Title: Towards Adaptive Decision Support: A Perspective from Intelligent and Annotated Visual Analytics for Exploring Big Urban Mobility Data

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Topics: Supporting trusted decision making

Challenges: As the critical component of many emerging data- and model-driven applications, visual analytics empowers the synergy of computational techniques with human reasoning to improve solutions to complex urban science and engineering problems. These techniques are frequently integrated with Cyber Geographic Information Systems (Cyber-GIS) to create intuitive and accessible visual analytical dashboards, providing new opportunities and solutions for enhancing the understanding of complicated urban dynamics. They also facilitate collaborative urban management by engaging non-scientific users (e.g., policymakers, the public, and business partners) into complex decision-making processes.

Despite their value and usefulness, the design and development of visualization and visual analytics applications for urban big data and large-scale urban simulations often face methodological challenges caused by the Big Data Tsunami, where the increased velocity, volume, variety, and veracity of data creates cognitive overload and noise. These challenges prevent effective interpretation for generating meaningful insights that benefit decision analyses. Although more recent visualization technologies (OpenGL and extended reality technologies) can render a tremendous number of geometries and graphics in a canvas or virtual environment, extracting useful knowledge and domain-related inferences for non-scientific users can still be very challenging. This situation is typical when the data patterns exist in multiple spatial (e.g., district, city, county, state, and nation) and temporal scales (e.g., hourly, daily, monthly, and yearly), or in other data-facets (e.g., multi-value and multivariate dimensions). An example would be identifying other urban and environmental variables and statistics parameters that may affect transportation planning at the corridor level using visual analytics dashboards. This white paper uses an existing ORNL project to demonstrate the methodological challenges through real-world scenarios for exploring urban big data.

The Chattanooga Digital Twin (CTwin) project creates a big data cyberinfrastructure that enables a wide variety of coordinated graphs, charts, and visual analytical dashboards that allow its users (e.g., urban planners, urban scientists, and city managers) to visually inspect and analyze the spatiotemporal variability of urban mobility attributes (e.g., traffic volume, speed, and lane performance) in response to other urban and environmental variables. Many of these urban mobility attributes are collected through the Internet of Things (IoT)-connected sensors and have generated second-resolution observations over three years. Even though the visual dashboard is implemented with modern user-interaction and data-transformation techniques that allow users to filter data, alter temporal and spatial aggregations, and select different mobility attributes for comparison, it remains time-consuming and labor-intensive for a user to go through years of sensor observations and comprehensive user-flows to perform an adequate search for useful insights. An example use case might include understanding what weather scenario, time of day, and within what regions do lane occupancy positively correlate with traffic speed. Many past studies arrange multiple plots and charts in a matrix to allow the overview of large-scale datasets, which is limited by the number of graphics and details that can be displayed through a matrix's layout and screen resolution. Even so, this technique requires repetitive and labor-intensive exploratory analysis and interpretation when the dataset has such extensive temporal and spatial coverage.

Opportunity: Following the vision of Intelligent Visual Analytics (Nazemi, 2018), this white paper proposes the use of Artificial Intelligence (AI) to bridge the gap between heterogeneous users and visual analytics techniques. We outline potential opportunities and benefits for developing intelligent visual analytics systems in the urban science sector. Based on the layer-based visual adaption (Nazemi, 2016), we propose our vision for leveraging the power of AI to capture different interests and evaluate the cognition capability of different target-user groups through user studies. Through user interaction analyses, we should be able to develop metrics for designing user stories and user-flows for individual user groups. The user-flows should cover the target users' demands/needs for decision supports by incorporating domain-specific decision support pipelines. For example, the presence of specific mobility patterns should lead to definite management practices for improving road design and traffic controls. The user-flows should provide more analytical capability than just visualizing a large volume of original data. The AI should also optimize the human-computer interactions in visual analytical dashboards by automating the data filter process to extract information and patterns of users' interest from the large volume and variety of data. In detail, the automated data filter should only spatially and temporally extract data subsets that entail useful insights and may contribute to the decision-making process.

On the visualization side, we propose to use the Computer Vision (CV) applications to make the graph and chart more intelligent, interpretable, and domain-focused (Wu et al., 2021). Many physical phenomena in urban mobility systems, such as the hysteresis in traffic flow, can be reflected by special graphical characteristics (e.g., a certain shape in the line charts) through the visualizations of traffic sensor observations. In addition, the CV applications can also be used to generate instructive annotations as components of a chart or map. These annotations can be placed next to the subtle graphical characteristics to highlight the critical physical process. This practice can help users prioritize their analyses, reducing their efforts for unnecessary interactions with the dashboard and visualizations. The message enabled in these annotations should associate special graphical characteristics with the domain knowledge to help the user interoperate the pattern and generate valuable insights. In this setting, we can construct a visual storytelling/narrative workflow to help users connect patterns from different datasets and variables to generate knowledge through a series of annotations from multiple coordinated charts in a dashboard. This practice can also help users gain a holistic understanding of the interconnected physical processes (from multiple scales and data facets) behind the data.

Timeliness and Maturity: The recent advent of the edge computing paradigm allows the development of a sophisticated visual analytics dashboard in a more modular and interoperable fashion. In this setting, the AI components can be independently created and readily integrated into visual dashboards using adaptive web services. The paradigm also effectively distributes the data processing across different computation nodes to ensure the intelligent visual analytical system's capability for analyzing large and complex datasets. The emerging social sensing and citizen science imitative promote more comprehensive user analyses to generate more practical user-flows. Our vision aims to improve the existing layer-based visual adaptation model by incorporating AI to facilitate human perception and cognition to guide/optimize the user interactions, shedding light on a more intelligent and user-center visual analytical system.

Reference

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