Journal of Visual Languages and Computing 000 (2017) 1–13

Contents lists available at ScienceDirect

Journal of Visual Languages and Computing

journal homepage: www.elsevier.com/locate/jvlc

A viewpoint based approach to the visual exploration of trajectory

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ARTICLE INFO

Article history:
Received 2 September 2015
Revised 9 May 2016
Accepted 5 April 2017
Available online xxx

Keywords:
Viewpoint
Spatiotemporal visualization
Trajectory
Google earth
KML
Visual analytics

ABSTRACT

We present a new viewpoint-based approach to improving the exploration effects and efficiency of trajectory datasets. Our approach integrates novel trajectory visualization techniques with algorithms for selecting optimal viewpoints to explore the generated visualization. Both the visualization and the viewpoints will be represented in the form of KML, which can be directly rendered in most of off-the-shelf GIS platforms. By playing the viewpoint sequence and directly utilizing the components of GIS platforms to explore the visualization, the overview status, detailed information, and the time variation characteristics of the trajectories can be quickly captured. A case study and a usability experiment have been conducted on an actual public transportation dataset, justifying the effectiveness of our approach. Comparing with the basic exploration approach without viewpoints, we find our approach increases the speed of information retrieval when analyzing trajectory datasets, and enhances user experiences in 3D trajectory exploration.

1. Introduction

With the increasing use of GPS devices, huge amounts of trajectory datasets are generated from different types of moving objects equipped with GPS sensors. Due to the spatial and temporal aspects of the moving objects and quantitative attributes about the encompassing environment of the routes, trajectories have become valuable sources of a number of applications, such as planning public transportation and analyzing human behavior.

Among all of the analysis requirements, directly exploring all the three aspects (space, time, attribute) of multiple trajectories is the most basic and important one, through which analysts can obtain high level characteristics of the entire datasets and preliminarily select a subset satisfying a specified filtering condition from huge amounts of raw data for further in-depth studies. An intuitive and effective exploration of trajectory is the foundation of performing different types of analysis tasks.

Trajectory simultaneously has spatial, temporal and multiple attribute dimensions, and the dependencies between them should be jointly analyzed to gain insight into the spatiotemporal dynamics of attributes. Most existing trajectory exploration/visualization techniques utilize aggregation or clustering to reduce the complexity (both amounts and dimensions) of raw datasets to arrange the visualization in a 2D plane. Information loss caused by aggregation and clustering makes it difficult to explore all the aspects of multiple trajectories in a plane view.

Therefore, 3D trajectory visualization techniques have become a common strategy of trajectory visualization. In most cases of 3D trajectory visualization, visual designers often utilize the vertical dimension to represent the temporal axis and stack multiple trajectories having the same routes [1–3]. Although the effectiveness of 3D visualization techniques on jointly displaying spatial, temporal, and attributes of trajectory data has been confirmed [4,5], they have the following two problems, which have not been well resolved in previous works: (1) Projecting 3D visualization objects in a 2D screen results in overlapping and clutter. The objects in the front hinders the user from observing other objects behind (seeFig. 1a and b). (2) Exploration parameters in 3D visualization space, such as the viewing direction, viewing distance, and external lighting, affect the display effect and the cognition speed. In an actual scene, to explore a customized 3D view containing lots of visualization objects (see Fig. 1c), the user has to manually change the exploration parameters by frequently utilizing a mouse to drag the screen to obtain an optimized display effect. Such two problems make the exploration in 3D space more time-consuming and error-prone than that in 2D space, because screen is frequently switched among different parts of the visualization to determine the findings. This problem is extremely serious for large datasets

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http://dx.doi.org/10.1016/j.jvlc.2017.04.001
1045-926X/

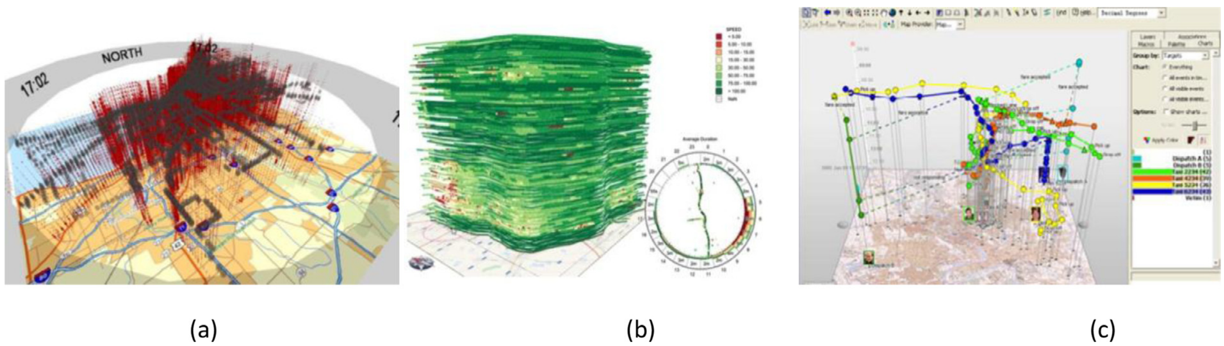

Fig. 1. Three 3D trajectory visualization techniques: (a) Space-Time Cloud [6] with a clutter problem when showing too much data. (b) Trajectory wall [1] preventing the users from viewing the objects behind the wall. (c) GeoTime [7] in which the viewpoint sequence and the angle of the sight line affect the display effects.

due to the fact that it is usually unclear where interesting patterns can be found and which trajectories needs to be looked at in detail. Quickly determining optimal exploration parameters to help analyst interactively explore visualization and effectively find dataset characteristics becomes a necessity for all kinds of trajectory analysis tasks.

In this paper, we present a viewpoint-based trajectory visual exploration approach which integrates the novel 3D trajectory visualization techniques and viewpoint generation algorithms to avoid the above issues. Given the input data and application requirements, our approach can automatically generate a 3D trajectory visualization together with a viewpoint sequence that provides the analysts an optimized exploration manner to quickly grasp the overview characteristic of the generated visualization. To avoid the uncertainty of the viewpoint generation algorithm caused by the diversity of the trajectory datasets, we propose a generic viewpoint generation framework with a client-server architecture. The analyst first interactively select a route on a software interface (see Section 6.1), then all the trajectories containing the selected route are collected to construct a visualization and the corresponding viewpoints are generated as well. The generated viewpoints provide optimal perspectives to the visual exploration of the generated visualization to support the viewer to sequentially and effectively observe different levels of the visualization. Different from existing 3D trajectory visualization techniques that mainly focus on the visual design, our framework attempts to balance the visual expression and human cognitive effects.

In summary, the major contributions of this paper include:

- A visual exploration framework for quickly exploring trajectory data based on viewpoint.
- Novel 3D visualization techniques for displaying attribute distribution of trajectory datasets.
- Two types of viewpoint generation algorithms specialized in observing the details and overview information respectively.
- A systematic evaluation, consisting of a case study with a real bus dataset and a usability experiment.

The remaining part of this paper is organized as follows. Section 2 reviews related work. The approach overview is described in Section 3, followed by the visual design, viewpoint selection algorithms and concrete usage of our approach in Sections 4–6 respectively. Section 7 evaluates our approach in a case study and an experiment. Finally, we discuss the advantages and drawbacks of our approach in Section 8 and conclude the paper in Section 9.

2. Related work

2.1. Trajectory visualization

As the most common type of spatiotemporal data, trajectory data are analyzed in numerous visualization works, involving multiple visualization strategies:

Multi-view is one of the most common used strategies of trajectory visualization. Guo et al. [8] developed a trajectory analysis system consisting of a radial layout map, a ThemeRiver, a Scatterplot, a Parallel Coordinate, etc. to analyze the traffic trajectory data at a road intersection. Nagel et al. [9] developed a multi-view system for visually exploring public transportation trajectory datasets on a multi-touch tabletop. Liu et al. [10] designed a radial layout visualization to find different routes connecting two regions. However, these works simultaneously contain several equally important views to show different facets of trajectory, lacking intuitive and compact methods for showing the overview in a single view. Operating a multi-view system mainly depends on interaction, which affects the analyst on quickly understanding the dataset and discovering the potential knowledge from huge amounts of trajectories.

Utilizing aggregation and clustering to reduce the complexity of trajectory is another common strategy. Andrienko et al. [11–13] designed a series of trajectory visualization techniques based on spatiotemporal aggregation and clustering. They also proposed a technique taxonomy for modeling the relationship between facets of trajectories and analysis tasks [14]. Landesberger et al. [15] aggregated huge amounts of trajectories to form a graph, in which node and edge represent spatial areas and trajectory transitions between two areas respectively. However, these techniques mainly utilize clustering and aggregation to reduce the complexity of facets to be visualized, lacking the capability of providing an overview of the whole dataset to help the analyst quickly identify high level spatiotemporal characteristics.

Coordinate transformation, or converting absolute locations (longitude/latitude) of moving objects to relative distances to a reference, is an effective strategy in analyzing group moving patterns. Crnovrsanin et al. [16] analyzed the trajectories of all persons at the scene of a terrorist explosion and identified multiple suspects by visualizing the distance variations of all the persons to different selected important locations, such as the exit or the explosion site. Andrienko et al. [17] found the difference of group movement patterns between human and baboon by visualizing the distance of each individual in a group to the real-time group center. However, coordinate transformation emphasizes on analyzing group movement patterns rather than providing intuitive explorative views.

Please cite this article as: J. Li et al., A viewpoint based approach to the visual exploration of trajectory, Journal of Visual Languages and Computing (2017), http://dx.doi.org/10.1016/j.jvlc.2017.04.001