J Geograph Syst (2005) 7:1–5
DOI: 10.1007/s10109-005-0146-7

Journal of Geographical Systems

Space-Time Intelligence Systems: Technology, applications and methods

Geoffrey M. Jacquez[1], Pierre Goovaerts[1], and Peter Rogerson[2]

[1] BioMedware and TerraSeer, 516 North State Street, Ann Arbor, MI 48104, USA
(e-mail: Jacquez@BioMedware.com)
[2] Department of Geography, Department of Biostatistics, and National Center for Geographic Information and Analysis, University at Buffalo, Wilkeson Hall, Buffalo, NY 14261, USA

Received: 13 November 2003 / Accepted: 25 October 2004

Abstract. Geographic Information System (GIS) software is constrained, to a greater or lesser extent, by a static world view that is not well-suited to the representation of time (Goodchild 2000). Space Time Intelligence System (STIS) software holds the promise of relaxing some of the technological constraints of spatial only GIS, making possible visualization approaches and analysis methods that are appropriate for temporally dynamic geospatial data. This special issue of the *Journal of Geographical Systems* describes some recent advances in STIS technology and methods, with an emphasis on applications in public health and spatial epidemiology.

Key words: STIS, Temporal GIS, Spatial analysis

Preface

The papers in this special issue are the product of two specialist workshops convened in Ann Arbor, Michigan, on January 11–12, 2002 and January 9–10 2003 (See Table 1 for a listing of participants). The objective of the first workshop was to share information about existing techniques for handling time in GIS, and to brainstorm on how STIS might be beneficial. Presentations were made in the areas of object- and field-based space-time models, visualization and analysis of space-time data, and applications of space-time analysis in geographic information science. The workshop concluded with presentations of the recommendations by four working groups regarding the functionality and techniques that should be incorporated into STIS

The STIS expert workshops were funded in part by grants R01CA092669 and R01CA096002 from the National Cancer Institute, and by grants R43-ES010220 and R44-ES010220 from the National Institute of Environmental Health Sciences. Gillian AvRuskin provided cheerful editorial assistance. We thank the participants at the workshops for providing invaluable expertise and critical insights.

Table 1. Participants at the 2002 and 2003 STIS workshops. Not all participants were present at both meetings

Elisabeth Addink, Ph.D., The University of Michigan, Environmental Spatial Analysis Laboratory
Luc Anselin, Ph.D., University of Illinois, Urbana-Champaign
Gillian AvRuskin, M.S.,BioMedware, Inc.
Cynthia Brewer, Ph.D., Penn State University, Department of Geography
Dan Brown, Ph.D.,The University of Michigan, School of Natural Resources & Environment, Environmental Spatial Analysis Laboratory
Amy Burnicki, The University of Michigan, School of Natural Resources & Environment
Eve Do, BioMedware, Inc.
Heidi Durbeck, M.A.,BioMedware, Inc.
Leah Estberg, DVM, Ph.D., BioMedware, Inc.
Pierre Goovaerts, Ph.D., BioMedware, Inc.
Dunrie Greiling, Ph.D., BioMedware, Inc.
Geoffrey Jacquez, Ph.D., BioMedware, Inc.
Nicholas Jacquez, MBA, TerraSeer, Inc.
Andrew Kaufmann, M.S., BioMedware, Inc.
MaryAnn Labant, M.S. MBA, TerraSeer, Inc.
David Mark, Ph.D., SUNY, Buffalo, Department of Geography
Jaymie Meliker, M.S., The University of Michigan, School of Public Health
John Nystuen, Ph.D., The University of Michigan,
Seige Rey, Ph.D., San Diego State University, Department of Geography,
Peter Rogerson, Ph.D., SUNY, Buffalo, Department of Geography
Bob Rommel, BioMedware, Inc.
Marilyn Ruiz, Ph.D.,University of Illinois, Urbana-Champaign, College of Veterinary Medicine
Melissa Slotnick, MPH, MESc,The University of Michigan, Department of Public Health,
Dan Wartenberg, Ph.D., Robert Wood Johnson School of Medicine, Department of Environmental and Community Medicine
Mark Wilson, Sc.D., The University of Michigan, School of Public Health and Department of Ecology and Evolutionary Biology

technology. Two of the working groups focused on the space-time analysis requirements of two research projects funded by the National Cancer Institute (NCI): "A Space-Time Information System for the NCI Cancer Atlas" (Grant R01CA092669), and "Arsenic Exposure and Bladder Cancer in Michigan" (Grant R01CA096002). The other working groups formulated recommendations on space-time analysis techniques in landscape change detection and in exposure assessment. In the year following the first workshop many of the recommendations from these groups were implemented in STIS software whose development was funded by the National Institute of Environmental and Health Sciences ("STroodle: A GIS Foundation Class Library", Grants R43-ES010220 and R44-ES010220). This STIS software was then employed as a platform technology for implementing the STIS for the NCI cancer atlas and a second STIS for reconstructing arsenic exposure from drinking water in bladder cancer cases and controls in southeastern Michigan.

The second workshop was convened to evaluate progress on these projects, and to make additional recommendations regarding future research directions. Eleven expert presentations were made in the areas of methods, applications, and software. On day two participants were organized into four working groups that evaluated the STIS cancer atlas software using data sets on lung, bladder, leukemia and breast cancer mortality in the United States from 1950 through 1994. Each of the working groups was observed as they interacted with the software to provide additional information on software usability. The working groups then presented their recommendations, many of which were implemented during the ensuing year. At the time of this writing (December 2004) the STIS for the national cancer atlas has been released over the web, development of the STIS for arsenic exposure reconstruction is in progress, and version 1.07 of the STIS resulting from the STroodle project has just been released.

This special issue provides a record of these proceedings and documents approaches and applications of the STIS software that were evaluated during the workshops. The eight papers in this special issue are organized into three sections: technology, applications and methods. The technology section begins with a description of the design and implementation of STIS for disease surveillance (Jacquez et al. 2005). This paper summarizes space-time analysis needs for analyzing health data which include but are not limited to disease rates, counts, and the residential histories of cases and controls. It then identifies implications for the design of data structures, space-time object models and queries, and applies the proposed approach in prototype STIS software for the surveillance of influenza in a hospital ward. In the next paper in this section Brown et al. (2005) observe that space-time systems may be represented using a common object-based orientation for both models of process and for models of data. They then explore the integration of agent-based models (ABM) and GIS using a tight-coupling employing middleware to link GIS and ABM software. Relationships defining how data models for GIS and ABM can interact are defined and include identity, causal, temporal and topological types. Example agent-based models are then used to illustrate this novel approach.

The applications section opens with initial results from a bladder cancer case-control study that illustrates the use of continuous exposure lifelines to model changes over time in individual arsenic exposure (Meliker et al. 2005). This study employed the STIS software platform evaluated in the second workshop, and reports a possible focused clustering of bladder cancer cases near automotive, paint and organic chemical industries in southeastern Michigan. To our knowledge, this paper is one of the first applications of STIS in exposure reconstruction and cluster assessment. The second paper in this section by Greiling et al. (2005) employs the STIS for the national atlas of cancer mortality to compare results from two local clustering techniques: the local Moran and G-statistics. They explore space-time patterns in colon cancer mortality in the southeastern United States from 1950 through 1994, and evaluate cluster concordance for the two methods. The techniques classify areas on a map into similar types (e.g. cluster of high values) 97% of the time. The software is also used to compare mortality rates for racial and gender subgroups. African American males were found to have the highest mortality rates, and these rates increased over the study time period. This paper illustrates how animation of maps and statistical graphics in a STIS can inform us regarding changes in cancer clusters and cancer disparities through time. In the third paper, Greene et al. (2005) analyze the space-time incidence of viral Meningitis in Michigan from 1993 to 2001. They quantify space-time clustering using scan statistics, and report clusters in lower Michigan that occurred in the summer and fall of 1998 and again in 2001. They recommend that data on laboratory isolates, sociodemographics and environmental exposures be integrated into STIS for the surveillance of infectious diseases.

The methods section begins with a new approach to monitoring spatial maxima on maps to identify statistically significant peaks in areas whose values are recorded over time (Rogerson 2005). Rogerson employs a cusum technique for the monitoring of peak values that are modeled as variates from the Gumbel distribution. He then applies the cusum statistic to monitor peak values in breast and prostate cancer mortality in the United States from 1968 through 1998. A substantial advantage of this new technique is that knowledge of the distributions of the underlying values is not required. In the next paper, Sinha and Mark (2005) define a method for evaluating similarity among geospatial lifelines. Geospatial lifelines have numerous applications in disease surveillance, including the modeling of residential histories, reconstruction of individual-level exposures, and the modeling of daily activity spaces. Sinha and Mark propose a Mahalanobis metric to quantify similarity between lifelines. When causative exposures are more likely to occur in certain geographic areas, similarity of residential histories seem a plausible approach to identifying people with similar exposure histories. The authors evaluate the use of their similarity metric for this purpose using simulation studies and application to self-reported residential history data from a case-control study of breast cancer. They conclude with recommendations regarding the use of this technique to locate past locations of environmental hazards. In the final paper, Goovaerts and Jacquez (2005) undertake a synthesis of geostatistics and spatial statistics to derive techniques for identifying temporal changes in the spatial distribution of cancer clusters that relax assumptions of spatial independence. They develop neutral modeling approaches that reproduce the amount of spatial autocorrelation observed in the data, and then incorporate models of the underlying risk that go beyond spatial uniformity. This results in local Moran statistics that detect clustering above and beyond underlying spatial autocorrelation in the disease rates. They employ this approach to identify significant changes in cervix cancer mortality rates relative to those observed in the prior time periods, and find that accounting for spatial autocorrelation under the null hypothesis finds fewer clusters than those identified using the assumption of spatial independence in mortality rates. Their paper is the first application of the local Moran's I statistic using spatially correlated neutral models to detect changes in mortality rates across space and time.

References

Brown DG, Riolo R, Robinson DT, North M, Rand W (2005) Spatial process and data models: Toward integration of agent-based models and GIS. *J Geograph Syst,* (this issue)

Goodchild M (2000) GIS and Transportation: Status and Challenges. *GeoInformatica*, 4:127–139

Goovaerts P, Jacquez GM (2005) Detection of temporal changes in the spatial distribution of cancer rates using the LISA statistics and geostatistically simulated spatial neutral models. *J Geograph Syst*, (this issue)

Greene S, Schmidt MA, Stobierski M, Wilson ML (2005) Spatio-temporal pattern of viral Meningitis in Michigan, 1993–2001. *J Geograph Syst*, (this issue)

Greiling DA, Jacquez GM, Kaufmann AM, Rommel RG (2005) Space time visualization and analysis in the Cancer Atlas Viewer. *J Geograph Syst*, (this issue)

Jacquez GM, Greiling DA, Kaufmann AM (2005) Design and implementation of a Space-Time Intelligence System for disease surveillance. *J Geograph Syst*, (this issue)

Meliker JR, Slotnick MJ, AvRuskin GA, Kaufmann A, Jacquez GM, Nriagu JO (2005) Improving exposure assessment in environmental epidemiology: Application of spatio-temporal visualization tools. *J Geograph Syst,* (this issue)

Rogerson P (2005) Monitoring spatial maxima. *J Geograph Sys*, (this issue)

Sinha G, Mark DM (2005). Measuring similarity between geospatial lifelines in studies of environmental health. *J Geograph Syst*, (this issue)