Development of a geovisual analytics environment for investigating archaeological events based upon the Space-time Cube.

Extended abstract for GIScience Geovisual Analytics Workshop
23 September 2008

Otto Huisman, Irvin Feliciano Santiago, Menno-Jan Kraak, Bas Retsios

International Institute for Geo-Information Science and Earth Observation (ITC), Hengelosestraat 99, P.O. Box 6, 7500 AA Enschede, The Netherlands.

huisman@itc.nl

Archaeology is an application domain that deals with data having inherent temporal and spatial components. The purpose of this paper is to present research results on the development of functions for Archaeological investigation within a prototype Geovisual Analytics environment based upon the Space-time Cube (STC). Generally speaking, the discipline of Archaeology focuses on recovering and analyzing remains and artefacts of past societies in order to reconstruct architectural structures, social organization, and gain insight into human behavior of past societies through consideration of the immediate geographical context and relationships to other finds or artefacts recovered in the area.

Over the past two decades, archaeologists have been developing and improving methods for collection, analysis, visualization and modelling of site information. GIS has been deployed in a range of decision-support applications (van Leusen, 1995; White, 2002), as well as analytical and modelling applications (Kohler et. al. 2000; Dean, et. al. 2000) in archaeological research. Specifically, applications such as viewshed analysis (Ruggles, et.al. 1993; Lobera et. al. 2003), spatial analytical applications for inverstigating or simulating the potential extent of a habitat/environment (Madry and Rakos, 1996; Williams, 2004), as well as a range of micro-level analyses documenting individual sites. This paper argues that, despite the increasing capabilities of GIScience tools in recent years, archaeology is an application domain where these capabilities have not been fully utilized, and there is significant scope for the development of new or extended tools and methods. The paper explores the potential of the STC environment to contribute to insights on archaeological phenomena, and in so doing, reports on extended geovisualisation functionality to support archaeological investigation. These are implemented and tested on a small subset of a significant archaeological database of approximately 900 archaeological sites from Puerto Rico.

The field of Geovisualization concerns itself with providing the necessary tools and the adaptability to handle complex geospatial datasets. It is important for geovisualizers to reassess the ways to explore, understand and satisfy the user's need in order to develop new applications that provide more meaningful results (Dykes et al, 2005). The Space-time Cube (STC) is a GIS-based implementation of Hägerstrand's (1970) original *Space-time Aquarium* for the visualization and analysis of space-time data. Two horizontal axes are used to represent the x-y geographic coordinates and the vertical axis the time (t) dimension. Together with attribute information, it is possible to explicitly represent the three main components of spatio-temporal data, namely *when, where, and what* – the key components of Pequet's Triad framework (Peuquet, 1994). In order to address questions at different scales, it is possible to employ different time granularities along the temporal (z) axis. Within the STC, the location of a find can be represented by a vertical line that has a color/thickness at the relevant time period. To indicate the findings of a particular type of artifact (i.e., bones, shells, pottery, etc.) the assignment of a color classification schema can provide the necessarily visual output to identify patterns or clustered artifact locations, and help the archaeologist to differentiate, associate and identify relationships in a more meaningful manner (Kraak and Koussoulakou, 2004). Alternatively, qualitative 'icons' could be used to distinguish these.

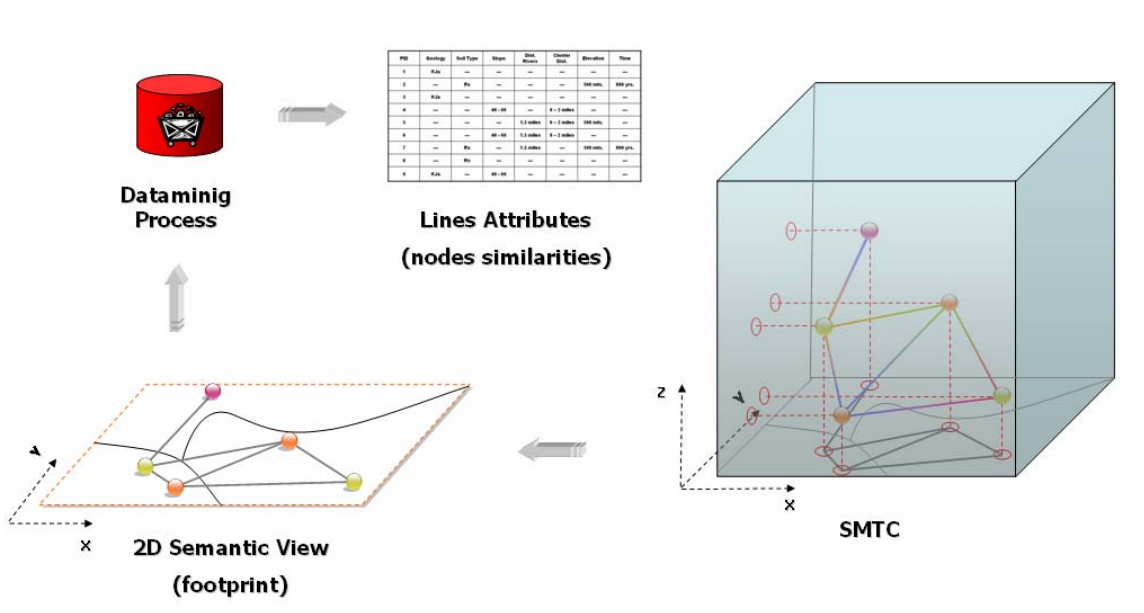

Figure 1: The extended Space-time Cube (STC) environment, drawing on relationships that exist between data from various sites in the database. These are connected according to selected criteria and can be visualized using multiple linked views.

A key issue in archaeological research concerns the relationships between sites and artefacts discovered at various sites in order to understand the interaction between cultures. To extend the existing capabilities of the STC, this research employs concepts from graph theory to examine the relationships between objects and events in space and time by abstracting them to a mathematical structure, i.e., a *graph*. Mathematically, a graph is defined as a pair of G = (V, E) of sets satisfying E [V]2; thus, the elements of E are 2-elements subsets of V. Therefore, elements of V represent vertices (nodes or points) of a graph G, and elements of E its edges (Diestel, 2000). In the field of visualization such graphs (or layouts) are referred to as networks composed of nodes and edges, in which each node in the graph can represent a particular entity such as classes, variables, or items of interest; and the edges (lines) between them represent various relationship characteristics (Ware, 2004).

The criteria used in this research for determining the tools and options to be added was based on an extensive literature review of graph theory, search levels and operational task topology (Andrienko, 2003), an evaluation of similar geovisualization environments, and an assessment of the current status of the STC software under development at ITC (Kraak and Huisman, *in press*). The realization of the prototype involved the development of automated functions for identifying/establishing relationships between attribute data in the database (data-mining), and facilitating direct import into the STC. One advantage of the extended functionality offered by the prototype is that relationships between attributes (database tuples) can be explicitly visualized and manipulated with various grouping and sorting functions, providing the user with a range of options for knowledge discovery. Figure 1 above illustrates the stages and elements involved in this procedure.

A range of visual variables can be employed for interactive geovisualisation to help answer the question such as: which cultures were present in the area, and how are they related? To demonstrate, Figure 2 above illustrates the notions of grouping nodes (archaeological sites with a color classification representing the ‘culture’ variable) into temporal intervals. This relates specific known cultures associated with finds at an archaeological site with either (Figure 2A) the first known associated period of a particular artifact found at a site, or the last known period for the same, and the result illustrates the number of sites participating in the relationships for the time periods. These can be combined into a single cube to give an insight into the periods with which specific finds are associated, or alternatively, viewed as ‘stations’ (Figure 2B) to illustrate potential associations between cultures (in the form of overlap).

The remainder of the paper discusses the issues above in greater depth, and demonstrates various geovisual analytical approaches to reasoning with the space-time cube. A range of artefacts can be derived from this information. For instance, an animated series of time-slices could be used to investigate the dominance of one culture over another (possibly revealed as the emergence of one culture and the displacement and eventual disappearance of another) as revealed by the discovery of artefacts related to those respective cultures. Multiple views can be used to support this investigation, aided by tools such as interactive filtering and sorting functions which can be applied to clarify patterns and relationships hidden in the data. The paper concludes with a critical discussion of the effectiveness and potential of the prototype and its functionality as well as reliability of observations and issues relating to data quality.

A

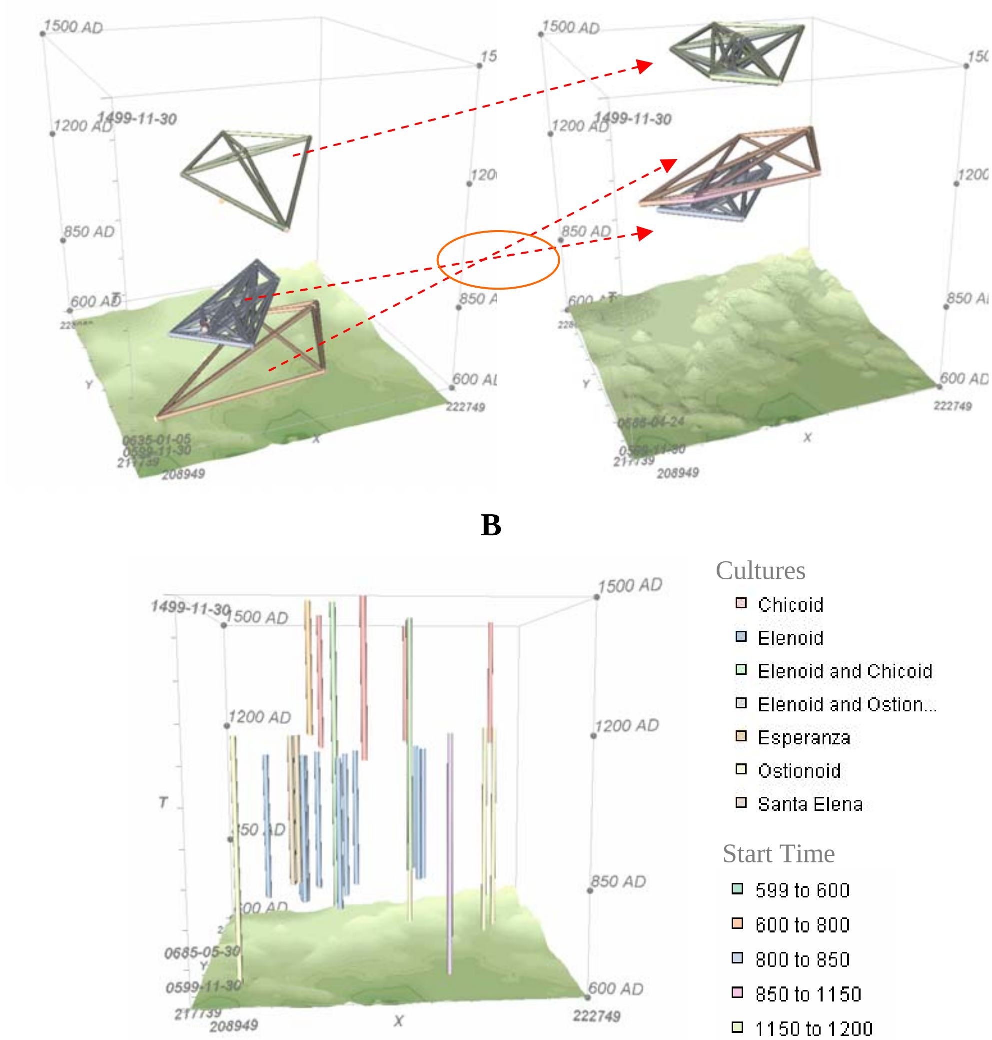

Figure 2: Archaeological time exploration. Top Left: Grouping by Start Time, Top Right: Grouping by End Time, crossing time lines between groups. Bottom: 'Station' view illustrating the duration associated with specific cultures at specific sites.

References

Andrienko, N., Andrienko, G., Gatalsky, P., 2003. Exploratory spatio-temporal visualization: an analytical review. Journal of Visual Languages & Computing, Vol.14, No. 6, Dec., 2003, pp. 503-541.

Dean, J., G. Gumerman, J. Epstein, R. Axtell, A. Swedlund, M. Parker, S. McCarroll. 2000. Understanding Anasazi culture change through agent-based modeling. In Agent-ased Modeling of Long-term Human Adaptive Systems, T. Kohler and G. Gumerman (eds) Oxford University Press. pp. 179-205.

Diestel, R., 2000. Graph Theory. Third Edition. Springer-Verlag, Heilderberg Graduate Texts in Mathematics.

Dykes, J. A., MacEachren, A. M. and Kraak, M.-J., 2005. Exploring Geovisualization, Oxford: Elsevier.

Hägerstrand, T. 1970. What about people in regional science? Papers of the Regional Science Association 24: 7-21.

Kohler, T. A., J. Kresl, C. V. West, E. Carr, and R. H. Wilshusen. 2000. Be there then: A modeling approach to settlement determinants and spatial efficiency among late ancestral pueblo populations of the Mesa Verde region, U.S. Southwest. Pages 145-178 in T. A. Kohler and G. J. Gumerman, eds. Dynamics in Human and Primate Societies. Oxford Univeristy Press, New York and Oxford.

Kraak, M-J. and O. Huisman, *forthcoming*. Beyond Exploratory Visualisation of Space-Time Paths. In Miller, H. and J. Han (editors), Geographic Data Mining and Knowledge Discovery, 2nd Edition. Taylor and Francis, London.

Kraak, M-J. and Koussoulakou, A., 2004. Visualization Environment for the Space - Time Cube. In: SDH 2004: Proceedings of the 11th international symposium on spatial data handling: advances in spatial data handling II. : 23-25 August 2004, University of Leicester. / ed. by P.F. Fisher. - Berlin etc.: Springer, 2004. pp. 189-200.

van Leusen, P. 1995 "GIS and archaeological resource management : a European agenda" In Lock G. Stancic, Z. (eds) (1995): Archaeology and Geographical Infromation Systems. A European perspective. London, Taylor and Francis.

Llobera, M. 2003. "Extending GIS-based visual analysis: the concept of visualscapes", International Journal of Geographical Information Science Vol.17 No.1, 2003, pp.25- 48.

Madry, S. L. H., and L. Rakos 1996. Line-of-Sight and Cost-Surface Techniques for Regional Research in the Arroux River Valley. In New Methods, Old Problems: Geographic Information Systems in Modern Archaeological Research, edited by H. D. G. Maschner, pp. 104–126. Southern Illinois University at Carbondale, Occasional Paper No. 23. Centre for Archaeological Investigation, Carbondale, Ill.

Peuquet, D.J., 1994. It's About Time: A Conceptual Framework for the Representation of Temporal Dynamics in Geographic Information Systems. Annals of the Association of American Geographers 84(3):441-461.

Ruggles C L N, Medyckyj-Scott D J, Gruffydd A, 1993, "Multiple viewshed analysis using gis and its archaeological application: a case study in northern Mull"', in Computing the Past Eds J Andresen, T Madsen, I Scollar (Aarhus University Press, Aarhus) pp. 125-132.

Ware, C., 2004. Information Visualization: Perception for Design, 2nd ed. San Francisco, CA: Morgan Kaufmann.

White, A. M. 2002. Archaeological Predictive Modeling of Site Location Through Time. Msc Thesis, University of Calgary.

Williams, M., 2004, Archaeology and GIS: Prehistoric Habitat Reconstruction ESRI User Conference Papers. Access on 25/4/2008: http://gis.esri.com/library/userconf/proc04/docs/pap1835.pdf