Interactive Visual Anomaly Detection and its Applications

Nan Cao

College of Design and Innovation, Tongji University

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2016 – Now Tongji University

2012 – 2016 IBM T.J. Watson

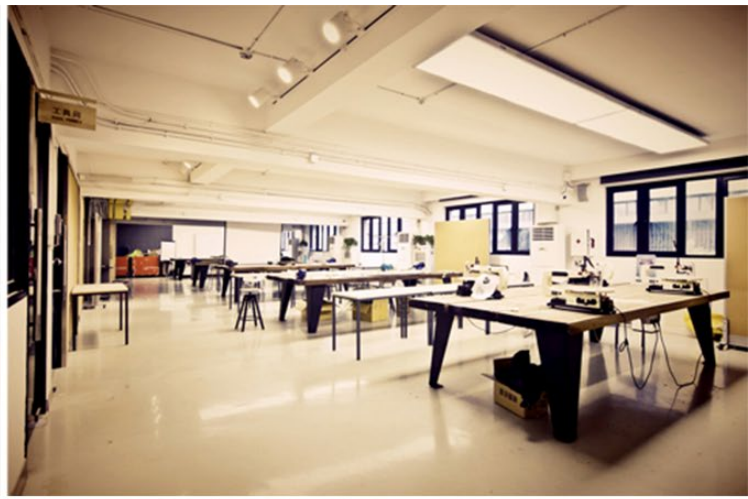
2005 – 2010 IBM CRL

A Big Data Visualization Researcher

Intelligent Big Data Visualization Lab (iDV^{x} Lab)

Tongji University, Shanghai, China

Tongji College of D&I



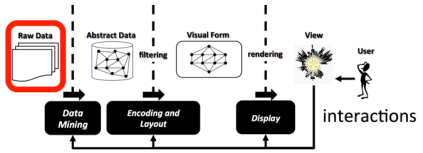
Intelligent Big Data Visualization (iDVˣ) Lab

http://idvxlab.github.io

iDVˣ Lab

Intelligent Big Data Visualization Lab is founded in 2016. It is an international research lab focuses on design and develop novel visualization, visual analysis, and HCI techniques. The Lab focused on develop novel visualization, visual analysis, UX, and HCI technologies to support anomaly detection and apply them in a variety of application fields, including internet security, smart city, business intelligence, healthcare informatics, and industry 4.0.

Visual Analytics



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InfoSec

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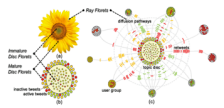
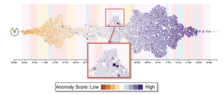
Anomalous Collective Behaviors

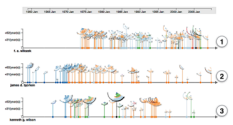


Monitoring and Tracing of Information Diffusion Process

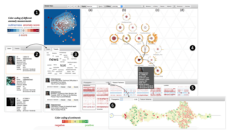


Visual Analysis and interpretation of anomalous information spreading

Anomalous Ego-Centric Behaviors



Interpretation of Ego-Centric Social Behaviors on Twitter



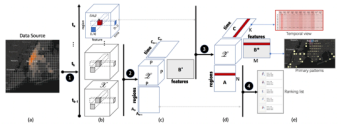
Visual Analysis System for Detecting Social Media Users with Anomalous User Behaviors such as Bots

Smart City

A smart city is an urban development vision to integrate information and communication technology and Internet of things technology in a secure fashion to manage a city's assets. A smart city is promoted to use urban informatics and technology to improve the efficiency of services. Our research in this filed focused on the public security problems in the city. We aim to leverage visual analysis systems to monitor and detect anomalous traffic and mobility patterns in the city to avoid incident such as 2014 Shanghai stampede.

Dynamic Region Segmentation

Anomalous Mobility Pattern Detection



Health Informatics

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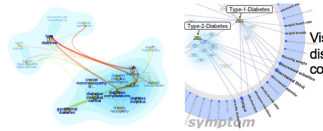
Disease Diagrams and Visualization



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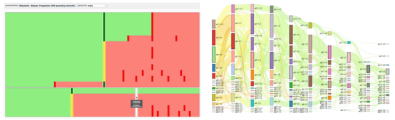
Analysis of Anomalous Care Plan



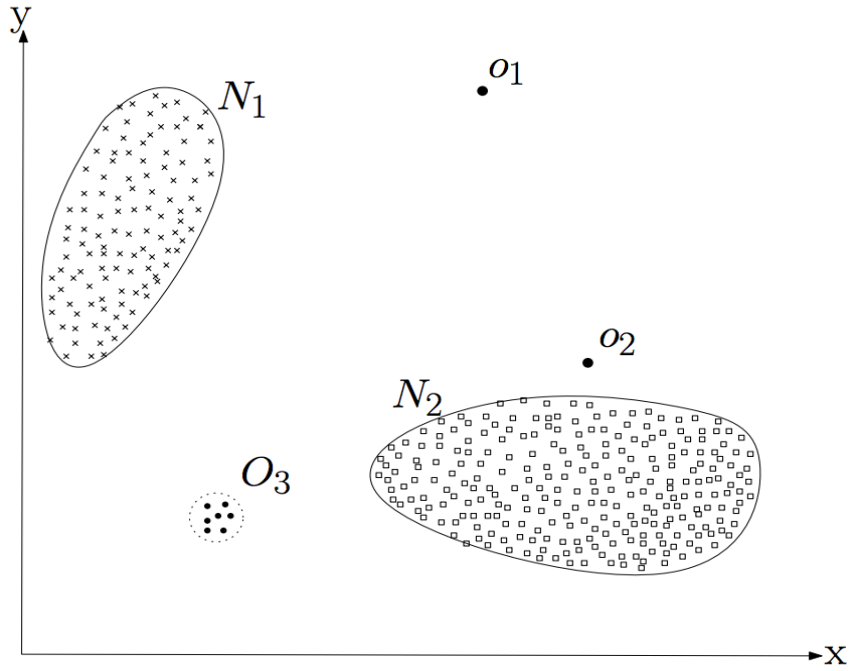
Detect Anomalous Cohort

Detect and interpret the anomalous cohorts

Anomaly Detection

Anomaly detection (also outlier detection) is the identification of items, events or observations which do not conform to an expected pattern or other items in a dataset. Visualization techniques are used for addressing two major challenges: (1) there is no clear boundary between normal and abnormal and (2) the unavailable of ground truth or labelled data making results validation difficult.

ANOMALY DETECTION



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-- Wikipedia

KEY CHALLENGES

- It is difficult to define what is normal or abnormal
- Unavailable of ground truth or labelled data making results validation difficult
- Existing algorithms produce results that are difficult to understand

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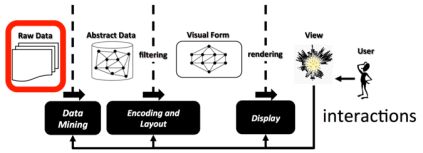

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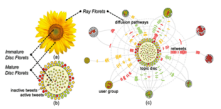

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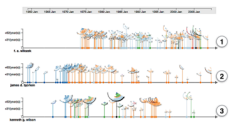

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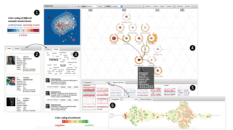

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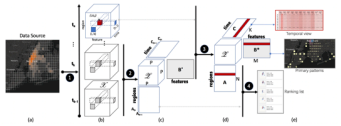

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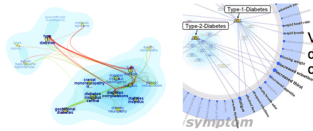

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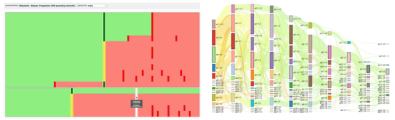

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The Growth of Social Media

http://www.jeffbullas.com/2014/01/17/20-social-media-facts-and-statistics-you-should-know-in-2014/

Do you trust your friends on social media ?

"On the Internet, Nobody Knows You're a Dog": A Twitter Case Study of Anonymity in Social Networks

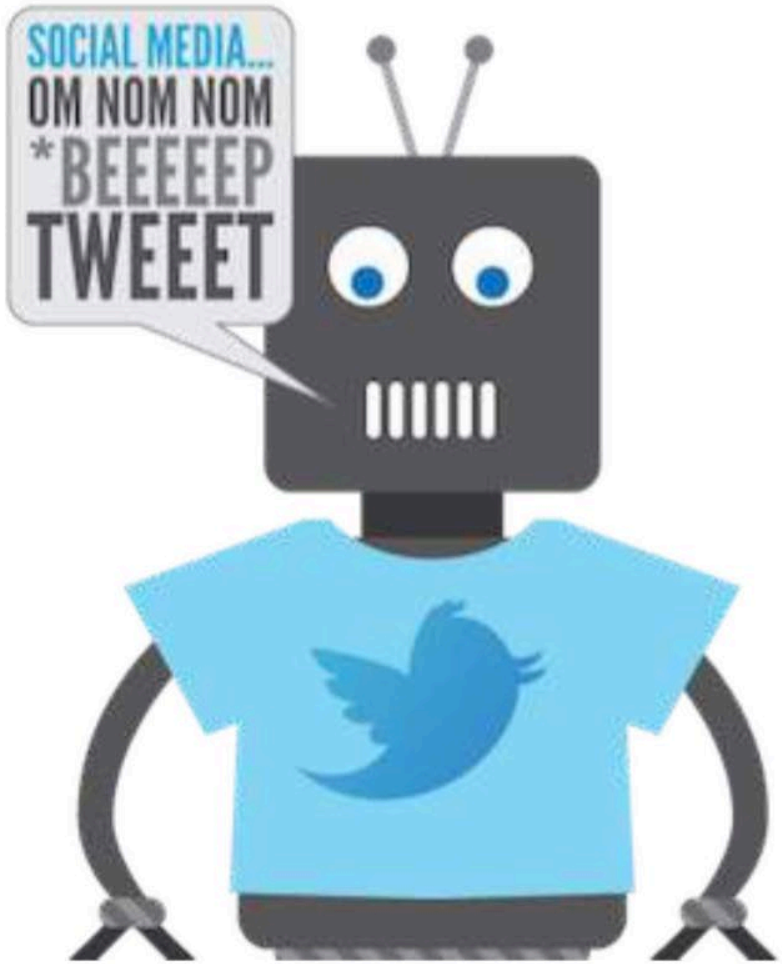
Sai Teja Peddinti* psaiteja@nyu.edu
Keith W. Ross*† keithwross@nyu.edu
Justin Cappos* jcappos@nyu.edu
*Dept. of Computer Science and Engineering, NYU Brooklyn, New York, USA
†NYU Shanghai Shanghai, China

(ACM Conference on Online Social Networks, 2014)

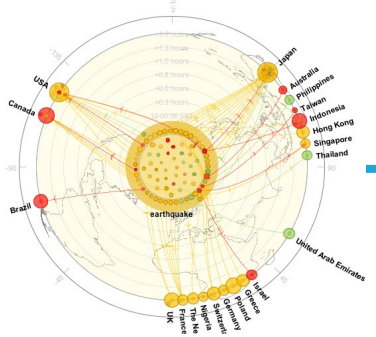
An adage since 1993

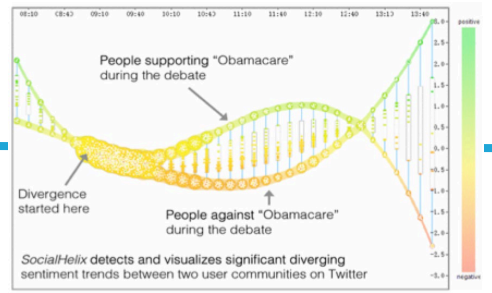
Anonymous users are potential threats to the society

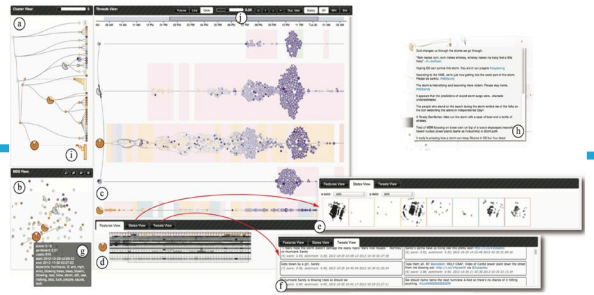
Ultimate goal: Catching users with anomalous behaviors



SOCIAL MEDIA

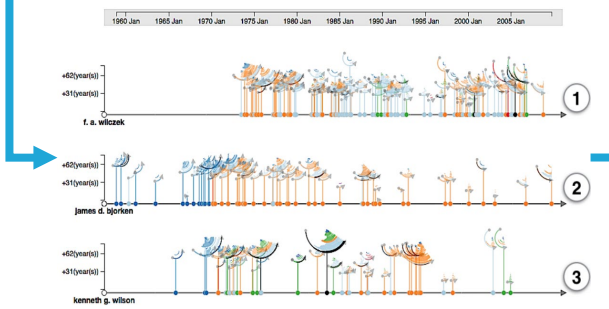


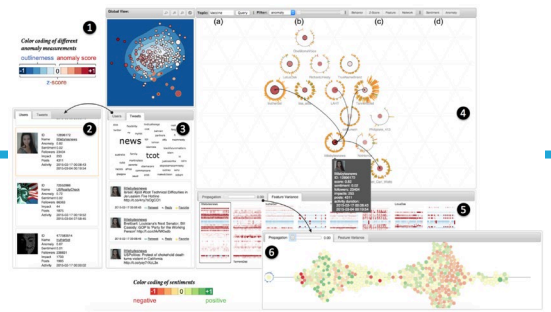




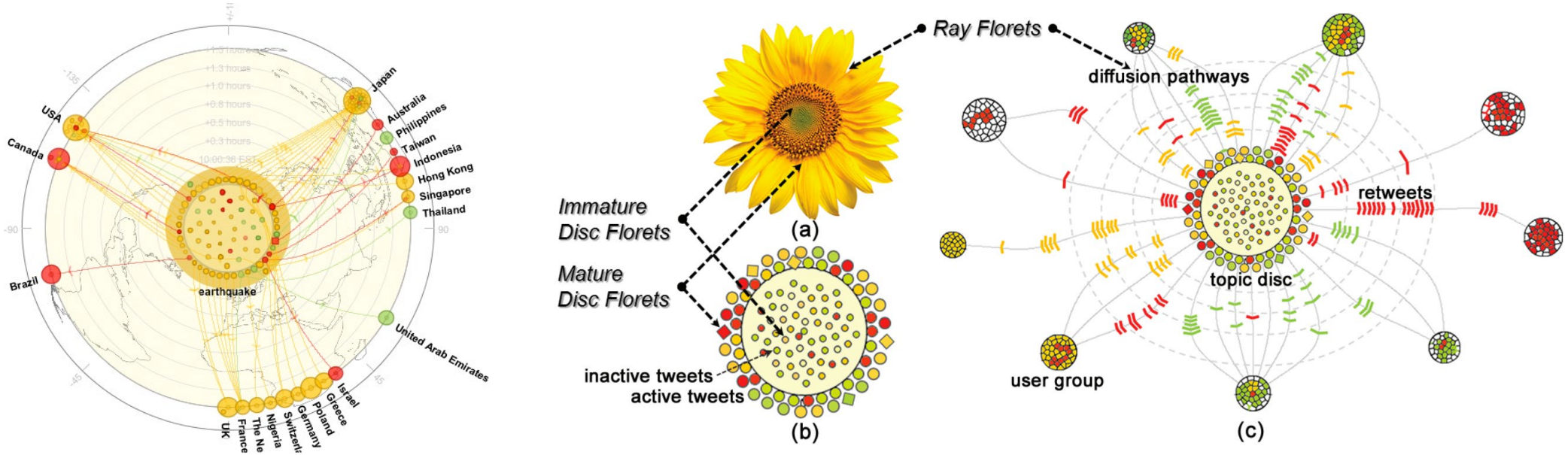
Understanding Anomalous Crowd Behaviors

Understanding Anomalous Ego Centric Behaviors



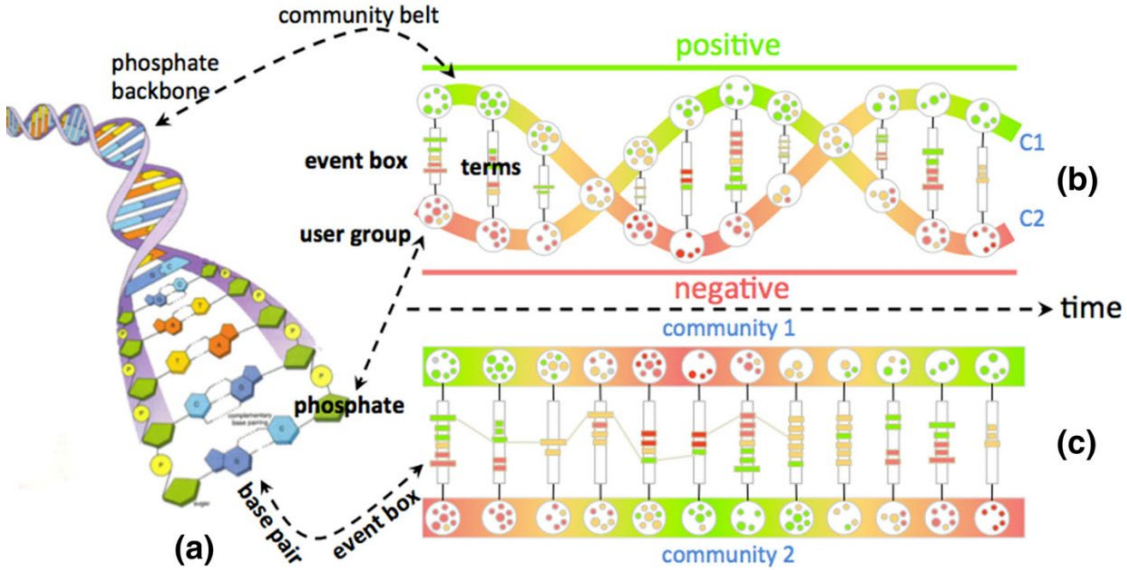


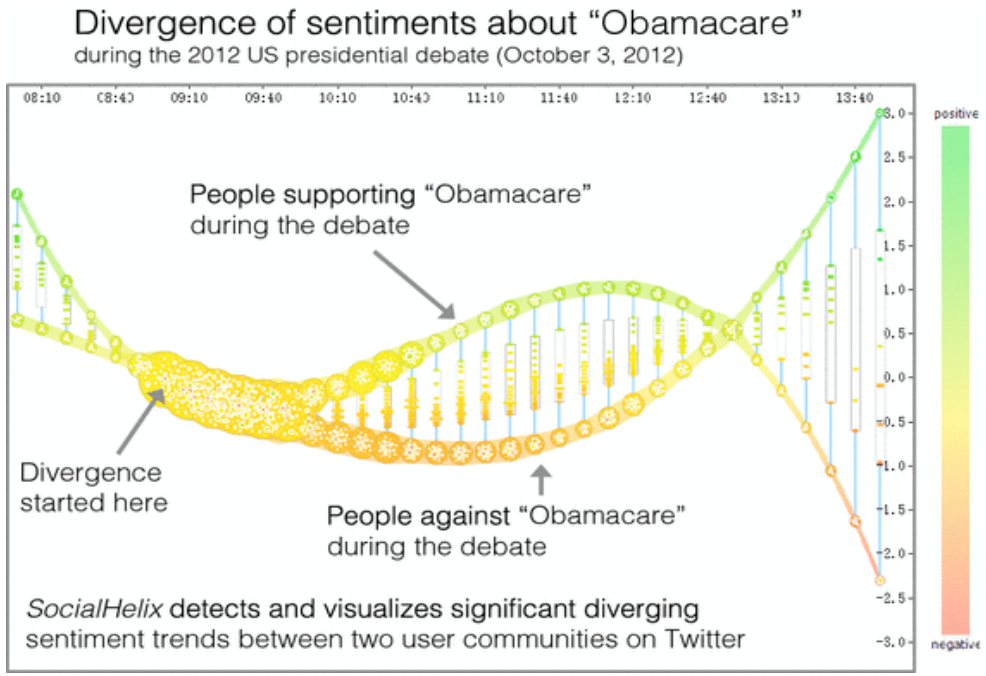
Whisper



"Whisper: Tracing the Spatiotemporal Process of ***Information Diffusion*** in Real Time",
IEEE TVCG, IEEE InfoVis 2012

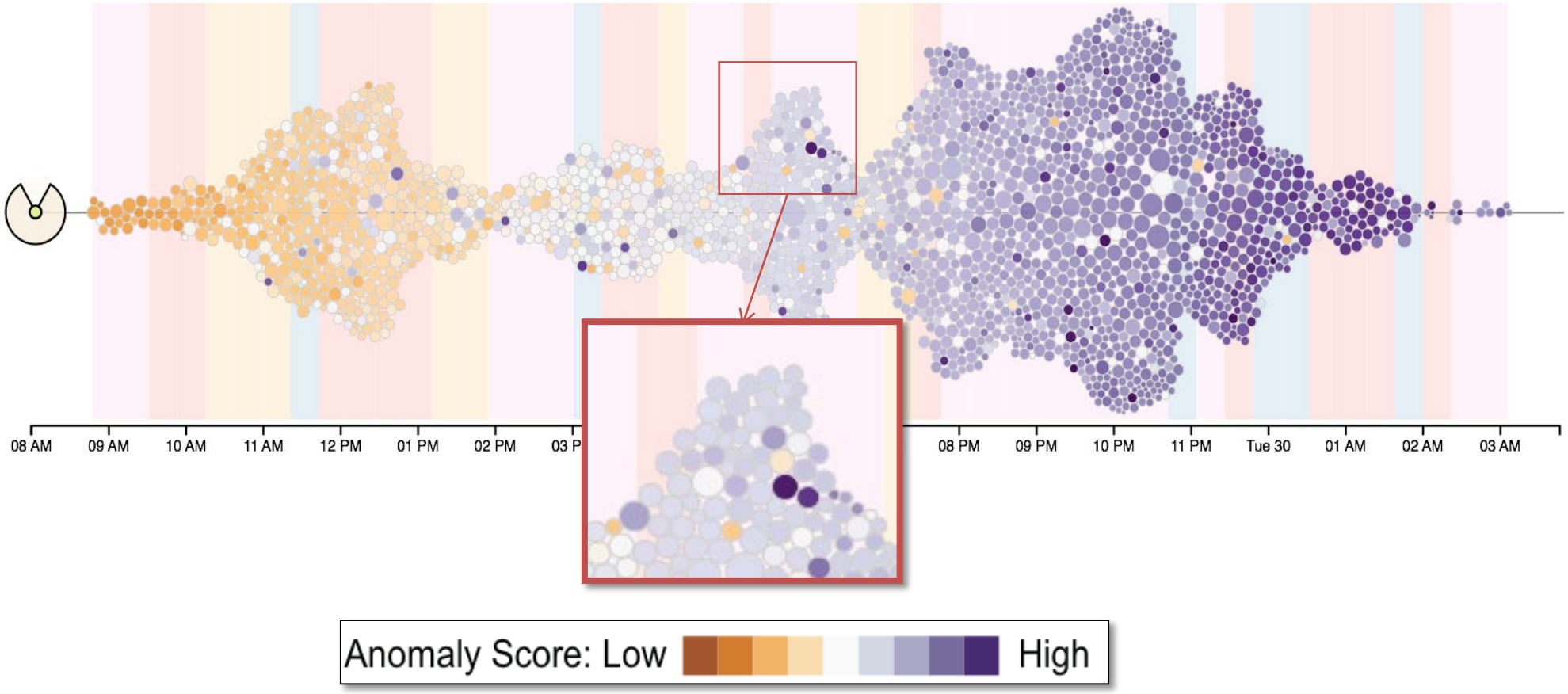
SocialHelix





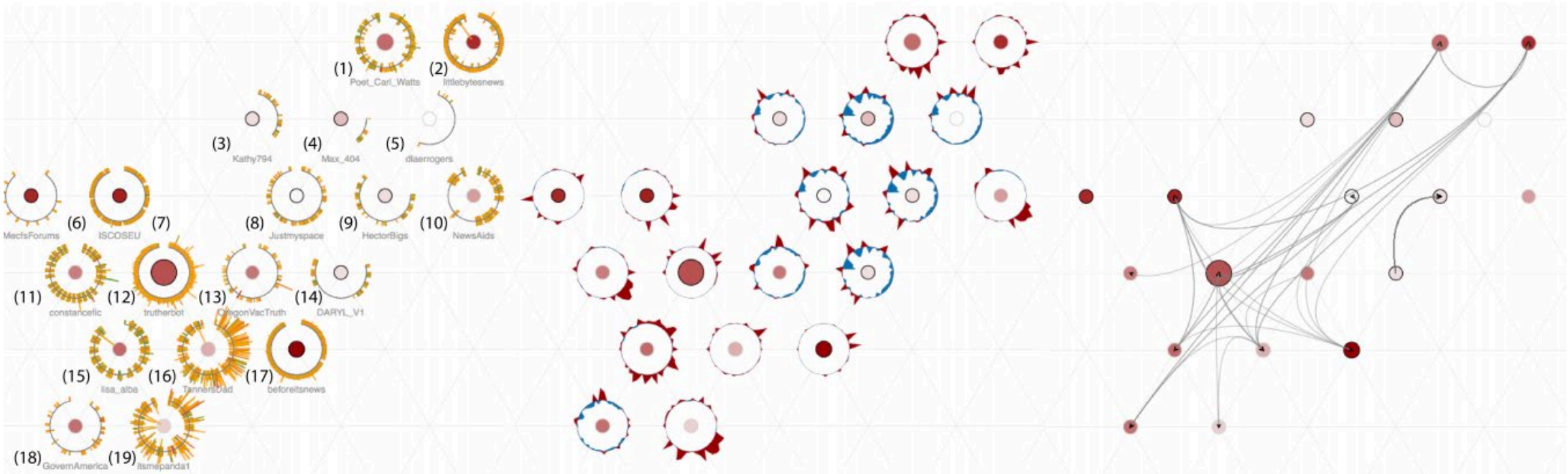
"SocialHelix: Visual Analysis of ***Sentiment Divergence*** in Social Media",
Journal of Visualization, May 2015, Volume 18, Issue 2, pp 221-235

FluxFlow



"#FluxFlow: Visual Analysis of ***Anomalous Information Spreading*** on Social Media",
IEEE TVCG, IEEE VAST 2014 (Honorable Mention)

TargetVue

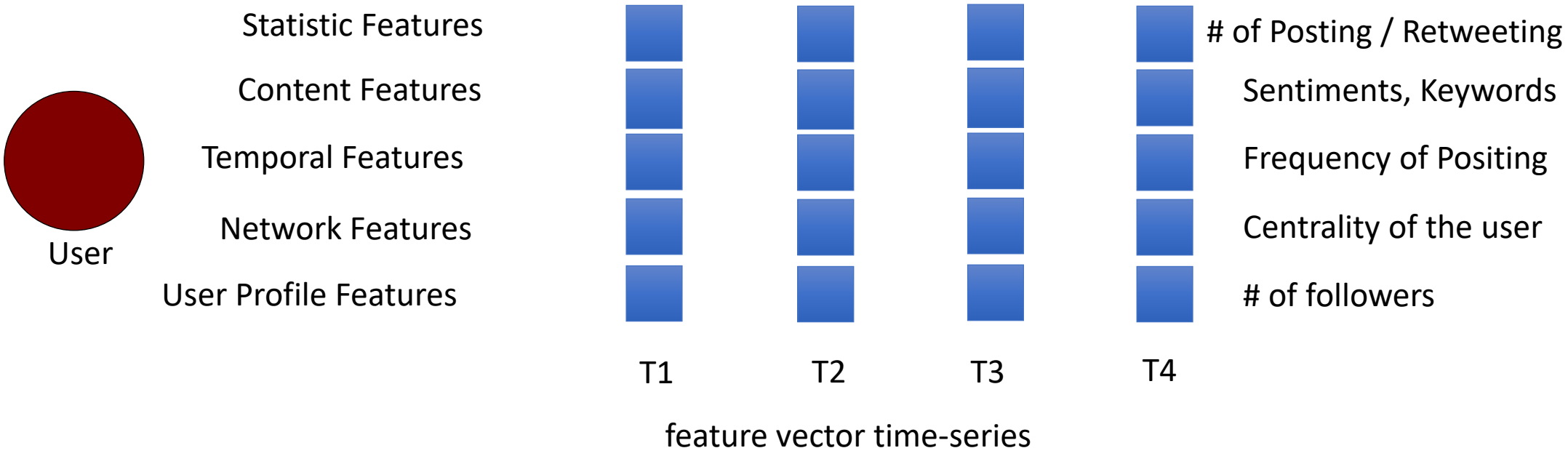


TargetVue: Visual Analysis of ***Anomalous User Behaviors*** in Online Communication Systems, IEEE TVCG 2016

User Behaviors

- Posting (Tweeting)
  - Create a message and post it to others
- Responding (Replying / Retweeting)
  - Spread the messages posted by others

Capturing User Behaviors via Features



Anomaly Detection

TLOF: Temporal Local Outlier Factor

$$s(X) = \alpha \cdot Z_1(X) + (1-\alpha) \cdot Z_2(X)$$

$$Z_1(X) = LOF(x_T) - \sum_{t=T-W}^{t=T-1} LOF(x_t)/W$$

$$Z_2(X) = 1 - P_N(LOF(x_T), \mu, \sigma)$$

The TLOF gives an anomaly measurement for every users by identifying the features that are significantly different from other users in the test data and the past history of his own

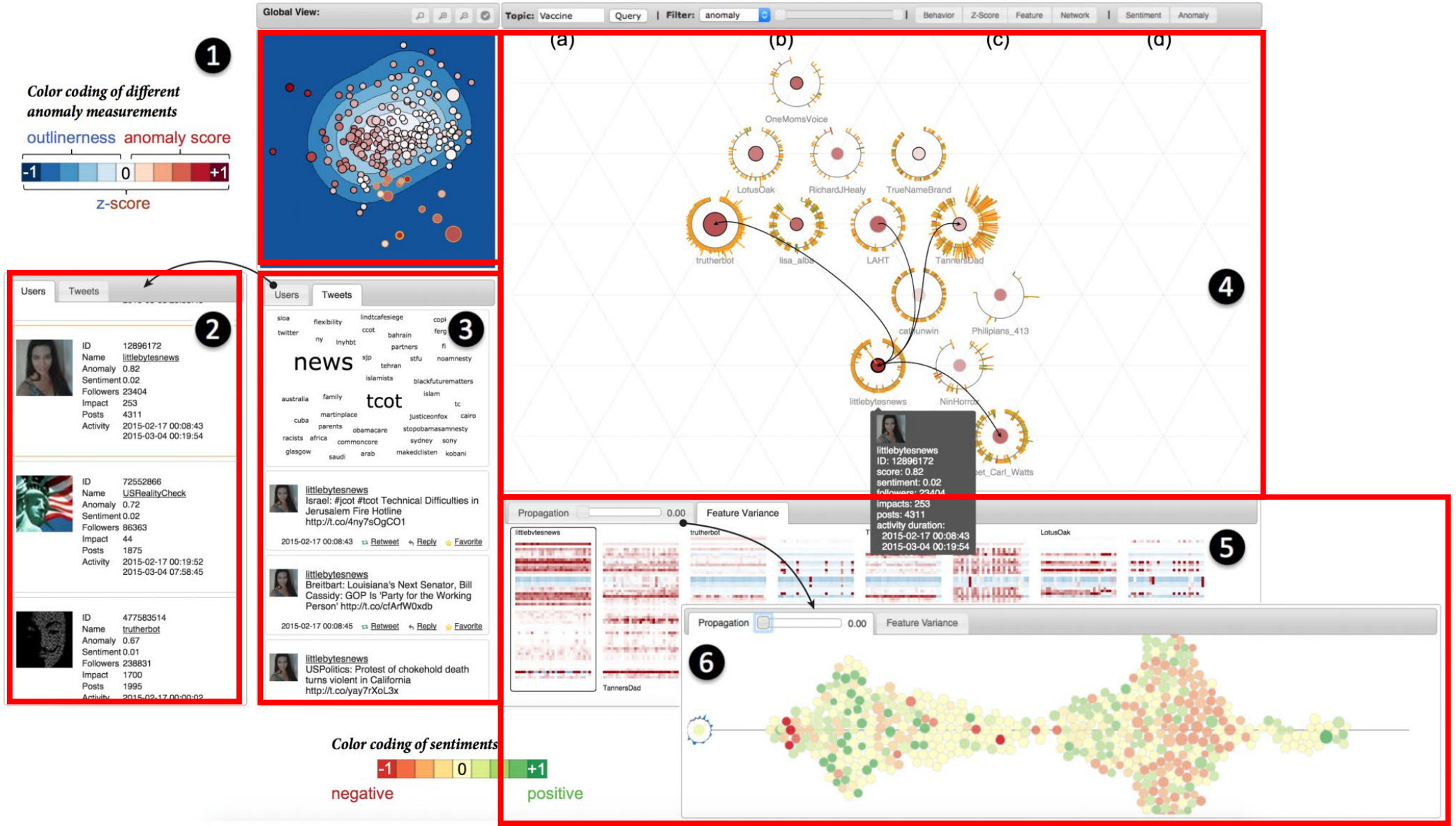
Breunig, Markus M., et al. "LOF: identifying density-based local outliers." ACM sigMOD record. Vol. 29. No. 2. ACM, 2000.

Introduction

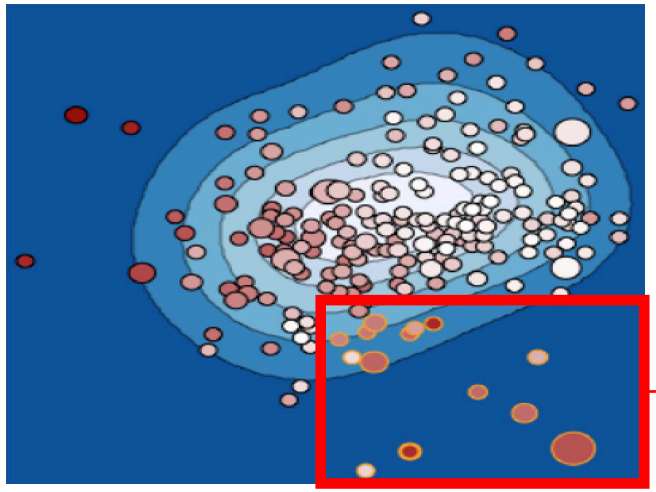
Visualization Design

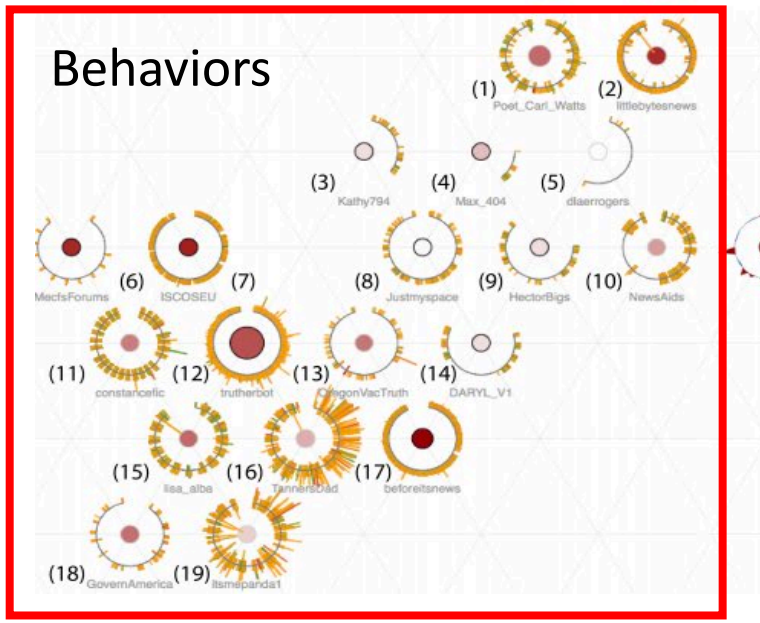
Evaluation

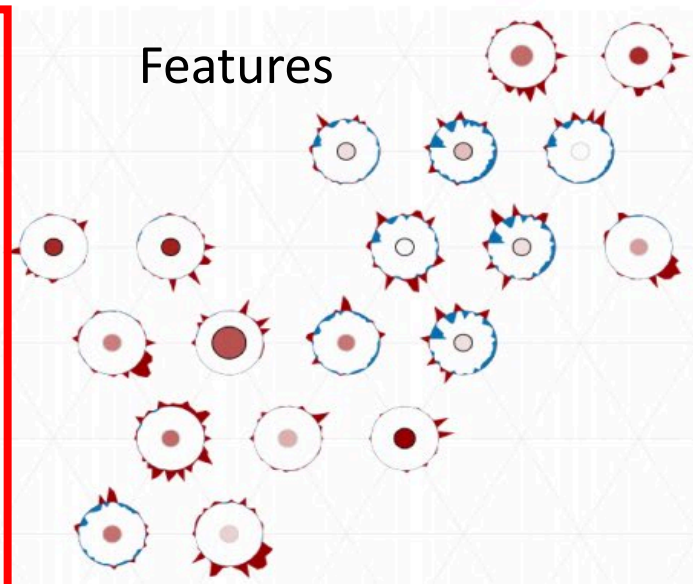
User Interface

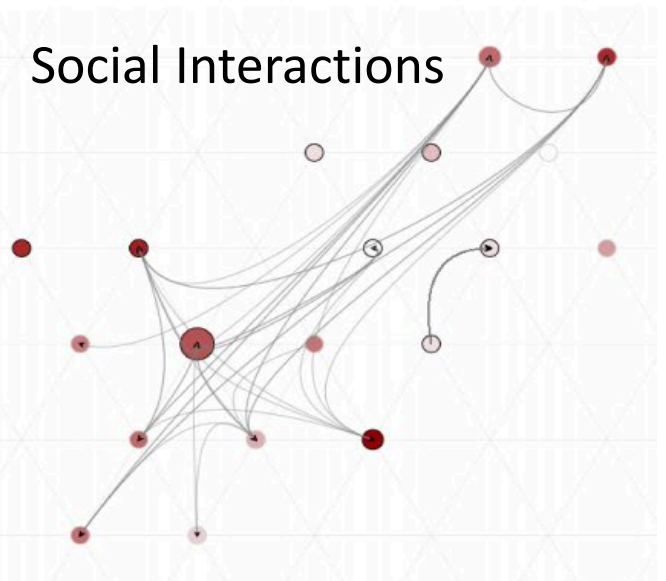


The Inspection View

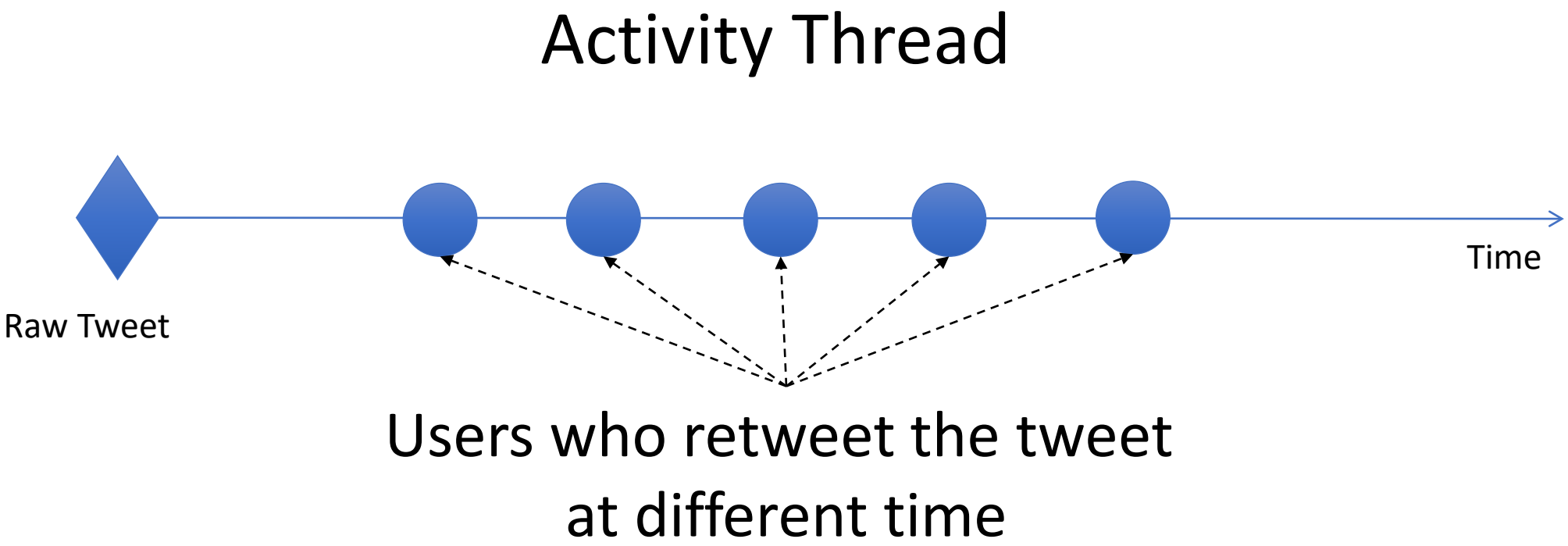








Showing Posting and Retweeting Activities



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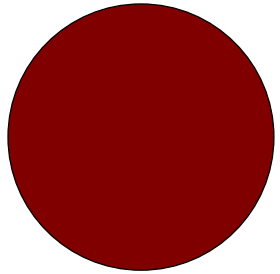
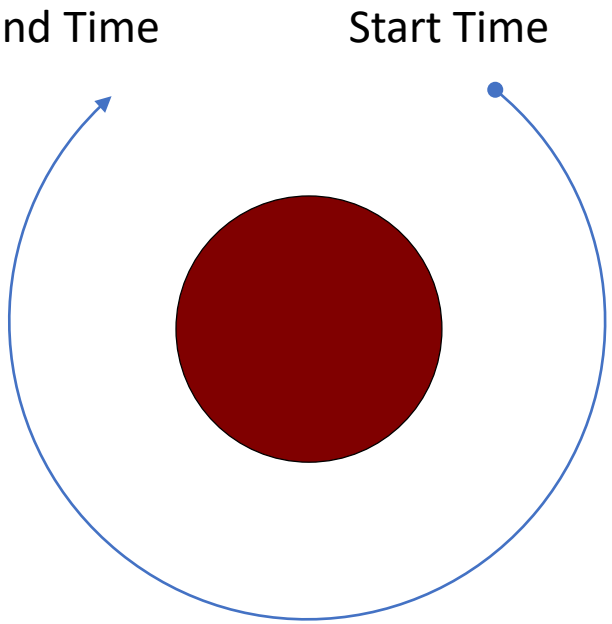


A user is visualized as circle sized by their importance and colored by their anomaly score

Showing Posting and Retweeting Activities



The centric user’s activity history is recorded in a circular timeline

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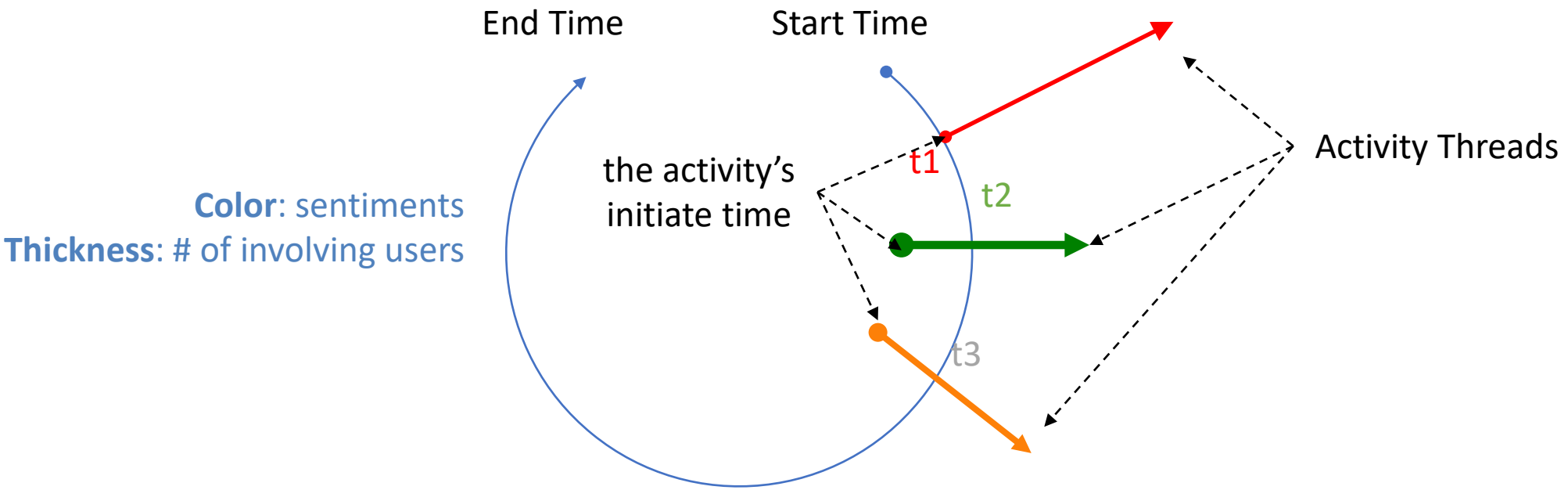

When the user posts or retweets a tweet, we draw the corresponding activity threads perpendicular to the time arc at the point when the activity occurred

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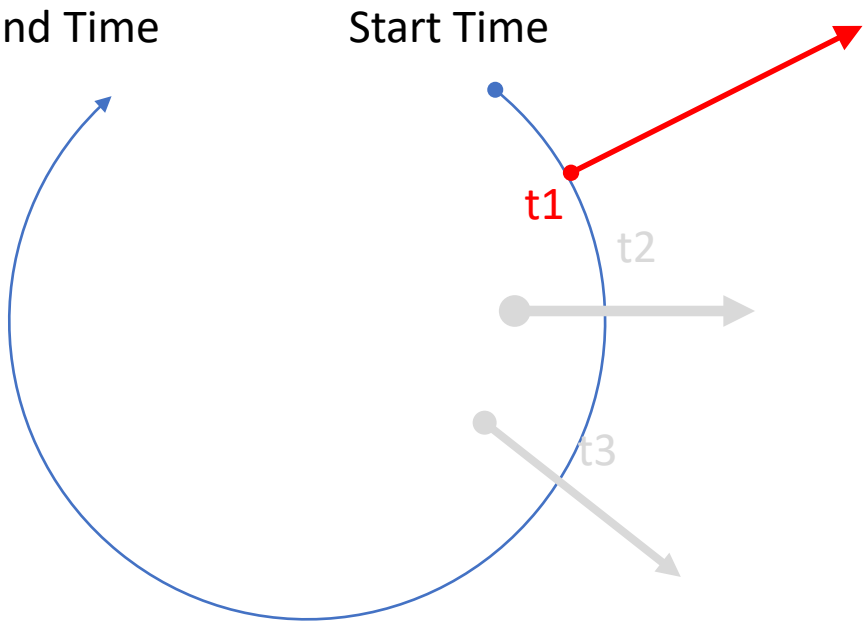

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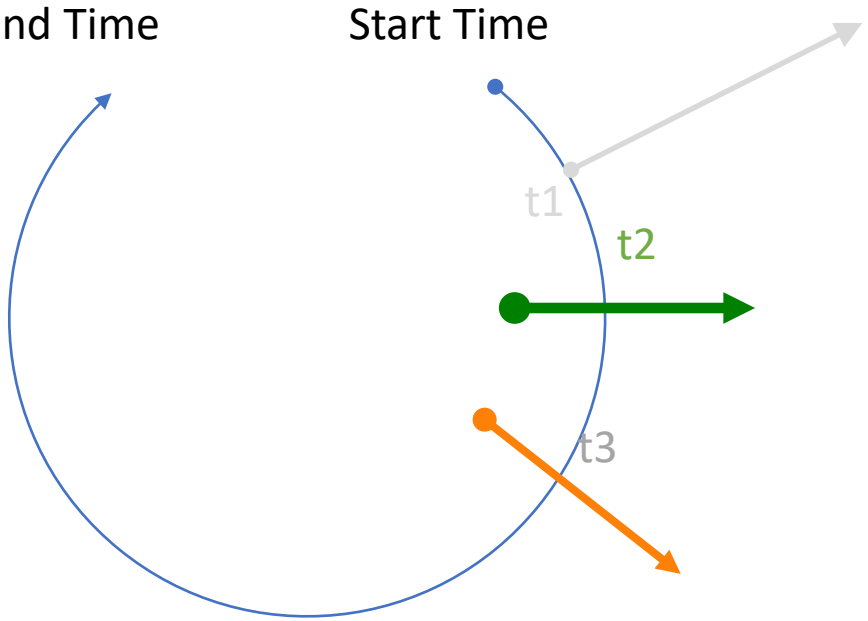

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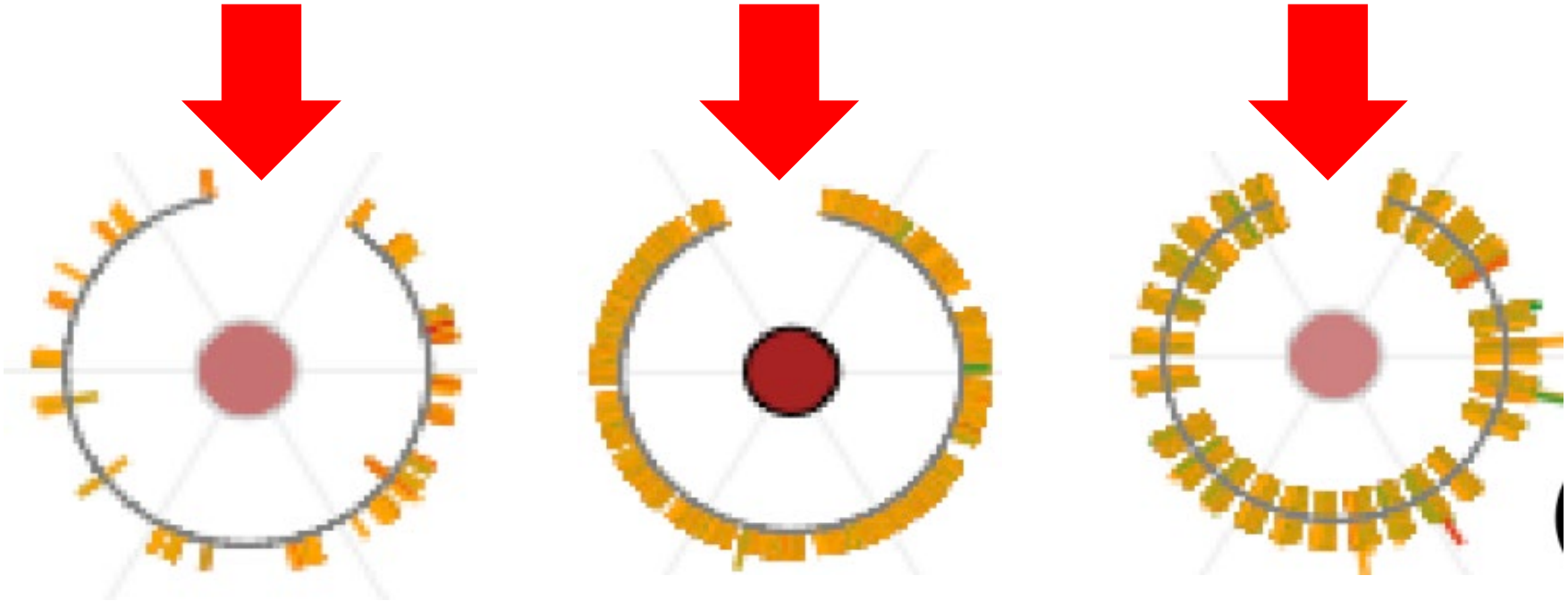

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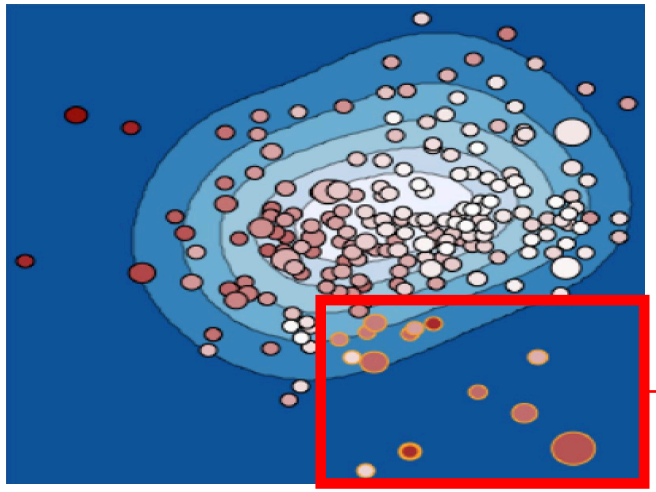
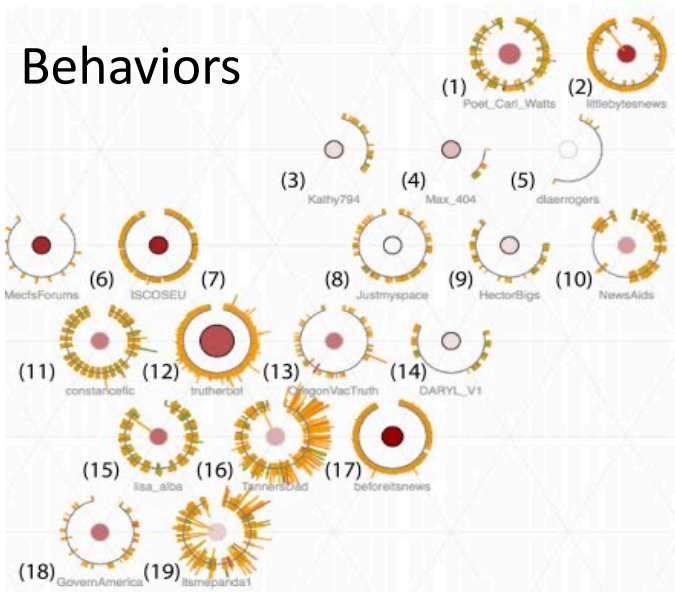
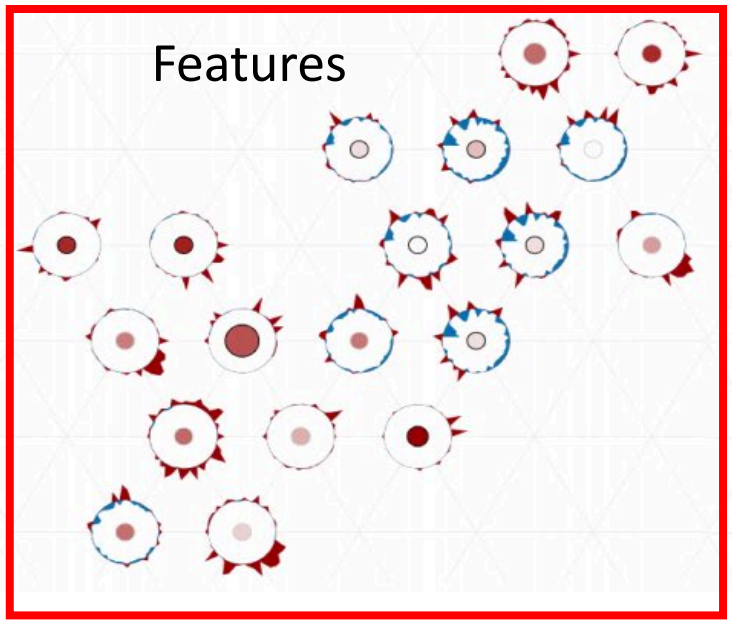
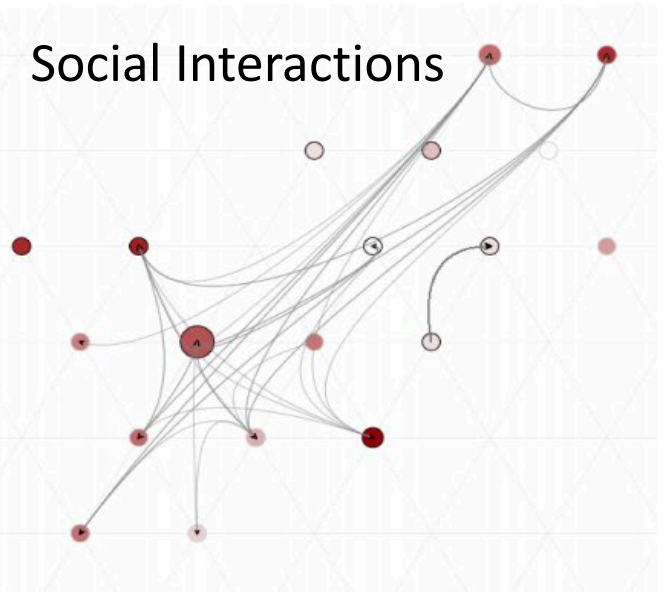
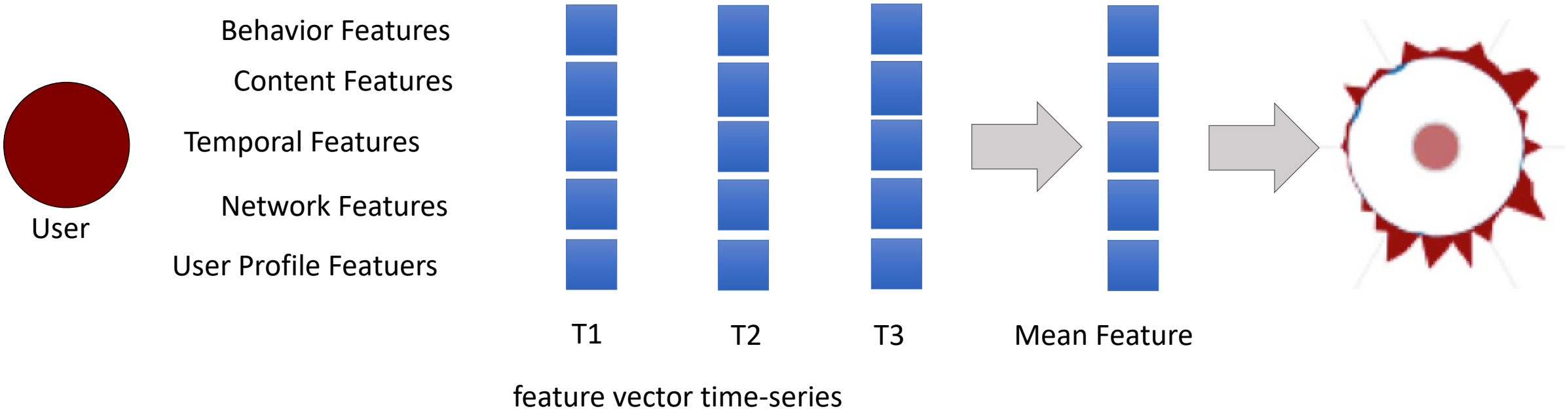




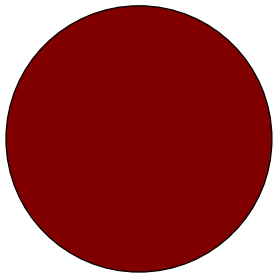




Showing a User's Features

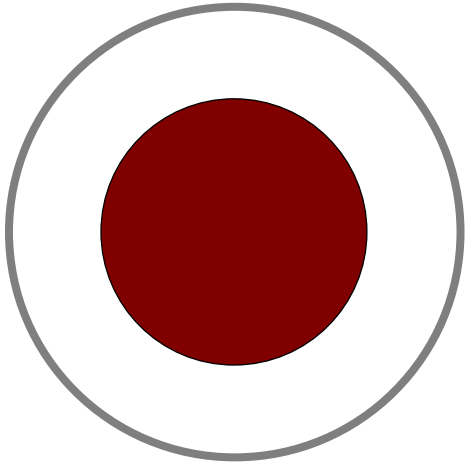


Visualizing a User's Features



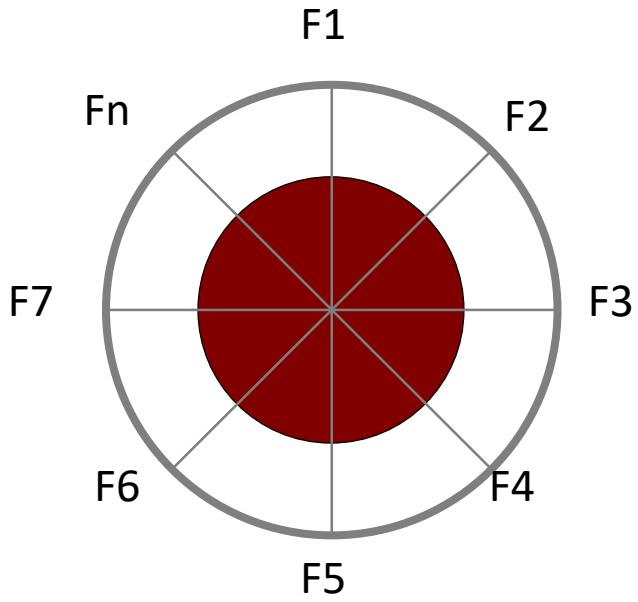
A user is visualized as circle sized by their importance and colored by their anomaly score

Visualizing a User's Features



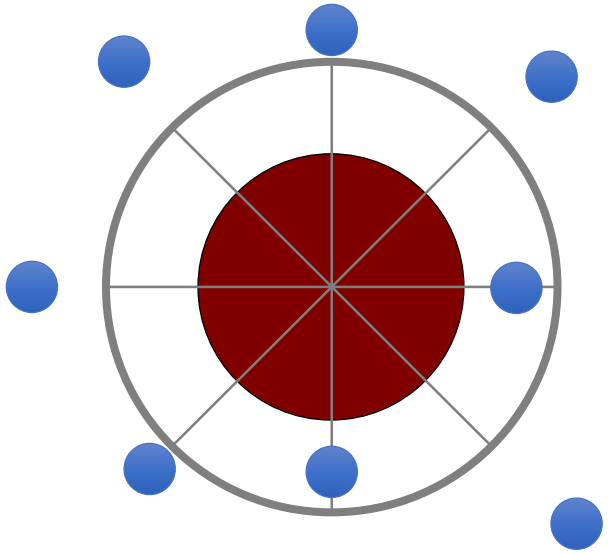
Using a baseline circle to indicate the mean feature values over all the users

Visualizing a User's Features



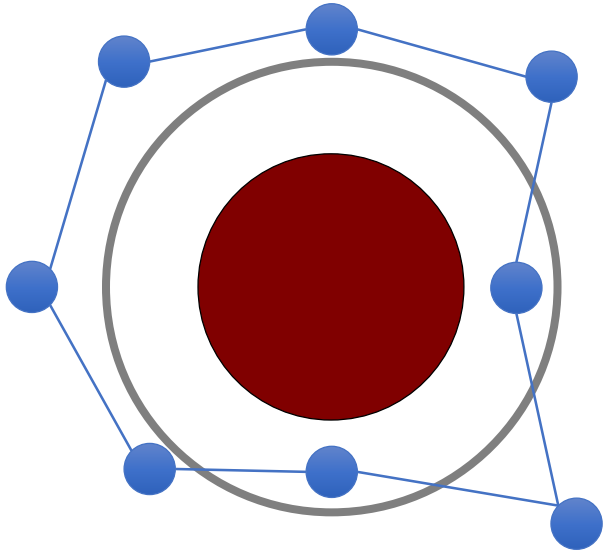
Feature axes are radially arranged

Visualizing a User's Features



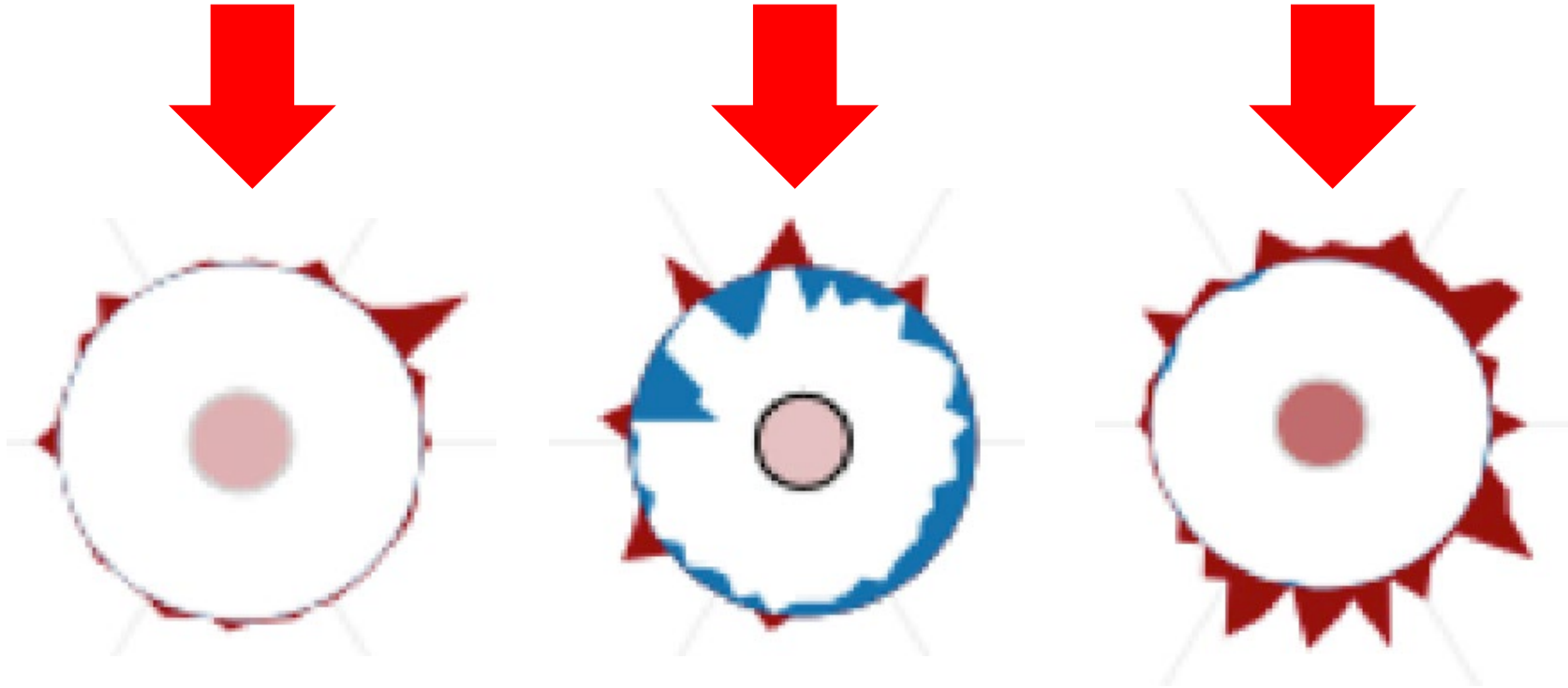
Plot the user's feature values along the feature axes surrounding the baseline

Visualizing a User's Features

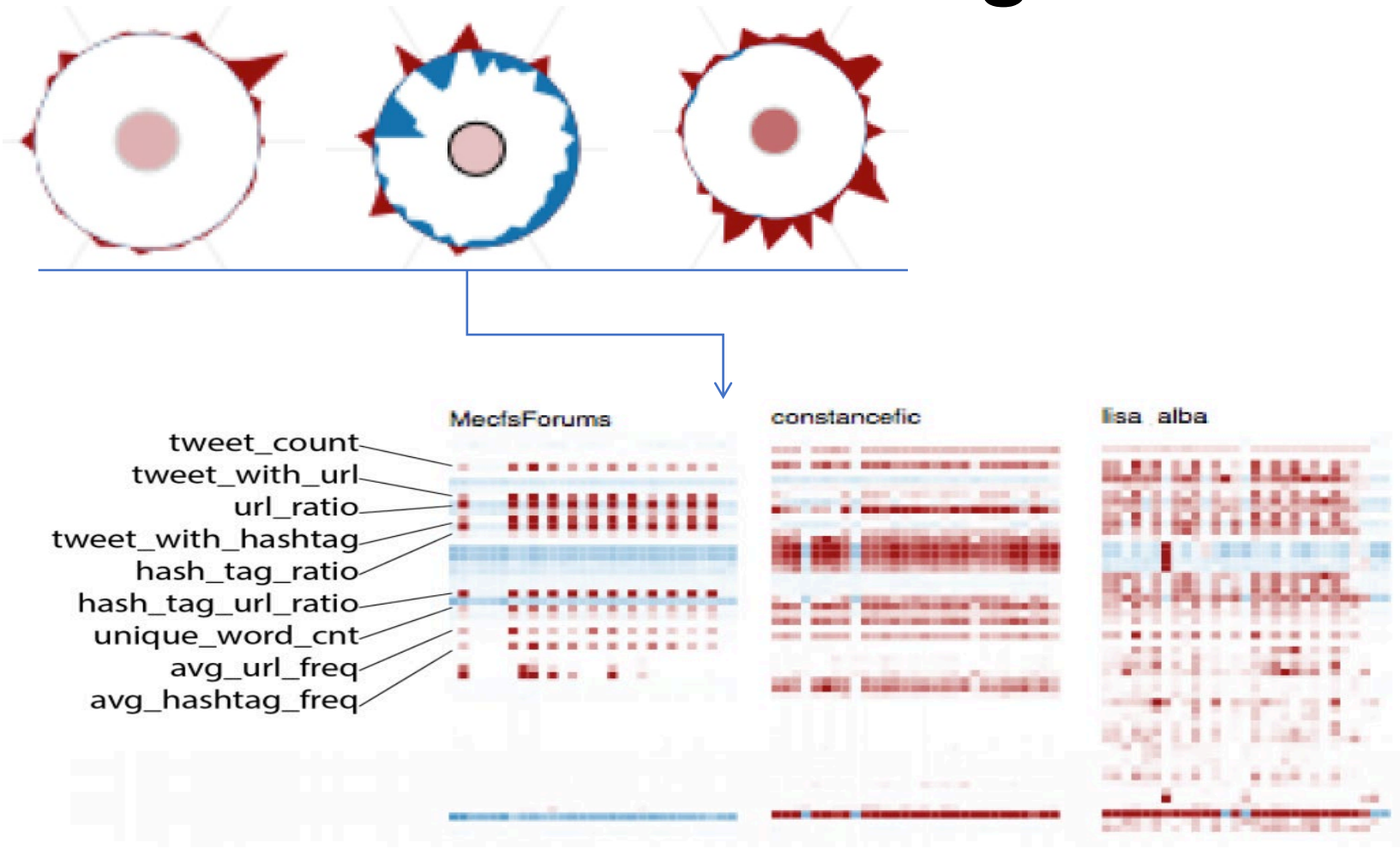


Connecting the data points to produce the feature glyph

Who is the normal user?



Context View 2: Showing Feature Dynamics

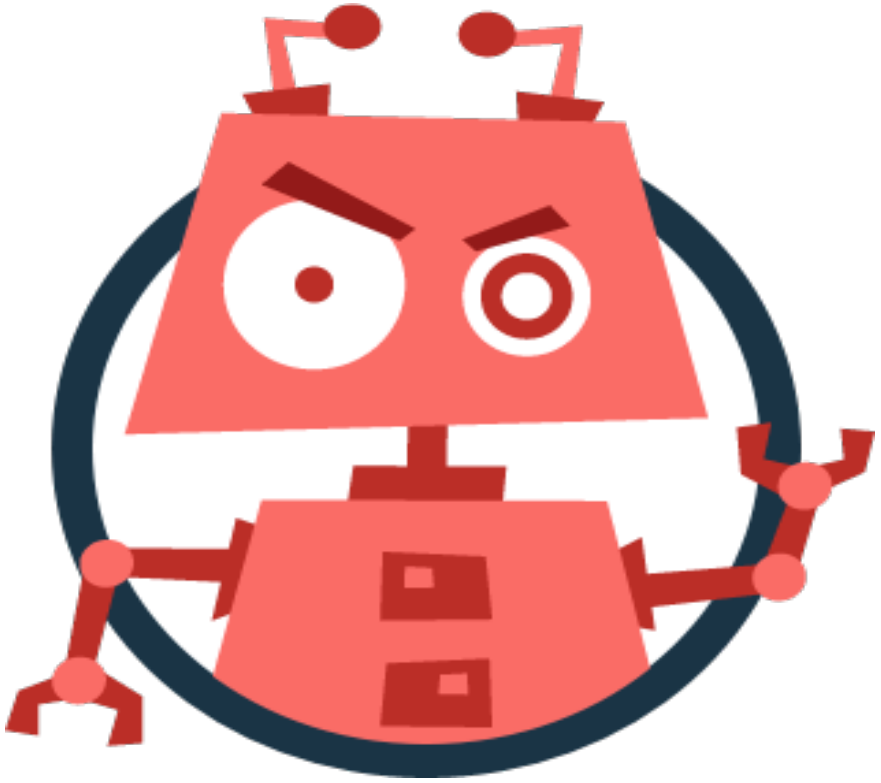


Showing the change of users' features over time in a heatmap

- Each user is shown as a heatmap
- **Row:** different features
- **Column:** different timestamp
- **Cell Color:** feature values (red: larger than mean, blue: smaller than mean)

Introduction
Visualization Design
Evaluation

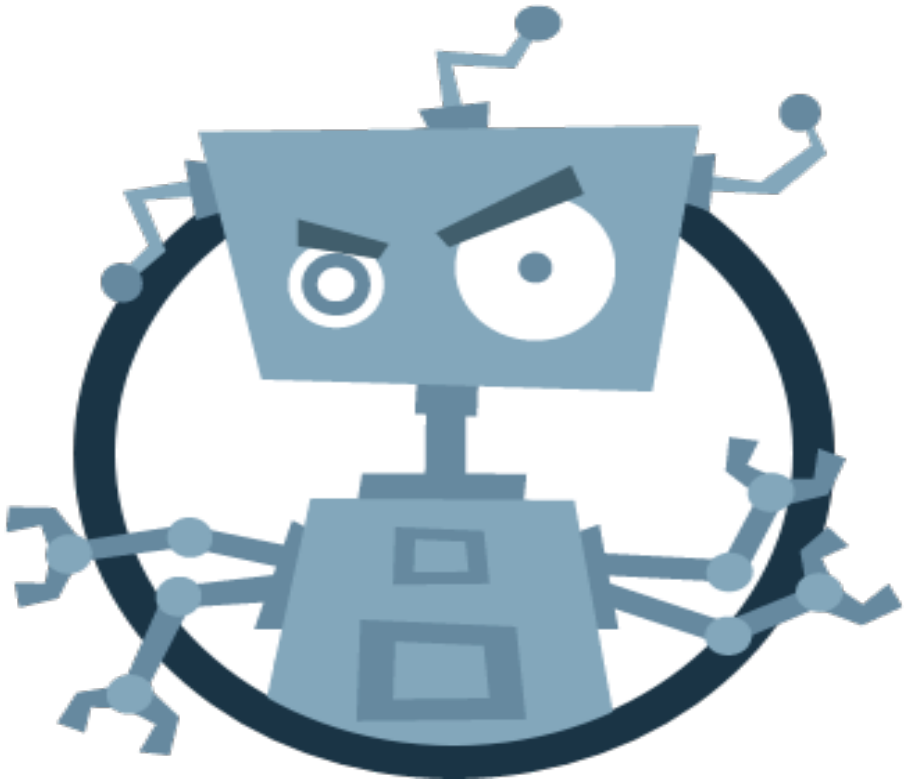
Evaluation: Bot Detection Challenge



Bot Influence Challenge

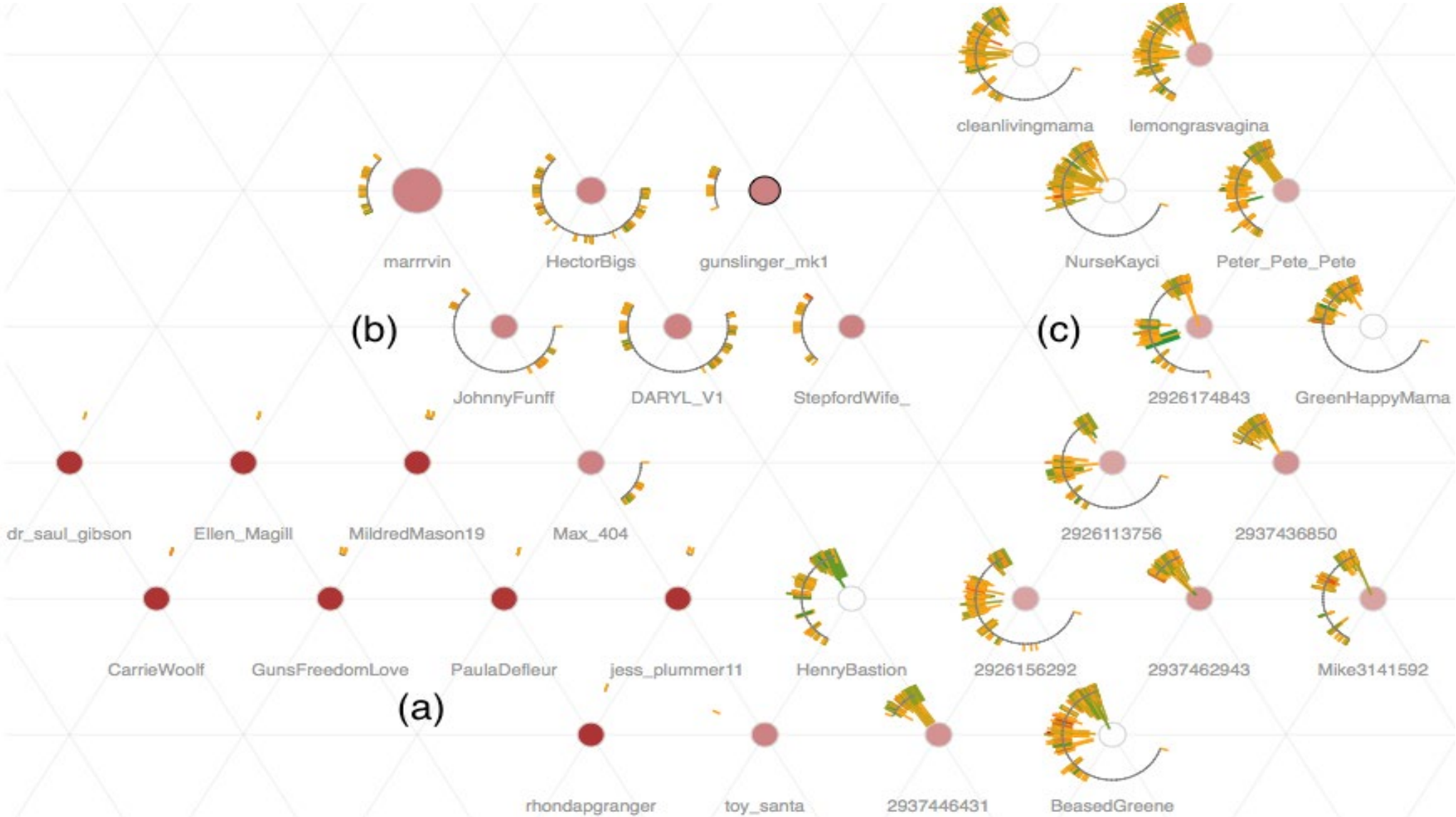
- The goal of the influence challenge was to
  - design social bots in Twitter to promote the advantages of vaccination
  - influence a target network of users who are supporters of anti-vaccine
- Lasted for a month during Dec 2014
- 8000 target users, 4 million tweets

Evaluation



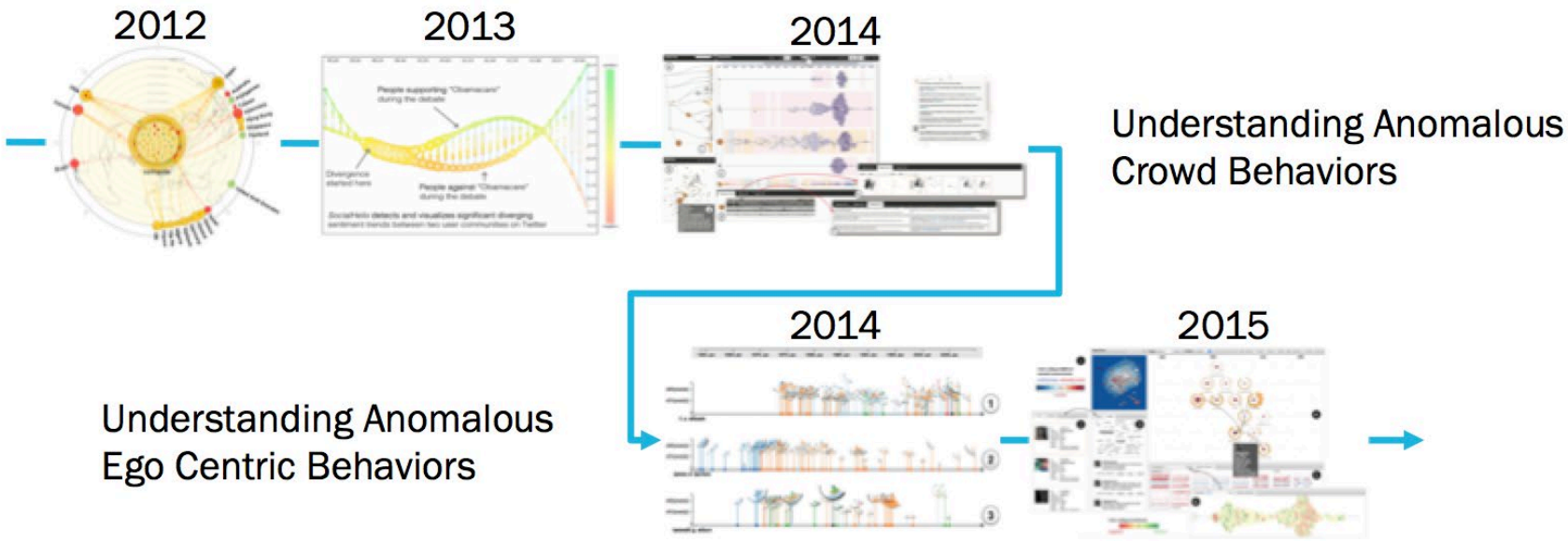
Bot Detection Challenge

Final Results



Conclusion

- Part I : Data Visualization
- Part II: Interactive Visual Anomaly Detection



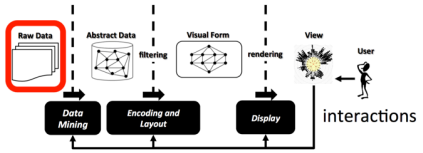
Intelligent Big Data Visualization (iDVˣ) Lab

http://idvxlab.github.io

iDVˣ Lab

Intelligent Big Data Visualization Lab is founded in 2016. It is an international research lab focuses on design and develop novel visualization, visual analysis, and HCI techniques. The Lab focused on develop novel visualization, visual analysis, UX, and HCI technologies to support anomaly detection and apply them in a variety of application fields, including internet security, smart city, business intelligence, healthcare informatics, and industry 4.0.

Visual Analytics

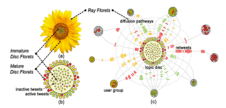


Visual analytics is "the science of analytical reasoning facilitated by interactive visual interfaces." It can attack certain problems whose size, complexity, and need for closely coupled human and machine analysis may make them otherwise intractable. Visual analytics advances science and technology developments in analytical reasoning, interaction, data transformations and representations for computation and visualization, analytic reporting, and technology transition. As a research agenda, visual analytics brings together several scientific and technical communities from computer science, information visualization, cognitive and perceptual sciences, interactive design, graphic design, and social sciences.

InfoSec

Our research of InfoSec focused on detecting anomalous user behaviors such as intrusion detection in Internet, fraud detection in finance, and rob detection on social media.

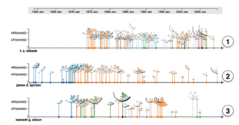
Anomalous Collective Behaviors



Monitoring and Tracing of Information Diffusion Process

Visual Analysis and interpretation of anomalous information spreading

Anomalous Ego-Centric Behaviors



Interpretation of Ego-Centric Social Behaviors on Twitter

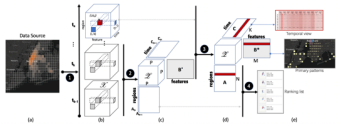
Visual Analysis System for Detecting Social Media Users with Anomalous User Behaviors such as Bots

Smart City

A smart city is an urban development vision to integrate information and communication technology and Internet of things technology in a secure fashion to manage a city's assets. A smart city is promoted to use urban informatics and technology to improve the efficiency of services. Our research in this filed focused on the public security problems in the city. We aim to leverage visual analysis systems to monitor and detect anomalous traffic and mobility patterns in the city to avoid incident such as 2014 Shanghai stampede.

Dynamic Region Segmentation

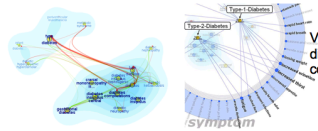
Anomalous Mobility Pattern Detection



Health Informatics

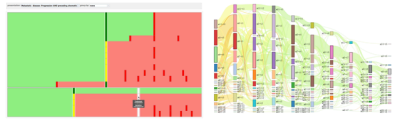
Health informatics is informatics in health care. It is a multidisciplinary field that uses health information technology (HIT) to improve health care. The disciplines involved include information science, computer science, social science, behavioral science, management science, and others. Our research focused on detection anomalous genes, patients, care plans, heatbeats in ECG, etc.

Disease Diagrams and Visualization



Visualizing diseases and their complications

Analysis of Anomalous Care Plan



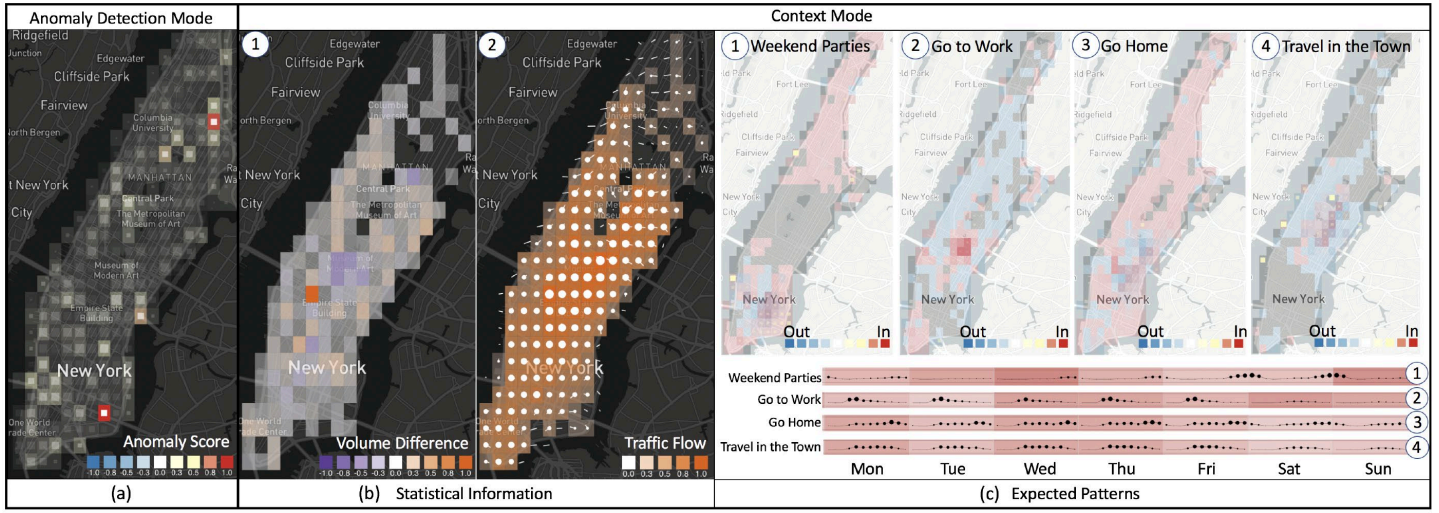
Detect Anomalous Cohort

Detect and interpret the anomalous cohorts

Anomaly Detection

Anomaly detection (also outlier detection) is the identification of items, events or observations which do not conform to an expected pattern or other items in a dataset. Visualization techniques are used for addressing two major challenges: (1) there is no clear boundary between normal and abnormal and (2) the unavailable of ground truth or labelled data making results validation difficult.

Voila: Visual Anomaly Detection and Monitoring with Streaming Spatiotemporal Data

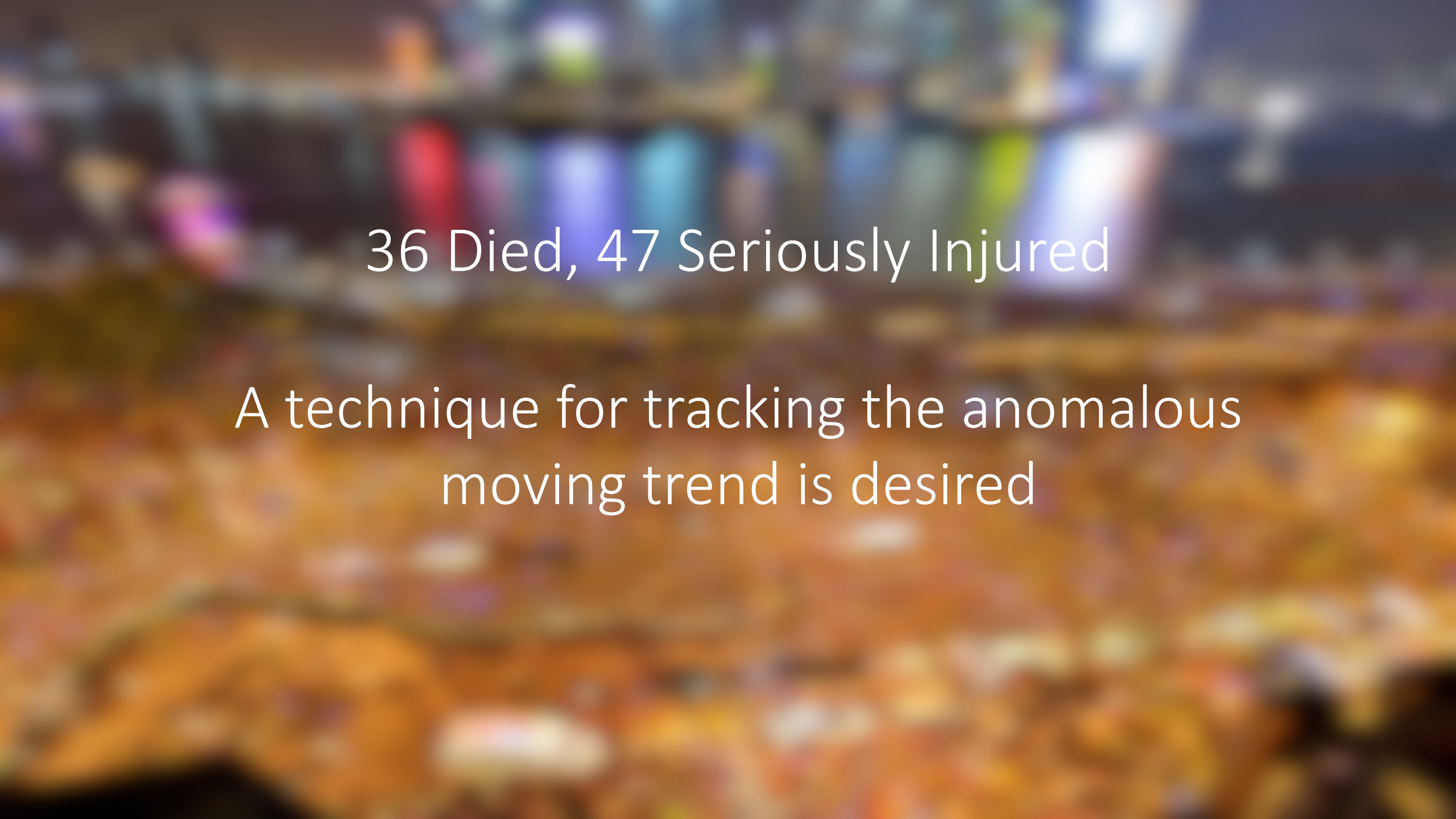


Nan Cao
Chaoguang Lin, Qiuhan Zhu

Yu-Ru Lin
Xian Teng, Xidao Wen


The Bund (外滩)

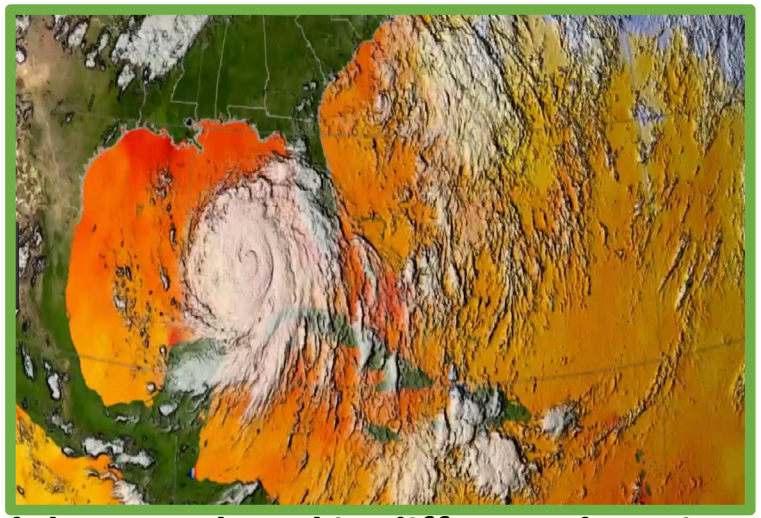

36 Died, 47 Seriously Injured


36 Died, 47 Seriously Injured
A technique for tracking the anomalous moving trend is desired

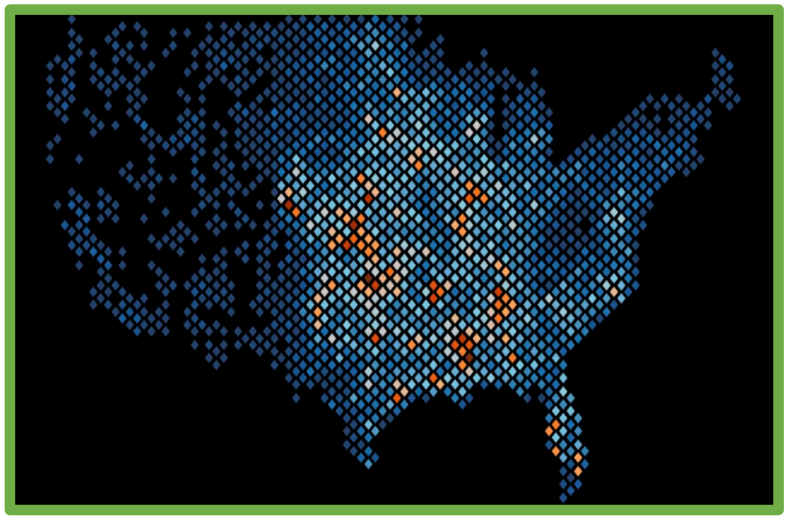
Research Goal

Urban computing

Meteorology



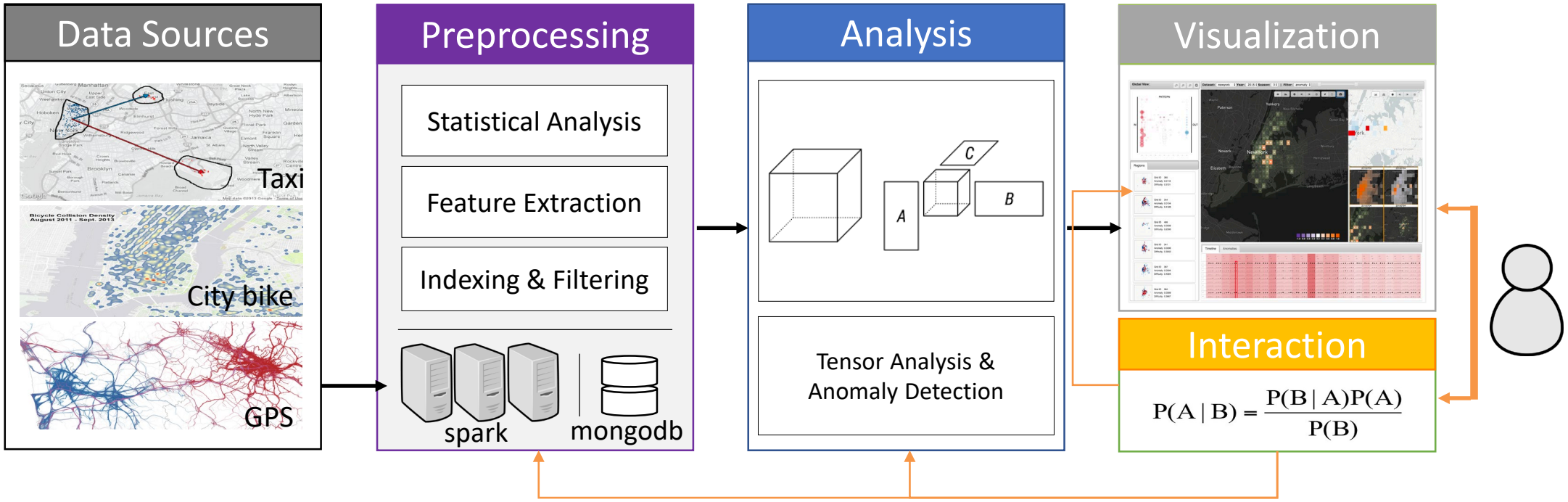
Public Health Surveillance



Streaming spatiotemporal data produced in different domains

- ***Monitoring*** the dynamic streaming spatiotemporal data
- ***Detecting*** anomalous events in time
- ***Forecasting*** rare spatiotemporal events (future work)

System Overview



Introduction

Tensor Based Anomaly Detection

Visualization Design

Evaluation

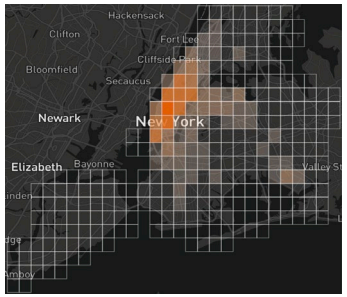
Conclusion

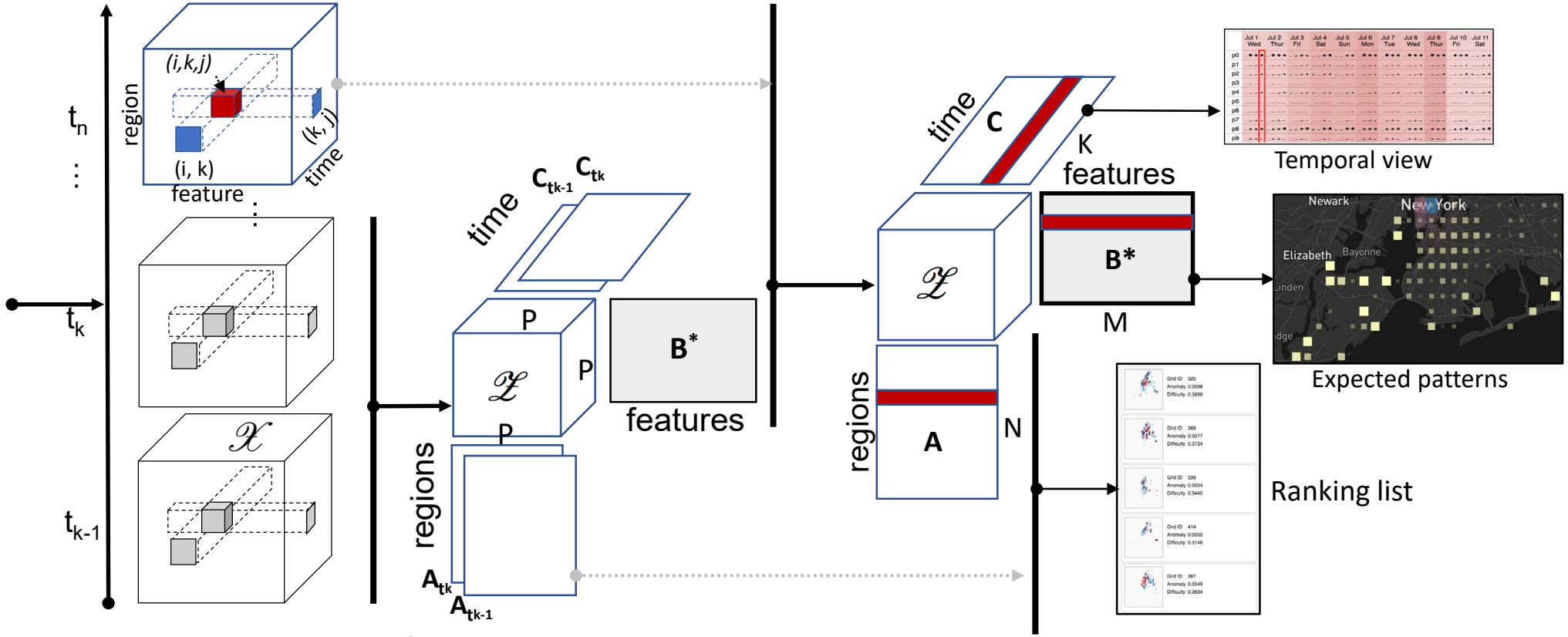
Tensor based Anomaly Detection

S-1: Data Transformation

S-3: Dynamic Pattern Analysis

Data Source





S-2: Expected Pattern Extraction

S-4: Anomaly Detection

Stage I: Data Transformation

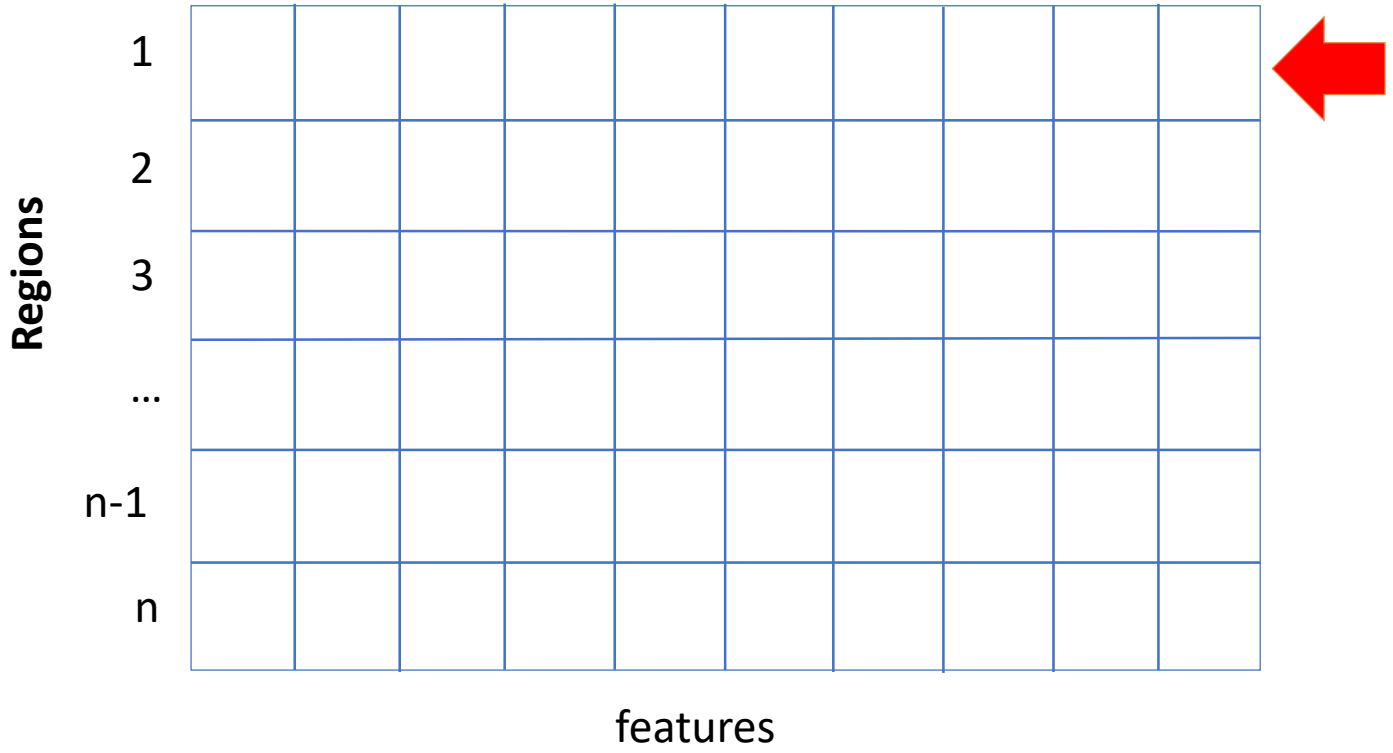
Data Source

Stage I: Data Transformation

Data Source

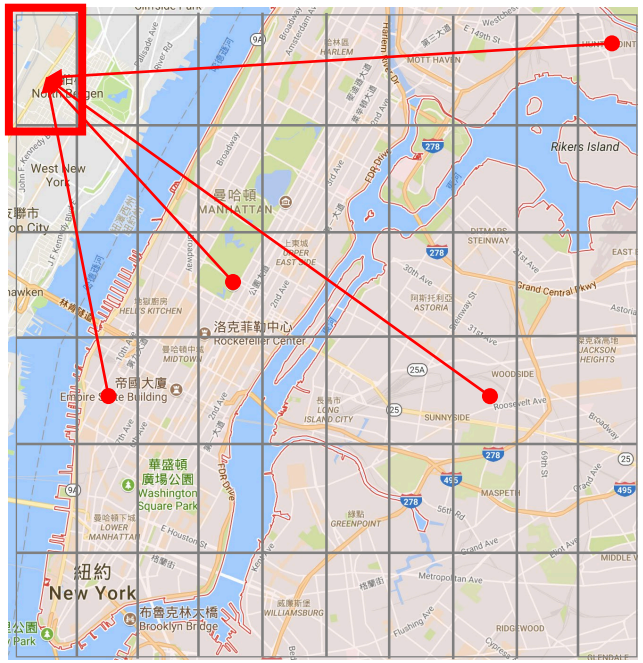
Stage I: Data Transformation

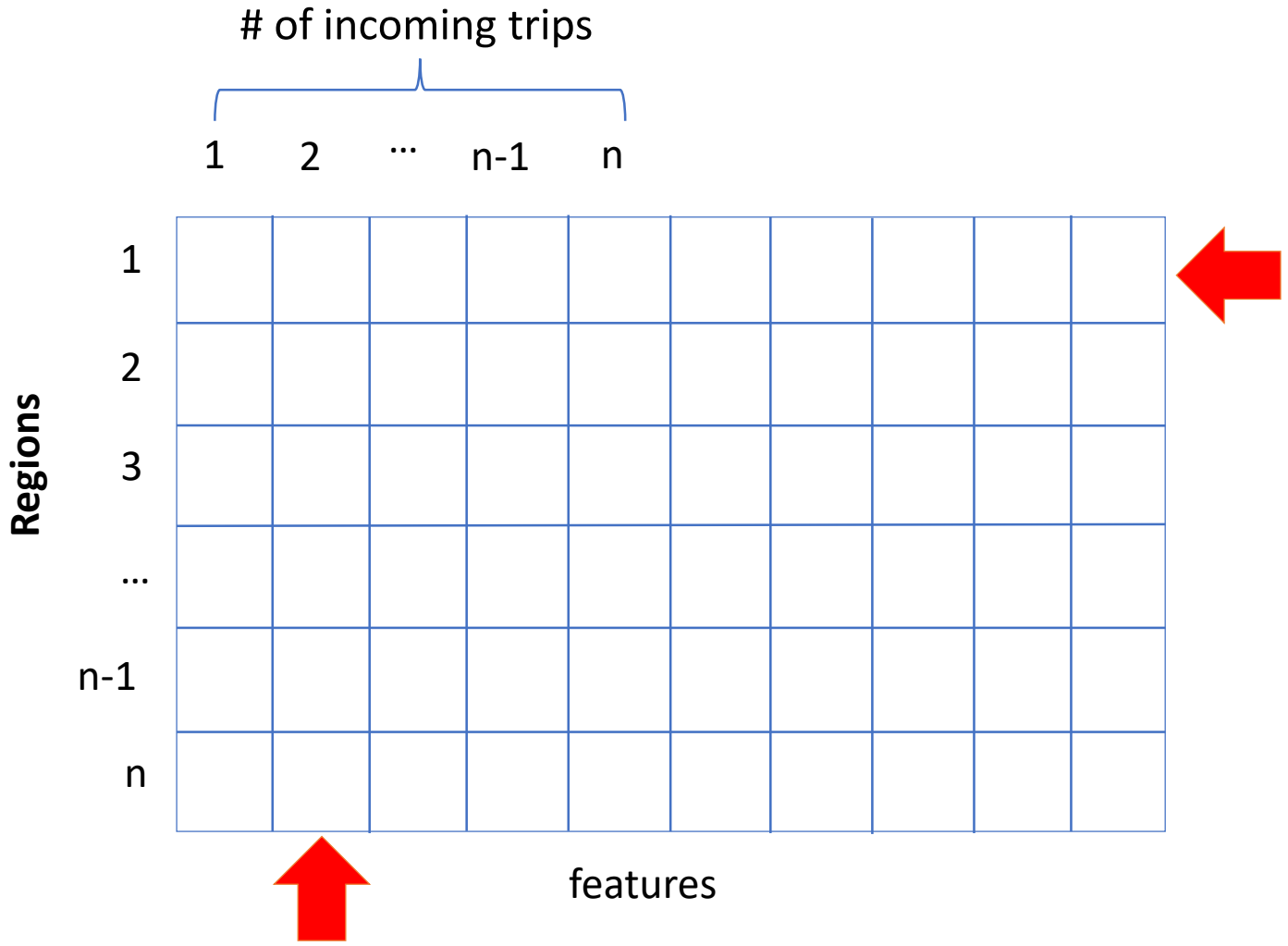
Data Source



Stage I: Data Transformation

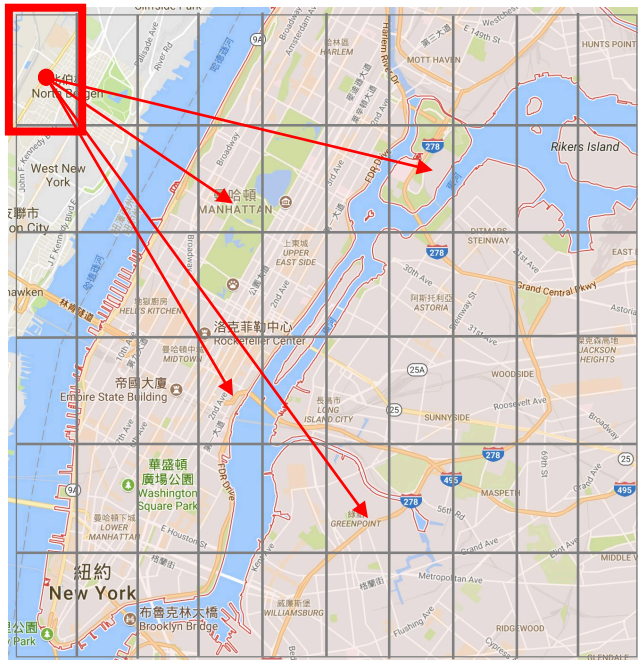
Data Source

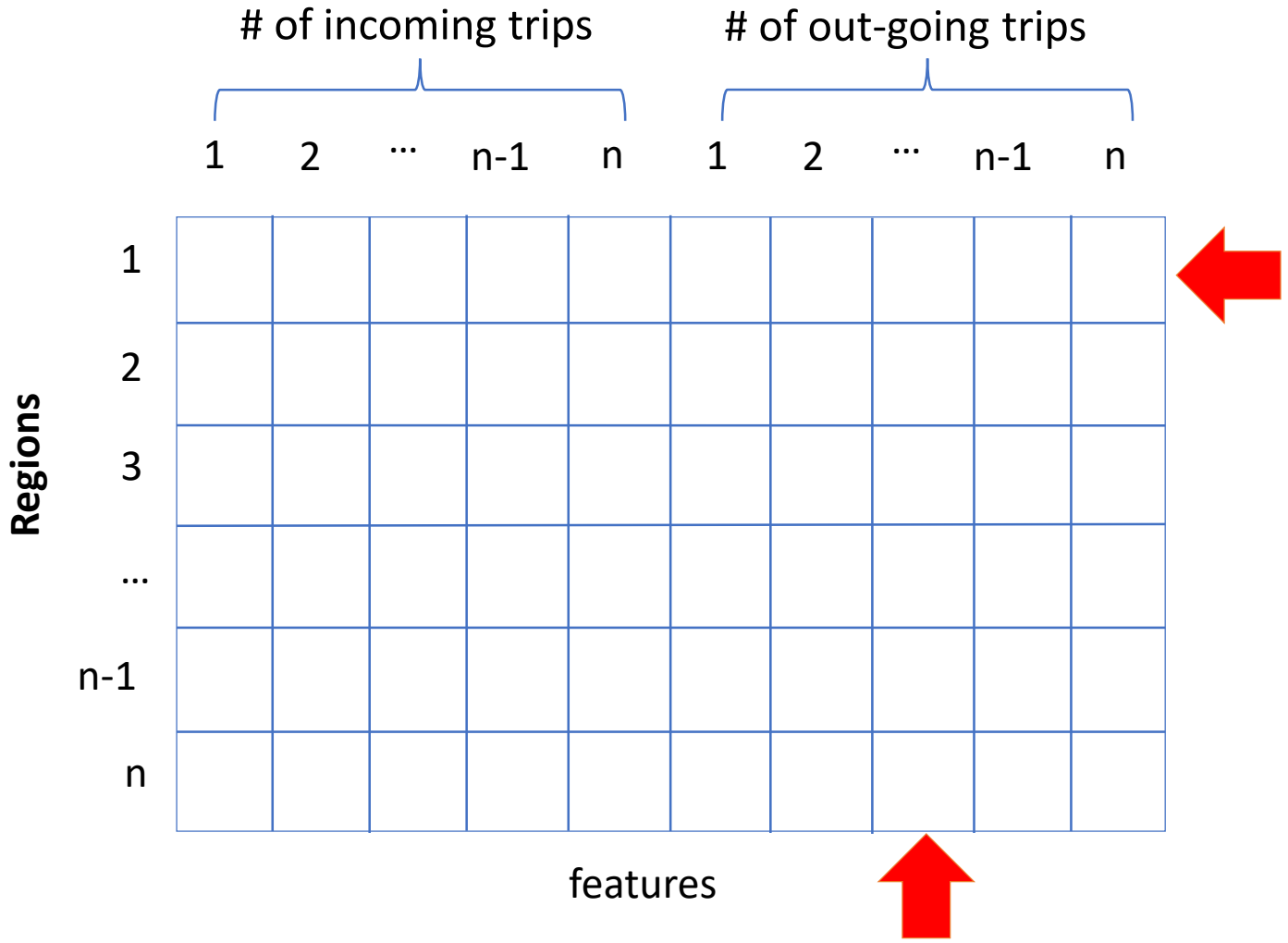




Stage I: Data Transformation

Data Source

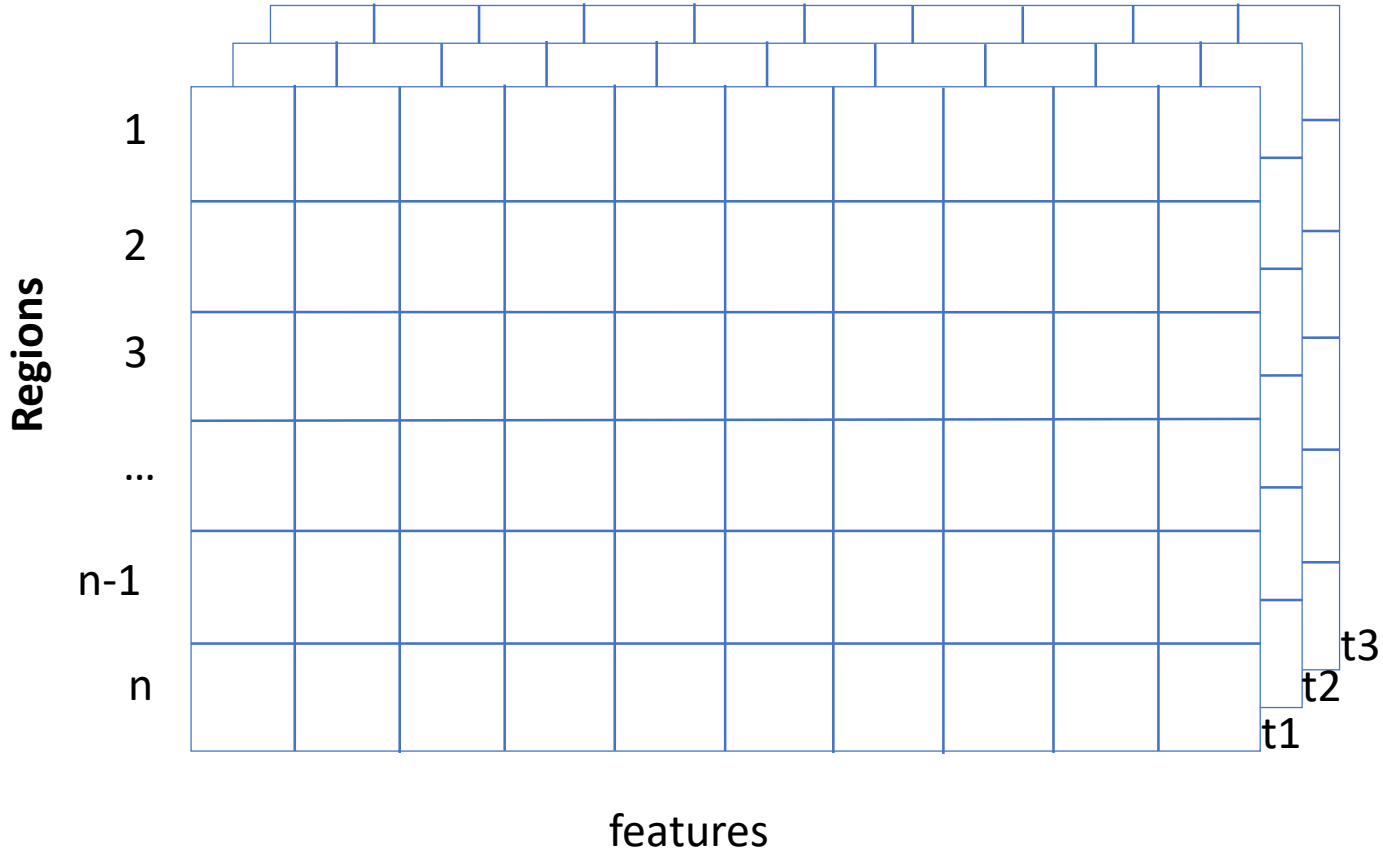




Stage I: Data Transformation

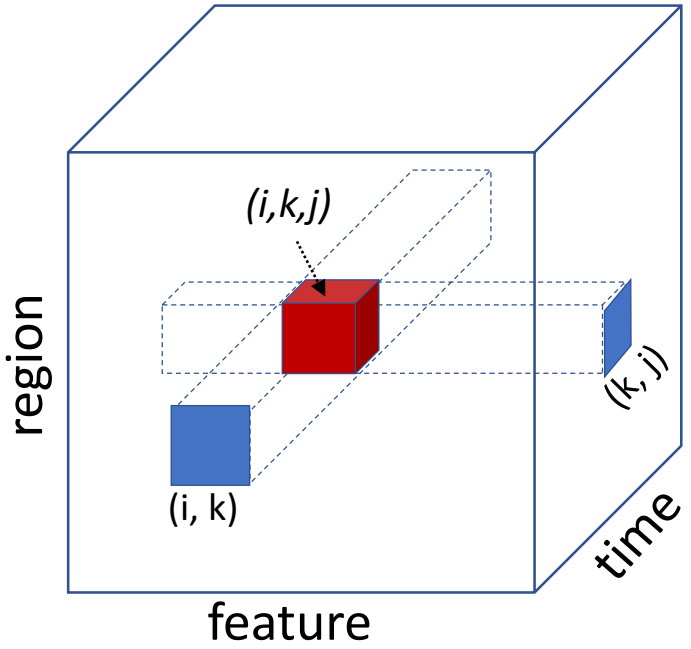
Data Source

Take temporal information into consideration



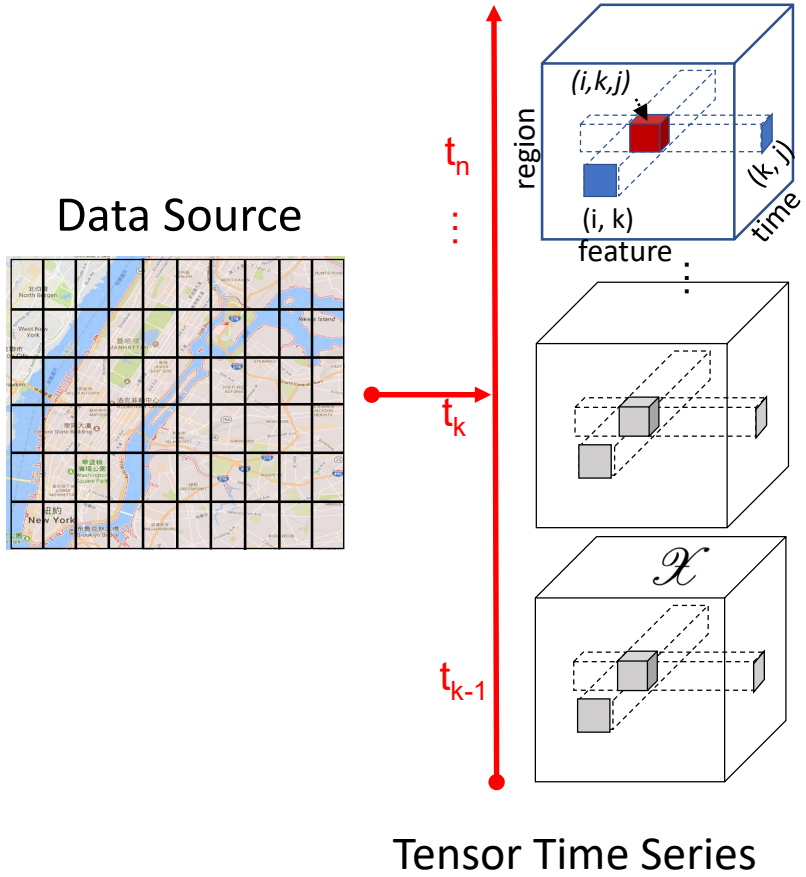
Stage I: Data Transformation

Data Source



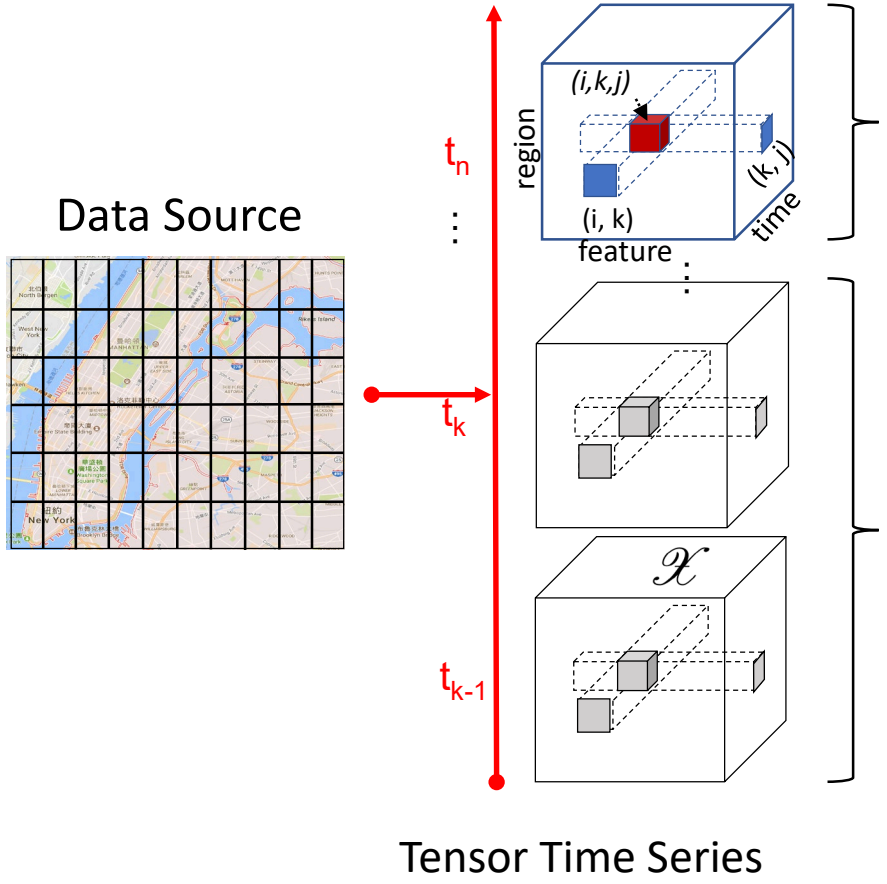
3-way tensor, with each dimension respectively represent region, feature, and time

Stage I: Data Transformation



Each tensor represent the data gathered within a given time period (e.g., 5min, an hour, or a day)

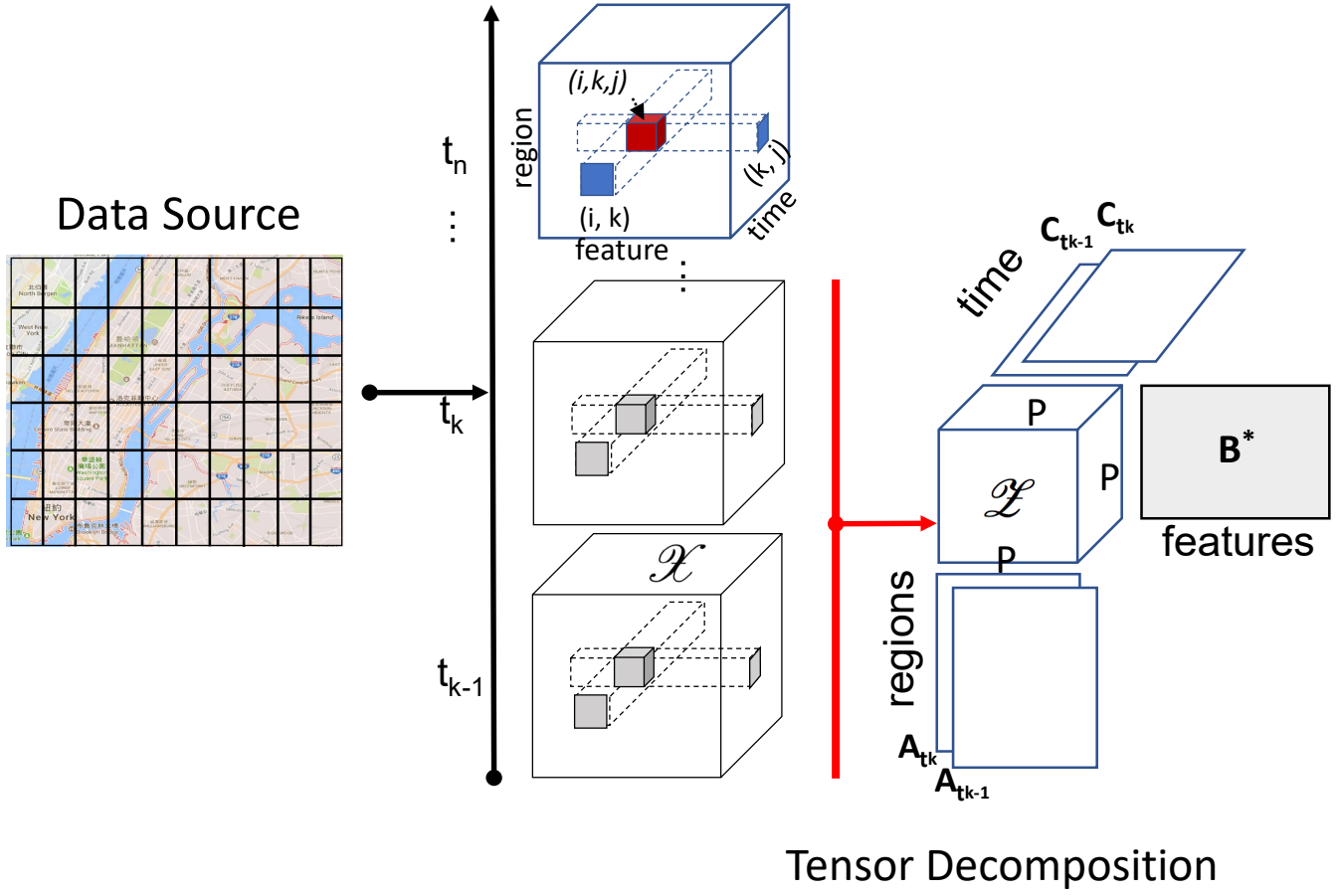
Stage I: Data Transformation



The data under monitoring for the dynamic pattern analysis

Historical data for the expected pattern extraction

Stage II: Expected Patten Analysis



Tensor Decomposition

$$min \| \mathscr{X} - [\![\mathscr{Z}; \mathbf{A}, \mathbf{B}, \mathbf{C}]\!] \|$$

$\mathscr{Z}$: Super diagonal core tensor with the diagonal elements indicates the weight

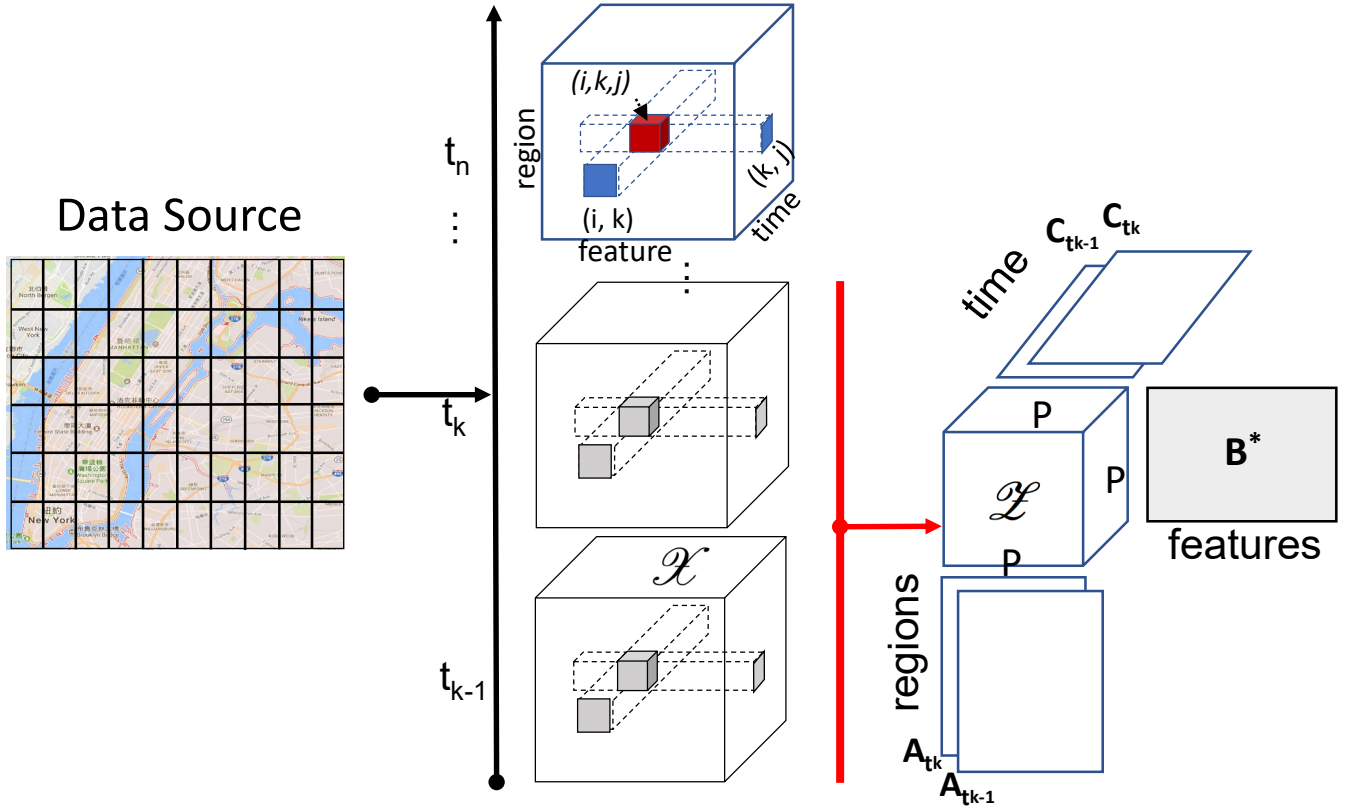
P : # of latent patterns

A : The distribution of latent patterns over regions

C : The distribution of latent patterns over time

B : Pattern- Feature matrix that interprets the meaning of the latent pattern

Stage II: Expected Patten Analysis



Tensor Decomposition

$$\mathbf{B}^* = arg\,min \sum_{t=1}^{n} (\| \mathcal{X}_t - [\![\mathcal{Z}; \mathbf{A}_t, \mathbf{B}, \mathbf{C}_t]\!] \|$$

Fix B but relax A and C

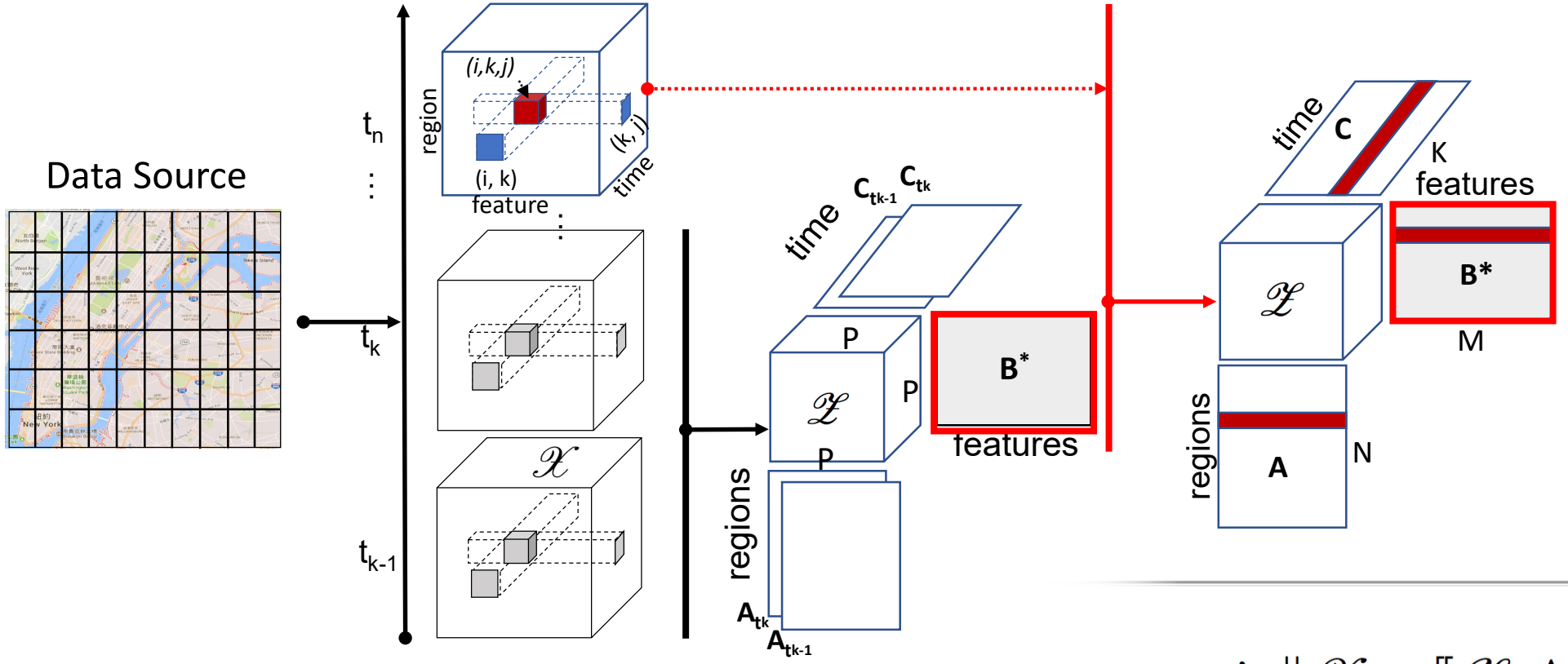
$$+ \alpha \| \mathbf{A}_t - \mathbf{A}_{t-1} \| + \beta \| \mathbf{C}_t - \mathbf{C}_{t-1} \|)$$

smooth A and C over time

B: Fixing B while the decomposition of historical data to find latent patterns that remain unchanged

A, C: Smoothing A and C over time to reduce data noise

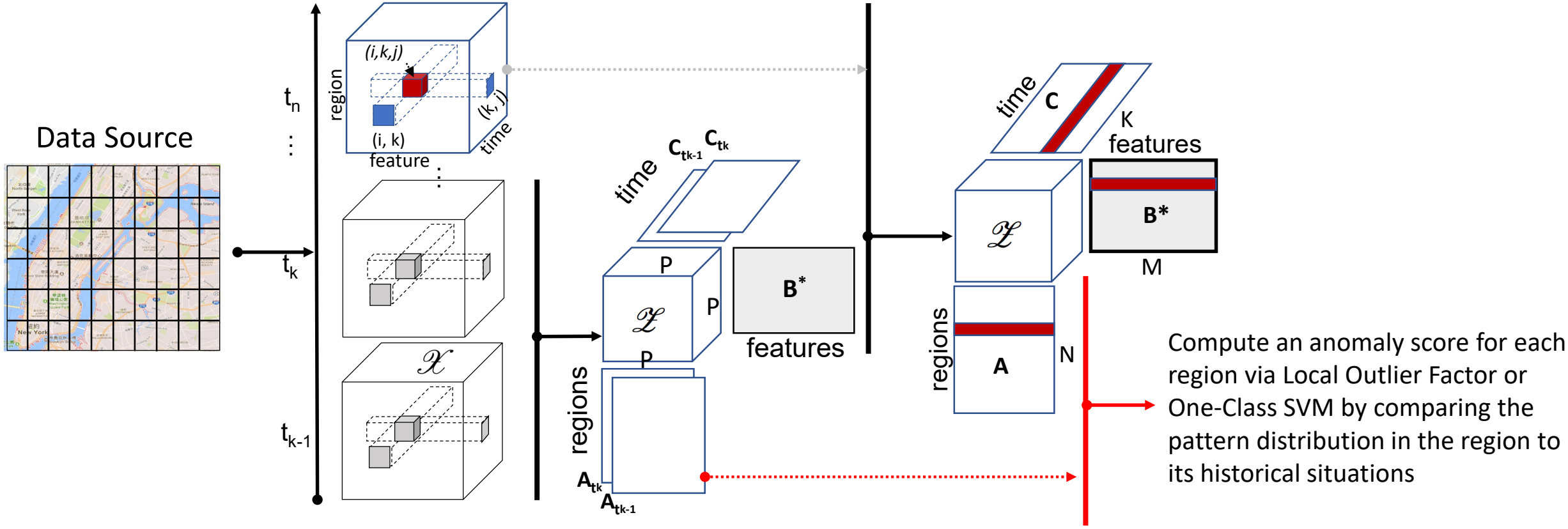
Stage III: Extracting Dynamic Patterns



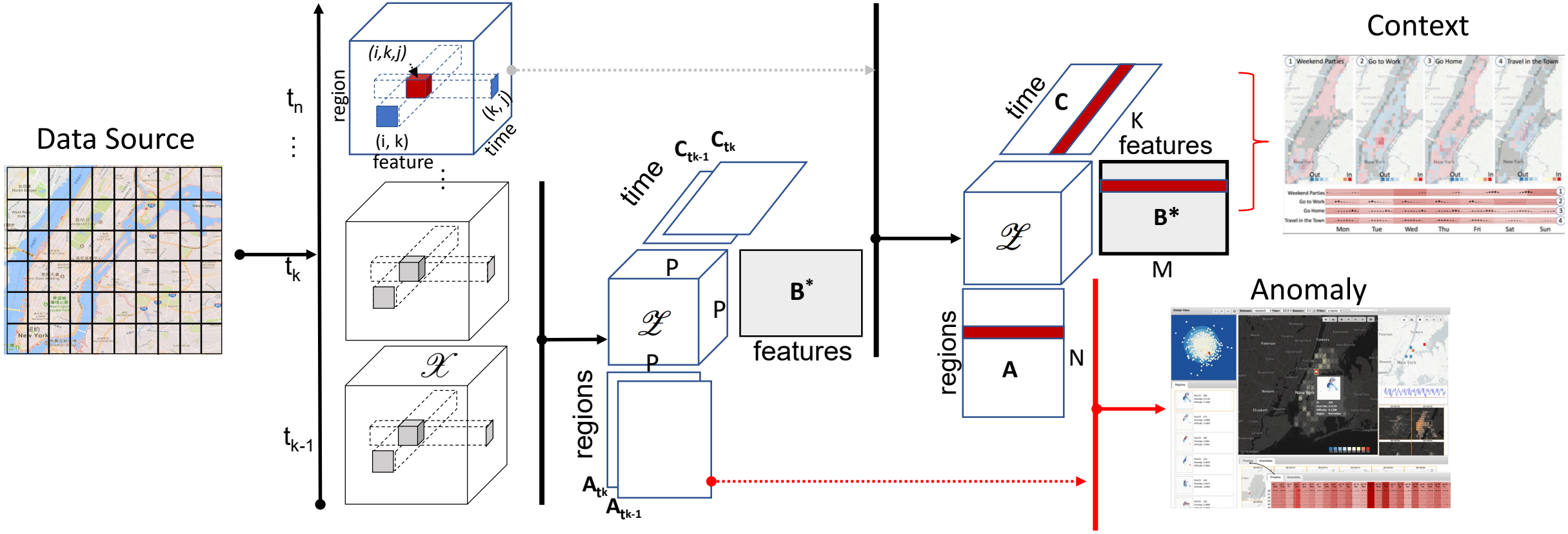
Examine how patterns are dynamically changed over region and time while B is fixed

$$min \| \mathcal{X}_t - [\![\mathcal{Z}; \mathbf{A}_t, \mathbf{B}^*, \mathbf{C}_t]\!] \|$$

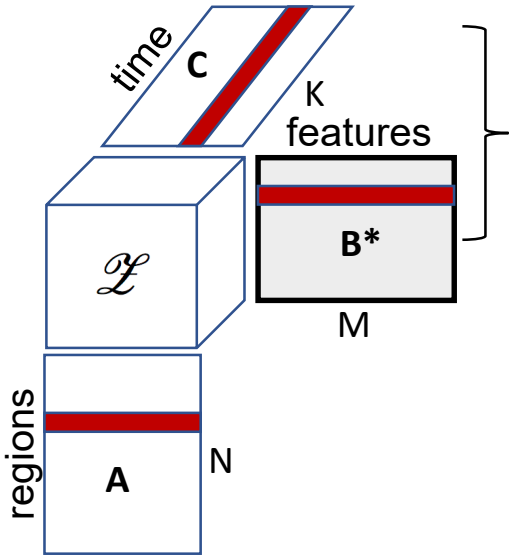
Stage IV: Anomaly Detection



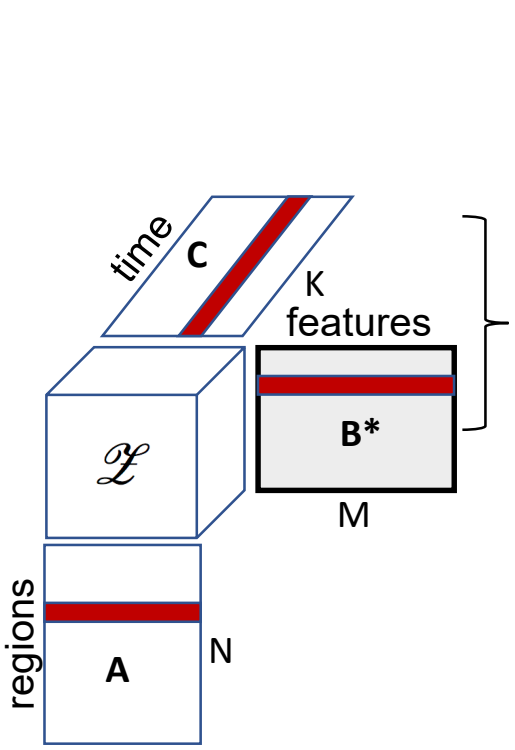
Stage V: Visualization

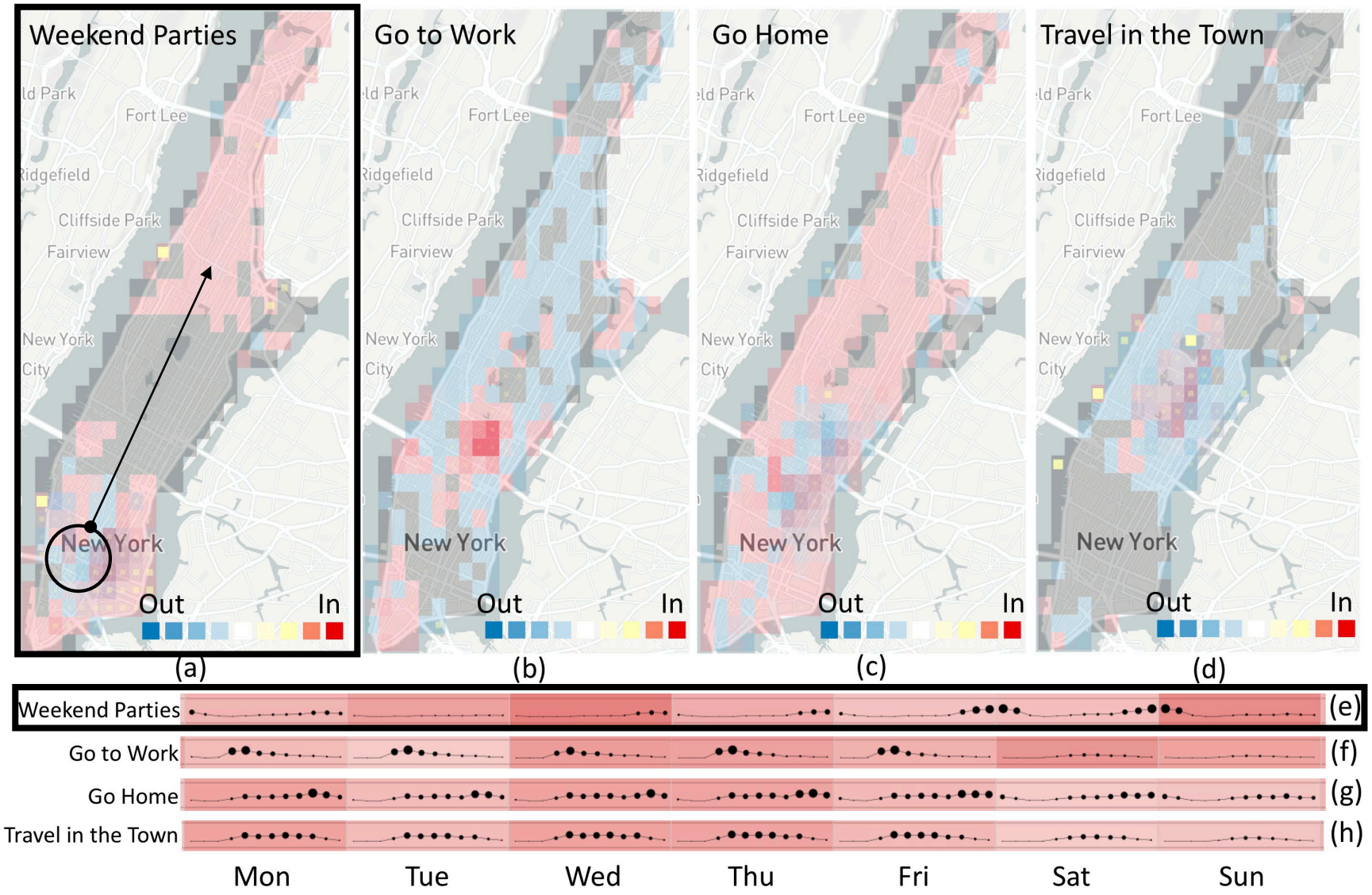


Showing Context: Expected Patterns

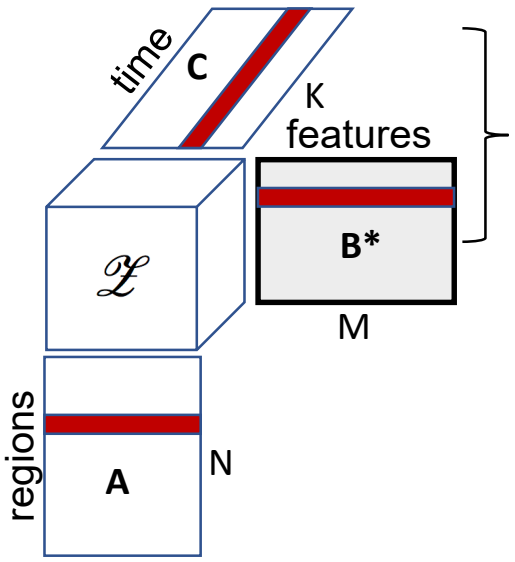


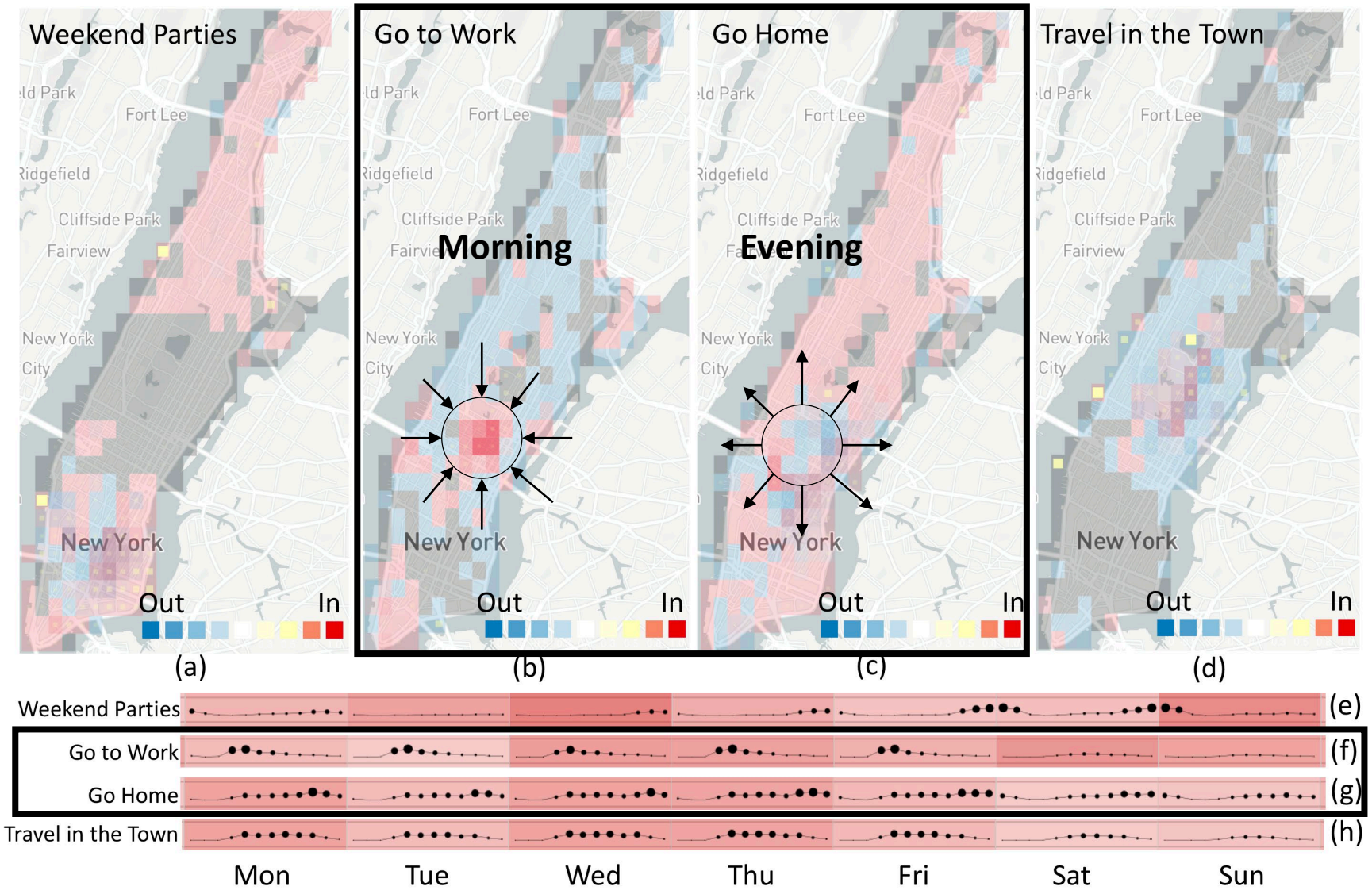
Showing Context: Expected Patterns



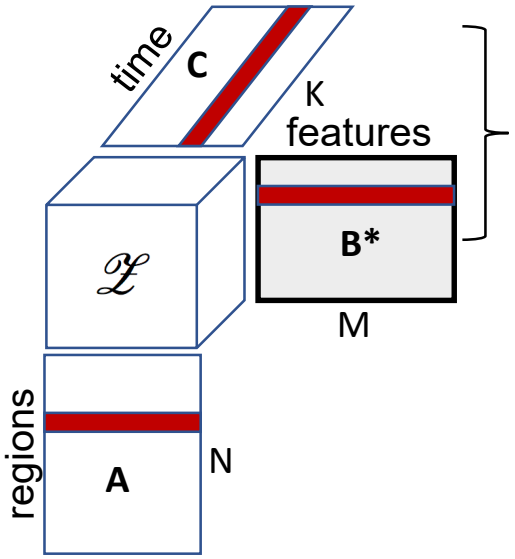


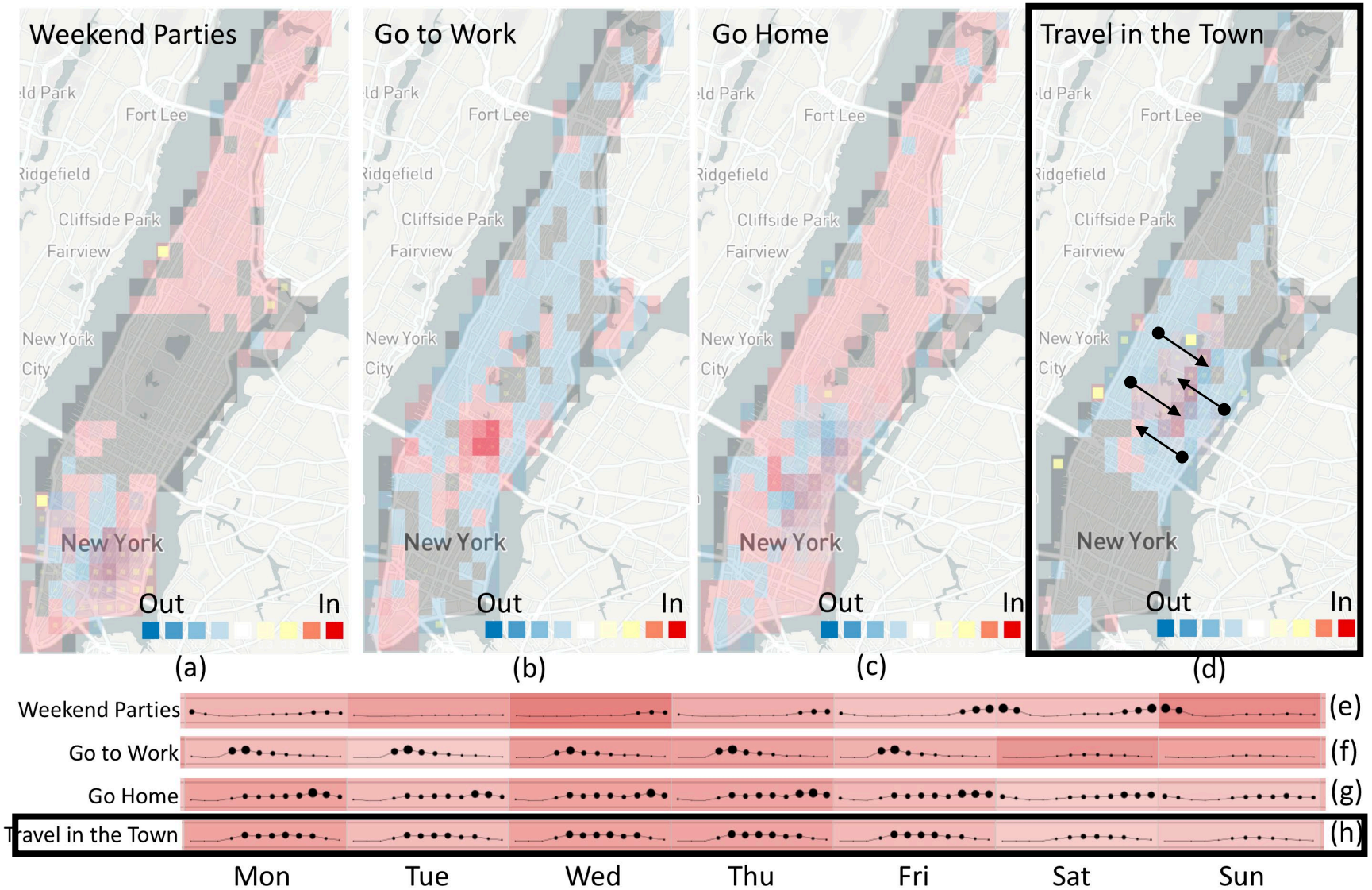
Showing Context: Expected Patterns



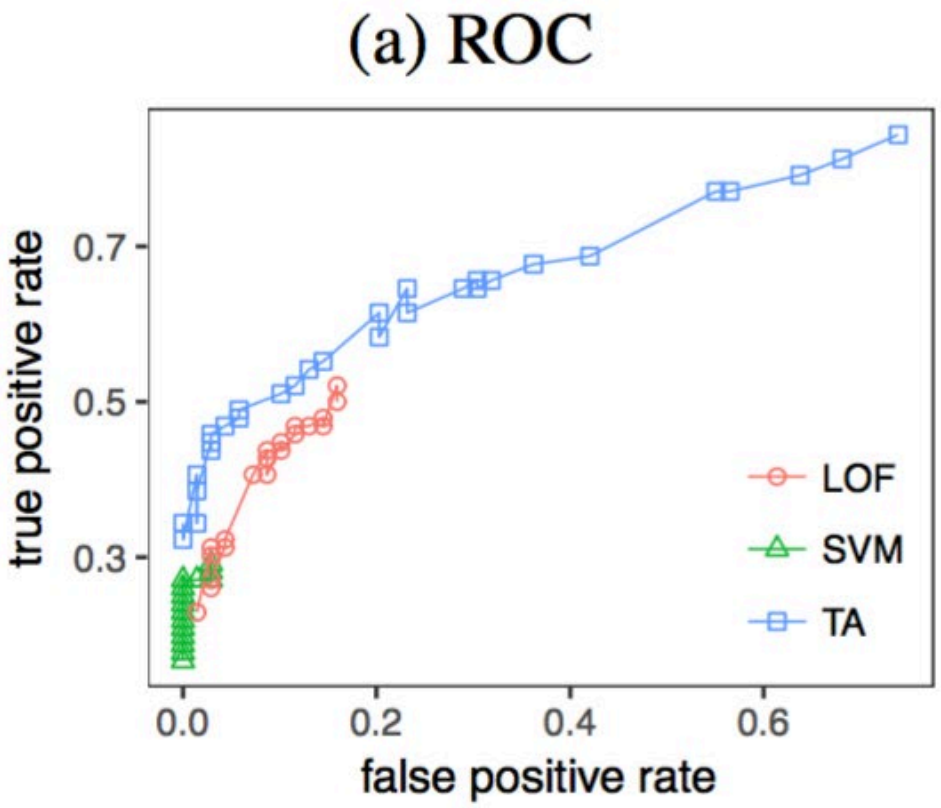


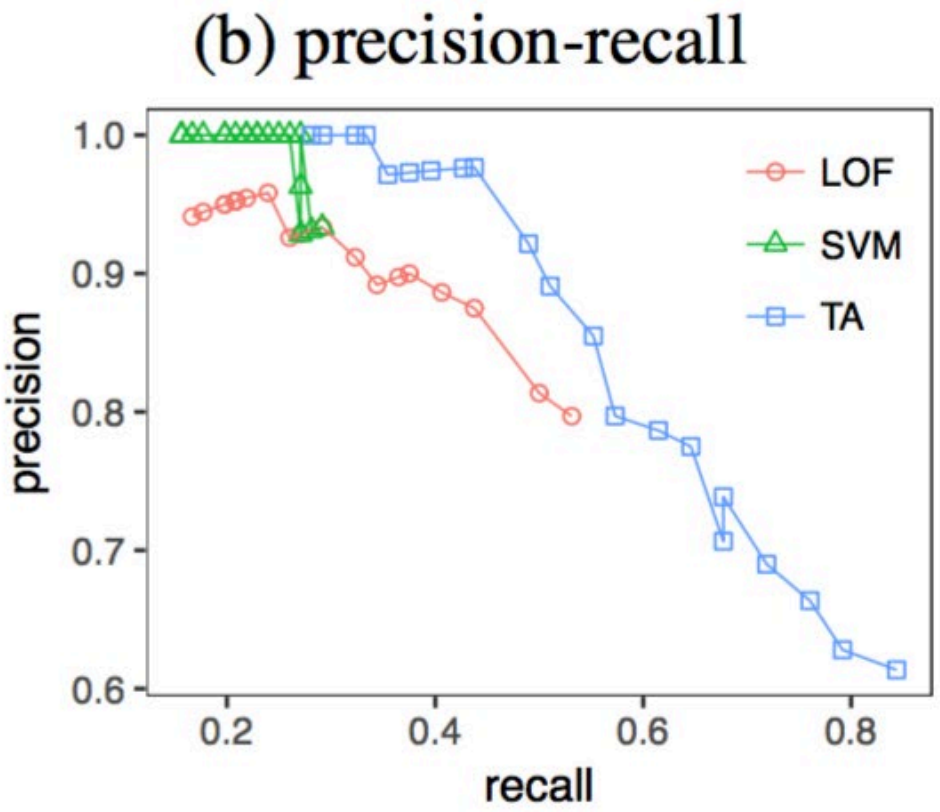
Showing Context: Expected Patterns



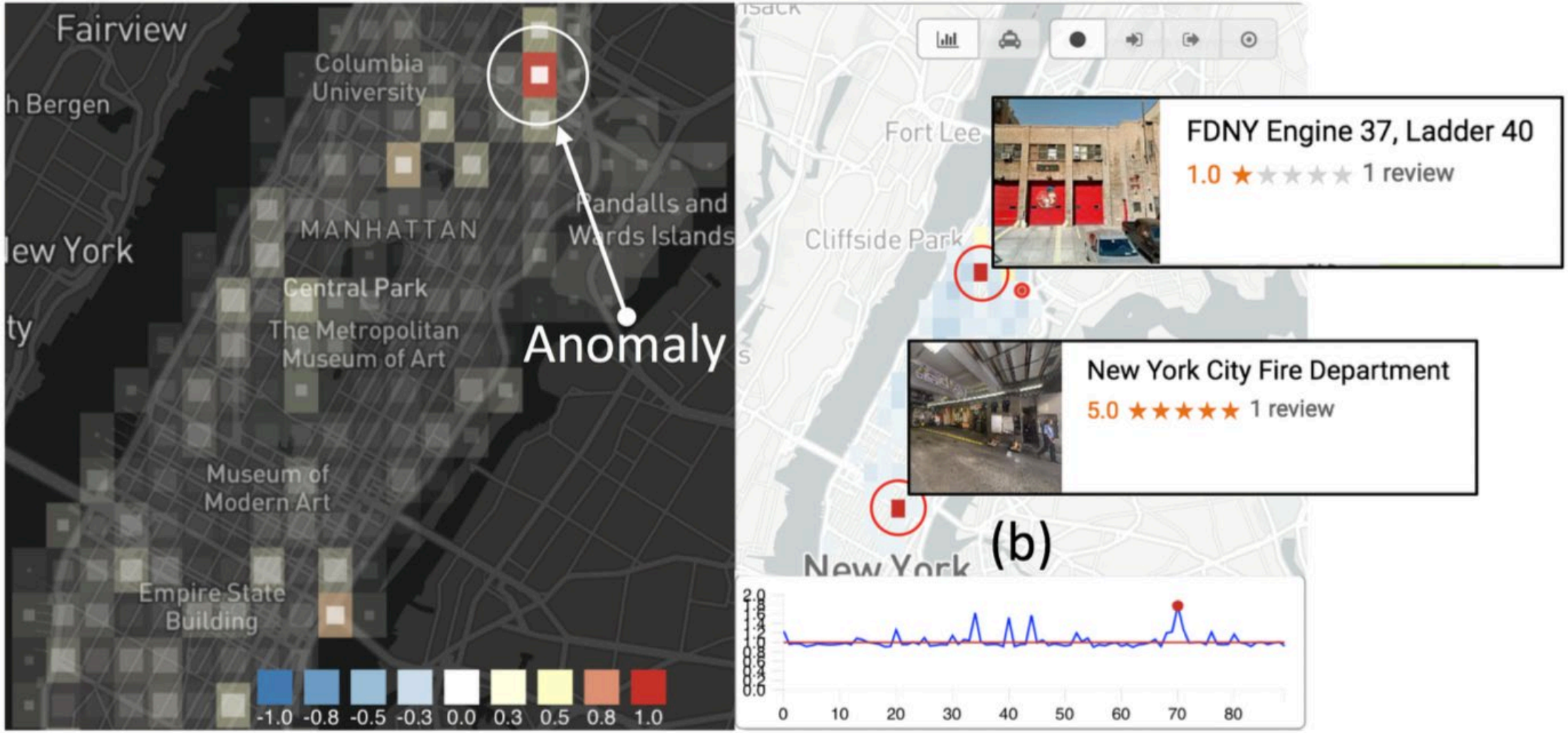


Quantitative Evaluation





What did we found ?



Intelligent Big Data Visualization (iDVˣ) Lab

http://idvxlab.github.io

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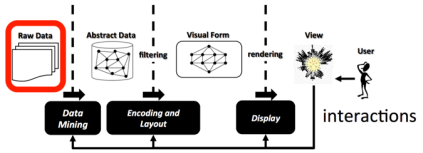
Visual Analytics



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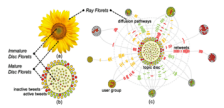
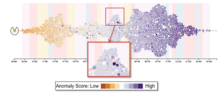
Anomalous Collective Behaviors

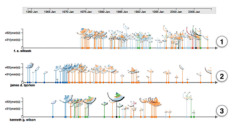


Monitoring and Tracing of Information Diffusion Process



Visual Analysis and interpretation of anomalous information spreading

Anomalous Ego-Centric Behaviors



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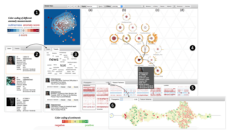

Visual Analysis System for Detecting Social Media Users with Anomalous User Behaviors such as Bots

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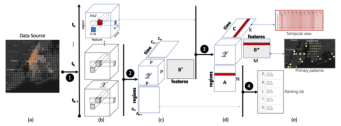
Dynamic Region Segmentation

Anomalous Mobility Pattern Detection



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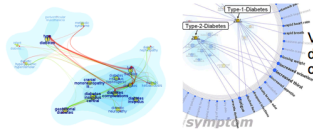
Disease Diagrams and Visualization



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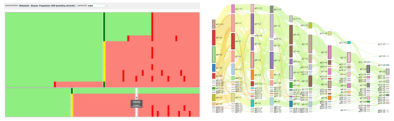
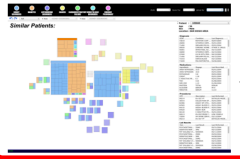


Detect Anomalous Cohort



Detect and interpret the anomalous cohorts

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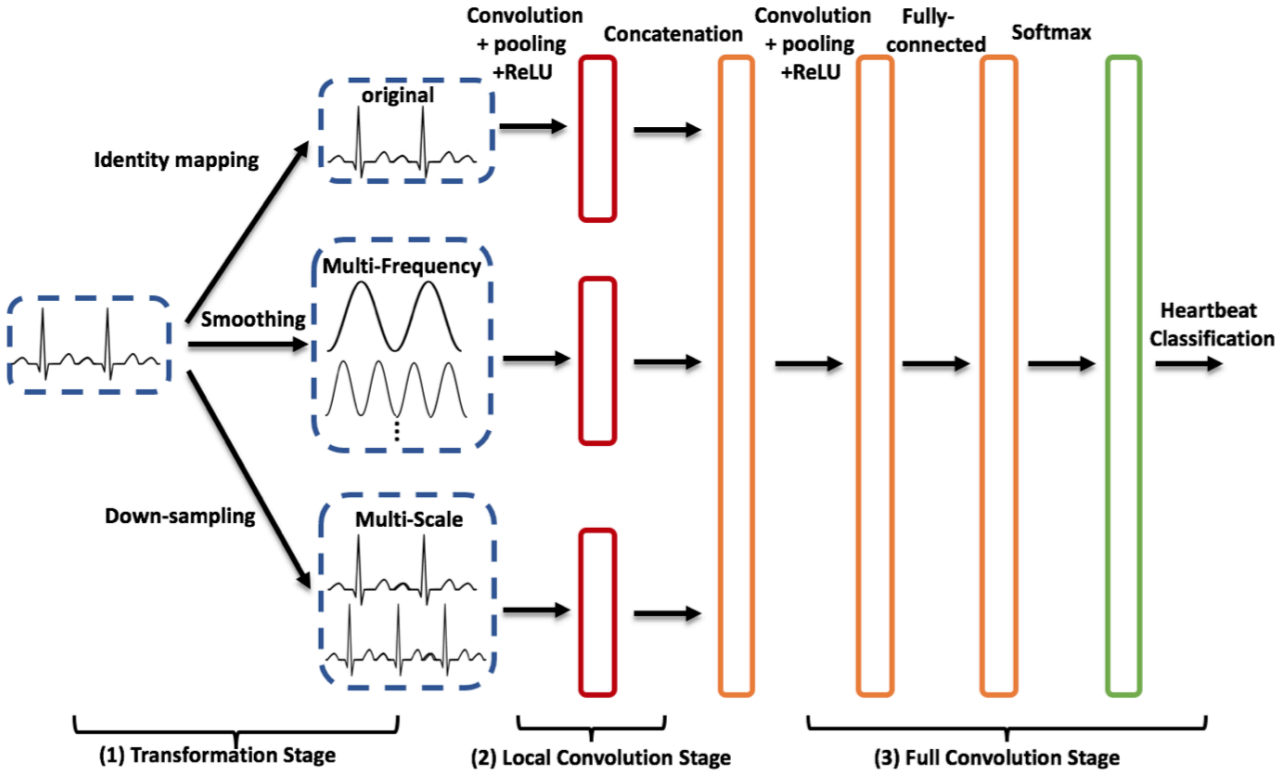
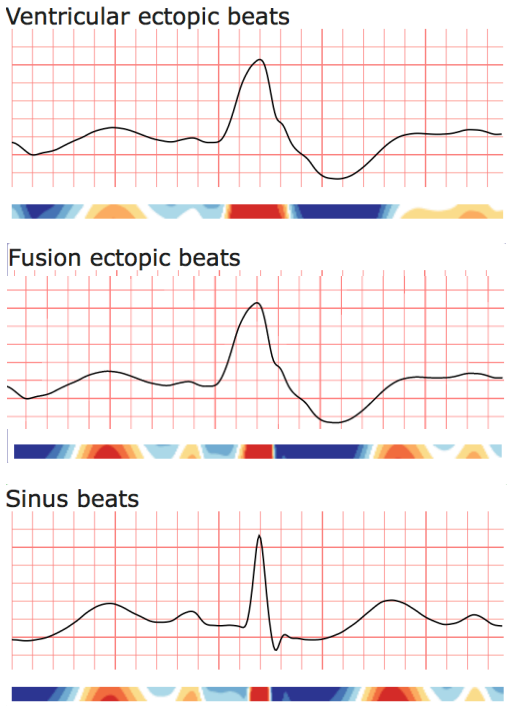
ECG DATA

A Hand-held ECG Halter Monitoring Recorder

- At least 24-hour data
- Sample frequency 360Hz
- 360 * 24 * 60 = 518400
- Driver’s Behavior Data
- Normal heart rate ranging from 60 to 100 in a minute
- 80 * 24 * 60 = 11520 heartbeats

DEEP LEARNING

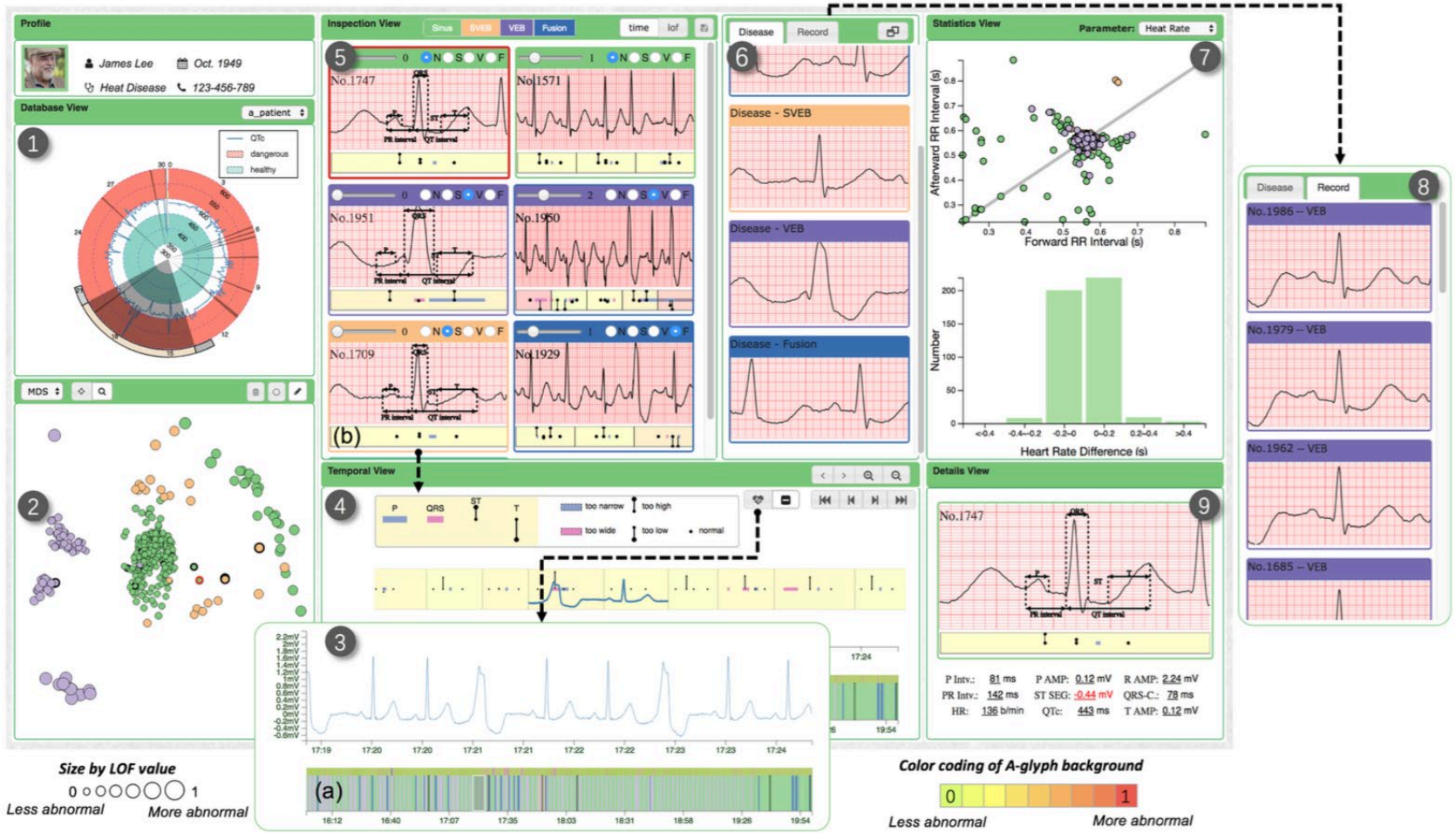




Heartbeat Classification

Accuracy : 91.5%

ECGLens



ECGLens: Interactive Visual Exploration of Large Scale ECG Data for Arrhythmia Detection

ACM CHI 2018 (Honorable Mention Award)

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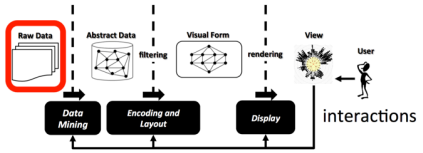

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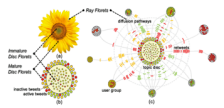

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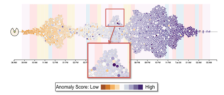

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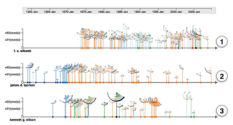

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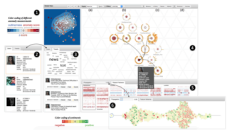

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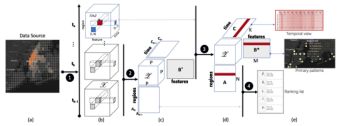

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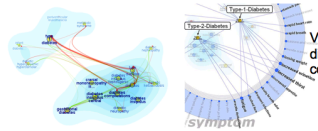

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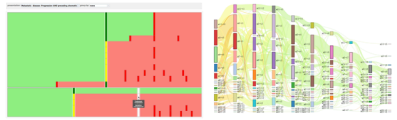

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Interactive Visual Anomaly Detection and its Application