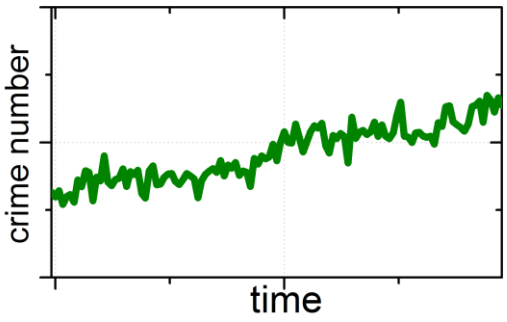
Modeling Temporal-Spatial Correlations for Crime Prediction

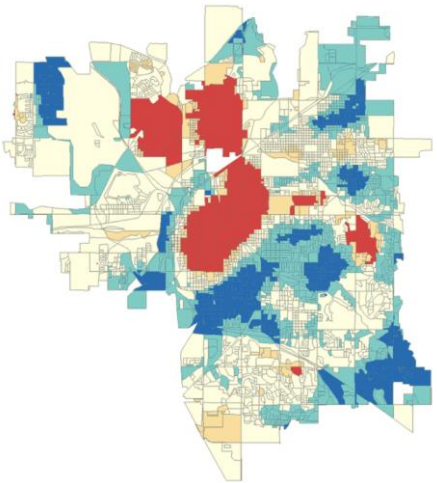
Xiangyu Zhao and Jiliang Tang

Data Science and Engineering Lab
Michigan State University

Background

- Urban Security and Safety
  - Eg. New York City
  - Weekly Crime Report (NYPD)
  - 1888 felony incident, July 4~10, 2016
- Urgent demand for accurate crime prediction





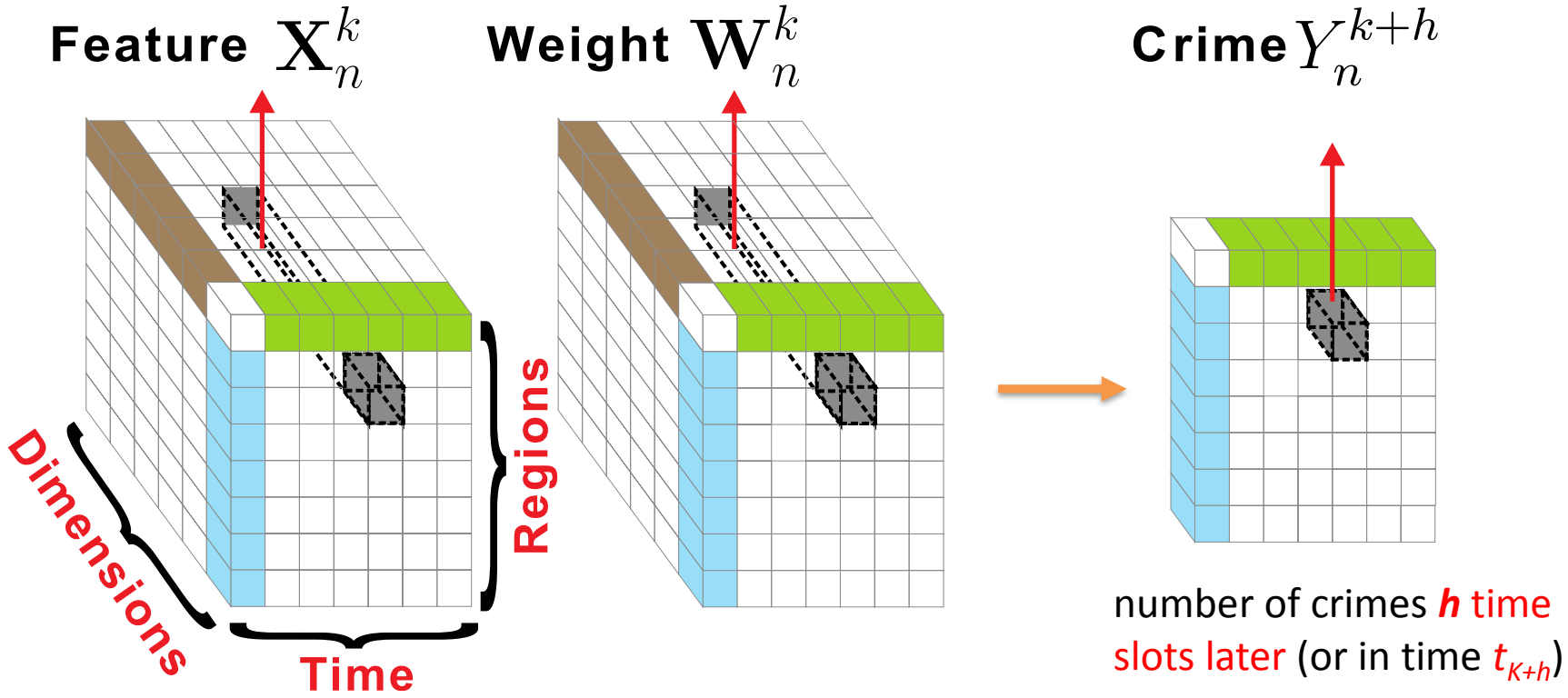
Motivation

- Recent development of new techniques to collect and integrate urban data:
  - Public safety data
  - Weather data
  - Point of interests (POIs) data
  - Human mobility data
  - 311 public-service complaint data

Motivation

- Two challenging questions
  - Q1: What temporal-spatial patterns can be observed about urban crimes
  - Q2: How to model these patterns mathematically for crime prediction

Problem Statement

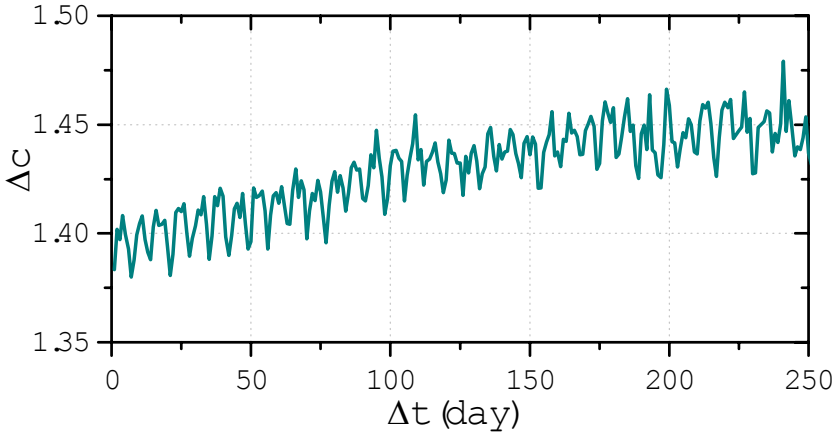


- $\mathbf{X}_n^k$: feature vector of n^{th} region in k^{th} time slot

- Basic Model $$\min_{\mathbf{W}_n^k} \sum_{k=1}^{K} \sum_{n=1}^{N} \left(L(\mathbf{X}_n^k \mathbf{W}_n^k, Y_n^k) + \theta \|\mathbf{W}_n^k\|_2^2 \right)$$

Q1:Temporal-Spatial Patterns

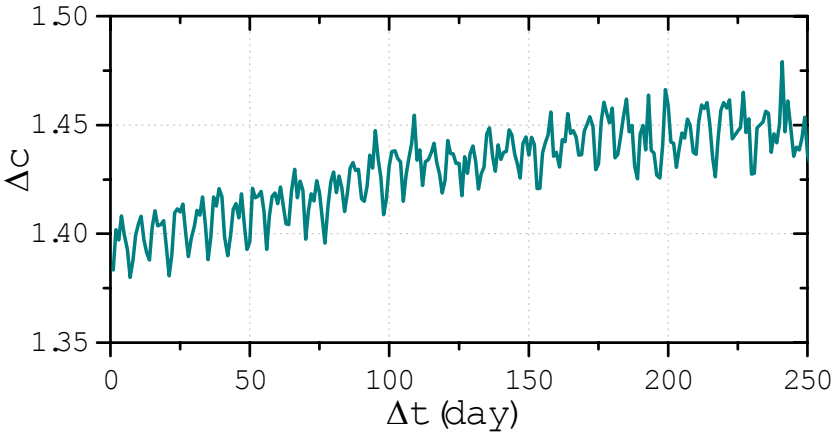
- Temporal pattern
  - how crime evolves over time for each region in a city
  - c_t and $c_{t+\Delta t}$: the crime number in time t and $t + \Delta t$
  - $\Delta c = |c_t - c_{t+\Delta t}|$

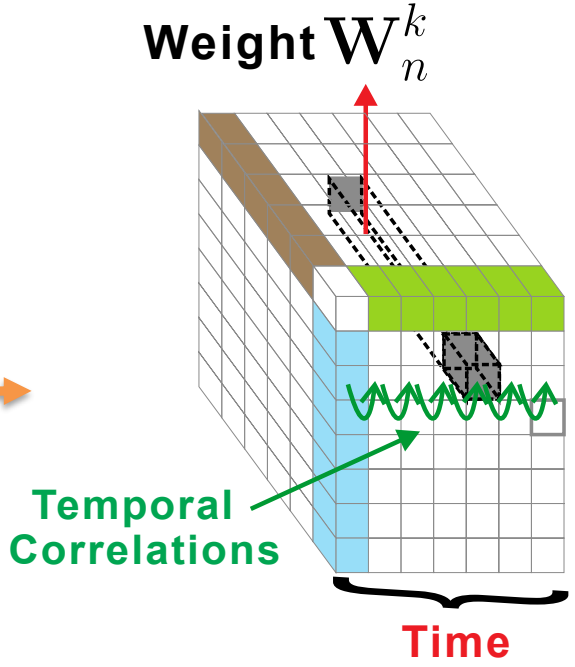


- Observations
  - two adjacent time slots → similar crime numbers
  - time differences Δt increase → crime difference Δc increase

Q1:Temporal-Spatial Patterns

- Intra-region temporal correlation

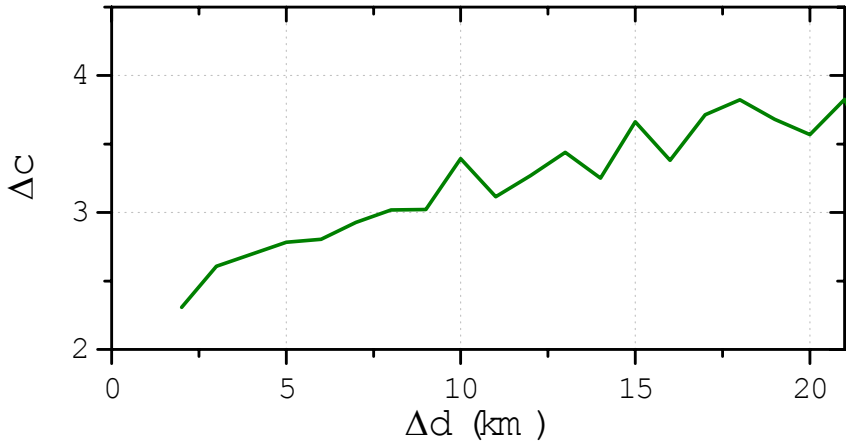




$$\sum_{n=1}^{N}\left(\sum_{k=1}^{K-1}\|\mathbf{W}_n^k-\mathbf{W}_n^{k+1}\|_1\right)$$

Q1:Temporal-Spatial Patterns

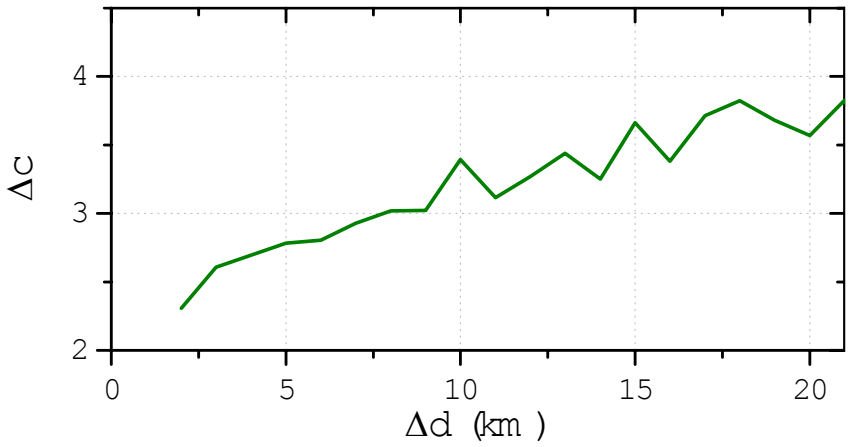
- Spatial pattern
  - geographical influence among regions in the city
  - c_i and c_j: the crime number in region i and region j
  - $\Delta c = |c_i - c_j|$

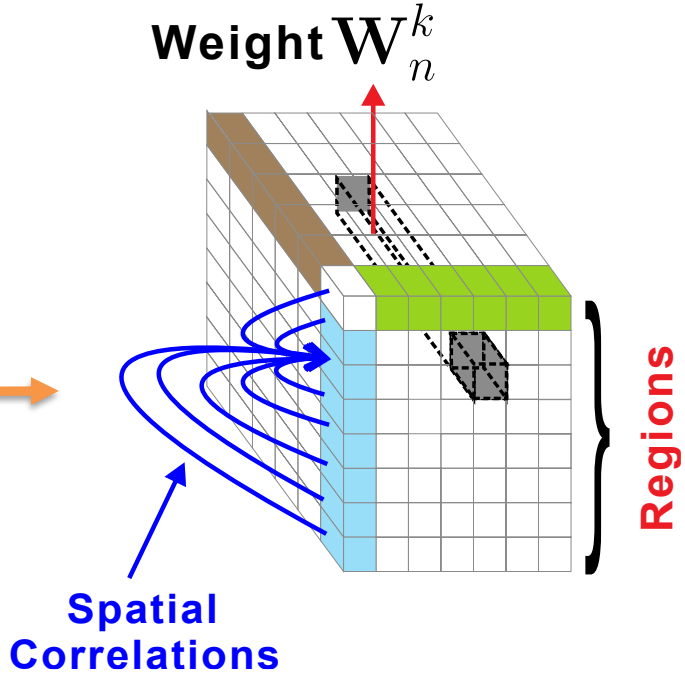


- Observations
  - two spatial close regions → similar crime numbers
  - spatial distance Δd increase → crime difference Δc increase

Q1:Temporal-Spatial Patterns

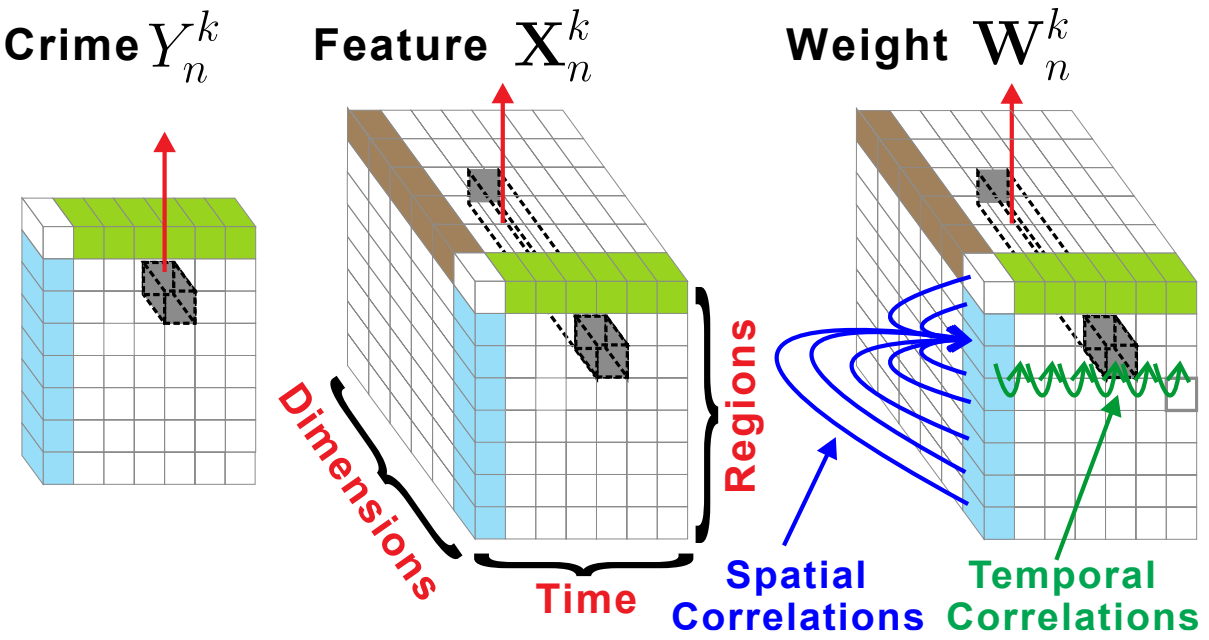
- Inter-region spatial correlation





$$\sum_{i=1}^{N}\sum_{j=1}^{N} g(d_{ij})\|\mathbf{W}_i^k - \mathbf{W}_j^k\|_1$$

Q2:TCP Framework

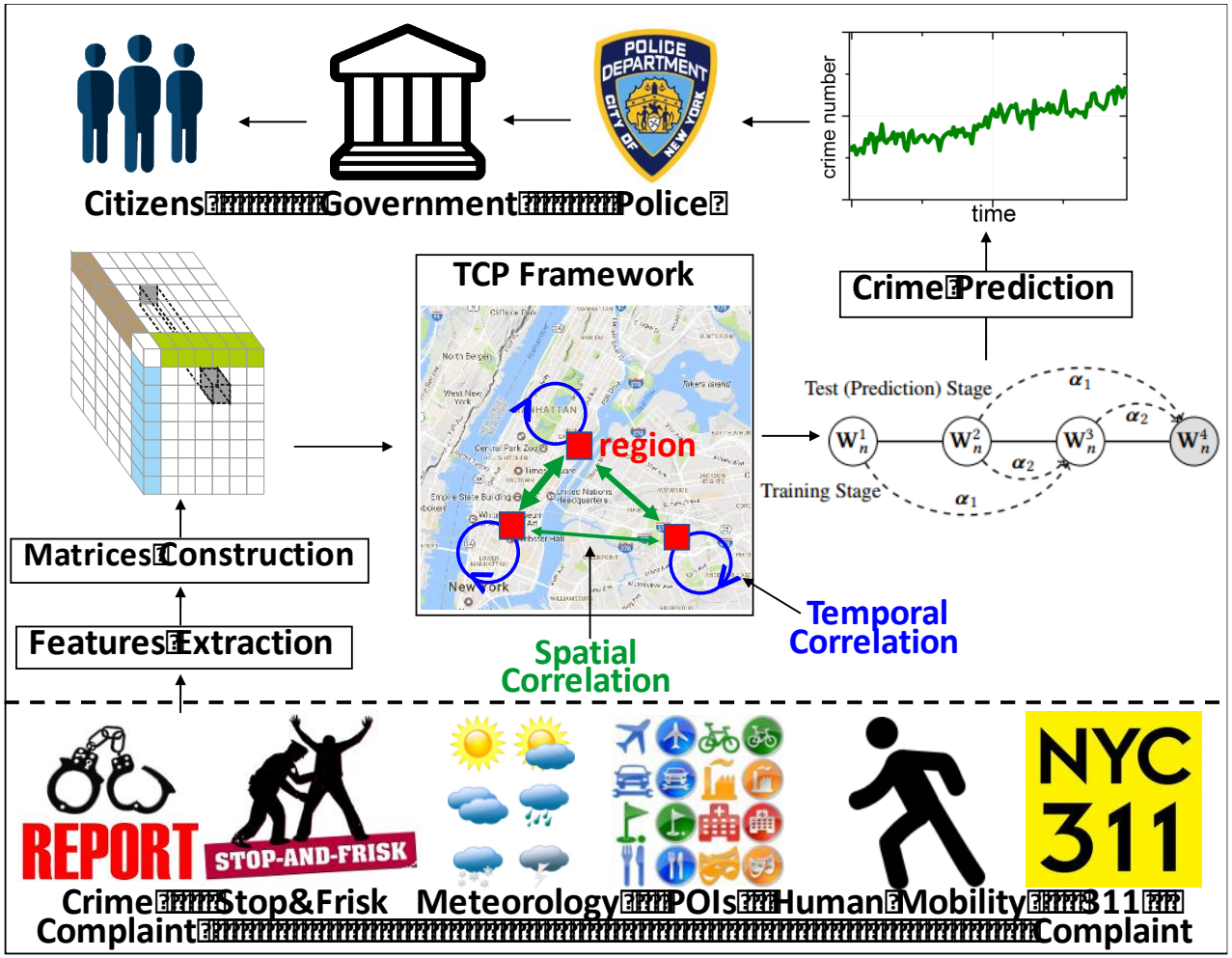


$$\min_{\mathbf{W}} L = \sum_{k=1}^{K} \left(\sum_{n=1}^{N} (\mathbf{X}_n^k \mathbf{W}_n^k - Y_n^k)^2 + \frac{1}{2} \sum_{i=1}^{N} \sum_{j=1}^{N} g(d_{ij}) \|\mathbf{W}_i^k - \mathbf{W}_j^k\|_1 \right) + \lambda \sum_{n=1}^{N} \sum_{k=1}^{K-1} \|\mathbf{W}_n^k - \mathbf{W}_n^{k+1}\|_1$$

- ADMM framework for optimizing objective function

An Overview of the Crime Prediction System

- Step 1: Feature Extraction
- Step 2: TCP framework
- Step 3: Crime Prediction



Experiment Settings

- Datasets
  - New York City
  - July 2012 – June 2013 (365 days)
  - 133 disjointed regions (2*km* × 2*km* grid)

- Metric
  - Average root-mean-square-error (RMSE)

$$aRMSE = \frac{1}{N}\sum_{n=1}^{N}\sqrt{\frac{1}{K_S}\sum_{k=1}^{K_S}\left(\hat{\mathbf{Y}}_n^k - \mathbf{Y}_n^k\right)^2}$$

Experiment Settings

- Two questions
  - QA: how TCP performs compared to baselines
  - QB: how the temporal and spatial patterns contribute to the performance

Experiment Results

- Baselines:
  - CSI: Cubic Spline Interpolation
  - ARMA: Auto-Regression-Moving-Average
  - LASSO: Lasso Regression
  - LR: Linear Regression
  - stMTL: Spatio-Temporal Multi-Task Learning

Experiment Results

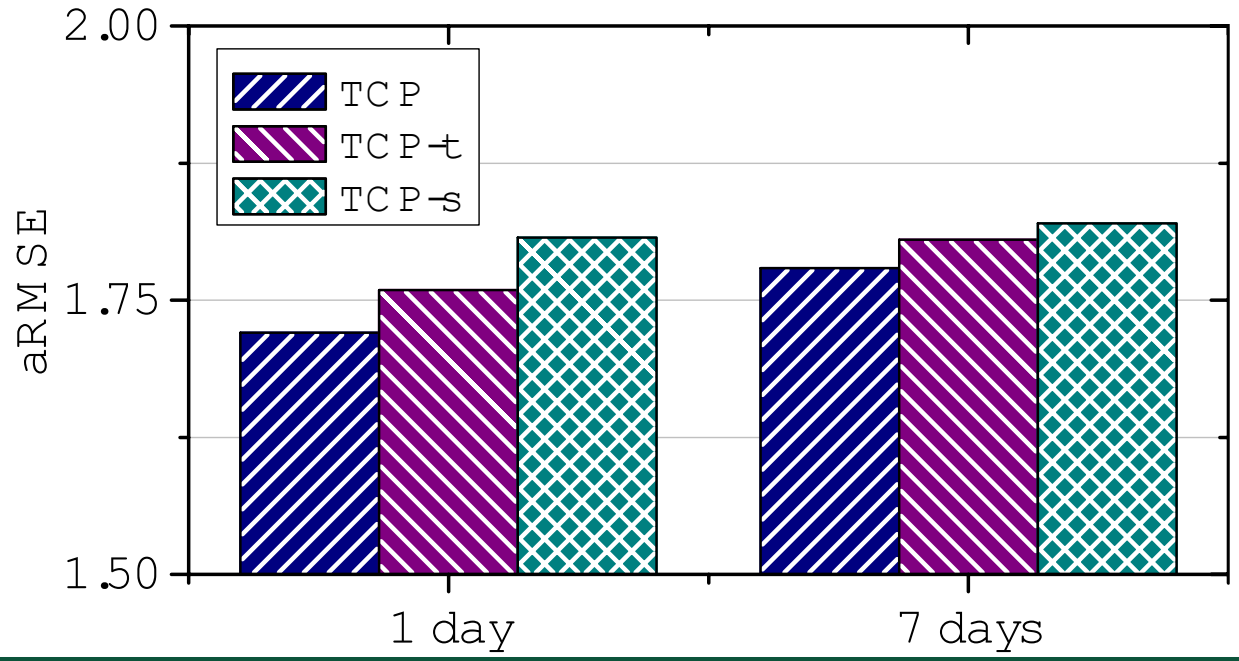
- QA: Overall performance Comparison

	1 day	7 days
CSI	13.223	33.562
ARMA	6.3135	12.2572
LASSO	2.8210	3.3956
LR	2.5498	2.8985
stMTL	2.2356	2.5365
TCP	**1.7205**	**1.7791**

Experiment Results

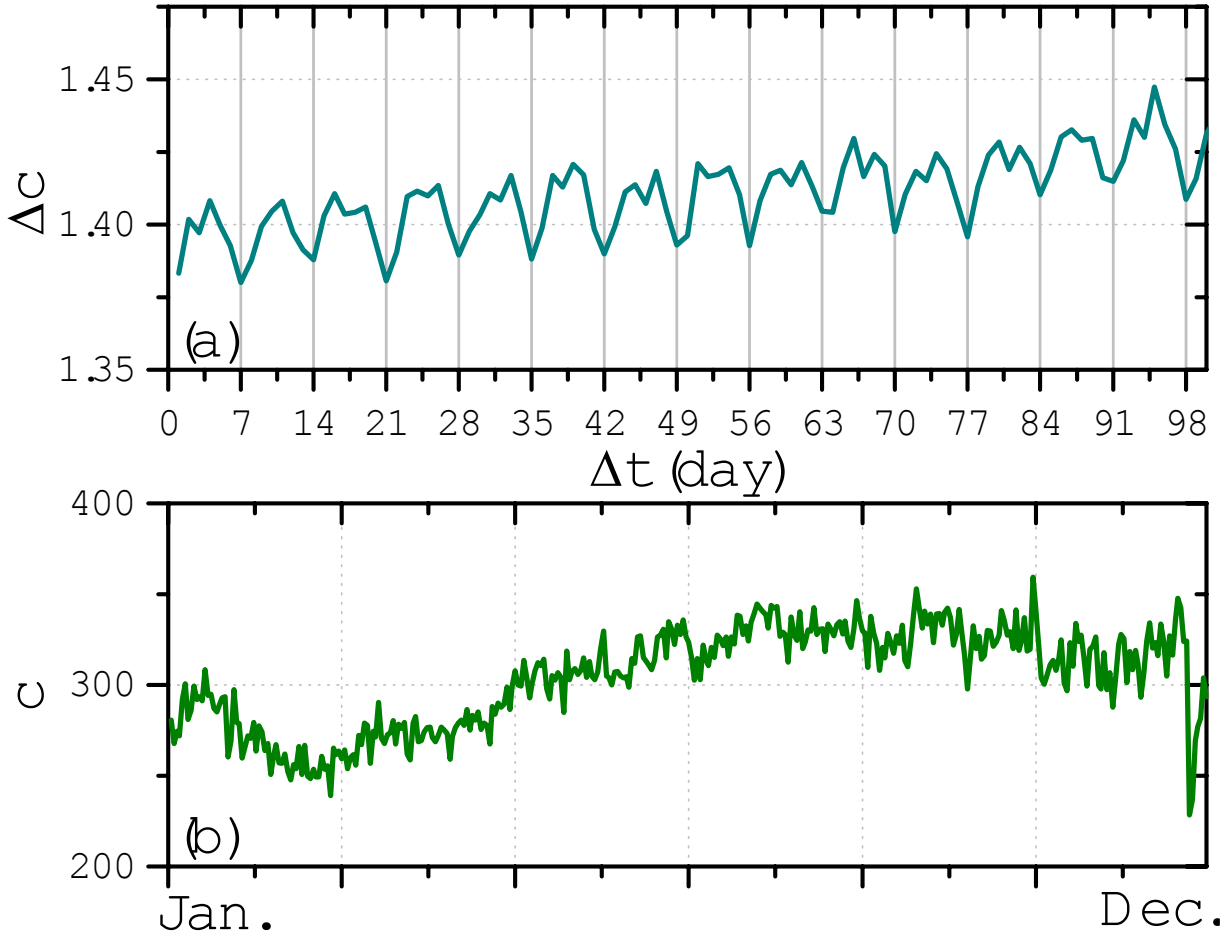
- QB: Contribution of Temporal and Spatial Correlations
  - TCP-t: evaluate temporal correlations
  - TCP-s: evaluate spatial correlations

$$\min_{\mathbf{W}} L = \sum_{k=1}^{K} \left(\sum_{n=1}^{N} (\mathbf{X}_n^k \mathbf{W}_n^k - Y_n^k)^2 + \frac{1}{2} \sum_{i=1}^{N} \sum_{j=1}^{N} g(d_{ij}) \|\mathbf{W}_i^k - \mathbf{W}_j^k\|_1 \right) + \lambda \sum_{n=1}^{N} \sum_{k=1}^{K-1} \|\mathbf{W}_n^k - \mathbf{W}_n^{k+1}\|_1$$



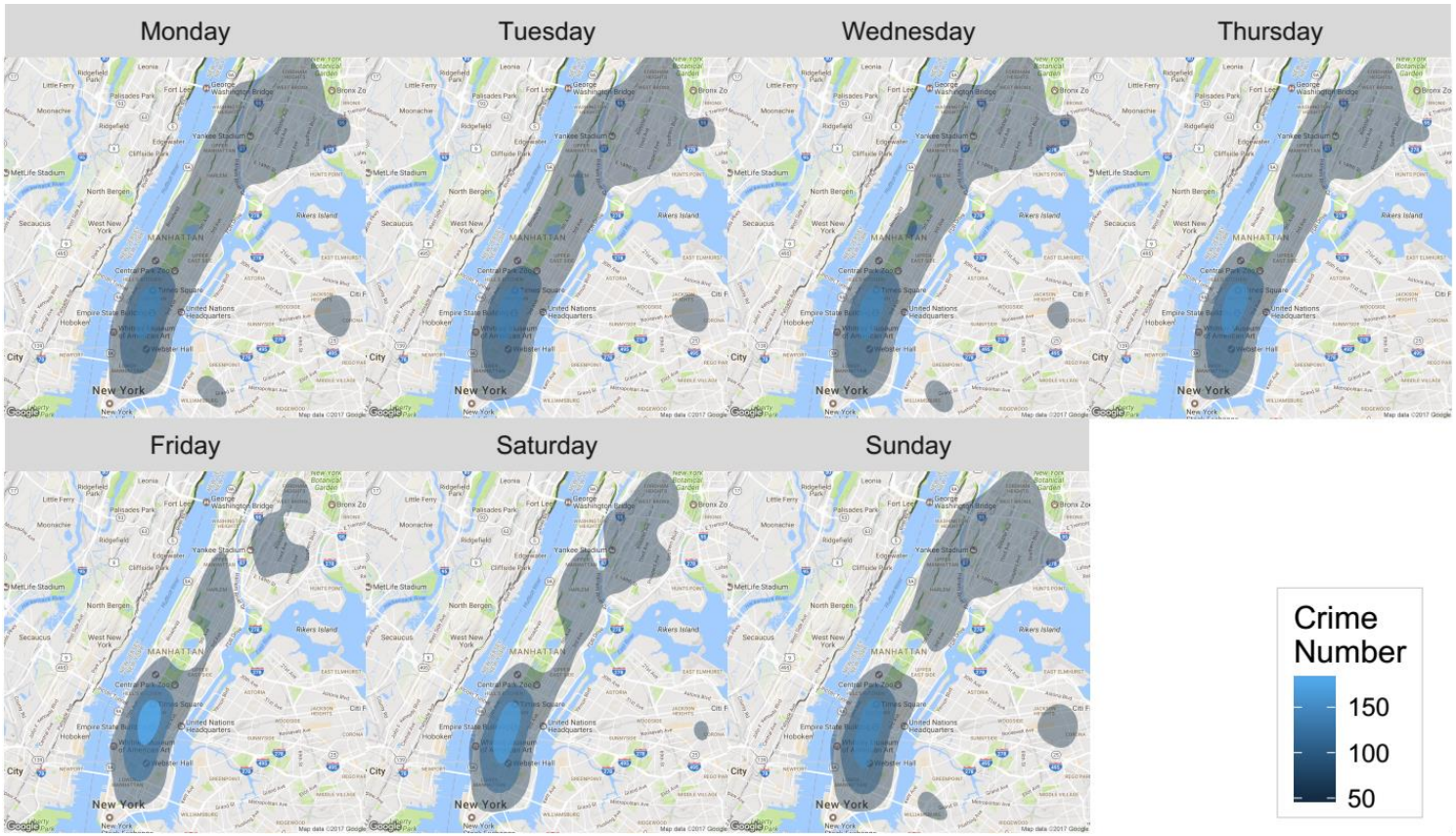
Experiment Results

- Further Probing on Temporal Patterns



Experiment Results

- How the spatial distribution of urban crimes varies with respect to days of a week?



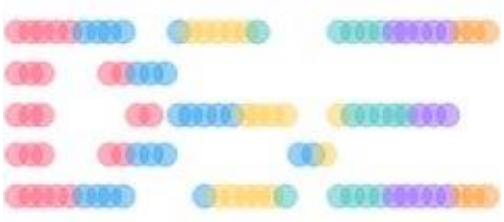
Future Work

- More sources
  - Social media, Crime networks…
- More temporal-spatial patterns
  - Weekly periodicity, Hotspot…
- More applications
  - Air quality prediction, Noise Detection…

Acknowledgements

- Thanks for the grant IIS-1714741 and IIS-1715940 from National Science Foundation (NSF)

- Thanks for the support from Data Science and Engineering Lab at Michigan State University



http://dse.cse.msu.edu/

- Authors' email:
  - {zhaoxi35, tangjili}@msu.edu

Thanks

http://www.cse.msu.edu/~zhaoxi35/