Visual analytics on big data of urban traffic trajectories

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Abstract: With the rapid development of Smart city and Big data concepts and technologies, how to quickly and accurately organize and reflect traffic data information has become the main topic of current research for urban traffic trajectory big data with increasing geometric quantity. Traffic trajectory visualization is favored for its ability to visually and vividly reflect traffic trajectory information. In this paper, the main research results of visual analysis of urban traffic trajectories in recent years are summarized from three main methods: direct visualization, aggregate visualization and feature visualization. The problems and future prospects of urban traffic trajectory data visual analysis research are summarized.

1. Introduction

In 1986, the us national science foundation held a seminar titled ‘graphics, image processing and workstation discussion’, which proposed the concept of ‘Visualization in Scientific Computing’ [1]. The following year, it changed its name to ‘Scientific Visualization’. In 1990, William f. Eddy [2] summarized in detail the dynamic visualization method for multivariate statistical data in his works. This approach has led to a re-examination of the subject of scientific visualization. In 1999, Card [3] et al. put forward the concept of ‘Information Visualization’, aiming to present data with interactive, supported and visualized technologies for enhancing people's understanding and cognition of complex and abstract data. In 2005, the national science foundation launched another discussion on visualization. The activity report points out the research status and possible challenges in the visualization field. The following year, the first IEEE Conference on Visual Analytics Science and Technology (IEEE VAST) was held, which, together with SciVis and InfoVis, became the three core conferences of IEEE VIS. Since then, Visual analysis has become an independent branch of research rather than a comprehensive subject of interdisciplinary research. In 2008, Andrienko [4] et al. divided visualization into three methods, namely direct visualization, aggregation visualization and feature visualization, according to the different positions of visualization in the analysis process.
In order to alleviate urban traffic problems, reduce economic losses and make full use of large traffic data, visual analysis technology plays an increasingly important role in analyzing and utilizing large traffic data, and has become an important intelligent transportation technology. Not only because of the deep mining of the data hidden information, at the same time, the visualization of the relationship between the maximum use of the data, with the combination of communication, urban planning, and other fields, for the department of transportation scheduling and provides the decision-making basis for road planning and construction, which also brought more intuitive to the average user information.

In recent years, research on urban traffic trajectory data visualization is endless, this article will further summarized on the basis of the frontier researchers, compared with Wang [5] and other Chinese literature review, this paper more intently on urban traffic trajectory visualization research methods and research results, and joined the many new research results, at the same time, for the development of urban traffic track large data visualization problems and prospect are put forward.

2. Methods contrast
In this paper, the author will define the three methods of direct visualization, aggregation visualization and feature visualization, as well as their advantages and disadvantages. The specific methods and sub-methods involved in this paper and the dimensions drawing involved in each method are shown in table 1 for the convenience of comparison by readers.

3. Direct visualization
For the visualization of urban traffic trajectory, the most basic thing is to visually display the traffic trajectory path into broken lines on the map, so as to display the spatial location information of the trajectory. This method is applicable to many fields, including pedestrian trajectory [7-8], vehicle trajectory [9-10], and even aircraft trajectory [11] and ship trajectory [12]. Of course, for the trajectory of an airplane or Marine life, the trajectory path needs to be plotted as a three-dimensional polyline to

| Table 1. Comparison of visual methods |
|------------------|------------------|------------------|------------------|------------------|
| Define           | Advantages        | Disadvantages    | Methods          | Child methods    |
| Direct visualization | Plot each trajectory one by one. | 1. Almost no complex processing of the data can be well tolerated abnormal | Location of the animation | The dimension |
|                  |                   | 1. Not applicable to large amount of data; 2. Serious inter-track occlusion; 3. Huge workload for users. | Path visualization | Time | Space | Attribute |
|                  |                   |                   | Space-time cube | ✓               | ✓     | ✓       |
|                  |                   |                   |                 | ✓               |       |         |
No matter which kind of traffic track is applied, our ultimate goal is to display the track property information to the user in the most intuitive way. Yaxing S [13] et al. used polar coordinate bar chart to display the daily traffic flow, and the bigger the traffic flow value, the darker the color. Yan X [14] et al., in the commercial application research of OBD data interactive visualization, intuitively displayed the vehicle track on the mobile phone interactive interface to provide users with ride-hailing services.

| Aggregation visualization | Feature visualization |
|---------------------------|-----------------------|
| 1. It is not applicable to the analysis of a large number of trajectory data. When there are many trajectories, the mutual occlusion will be very serious; 2. Users need to complete almost all the analysis work; 3. The user analysis process is sometimes difficult to reproduce, the results are difficult to evaluate. | First, the characteristics of the trajectory data are determined, and then the data displaying the characteristics are plotted by direct or aggregate methods. |
| 1. Aggregation visualization will ignore the changes of minor problems, especially when it reflects minor problems in a large scope [6], which will display wrong information and lead to wrong decisions; 2. Aggregation visualization can only undertake low-level visualization analysis, and cannot better study the interaction between trajectories and relative motions [21]; 3. Aggregate computing requires a larger programming task. | 1. Support visual analysis of a large number of estimates; 2. Directly display the track and information of features required by users; 3. Work with a clear purpose. |

| Time-varying visualization | Attribute visualization | Space-aggregation visualization | Time-aggregation visualization | Attribute-aggregation visualization | Space-time aggregation visualization |
|---------------------------|-------------------------|-------------------------------|-------------------------------|-----------------------------------|----------------------------------|
| ✓                         | ✓                       | ✓                            | ✓                            | ✓                                 | ✓                                |

| Space-aggregation visualization | Time-aggregation visualization | Attribute-aggregation visualization | Space-time and attribute aggregation visualization |
|---------------------------------|---------------------------------|-------------------------------------|---------------------------------------------------|
| ✓                               | ✓                               | ✓                                   | ✓                                                  |

| OD aggregation | Flow graph | ✓ | ✓ | ✓ |
| OD matrix      | ✓          | ✓ | ✓ | ✓ |
| OD figure      | ✓          | ✓ | ✓ | ✓ |

| Event visualization | Pattern visualization |
|---------------------|-----------------------|
| ✓                   | ✓                     |

| General feature pattern visualization | Visualization of behavior pattern |
|--------------------------------------|----------------------------------|
| ✓                                    | ✓                                |

provide height or depth information, which we won't discuss here. No matter which kind of traffic track is applied, our ultimate goal is to display the track property information to the user in the most intuitive way. Yaxing S [13] et al. used polar coordinate bar chart to display the daily traffic flow, and the bigger the traffic flow value, the darker the color. Yan X [14] et al., in the commercial application research of OBD data interactive visualization, intuitively displayed the vehicle track on the mobile phone interactive interface to provide users with ride-hailing services.
In order to display the change of spatial dimension of track properties at any time, visual codes such as color [9-10], texture [15] and height [8] can be used. Liu et al. [10] used red to indicate low vehicle speed to indicate congestion, and green to indicate high speed to indicate patency. Tominski [16] will track points, such as line extended to track with the two-tone color time, using time varying visual representation of vehicle speed change over time, but it is not a simple superposition, but by a high degree of different track shows side by side, in order to track the property comparison between tasks and weather processing Tominski [16] this method is extended to ship trajectory, also apply. Sometimes the road lines are too long and the current operating status is limited, so people cannot completely determine the path position of vehicles. In order to express the uncertainty of vehicle position, the position points at a certain moment can be converted into 'ghost wave zone', and the possibility of each position can be represented by color perspective changes [17]. As a bus, the path of a completely fixed vehicle can be seen, and users can use a line chart with color changes to represent the change of its properties with the location, not limited to the map [18].

Vehicle trajectory has multiple attributes. In order to display different attribute values of the trajectory and the correlation between attributes, we can establish a high-dimensional data visualization method, namely parallel coordinate visualization. Guo [9] et al., when studying the traffic trajectory of an intersection, realized visualization of various attributes of the trajectory, including starting time, minimum speed, average speed, maximum speed, moving distance, etc. They studied the relationship between different attributes and searched for abnormal traffic events in vehicles through the combination of different attributes. Wei T [19] et al. studied the total traffic distribution of main roads in Jiashan county, Zhejiang province in three months, and used funnel graph, broken line graph, thermal diagram and parallel coordinate graph to display and compare them, and finally used taxi track data to analyze hot spots, as shown in FIG. 2. In view of the serious disadvantages of direct visualization of occlusion between paths, Sun [20] et al. proposed a new visualization technology 'path scaling', which can seamlessly embed spatio-temporal information into the map by deforming the road network and widening the selected road, so as to realize the unshielded visualization of spatio-temporal data.

4. Aggregation visualization

The aggregation calculation of trajectory data is generally based on the data model of multidimensional space, that is, one or more dimensions of time (T), space (S), path (R) of trajectory and attribute value (A) of trajectory record points are selected to classify and statistic the data. For example, Pengyu W [22] et al., when studying the distribution of bus routes, adopted the color scheme of blue to red ribbon rendering, and avoided the occlusion problem of bus routes caused by direct visualization through convergence calculation. In addition, Tominski [16] and Guo [9] above take the
time axis as the statistical dimension of traffic trajectory data. Among them, Guo [9] et al. also used ThemeRiver technology to show the changes of traffic flow facing different themes at an intersection over time. Liu [10] et al. adopted a similar design and adopted clock layout to represent the change of travel speed and path congestion with the duration. Kim [23] et al. proposed an interactive visual analysis system and drew a timeline view to provide daily, weekly and monthly traffic data to meet user analysis requirements. Song [24] et al. drew a polar coordinate pie chart when studying traffic flow data at time-varying intersections, which was divided into 7 days (7 concentric circles) and 24 hours, and real-time display of traffic flow at intersections every day, as shown in FIG. 3. Bin C [25] et al. drew the spatio-temporal stack view to show the change rule of the number of taxis in different areas with time, and used the tree ring diagram to show the number of active taxis in the area in 24 hours.

As for spatial properties, people tend to make more detailed division. For example, Andrienko [26] et al. divided the Italian city of Milan into evenly divided grids of 17 columns and 20 rows to create a bar chart of directions, the length of which is proportional to the number of cars moving in each direction at a selected time interval. A Mosaic of seven columns and 24 rows (corresponding to the seven days of the week and the 24 hours of the day) was also drawn in each reticulated area to map the time distribution, showing the speed of vehicles per hour of the day. In this way, they can carry out both temporal and spatial clustering analysis of traffic data of Milan. Wei T [19] et al., when analyzing hot spots with taxi tracks, combined the taxi space tracks with the calendar map to show the daily travel situation of residents in a macro way. Pu [27] et al. referred to the Mosaic chart for their work. They used the circular pattern to represent the changes of vehicle density or average driving speed in various urban areas over time. Chaojie S [28] et al., when studying large-scale urban traffic trajectory data, took Hangzhou city as an example to conduct regional division, selected representative hot spots to draw hot spot block map, and based on the topological structure combination, realized urban functional block division through the form of Voronoi diagram. Rui G [29] et al. used the k-means clustering method to divide Chengdu city into 5 natural zones, draw the 24-hour visit heat comparison diagram of taxis on weekdays and weekends, and analyze the peak time, traffic trend and traffic density locations. Baskaran [30] et al. proposed a completely different idea of the spatial attribute of the track and called it ‘time curve’. They mapped the time code into the color space and used it to describe the GPS track of taxi in Beijing city.

The display of movement direction leads to a new way of aggregation - starting point - destination aggregation. When users use maps, most of the functions are from the starting point to the destination. As the research object, such track characteristics have actually been converted into the starting point and destination data, OD data. OD data can be converted into intuitive flow chart and OD chart, and OD matrix can also be represented by matrix of the graph. Lu [31] et al., when studying different route selection, used route width and arrow symbols to display traffic flow and average flow direction, and compared correlation coefficients of different paths in terms of passage distance, number of signal lights, main and auxiliary roads and passage time. When studying the traffic trajectory data of Milan, Andrienko [26] et al. mentioned above not only used the flow chart, but also established the OD
matrix. Each row and column in the matrix corresponds to a region, and the cells corresponding to the combination of rows and columns correspond to the traffic flow between different regions. Obviously, OD matrix clearly shows the clustering characteristics of traffic flow between regions, but ignores users' perception of spatial information. Using the idea of nesting, Wood [32] et al. visualized the OD matrix directly while retaining the geographical environment, and provided users with an intuitive OD map to identify travel behaviors changing with time and space. It used this method to study the use data of public bike rental in London, UK, to help the station establish balance. Pengyu W [22] et al., when studying big bus data, drew a regional OD chord diagram based on regional travel statistics, intuitively showing the passenger flow distribution from one region to other regions.

![Visual analysis based on attribute dimensions](image)

In addition to the track attributes mentioned above, dimensions of vehicle attributes can also be selected for visual analysis. It for track properties such as Häußler [33] made a more detailed division, they according to the traffic intersection frequency, speed and engine speed map dense pixels, and according to the average carbon dioxide emissions mapped the German cities borussia monchengladbach all travel trajectory exact route, and with the clock shows the number of data points, vehicle speed and the average carbon dioxide emissions, along with the development of the time, as shown in figure 4.

5. Feature visualization

Feature visualization methods can be roughly divided into event visualization and pattern visualization. Event visualization refers to partial trajectories and related events that meet certain conditions. Andrienko et al. [34] divided spatio-temporal data into four categories: spatial event data, spatial timing data, trajectory data and flow data. For urban traffic track, vehicles and pedestrians have time and space information, so urban traffic track events are spatio-temporal data events. Andrienko et al. [35] used temporal and spatial indexes to avoid searching all locations for better efficiency. A time strip graph is established to show the temporal distribution of events, and a spatio-temporal cube is established to show the spatial distribution of events. After that, they further summarized the trajectory data event visualization process: trajectory -- event -- location -- space-time sequence -- visual analysis. First, the user can determine the speed value as the characteristic attribute to extract the slow track data of the vehicle as the subject event. Then, users cluster the extracted theme events according to the attributes of time, space and traffic direction to obtain the urban traffic congestion area. After that, according to clustering attributes and extracted events, users conduct aggregation calculation to obtain attribute distributions such as time distribution, flow distribution, spatial density and spatial length. Finally, the data results are displayed to users for interactive analysis. When studying slow road events, Andrienko et al. [36] clustered the events according to the dimensions of time, space and velocity properties, and then used color bands to display the changes of velocity values with time and space in the space-time cube. As for urban traffic congestion, Wang et al. [37], according to the communication relations of congestion events on different sections, drew a traffic congestion communication graph shaped like an 'eagle's eye graph'. Users can view the spatial and temporal distribution, road speed, traffic jam density, propagation direction, propagation length and topology type of all the locations,
and filter and sort them accordingly. You can also view the details of individual location propagation maps. Liu [38] et al. first obtained key areas by combining the temporal and geospatial attributes of traffic data, and created a clear traffic flow map, and then users captured potential attribute information according to the theme model.

Figure 5. Visibility based on user search vocabulary

Pattern visualization refers to the changing pattern of a feature in all data at any time, space and property. Krüger [39] et al., when analyzing the GPS track of bicycles, added search keywords near the end point and marked them on the map, which helped to better understand mobile data and related user behaviors, as shown in FIG. 5. In the subsequent work [40], they also tried to conduct semantic analysis of the tracks according to the search keywords near the end point. Ding et al. [41] borrowed the LDA model in text analysis technology to generate taxi theme, which reflects the flow pattern and trend of the city. Then, they visualized the theme information of probability through taxi theme map, theme route, Street Clouds and parallel coordinates. On the other hand, Zeng [42] et al. studied the urban traffic accessibility analysis and designed OD journey view, showing the time, route, transfer and other detailed mobile related information of users from one bus or subway station to other stations and their all-weather changes. Qu ruitao et al. [6] proposed an improved inverse distance weight interpolation algorithm based on the location and geometric relationship of traffic track data, which carried out interpolation and reconstruction of the data missing section of vehicle track, divided urban areas into paths, administration and data features, and built a visual platform for urban traffic data.

6. Problems and prospects

With the development of cities, more and more urban traffic trajectory data will be collected, stored, extracted and analyzed, and the sorting and mining of these data is imminent. Using traffic big data visualization is an effective way. However, the field still faces many important problems and challenges, which require further research and innovation. There is a large amount of urban traffic track data. How to realize efficient storage and extraction is a difficult problem for researchers. Although we now have many platforms such as Hadoop, the current storage and extraction level still cannot meet the needs of the era of big data; In most real data analysis, data preprocessing is the most time-consuming step [5], so is urban traffic trajectory data. In view of the current situation of most cities in China, there are a lot of problems in the data obtained by the detector, such as: absence, irregular timing and errors, etc. [43]. In the future, the most important direction for the application of traffic big data is the improvement of data ‘processing capacity’, which will inevitably require the formation of standardized data structure and real-time data processing mechanism [44]. Therefore, how to realize the rapid processing of large amount of data is also a research problem that needs to be considered. Visualization of urban traffic trajectory is a long-term and large-scale research field. According to the domestic situation, how to combine the domestic and foreign big data technology with the current situation of urban traffic and big data standardization to form a complete system to better solve practical problems is also a problem that researchers have to consider.

In the background of intelligent development, the visualization of urban traffic trajectory big data will become an effective driving force for the development of traffic big data. With regard to highway
infrastructure, through visual analysis of traffic trajectory and based on unified data technology and management standards, highway infrastructure performance evaluation [45] and decision support for highway reconstruction and expansion can be carried out to provide help for urban traffic network and even regional traffic network construction. In the field of urban transportation, based on the visual analysis results of the trajectory, traffic flow simulation and prediction and traffic travel characteristics analysis of urban agglomeration are carried out to divide urban functional areas, providing theoretical basis for urban planning and construction. Predict the travel peak in advance, adjust the vehicle route and signal timing, and alleviate traffic congestion; Visual analysis of traffic track big data will also accelerate the development of vehicle-road collaboration technology, unmanned driving technology, urban traffic brain and other traffic intelligence technologies, and provide track data and characteristic analysis results for them. Relying on the unified standardized management idea, making full use of the big data of traffic trajectory, and deeply mining the value of data resources through visual analysis technology, not only can provide more opportunities for the development of various fields of transportation, but also provide more convenient, safe and efficient travel environment for the public [45].

7. Conclusion
Intelligent transportation is the key to improve the operation efficiency, service quality and safety level of urban traffic, and big data visualization of traffic trajectory is a link that cannot be ignored in urban intelligent transportation. This paper summarizes three main methods and research results of visualization of big data of urban traffic trajectory, and puts forward the challenges and future development opportunities of visualization of urban traffic trajectory. Faced with challenges and opportunities, researchers need to combine domestic and foreign technologies and industrial status quo to continuously promote the construction of big data visualization of traffic trajectory.

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