The Visualization Representation of Space-Time-Path in The Space-Time-Cube

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Abstract. Map is a traditional visualization tool to represent distribution and interaction of spatial objects or spatial phenomenon. However, with the continuous development of acquisition and processing technologies for spatio-temporal data, traditional map can hardly meet the visualization requirement for this type of data. In other words, the dynamic information about spatial object or phenomenon cannot be expressed fully by traditional map. The Space-Time-Cube (STC), as a three-dimensional visualization environment, whose base represents the two-dimensional geographical space and whose height represents the temporal dimension, can simultaneously represent the spatial distribution as well as the temporal changes of spatio-temporal data. For some spatial object or phenomenon, its moving trajectory can be visualized in STC as a Space-Time-Path (STP), by which the speed and state of motion can be clearly reflected. Noticeably, the problem of visual clutter about STP is inevitably due to the complexity of three-dimensional visualization. In order to reduce the impact of visual clutter, this paper discusses different aspects about visualization representation of STP in the STC. The multiple scales representation and the multiple views display can promote interactive experience of users, and the application of different visual variables can help to represent different kinds of attribute information of STP. With the visualization of STP, spatio-temporal changes and attributive characters of spatial object or phenomenon can be represented and analysed.

1. Introduction

Human progress cannot be separated from the exploration of our planet, during which map played an important role as main products for geographic data storage and handling. According to Kraak &
Ormeling [1], maps help people better understand the geospatial relationships and patterns. While, as more and more new techniques for geographical data acquisition were invented, geographic data are increased on quantity as well as quality. At the same time, time information can be recorded along with spatial data, which enables to analyse spatial objects’ changing and moving over time. While, analysing temporal data introduces difficulties for map visualization. Rooted in Hägerstrand’s time geography [2], Space-Time-Cube (STC) was introduced, which is a 3-D visualization environment and is increasingly important and widely used. The moving trajectory of some spatial object can be visualized as Space-Time-Path (STP) in STC. In order to assist exploring STPs and reduce effects of visual clutters, for which different aspects about visualization representation are discussed in this paper.

2. STC and STP

Space-Time-Cube (STC) is a part of the time-geography and displays it graphically. It is considered as the most prominent element in Hägerstrand’s approach [3]. There are three dimensions in the STC model, namely X, Y and T. The X and Y dimensions, which are used to define a plane, represent geographical coordinates, just like a 2D map. The T dimension displays the time [2]. A base map is usually attached to the 2-D plane and marks the precise location of individual(s). Points in three-dimensional space, where the vertical dimension corresponds to time, represent the positions of an object at different time moments. [4] In other words, the projection of a point onto the spatial plane is its geographic position, and the projection onto vertical dimension is the time moments. The STC is “a project of dynamic visualization environment” [5].

The life path describes the trajectory of an individual in space-time. When put it into the STC model, it is termed as the Space-Time-Path. It is an unbroken trajectory which never goes backward, since time can be neither escaped nor jumped, nor reversed back. The footprint of Space-Time-Path on a 2-D plan (e.g. a basemap) traces the object’s movement in space. It could be observed as to project it on the map. [3] The footprint on the third dimension, namely the T-dimension, on the other hand records the time on which the object is at some certain location. Through simple analysis, information like how long it takes to go through some distance and the travelling speed of the objects could be figured out. The more is the Space-Time-Path close to be horizontal, the faster does the object travel. A vertical line, which means there is no movement and the object retains at a particular location for a while, is termed as “station

3. Related Works

The Space-Time Cube model was proposed by Hägerstrand [2]. Since modern computer technologies and new spatiotemporal data sources, as like data of GPS, were introduced, many researches have been done in the STC. Some researches focus on visualization environment of STC [3], while more researches are about its application, as like human activities [6], public health [7], earthquakes [4], urban environment [8], et al. The STC, which preserves continuity on space as well as on time, helps to identify the space-time cluster pattern and developing tendency. It is suitable for visualizing complex spatiotemporal data sets. The STP is usually applied on route analysis and mining effective information. For example, quality of tourists’ experience of Ocean Park in Hong Kong was studied through the method of STP [9]; or, applying STP on transportation to analyse time reliability of urban
public transportation [10], vehicles’ fuel consumption and emissions [11], and so on. In addition, there are researches on data processing technologies about STC and STP [12].

4. Visualization Representations

Similar to map, there will be unavoidably visual clutters for STPs visualization in STC due to different factors, such as the exceeded number of STPs, the unmatched scale for displaying STPs’ details, STPs to visually block one other etc. The application of different visual variables may also introduce visual confusion in order to reflect attribute information of STPs. Therefore, visualization representation approaches are discussed below for these problems.

4.1 Multi-perspectives Observations

Combined time dimension, the STC is a 3D visualization environment. It enables users to research objects’ moving in space and changing on attributes, but it is a hard-understanding visualization approach compare to 2D map. The STPs are “suspending stares” in the cube, and usually untouched to neither its 2D plane - a referential map - nor the third time dimension. For researching intension, auxiliary functions are applied for users to better understanding. For example, when moving the 2D plane flexibly up and down or adding auxiliary 2D planes at necessary timing moments, the intersection points of STPS and 2D map can be observed by users. Besides, for better observation, different viewing perspectives are necessary, which enables users to observe the STC from different perspectives. The perspective drawing is the overall view of STC, and users can get a general impression of STPs. Top view is the view projecting the STPs to the 2D map, which is as same as observing tracks on map. Front view is the view projecting the STPs to the 2D plane constituted by X and T coordinates, which enables users to observe moving speed on X coordinate. Similarly, side view enables users to observe moving speed on Y coordinate. In condition, multi-view enables users observe the STPs from different perspectives and helps better understanding and researching, especially when there are more than one STP and they block each other.

4.2 Classification and Displaying of STPs

When the number of STP is huge and exceeds the capacity of STC, visual clutters are generated and little efficient information can be analysed by users. To avoid that situation, the STPs must be classified when being created, and the function of displaying/hiding for each STP is necessary. Users only research STPs they needed through selecting interested categories or individuals of STP.

4.3 Multi-scale Representation

Here, multi-scale representation means that the same STP is represented in different levels of details at different scales. The multi-scale problem of STP model is usually due to a huge speed difference and mainly caused by different kinds of transportation. For example, some person moving by walk and then on by car, and the STP for him is drew in the STC. Compared segment of walking with segment of riding, the former one is nearly vertical and the latter is nearly horizontal. Details for walking, where he passed by or where he stopped, cannot be distinguished, because its spatial occupation in STC is much too small compared to riding. See Figure 1, the segments selected in boxes are too crowded to represent details. Therefore, multi-scale representation is applied on STP visualization.
Visualization scales are various not only on 2D geographical coordinates, but also the time coordinate, which enable users to observe different STPs or different segments at a suitable scale.

![Image](image_url)

**Figure 1.** A traveler’s STP using different kinds of transportation

4.4 Multi-window Representations
Similar to mapping application, which is observable as an interface to geospatial data and conveys information or even knowledge, the STC can also be one to improve our insights and understandings in geospatial-temporal data [13]. Alternative views, or multiple views – of which each view focuses one aspect; the same content impresses viewers from different directions. An alternative perspective on the data will sparkle the mind with new ideas, according to Kraak [13]. Therefore multi-window representation significantly makes it better for exploration and understanding. Each window emphasizes one of aspects of information about STPs and they together convey integrated information to users.

4.5 Visual Variables for STPs
There are six visual variables presented by Bertin [14] for 2D maps, including size, shape, colour, value, orientation and texture, which are used to represent attribute information of geographic objects on map. Similarly, some visual variables can be applied on STPs to represent attribute information, such as quantity or quality differences.

Colour is usually used to distinguish different STPs and, if necessary, can be combined with literal name. Path width can be used to represent quantitative characteristics, but the disadvantage of it is that visual clutter problem may be more serious at segments where STPs are wider. Besides, the attributes could also be attached out of STPs. The size, colour, shape of attachments can stand for quantity or quality difference of attributes.

4.6 Visualization Conceptual Prototype
As discussed above, by applying multi-perspectives observations, classification and displaying, multi-scale representation, multi-window representations and the application of visual variables on
STPs, an interactive representation prototype is created. And the highlight displaying helps link different windows. (See Figure 2)

![Interactive multi-view](image)

**Figure 2. Interactive multi-view**

5. Conclusions
This paper discussed visual clutters of STPs displayed in the 3D visualization environment. Through different interactive approaches applied, a visualization conceptual prototype is created, which gives better interactive experience for users.

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