Methods for Space-Time Analysis and Modeling: An Overview

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ABSTRACT

With increasing availability of spatio-temporal data and the democratization of Geographical Information Systems (GIS), there has been a demand for novel statistical and visualization techniques which can explicitly integrate space and time. The paper discusses the nature of spatio-temporal data, the integration of time within GIS and the flourishing availability of spatial and temporal-explicit data over the Internet. The paper attempts to answer the fundamental question on how these large datasets can be analyzed in space and time to reveal critical patterns. The authors further elaborate on how spatial autocorrelation techniques are extended to deal with time, for point, linear, and areal features, and the impact of parameter selection, such as critical distance and time threshold to build adjacency matrices. The authors also discuss issues of space-time modeling for optimization problems.

Keywords: *Autocorrelation, Geographic Information Systems (GIS), Optimization, Pattern Analysis, Spatio-Temporal Modeling*

INTRODUCTION

With an increasing availability of geospatial information over the last fifty years, spatial scientists have dedicated their efforts to the development of tools and techniques for the spatial and temporal analysis of georeferenced data (Anselin, 1999; Fischer & Getis, 2010). Analytical and geovisualization methods have proved critical in a growing number of spatially integrated application domains such as ecology, population geography, crime analysis, urban planning, location modeling, economic, environmental and health sciences. Consequently, there is now an abundance of robust statistical and data mining methods specifically designed to deal with geospatial data. These methods have facilitated the extraction and detection spatio-temporal patterns, eventually leading to the understanding of complex spatial relationships.

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Developments in computational science and mapping technologies have enabled effective and efficient visualization of large geospatial data sets such as social media data on the Web. To that end, Geographical Information Systems (GIS) provide a unique platform to integrate these methods and visualization capabilities (Longley, Goodchild & Maguire, 1999).

The purpose of this paper is to provide an overview of methods that can be used for space-time analysis and modeling. We start by situating our discussions in a context of the uniqueness of spatio-temporal data, its increasing availability through the Internet and social media, and the increasing need of methods to extract space-time patterns. We then review critical methods for spatio-temporal analysis, applied to point and areal features (with and without attributes) and linear features, with an emphasis placed on how to extend the concept of spatial autocorrelation in time. We focus our discussion on space-time modeling using an example of spatial optimization for planning and environmental modeling, where GIS and location modeling can be coupled together for data acquisition, analysis and result visualization. We conclude the paper with a revisit of the broad issues in space-time methodology.

SPATIO-TEMPORAL DATA

The Uniqueness of Spatio-Temporal Data Unique and the Critical Role of GIS

Spatial data is characterized by a set of longitude and latitude coordinates (or x and y), and usually modeled from an object-based or location-based approach (Peuquet, 2002). These modeling approaches are not contradictory, but rather complimentary. For instance point data is used when mapping crime events and disease occurrence (McElroy et al., 2003; Chainey & Ratcliffe, 2005) and can easily be overlaid with raster data, while linear features are used for network modeling. An interesting question is whether the spatial distribution of these events is clustered or not, leading to the identification of hot spots. Increasingly however, spatial data has also been augmented with attributes and temporal coordinates, for instance the time stamp associated with an event.

Researchers (Peuquet, 2002; Andrienko & Andrienko, 2006) have proposed two approaches to incorporating time in spatial data. In an object-based approach, temporal extent is attached to each entity as an attribute, while in a continuous approach individual objects are considered as attributes and attached to a given location in space and time. In the object based approach for instance, GIS provide a unique platform that facilitates the linking of temporal and non-spatial attributes to geospatial locations by means of a unique identifier (ID). By means of structured query language (SQL), events occurring within a certain time interval can be extracted, and statistical techniques applied to test whether they exhibit space-time patterns.

Due to the unique nature of space-time data, it is thus straightforward to combine temporal and spatial queries. Consequently GIS is undergoing a new phase where two critical issues are in (1) the development and applications of techniques for the identification of clusters of spatial association in space and time -or in the attribute space, and (2) the development of space-time visualization techniques. These issues can be very challenging for large datasets. Our paper fits directly into the first concern, which is the development and application of space-time methods to identify clusters in space and time.

The Increasing Availability of Spatio-Temporal Data on the Internet

Spatial temporal analysis of Web-based data has been explored extensively in recent years mainly with focus on topics such as space time query over the Internet using spatial temporal conditions (Tezuka & Tanaka, 2005), attribute extraction combined with spatio-temporal queries (Perry et al., 2007), knowledge organization of space time data (Janowicz, 2010) and