도시 통행 분석을 위한 통합형 지리공간 시각화 도구

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Integrative Geospatial Visualization for Urban Mobility Analysis

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Abstract

This study introduces a visualization tool that integrates dynamic urban mobility data with static geographic and demographic datasets to enhance urban analysis. Employing GeoHash-based techniques, the tool facilitates the exploration and understanding of complex urban patterns in a multifaceted way. It leverages real-time and historical data from sources such as the New York Taxi Origin-Destination dataset and US Census information, enabling users to visualize and interpret urban mobility with unprecedented granularity and precision. By providing a dynamic, interactive platform, the tool not only supports urban planners in making informed decisions but also contributes to the broader field of smart city initiatives, fostering more sustainable and efficient urban environments. This paper details the tool's development, showcases its practical applications through use cases, and discusses its potential for future integration with advanced analytical models.

1. Introduction

In urban planning and transportation management, understanding human mobility is fundamental. Traditional Origin-Destination (OD) datasets, widely used for transportation analysis, provide essential insights into traffic flow and movement patterns [1, 2, 3]. However, these datasets often overlook the complex interplay of geographic, demographic, and socioeconomic factors around urban space influencing travel [4, 5]. Current visualization methods for OD data struggle to integrate these layers, resulting in a limited understanding of urban mobility [6]. The challenge extends beyond mapping physical trajectories to embedding the nuanced contexts within which travel occurs [7, 8].

To address these limitations, this paper[1] introduces a novel visualization tool that enriches OD datasets with comprehensive contextual information and introduces innovative approaches in travel path generation and path-to-string encoding [9, 10]. Our interface offers a dynamic, multi-dimensional view of travel patterns, enhancing the understanding of human mobility in urban spaces.

The study of urban mobility necessitates sophisticated analytical tools that can process and interpret the vast arrays of data generated by city dwellers and their environments. Traditional tools often fall short in capturing the dynamic interplay of spatial and temporal data with socio-economic variables. This paper introduces an innovative visualization tool designed to address these challenges by utilizing advanced GeoHash encoding and comprehensive data integration techniques. The tool enables urban planners, researchers, and policymakers to derive actionable insights from complex urban data sets, thereby facilitating strategic decision-making and urban policy formulation.

2. Methodological Framework

The analytical framework of our tool is built on a foundation combining sequential and geospatial data:

- **Sequential Dataset**

  We utilize paths generated from the New York Taxi Origin-Destination dataset through the A* algorithm.
- **Geospatial Dataset**

[1] This work was supported by Institute of Information & communications Technology Planning & evaluation (IITP) grant funded by the Korea government (MSIT) (No.2019-0-01126, Self-learning based Autonomic IoT Edge Computing)

Alongside movement data, we incorporate detailed layers of US Census data, which provide a static backdrop of demographic and socioeconomic landscapes across various urban settings.

The spatial granularity of our analysis incorporates GeoHash grids, OpenStreetMap nodes, and census tracts, providing multiple lenses through which urban data can be viewed and understood. This approach allows us to transform travel paths into sequences of GeoHash letters, creating textual representations (path-to-string) of urban movement that are both accessible and analytically valuable.

3. Methodological Framework

3.1. Overall Architecture

The system architecture comprises a robust backend and a user-oriented interface, as shown in Figure 1:

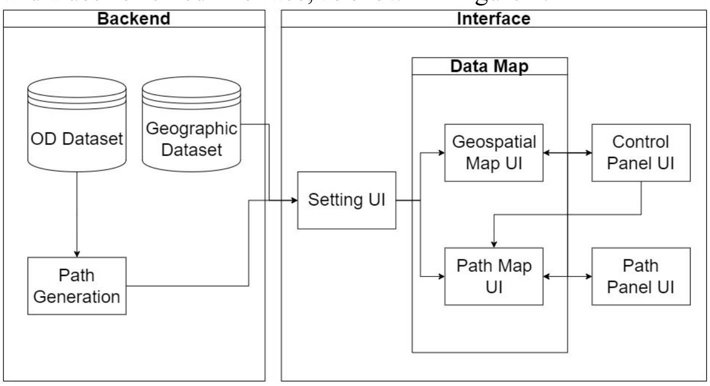

Figure 1 System Interface Architecture

3.2. User Interface Components

- **Setting UI** provides initial setup options for users to select and configure datasets, defining the scope of their analysis.
- **Data Map** acts as the visualization centerpiece, using the Mapbox library to integrate and display both geographic and path data.
- **Region and Path Visualization UIs** allow for the detailed depiction of both static and dynamic data elements through choropleth maps, heatmaps, and line visualizations.
- **Control and Path Panel UIs** facilitate advanced user interactions such as data filtering, temporal adjustments, and visualization customization, enhancing the analytical capabilities of the tool.

4. Use Cases

The visualization tool developed in this study offers a wide array of functionalities that can be illustrated through several practical use cases. These examples highlight the tool's versatility and effectiveness in transforming complex urban data into actionable insights. The selected use cases showcase the tool's application in visualizing the New York Taxi Origin-Destination (OD) dataset, enhancing user interaction with data, and adapting visualization strategies according to user needs.

The tool's ability to depict the generated paths from New York Taxi Origin-Destination (OD) dataset. This visualization maps taxi pickups and drop-offs, revealing traffic patterns that assist in urban planning and congestion management. Figure 2 illustrates the tool's interactive feature, where selecting a path highlights its paths and corresponding GeoHash-encoded letters, enabling detailed analysis of specific travel patterns.

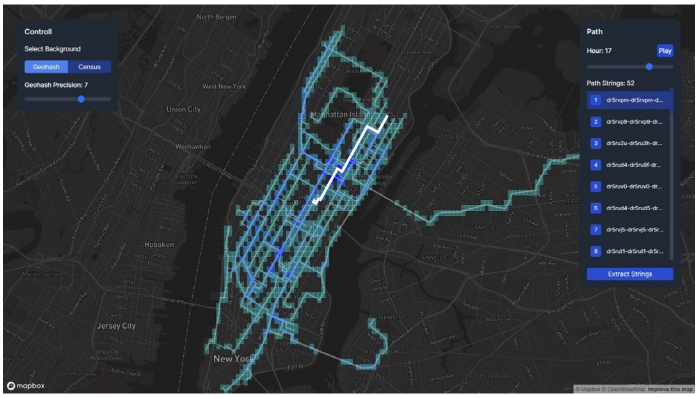

Figure 2 Visualization of Generated Paths from New York Taxi Origin-Destination Dataset

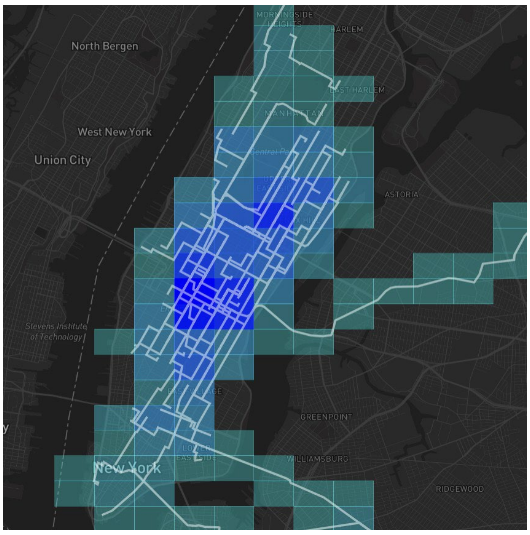

Figure 3 Path Heatmap Visualization in Different Precision Level of GeoHash

The tool adapts to different spatial resolutions as users modify GeoHash precision, as shown in Figure 3. This functionality enhances the granularity of urban analysis, from broad patterns to detailed street-level data.

Figure 4 showcases a choropleth map of the US Census dataset, highlighting land area differences across regions. This visualization supports demographic and geographic analyses crucial for regional planning.

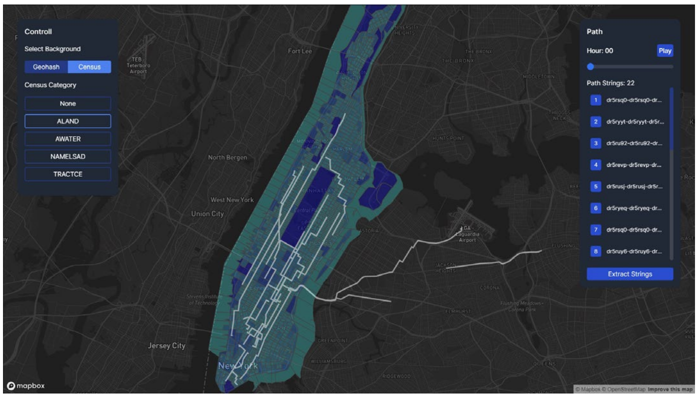

Figure 4 Choropleth Map Showing Land Area (ALAND) from the Census Dataset

5. Conclusion

The development of this advanced geospatial visualization tool marks a substantial progression in urban analytics. By employing innovative GeoHash-based encoding and integrating comprehensive data sources like OD datasets and the US Census, the tool enhances the analysis and visualization of urban mobility, converting complex data into actionable insights for urban planning and policy-making.

Despite its strengths, the tool has limitations, such as the GeoHash-based encoding's inability to distinctively characterize individual paths and the heatmap's insufficient capture of complex travel behaviors. Future enhancements will focus on integrating Large Language Models (LLMs) to refine path data encoding and developing methods to analyze encoded string similarities more effectively. These improvements aim to provide deeper insights into urban mobility patterns and adapt to the dynamic nature of urban environments.

In summary, while this tool advances urban mobility analysis significantly, its continuous development is crucial. By addressing its current limitations and incorporating new technologies, the tool will better serve urban planning and decision-making, contributing to the creation of smarter, more sustainable urban futures. To explore the tool and experience its capabilities, visit: https://manhattan-geo.vercel.app/

References

[1] M. Bierlaire, "The total demand scale: a new measure of quality for static and dynamic origin–destination trip tables," *Transportation Research Part B: Methodological*, vol. 36, no. 9, pp. 837–850, 2002.

[2] A. P. Riascos and J. L. Mateos, "Networks and long-range mobility in cities: A study of more than one billion taxi trips in new york city," *Scientific Reports*, vol. 10, no. 1, p. 4022, 2020.

[3] N. Ferreira *et al.*, "Visual exploration of big spatio-temporal urban data: A study of new york city taxi trips," *IEEE Transactions on Visualization and Computer Graphics*, vol. 19, no. 12, pp. 2149–2158, 2013.

[4] C.-H. Wen and F. S. Koppelman, "A conceptual and methodological framework for the generation of activity-travel patterns," *Transportation*, vol. 27, pp. 5–23, 2000.

[5] R. Kitamura *et al.*, "Micro-simulation of daily activitytravel patterns for travel demand forecasting," *Transportation*, vol. 27, pp. 25–51, 2000.

[6] M.-P. Kwan, "The uncertain geographic context problem," *Annals of the Association of American Geographers*, vol. 102, no. 5, pp. 958–968, 2012.

[7] M.-P. Kwan, "Interactive geovisualization of activity-travel patterns using three-dimensional geographical information systems: A methodological exploration with a large data set," *Transportation Research Part C: Emerging Technologies*, vol. 8, no. 1-6, pp. 185–203, 2000.

[8] H.-M. Kim and M.-P. Kwan, "Space-time accessibility measures: A geocomputational algorithm with a focus on the feasible opportunity set and possible activity duration," *Journal of Geographical Systems*, vol. 5, pp. 71–91, 2003.

[9] S. Han *et al.*, "Enhancing spatio-temporal traffic prediction through urban human activity analysis," in *Proceedings of the 32nd ACM International Conference on Information and Knowledge Management*, 2023.

[10] Y. Park and S. Han, "Encoding urban trajectory as a language: Deep learning insights for human mobility pattern," tech. rep., Annual Conference of Association of Collegiate Schools of Planning, 2023.