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Exploring Immersive Analytics for Spatiotemporal Patterns: A Case Study on Origin-Destination Data

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Abstract Immersive analytics is an emerging field that enhances the visual analysis of big geodata through large displays and natural interactions. However, existing immersive geovisualizations primarily focus on showing original geographic locations of data, while complex data patterns, such as clusters and networks, remain understudied. In this case study, we enhance an immersive analytical interface by integrating data mining methods, including automated stop detection and descriptive statistics, for origin-destination data. This approach deepens the analytical capabilities of immersive visualizations, enabling more effective pattern recognition. Our prototype shows the potential of combining immersive analytics and data mining for advanced spatiotemporal data exploration.

1 Introduction

Spatiotemporal patterns are prevalent in many natural phenomena and human activities, such as weather changes, traffic flows, and language evolution. Understanding these patterns increasingly relies on the interpretation of large, complex spatiotemporal datasets. Encoding the data structures in graphical symbols can improve the interoperability of spatiotemporal data (Andrienko et al., 2003). Utilizing vertical space to show the temporal information, space-time cube (STC) was proposed and

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widely used to show the distribution of spatiotemporal data (Kraak, 2003). The geographic locations and temporal dynamics are visually perceivable in a at-a-glance view.

Immersive environments offer large displays and natural interactions, allowing users to explore data from multiple perspectives. A pioneer study proposed an interface that displays the location and time of taxi pick-ups and drop-offs with a space-time cube (Wagner et al., 2024). It reveals spatiotemporal hotspot and coldspot patterns and allows users to view them in the context of real-world locations. We argue that the visualizations can be color-coded to reveal semantic information. Another study shows that multiple views in immersive environments facilitate users to perform high-level analyzing tasks, such as exploration search and comparison (Satriadi et al., 2020). We then identify that multiple views and 3D glyphs could be combined to provide more information in immersive environments.

In this case study, we integrate data mining methods into an immersive analytical interface. Our approach not only visualizes origin-destination (OD) data geographically but also introduces automated stop detection and descriptive statistics based on travelers' information. This integration enhances the analytical depth of immersive visualizations, offering users a more powerful tool for spatiotemporal data exploration and decision-making.

2 Data and Methods

2.1 Data description and processing

We chose Origin-Destination (OD) data to test the immersive analytical method. The test data was generated by a simulator MATSim [1] covers the French island of Corsica over 30 hours from 6 am to the next day 6 am. The dataset included 11,109 trips, divided into 10,530 legs (sections of trips may be caused by transitions), and 2,953 agents. The simulated transportation modes include 65.3% car (as a driver), 25.6% walking, 8.0% car (as a passenger), 0.6% public transport, and 0.5% bike.

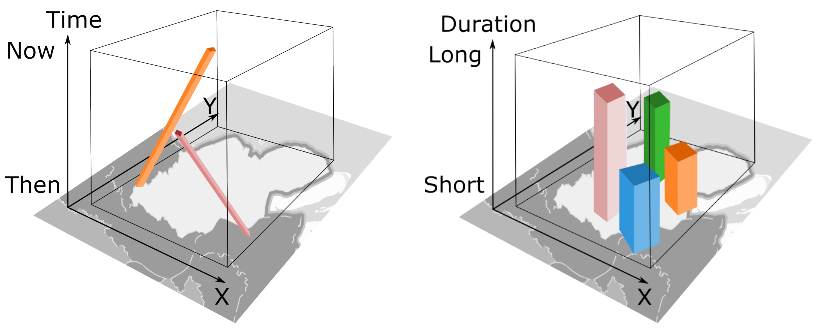
The dataset was preprocessed before visualization, including converting the coordinate system from a local coordinate system (EPSG:27564) to a global coordinate system (WGS84) and converting the unit of time and distance from seconds and meters into hours and kilometers. In addition, the statistical methods, i.e., identifying transitional stops, identifying activity stops, calculating the proportion of transportation modes, and calculating descriptive statistics of the number of agents, number of trips, number of legs, average distance, and average speed. These statistical methods were integrated into the visual interface. According to the agent and trip IDs, we calculated the transitional stops and activity stops.

[1] https://matsim.org/

2.2 Visualization methods

After interviewing two transportation experts who used the simulated data for transportation planning, we summarized five design goals: 1) show the spatial and temporal information of the OD pairs, 2) show the general descriptive statistics of the data, 3) show the aggregated locations of transitional and activity stops between ODs, 4) allow user selection of the dataset, and 5) the interface should be self-explanatory.

We adopted the space-time cube (STC) method to represent the OD pairs in a 3D scene. As shown in Figure 1a, the OD pairs were represented by 3D lines by connecting the location of the origin and destination points. We used 3D symbol maps to show the accumulated stop duration of places (Figure 1b).



(a) The space-time cube design

(b) The 3D chart map design

Fig. 1: 3D visualization methods

To support the use of STC and 3D maps, we adopted the dashboard design concept (Conrow et al., 2023; Zuo et al., 2024) to provide user interactions and statistical charts in a carefully considered layout (Figure 2). Users could filter the displayed data by departure time, travel duration, travel distance, and transportation mode. The selected data are then shown in the Map Zone and Statistics and Chart Zone.

3 Immersive interface implementation

We have implemented the design to an augmented device Apple Vision Pro. Figure 3 shows a screenshot of the immersive dashboard. It allows users to discover data insights such as **identify geographic locations** of OD data, **identify temporal distribution**, **identify hot/cold spots**, and **infer human activities**. For instance, a significant number of trips originated from the central-western area of the island, with the majority undertaken by car (as a driver). Based on the visualizations, peak travel times were identified between 9–11 AM and 4–6 PM. Public transportation

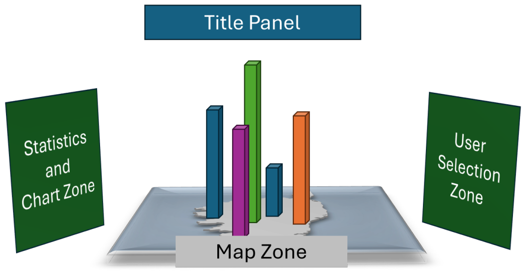


Fig. 2: The layout design of the immersive dashboard

was used as a major choice, and we assumed that the availability of public transportation is low.

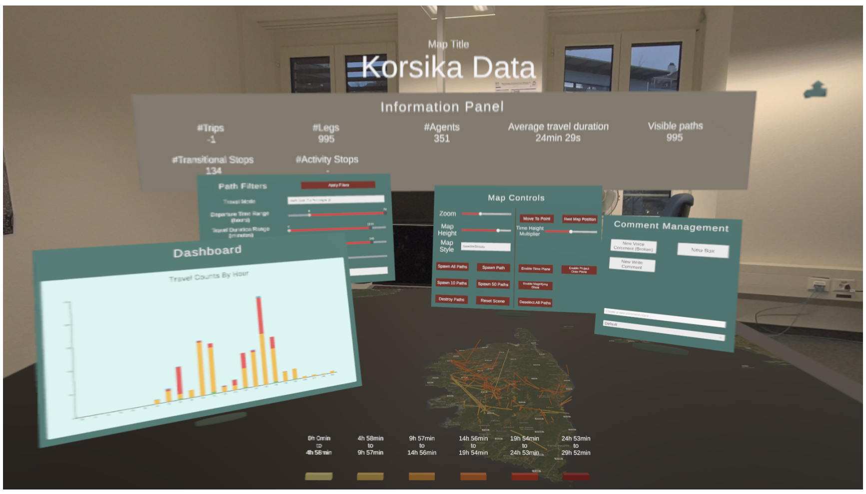


Fig. 3: The screenshot of the immersive dashboard

4 Conclusion and Outlook

In this work, we present an immersive dashboard designed for spatiotemporal data analysis, providing users with an interactive and intuitive way to explore complex datasets. By leveraging immersive space for visual exploration, our approach improves the clarity of spatiotemporal visualizations and reduces clutter through largescale displays and intuitive design elements. This setup also has the potential to enhance the memorability of discovered insights.

In the future, we aim to integrate storytelling techniques into the immersive interface to support more effective data interpretation. Through narrative-driven elements, we hope to guide users in reading and analyzing data in a clearer and logical sequential way. Ultimately aims not only represent the data structure, but help viewers to enjoyably interpret them.

In the future, we aim to integrate storytelling techniques into the immersive interface to support more effective interpretation of data. By incorporating narrative-driven elements, we hope to guide users through the data in a clear and logically structured way. Ultimately, our goal is not only to represent the underlying data structure but also to make the interpretation process more engaging and enjoyable for users.

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