Exploratory Visualization of Mobile Object Data in Attribute-time Space

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1. Introduction

Recent years witnessed the emergence of massive individual-based movement data due to the location-aware devices such as global positioning system (GPS), mobile phones and radio-frequency identification (RFID) (Brimicombe and Li, 2006). GPS and RFID devices are increasingly connected to vehicles and objects in fleet management and logistics, created fine-grained data on movements of these entities within supply chains (see Roberti 2003). Researchers in ecology and biology are also using LATs to track movements of animals, creating new insights into territoriality and ecosystem dynamics (e.g., Wentz 2003)

These data are overwhelming the techniques of traditional spatial analytic techniques. Researchers and practitioners are turning to spatio-temporal knowledge discovery and exploratory visualization techniques to find patterns, trends and relationships hidden in the large volume mobile object datasets (Laube et al. 2005; Sinha and Mark 2005; Andrienko and Andrienko 2008). However, most studies focus on spatial and temporal domain: it is rare to examine the attribute domain which is rarely linked with the growing area of geographic data mining and knowledge discovery (Miller and Han 2009; Skupin 2008; Skupin and Hagelman 2005).

2. Methodology

This research develops a method to visualize mobile object data in both space-time and attribute-time to discover hidden knowledge about the evolution of dynamic path properties in concert with its location in space with respect to time. Reprojection techniques project mobile object trajectories from geographic space and time to a multivariate space and time defined by choosing three other dynamic attributes of the path and forming a space from the cross-product of these attributes with time. The attributes may be other spatial or geometric properties of the path, or non-spatial quantitative attributes that are dynamic. Dual visualizations of trajectories within space-time and attribute-time can provide new insights to the dynamic evolution of individual and collective spatio-temporal patterns. We also discuss a visualization software environment that implements these concepts, as well as a case study application to empirical trajectory data.

2.1 Reprojection from Space-time Trajectory to an Attribute Space

This research proposes a reprojection from space-time trajectories to attribute space objects using attribute information of space-time trajectories. This research utilizes five measureable attributes of geometric characteristics of space-time trajectories. These are *sinuosity*, *egocentric direction*, *velocity*, *locality* and *spatial range*. Sinuosity measures the deviation of the trajectory from a straight line. It is the ratio of the total length of the trajectory and the Euclidean distance between the origin and destination. Egocentric direction captures the relative or egocentric direction of the trajectory. Velocity indicates the relative speed of the object in the sample. Locality is the ratio between the distance between a trajectory's origin and its final destination and the distance between the origin and the farthest location in the trajectory. This is a measure of the relative focus of the trajectory with respect to its initial and final location within the chosen temporal range. Spatial range measures the relative spatial extent of the movement. It is the area of convex hull that contains a trajectory divided by the area of the convex hull that contains all the trajectories in the database. The indices map the trajectory to a point in a multidimensional space, which is an attribute space with five indices that each dimension represents each index. Figure 1 illustrates this in a three-dimensional space for clarity. *a*, *b* and *c* in the right side figure represent attribute values that are calculated from space-time trajectories.

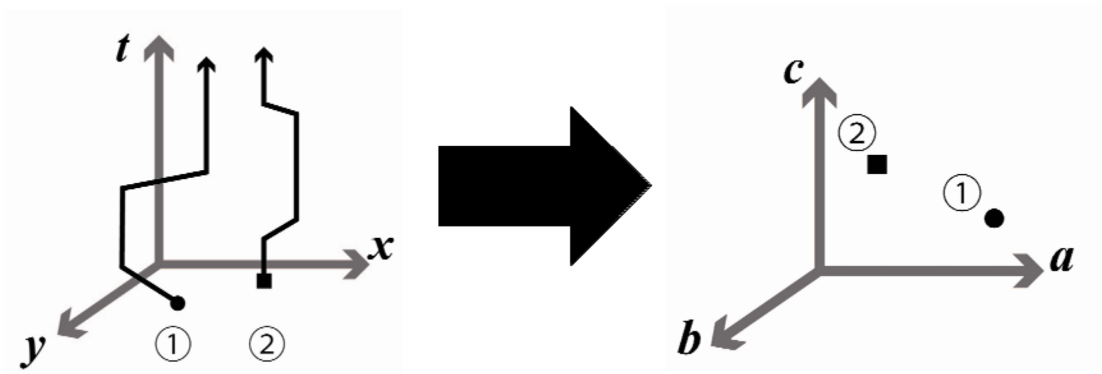


Figure 1. Reprojection of space-time trajectories into the attribute space representation.

2.2 Attribute-time Trajectory

Attribute-time space is the extension of the attribute space: attribute-time space incorporates temporal aspect into the attribute space. Figure 2 illustrates the concept. The upper row illustrates space-time trajectories with three different time range (6:00 – 9:00, 6:00 – 12:00, and 6:00 – 15:00). On the other hand, the lower row illustrates attribute-time trajectories with the same three time ranges. In the case of mobility with time range of 6:00 – 9:00, space-time trajectories are represented as single points in the attribute space using three attributes extracted from space-time trajectories. As the time range increases, the single points in the attribute space become moving points because the values of attributes change along with the change in the shape of space-time trajectories. Change of attribute values with respect to time enables dynamic visualization in the attribute space. Note that moving points that are closer to each other in attribute-time space indicates the similar movement pattern of space-time trajectories with respect to the attribute values that are used in visualization: closer points in the attribute-time space possess similar attribute values.

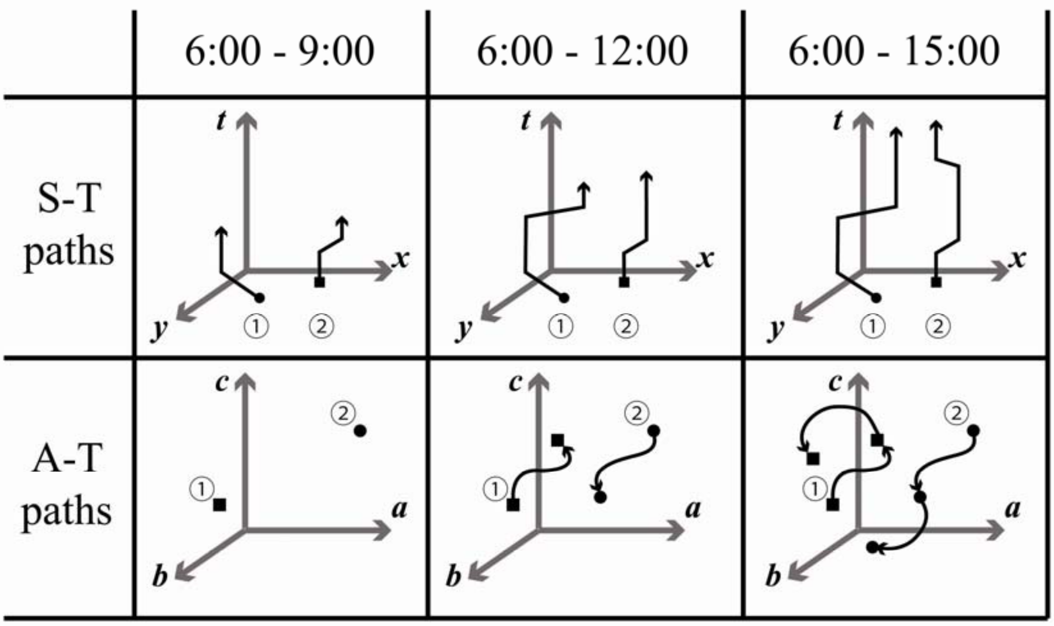


Figure 2. Attribute-time representation.

2.3 Dual Visualization with Software Environment

This research implemented the concept of attribute-time space in the standalone software environment which enables dual visualization of space-time representation and attribute-time representation: two space-time representation (two-dimensional view and three-dimensional view), and attribute-time representation (Figure 3).

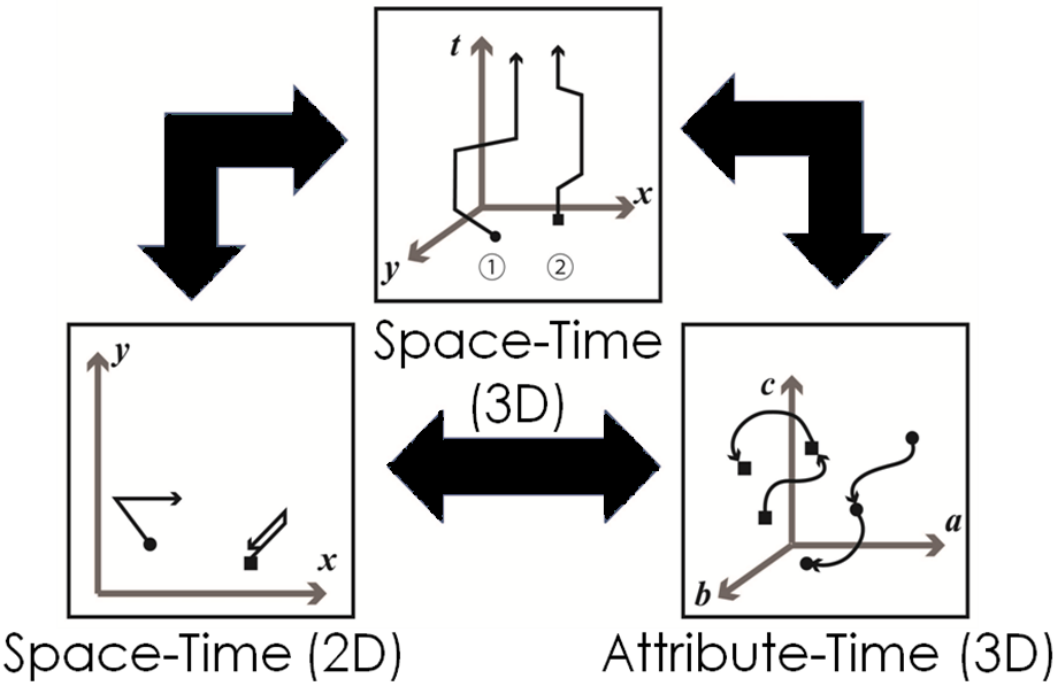


Figure 3. Dual visualization of space-time representation and attribute-time representation.

Figure 4 shows the graphical user interface of the software: upper left visualization is two-dimensional space-time representation; visualization in the middle in the left is three-dimensional space-time representation; and visualization in the right is attribute-time representation. Charts at the bottom of the interface visualize change in values of each geometric property. We developed the user interface using the C++ programming language with OpenGL technology for visualization.

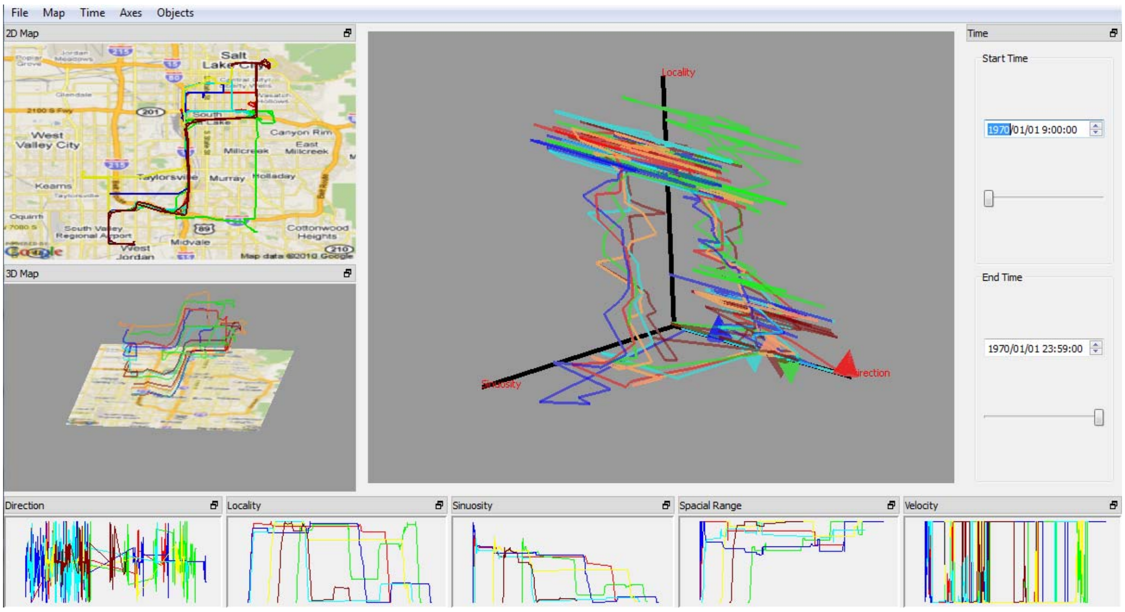


Figure 4. The user interface of the visualization toolkit.

3. Preliminary Results

A case study with the investigator's self tracking GPS data in Salt Lake county, Utah is demonstrated as preliminary results: the investigator's daily trajectories of six days in December 2008 (6^{th}, 14^{th}, 21^{st}, 22^{nd}, 23^{rd}, and 24^{th}) is utilized in this case study. These seven days are selected because the investigator moved similar geographic locations with similar orders: the investigator commuted from his home to the University of Utah, then went back to his home later in each day using similar road network. Figure 5 illustrates the visual results of time range between 11:21 and 13:30. Two trajectories appeared at 11:21 and moved on the almost same road network until 11:25. Although two trajectories showed similar movement in space-time representation, attribute values and their transition are different from each other (see top row image in Figure 5). This detail visual exploration can differentiate one trajectory from another with respect to attribute information. As the time range grows, third, fourth and fifth trajectory appeared in the visualization. It is notable that attribute-time trajectories trace similar locations in all of five trajectories. In addition, there is a clear trend in the transition of attribute values that are shown at the bottom of the interface: properties of direction (the left most chart) and velocity (the right most chart) show high variety in transition of values while other properties (sinuosity, spatial range, and locality) show similar transition. Attribute-time space provides a different perspective in data exploration which is difficult in visual data exploration in space-time representation

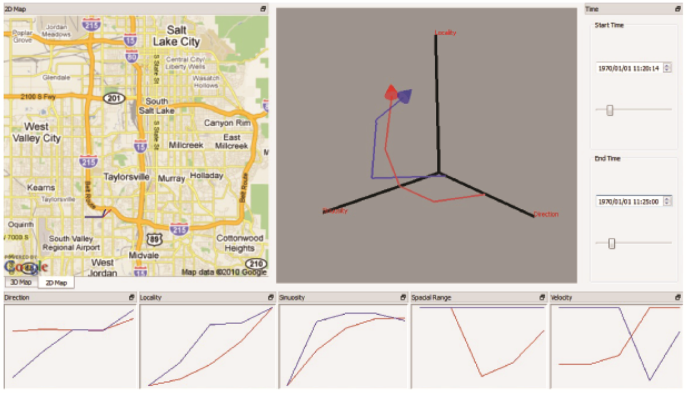
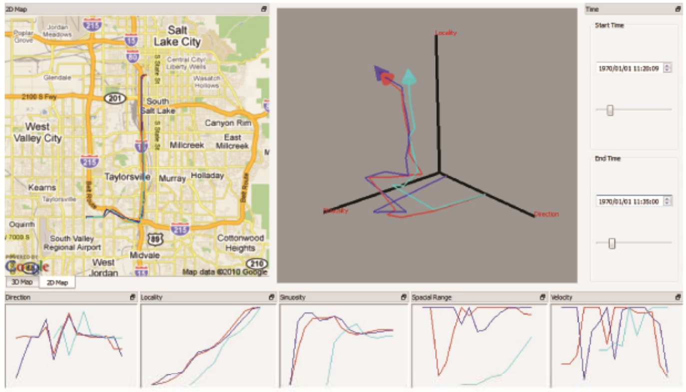
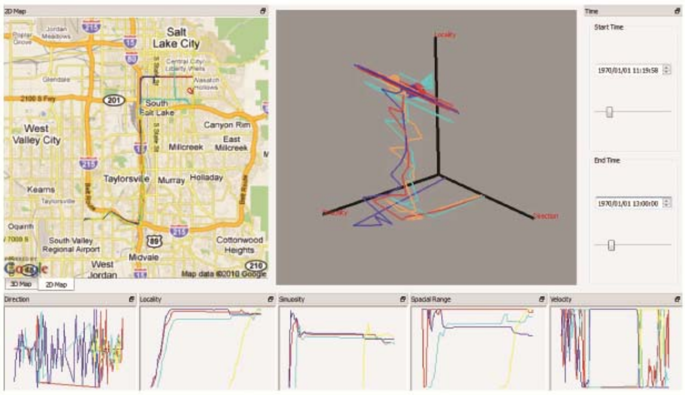
time range	visualization result
11:21 - 11:25	
11:21 - 11:35	
11:21 - 13:00	
11:21 - 13:30	

Figure 5. Comparison of similar space-time trajectories with attribute-time space.

4. Conclusion

There is a growing demand of discovering interesting patterns in emerging mobile object datasets. This research proposed attribute-time space representation of mobile object data to uncover patterns that leads to knowledge construction. Dual visualization of space-time representation and attribute-time representation enables detail analysis of attributes of mobile objects with respect to time. Mobility patterns in a case study showed the effectiveness of dual visualization and transition of geometric properties of space-time trajectories.

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