Tutorial: Urban Trajectory Visualization

Overview of Visualization Design Space and Techniques

Jing Yang

Outline

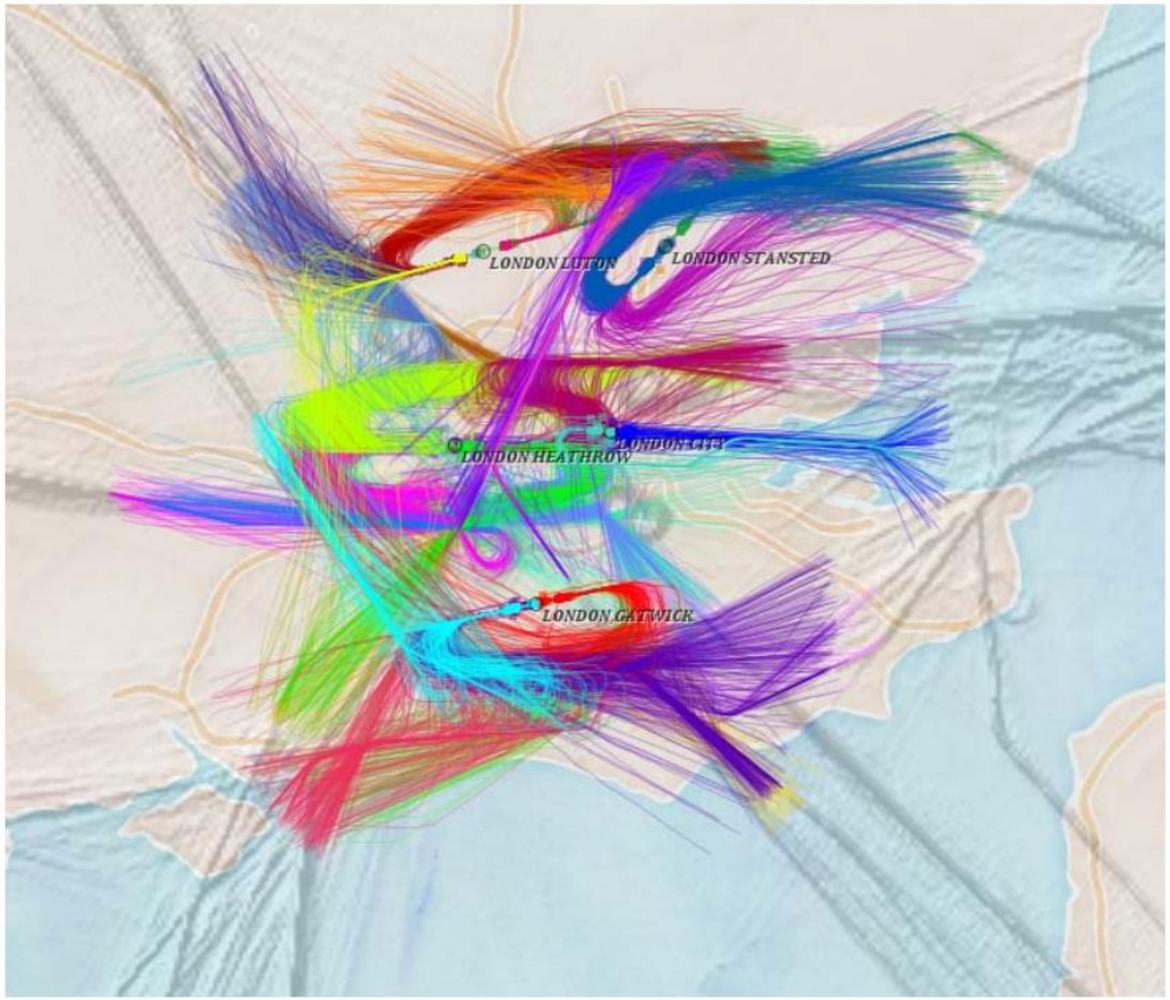
- Visualization of Trajectories
  - Visualization Where Each Trajectory Has Its Own Markers
  - Density Plot Visualization
  - Visualization of Aggregated Trajectories
- Visualization of Flows Between Origins and Destinations
- Interactions

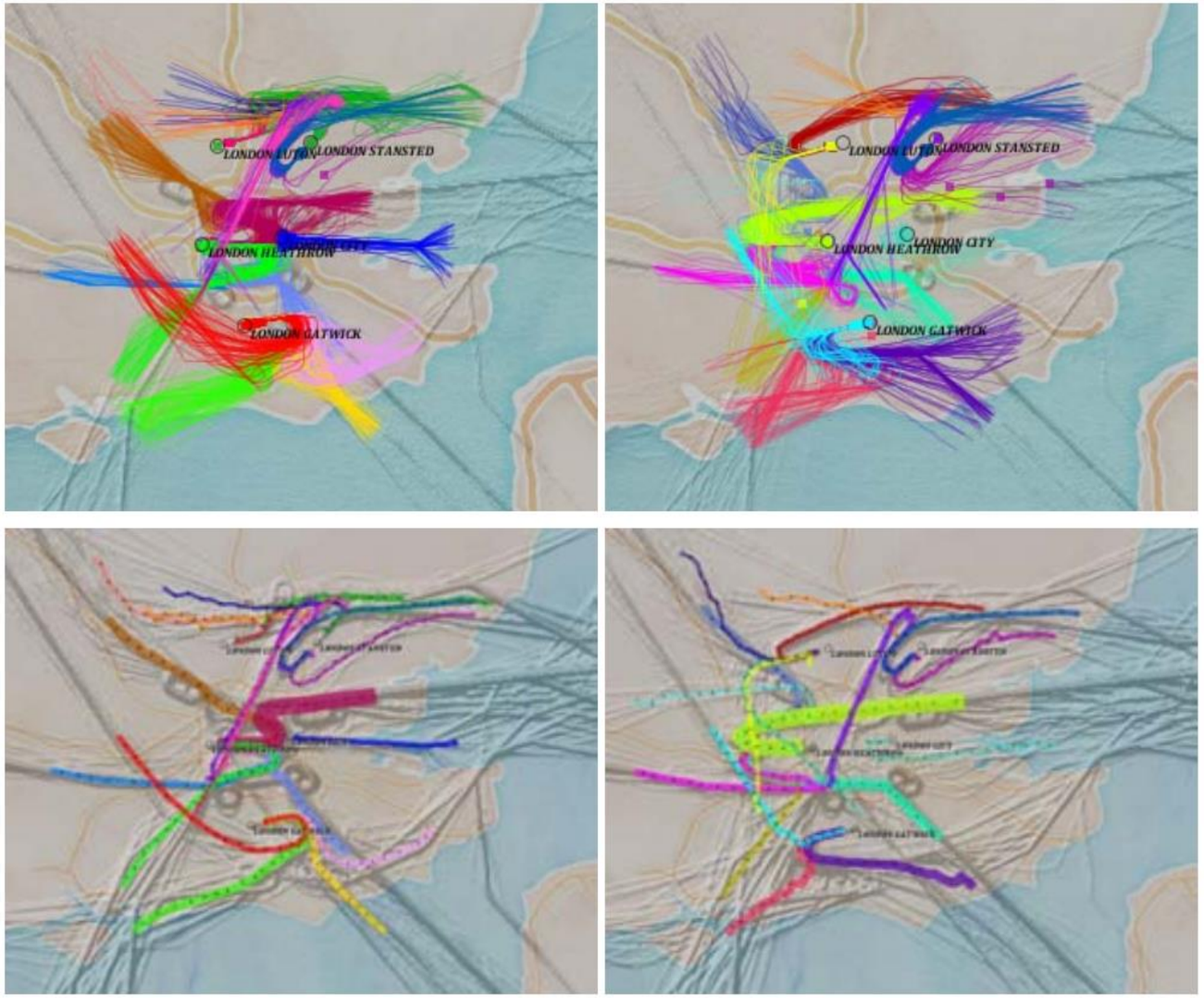
Outline

- Visualization of Trajectories *
  - Visualization Where Each Trajectory has Its Own Markers
  - Density Plot Visualization
  - Visualization of Aggregated Trajectories
- Visualization of Flows Between Origins and Destinations
- Interactions

* This categorization follows Ben Shneiderman’s “Atomic, aggregate, and density plot visualization” in "Extreme visualization: squeezing a billion records into a million pixels." In *Proceedings of the 2008 ACM SIGMOD international conference on Management of data*, pp. 3-12. ACM, 2008.

Lines, Density Map, Tubes





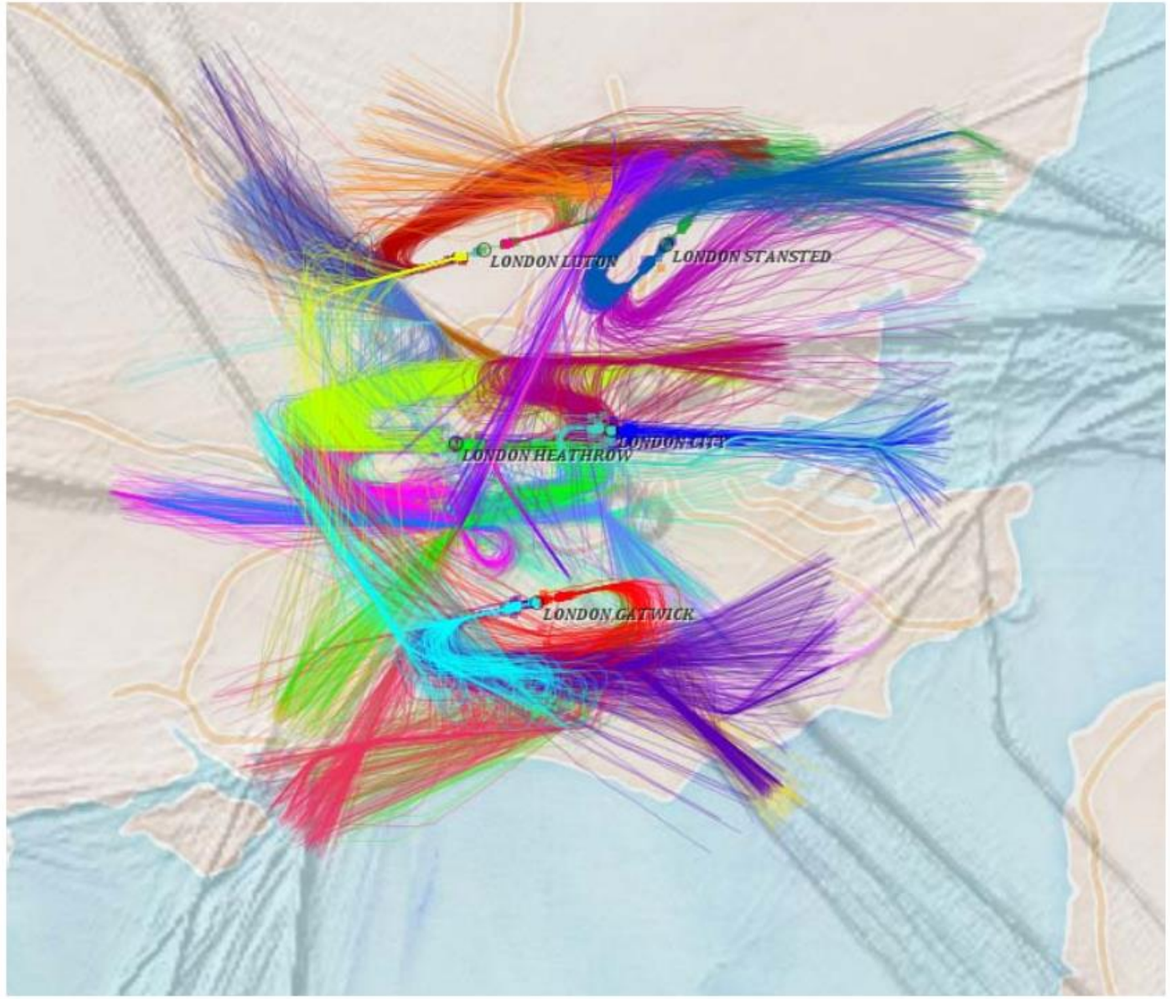
VIS 2018

Gennady Andrienko, Natalia Andrienko, Georg Fuchs, and Jose Manuel Cordero Garcia. "Clustering trajectories by relevant parts for air traffic analysis." *IEEE transactions on visualization and computer graphics* 24, no. 1 (2018): 34-44.

Outline

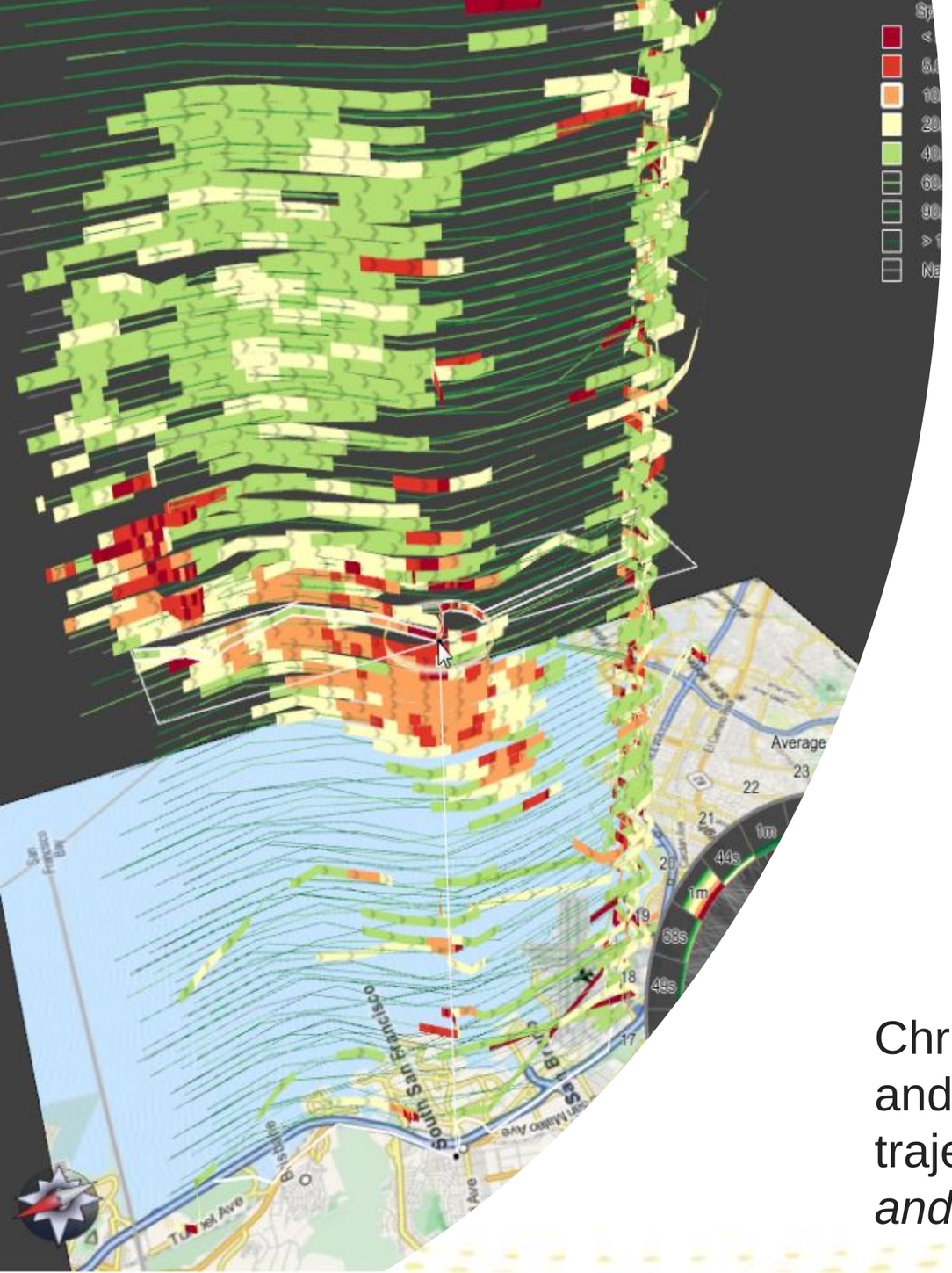
- Visualization of Trajectories
  - Visualization Where Each Trajectory has Its Own Markers
  - Density Plot Visualization
  - Visualization of Aggregated Trajectories
- Visualization of Flows Between Origins and Destinations
- Interactions

Lines



Color: cluster membership

Gennady Andrienko, Natalia Andrienko, Georg Fuchs, and Jose Manuel Cordero Garcia. "Clustering trajectories by relevant parts for air traffic analysis." *IEEE transactions on visualization and computer graphics* 24, no. 1 (2018): 34-44.



Stacked 3D Trajectory Bands

The development of a traffic jam in San Francisco. Color-coded bands - attribute data of individual trajectories;
Stacked bands - a set of trajectories.

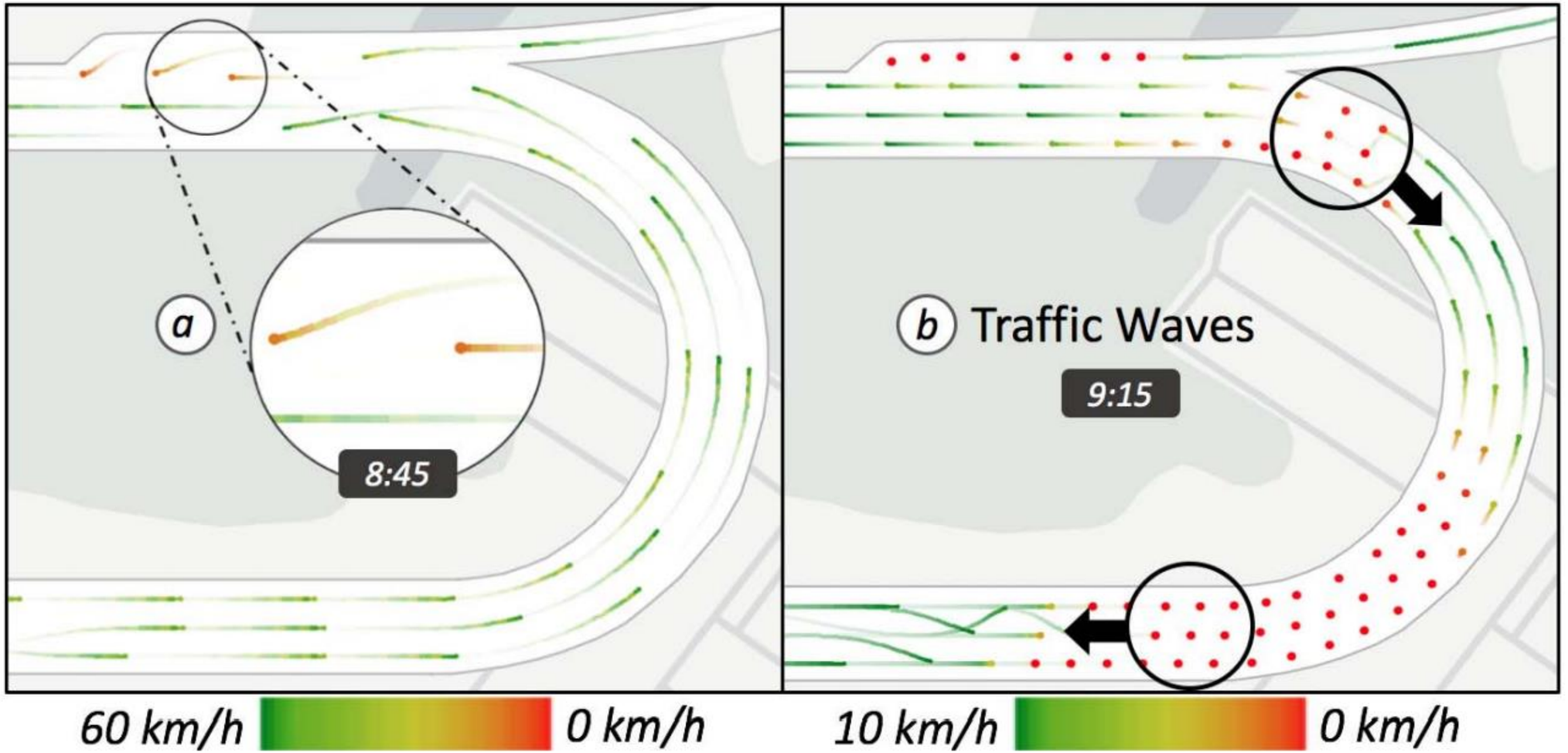
Christian Tominski, Heidrun Schumann, Gennady Andrienko, and Natalia Andrienko. "Stacking-based visualization of trajectory attribute data." *IEEE Transactions on visualization and Computer Graphics* 18, no. 12 (2012): 2565-2574.

Animation

Dot: Train; Color: delay; Size: # of passengers

Kristian Kloeckl, Xiaoji Chen, Christian Sommer, Carlo Ratti, and Assaf Biderman. Trains in time. http://senseable.mit.edu/trainsofdata/

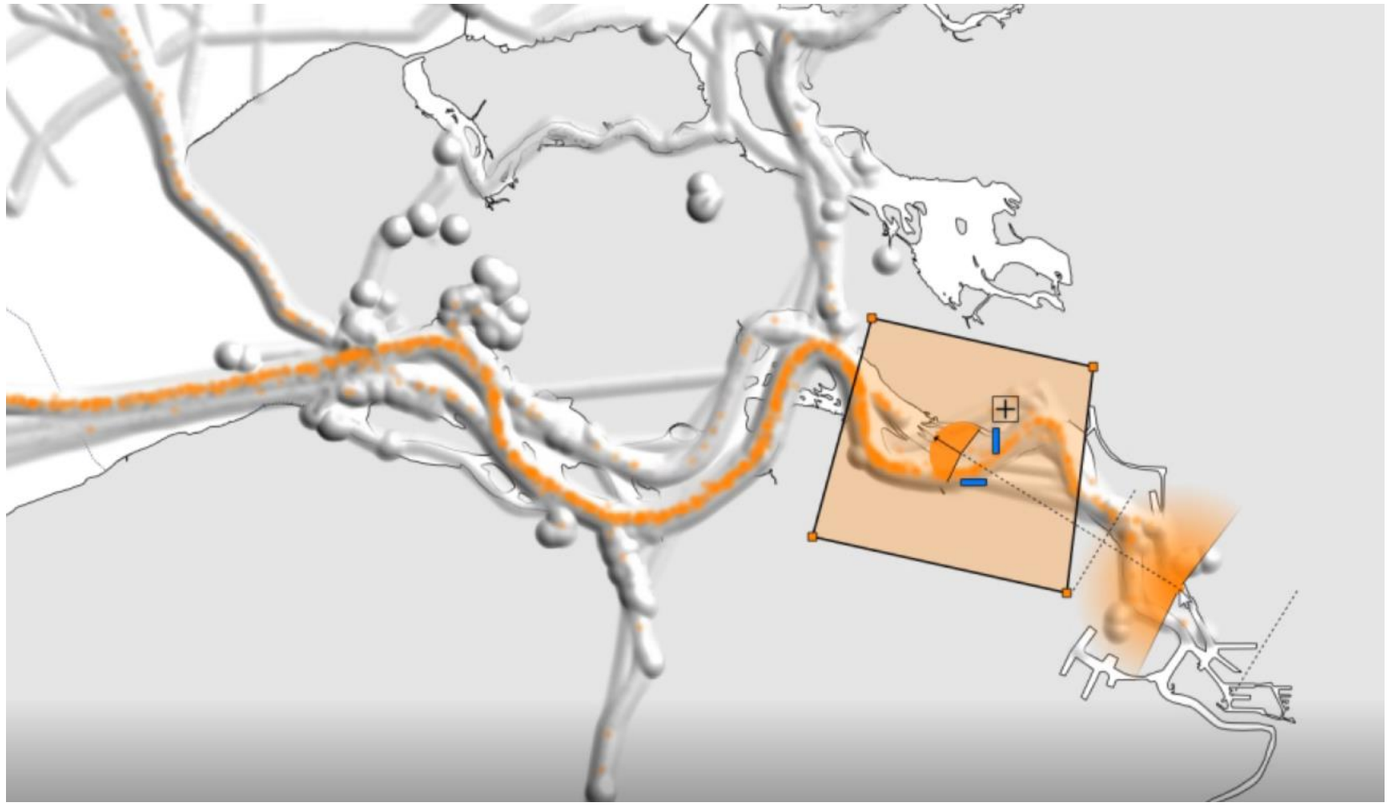
Animation with Trails



Vehicles access the main road. Traffic waves are circled.

George A.M. Gomes, Emanuele Santos, and Creto A. Vidal. "Interactive Visualization of Traffic Dynamics Based on Trajectory Data." In *Graphics, Patterns and Images (SIBGRAPI), 2017 30th SIBGRAPI Conference on*, pp. 111-118. IEEE, 2017.

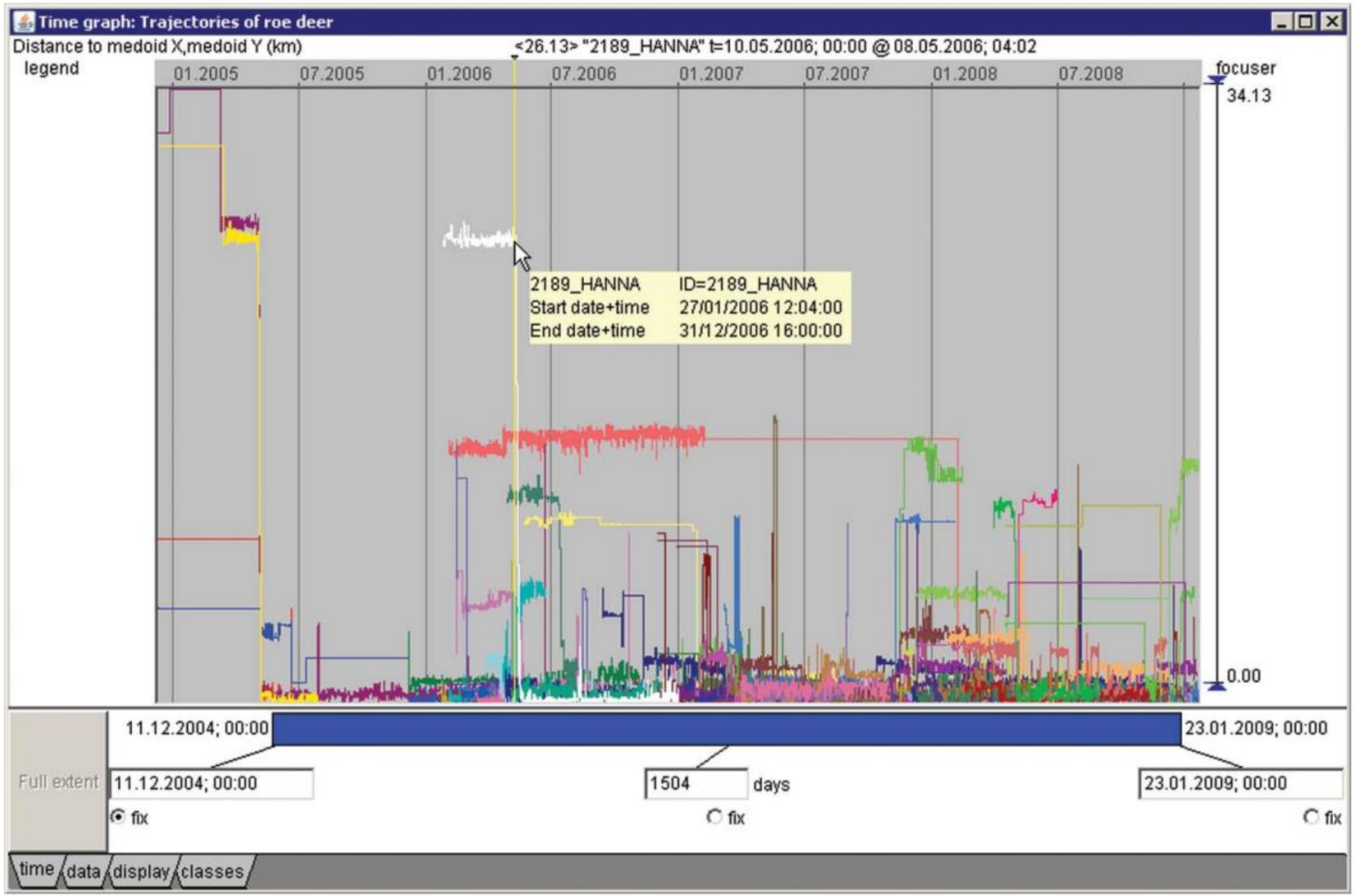
Density Map + Particle System (Animation)



Density map: all trajectories; Animated particles: moving objects. Orange particles: selected objects

Roeland Scheepens, Christophe Hurter, Huub Van De Wetering, and Jarke J. Van Wijk. "Visualization, selection, and analysis of traffic flows." *IEEE transactions on visualization and computer graphics* 22, no. 1 (2016): 379-388.

Time Graph

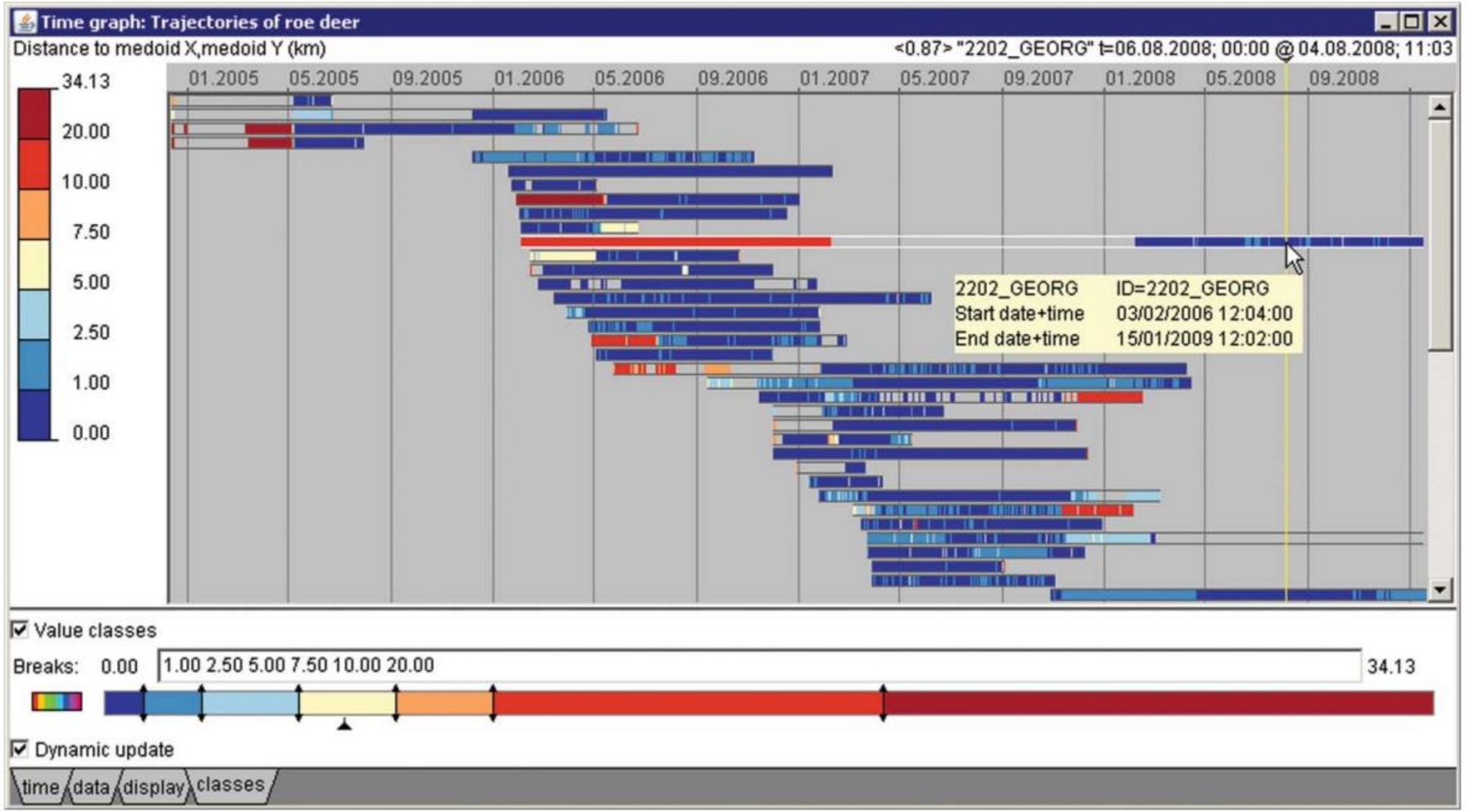


Lines: Trajectories; X: Time axis; Y: Distance to medoid of a trajectory

Gennady Andrienko, Natalia Andrienko, and Marco Heurich. "An event-based conceptual model for context-aware movement analysis." *International Journal of Geographical Information Science* 25.9 (2011): 1347-1370.

VIS 2018

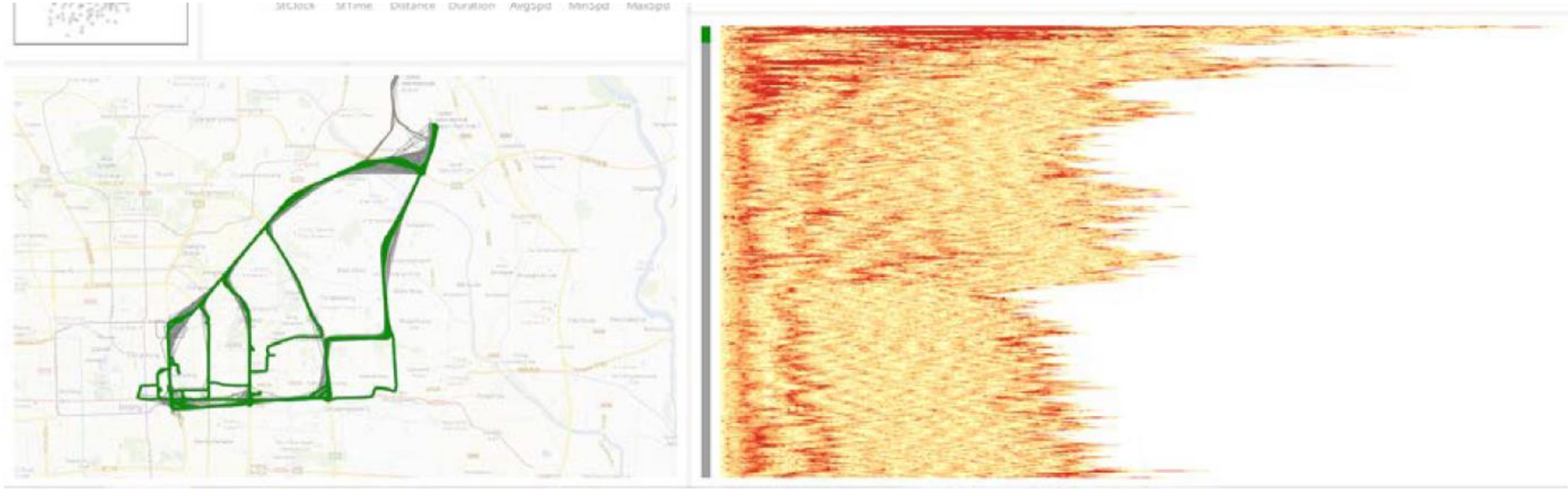
Time Bar



Bars: Trajectories; X: Time axis; Color: Distance to trajectory medoid

Gennady Andrienko, Natalia Andrienko, and Marco Heurich. "An event-based conceptual model for context-aware movement analysis." *International Journal of Geographical Information Science* 25.9 (2011): 1347-1370.

Timelines

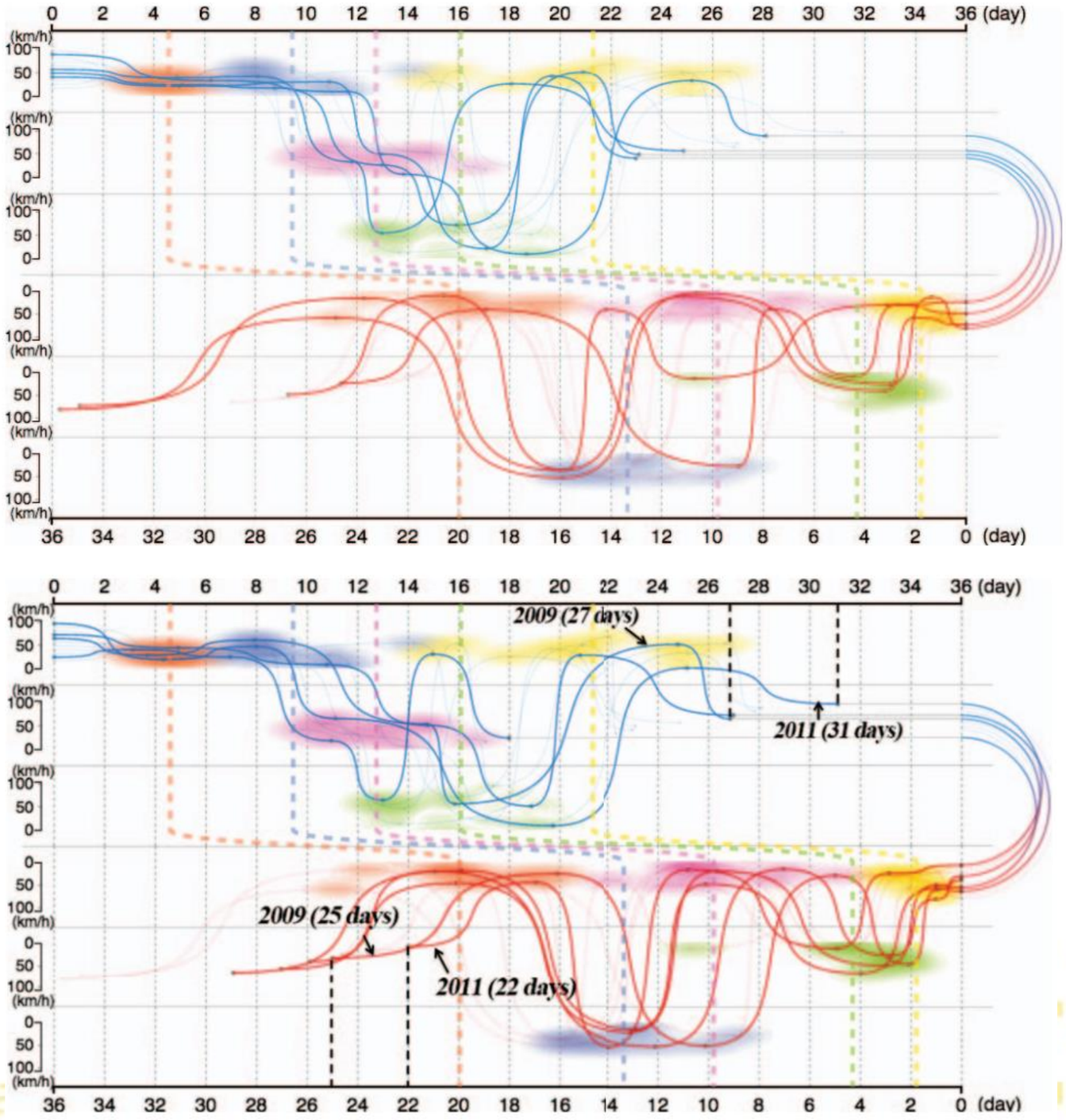


Right: Timelines where each line represents a trip; X – travel time; Red – Significant stops; Orange – smooth travel. Green: selected trajectories

Zuchao Wang and Xiaoru Yuan. "Urban trajectory timeline visualization." In *Big Data and Smart Computing (BIGCOMP), 2014 International Conference on*, pp. 13-18. IEEE, 2014.

Isotime Storyline for Bi-Directional Movement

Different migration patterns of two vultures. X - Time from origin to /destination (top axis) and from destination to origin (bottom axis); Y - Speed

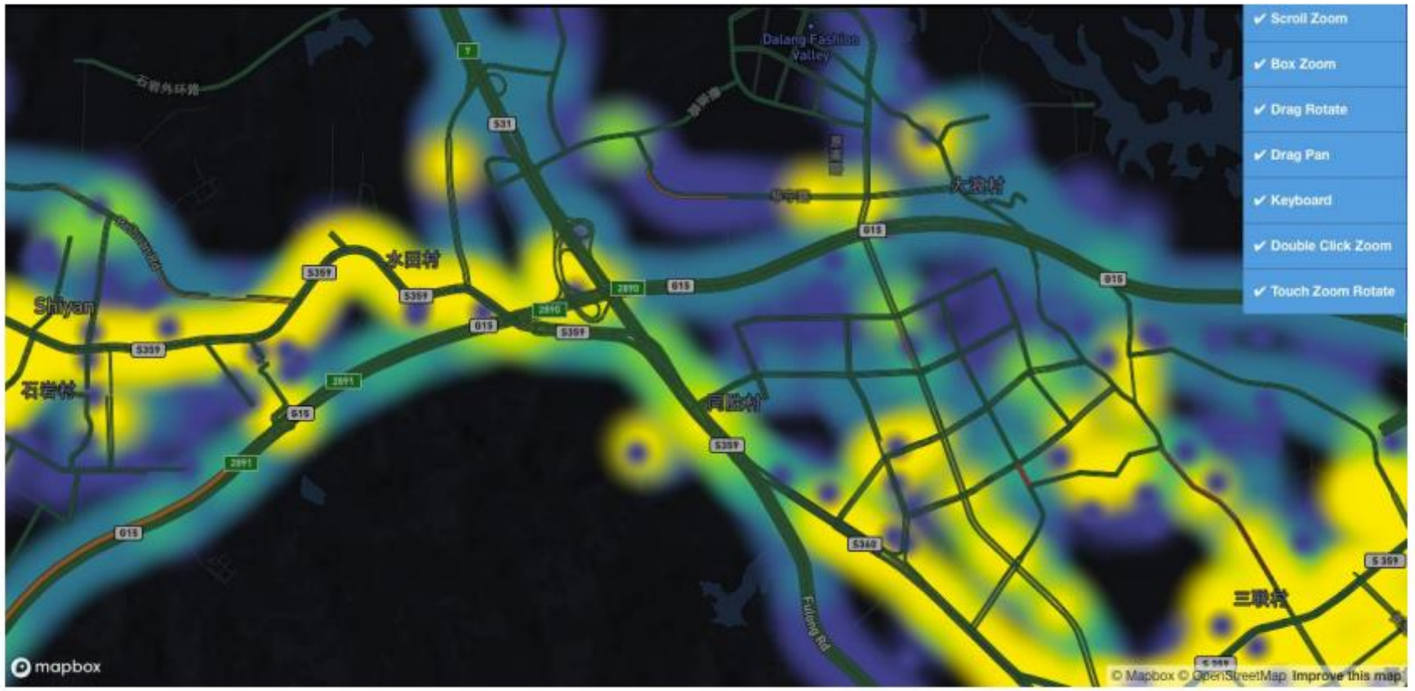


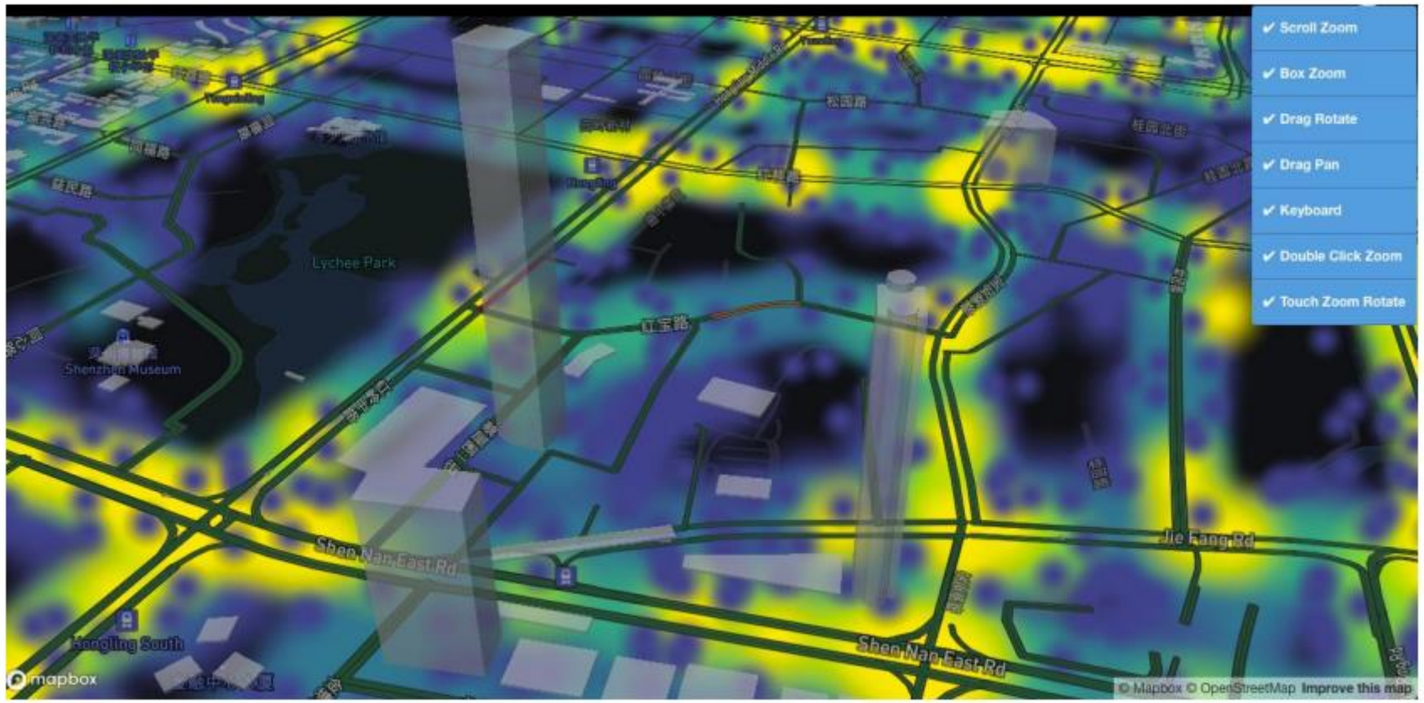
Yixian Zheng, Wenchao Wu, Huamin Qu, Chunyan Ma, and Lionel M. Ni. "Visual analysis of bi-directional movement behavior." In *Big Data (Big Data), 2015 IEEE International Conference on*, pp. 581-590. IEEE, 2015.

Outline

- Visualization of Trajectories
  - Visualization Where Each Trajectory has Its Own Markers
  - Density Plot Visualization
  - Visualization of Aggregated Trajectories
- Visualization of Flows Between Origins and Destinations
- Interactions

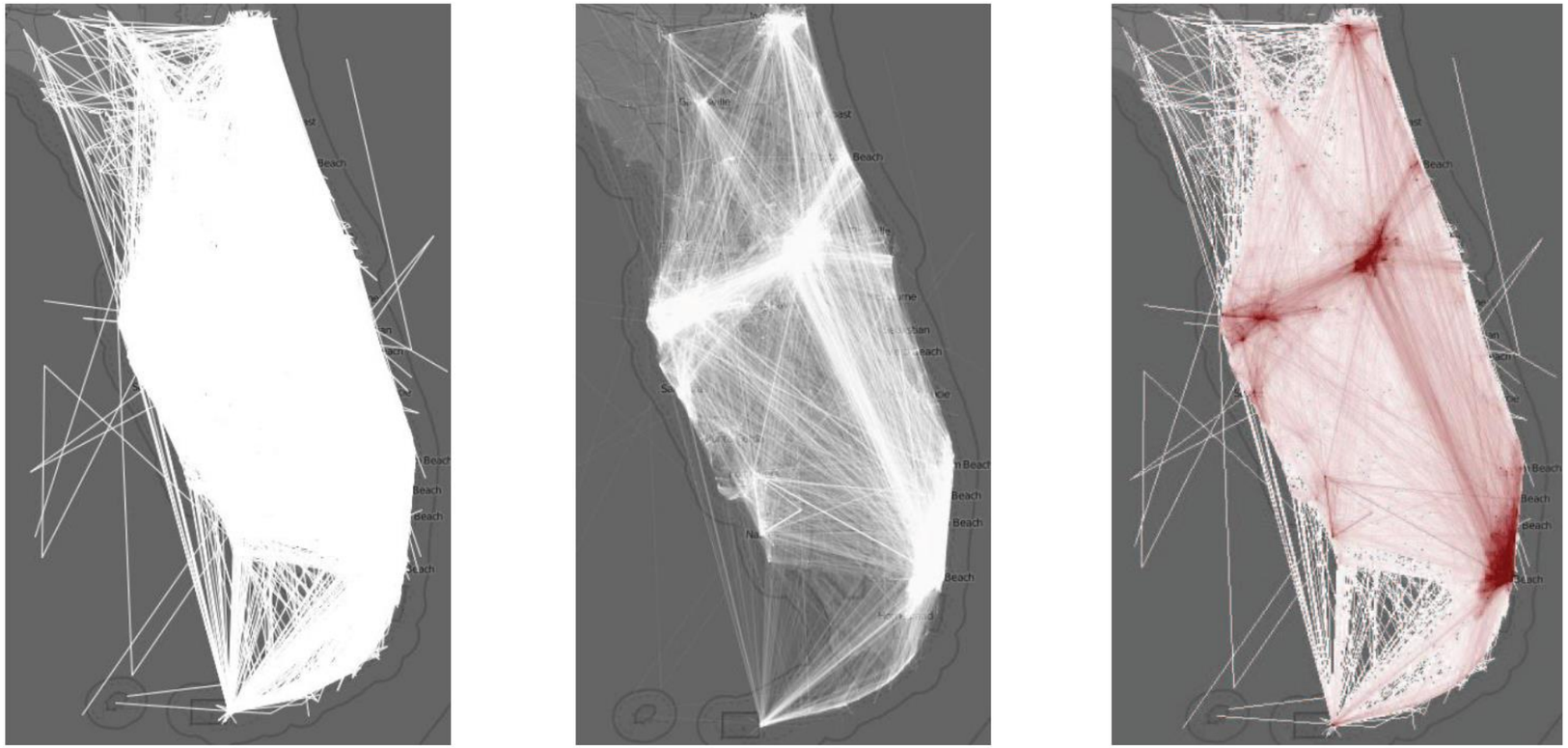
Animated Heatmap





Christian F. Huacón and Luke Pelegrin. "SURV: A system for massive urban data visualization." In *Undergraduate Research Technology Conference (URTC), 2017 IEEE MIT*, pp. 1-4. IEEE, 2017.

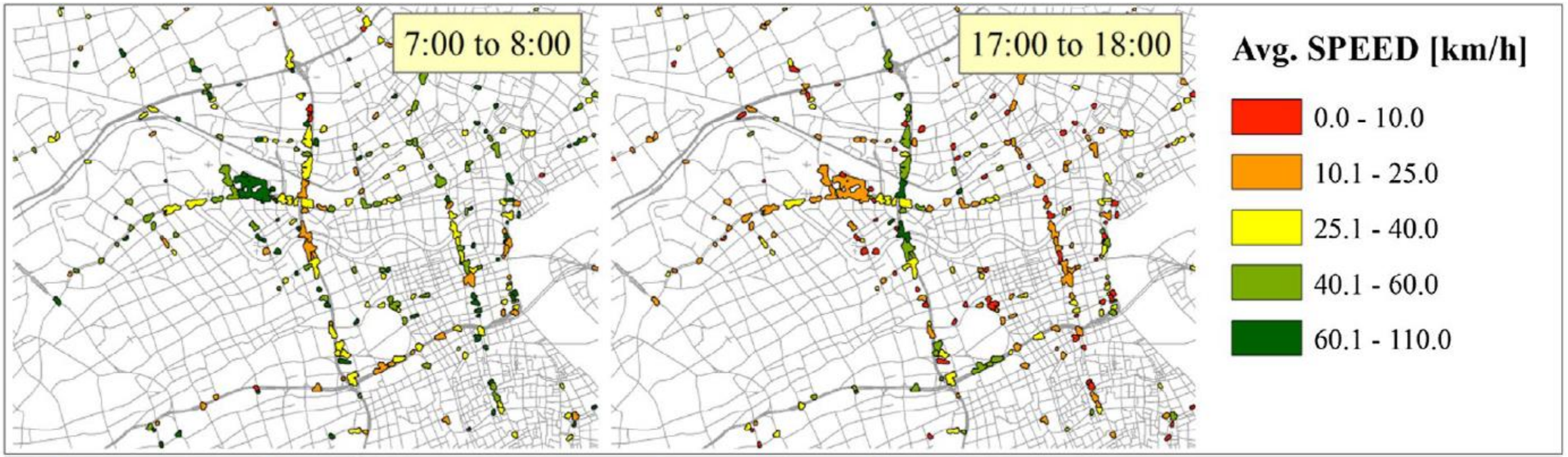
Edge Splatting



Trajectories drawn with full opacity (left), alpha-blending (center), and edge splatting (right). Pixel color in edge splatting reflects density of intersecting trajectories

Robert Krueger, Guodao Sun, Fabian Beck, Ronghua Liang, and Thomas Ertl. "TravelDiff: Visual comparison analytics for massive movement patterns derived from Twitter." In *Pacific Visualization Symposium (PacificVis), 2016 IEEE*, pp. 176-183. IEEE, 2016.

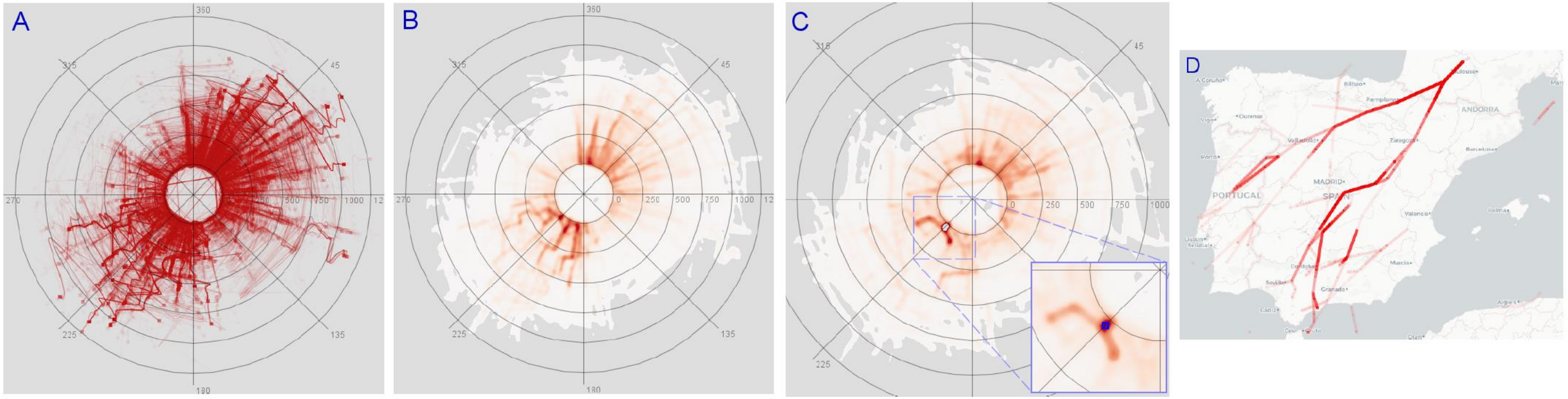
Density-Based Clusters



Polygons - convex hulls of density-based taxi trajectory intersection point clusters, which indicate regions of frequent taxi movement; Color - Average speed

Andreas Keler, Jukka M. Krisp, and Linfang Ding. "Detecting vehicle traffic patterns in urban environments using taxi trajectory intersection points." *Geo-spatial Information Science*20, no. 4 (2017): 333-344.

Artificial Space With Polar Coordinates



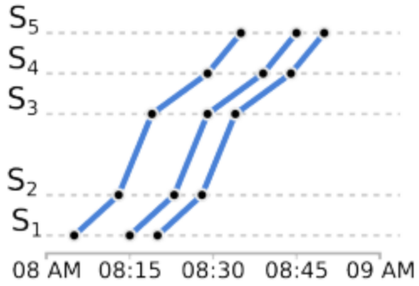
Angle - movement direction; Radius - distance from start point.
A: all planned flight trajectories; B: density map summarizing all planned trajectories; C: density map summarizing segments substituted by shorter paths in real flights; D: Trajectories crossing the hot spot in a geographic map.

Natalia Andrienko, Gennady Andrienko, Jose Manuel Cordero Garcia, and David Scarlatti. "Analysis of Flight Variability: a Systematic Approach." *IEEE transactions on visualization and computer graphics* (2018).

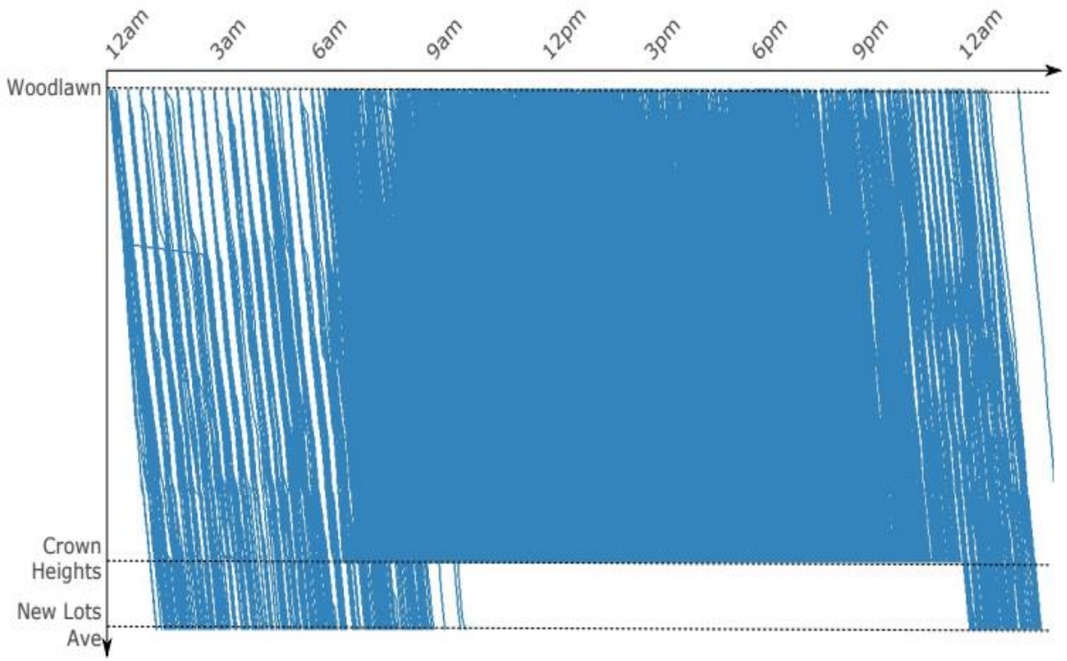
Density Map of Marey's Graph

S_1	S_2	S_3	S_4	S_5
8:05	8:13	8:19	8:29	8:35
8:15	8:23	8:29	8:39	8:45
8:20	8:28	8:34	8:44	8:50

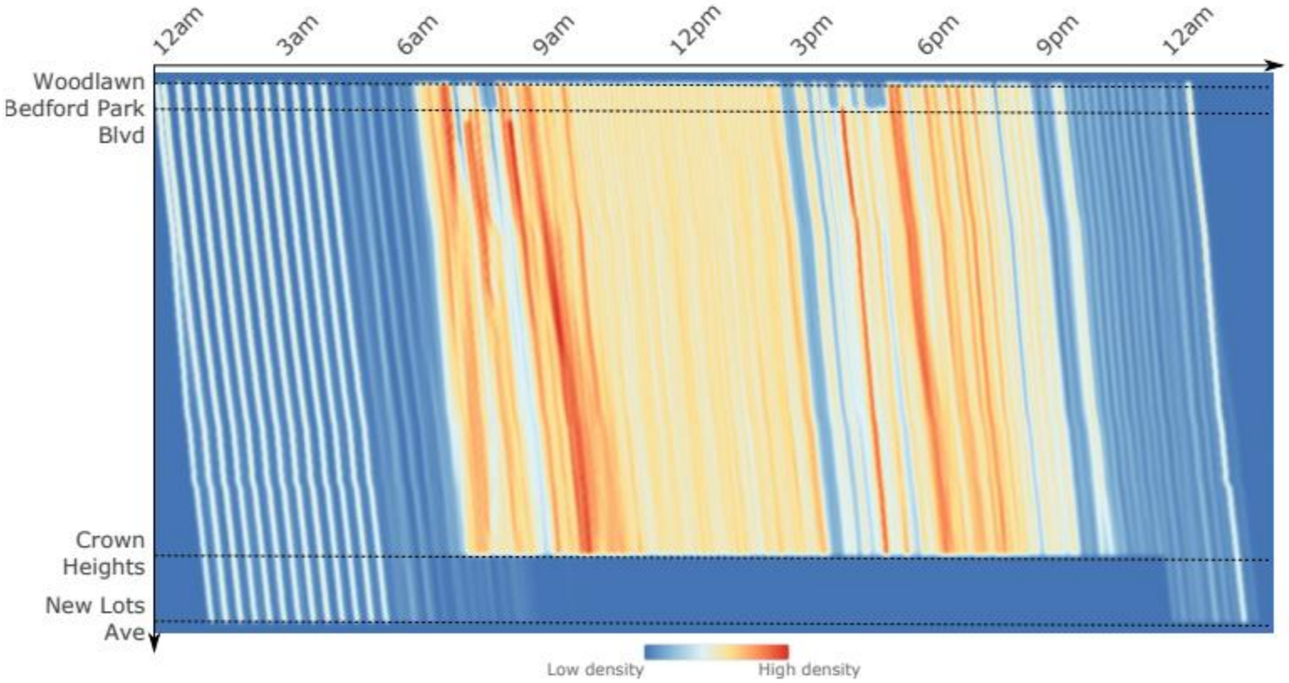
(a) Transportation Schedule



(b) Marey's Graph



(c) Original Marey's graph gets cluttered with a large number of trips



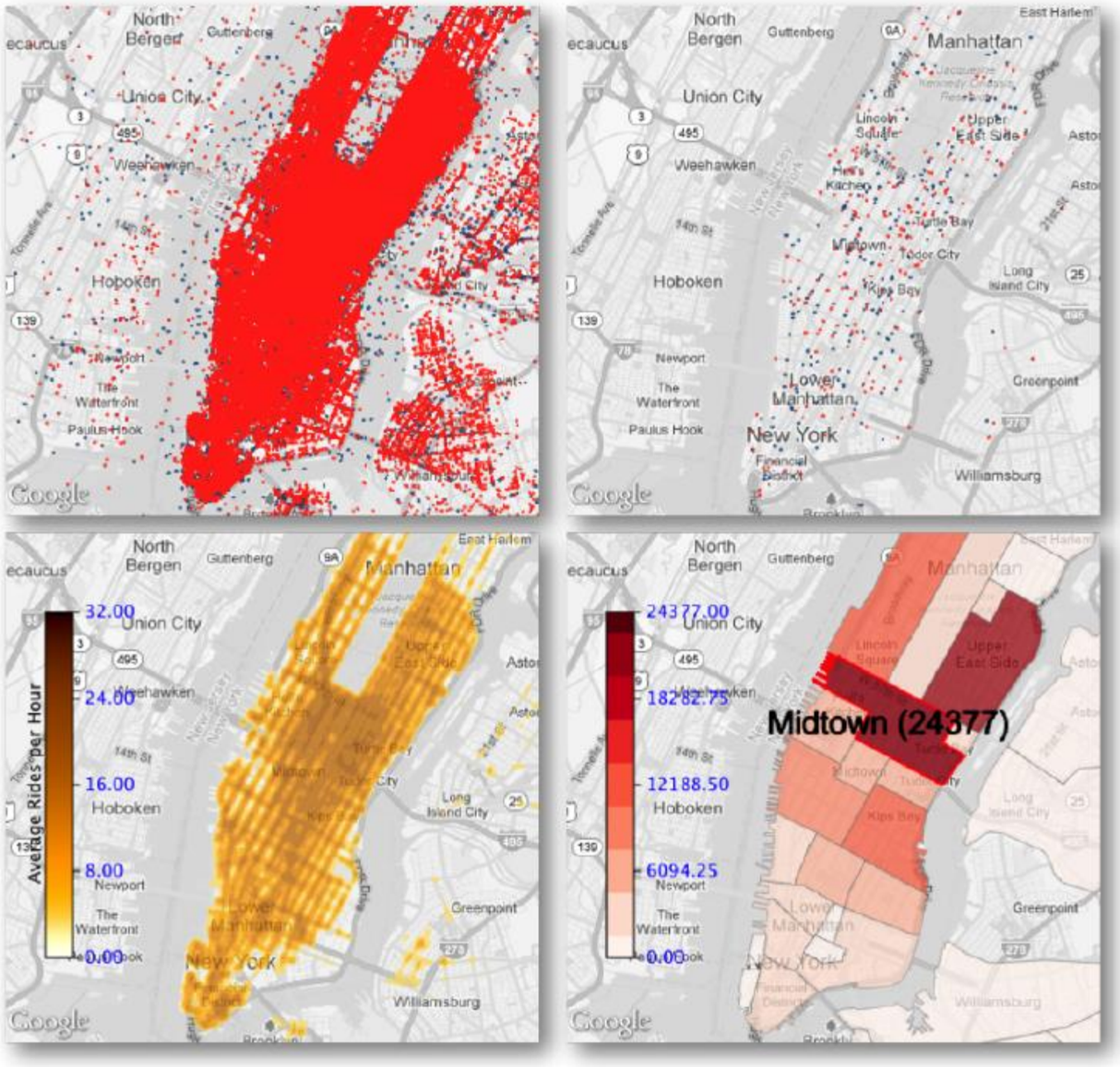
(d) Using Kernel Density Estimation on lines to reduce clutter

VIS 2018

Cesar Palomo, Zhan Guo, Cláudio T. Silva, and Juliana Freire. "Visually exploring transportation schedules." *IEEE transactions on visualization and computer graphics* 22, no. 1 (2016): 170-179.

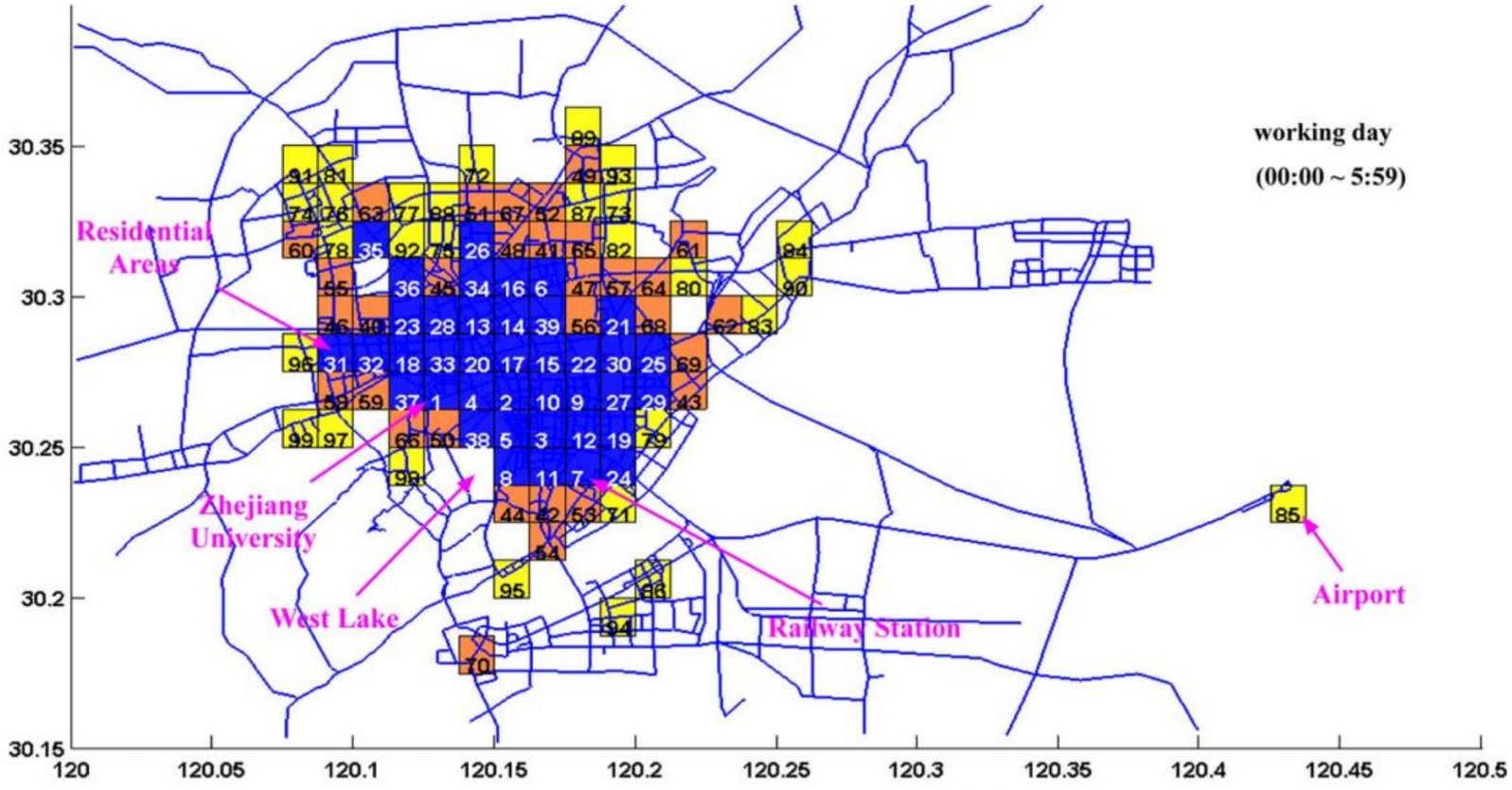
Point Cloud, Sampling, Heat Map, Grid Map

Visualizations of taxi pickup and dropoff locations
Top left: Point cloud;
Top right: Hierarchical sampling of the original point cloud;
Bottom left: Density heat map;
Bottom right: Grid map of well-defined regions



Nivan Ferreira, Jorge Poco, Huy T. Vo, Juliana Freire, and Cláudio T. Silva. "Visual exploration of big spatio-temporal urban data: A study of new york city taxi trips." *IEEE Transactions on Visualization and Computer Graphics* 19, no. 12 (2013): 2149-2158.

Gridmap, Ranking, Static Scenario



Top 99 pickup locations. Blue: ranked 1-39; Orange: ranked 40-70; Yellow: ranked 71-99

Zhang, Daqing, Lin Sun, Bin Li, Chao Chen, Gang Pan, Shijian Li, and Zhaohui Wu. "Understanding taxi service strategies from taxi GPS traces." *IEEE Transactions on Intelligent Transportation Systems* 16, no. 1 (2015): 123-135.

Cubes

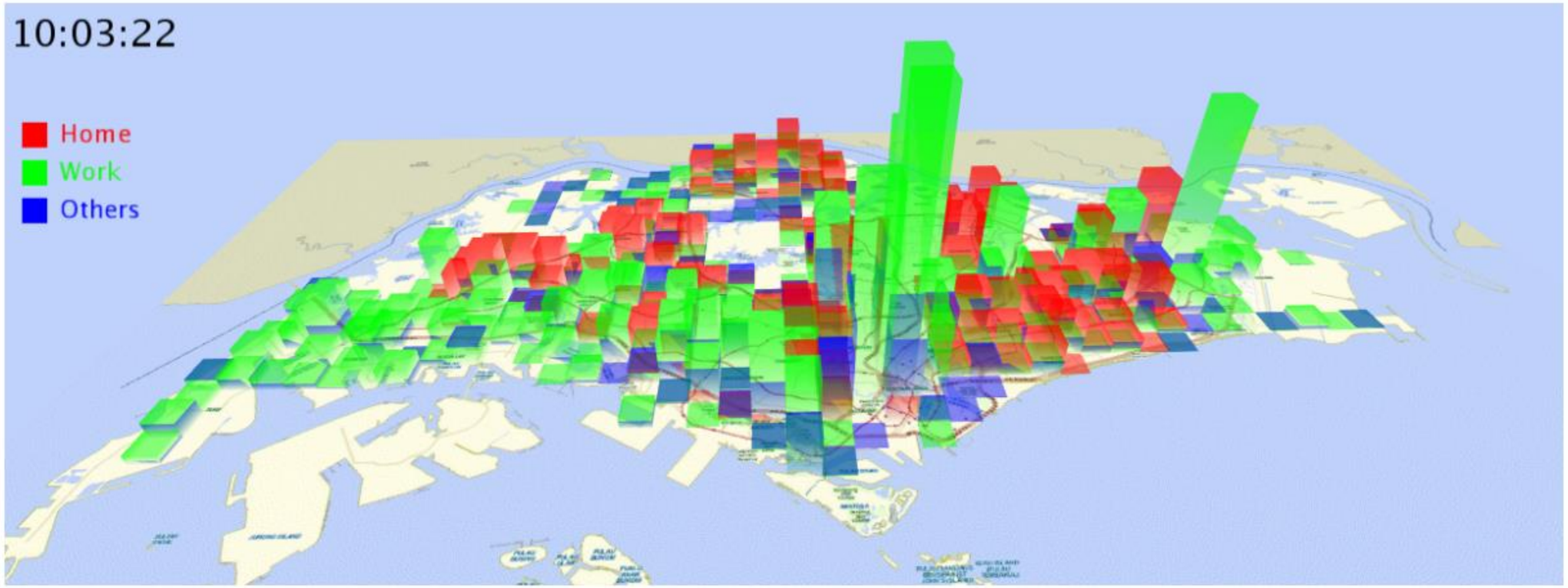


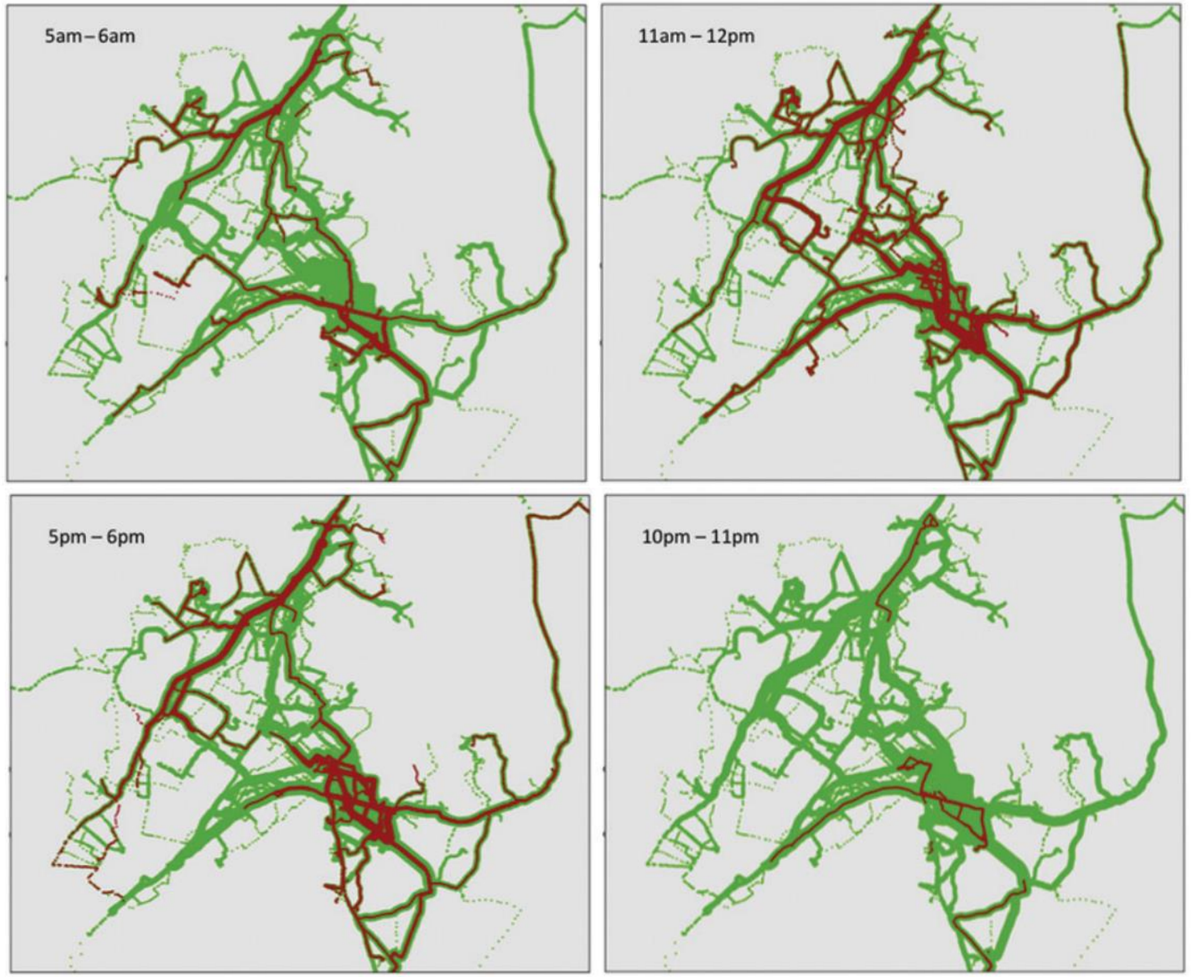
Figure 1: Where people live, work and play on a weekday morning around 10AM in Singapore?

Yu, Liang, et al. "iVizTRANS: Interactive visual learning for home and work place detection from massive public transportation data." *Visual Analytics Science and Technology (VAST), 2015 IEEE Conference on*. IEEE, 2015.

Outline

- Visualization of Trajectories
  - Visualization Where Each Trajectory has Its Own Markers
  - Density Plot Visualization
  - Visualization of Aggregated Trajectories
- Visualization of Flows Between Origins and Destinations
- Interactions

Dots

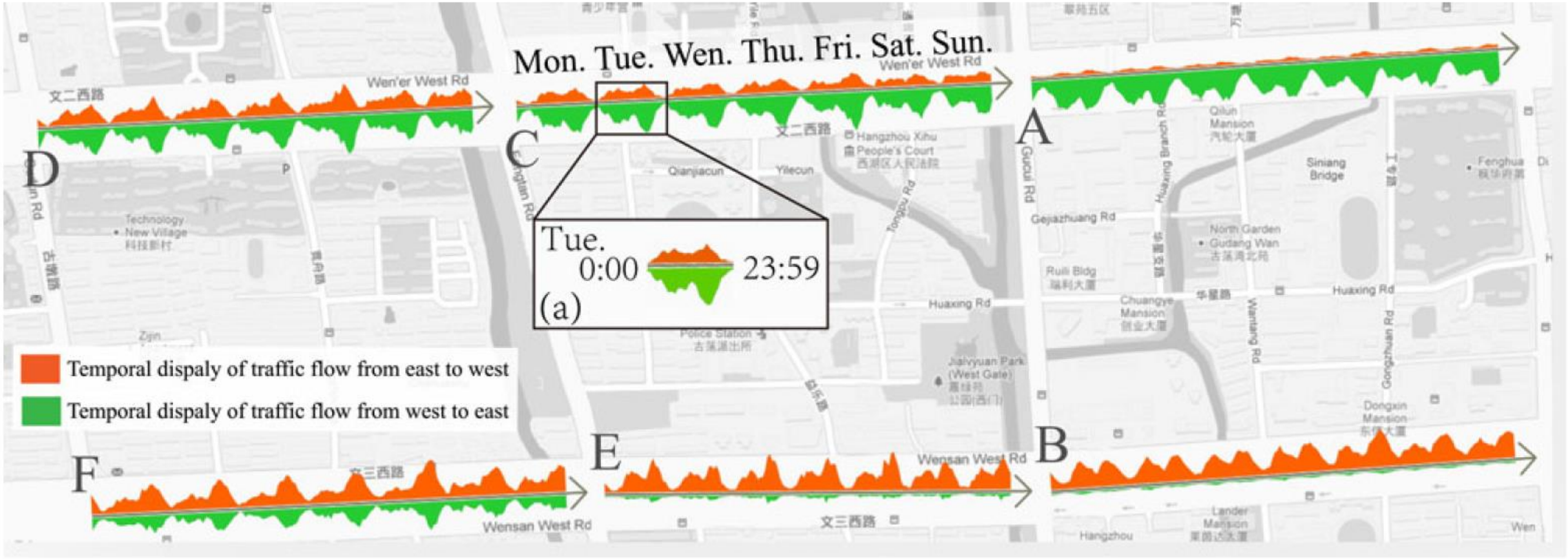


Dots - representative points of GPS locations; size - # of trajectories
Green: total trajectories; Red: trajectories in a selected time frame

VIS 2018

Diansheng Guo, Shufan Liu, and Hai Jin. "A graph-based approach to vehicle trajectory analysis." *Journal of Location Based Services* 4, no. 3-4 (2010): 183-199.

Glyphs

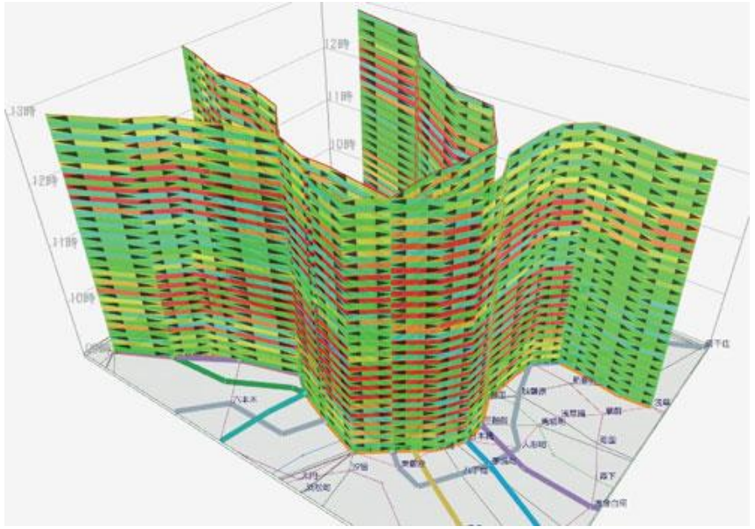


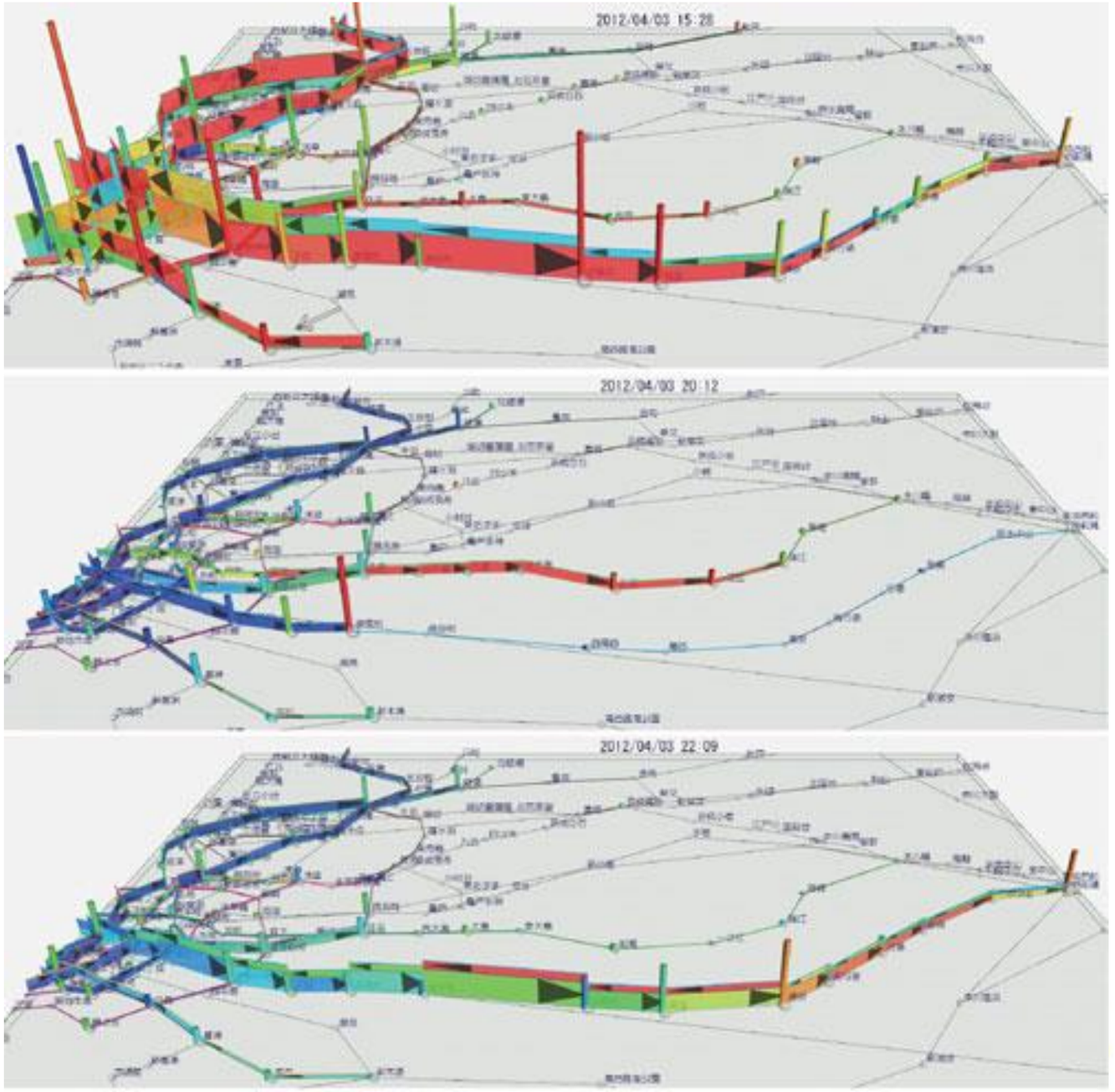
Glyphs representing temporal information of traffic flow on the roads

VIS 2018

Guodao Sun, Ronghua Liang, Huamin Qu, and Yingcai Wu. "Embedding spatio-temporal information into maps by route-zooming." *IEEE Transactions on Visualization & Computer Graphics* 5 (2017): 1506-1519.

AnimatedRibbon

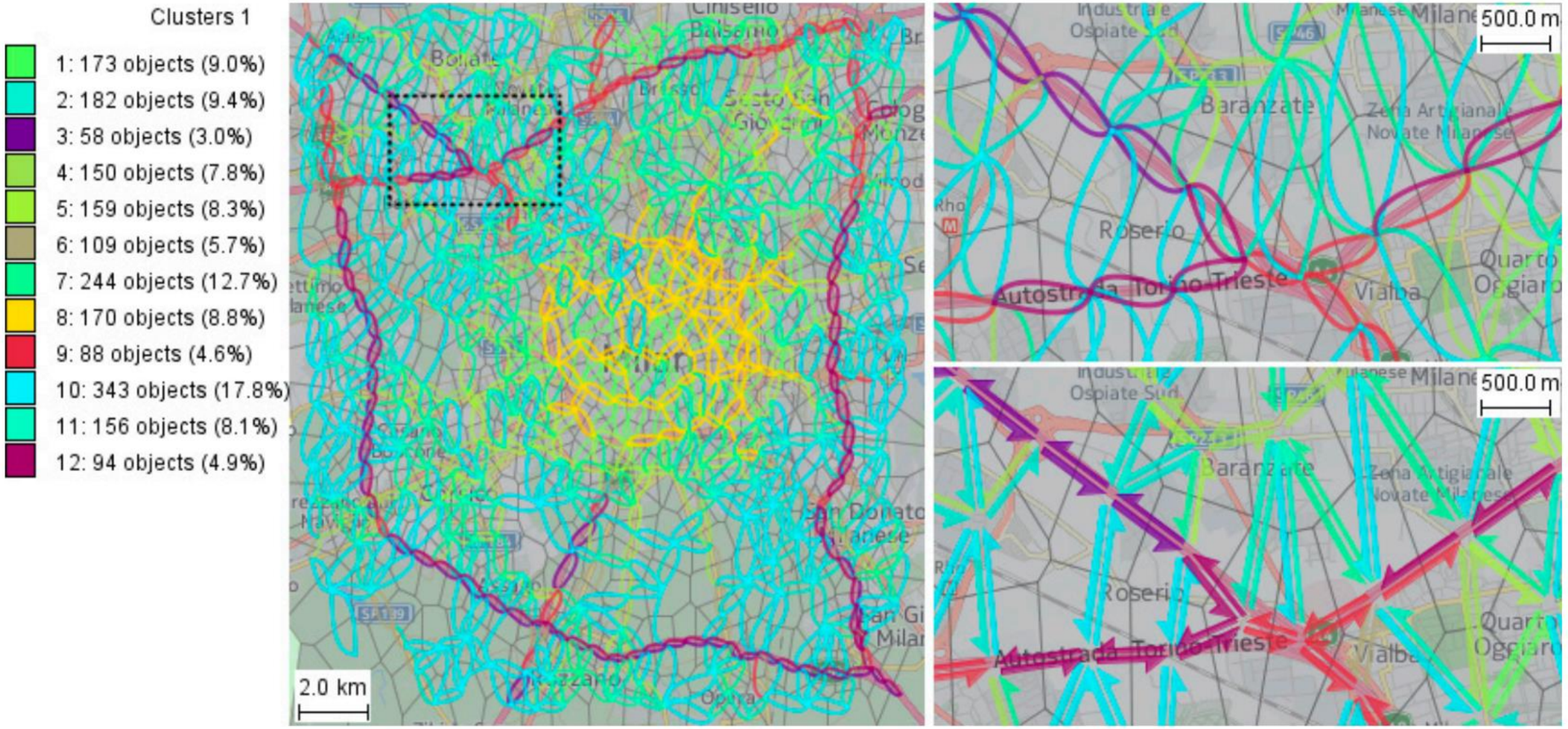




Left: 3D Wall Map.
Right: AnimatedRibbon. Height and color represent two attributes of traffic

Itoh, Masahiko, Daisaku Yokoyama, Masashi Toyoda, Yoshimitsu Tomita, Satoshi Kawamura, and Masaru Kitsuregawa. "Visual Exploration of Changes in Passenger Flows and Tweets on Mega-City Metro Network." *IEEE Trans. Big Data* 2, no. 1 (2016): 85-99.

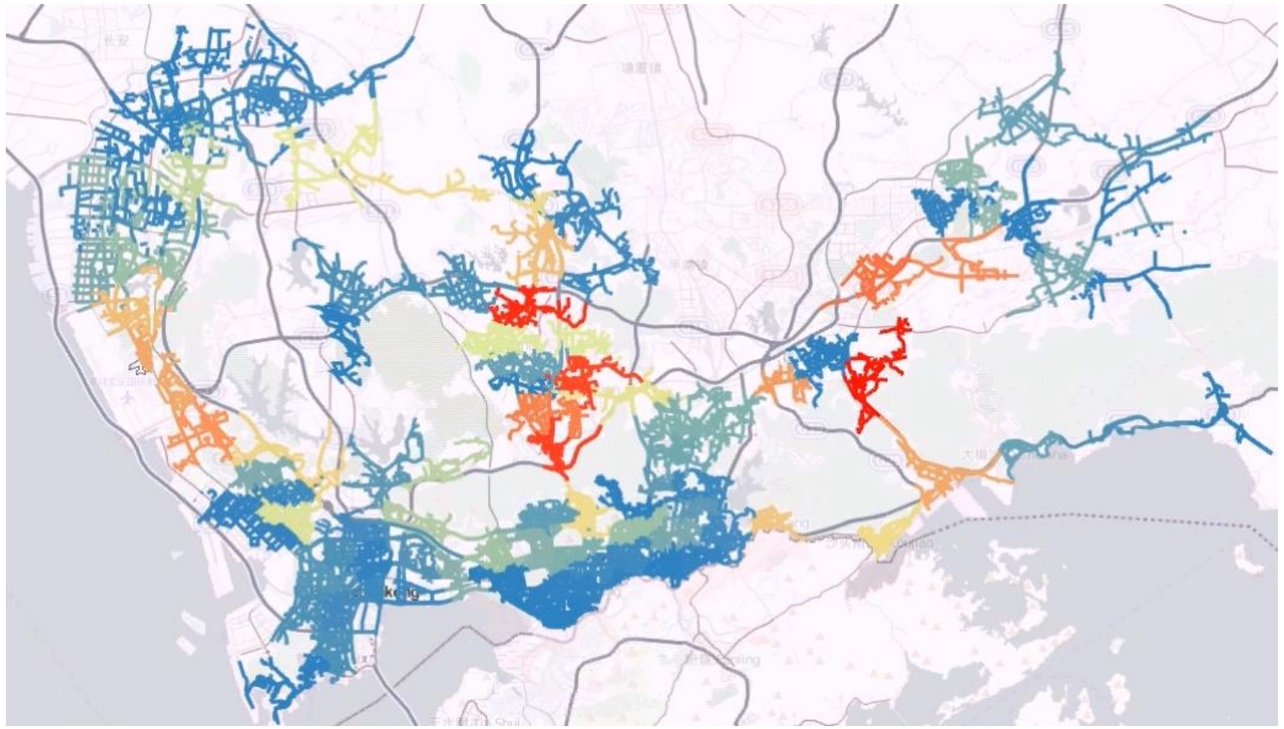
Flow Map and Voronoi Polygons



Links with similar colors have similar traffic intensities and mean speeds.

Natalia Andrienko, Gennady Andrienko, and Salvatore Rinzivillo. "Exploiting spatial abstraction in predictive analytics of vehicle traffic." *ISPRS International Journal of Geo-Information* 4, no. 2 (2015): 591-606.

Lines, Derived Values



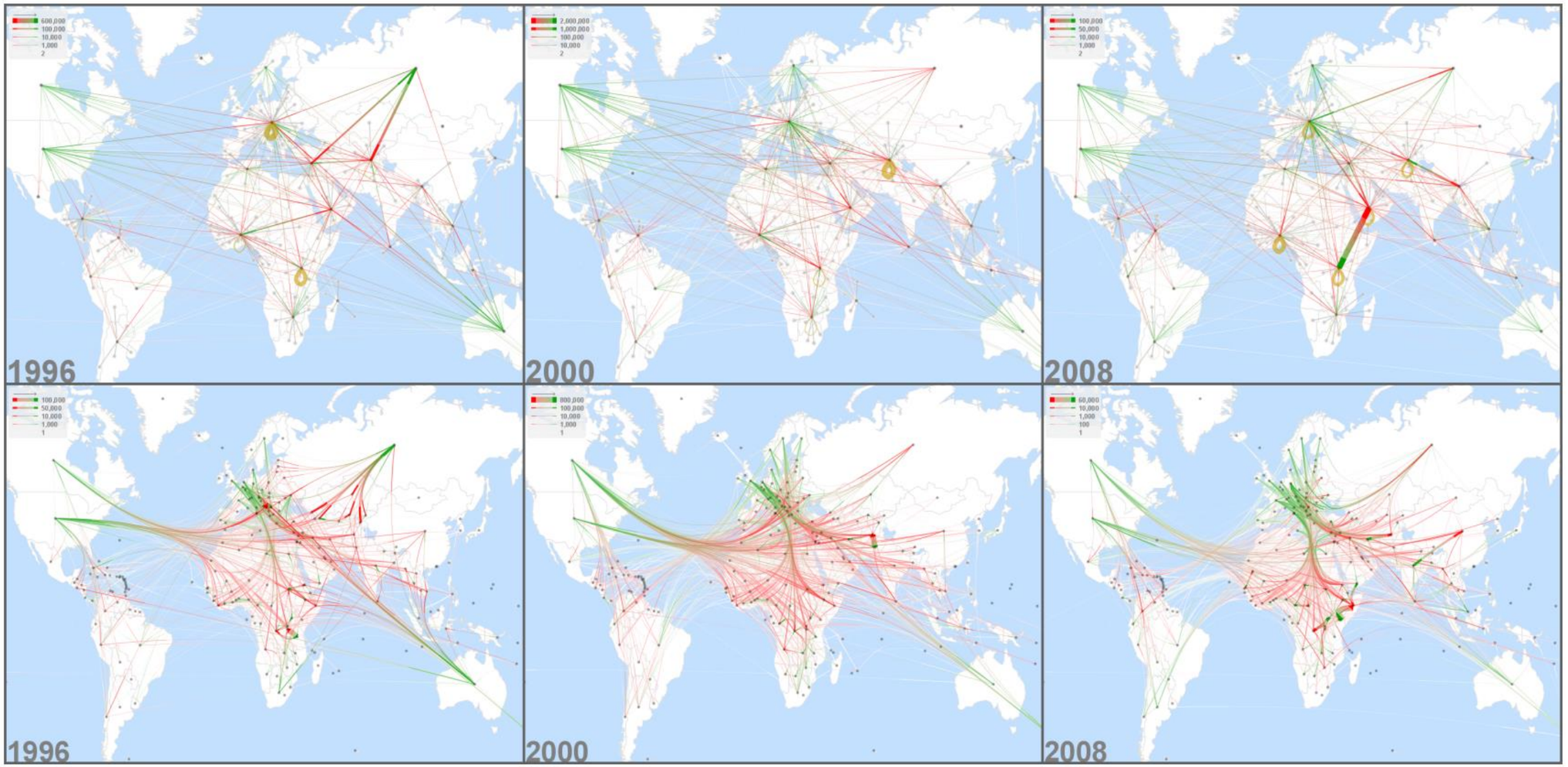
Colors indicate how important a road segment is as a backbone on fast paths (red – high, blue – low). This information is calculated based on real travel time of the trajectories on the roads.

Xiaoke Huang, Ye Zhao, Chao Ma, Jing Yang, Xinyue Ye, and Chong Zhang. "TrajGraph: A graph-based visual analytics approach to studying urban network centralities using taxi trajectory data." *IEEE transactions on visualization and computer graphics* 22, no. 1 (2016): 160-169.

Outline

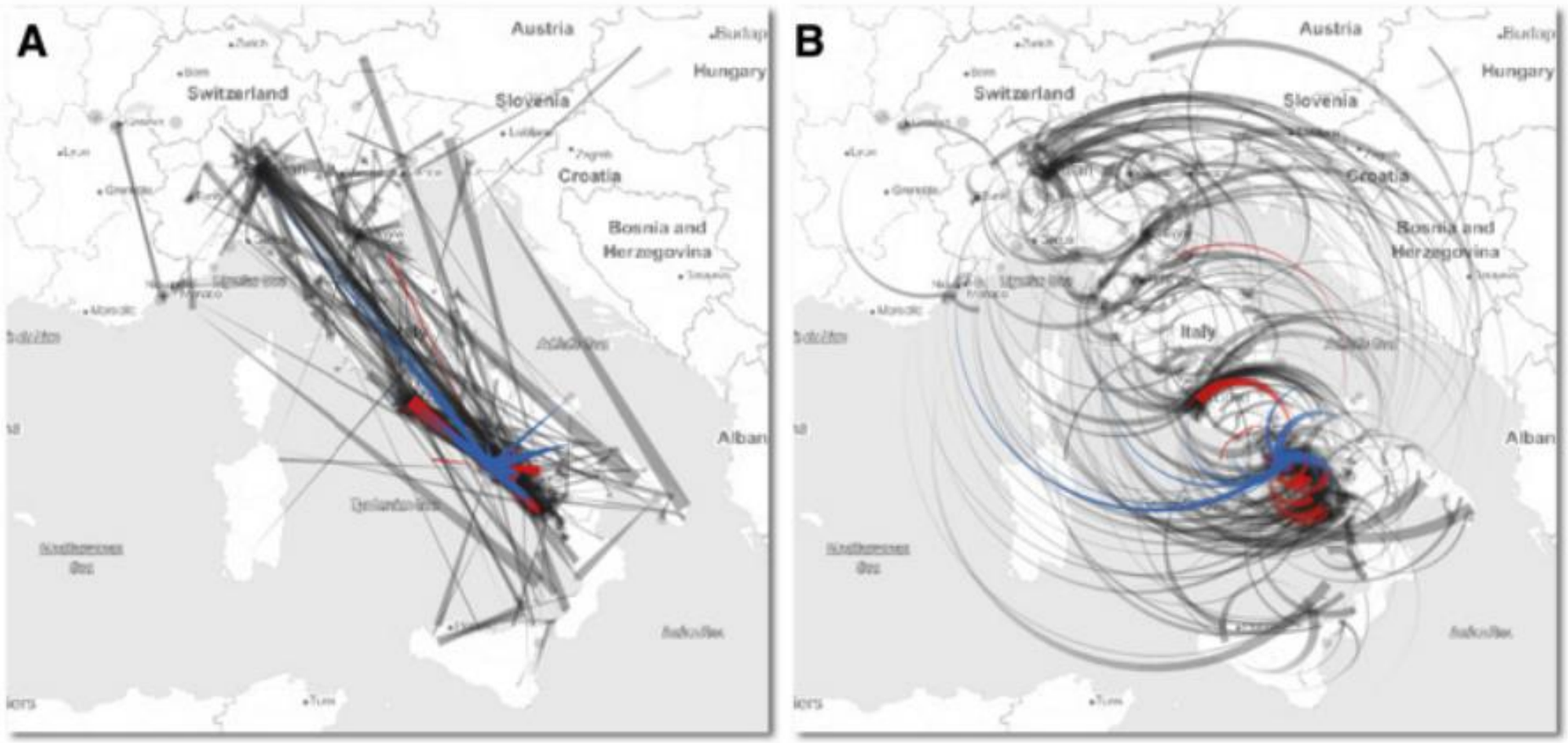
- Visualization of Trajectories
  - Visualization Where Each Trajectory has Its Own Markers
  - Density Plot Visualization
  - Visualization of Aggregated Trajectories
- Visualization of Flows Between Origins and Destinations
- Interactions

Flow Map With and Without Edge Bundling



Ilya Boyandin, Enrico Bertini, and Denis Lalanne. "Using flow maps to explore migrations over time." In *Geospatial Visual Analytics Workshop in conjunction with The 13th AGILE International Conference on Geographic Information Science*, vol. 2, no. 3. 2010.

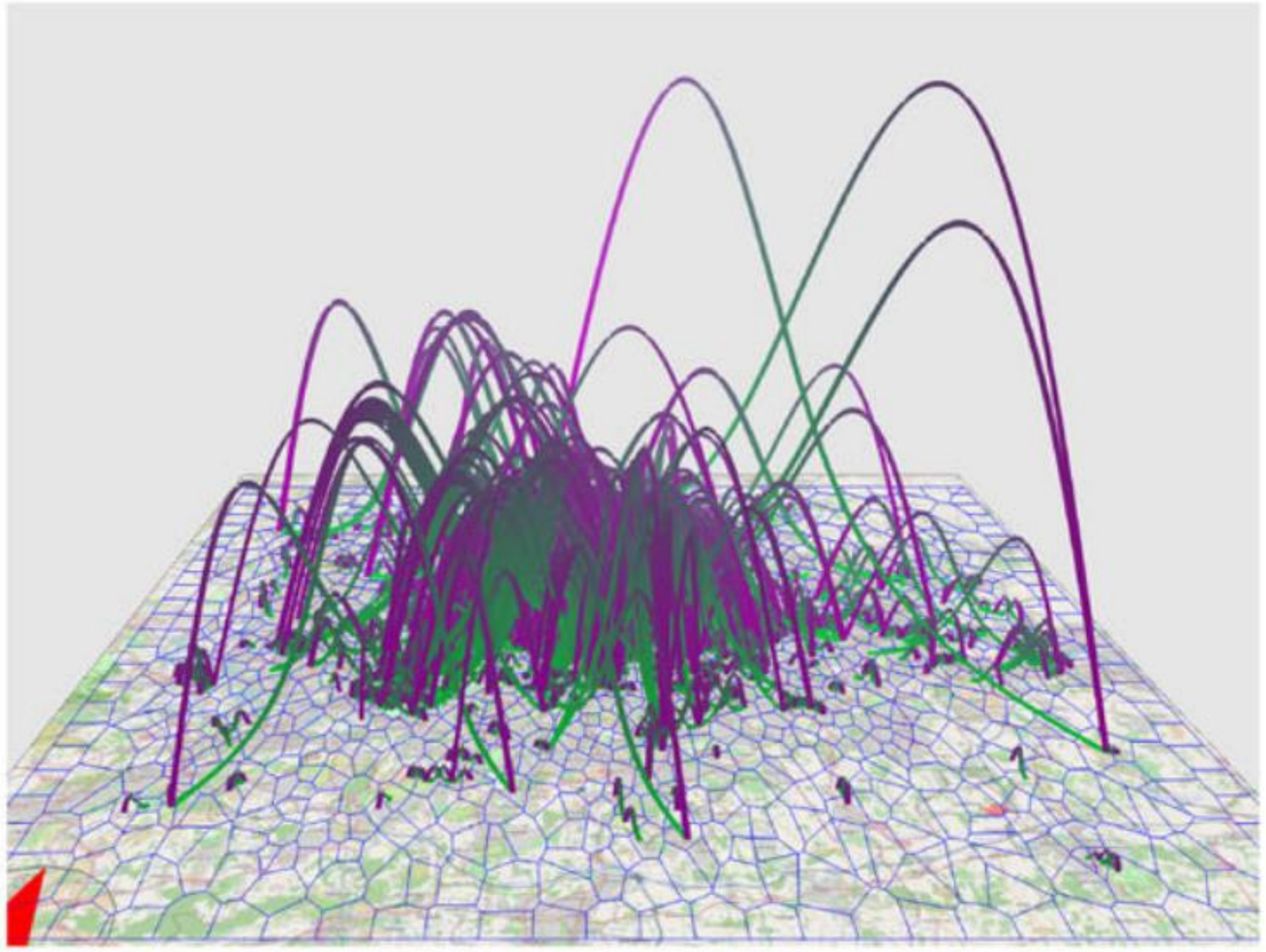
Flow Map with Arcs



Arc representations separate short flows from long flows

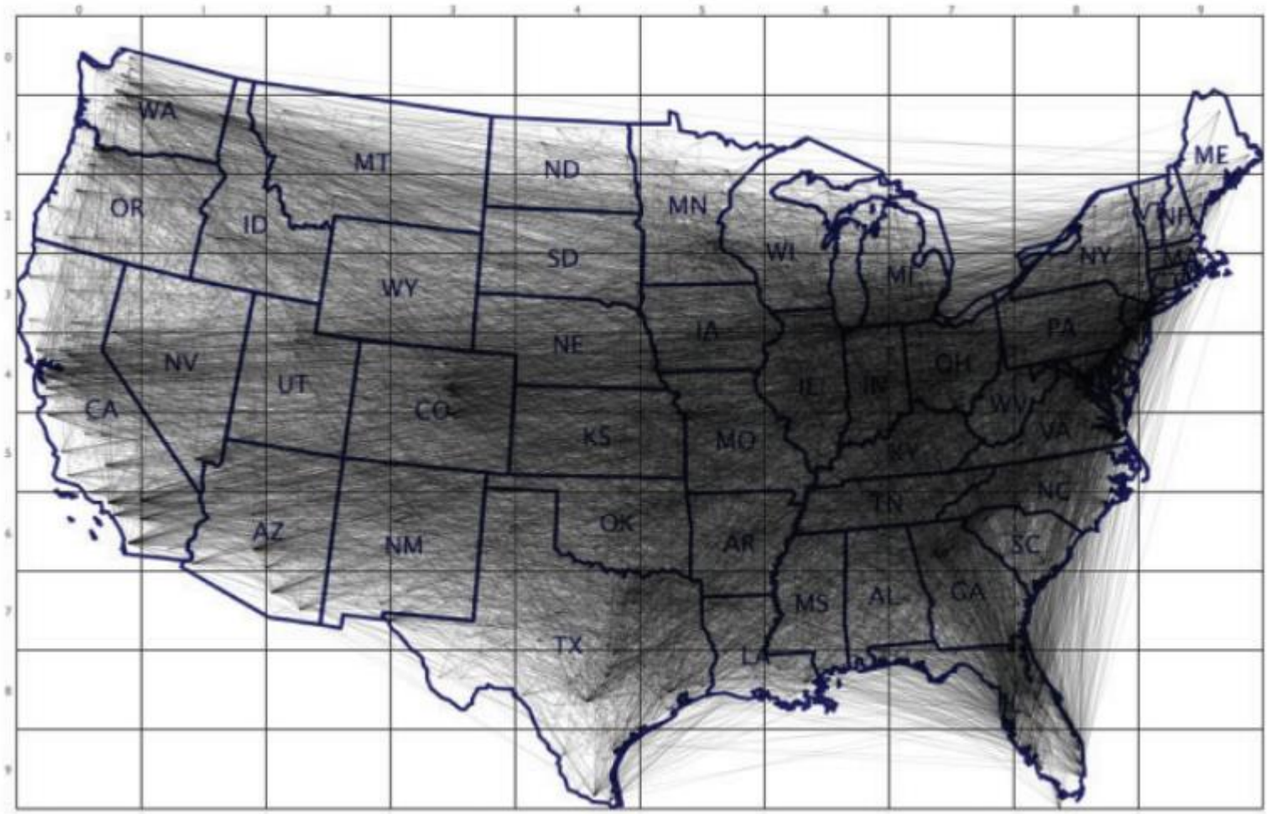
Alvin Chua, Ernesto Marcheggiani, Loris Servillo, and Andrew Vande Moere. "FlowSampler: Visual analysis of urban flows in geolocated social media data." In *International Conference on Social Informatics*, pp. 5-17. Springer, Cham, 2014.

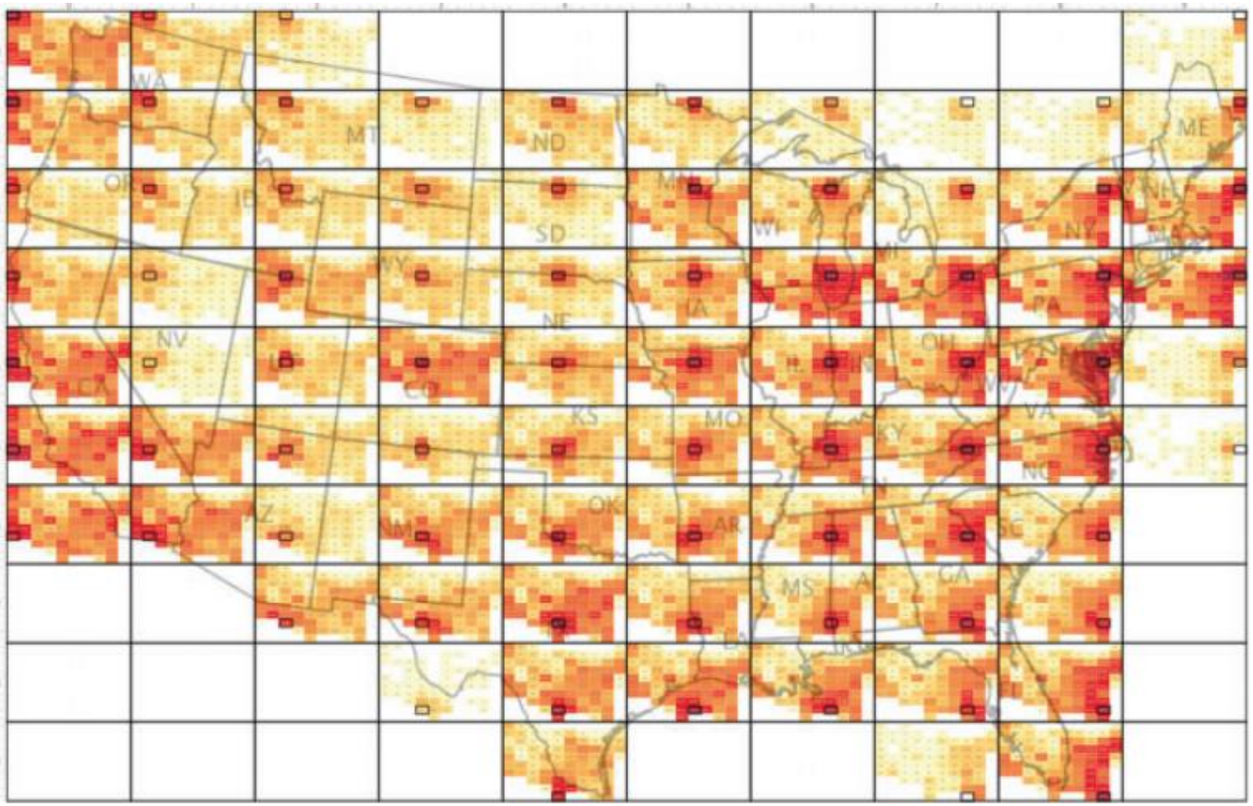
3D Flow Map



Katerina Vrotsou, Georg Fuchs, Natalia Andrienko, and Gennady Andrienko. "An Interactive Approach for Exploration of Flows Through Direction-Based Filtering." *Journal of Geovisualization and Spatial Analysis* 1, no. 1-2 (2017): 1.

OD Maps (Gridded Two-Level Spatial Treemap)



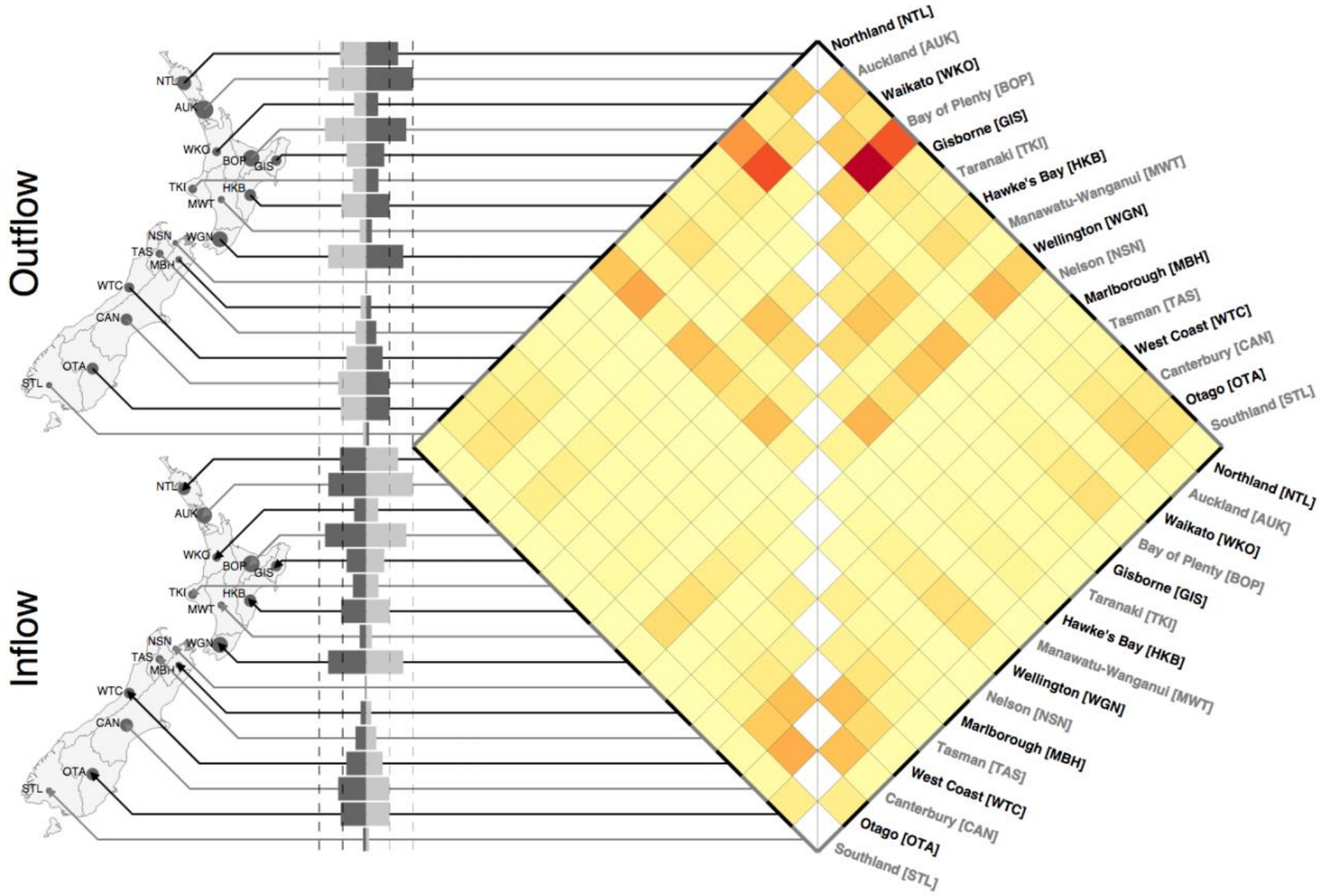


Left: Vector flow map;
Right: OD maps. Large grid cells represent origin locations. Density maps of their destinations are drawn within them.

VIS 2018

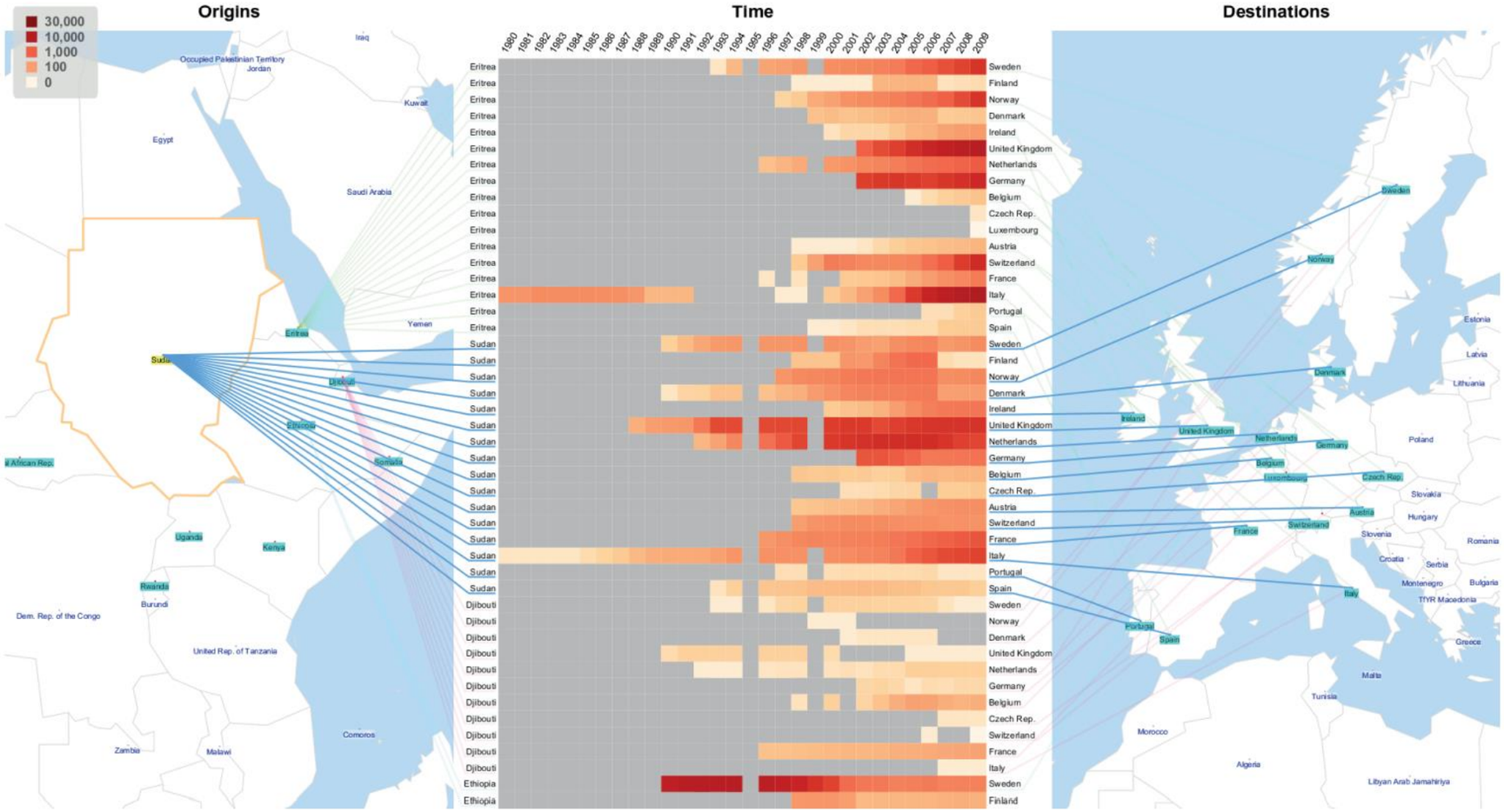
Jo Wood, Jason Dykes, and Aidan Slingsby. "Visualisation of origins, destinations and flows with OD maps." *The Cartographic Journal* 47, no. 2 (2010): 117-129.

Map + OD Matrix



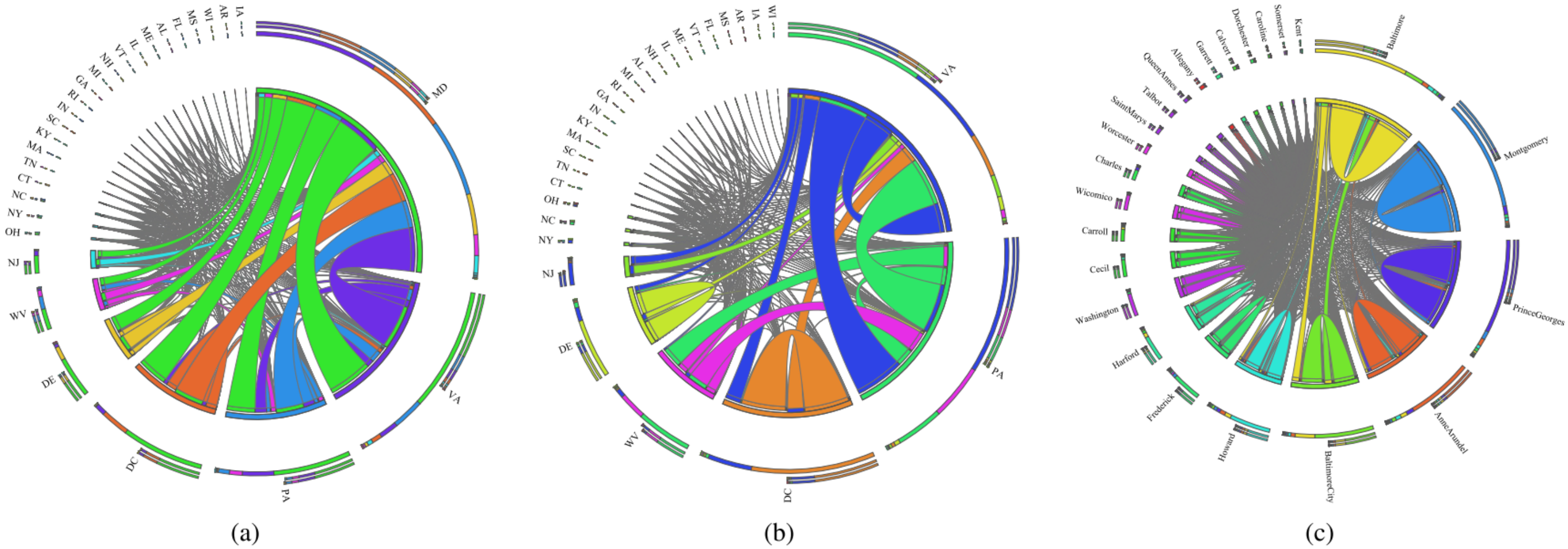
Yalong Yang, Tim Dwyer, Sarah Goodwin, and Kim Marriott. "Many-to-many geographically-embedded flow visualisation: an evaluation." *IEEE transactions on visualization and computer graphics* 23, no. 1 (2017): 411-420.

Map + Matrix + Map



Ilya Boyandin, Enrico Bertini, Peter Bak, and Denis Lalanne. "Flowstrates: An approach for visual exploration of temporal origin-destination data." In *Computer Graphics Forum*, vol. 30, no. 3, pp. 971-980. Oxford, UK: Blackwell Publishing Ltd, 2011.

Circular Flow Map



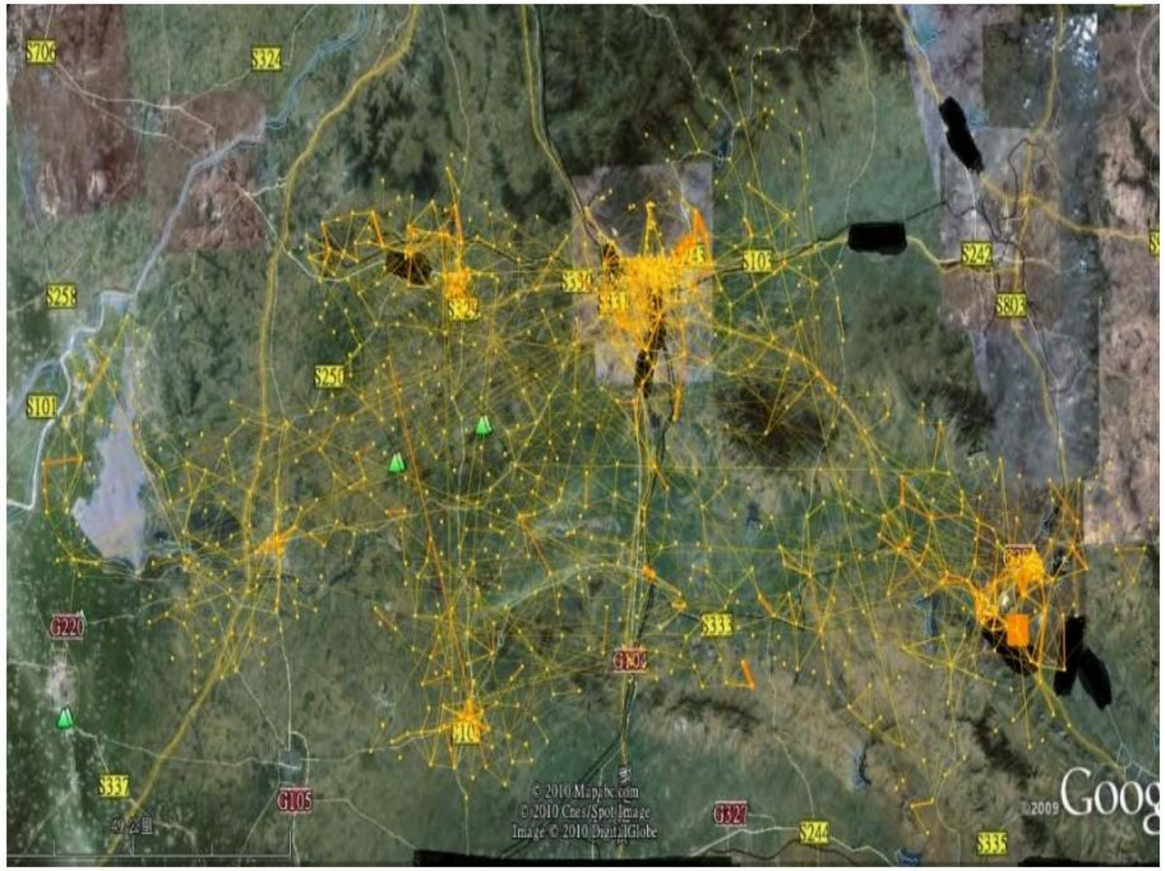
(a) (b) (c)

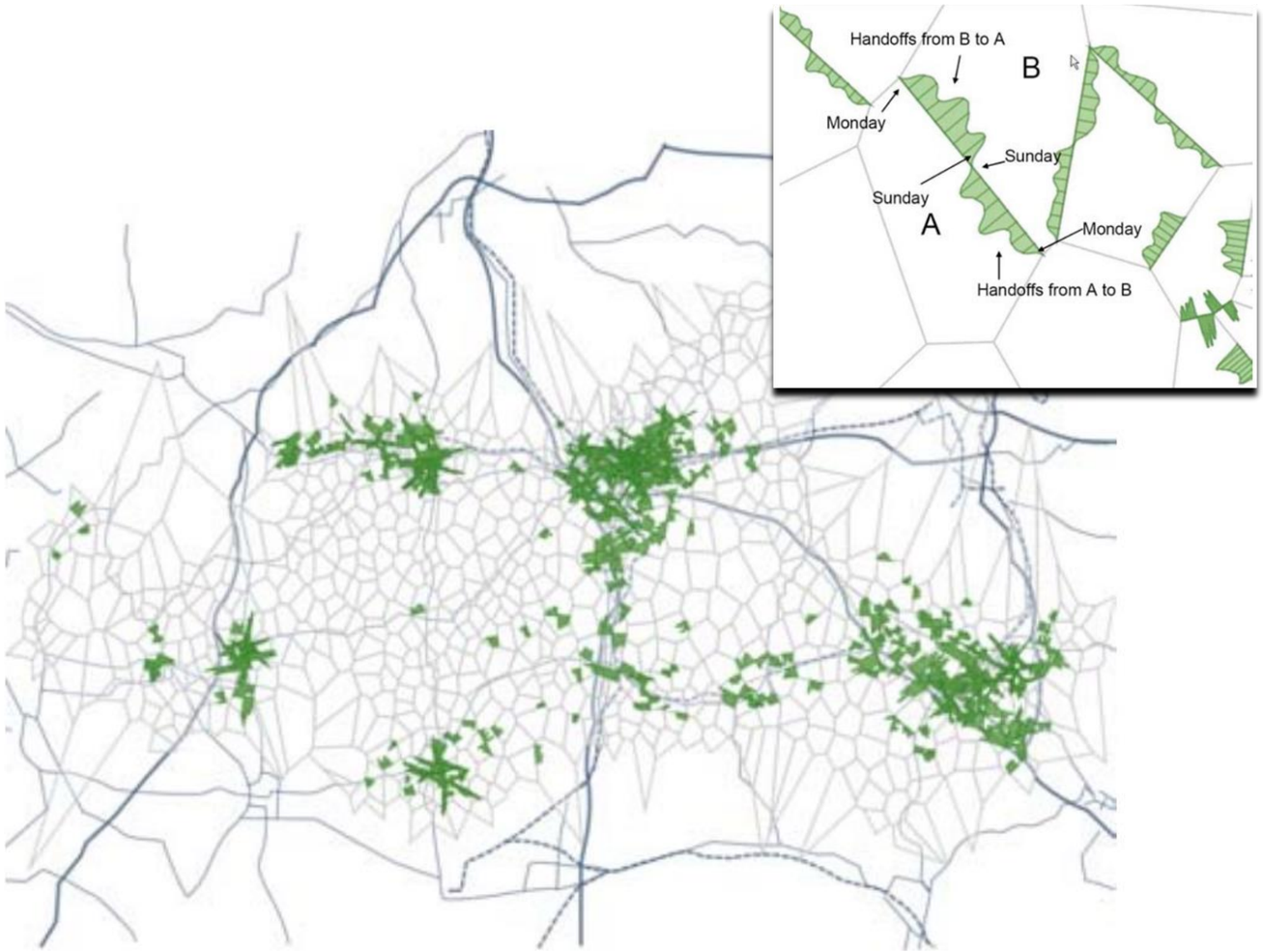
(a) Trips between MD and other states. (b) Trips traversing MD. (c) Trips within and between counties in MD

VIS 2018

N. Marković, P. Sekuła, Z. Vander Laan, G. Andrienko and N. Andrienko, "Applications of Trajectory Data From the Perspective of a Road Transportation Agency: Literature Review and Maryland Case Study," in *IEEE Transactions on Intelligent Transportation Systems*. doi: 10.1109/TITS.2018.2843298

Glyphs, Voronoi Polygons, Dynamic Scenario



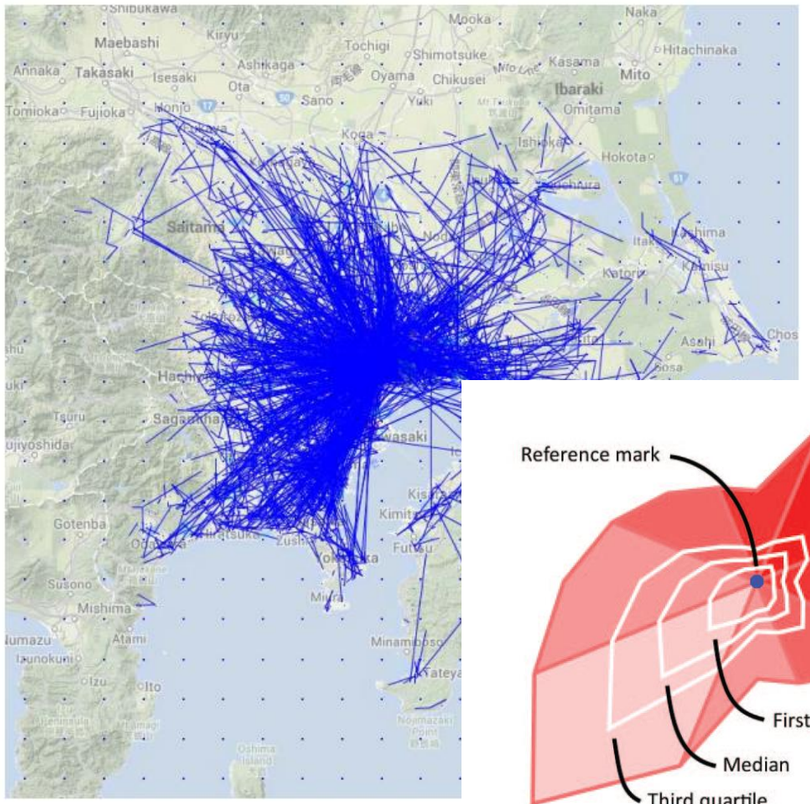


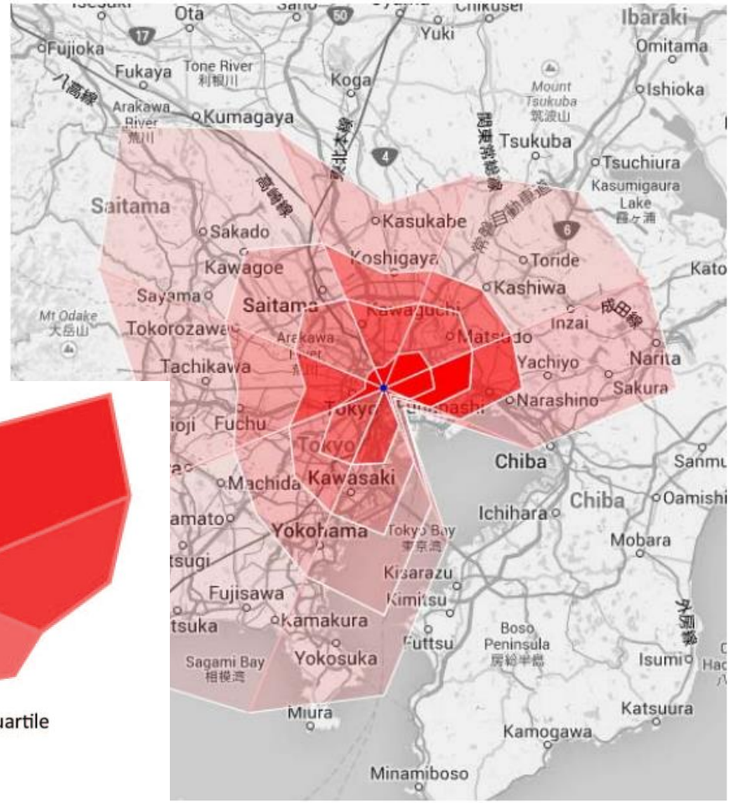
Left: Trajectories as straight lines; Right: Glyphs encode traffic between adjacent regions

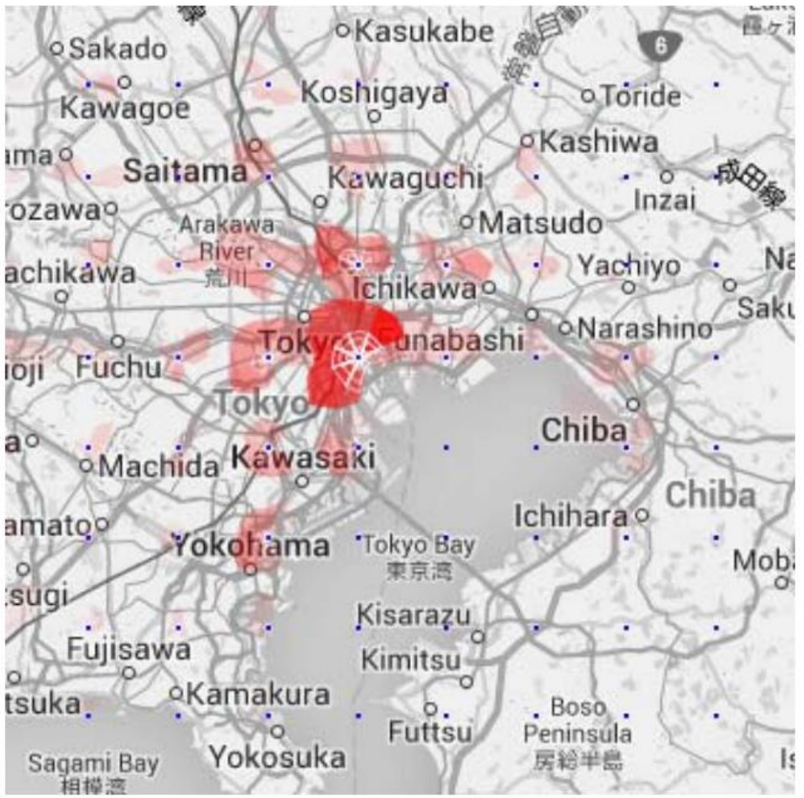
VIS 2018

Jiansu Pu, Panpan Xu, Huamin Qu, Weiwei Cui, Siyuan Liu, and Lionel Ni. "Visual analysis of people's mobility pattern from mobile phone data." In *Proceedings of the 2011 Visual Information Communication-International Symposium*, p. 13. ACM, 2011.

Amoeba Representation





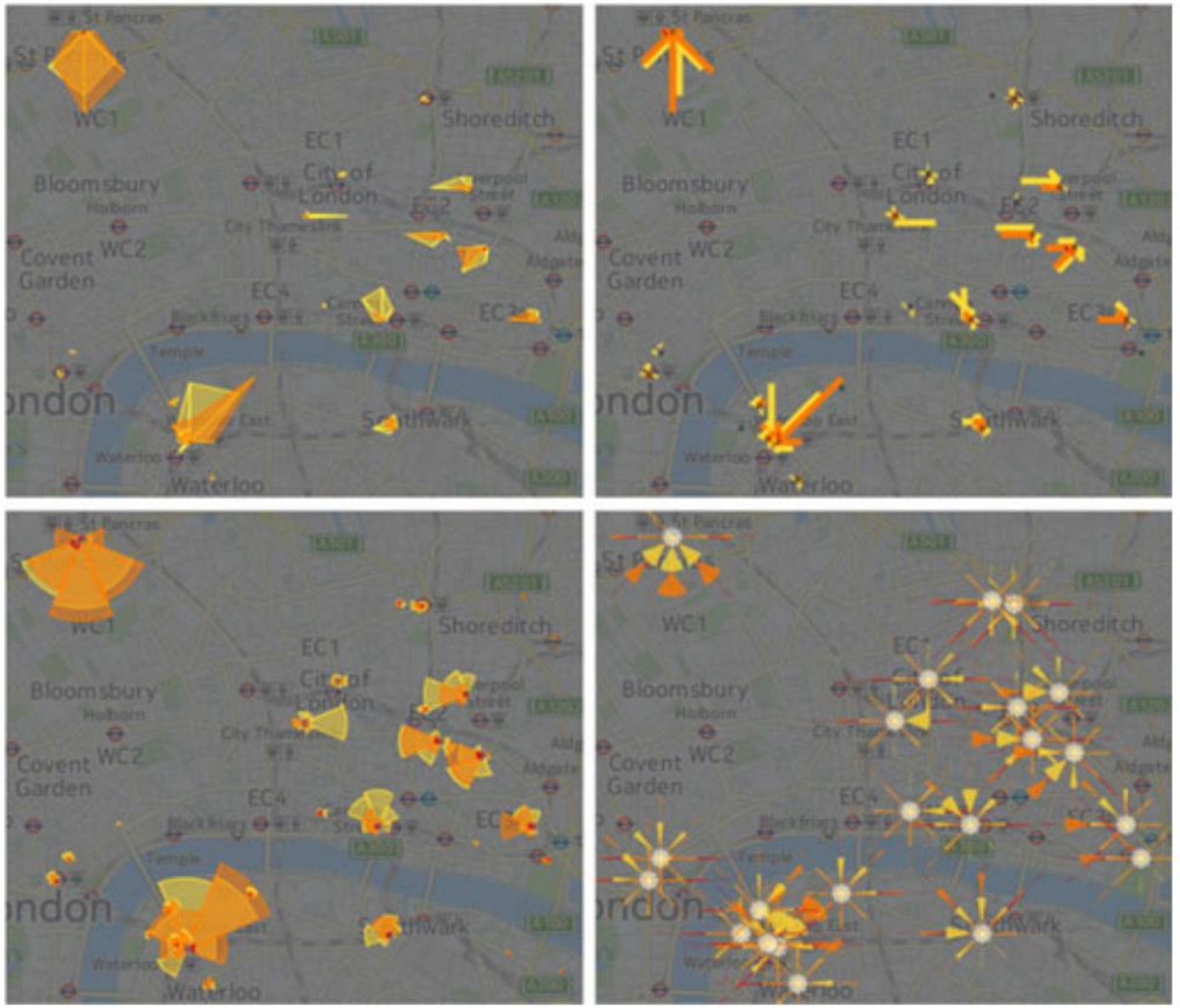


Left: vector flow map; Center: aggregated visualization for moving objects from one start point; Right: aggregated visualization for all flows

VIS 2018

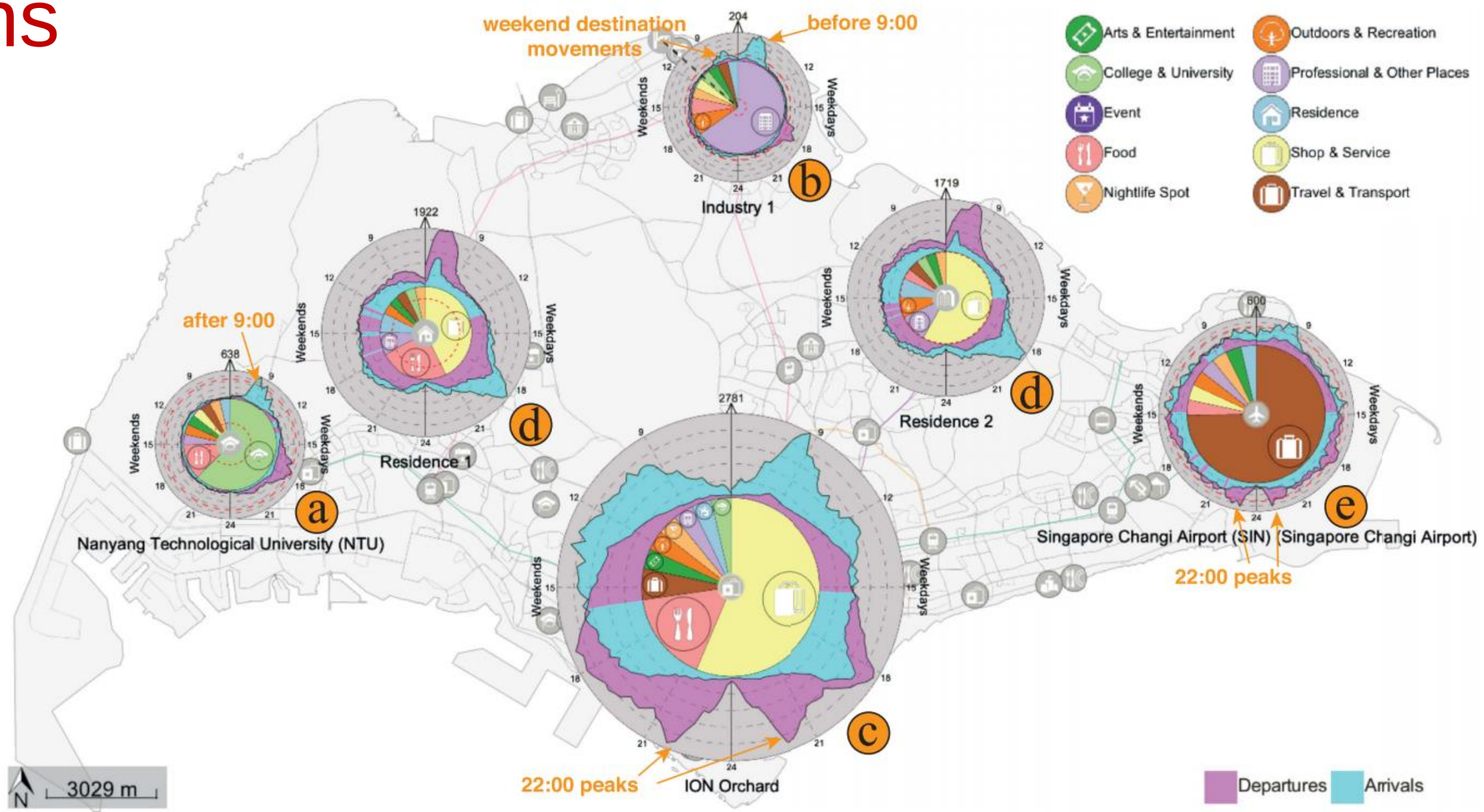
Yuuki Hyougo, Kazuo Misue, and Jiro Tanaka. "Directional Aggregate Visualization of Large Scale Movement Data." *Information Visualisation (IV), 2014 18th International Conference on*. IEEE, 2014.

Flow Diagrams



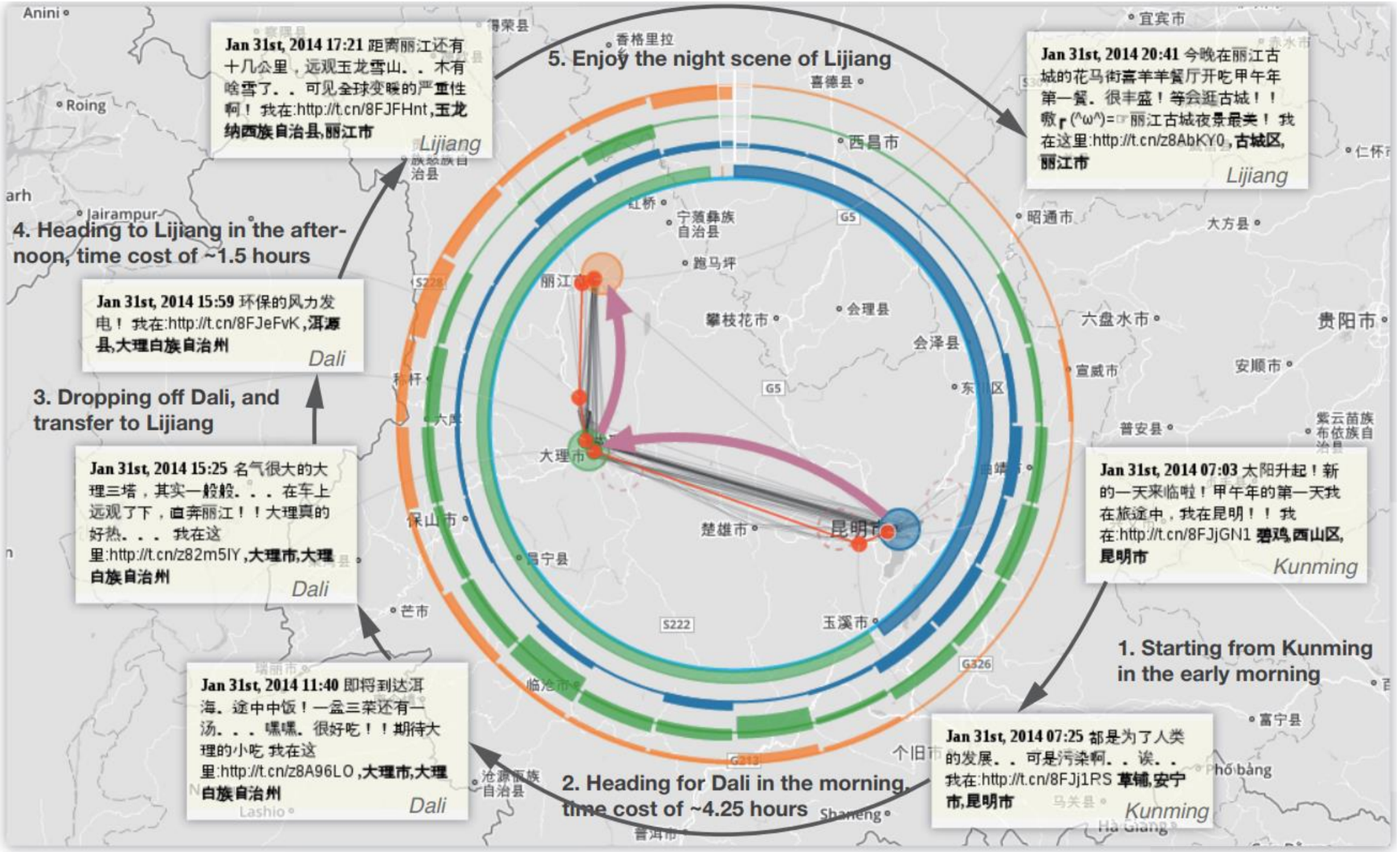
Gennady Andrienko, Natalia Andrienko, Georg Fuchs, and Jo Wood. "Revealing patterns and trends of mass mobility through spatial and temporal abstraction of origin-destination movement data." *IEEE Transactions on Visualization & Computer Graphics* 1 (2017): 1-1.

Glyphs



Wei Zeng, Chi-Wing Fu, Stefan Müller Arisona, Simon Schubiger, Remo Burkhard, and Kwan-Liu Ma. "Visualizing the relationship between human mobility and points of interest." *IEEE Transactions on Intelligent Transportation Systems* 18, no. 8 (2017): 2271-2284.

Circular Glyph

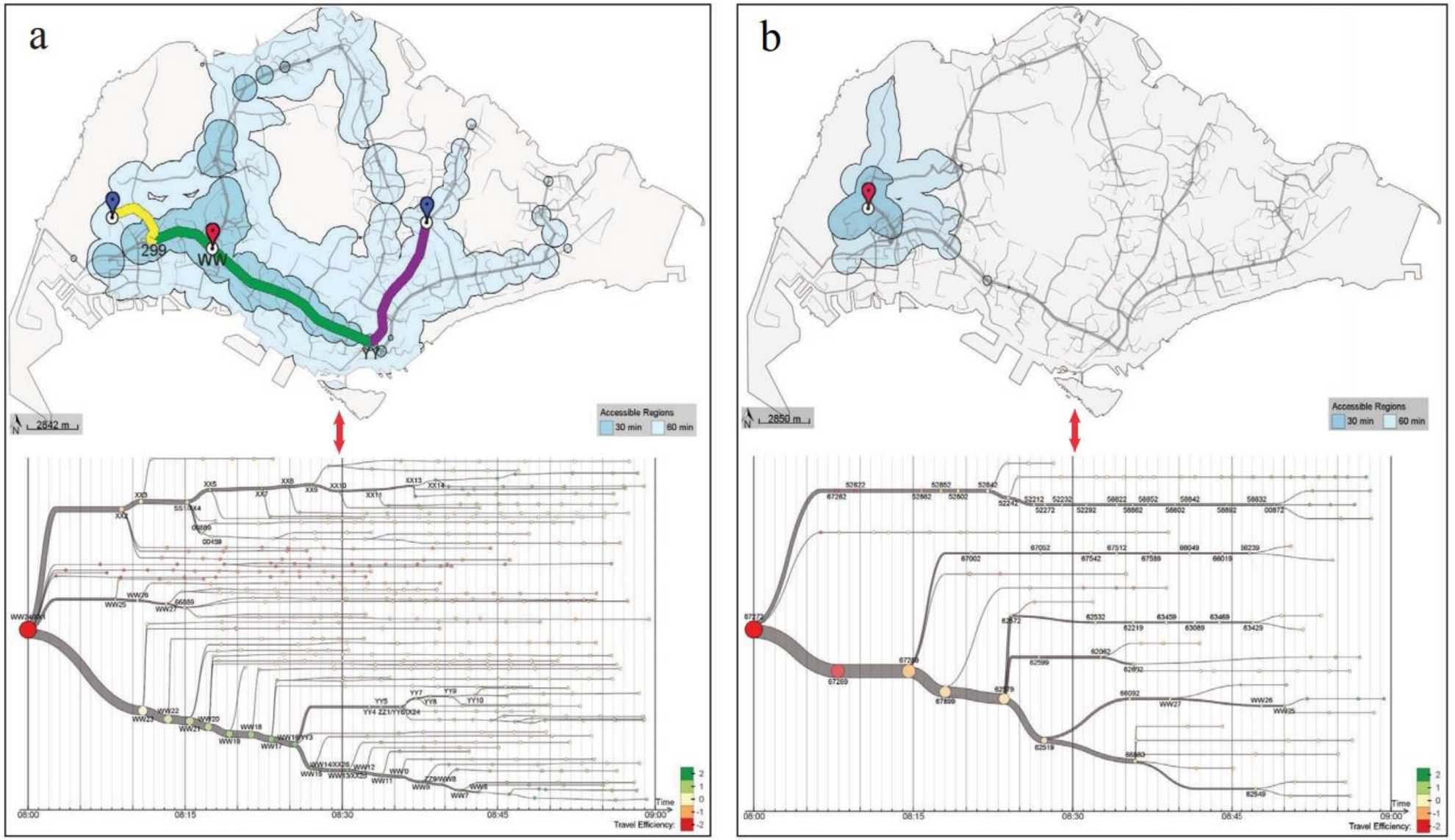


Circular temporal view of foci displayed around the focus region

VIS 2018

Siming Chen, Xiaoru Yuan, Zhenhuang Wang, Cong Guo, Jie Liang, Zuchao Wang, Xiaolong Luke Zhang, and Jiawan Zhang. "Interactive visual discovering of movement patterns from sparsely sampled geo-tagged social media data." *IEEE transactions on visualization and computer graphics* 22, no. 1 (2016): 270-279.

Isochrone Map, Isotime flow map



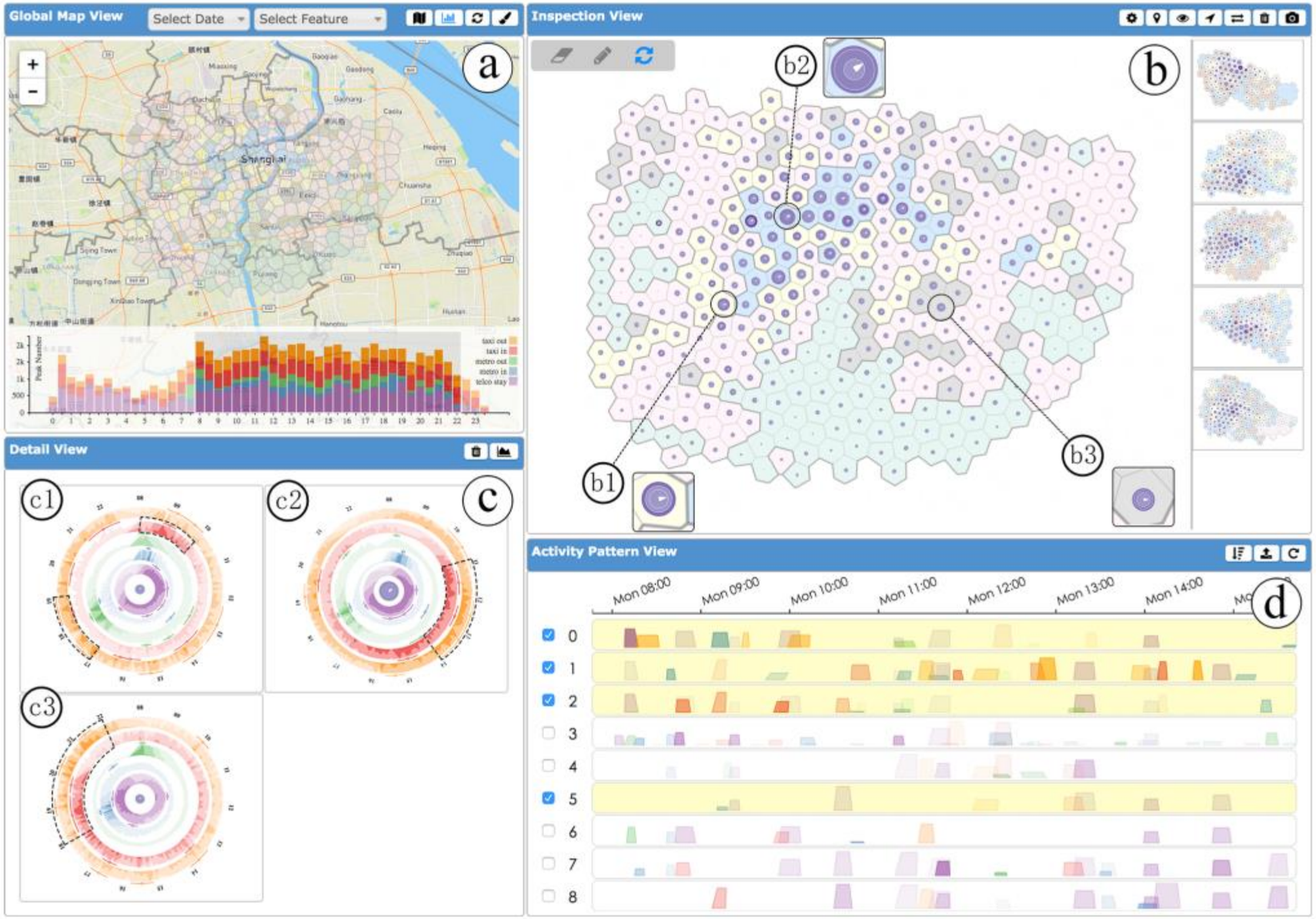
Mobility starting from (a) a MRT station and (b) a rural area bus stop

Wei Zeng, Chi-Wing Fu, Stefan Müller Arisona, Alexander Erath, and Huamin Qu. "Visualizing mobility of public transportation system." *IEEE transactions on visualization and computer graphics* 20, no. 12 (2014): 1833-1842.

Outline

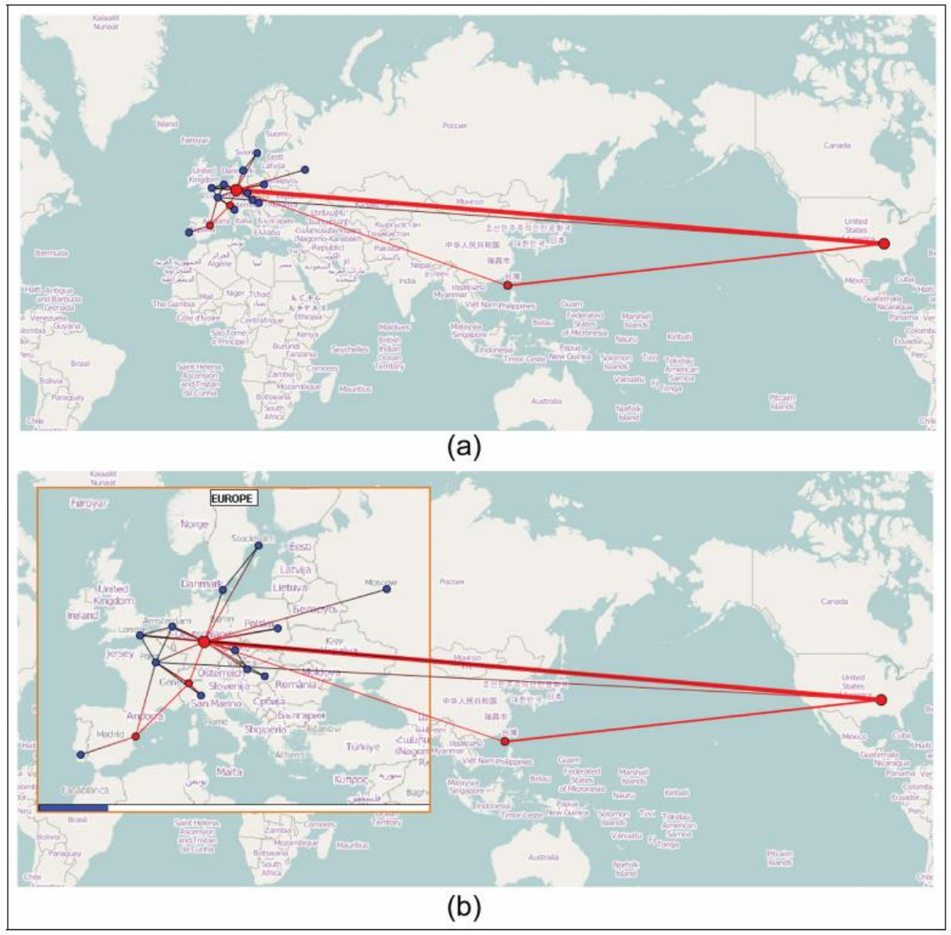
- Visualization of Trajectories
  - Visualization Where Each Trajectory has Its Own Markers
  - Density Plot Visualization
  - Visualization of Aggregated Trajectories
- Visualization of Flows Between Origins and Destinations
- Interactions

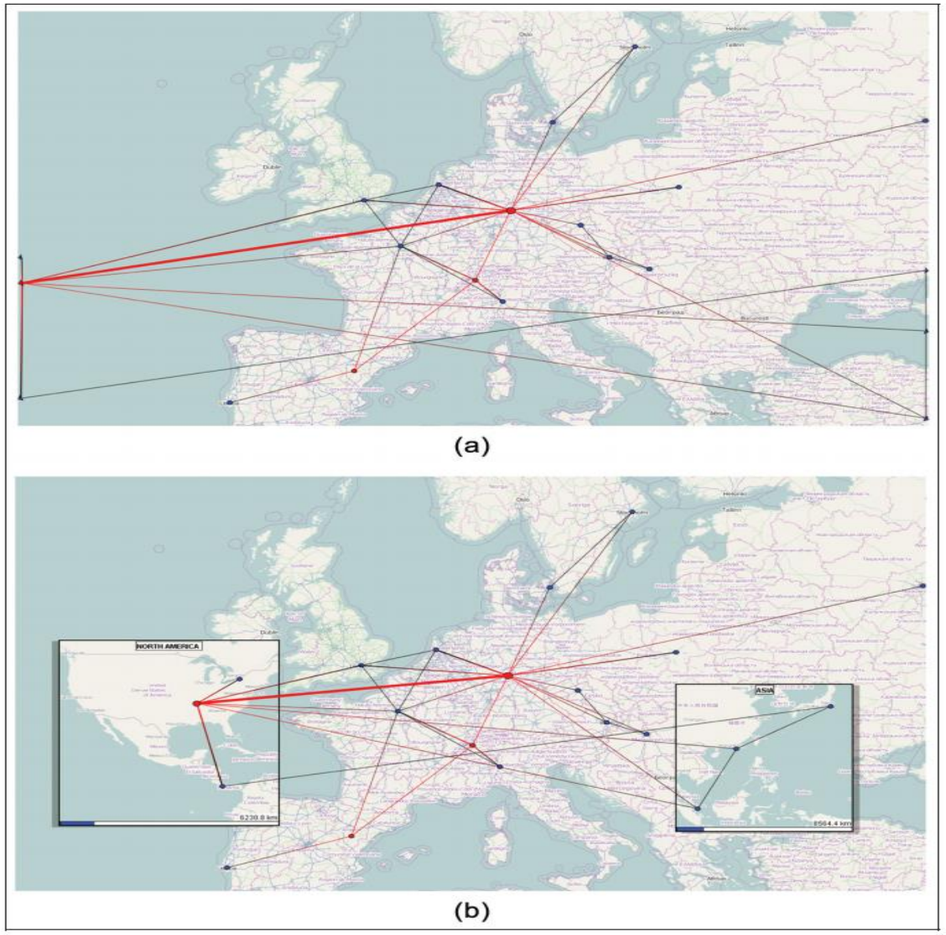
Coordinated Views



Wenchao Wu, Yixian Zheng, Nan Cao, Haipeng Zeng, Bing Ni, Huamin Qu, and Lionel M. Ni. "MobiSeg: Interactive region segmentation using heterogeneous mobility data." In *2017 IEEE Pacific Visualization Symposium (PacificVis)*, pp. 91-100.

Overview with Details

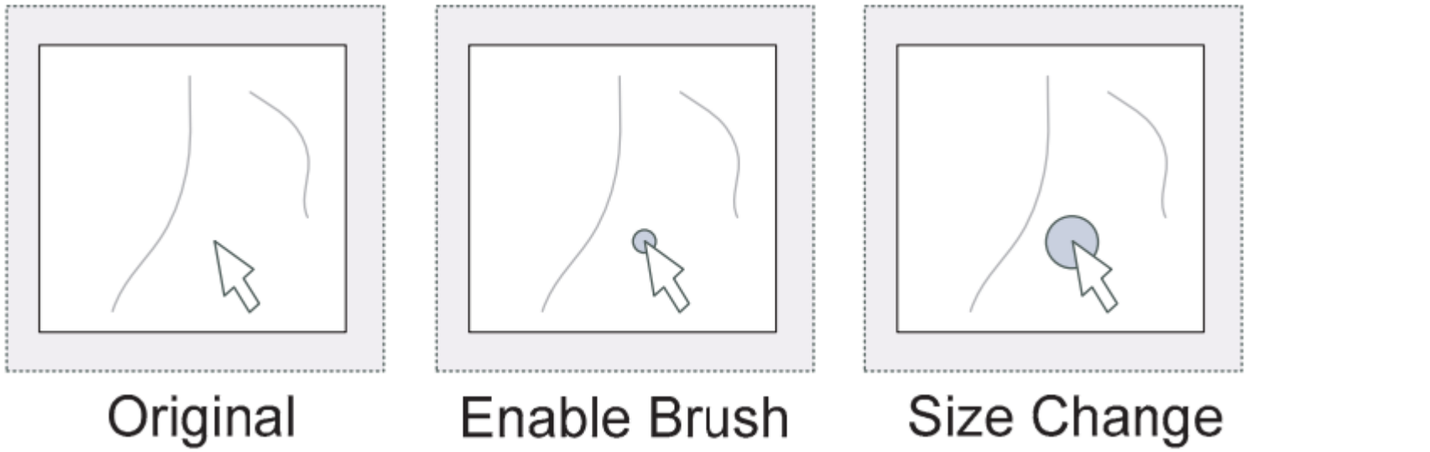


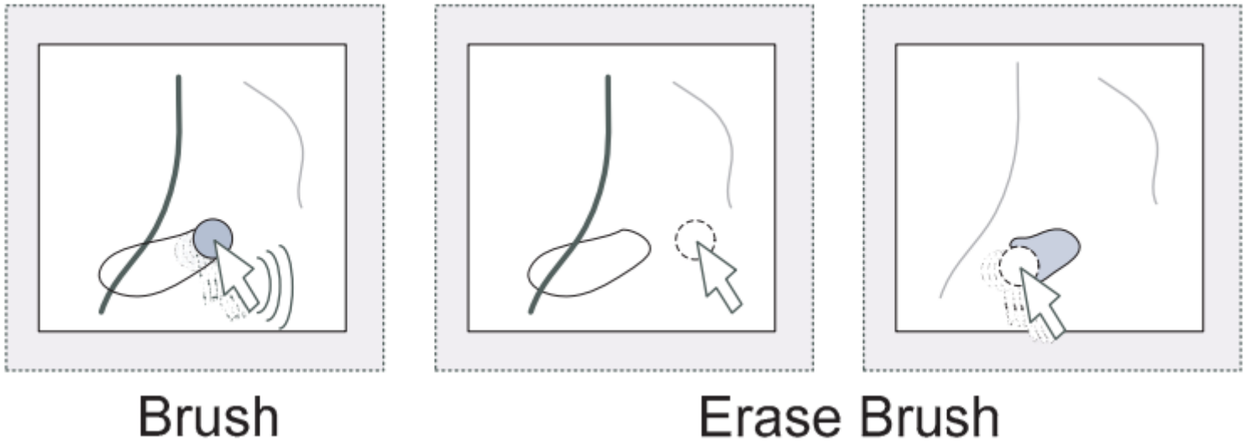


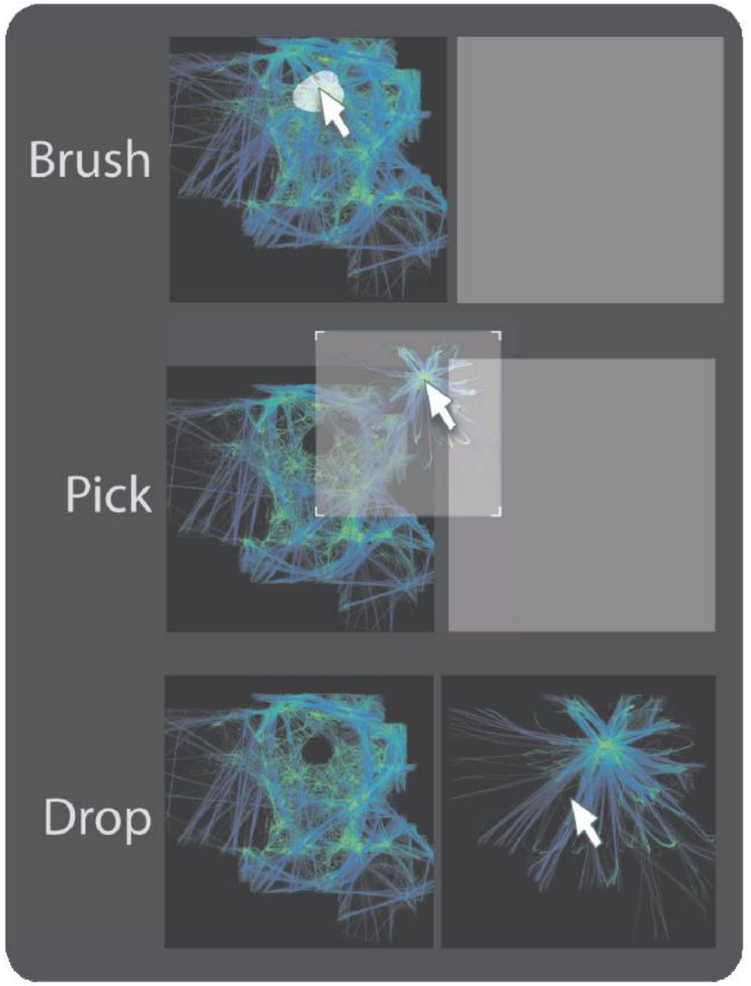
Insects show details of subgraphs. Left: on-screen insets. Right: off-screen insets.

Felix Brodkorb, Arjan Kuijper, Gennady Andrienko, Natalia Andrienko, and Tatiana Von Landesberger. "Overview with details for exploring geo-located graphs on maps." *Information Visualization* 15, no. 3 (2016): 214-237.

Brushing, Pick and Drop, Set Operations



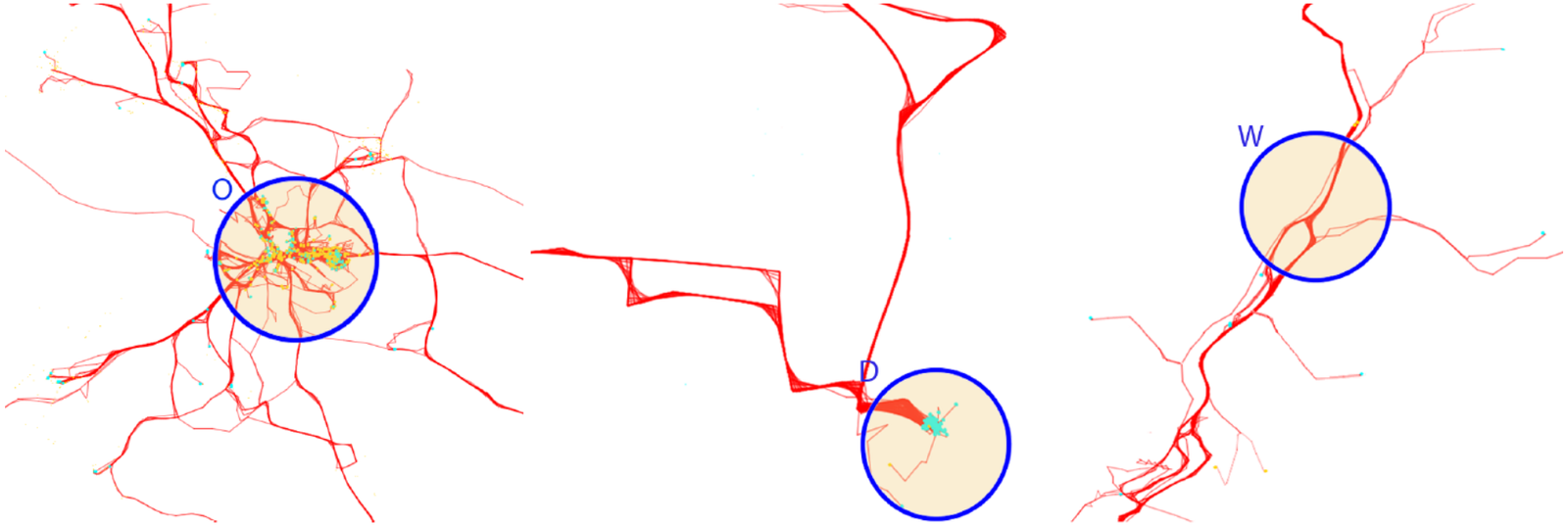




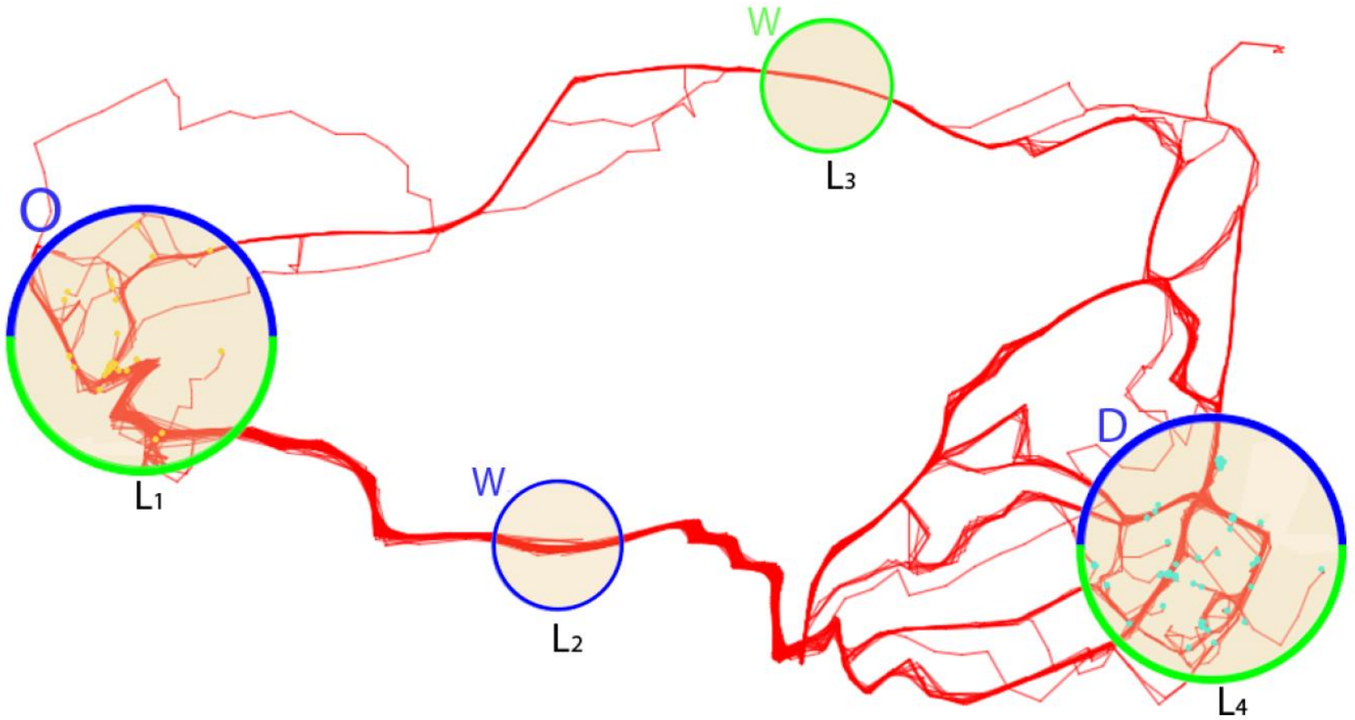
Hurter, Christophe, Benjamin Tissoires, and Stéphane Conversy. "Fromdady: Spreading aircraft trajectories across views to support iterative queries." *IEEE transactions on visualization and computer graphics* 15, no. 6 (2009): 1017-1024.

TrajectoryLens (Spatial Filter)

Top: three types of filters
Bottom: set operations

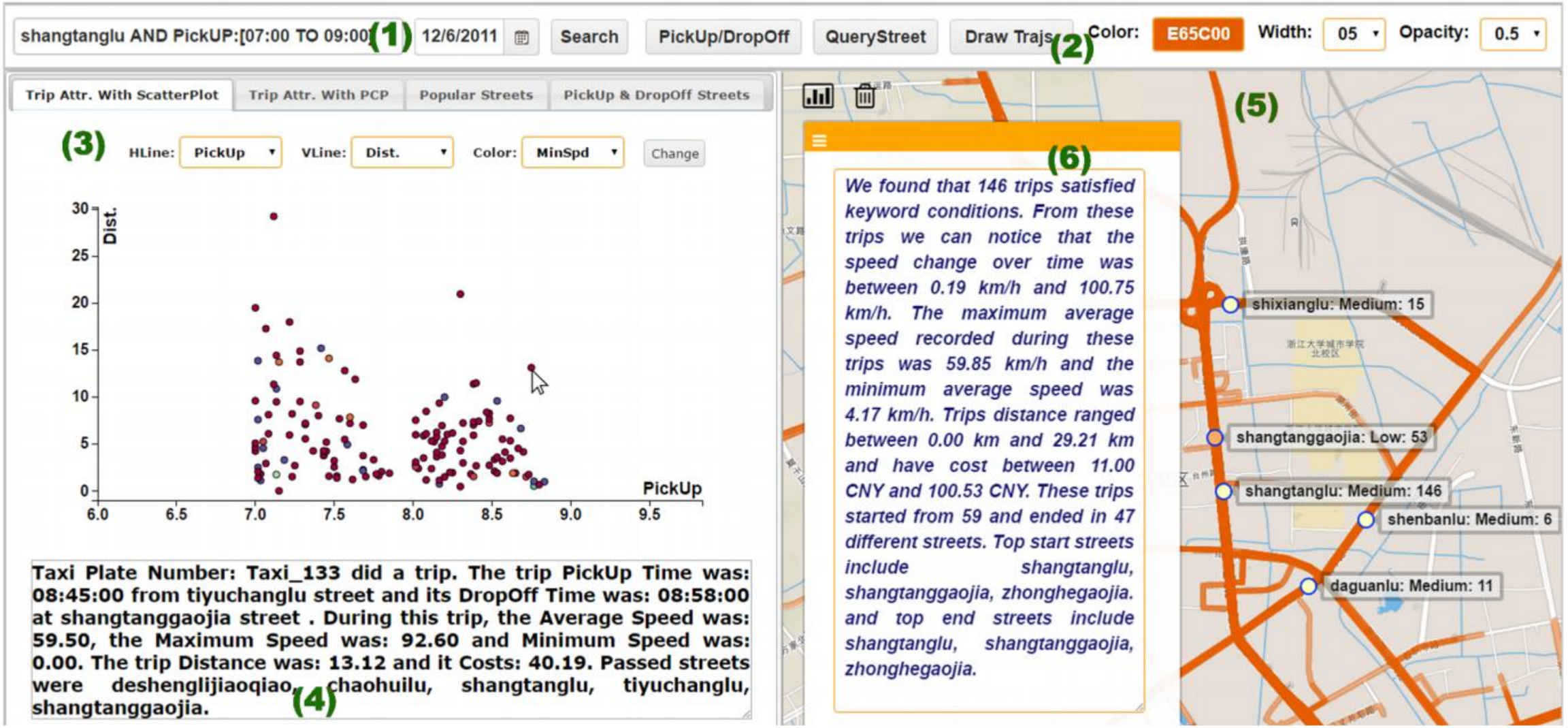


(a) origin lens (b) destination lens (c) waypoint lens



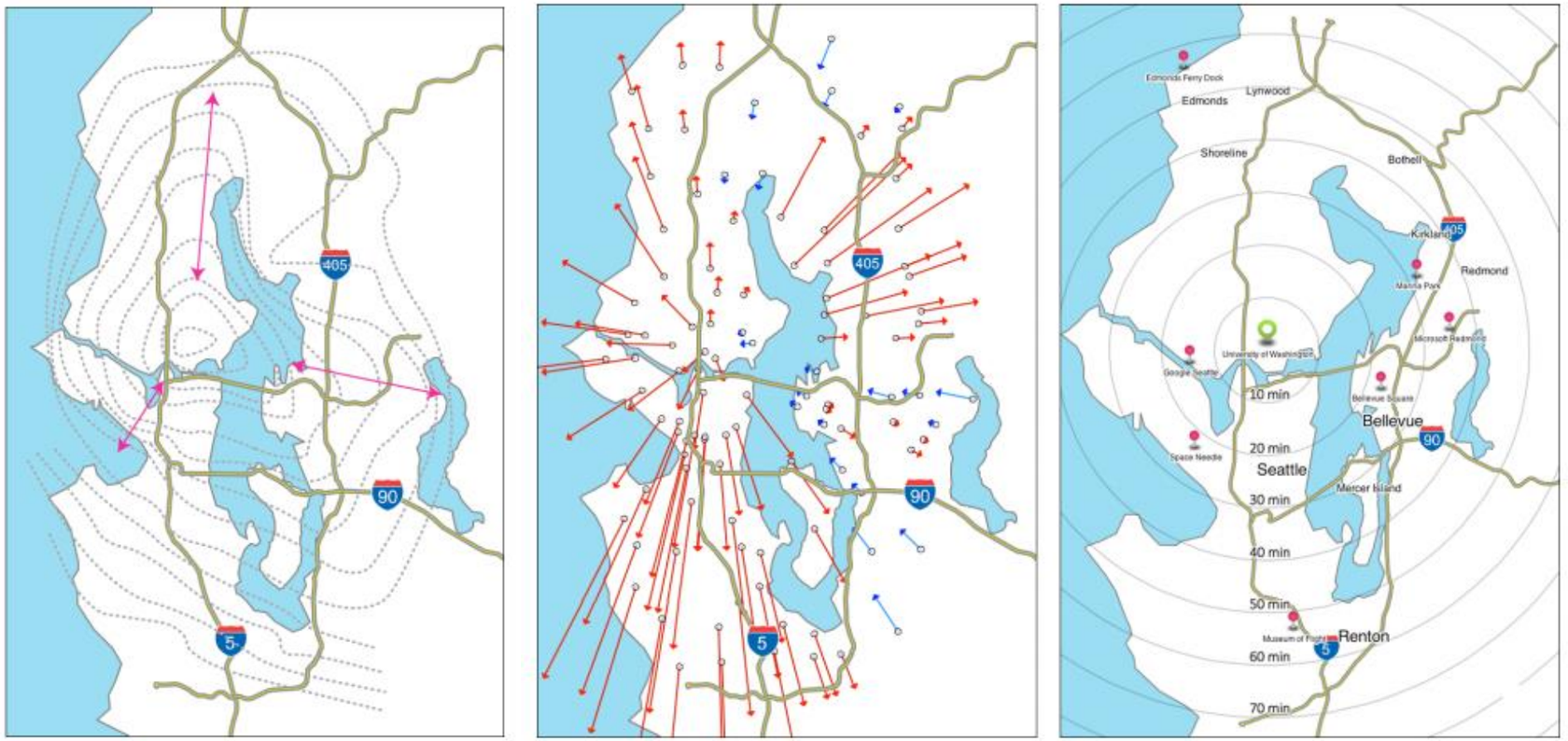
Robert Krüger, Dennis Thom, Michael Wörner, Harald Bosch, and Thomas Ertl. "TrajectoryLenses–A Set-based Filtering and Exploration Technique for Long-term Trajectory Data." In *Computer Graphics Forum*, vol. 32, no. 3pt4, pp. 451-460. Oxford, UK: Blackwell Publishing Ltd, 2013.

Semantic Query



Shamal Al-Dohuki, Yingyu Wu, Farah Kamw, Jing Yang, Xin Li, Ye Zhao, Xinyue Ye, Wei Chen, Chao Ma, and Fei Wang. "SemanticTraj: A new approach to interacting with massive taxi trajectories." *IEEE transactions on visualization and computer graphics* 23, no. 1 (2017): 11-20.

Distortion with Isochronal Warping



Left: Isochrone map; Center: Warping; Right: Warped map

Sungsoo Ray Hong, Yea-Seul Kim, Jong-Chul Yoon, and Cecilia R. Aragon. "Traffigram: distortion for clarification via isochronal cartography." In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pp. 907-916. ACM, 2014.

Route Zooming

Glyphs representing temporal information are overlaid on the broadened roads (left), overliad on the undeformed roads (center), and displayed in separate views (right).

Guodao Sun, Ronghua Liang, Huamin Qu, and Yingcai Wu. "Embedding spatio-temporal information into maps by route-zooming." *IEEE Transactions on Visualization & Computer Graphics* 5 (2017): 1506-1519.

Tutorial: Urban Trajectory Visualization

Thank You!