Tutorial: Urban Trajectory Visualization

Introduction

Welcome!

Tutorial Organizers and Presenters

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  - University of North Carolina at Charlotte, USA
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  - Kent State University, USA
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  - Kent State University, USA

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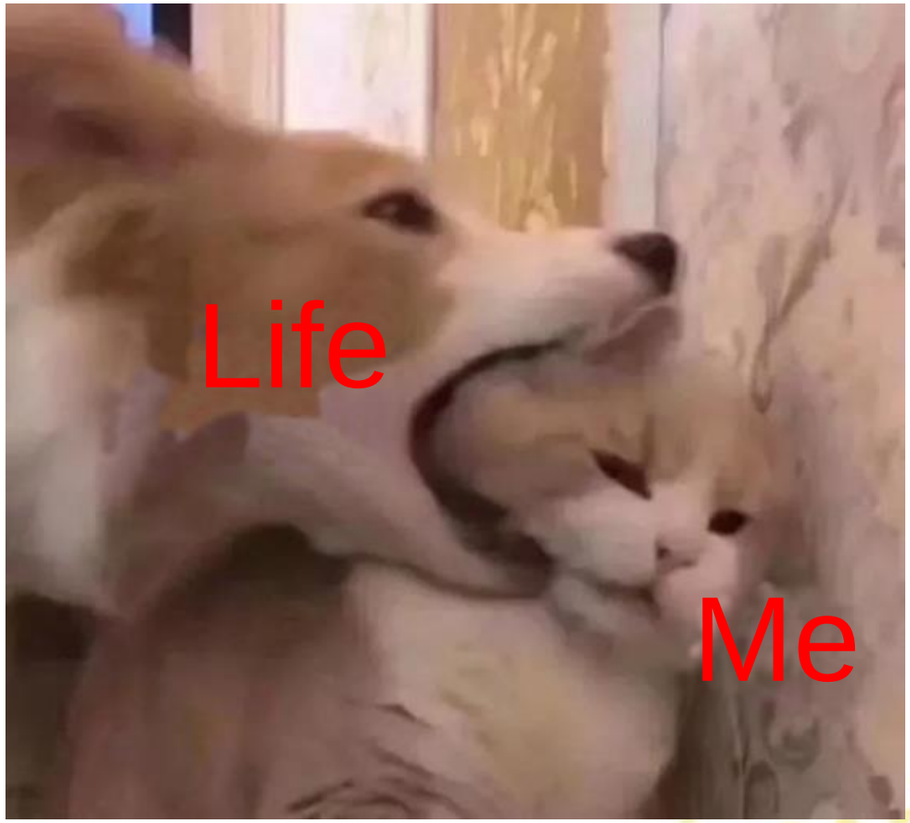
  - The National 973 Program of China 2015CB352503
  - National Natural Science Foundation of China 61772456, U1609217

Agenda

- 9:00am-9:30am
  - Welcome (Zhao)
  - Introduction: Urban Data and Visualization (Huang)
- 9:30am-10:30am
  - Trajectory Data Model and Management (Zhao)
- 10:30am-11:00am Coffee Break
- 11:00am-11:40am
  - Trajectory Data Visualization (Yang)
- 11:40am-12:40pm
  - Visual System Implementation (AL-Dohuki)
  - Visual System Examples (Zhao)
  - Conclusion (Zhao)

Urban Data

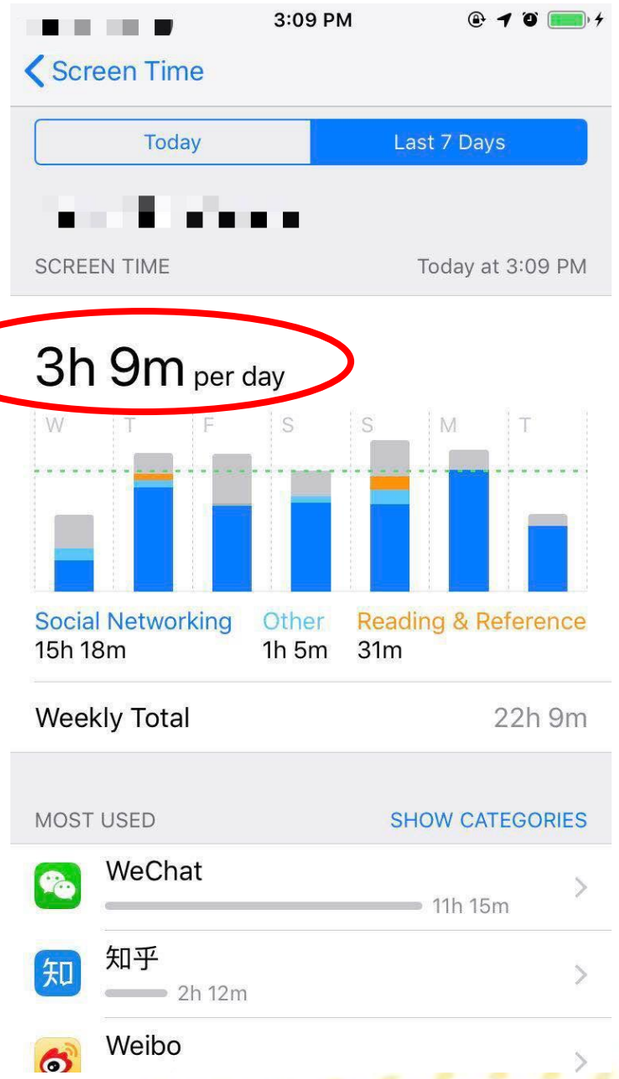
Man was born free, and he is everywhere in chains



Urban Data


刷卡区
1.50元
手机刷码区


微信支付


3:09 PM
Screen Time
Today
Last 7 Days
SCREEN TIME
Today at 3:09 PM
3h 9m per day
W T F S S M T
Social Networking
15h 18m
Other
1h 5m
Reading & Reference
31m
Weekly Total
22h 9m
MOST USED
SHOW CATEGORIES
WeChat
11h 15m
知乎
2h 12m
Weibo

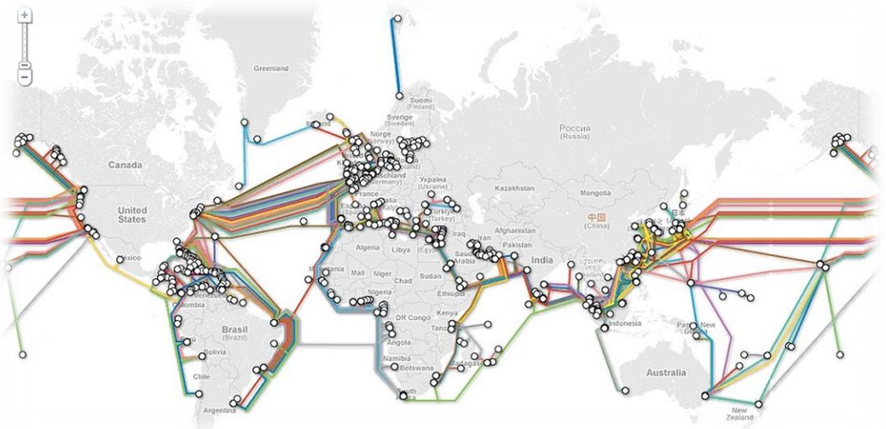
Urban Data

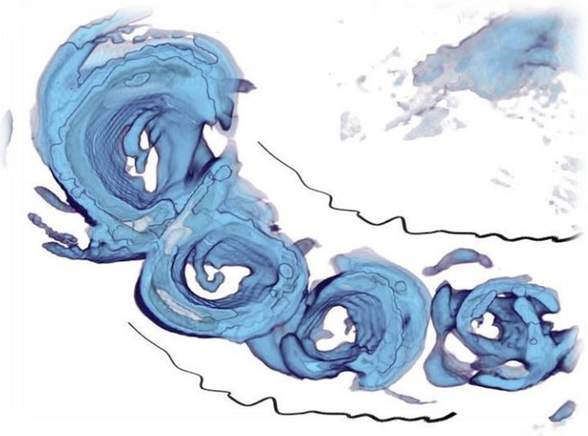
- Human mobility
  - Active recording
    - Travel logs
    - Sport analysis
    - Twitter
    - …
  - Passive recording
    - Credit card transactions
    - Public transit records
    - Mobile phone signal, Wi-Fi…
    - ….



Urban Data

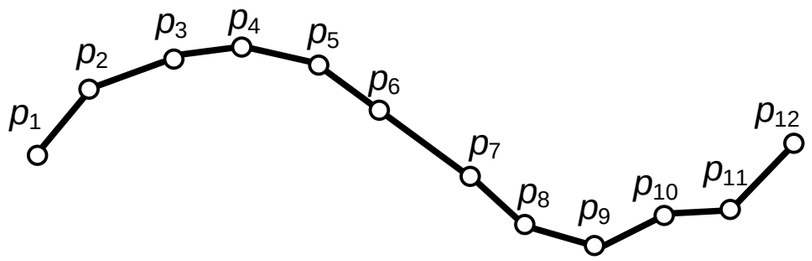
- Mobility of Animals
  - Migration: Birds, zebra, tiger
- Mobility of natural phenomena
  - Hurricane, tornado,…
- Urban events
  - Crime, Festival, Complaint





Urban Data ---Spatial Trajectories

A *spatial trajectory* is a trace generated by a moving object in geographical spaces, usually represented by a series of chronologically ordered points, e.g., $p_1 \rightarrow p_2 \rightarrow \cdots \rightarrow p_n$, where each point consists of a geospatial coordinate set and a timestamp such as $p = (x, y, t)$

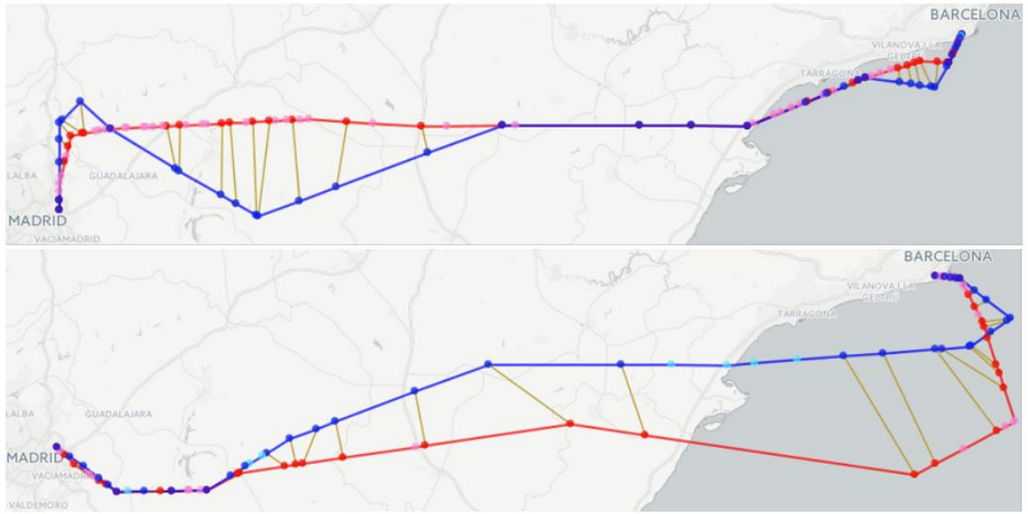


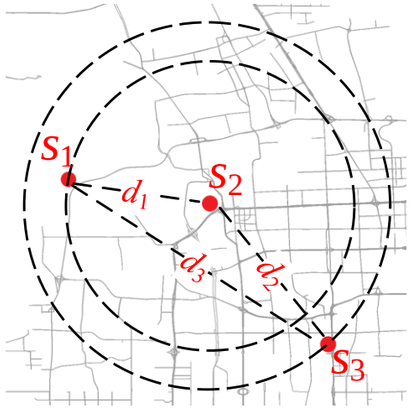
Why Urban Data is Unique?

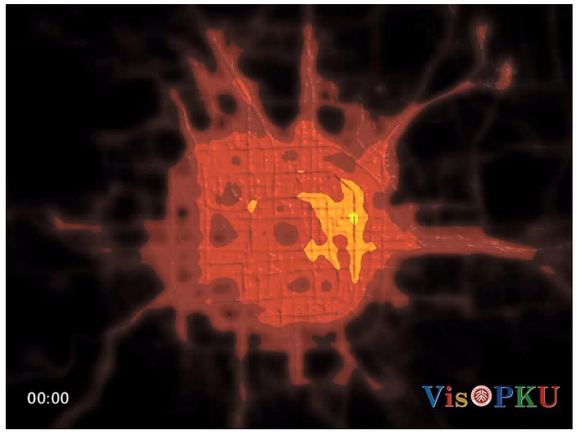
- Spatial Properties
  - Distance
    - Spatial closeness
    - Triangle inequality:

$$|d_1 - d_2| \leq d_3 \leq |d_1 + d_2|$$

  - Hierarchy
    - Different spatial granularities
    - City structures



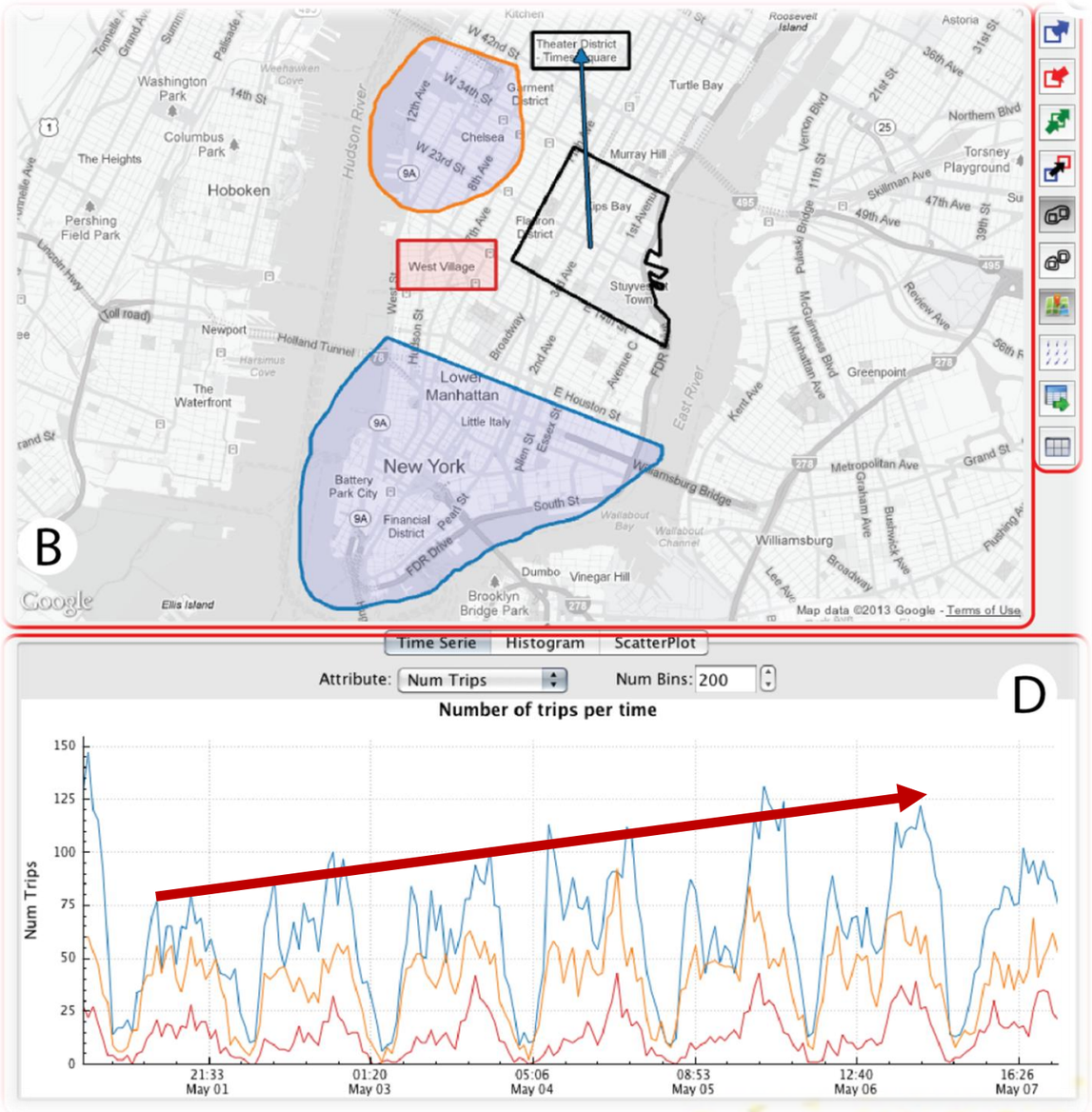




Andrienko, N., Andrienko, G., Garcia, J. M. C., & Scarlatti, D. (2018). Analysis of Flight Variability: a Systematic Approach. *IEEE transactions on visualization and computer graphics*.

Why urban data is unique?

- Spatial Properties
- Temporal properties
  - Temporal closeness
  - Periodicity
  - Trend



Ferreira, N., Poco, J., Vo, H. T., Freire, J., & Silva, C. T. (2013). Visual exploration of big spatio-temporal urban data: A study of new york city taxi trips. *IEEE Transactions on Visualization and Computer Graphics*, *19*(12), 2149-2158.

When we need urban data?

Manager of supermarket

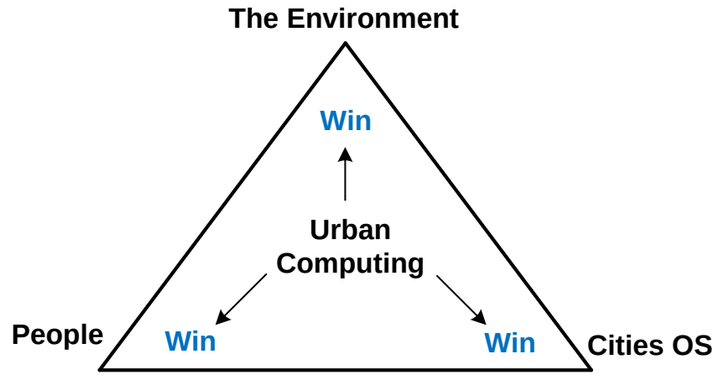
How to set the bus line in the city to help people come to the mall to shop?

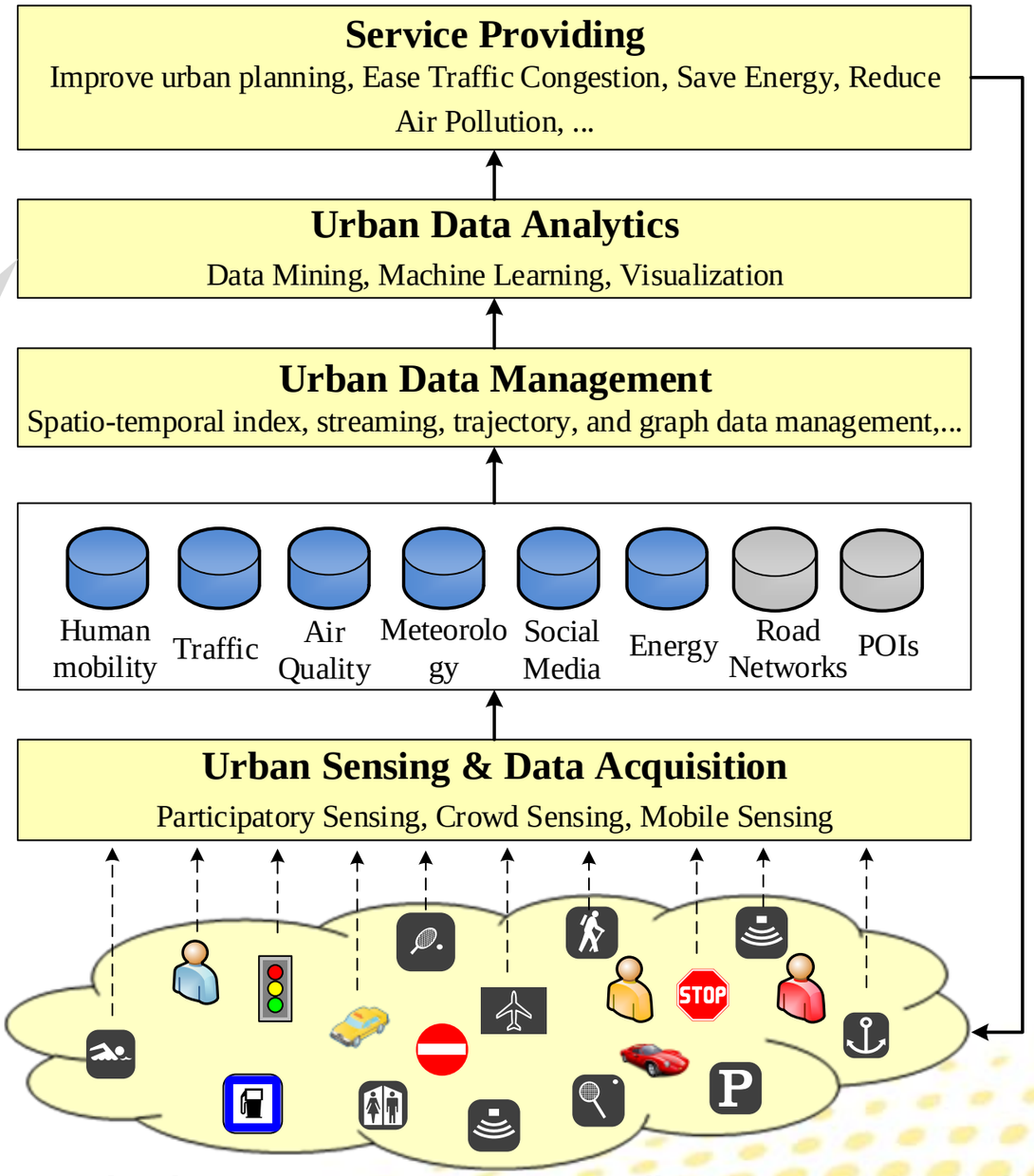
Police officer

Who witnesses the crime?
Where to catch the suspect?

How to use urban data?

- Texts and images → spatial and spatio-temporal data;
- A single data source → Data cross different domains
- Separate data mining algorithms → machine learning + data management
- Visual and interactive data analytics





Zheng, Y., et al. Urban Computing: concepts, methodologies, and applications. *ACM transactions on Intelligent Systems and Technology*.

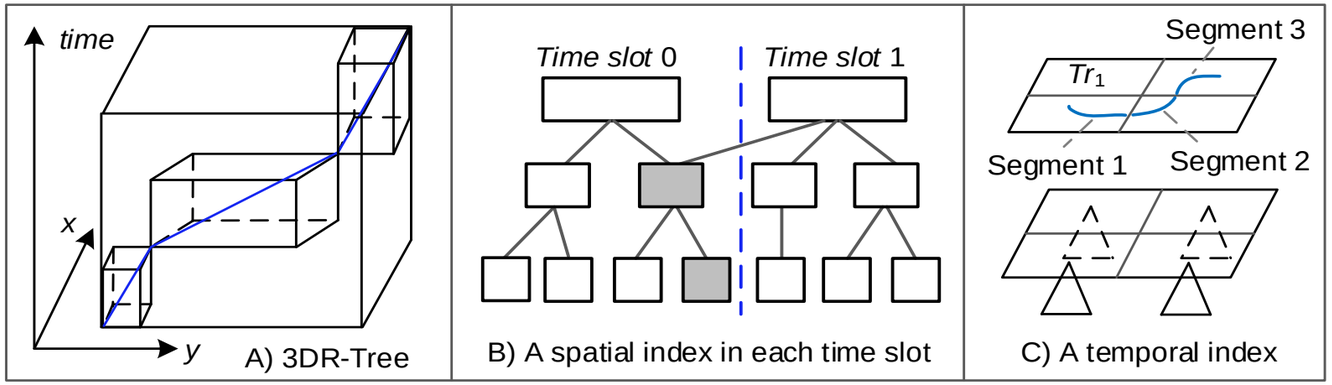
Visualization Tasks and Challenges

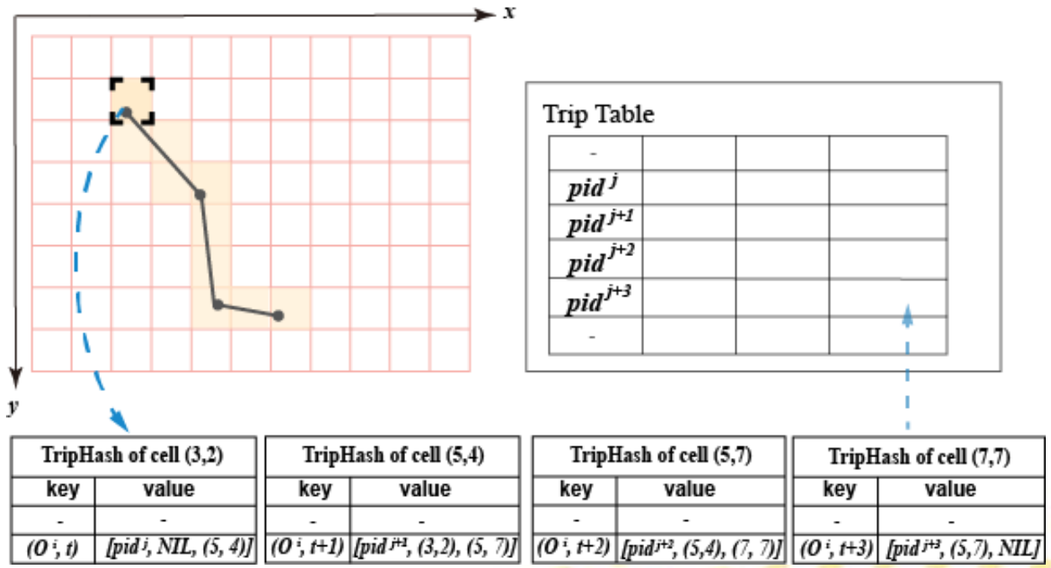
- Data Management & Data Preprocessing
- Data Uncertainty
- Data Mining & Data Classification
- Data Transformation (Graph, Matrix,…)

Data Management & Data Preprocessing

M&P U M&C Trans

- Spatial Databases
- Queries
  - Range queries
  - KNN queries
- Distance metrics
  - The distance between a point and a trajectory
  - The distance between two trajectories
  - The distance between two trajectory segments
- Indexing structures
  - Space-Time-Cube
- Retrieval algorithms

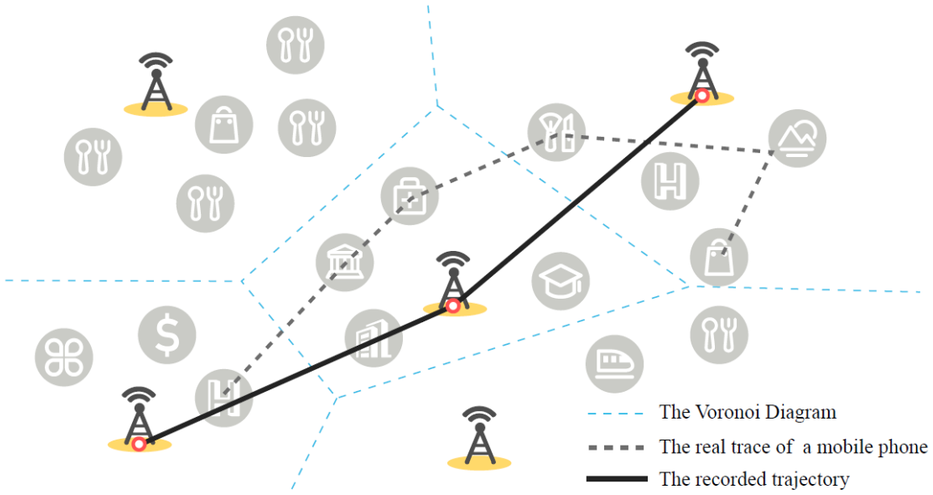


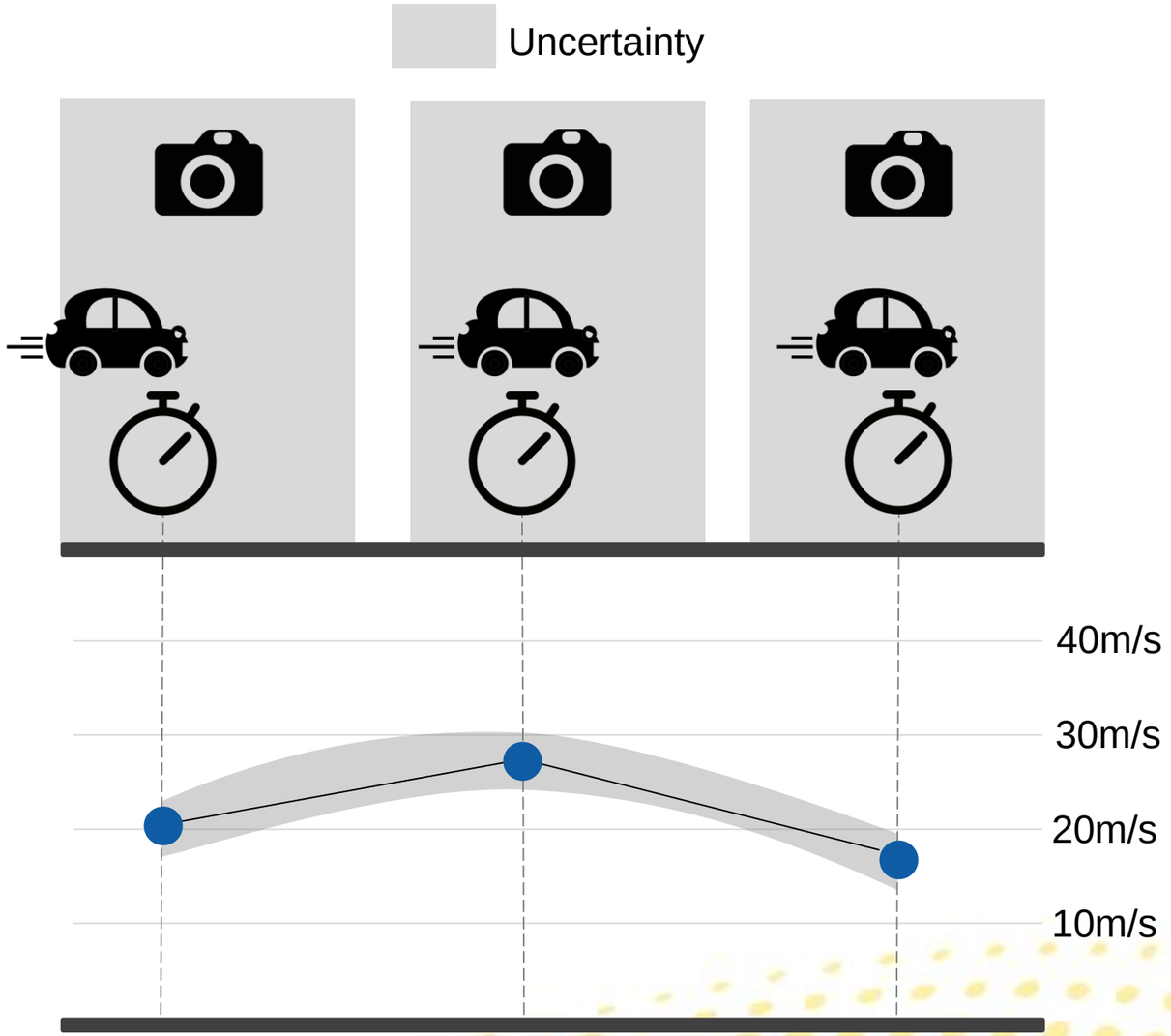


Wang, F., Chen, W., Wu, F., Zhao, Y., Hong, H., Gu, T., ... & Bao, H. (2014, October). A visual reasoning approach for data-driven transport assessment on urban roads. In *Visual Analytics Science and Technology (VAST), 2014 IEEE Conference on* (pp. 103-112). IEEE.

Data Uncertainty

- Spatial uncertainty
- Temporal uncertainty
- Attribute uncertainty





Kinkeldey, C., MacEachren, A. M., Riveiro, M., & Schiewe, J. (2017). Evaluating the effect of visually represented geodata uncertainty on decision-making: systematic review, lessons learned, and recommendations. *Cartography and Geographic Information Science*, *44*(1), 1-21.

Data Uncertainty

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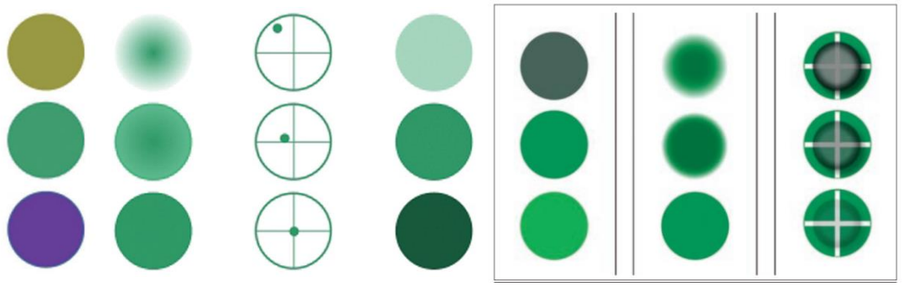
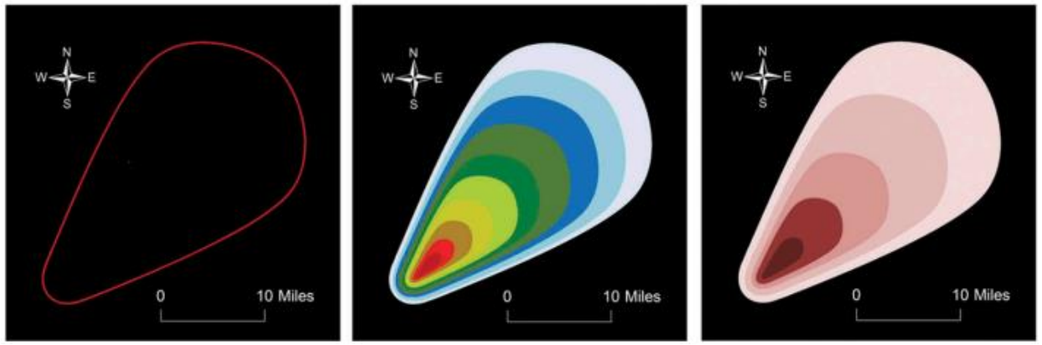
- Temporal uncertainty
- Attribute uncertainty





Data Type / Data Quality	Positional Accuracy	Attribute Accuracy	Logical Consistency	Completeness	Lineage
Discrete Points and Lines	Size Shape (Error ellipses) (Epsilon bands)	Value Color Saturation (Feature code checks)	Color mixing Redundancy by overprinting Slivers by solid fills (Topological cleaning)	Mapping Technique Density traces Marginalia Generalization algorithm Mapping tolerance Buffer size	Mapping Technique Minimum Bounding Rectangles
Categorical Aggregation & Overlay (Tesselation, tiling, Areal coverages)	Texture Value (Certainty of boundary location)	Color mixing (Attribute code checks) (Topographic classifier)	lack error models	Mapping Technique Missing values Logical adjacency surface Marginalia Discrete model weights	
Partitioning & Enumeration (Metric class breaks)	not meaningful	Size = height (Blanket of error)	Size = height (Maximum likelihood prism maps)	Mapping Technique Missing values Missclassification matrix Classing scheme OAL/TAI	Marginalia Source of data Scale/Resolution Date Geometry
Continuous Interpolation (Surfaces and volumes)	no clear distinction b/w the two Value Color Saturation (Continuous tone vignettes) (Continuous tone isopleths)		Size = line wt Color Shape = compactness (TIN links)	not possible by definition Mapping Technique Surface of search attenuation Marginalia Interpolation algorithm	
Graphical Syntax ⟷			**Graphical/Lexical Syntax** ⟷		

Ash, K. D., R. L. Schumann, and G. C. Bowser. 2014. “Tornado Warning Trade-Offs: Evaluating Choices for Visually Communicating Risk.” Weather, Climate, and Society 6 (1): 104–118. doi:10.1175/WCAS-D-13-00021.1.

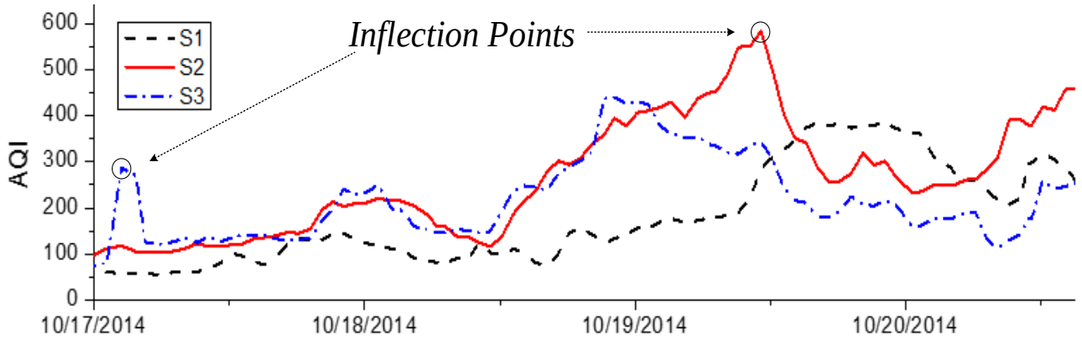
Buttenfield, B. P., and R. Weibel. 1988. Visualizing the quality of cartographic data. Presented at Third International Geographic Information Systems Symposium (GIS/LIS 88), San Antonio, Texas.

Kinkeldey, Christoph, Alan M. MacEachren, and Jochen Schiewe. "How to assess visual communication of uncertainty? A systematic review of geospatial uncertainty

Data Uncertainty

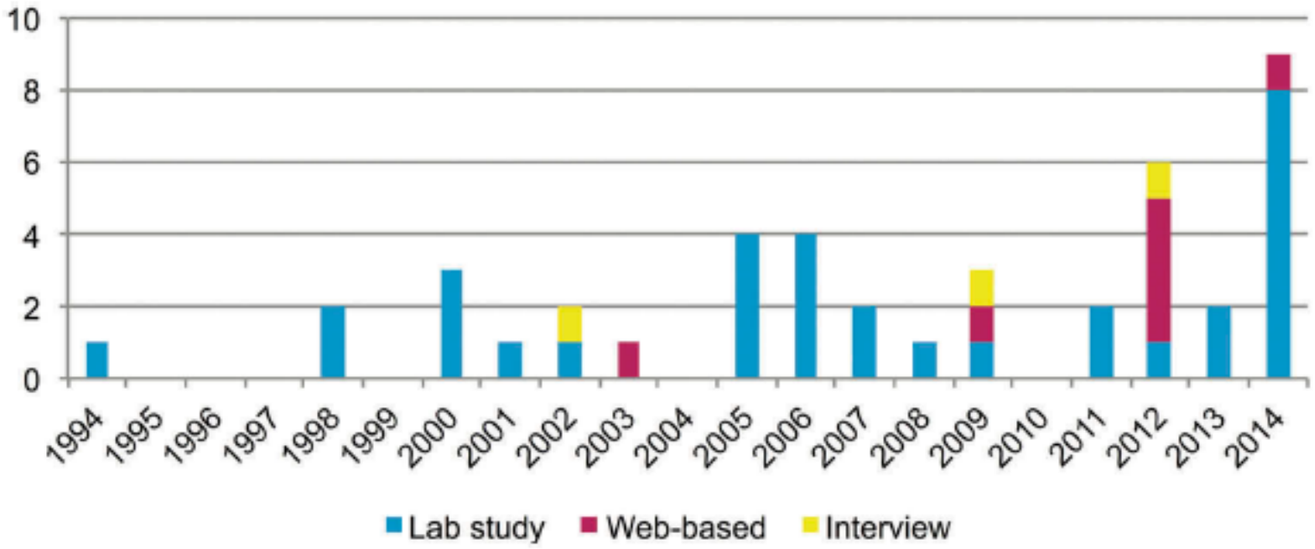
Challenges

- Multiple complex factors vs. insufficient and inaccurate data
- Inflection points and sudden changes



AQI of different stations changing over time of day

Number of user studies assessing the effect of uncertainty visualization



Data Mining & Data Classification

Trajectory classification

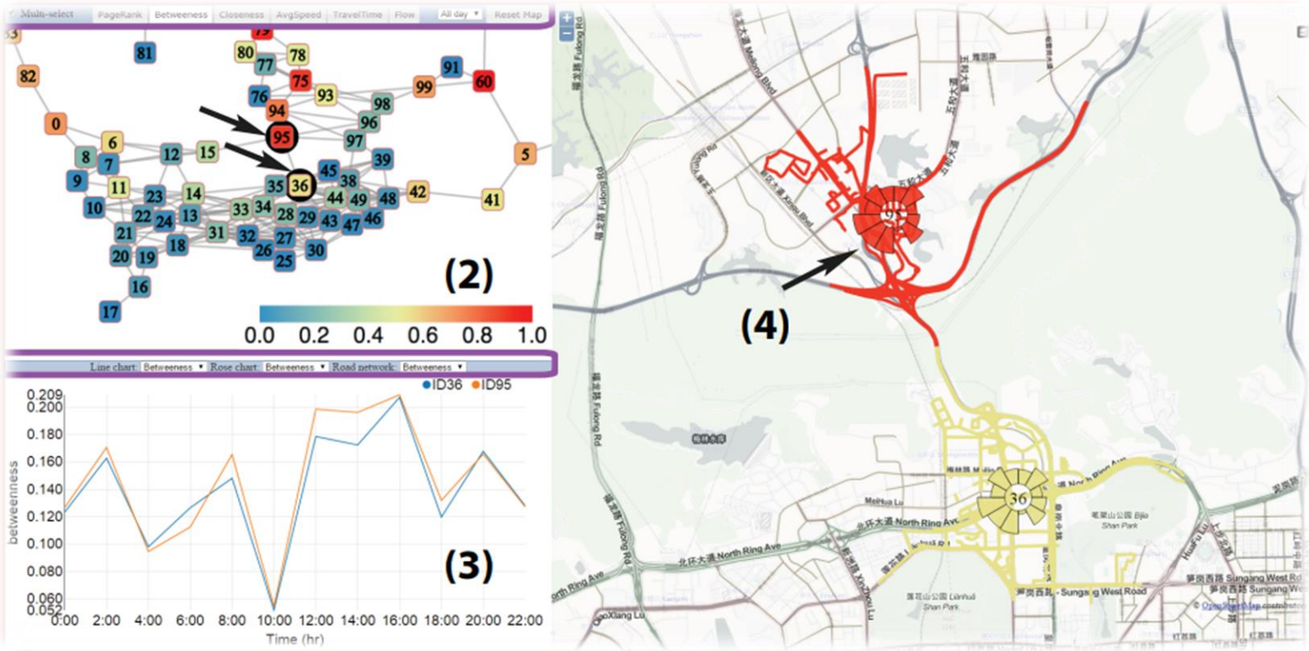
- Motivation
  - For users:
    - Reflect on past events and understand their own life pattern
    - Obtain more reference knowledge from others' experiences
  - For service provider:
    - Classify trajectories of different transportation modes
    - Enable smart-route design and recommendation
- Challenges
  - The big volume of the urban data
  - The diversity of the transportation modes
  - The complexity of the urban conditions

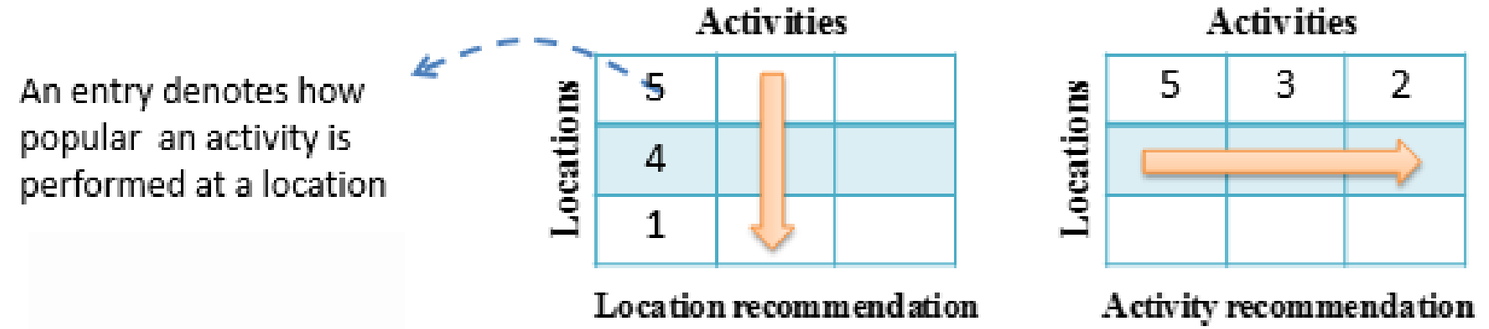
Yu Zheng, Trajectory Data Mining, ACM Transactions on Intelligent Systems and Technology. 2015, vol. 6, issue 3

Data transformation (Graph, Matrix,…)

M&P U M&C **Trans**

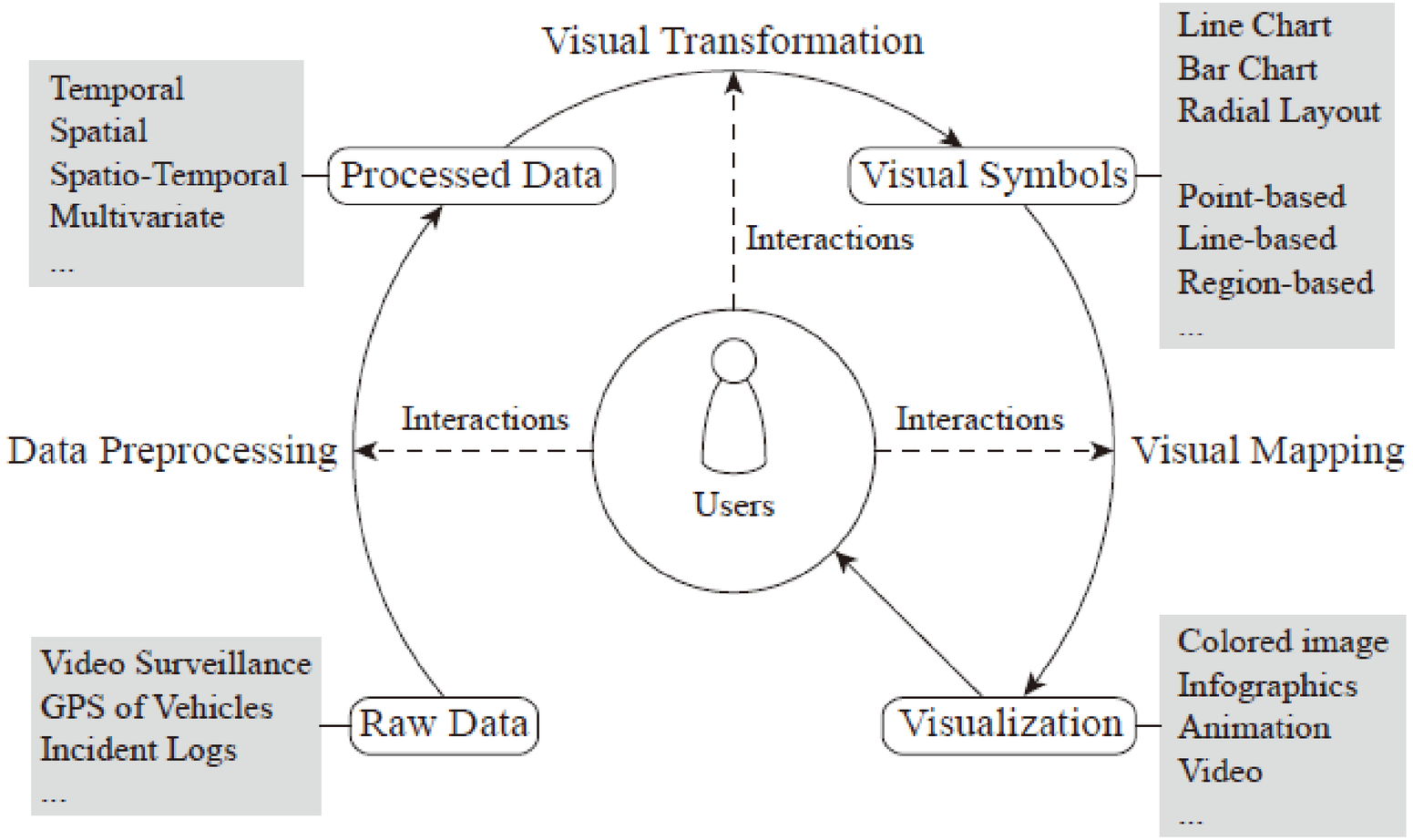
- Graph based
  - Node link
- Matrix based
  - Collaborative Filtering (CF)
  - Context-aware matrix factorization
- Challenges
  - Lack of data
  - Well designed model





TrajGraph: A Graph-Based Visual Analytics Approach to Studying Urban Network Centrality Using Taxi Trajectory Data, Xiaoke Huang, Ye Zhao, Jing Yang, Chao Ma, Chong Zhang, and Xinyue Ye, IEEE Transactions on Visualization and Computer Graphics

Overview of Existing Work



Conceptual pipeline of traffic data visualization

Chen W, Guo F, Wang F Y. A survey of traffic data visualization[J]. IEEE Transactions on Intelligent Transportation Systems, 2015, 16(6): 2970-2984.

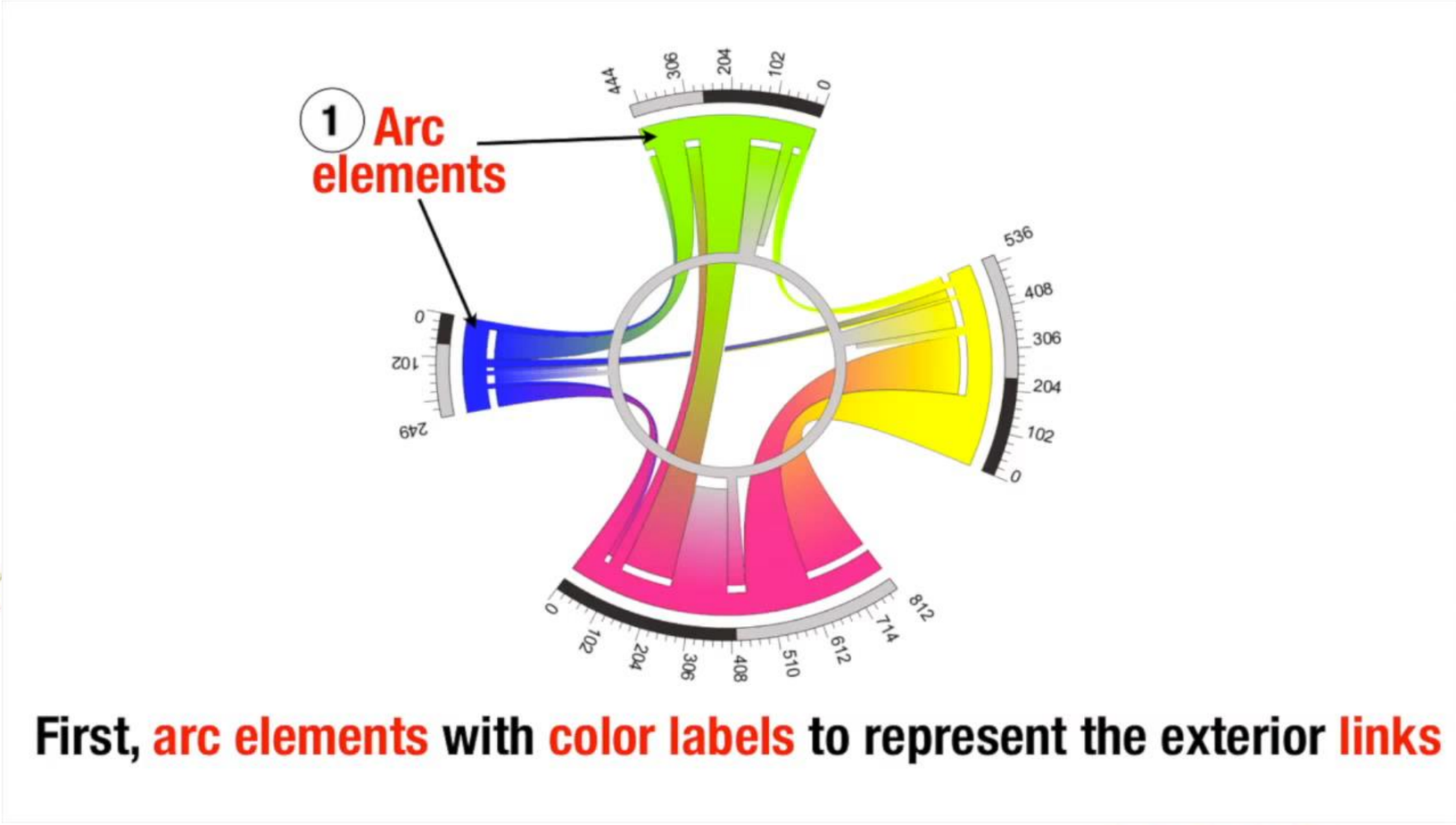
Visualization of Time

- Type
  - Linear Time
  - Periodic Time
  - Branching Time
- Visual elements
  - Time axis (line, radial,…)
  - Storyline

Wunderlich M, Ballweg K, Fuchs G, et al. Visualization of Delay Uncertainty and its Impact on Train Trip Planning: A Design Study[C] Computer Graphics Forum. 2017, 36(3): 317-328.

Visualization of Spatial Properties

- Data Type
  - Points
  - Lines
  - Regions

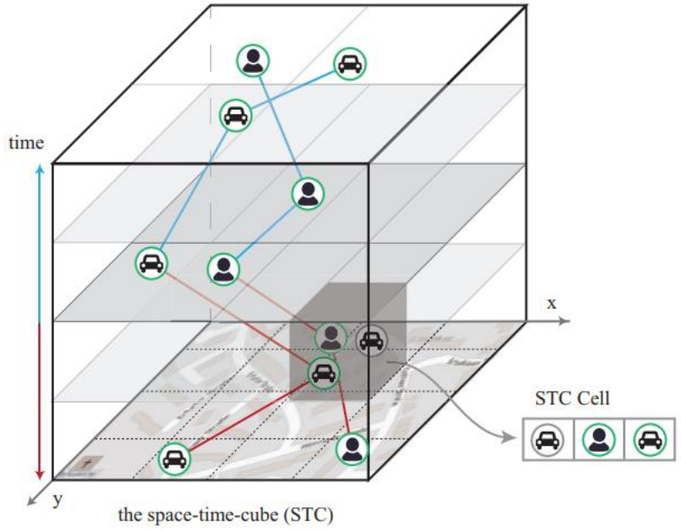


O. Ersoy, C. Hurter, F. V. Paulovich, G. Cantareiro, and A. Telea, “Skeleton-based edge bundling for graph visualization,” IEEE Transactions on Visualization and Computer Graphics, vol. 17, no. 12, pp. 2364–2373, 2011.

W. Zeng, C.-W. Fu, S. M. Arisona, and H. Qu, “Visualizing interchange patterns in massive movement data,” in Computer Graphics Forum, vol. 32, no. 3pt3. Wiley Online Library, 2013, pp. 271–280.

Spatio-temporal Visualization

- Space-Time-Cube
  - Query
  - Visualization
  - Exploration
- Mobile objects



Chen, S., Chen, S., Lin, L., Yuan, X., Liang, J., & Zhang, X. (2017). E-map: A visual analytics approach for exploring significant event evolutions in social media. In Proceedings of the IEEE Conference on Visual Analytics Science&Technology (VAST).
Chen, W., Huang, Z., Wu, F., Zhu, M., Guan, H., & Maciejewski, R. (2018). Vaud: A visual analysis approach for exploring spatio-temporal urban data. *IEEE Transactions on Visualization & Computer Graphics*, (9), 2636-2648.

Visualization of Multiple Properties

- Type:
  - Numerical Properties
  - Textual Properties
  - …
- Visual techniques
  - 2D chart
  - Parallel coordinates
  - Glyphs

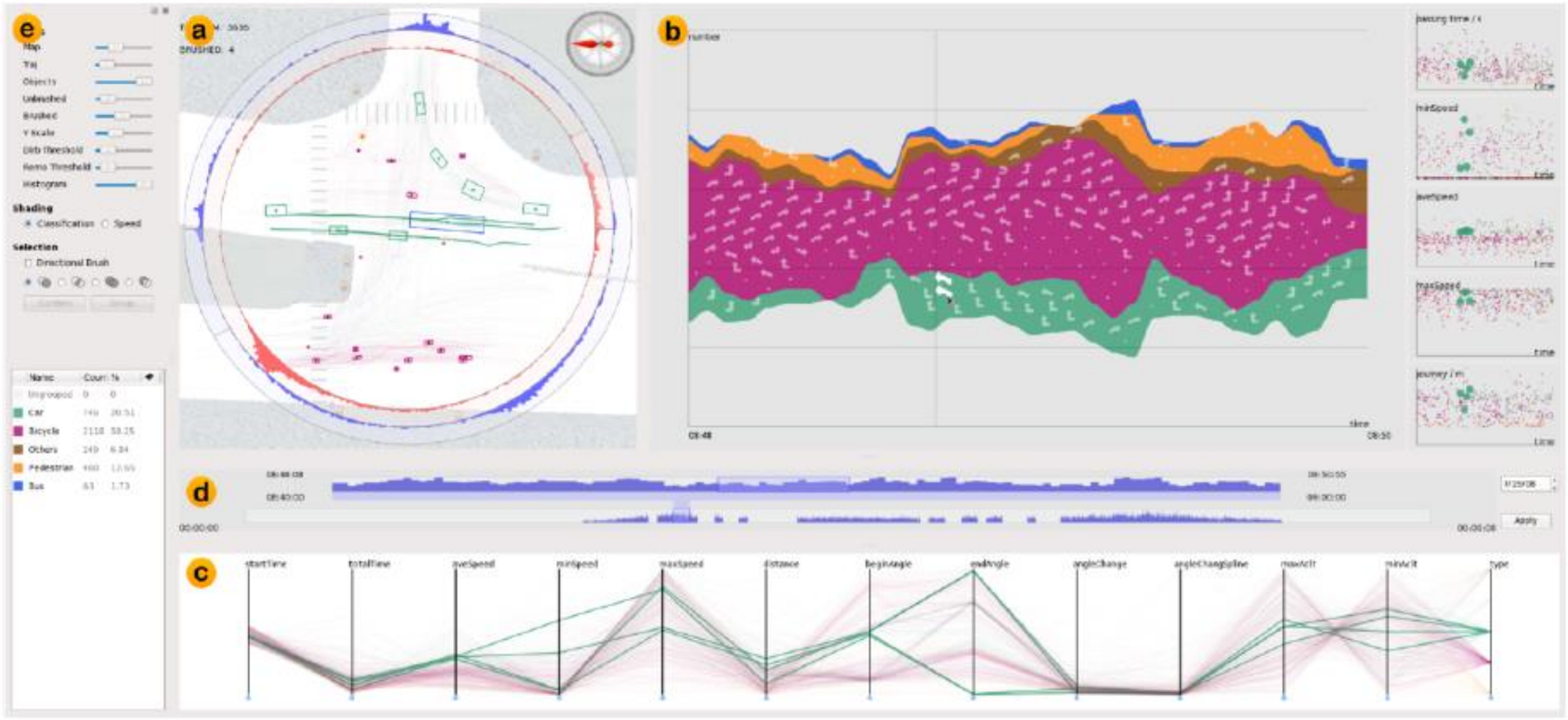


Fig. 17. TripVista is a visual analytics system for finding traffic flow patterns at a road intersection [23].

H. Guo, Z. Wang, B. Yu, H. Zhao, and X. Yuan, “Tripvista: Triple perspective visual trajectory analytics and its application on microscopic traffic data at a road intersection,” in IEEE Pacific Visualization Symposium, 2011, pp. 163–170.

VISUAL ANALYSIS OF URBAN DATA

Situation-aware exploration and prediction

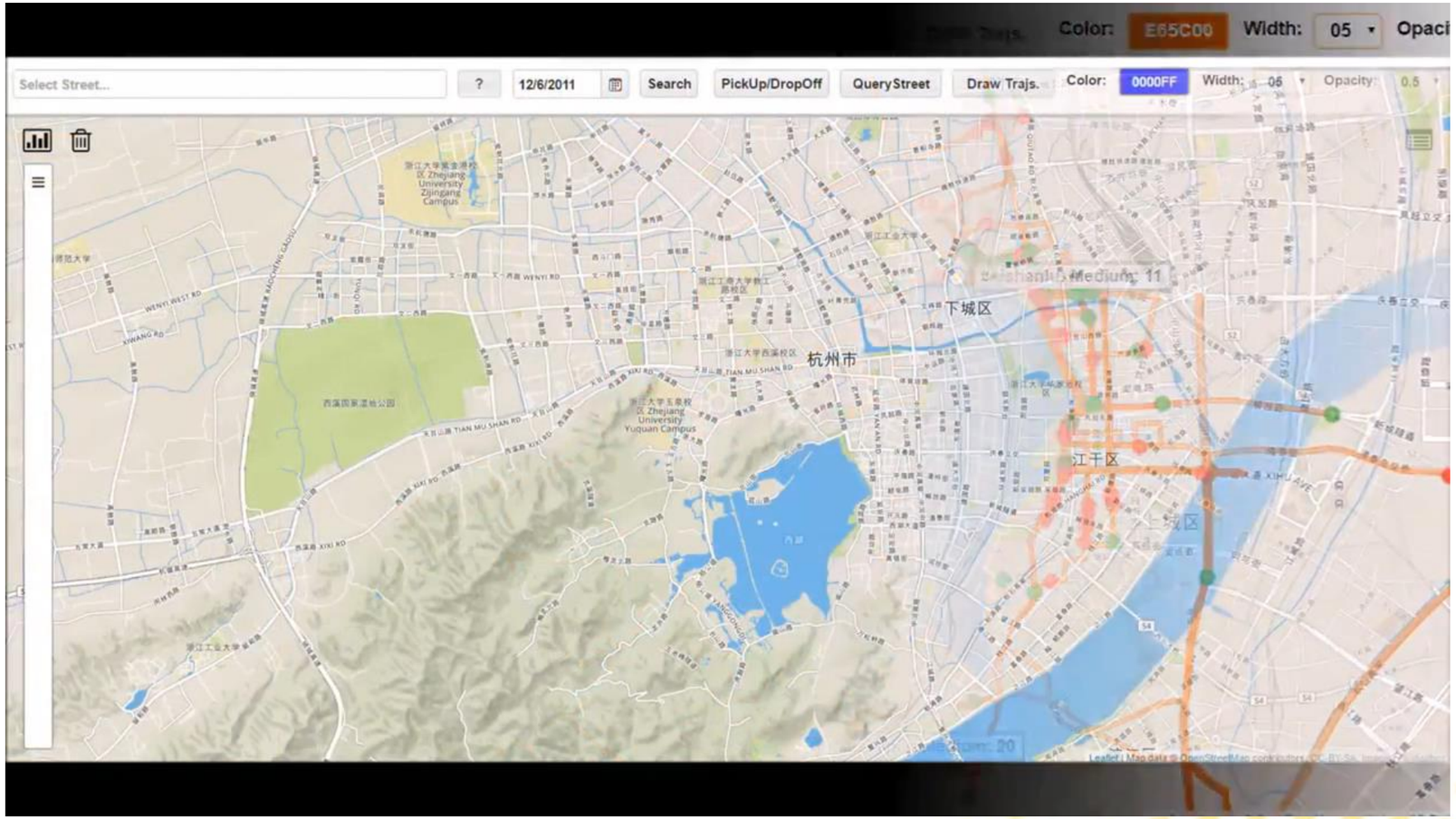
- Multisource
  - Trajectories
  - POIs
  - Twitter
  - Social media
- Heterogeneous
- Visual Querying
- Visual Reasoning
- Exploration

Chen, W., Huang, Z., Wu, F., Zhu, M., Guan, H., & Maciejewski, R. (2018). Vaud: A visual analysis approach for exploring spatio-temporal urban data. *IEEE Transactions on Visualization & Computer Graphics*, (9), 2636-2648.

VISUAL ANALYSIS OF URBAN DATA

Situation-aware exploration and prediction

- Trajectory data
- Semantics
  - Speed
  - Location
  - Time
- Visual Querying
- Summary

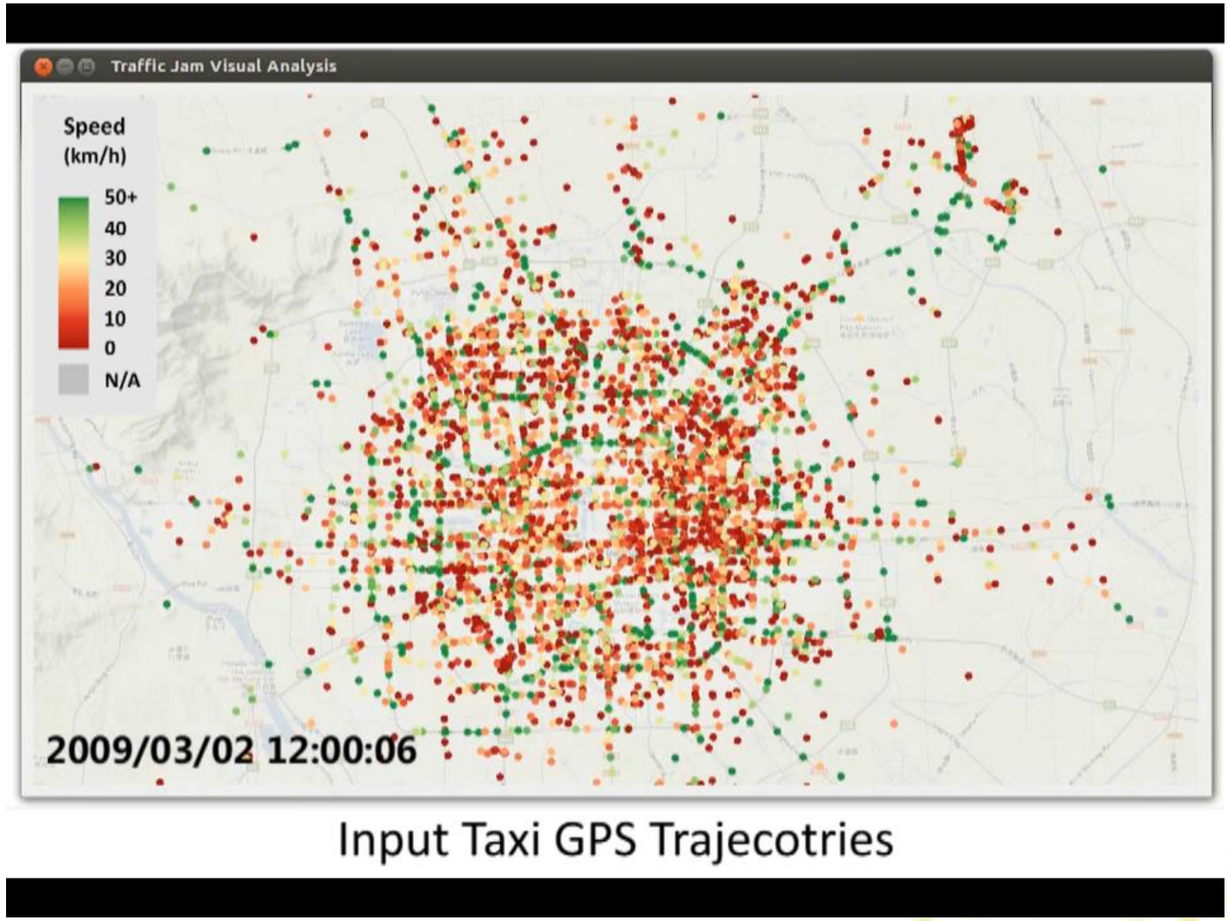


Al-Dohuki, S., Wu, Y., Kamw, F., Yang, J., Li, X., Zhao, Y., ... & Wang, F. (2017). SemanticTraj: A new approach to interacting with massive taxi trajectories. *IEEE transactions on visualization and computer graphics*, *23*(1), 11-20.

VISUAL ANALYSIS OF URBAN DATA

Situation-aware exploration and prediction

- Trajectory data
- Prediction
  - Traffic
  - Street based
  - Heatmap
- Detail visualization



Input Taxi GPS Trajecotries

Z. Wang, M. Lu, X. Yuan, J. Zhang, and H. v. d. Wetering, “Visual traffic jam analysis based on trajectory data,” IEEE Transactions on Visualization and Computer Graphics, vol. 19, no. 12, pp. 2159–2168, 2013.

VISUAL ANALYSIS OF URBAN DATA

Situation-aware exploration and prediction

- Trajectory data
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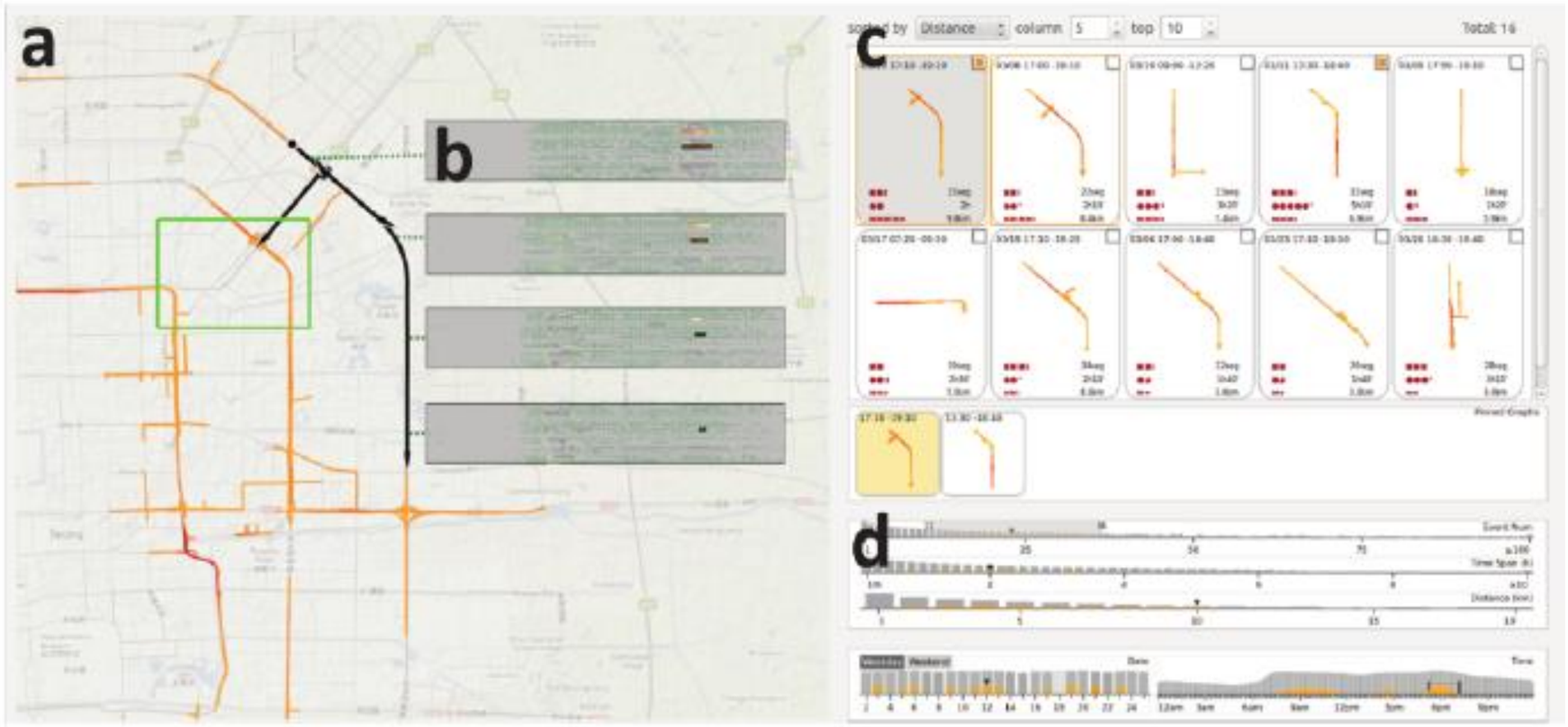

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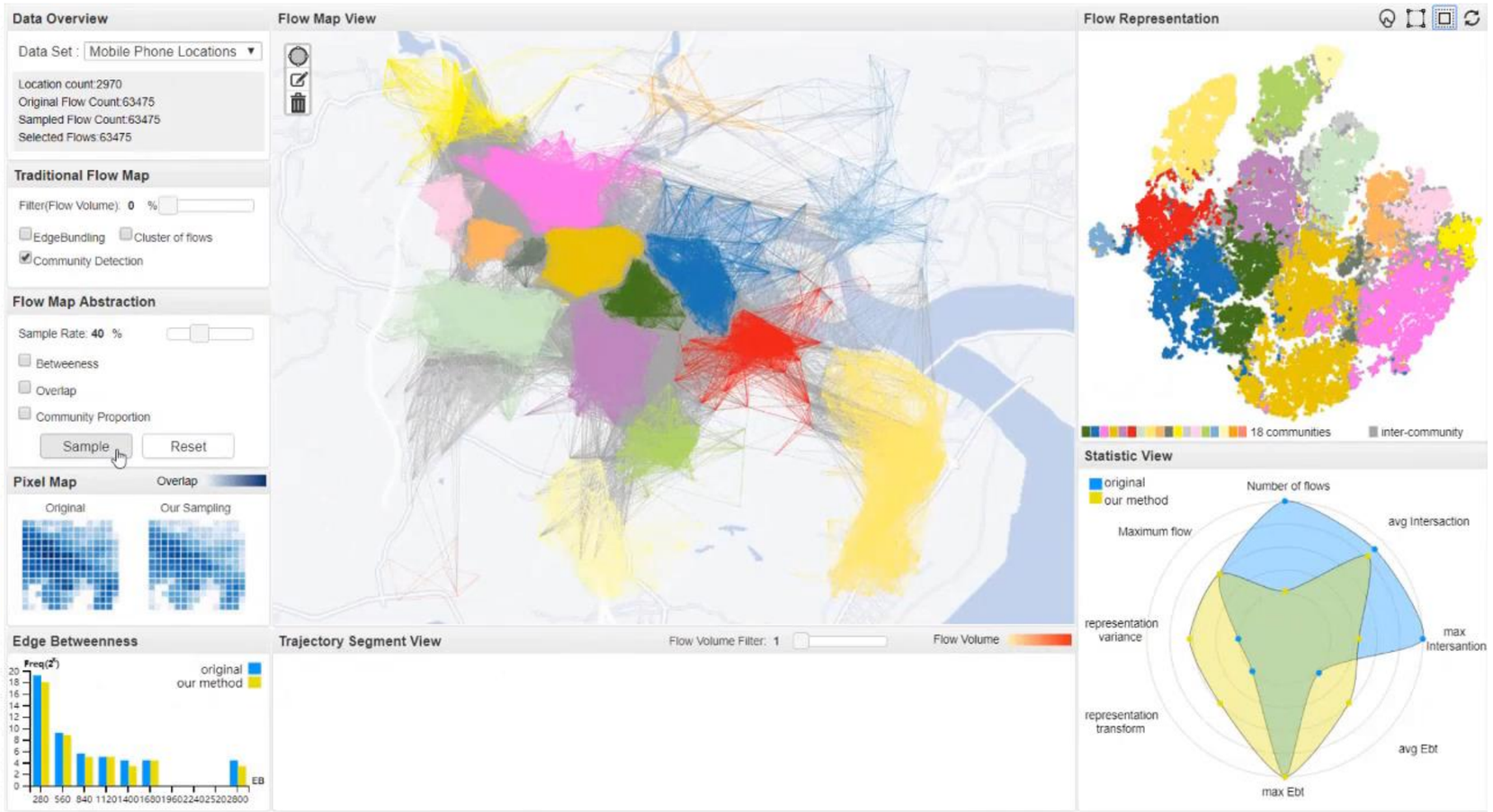
VISUAL ANALYSIS OF URBAN DATA

Pattern Discovery and Clustering

- Trajectory data
- Clustering
- Summary
- Simplification

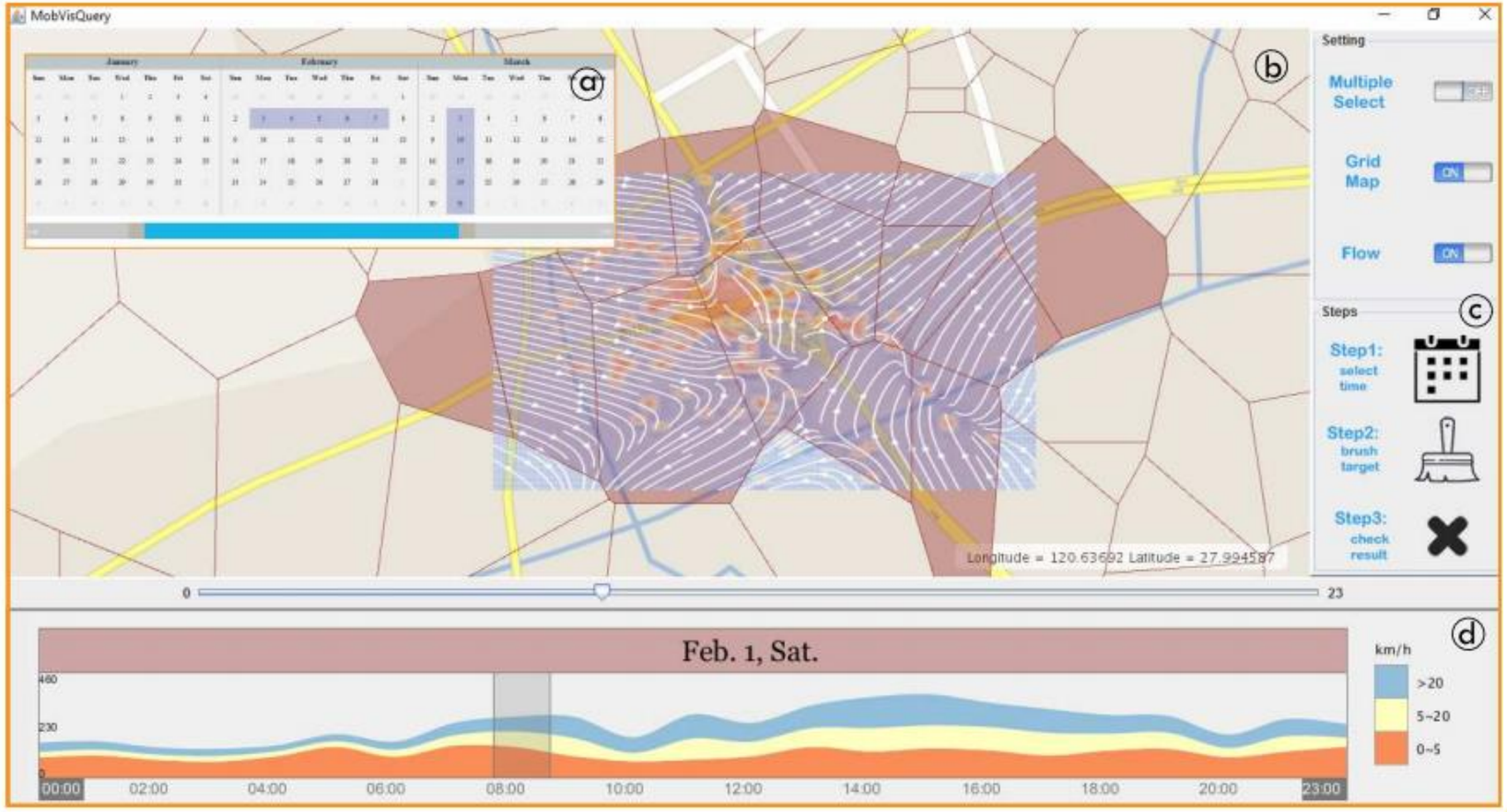


Zhou, Z., Meng, L., Tang, C., Zhao, Y., Guo, Z., Hu, M., & Chen, W. (2018). Visual Abstraction of Large Scale Geospatial Origin-Destination Movement Data. *IEEE transactions on visualization and computer graphics*.

VISUAL ANALYSIS OF URBAN DATA

Visual monitoring of traffic situations

- Trajectory data
- Traffic situations
  - Traffic direction
  - Traffic volume
  - Interactively exploration
- Citywide analysis



Wang, F., Chen, W., Zhao, Y., Gu, T., Gao, S., & Bao, H. (2017). Adaptively Exploring Population Mobility Patterns in Flow Visualization. *IEEE Transactions on Intelligent Transportation Systems*, *18*(8), 2250-2259.

VISUAL ANALYSIS OF URBAN DATA

Visual monitoring of traffic situations

- Trajectory data
- Traffic situations
  - Traffic direction
  - Traffic speed
  - Interactively exploration
- Detail visualization

Wang, F., Chen, W., Wu, F., Zhao, Y., Hong, H., Gu, T., ... & Bao, H. (2014, October). A visual reasoning approach for data-driven transport assessment on urban roads. In *Visual Analytics Science and Technology (VAST), 2014 IEEE Conference on* (pp. 103-112). IEEE.

Urban Data Visualization

Visualization System of Urban Data?