Time-Space Distortion Mapping

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Executive Summary

The **Time-Space Distortion Mapping** project reimagines geographic visualization by dynamically warping spatial maps based on travel time rather than physical distance. This tool leverages modern web technologies such as React, TypeScript, Leaflet, D3.js, and Turf.js. Designed for applications in urban planning, transportation, and GIS analysis, the project integrates methodologies from spatial statistics, network analysis, and cartographic visualization. This report outlines the theoretical foundations, technical components, and future developments.

Technical Background

Time-Geography Theory

The concept of time-space compression, rooted in Torsten Hägerstrand's time-geography theory, underpins this project. Modern research extends this framework into dynamic visualizations, integrating computational techniques to model real-time spatial accessibility.

Spatial Accessibility Metrics

Spatial accessibility quantifies the ease of reaching specific destinations, often modeled through isochrone mapping. The accessibility score A for a given location can be defined as:

$$A = \sum_{i=1}^{n} \frac{P_i}{T_i^{\beta}}, \tag{1}$$

where P_i is the population at location i, T_i is the travel time to location i, and β is a decay parameter reflecting the effect of increasing travel time on accessibility.

Transportation Network Analysis

Transportation networks are modeled using graph theory. Travel times are computed using Dijkstra's Algorithm:

$$D(u) = \min_{v \in V} \{D(v) + w(v, u)\}, \tag{2}$$

where $D(u)$ is the shortest distance to vertex u, v represents adjacent vertices, and $w(v, u)$ is the edge weight. Betweenness centrality C_B for a node v is calculated as:

$$C_B(v) = \sum_{s \neq v \neq t} \frac{\sigma_{st}(v)}{\sigma_{st}}, \tag{3}$$

where σ_{st} is the total number of shortest paths from s to t, and $\sigma_{st}(v)$ is the number of those paths passing through v.

Geographic Visualization Techniques

Interactive cartographic distortion adjusts coordinates based on travel times:

$$\delta = \frac{t_{avg}}{60}, \tag{4}$$

$$x' = x + \cos(\theta) \cdot \delta, \tag{5}$$

$$y' = y + \sin(\theta) \cdot \delta, \tag{6}$$

where θ is the angular direction from the origin.

Implementation Details

Example Code: Distortion Function

Listing 1: Distortion Function in TypeScript

```
export function distortPoints(points, timeMatrix) {
  return points.map((point, i) => {
    const avgTime = timeMatrix[i].reduce((a, b) => a + b, 0) / points.length;
    const distortionFactor = avgTime / 60;
    const direction = Math.atan2(
      point.coordinates[1] - points[0].coordinates[1],
      point.coordinates[0] - points[0].coordinates[0]
    );

    return {
      ...point,
      coordinates: [
        point.coordinates[0] + Math.cos(direction) * distortionFactor,
        point.coordinates[1] + Math.sin(direction) * distortionFactor,
      ],
    };
  });
}
```

Mathematical Distortion Function

The distortion logic uses multidimensional scaling (MDS). The pairwise travel time matrix T is converted into a distance matrix D:

$$D_{ij} = \sqrt{T_{ij}}, \tag{7}$$

where T_{ij} is the travel time between points i and j. Double centering and eigen decomposition yield:

$$B = -\frac{1}{2} H D^2 H, \tag{8}$$

where $H = I - \frac{1}{n}\mathbf{1}\mathbf{1}^T$ is the centering matrix.

Applications

Urban Planning

Optimize infrastructure placement and evaluate public transport efficiency.

Transportation

Enhance route optimization for services like Uber or Transit.

Geographic Information System (GIS) Analysis

Provide advanced spatial analytics for companies like ESRI or Carto.

Future Developments

- Integration with real-time traffic data.
- Multi-modal transportation support.
- Augmented Reality (AR) for accessibility visualization.

Link to the Final Product

Explore the final application here: `https://time-distortion.vercel.app`

References

- Barthélemy, M. (2011). Spatial Networks. *Physics Reports*, 499(1-3), 1-101.
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- Salas-Olmedo, M. H., et al. (2018). Isochrone Maps: A Comparative Analysis of Transport Systems in Major Cities. *Computers, Environment and Urban Systems*, 70, 47-59.