# CityMomentum: An Online Approach for Crowd Behavior Prediction at a Citywide Level

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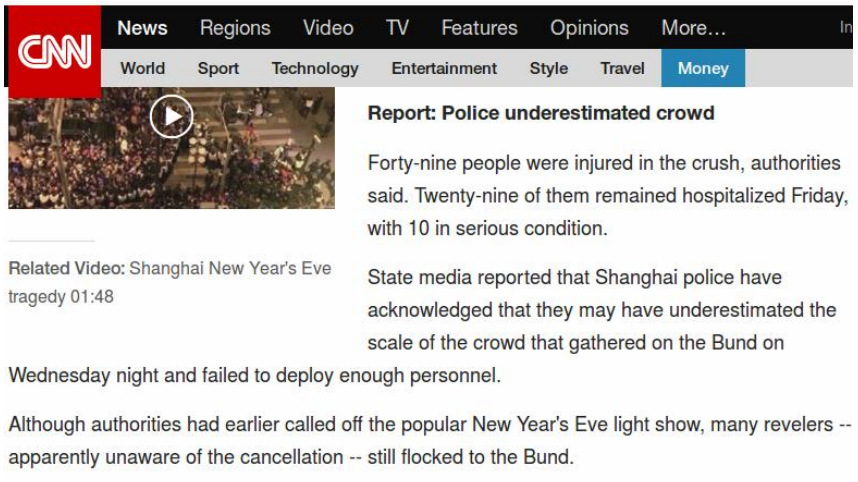
# Crowd Disasters


2014 Shanghai Stampede

300,000 gathered for new year celebration

36 killed, 49 injured

the police admitted that they had underestimated the crowds density.



CNN

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World Sport Technology Entertainment Style Travel Money

**Report: Police underestimated crowd**

Forty-nine people were injured in the crush, authorities said. Twenty-nine of them remained hospitalized Friday, with 10 in serious condition.

Related Video: Shanghai New Year's Eve tragedy 01:48

State media reported that Shanghai police have acknowledged that they may have underestimated the scale of the crowd that gathered on the Bund on Wednesday night and failed to deploy enough personnel.

Although authorities had earlier called off the popular New Year's Eve light show, many revelers -- apparently unaware of the cancellation -- still flocked to the Bund.

# How to prevent tragedy from repeating?

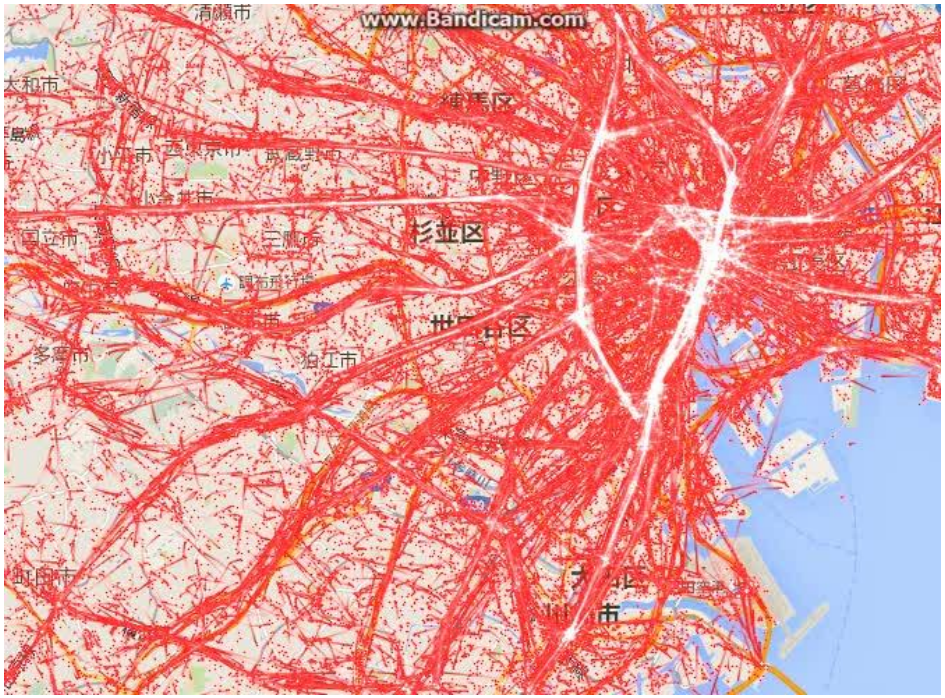
Traditional way of crowd safety surveillance fails.

We need a **CITYWIDE** human mobility **PREDICTOR**:

1. **Spatial**: from "local" to "citywide"
2. **Temporal**: from "detection" to "prediction"

# Beyond local population density, a citywide view

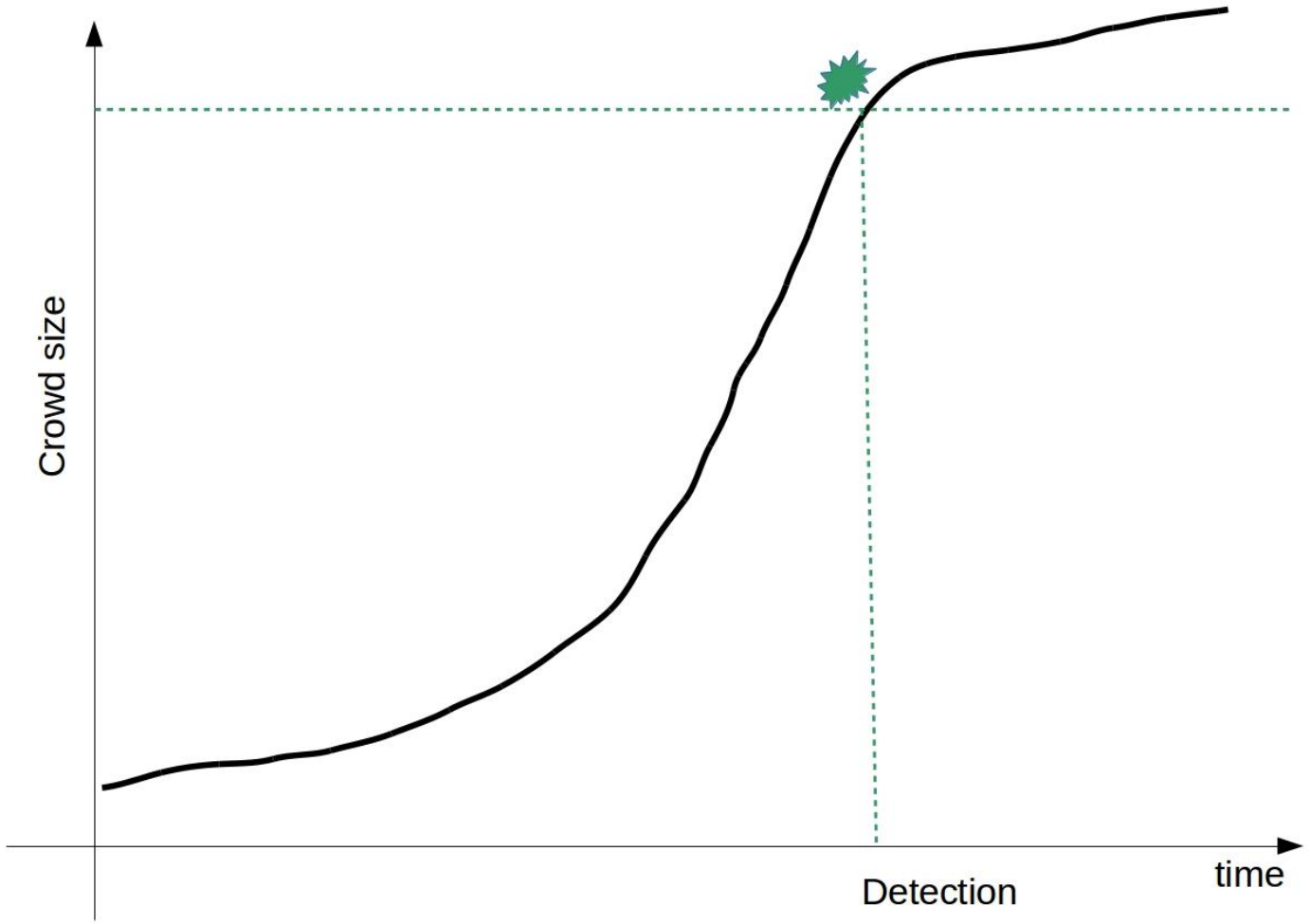
Policemen's eye and experience



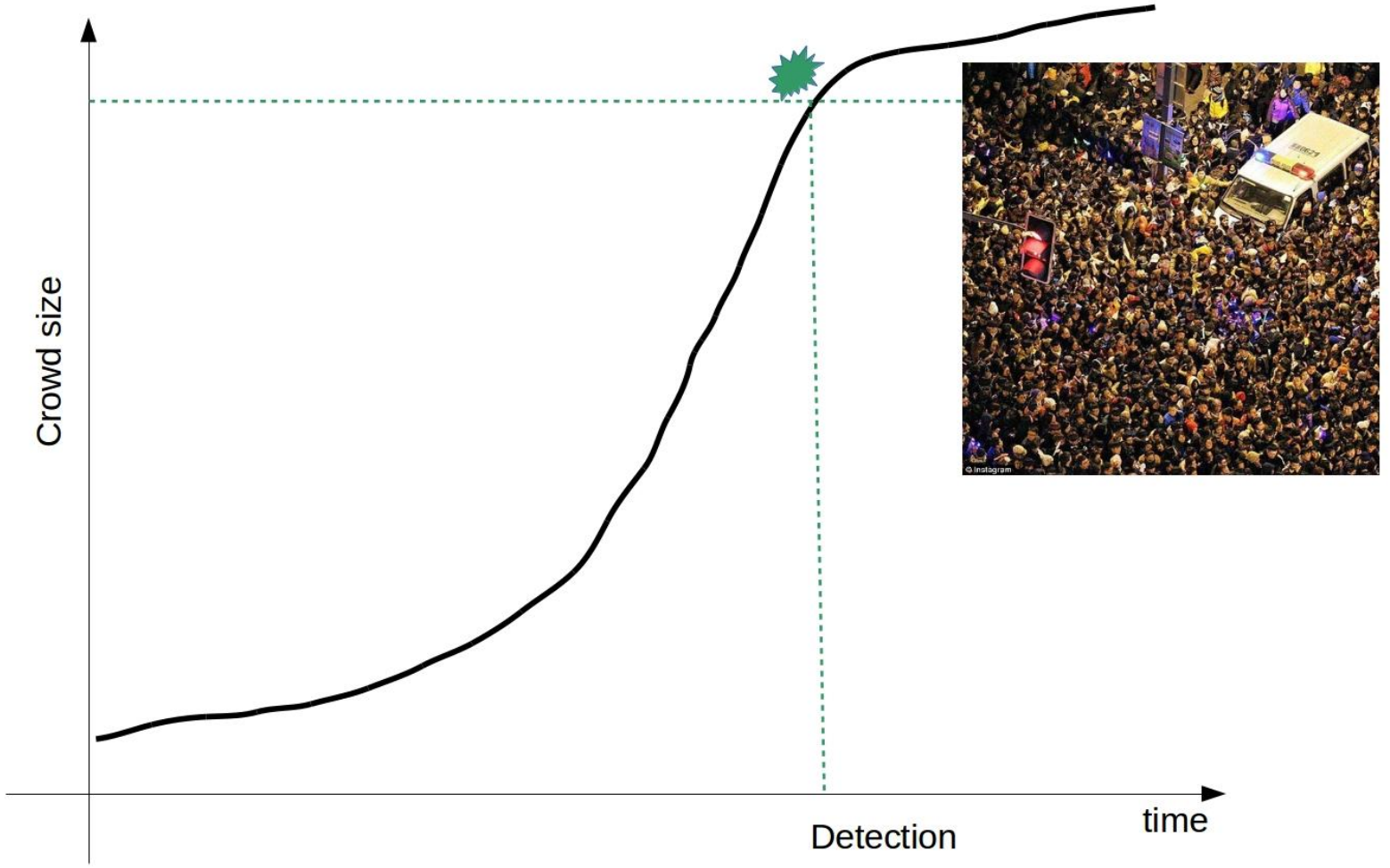

Citywide integration of GPS trajectories

From "local" to "citywide"

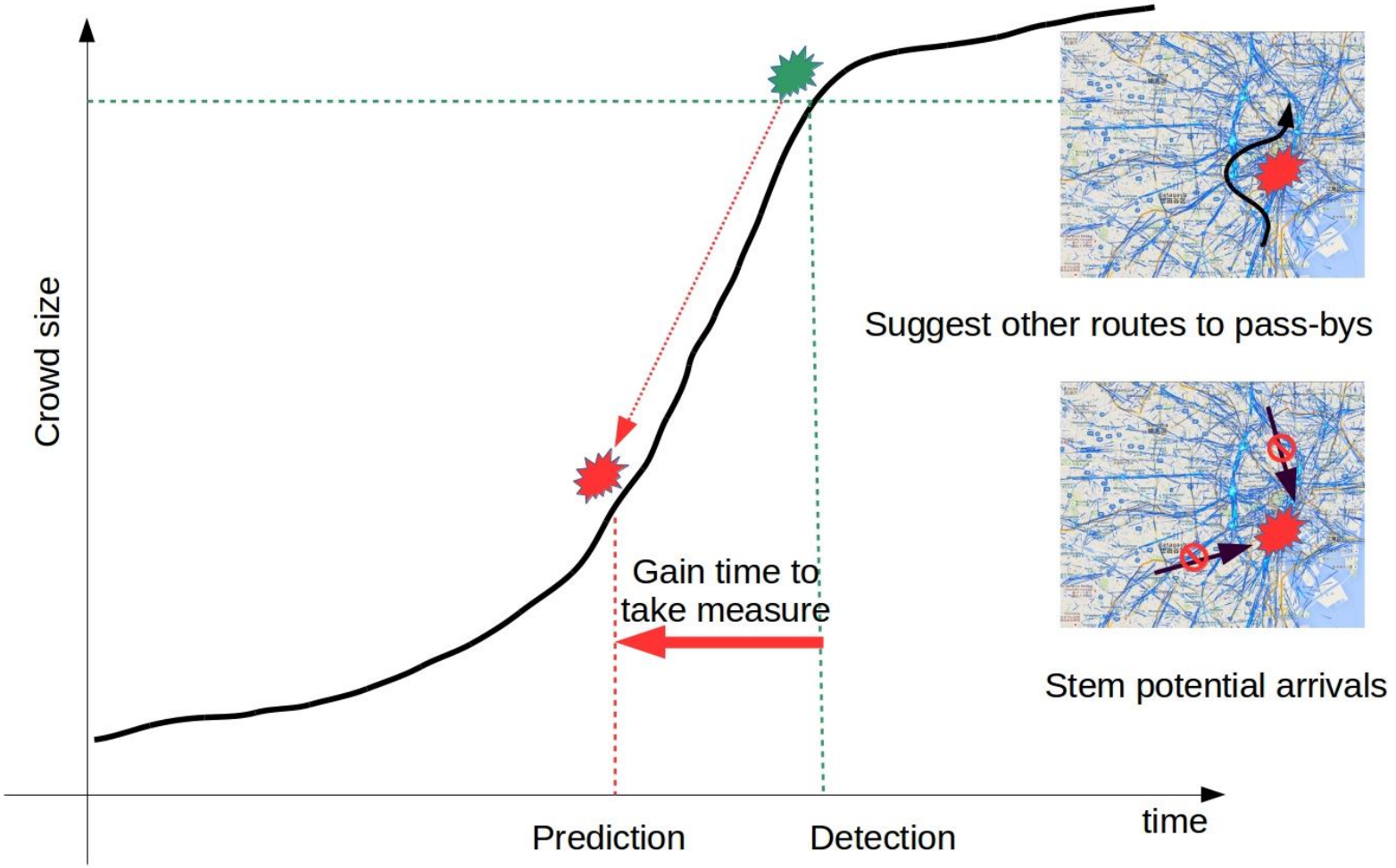
# From “detection” to “prediction”



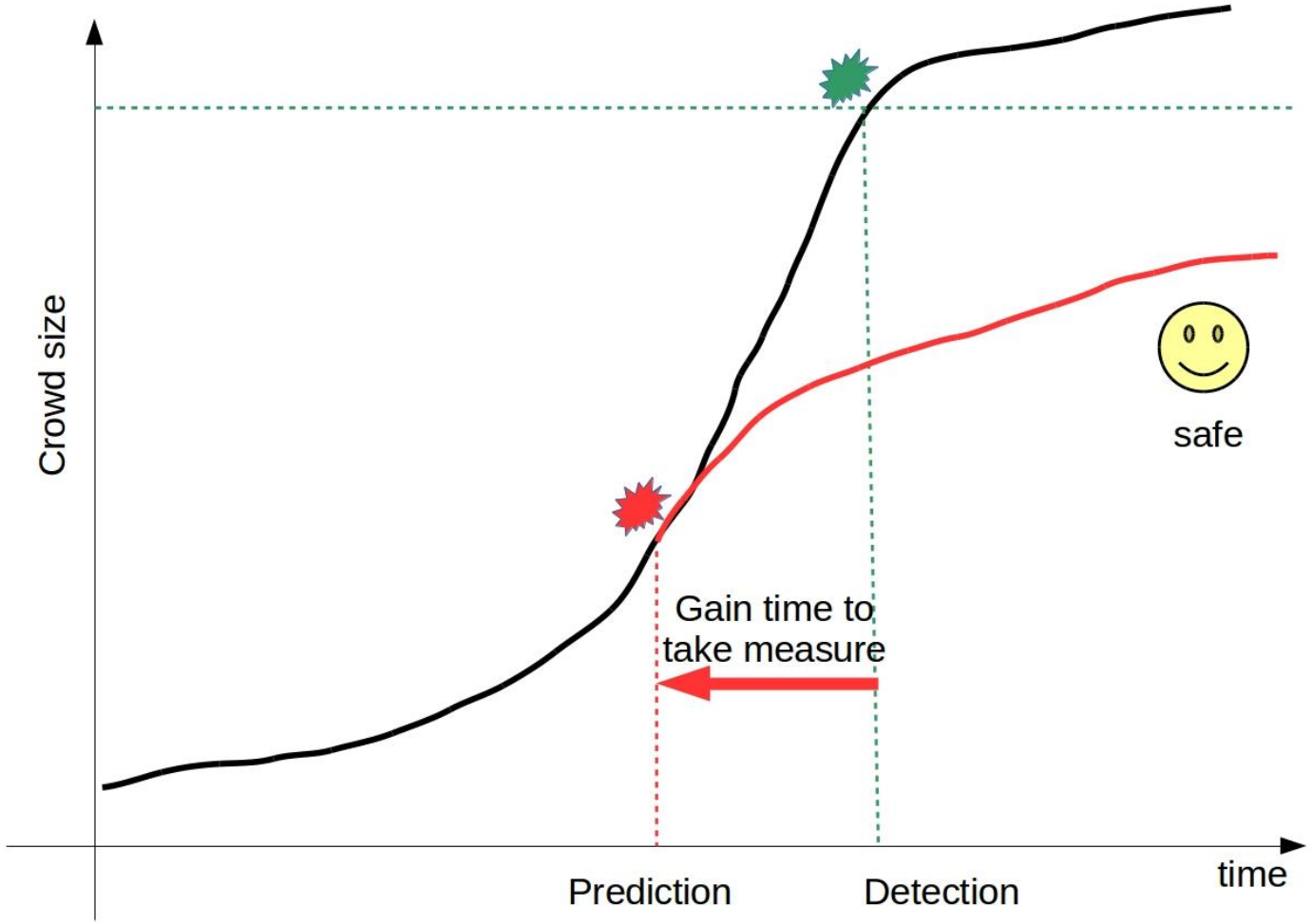
# From “detection” to “prediction”



# From “detection” to “prediction”



# From “detection” to “prediction”



# Overview

1. Background
2. Citywide human mobility prediction
   - Regular vs rare
   - Assumption
3. Naive Movement Predictor & CityMomentum model
   - Intuition
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   - Predicting
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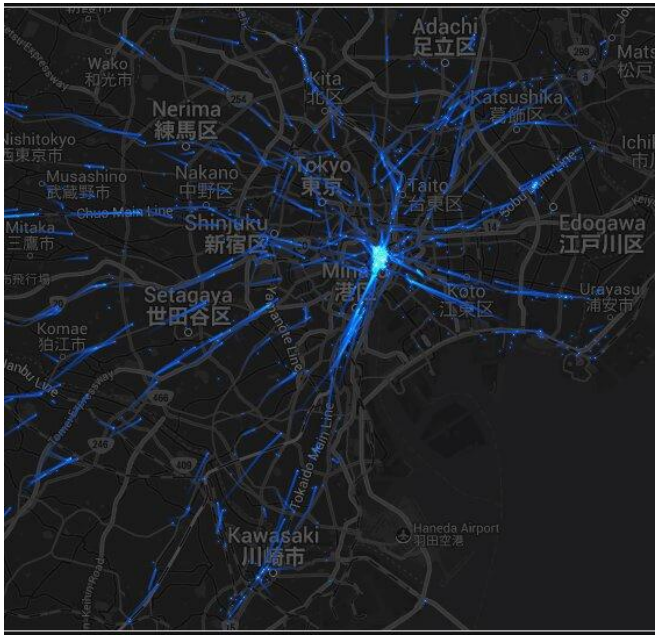
# We need a citywide robust human movement predictor

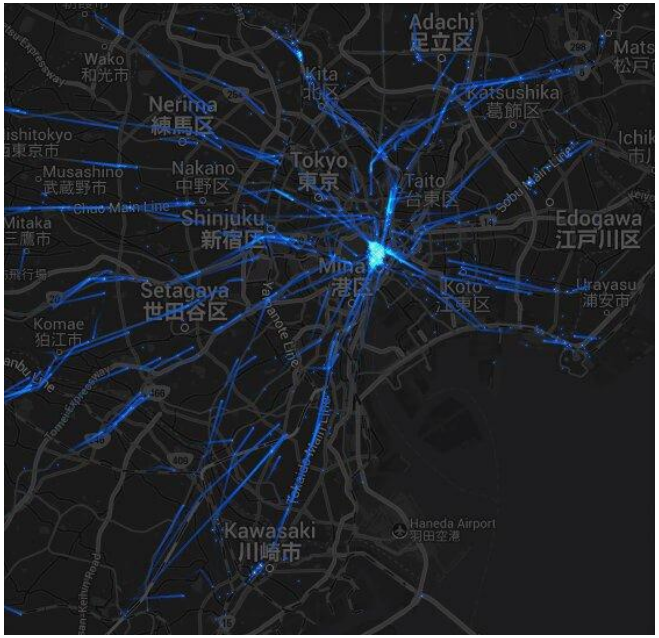
A robust human mobility predictor should well deal with both:

- **Regular** crowd behavior
- **Rare** crowd behavior

# Regular crowd behavior



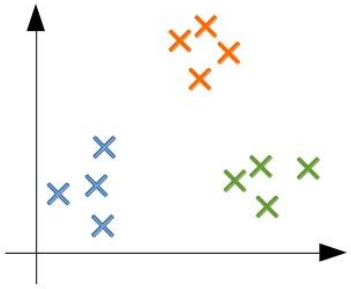

2011-08-01 7-9 a.m.

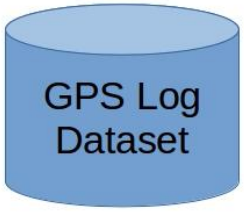


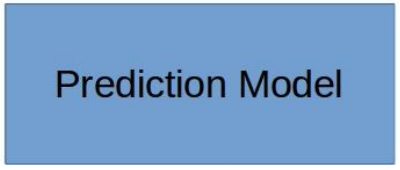

2011-08-02 7-9 a.m.

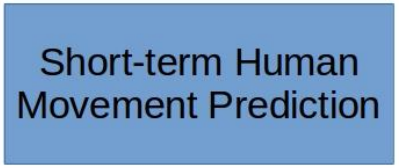
There is no big different between regular days.

# Easy to predict during regular days






| AUGUST 2011 | | | | | | |
|---|---|---|---|---|---|---|
| SUN | MON | TUES | WED | THURS | FRI | SAT |
| | 1 | 2 | 3 | 4 | 5 | 6 |
| 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| 14 | 15 | 16 | 17 | 18 | 19 | 20 |
| 21 | 22 | 23 | 24 | 25 | 26 | 27 |
| 28 | 29 | 30 | 31 | | | |

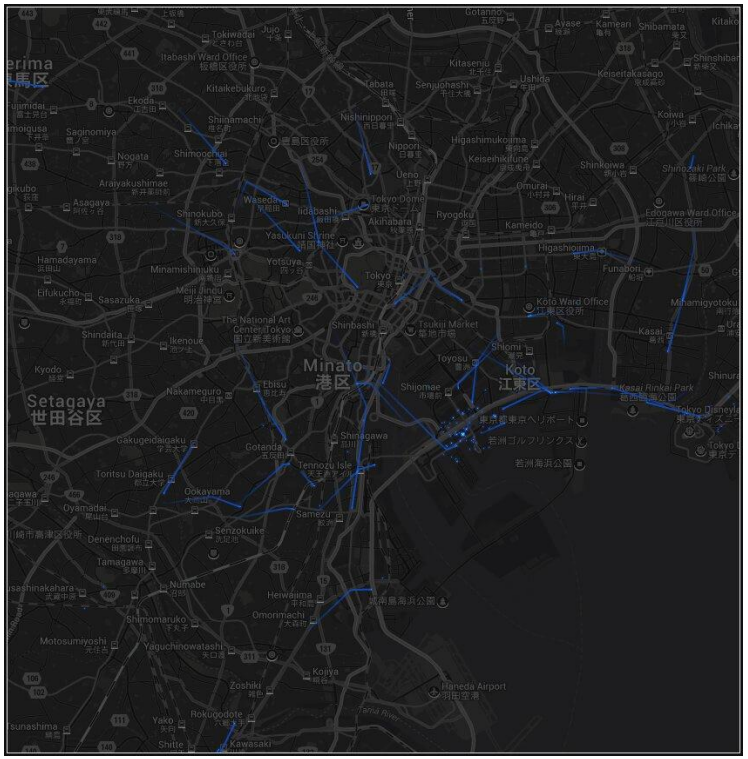
Regular days

| AUGUST 2011 | | | | | | |
|---|---|---|---|---|---|---|
| SUN | MON | TUES | WED | THURS | FRI | SAT |
| | 1 | 2 | 3 | 4 | 5 | 6 |
| 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| 14 | 15 | 16 | 17 | 18 | 19 | 20 |
| 21 | 22 | 23 | 24 | 25 | 26 | 27 |
| 28 | 29 | 30 | 31 | | | |

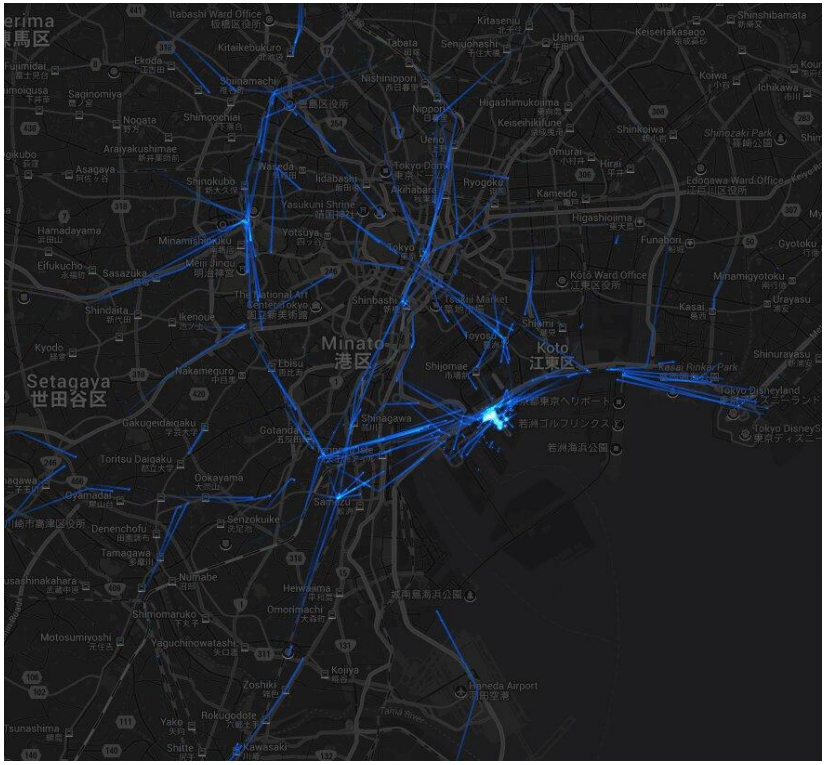
Regular day

It works, but trivial

# Rare crowd behavior



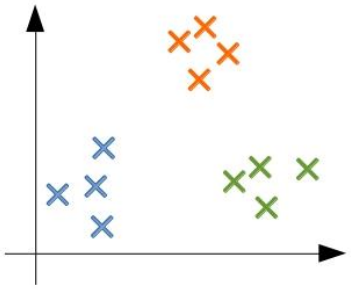

2011-08-02 7-9 a.m.

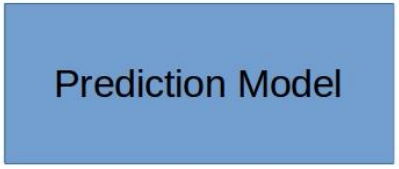


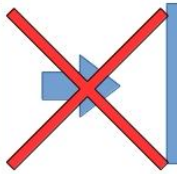

2011-08-12 7-9 a.m.

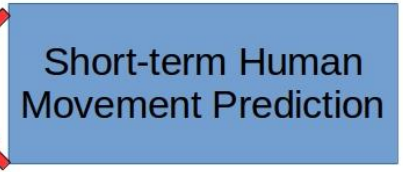
Human mobility during rare event are different from regular days.

# Hard to predict during rare events





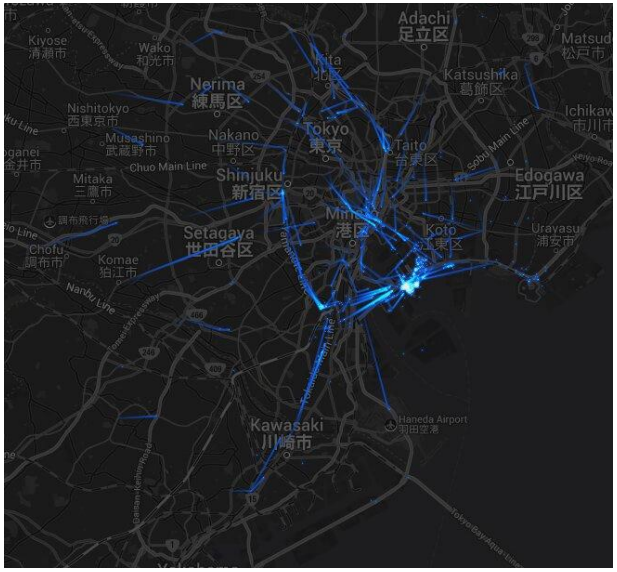


Regular days

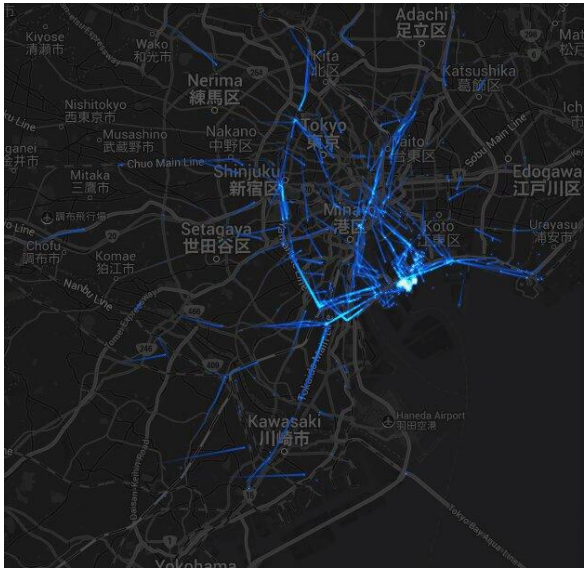

Rare event day

Rare crowd behavior is essential to crowd safety, but **hard** to predict

# What information can be used for prediction?



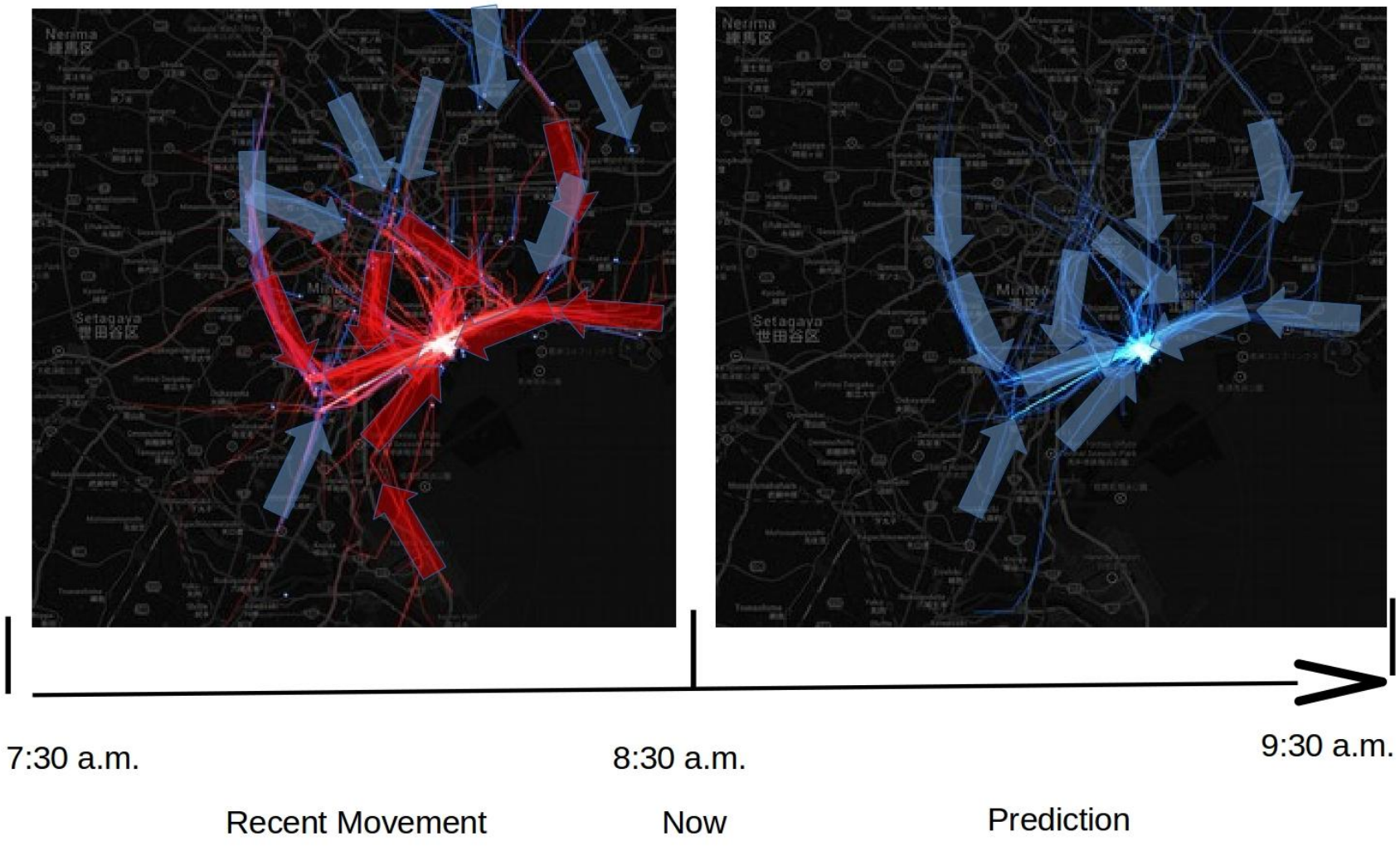

2011-08-12 6:30-8:30 a.m.




2011-08-12 7:30-9:30 a.m.

It is similar!

# Use earlier arrivals to predict later arrivals




Learn from the most recent human mobility to make short-term prediction.

# Overview

# Make it feasible!

## Basic assumptions

1. **Crowds gather gradually** so we can predict the late arrivals based on the information provided by those who arrived earlier.

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2. Subjects sharing **similar recent trajectories** will have a **similar bifurcating behavior** in the short-term future.

# Make it feasible!

## Basic assumptions

1. **Crowds gather gradually** so we can predict the late arrivals based on the information provided by those who arrived earlier.
2. Subjects sharing **similar recent trajectories** will have a **similar bifurcating behavior** in the short-term future.
3. The bifurcating pattern can be assumed to be **invariant** during a short period.

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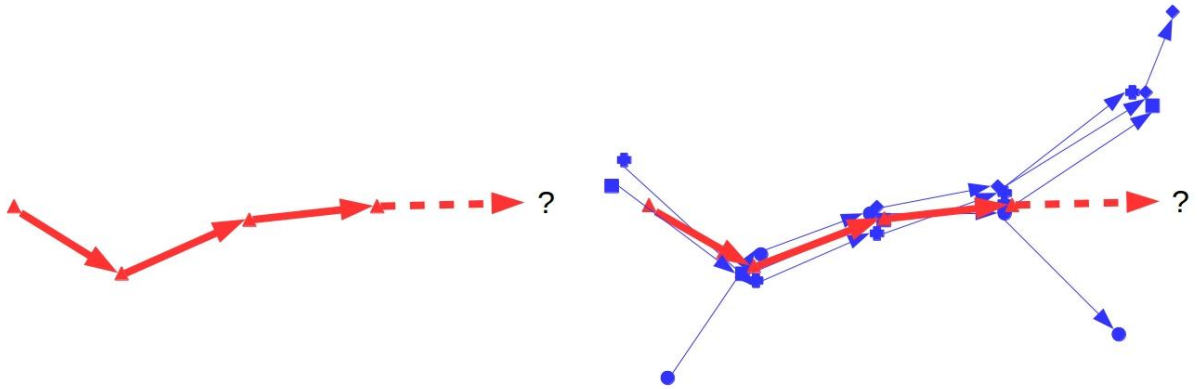
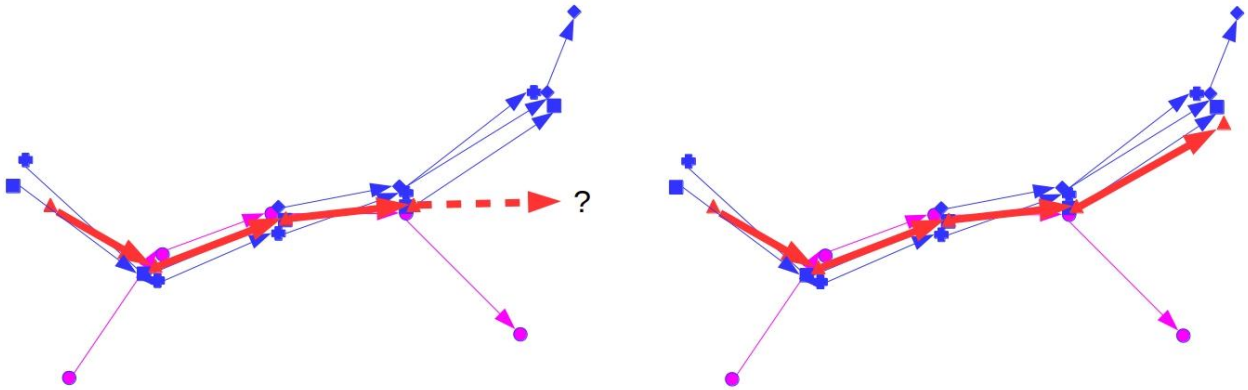
# Intuition (Naive Movement Predictor)

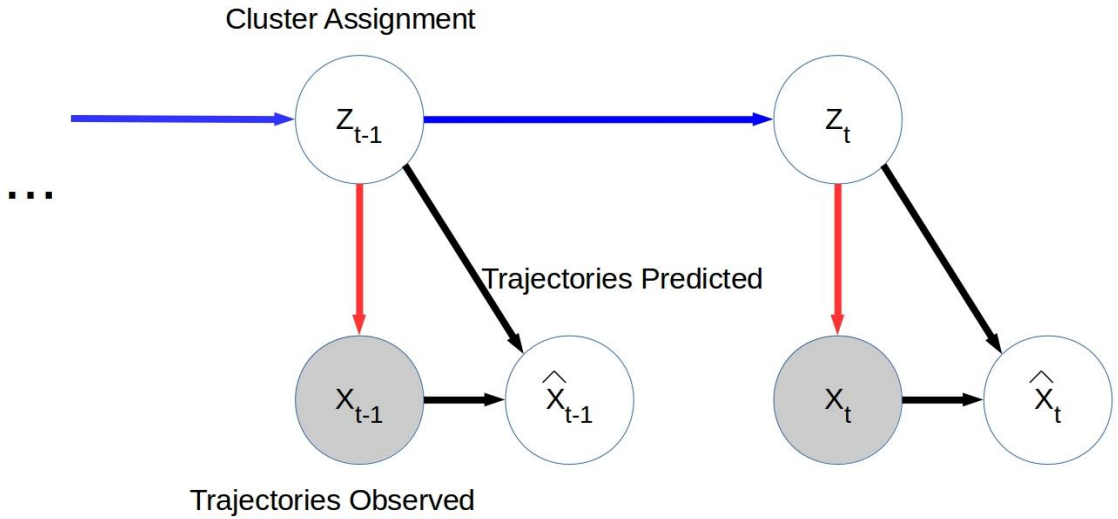

Prediction based on the most recent observation.

# Intuition (CityMomentum model)




Prediction based on the most recent trajectory clustering.

# Approach Overview



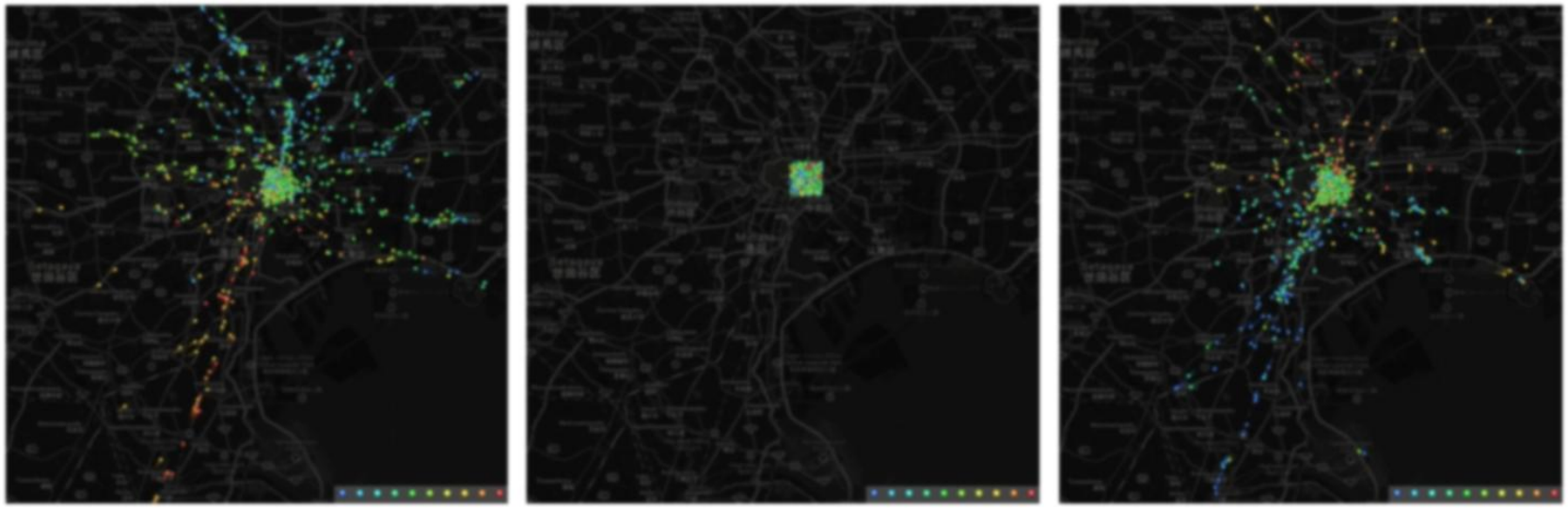

## Key algorithms

- Gibbs-sampling-based citywide bifurcating minimization clustering
- Random walk predictor

## Joint probability distribution

$$p\left(\hat{X}_{1:t}, Z_{1:t}, X_{1:t}\right) = \underbrace{p(Z_1)\prod_{\tau=2}^{t} p(Z_\tau|Z_{\tau-1})}_{\text{state transition}} \overbrace{\prod_{\tau=1}^{t} p(X_\tau|Z_\tau)}^{\text{clustering posterior}} \underbrace{p\left(\hat{X}_\tau|X_\tau, Z\tau\right)}_{\text{prediction}}$$

# Citywide bifurcating minimization clustering




## Citywide bifurcating minimization clustering

- A global bifurcating is minimized to reduce the prediction uncertainty.
- Clustering provides a sequential pattern for the human movement at a citywide level.

# Examples of trajectory clusters

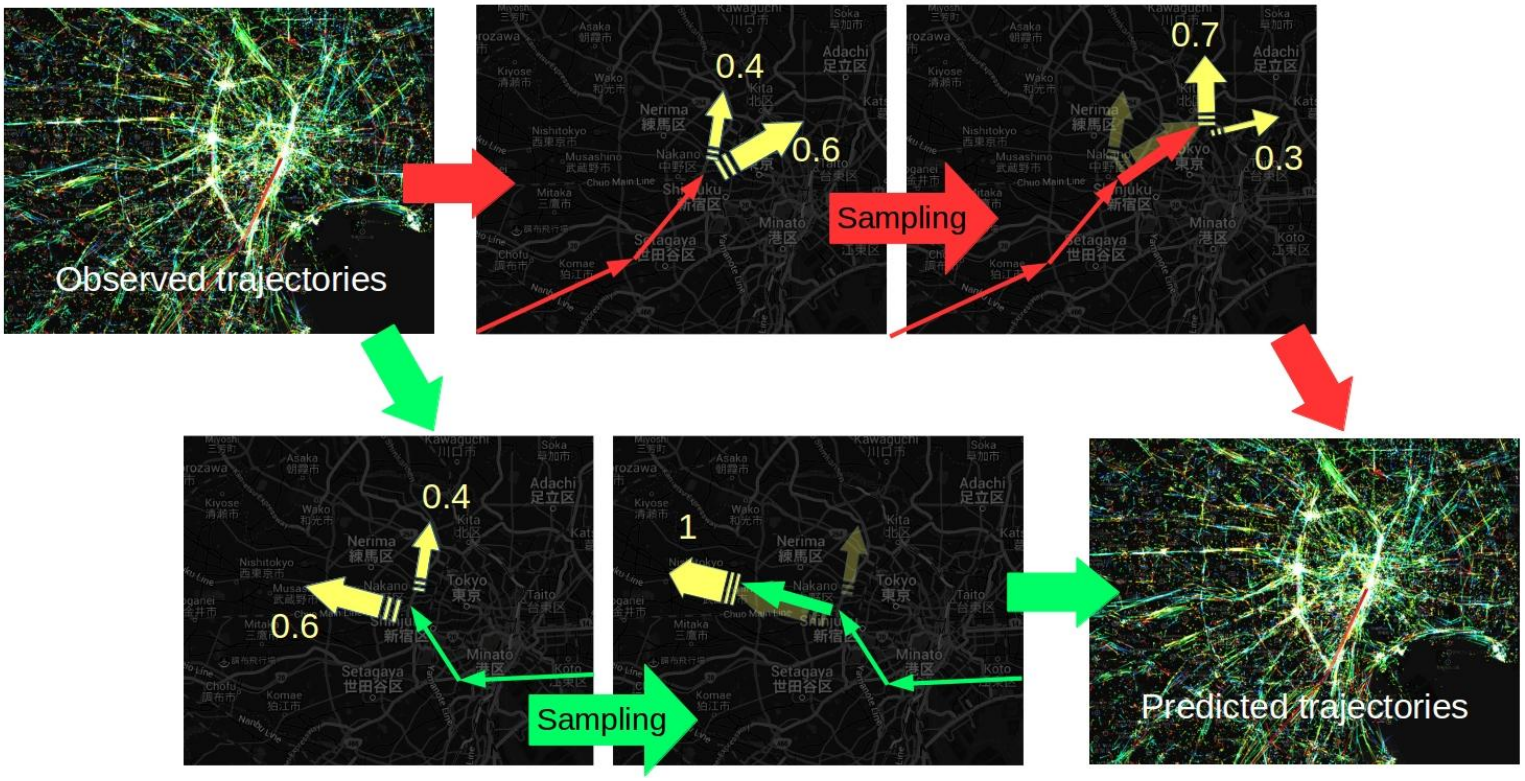
2011-08-11 8:20-9:20 a.m.


Cluster 1


Cluster 2

hue by trajectory direction

# Random walk predictor




## Random walk predictor

Input: 1h observed trajectories, cluster assignment

Output: 1h predicted trajectories

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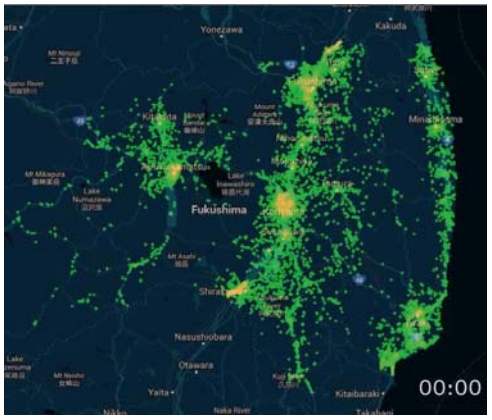
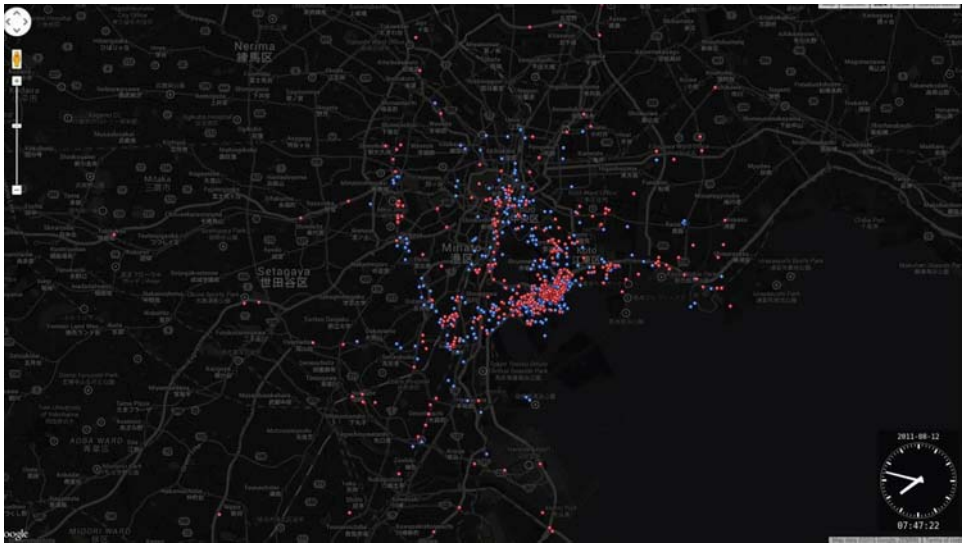
# Data


- Mobile phone GPS data: Auto-GPS mobile sensing data
  - allover Japan
  - 1.6 million users
  - 3 years (2010.8.1 - 2013.7.31)
  - 5 min interval
- With users permission and anonymization & aggregation are conducted
- We test our algorithm on some rare events. e.g. Comiket 80, New year's celebration.

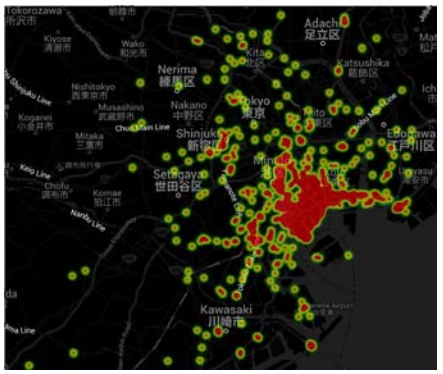
# Prediction on Comiket 80 (Arrivals)



Comiket 80 gathering

Red: Ground truth
Blue: Prediction

8:30(our results)



8:30(Ground truth)

2011-08-12 9:30

# Prediction on Comiket 80 (Leaves)

Comiket 80 dispersion

Red: Ground truth
Blue: Prediction

2011-08-12 15:30

16:30(our results)

16:30(Ground truth)

# Evaluation

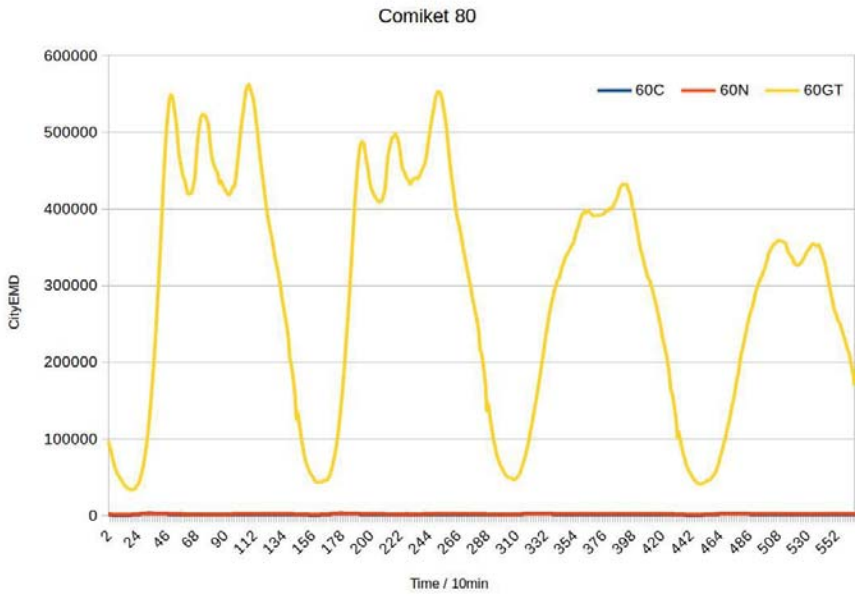
## Metric: Earth Mover Distance

$$CityEMD\,(t) = \sum_{\mathbf{o}} dist\left(p\,(\mathbf{d}|\mathbf{o})\,, \hat{p}\left(\hat{\mathbf{d}}|\mathbf{o}\right)\right)$$

where $\mathbf{d}$, $\hat{\mathbf{d}}$ are the ground truth/predicted locations of subjects originated from $\mathbf{o}$.

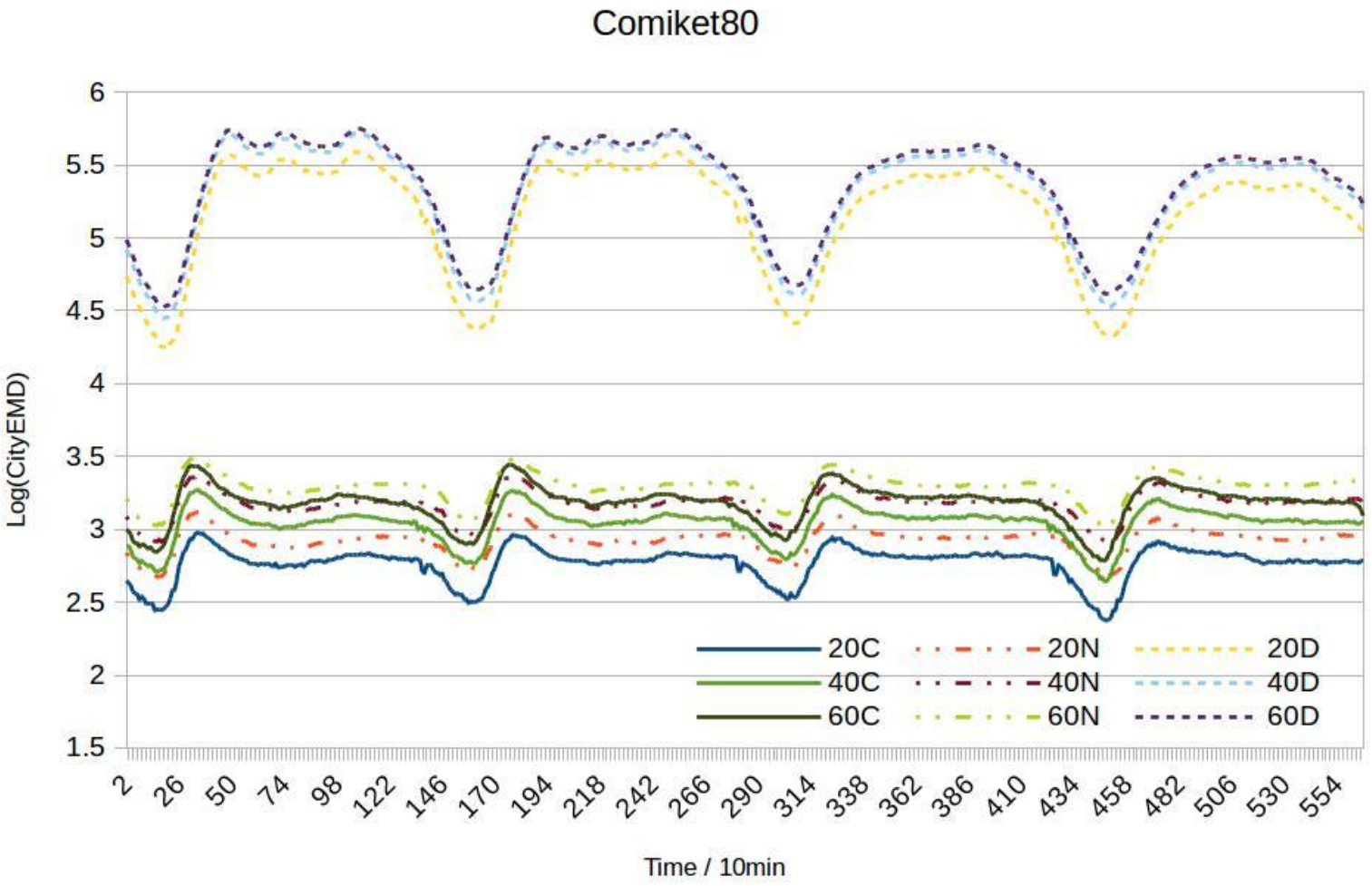
## Dummy predictor

- Assume no subjects move
- Higher intensity of human mobility $\rightarrow$ larger EMD
- vice versa




D: Dummy, N: Naive Movement, C: CityMomentum

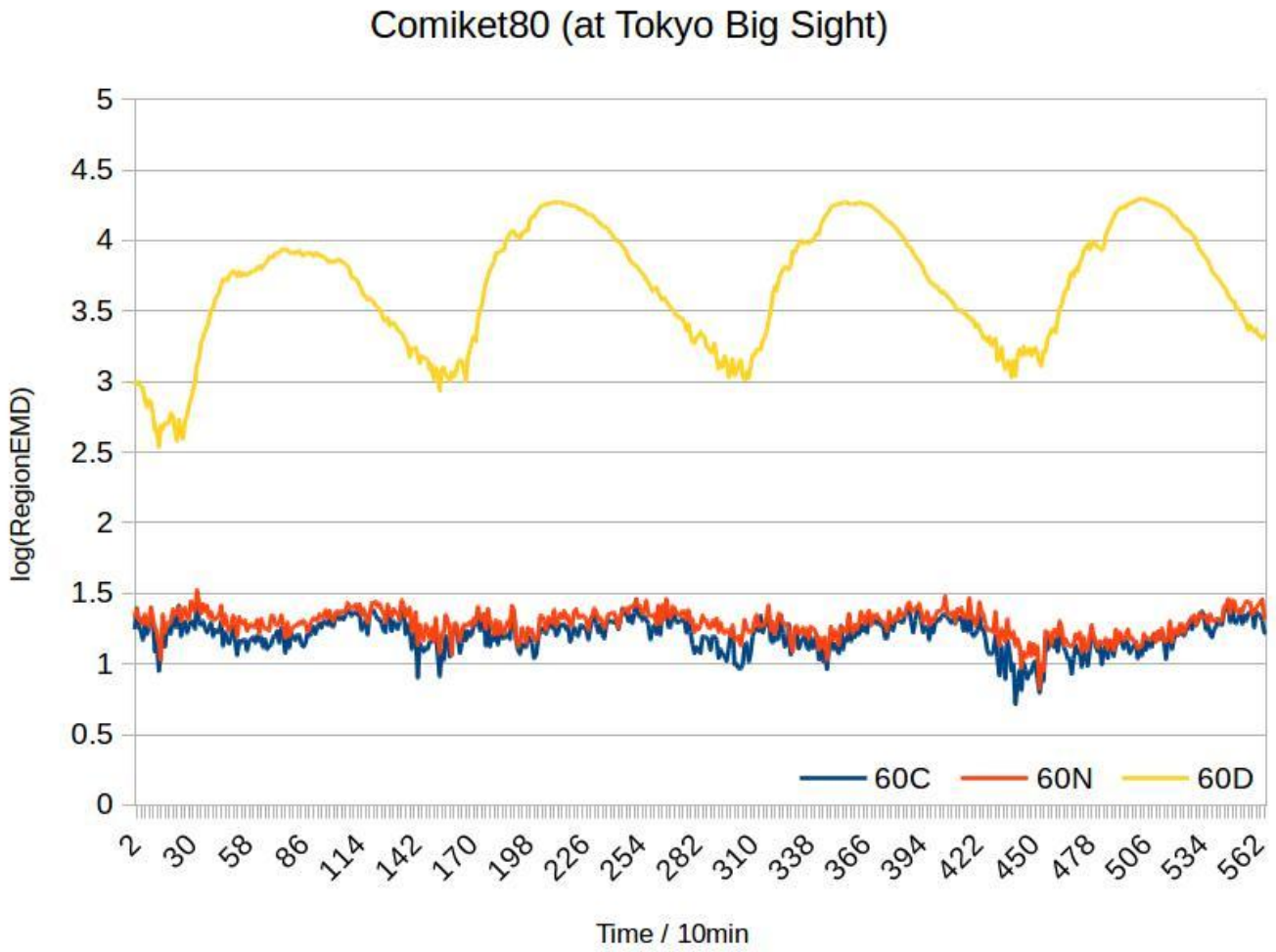
# Evaluation(Logarithmic scale)




D: Dummy, N: Naive Movement, C: CityMomentum

20: 20 min prediction, 40: 40 min prediction, 60: 60 min prediction

# Evaluation(Tokyo Big Sight Only)




D: Dummy, N: Naive Movement, C: CityMomentum, 60: 60 min prediction

# Conclusion

- From local to citywide, from detection to prediction.
- The most recent observations are important for rare event prediction.
- Bifurcation-minimization clustering works.
- This is an online learning algorithm and can be run in real-time. Very promising to be applicable.
- Promising extension:
  - More sources of data (e.g. digital map, SNS)
  - Rethink what can we know from massive data from regular days.

# Thank you for your attention!