Geographical Visualization Interface of Human Travel Path to Understand Human Mobility

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Abstract

This paper proposes a new visualization tool for effectively understanding human mobility patterns in the fields of urban development and transportation management. Going beyond traditional origin-destination datasets, our tool adopts an innovative approach in travel path generation and path-to-string encoding to address various aspects of urban mobility. Leveraging the New York City Taxi Fare Prediction dataset and Census Cartographic Boundary datasets, we integrate geographical, demographic, and socioeconomic factors for a more detailed understanding of travel patterns. Our tool provides linear representation of paths and emphasizes spatial density and visitation patterns through heatmaps. With a user-friendly interface and dynamic path filtering, it offers a deeper understanding of urban mobility. Applying Large Language Models (LLM) to path-to-string encoding in the future would render this tool even more meaningful by allowing the characterization of each path through strings.

Keyword

Urban Mobility, Trip Origin-Destination, Travel Path Visualization, Geographic Data

1. Introduction

In urban planning and transportation management, understanding human mobility is fundamental. [1] Traditional Origin-Destination (OD) datasets [2,3], widely used for transportation analysis, provide essential insights into traffic flow and movement patterns. [4,5] However, these datasets often overlook the complex interplay of geographic, demographic, and socioeconomic factors around urban space influencing travel. [6,7]

Current visualization methods for OD data struggle to integrate these layers, resulting in a limited understanding of urban mobility. [8] The challenge extends beyond mapping physical trajectories to embedding the nuanced contexts within which travel occurs. Current tools are limited in their capacity to reveal the full story behind each journey, from its inception to its conclusion. [9,10]

To address these limitations, this paper 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. [11,12] Our interface offers a dynamic, multi-dimensional view of travel patterns, enhancing the understanding of human mobility in urban spaces.

2. Dataset

In this interface, two types of datasets are used. The first is the Path Generation Dataset, which is generated based on the trip OD dataset. Trip OD dataset, which has been published by the Transportation Bureau, contains pickup and dropoff locations as well as timestamps.

We leverage the dataset New York City Taxi Fare Prediction as OD dataset. [15] Figure 1 shows how we generate a taxi travel path using the road network from OpenStreetMap data and how to extract the shortest travel path using the A* algorithm.

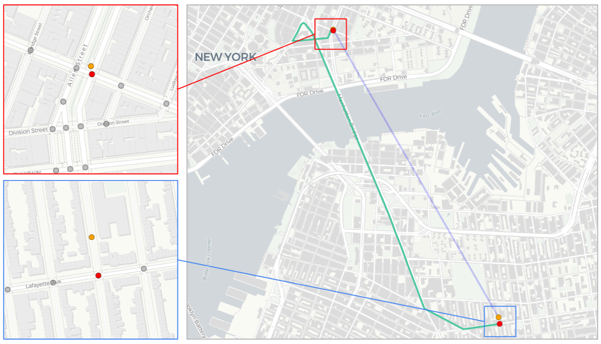

Figure 1. Path Generation with A* algorithm: (left) We match the orient and destination points(orange) to the OSM nodes(red), and then we generate the travel path (green) which differs from the shortest line (blue).

The second, a geospatial dataset, contains geographical, demographic, and socio-economic features in a particular area.

We leverage the Census Cartographic Boundary Files as geospatial dataset. [16]

3. Implementation Approach

Before proceeding with the implementation, it was imperative to establish a set of requirements and provide corresponding implementation guidelines for the development content.

3.1 Requirements

Before proposing the design, requirements were gathered based on the data and users.

Table 1. Requirements from Path Generation Dataset

Index	Requirement from path generation dataset
R1	Visualization of paths generation based on orientation and destination
R2	Visualization of patterns for the entire path
R3	Identification of path patterns based on specific time units
R4	Encoding and display of paths as strings
R5	Enable to select specific paths
R6	Acquisition of Encoding Strings for Research Purposes

Table 2. Requirements from Geospatial Dataset

Index	requirement from geographic dataset
R7	Enable for users to select desired properties, as Geospatial data properties vary.
R8	Different visualization based on whether each geographic data property is categorical or quantitative.

Table 3. Requirements from User

Index	requirement from user
R9	Users should be provided only with the information they intend to utilize.

3.2 Implementation Guideline

We selected the following implementation guidelines based on the requirements:

Table 4. Implementation Guidelines

Index	Implementation Guidelines	Reqs
G1	Represent each path with a line.	R1
G2	Depict path frequencies using a Heatmap.	R1, R2
G3	Utilize a range slider for path filtering and subsequent visualization.	R3
G4	Illustrate path changes over time through animated transitions based on range variations.	R2. R3
G5	Present a list of filtered paths, allowing for specific path selection.	R4, R5

G6	Facilitate copying the string representation of a chosen path.	R5
G7	Provide the functionality to download path strings as a TXT file.	R6
G8	Implement a feature enabling user-driven data selection from geographic data.	R7, R8, R9
G9	Specify lower and upper bounds for the visualization of quantitative values.	R8, R9

4. Implementation

We propose the development of a Human Travel Path Visualization Tool based on the implementation guideline

4.1 Overall Architecture

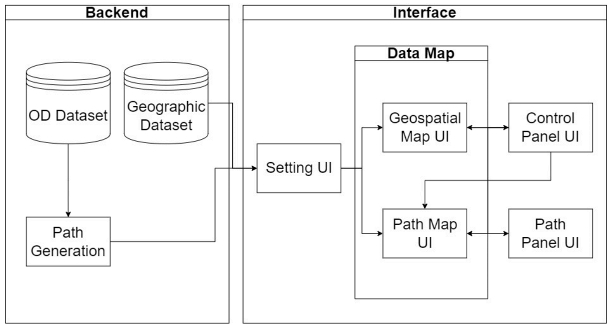

Figure 2. System (Interface) Architecture

The overall architecture is as follows. Detailed explanations and functionalities provided in Section 4.3.

- Setting UI: UI for setting initial values and customization for utilizing the interface.
- DataMap: Wrapper for rendering Geospatial Maps and Path Maps.
- Geospatial Map UI: UI intended for visualizing Geospatial Datasets.
- Path Map UI: UI intended for visualizing Path Generation Datasets.
- Control Panel UI: UI for selecting visualizations appearing in Geospatial
- Path Panel UI: UI for filtering Path Generation Datasets.

4.2 Visualizations

The interface presents a total of four distinct visualizations, each catering to specific data representation (refer Appendix A)

The primary visualization is the Line Path. Additionally, three distinct visualizations are offered as sub-visualizations based on user selection.

- Line Path

The Line Path feature presents data through a linear representation, which directly represents the paths. Moreover, users can focus on specific paths through path selection interactions.

- Path Heatmap

The Path Heatmap visualization offers a heatmap that accentuates spatial density or visiting patterns.

- Choropleth for Quantitative Data

This choropleth map effectively illustrates quantitative data. We established the upper / lower limit as the mean ± 2 * standard deviation to minimize visual distortions from outliers.

- Choropleth for Categorical Data

This choropleth map assigns distinct colors or patterns to different categories.

4.3 User Interface

The interface created utilizing the presented visualization is as follows. (refer Appendix B)

- Setting UI

Users input the data URLs for Path Generation Datasets and Geospatial Datasets. They select the time range unit for filtering in Path Generation Datasets, and the category from Geospatial Datasets,

- DataMap

The initial setup is performed to utilize the Mapbox library and initialize the Geospatial Map UI and Path Map UI.

- Geospatial Map UI

Geospatial Map UI provides visualizations based on Geospatial Datasets, presenting a choropleth map for quantitative data and categorical data.

- Path Map UI

Path Map UI provides visualizations based on Path Generation Datasets, presenting Line Path and Path Heatmap.

- Control Panel UI

Control Panel UI allows users to choose sub-visualizations. For Path Heatmap, users can adjust the GeoHash precision, while for a choropleth map, they determine which property of the geospatial datasets to visualize.

- Path Panel UI

Path Panel UI enables users to filter paths based on the selected time range using a range slider. Also, it shows the changes in paths over time by play button, Filtered path list is displayed on the panel. Users can emphasize specific paths and copy the string representation of those paths by clicking, Users are also able to download the path string list in txt file format.

5. Conclusion and Discussion

This study proposes an innovative visualization tool that enhances Origin-Destination (OD) datasets with contextual information while simultaneously innovating in travel path generation and path-to-string encoding. To achieve this, we strengthen the context of paths using path generation datasets and augment the contextual information of specific regions with geographic datasets, considering factors such as population and geographical conditions. Additionally, we establish implementation guidelines based on datasets and user requirements, providing a foundation for the development of a tool capable of appropriately visualizing travel paths.

However, several limitations still remain. Firstly, the current geohash-based path-to-string encoding lacks the provision of distinctive features for paths. Secondly, visualization methods for understanding the characteristics of travel paths are limited to heatmaps.

To overcome these limitations, it needs further research. Firstly, leveraging the Large Language Model (LLM) to transform the encoded path into a sentence-like format with features characteristic of the path. Secondly, developing techniques for measuring the similarity of encoding strings and visualizing based on the similarity of path to enhancing a deeper understanding of urban mobility patterns.

Acknowledgement

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Appendix

A. Visualization Images

Figure 3. Line Path Visualization

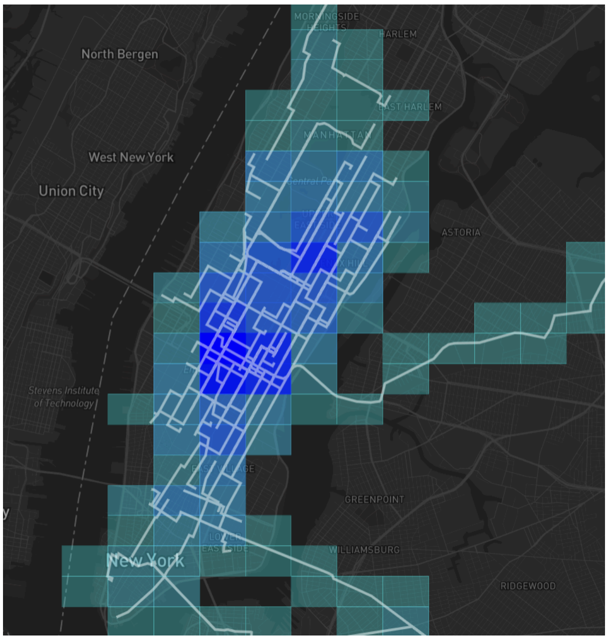

Figure 4. Path Heatmap Visualization

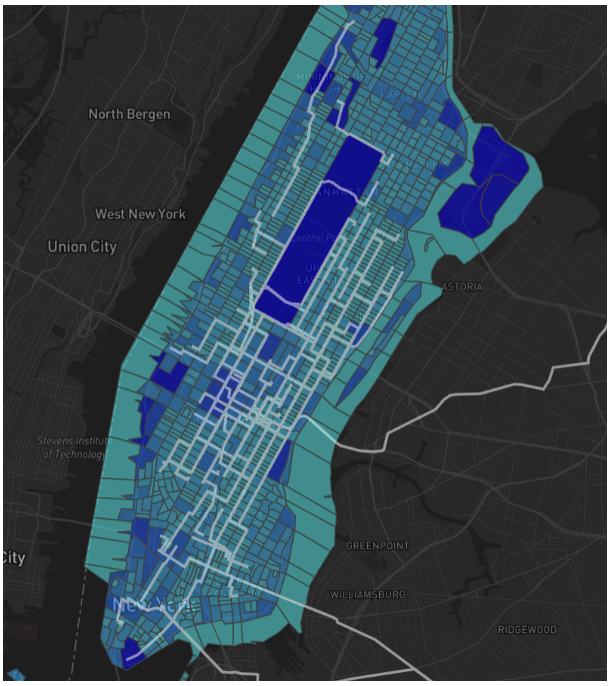

Figure 5. Choropleth for Quantitative Data Visualization

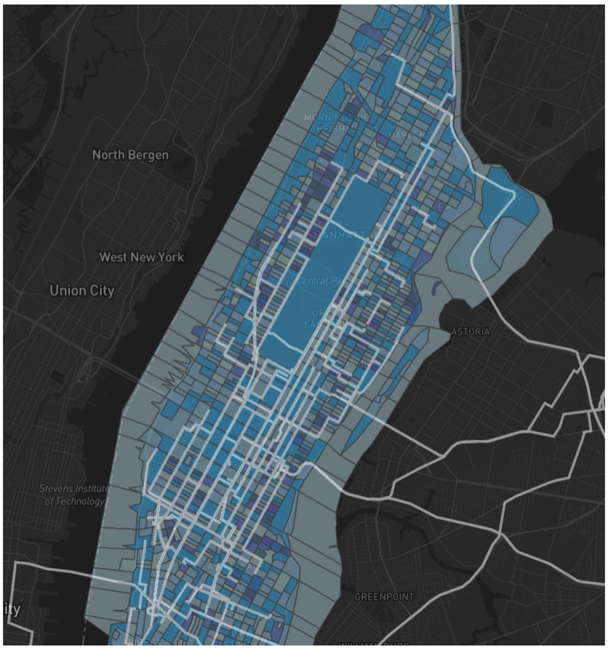

Figure 6. Choropleth for Categorical Data Visualization

B. User Interface Images

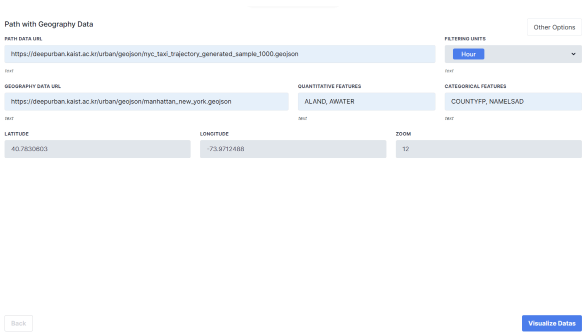

Figure 7. Setting UI

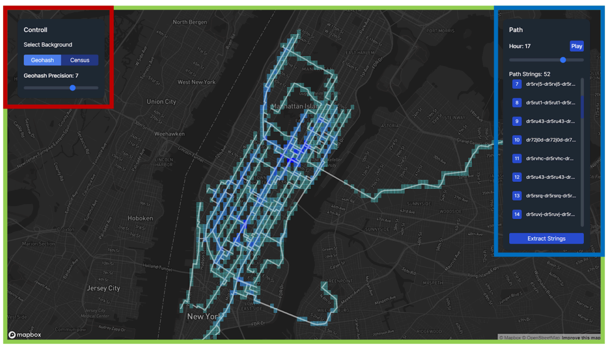

Figure 8. Control Panel UI (red box), DataMap (green box), Path Panel (blue box)

C. Use Cases

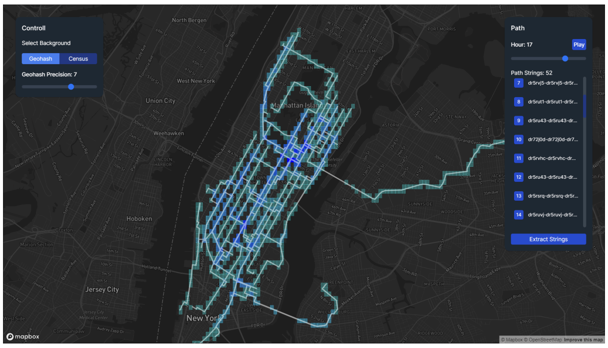

Figure 9. Original visualization

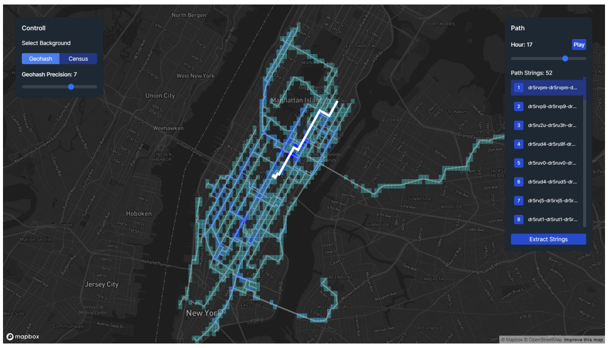

Figure 10.Focusing certain path

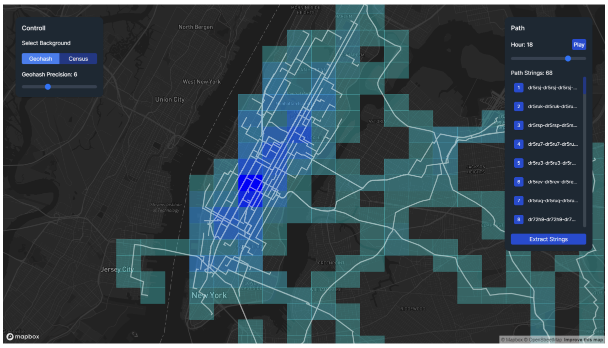

Figure 11. Visualization with bigger geohash Precision (value = 6)

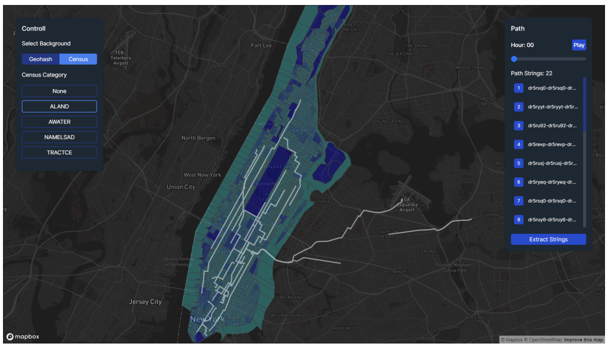

Figure 12. Visualization about ALAND property in geographic dataset

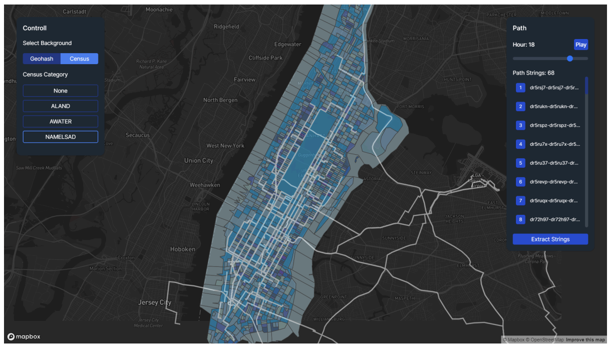

Figure 13. Visualization about NAMELSAD property in geographic dataset