaeological data should constitute the recording of all archaeological data.

A spatiotemporal database that includes an "era-stamp" for archaeological objects and features can be used to determine whether or not any disturbance has occurred in the stratigraphy. For instance a search can be made for all objects of a given chronological era, in relation to their elevation points or z coordinates. It can be assumed that the depth of each object is directly connected to its time of existence, except for those instances of disturbance in the occupational sequence, which can only be determined retrospectively. These representations and resulting queries of spatiotemporal analysis can assist archaeologists to query the data to examine, for instance, the type of material found in one horizontal stratum to determine whether they all belong to the same era. Other issues they deal with are whether the depth of the strata reflects a certain time span or whether one culture lasted longer than another? The reasoning processes behind such issues include time; hence the importance of continuing research to improve data models for truly integrated spatiotemporal GIS. Research into this area has been practically applied in a recent project to allow geologists to view past landscapes. GEOTOOLKIT supports the animation of geological processes allowing the ability to follow a topological evolution of geological entities (Breunig, *et al.*, 2003). The representation of different states of the same spatial object a class called TimeStep was introduced and contains a time tag and 2 references (pre- and post-) to spatial objects. The TimeSteps between objects can differ and don't have to be equidistant. A time frame representation of a 4D model is the set of object states at a distinct time. From this 4D model a temporal sequence of changes in the geology of a region can be deduced and calibrated against observations providing new insights into the origin and development of the landscape that can then be viewed. What this means for archaeologists is that a prototype tool such as this can be modified to gain insight into the location of material culture at a site and what this means for the chronology of that material.

5. CONCLUSIONS

Time is essential to archaeology. Were it not for time, archaeological data would not exist. Therefore the storage and analysis of time is integral to archaeological research. The fundamental element of time, which in fact governs changes, has been largely neglected due to the fact that GIS technology currently lacks the capability of *fully* integrating the temporal or t-coordinate. The requirement of spatiotemporal analysis is integral for the development of a GIS that can offer the capability of modelling landscapes affected by human activity. As the spatio-temporal component of GIS technology improves GIS programs will most probably contribute to a more accurate query facility for reconstructions of stratigraphy, particularly for sites where the stratigraphy has been distorted by disturbances such as earthquakes, floods or thieves. A GIS may eventually provide the capability to reconstruct archaeological data utilising artificial intelligence modules to reorganise the position of features and objects to suit their expected stratigraphic position in contrast to the position they have been found in when excavated. Ongoing research expects to facilitate a more comprehensive integration of time into GIS database structures so that we can find our way in time with a GIS "time compass". Archaeological data can provide a unique contribution to the field of spatiotemporal GIS research because they yield an abundant source of temporally referenced data. Ongoing research expects to facilitate a more comprehensive integration of time into GIS database structures

REFERENCES

ARMSTRONG, M. P. (1988) – "Temporality in spatial databases." In *Proceedings: GIS/LIS '88* 2, p. 880-889.

BREUNIG, M. *et al.* (2003) – Architectures and Implementations of Spatio-temporal Database Management Systems. In

SELLIS, T. and KABOURAKIS, M., eds. (2003) *Spatio-Temporal Databases: The Chorochronos Approach.* LNCS 2520

Berlin: Springer-Verlag, p. 263-318.

BURROUGH, P. A. (1986) – *Principles of Geographical Information Systems for Land Resources Assessment.* Oxford: Oxford University Press.

HARRIS, E. C. (1989) – *Principles of Archaeological Stratigraphy.* 2nd edition. London: Academic Press.

HAZELTON, N. W. J. (1991) – *Integrating Time, Dynamic Modelling and Geographical Information Systems: Development of Four-dimensional GIS.* PhD dissertation. University of Melbourne.

HUNTER, G.; WILLIAMSON, I. P. (1990) – The development of a historical digital cadastral database. *Geographical Information Systems*, Vol. 4, p. 169-179.

SELLIS, T.; KABOURAKIS, M., eds. (2003) – *Spatio-Temporal Databases: The Chorochronos Approach.* LNCS 2520 Berlin: Springer-Verlag.

LANGRAN, G. (1992) – *Time in Geographic Information Systems.* London: Taylor and Francis.

MCDONALD, J. R.; PULLAN-CUTHBERTSON, T. M. (1989) – *Time and Spatial Information Systems.* Paper presented at The Inaugural Colloquium of the Spatial Information Research centre, University of Otago, New Zealand.

OTT, T.; SWIACZNY, F. (2001) – *Time-integrative Geographic Information Systems-Management and Analysis of Spatio-Temporal Data.* Berlin: Springer-Verlag.

FIGURES

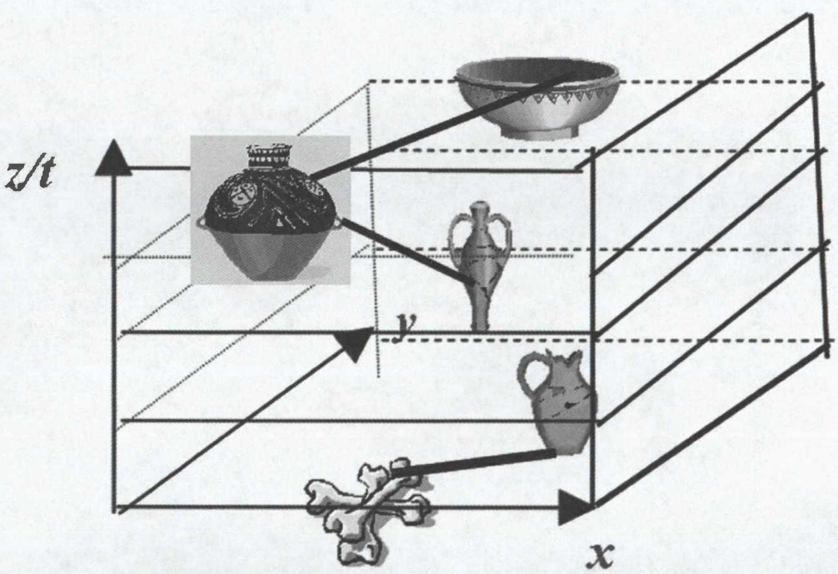
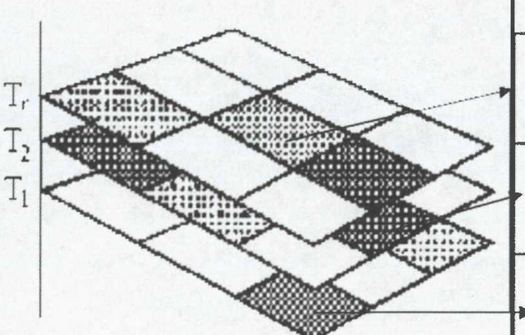


Fig. 1 – The Spatial-Temporal relationship amongst archaeological data.



x	y	z	t_A	t_{RC}
2	2	3	–	Myc.
2	1	2	1250 BC	–
1	1	1	1400 BC	–

Fig. 2 – Recording archaeological time, based on Armstrong (1988).