

# Deep Learning for Human Mobility Analytics

## -- L1: Overview and Introduction

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INTR & DSA Thrust

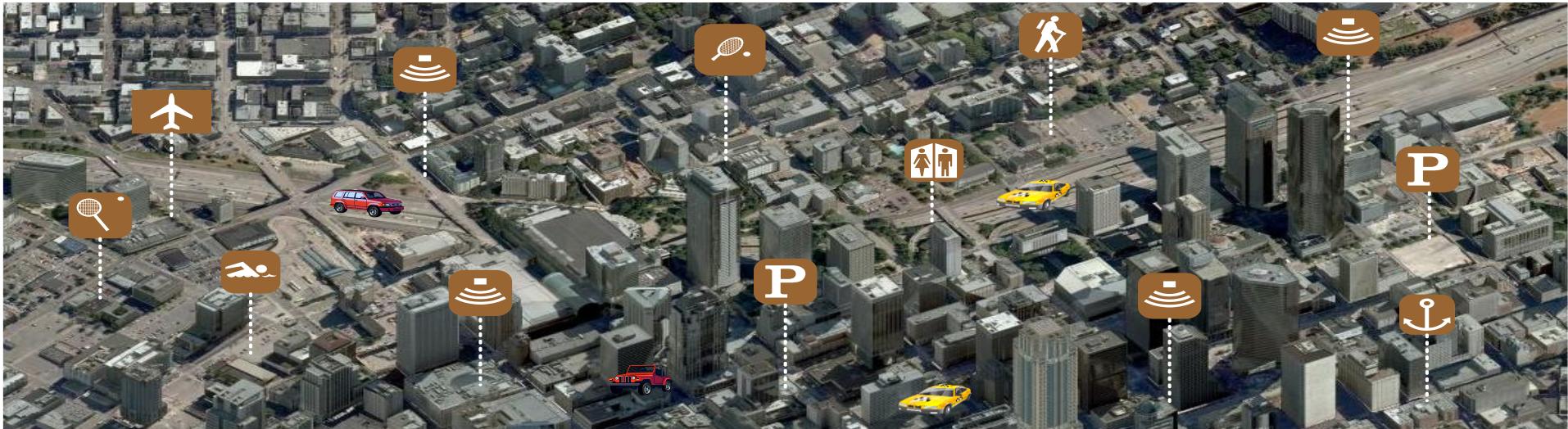
[yuxuanliang@hkust-gz.edu.cn](mailto:yuxuanliang@hkust-gz.edu.cn)





# Background of INTR 6000M

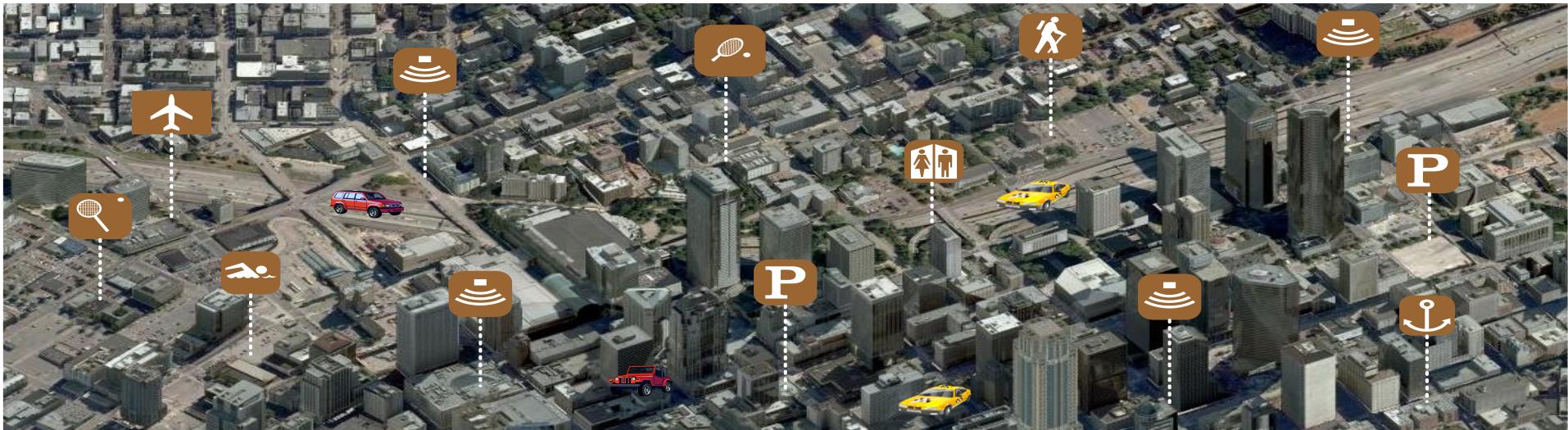
- As urbanization continues to grow, there is an increasing demand for data-driven solutions to address urban challenges, such as intelligent transportation
- This **interdisciplinary** course aims to provide PG students with a comprehensive understanding of AI and data mining concepts, techniques, and applications in human mobility analytics.



# INTR 6000M vs INTR 6000J



- INTR 6000J: Spatio-Temporal Data Mining & Analytics (STDMA)
  - Discussing advances in many different types of ST data
- INTR 6000M will focus more on **human mobility** and **deep learning**



# Covering Topics in INTR 6000M



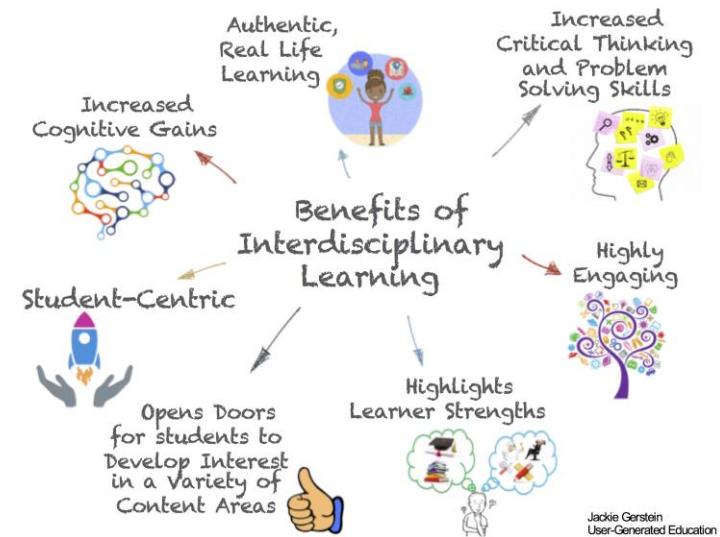
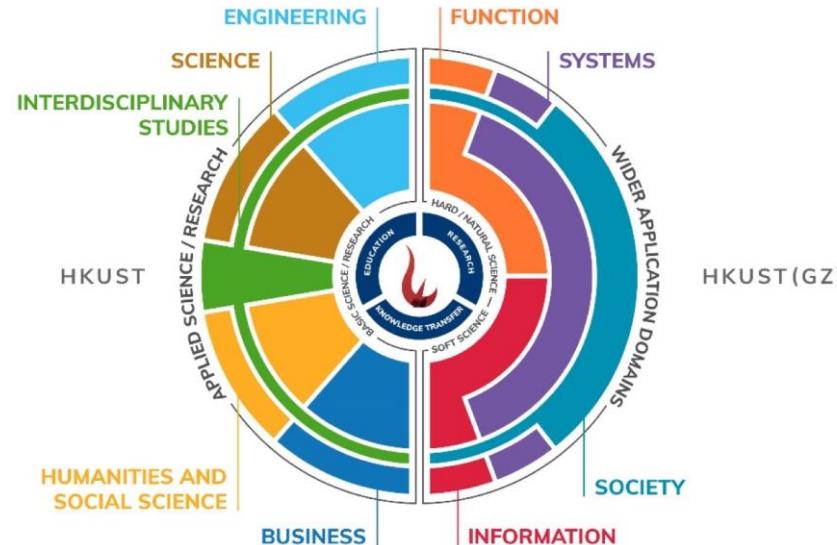
To introduce

- The concepts of Spatio-Temporal (ST) data, especially human mobility data
- The rich and exciting areas of human mobility analytics research
- The recent advances in research and applications
- The future research trends
- Hands-on exercises using real-world mobility datasets



# Target Students

- Targeting students from various disciplines like **computer science**, **transportation**, **urban planning**, **geography**, and **environmental science**, the course will promote collaboration and knowledge exchange



# Requirements



Could you please list some requirements for PG students to enroll the course of "Deep Learning for Human Mobility Analytics"



Here are some potential requirements for postgraduate (PG) students to enroll in the course "Deep Learning for Human Mobility Analytics":

## Prerequisite Knowledge

1. **Machine Learning Basics:** Understanding of fundamental concepts in machine learning, including supervised and unsupervised learning, basic algorithms (e.g., linear regression, decision trees), and evaluation metrics.
2. **Deep Learning Fundamentals:** Familiarity with deep learning concepts, such as neural networks, backpropagation, convolutional neural networks (CNNs), and recurrent neural networks (RNNs).
3. **Programming Skills:** Proficiency in Python and experience with deep learning libraries like TensorFlow or PyTorch.
4. **Mathematical Foundations:** Solid background in linear algebra, calculus, probability, and statistics, as these are essential for understanding deep learning models and algorithms.
5. **Data Science Skills:** Experience with data processing, data visualization, and basic data analytics techniques, particularly in handling large datasets.

# Benefits of Taking INTR 6000M



- By equipping students with the necessary skills to analyze, model, and visualize human mobility data, this course will contribute to the development of a new generation of professionals adept at harnessing the power of spatio-temporal data to create smarter, more sustainable cities and foster interdisciplinary research in smart cities and beyond.





# Objectives of this Course

To introduce

- The concepts of Spatio-Temporal (ST) data, especially human mobility data
- The Urban Computing Framework
  - Urban Sensing & Data Acquisition
  - Urban Data Management
  - Urban Data Analytics
  - Service Providing
- Case Study in Industry
- The criteria for a good ST data mining research
- Course Outline

# What is Spatio-Temporal Data?

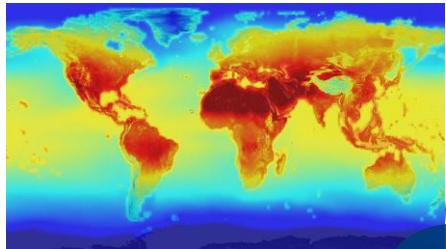
# Big Challenges in Big Cities





# What is Spatio-Temporal (ST) Data?

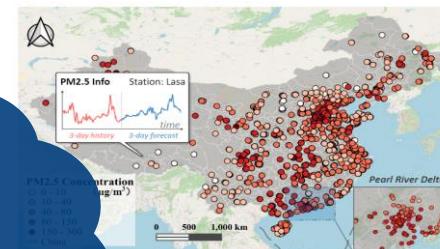
- With recent advances in sensing technologies, a myriad of **Spatio-Temporal Data** has been collected and contributed to various disciplines



Climate



Time, Location,  
Epidemiology  
Event



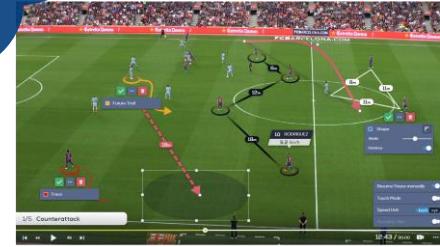
Environment



Social Science



Transportation

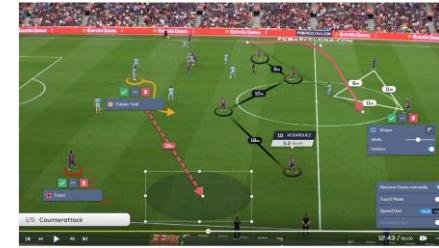
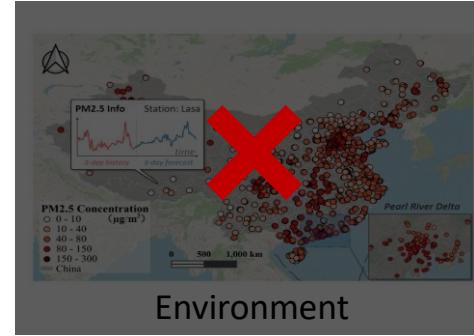
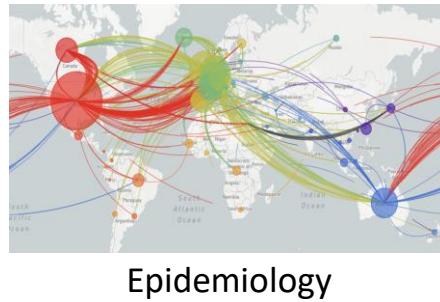
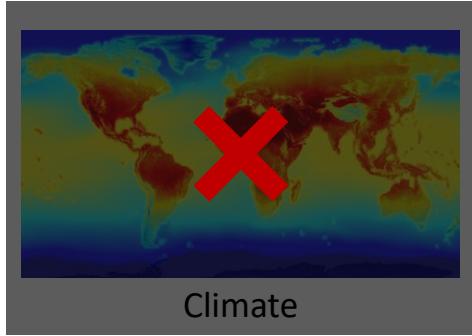


Sports Analysis

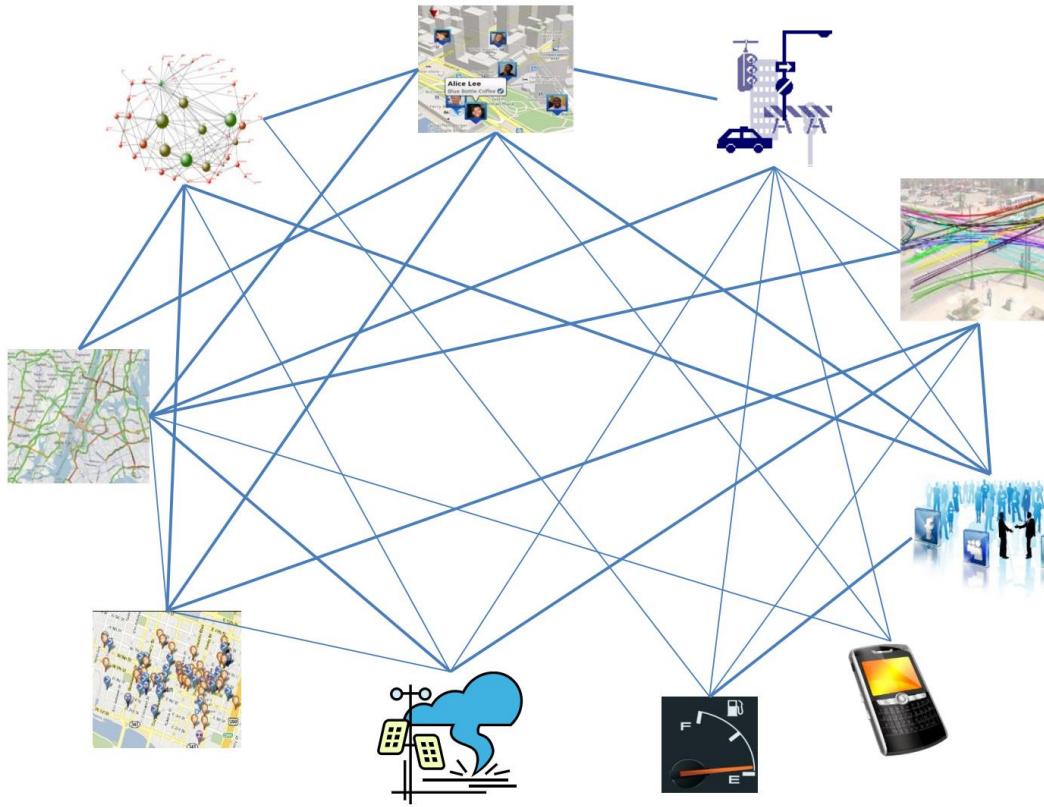


# Human Mobility Data

- Human mobility data is a representative data type of ST data



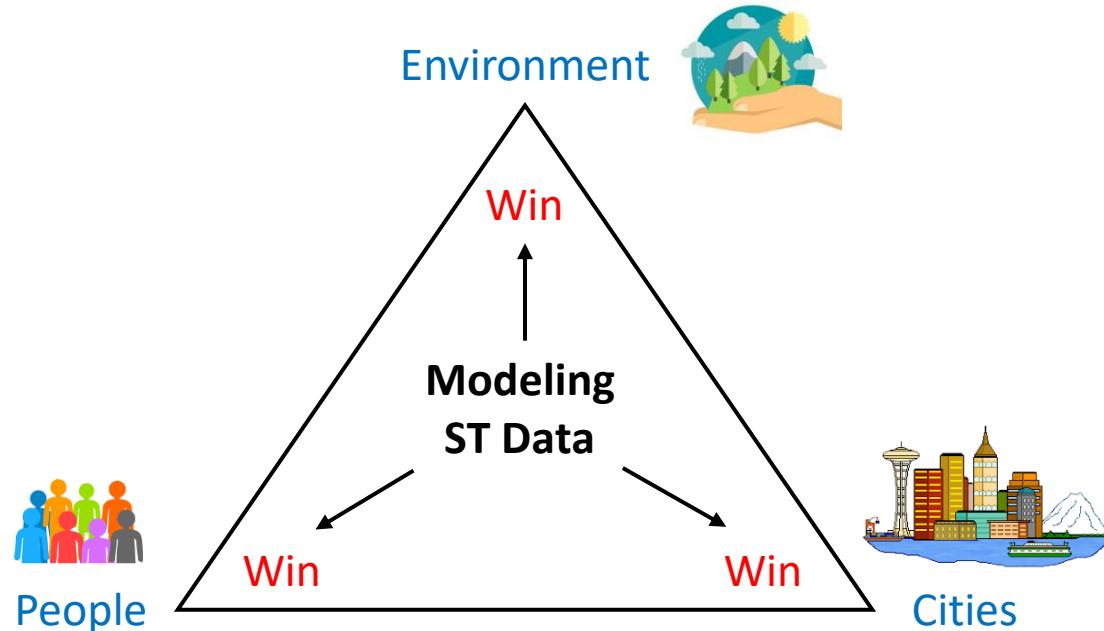
# ST Data are Connecting Each Other





# Motivation

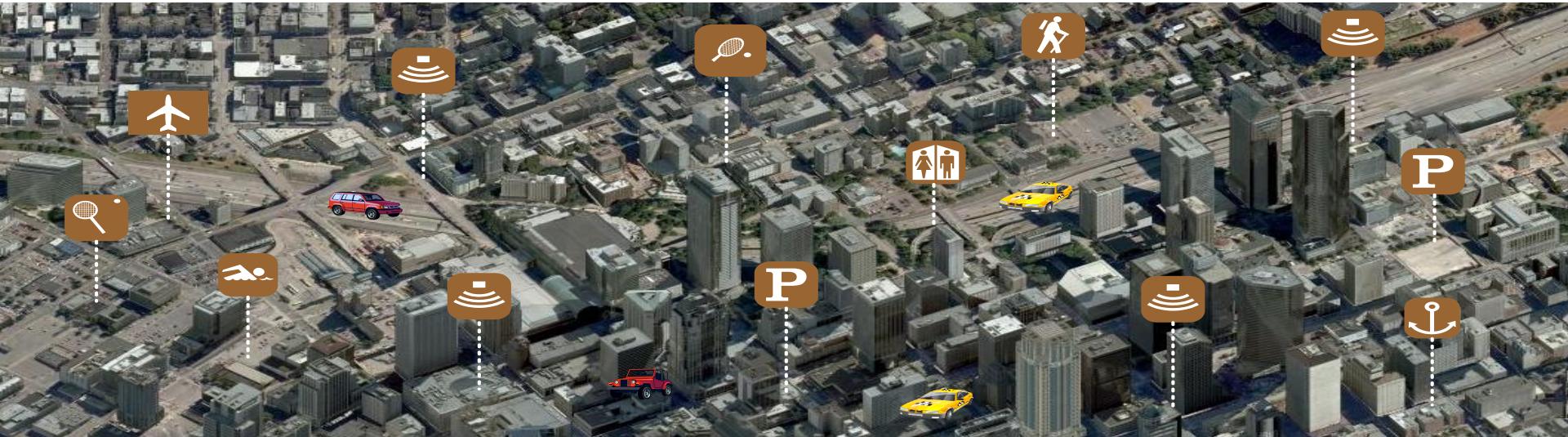
- Modeling ST data is the foundation of many real-world applications with high social impacts.
- **Creating win-win-win solutions** that improve the environment, human life quality, and city operation systems





# Urban Big Data - Taxonomy

- Spatially and temporally static data
- Spatially static and temporally dynamic data
- Spatially and temporally dynamic data





# Spatially and Temporally Static Data

- Points & Locations



Los Santos

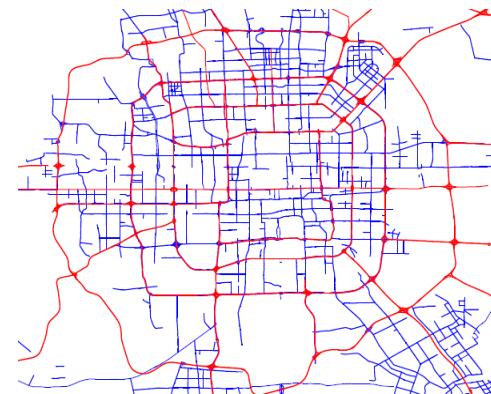


AC: Odessey



# Spatially and Temporally Static Data

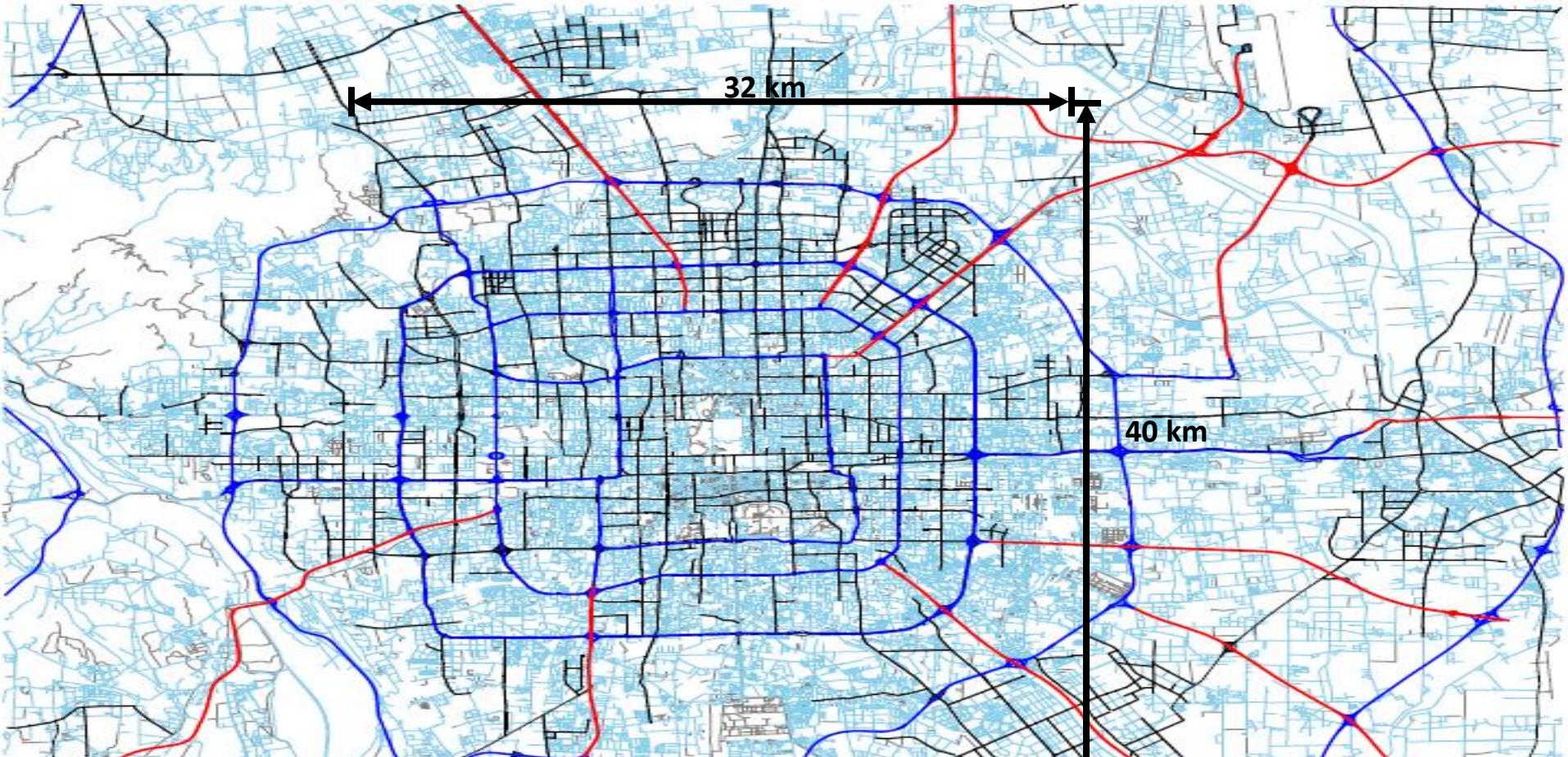
- Points & Locations
- Lines
  - Route, pipeline,
  - Rivers, coast,...
- Graphs
  - Road networks
  - Air lines



# POI Data (2007 – 2012)



+ pub/bar  
\* theaters



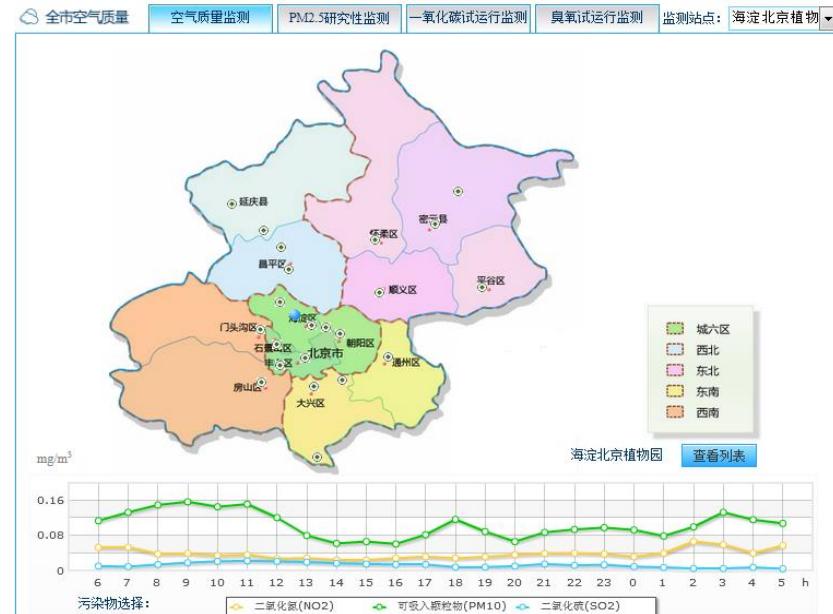
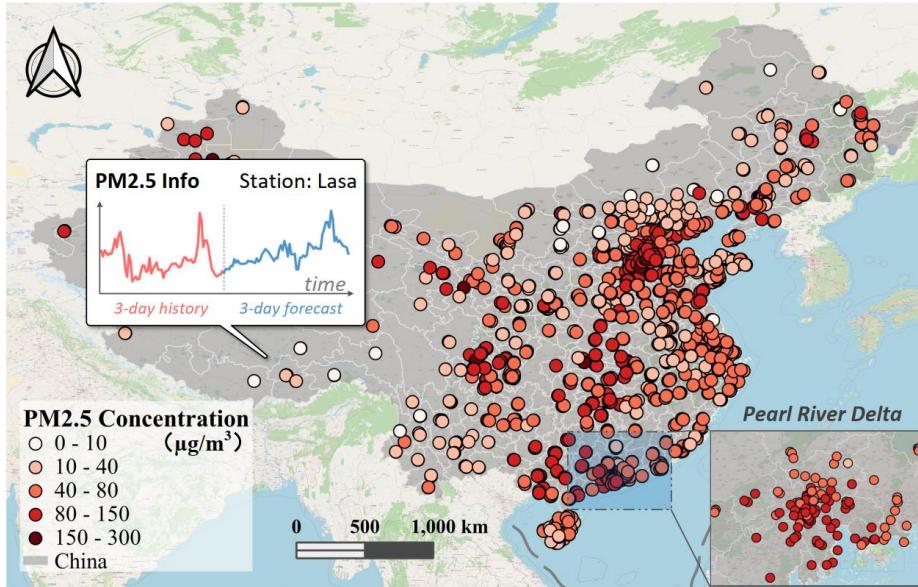
2011: 121,771 nodes and 162,246 segments, 19,524km

**Beijing road networks 2009-2011**

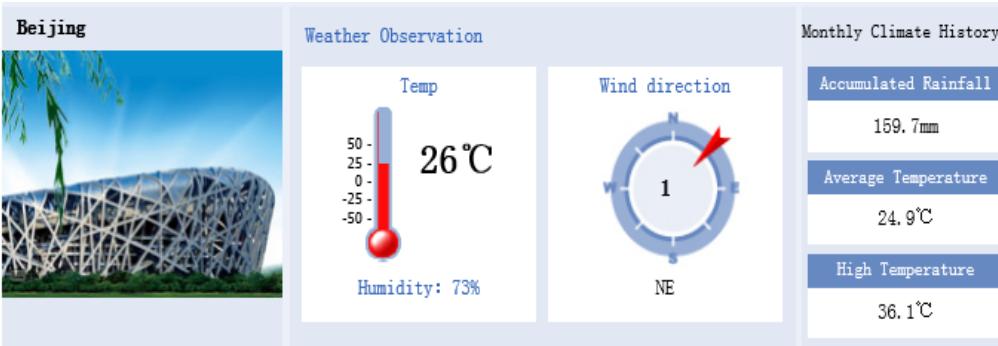


# Spatially Static and Temporally Dynamic Data

- Usually derived from sensors deployed in different locations



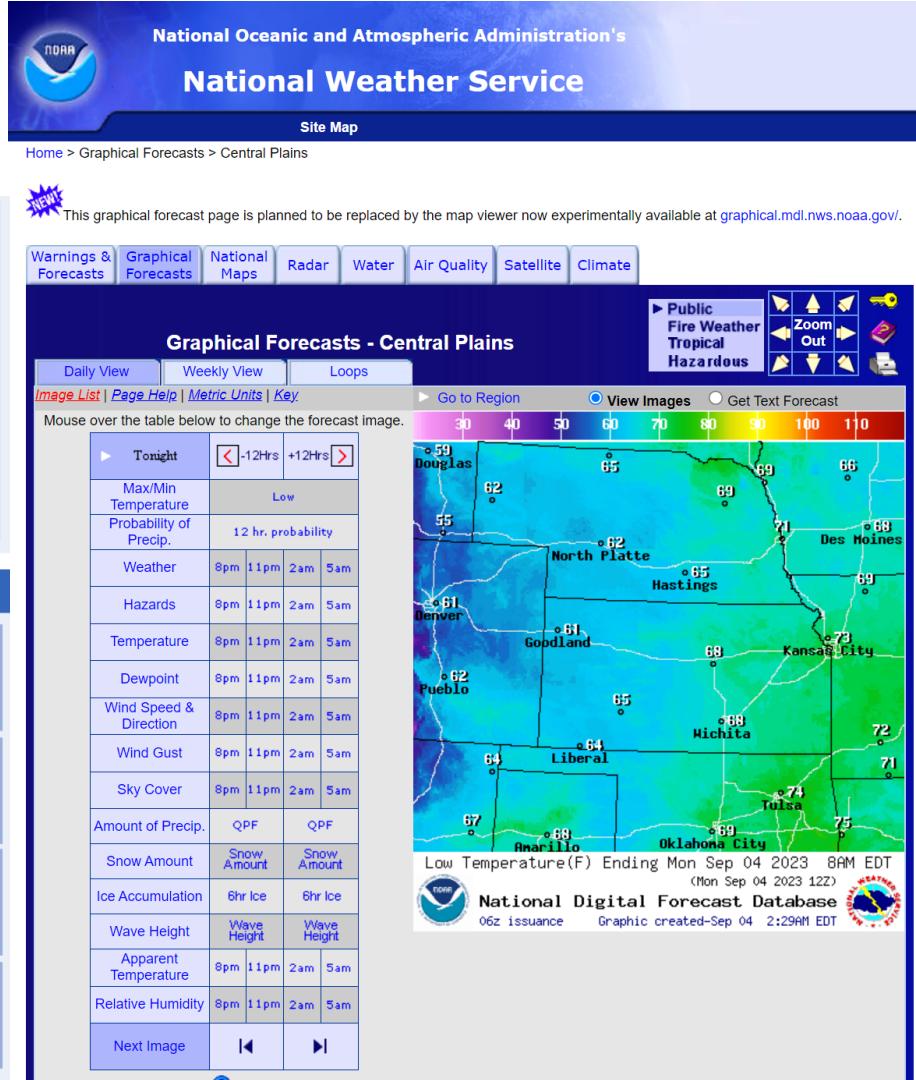
# Meteorological Data

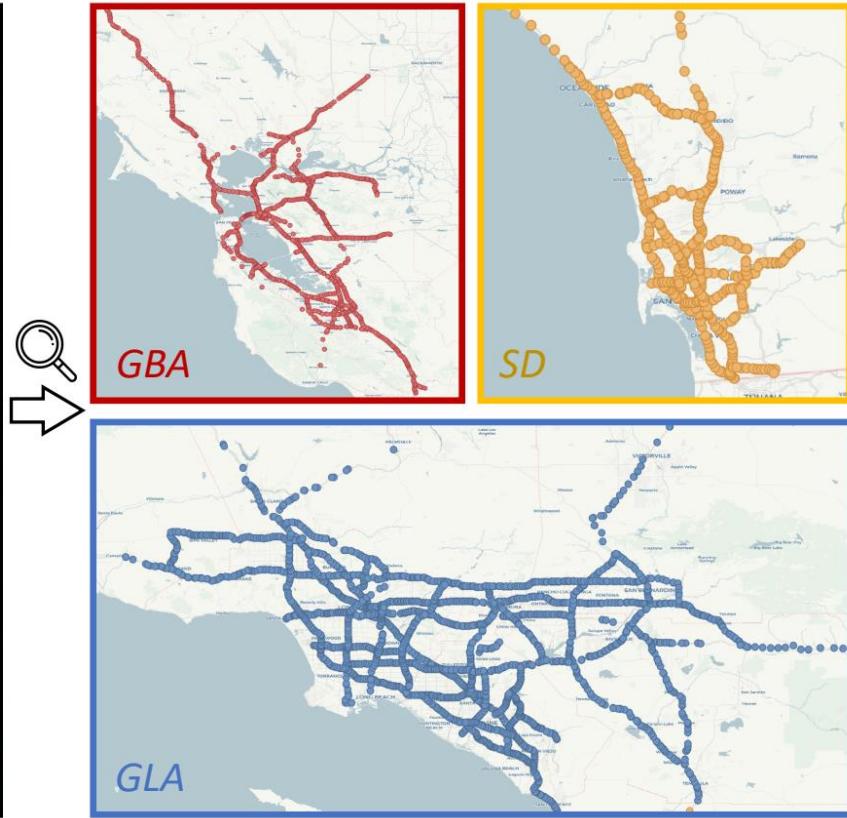
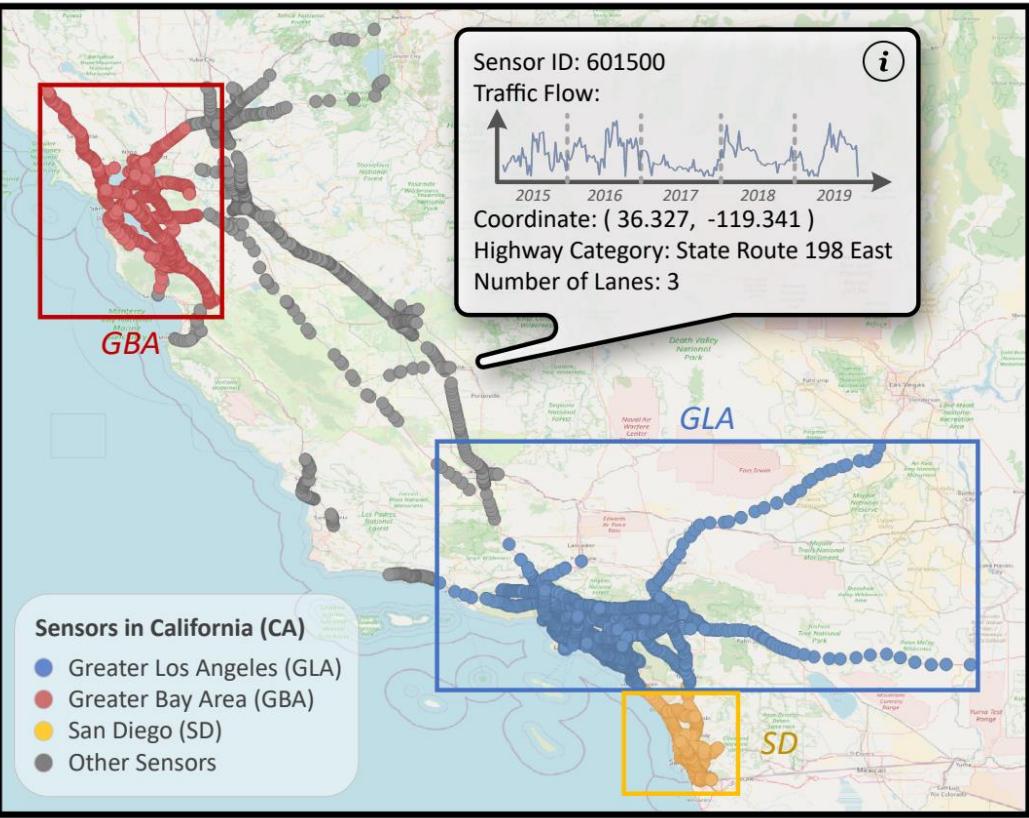


**Beijing Weather Forecast (2013-08-20 18:00)**

**4-7 Days Forecast**

Date		weatherForecast	Temperature	wind
Tuesday Aug 20	night		Shower	Low: 23°C (73°F) <12km/h
Wednesday Aug 21	day		Cloudy	High: 30°C (86°F) <12km/h
	night		Cloudy	Low: 22°C (72°F) <12km/h
Thursday Aug 22	day		Sunny	High: 29°C (84°F) <12km/h
	night		Sunny	Low: 22°C (72°F) <12km/h
Friday Aug 23	day		Sunny	High: 32°C (90°F) <12km/h
	night		Sunny	Low: 22°C (72°F) <12km/h



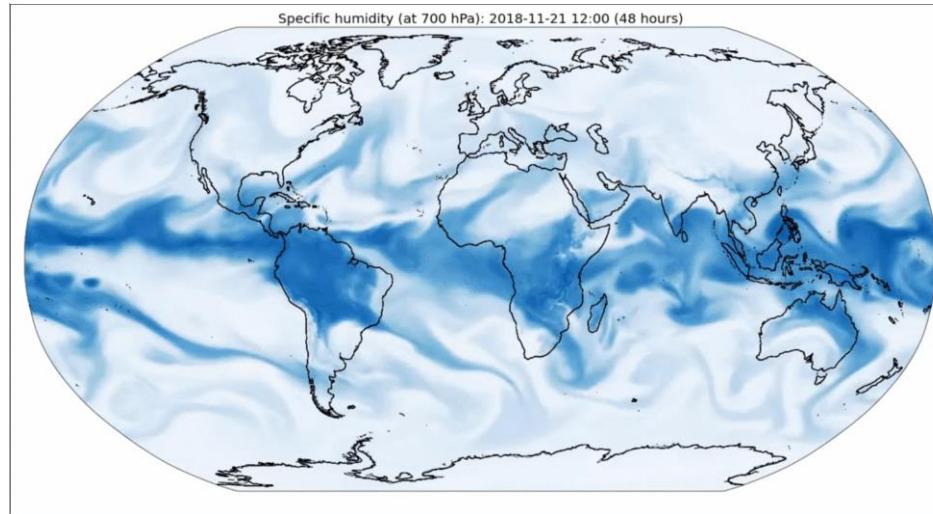
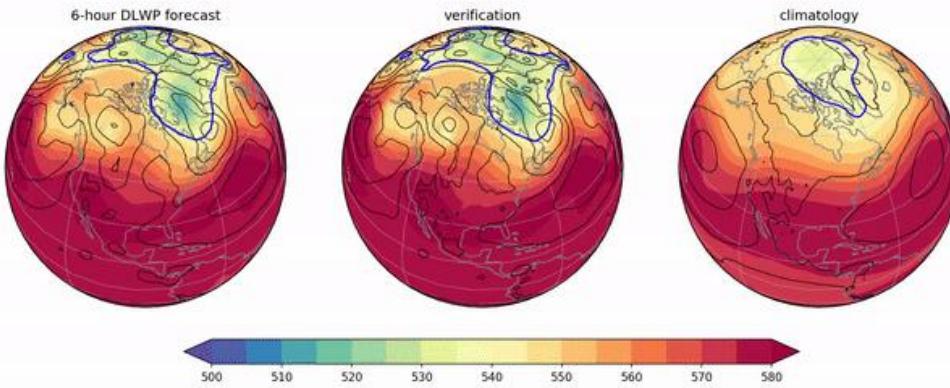


# Traffic Volume Data in California

# Real Estate Market

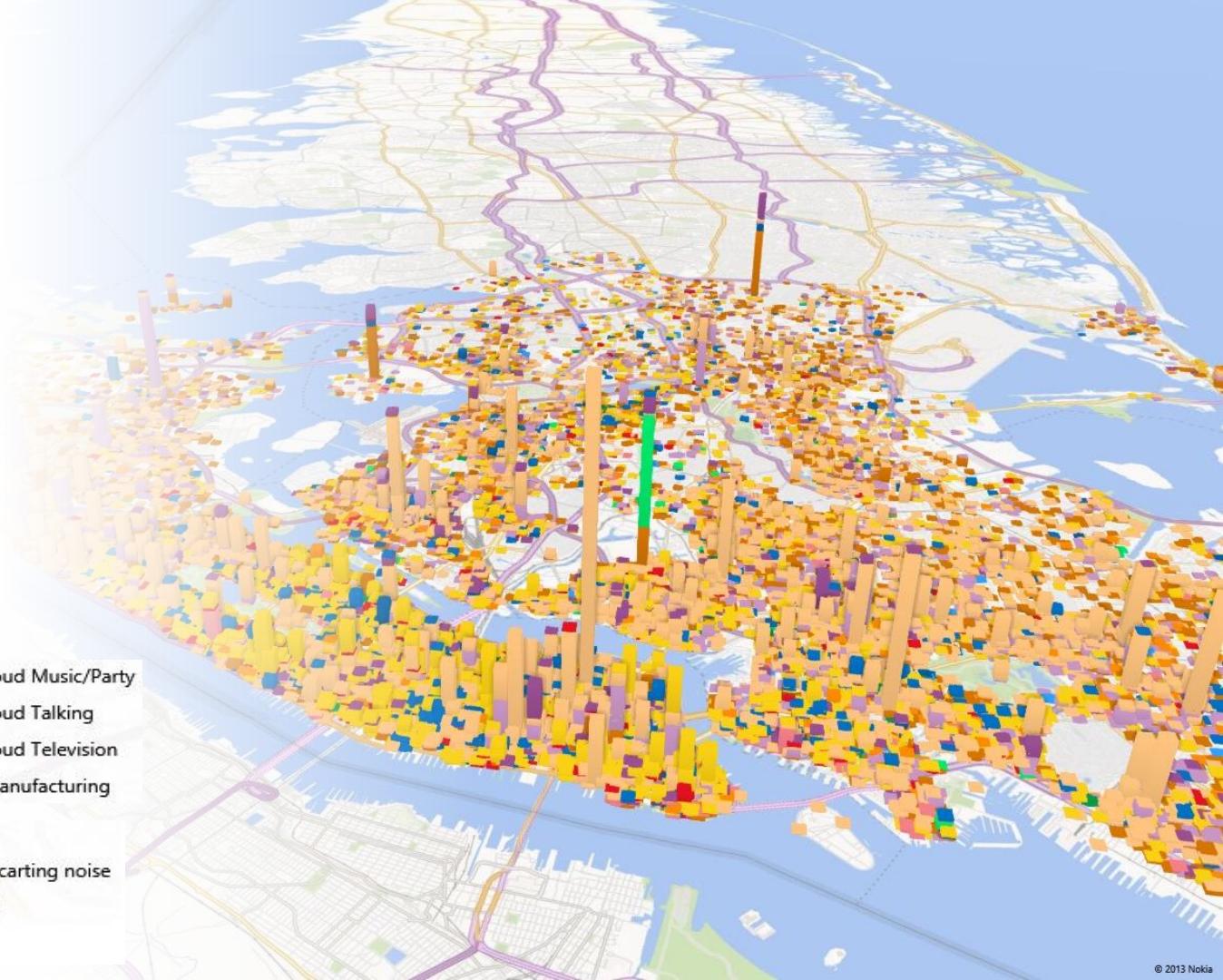


Valid: 2017-07-04 06:00 Z



# NYC 311 Complaint Data

- [Blue square] Air condition/Ventilation equipment
- [Orange square] Alarms
- [Purple square] Banging/Pounding
- [Yellow square] Construction
- [Green square] Horn Honking Sign Requested
- [Red square] Jack Hammering
- [Light blue square] Lawn care equipment
- [Orange square] Loud Music/Party
- [Purple square] Loud Talking
- [Yellow square] Loud Television
- [Green square] Manufacturing
- [Pink square] Others
- [Dark blue square] Private carting noise
- [Brown square] Vehicle





# Spatially and Temporally Dynamic Data

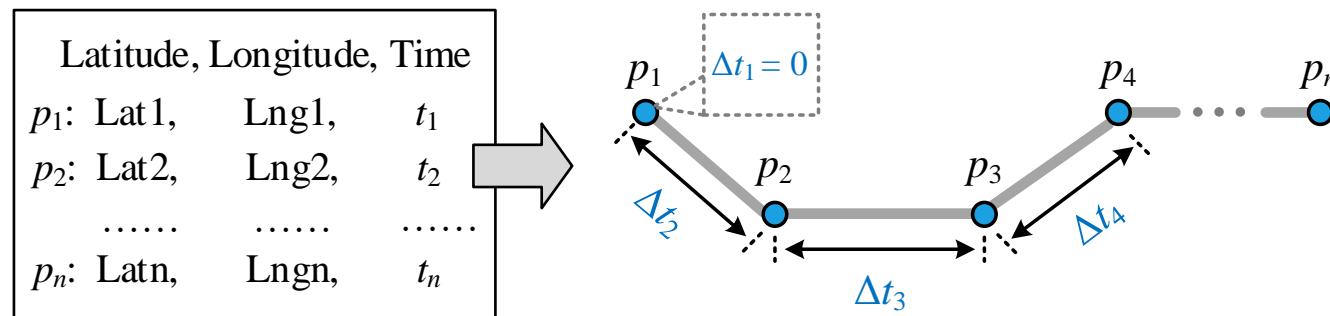
- Spatial and temporal values varying in time

- Moving objects
- Trajectories

$$T = p_1 \rightarrow p_2 \rightarrow \dots \rightarrow p_n, \quad p_i = (\underline{a_i}, \underline{b_i}, \boxed{t_i})$$

Timestamp  
Location (latitude & longitude)

- A spatial trajectory is a sequence derived from a moving object in geographical spaces, formulated by a series of chronologically ordered points

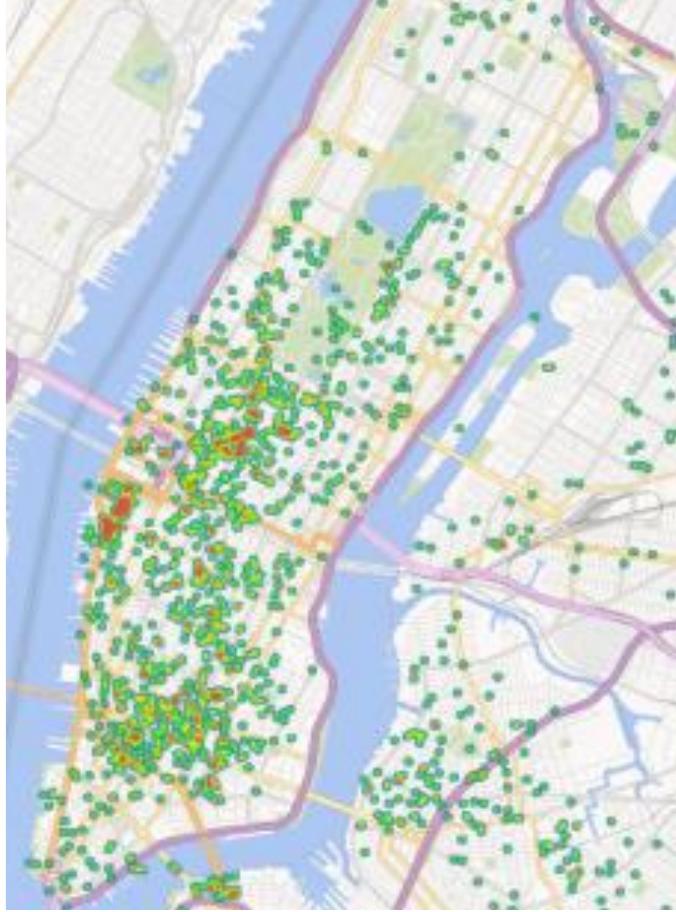




# Trajectory Data

- Human mobility
  - Travel logs
  - Check-ins
  - Credit card transactions
  - Phone signal, Wi-Fi...
- Human mobility
  - Taxis, buses, truck trajectories
  - Airplanes, ferries, cruise, ...
- Animals migration
- Natural phenomena

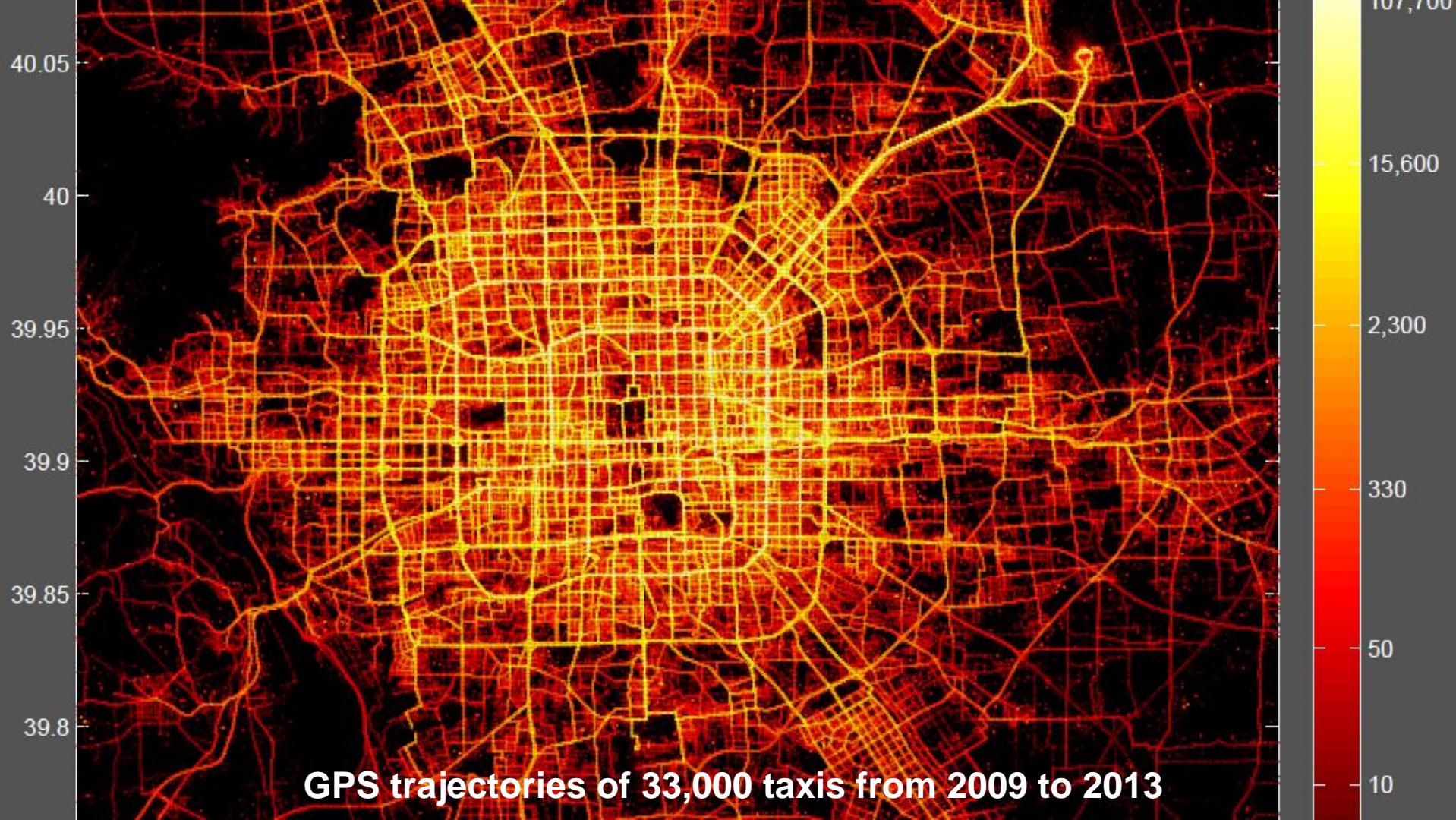




Check-in: Entertainment



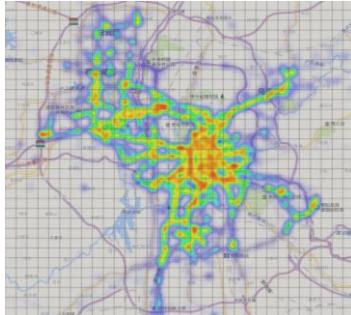
Check-ins: Nightlife Spot





# ST Raster Data

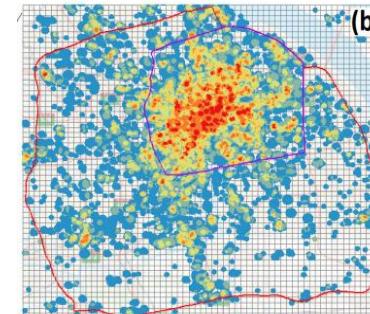
- We partition an area of interest (e.g., a metropolitan) evenly into grid cells, leading to an image-like data format called **ST raster data**
  - A pixel → **A region**
  - RGB → **Observations / Attributes**
- Real-world examples



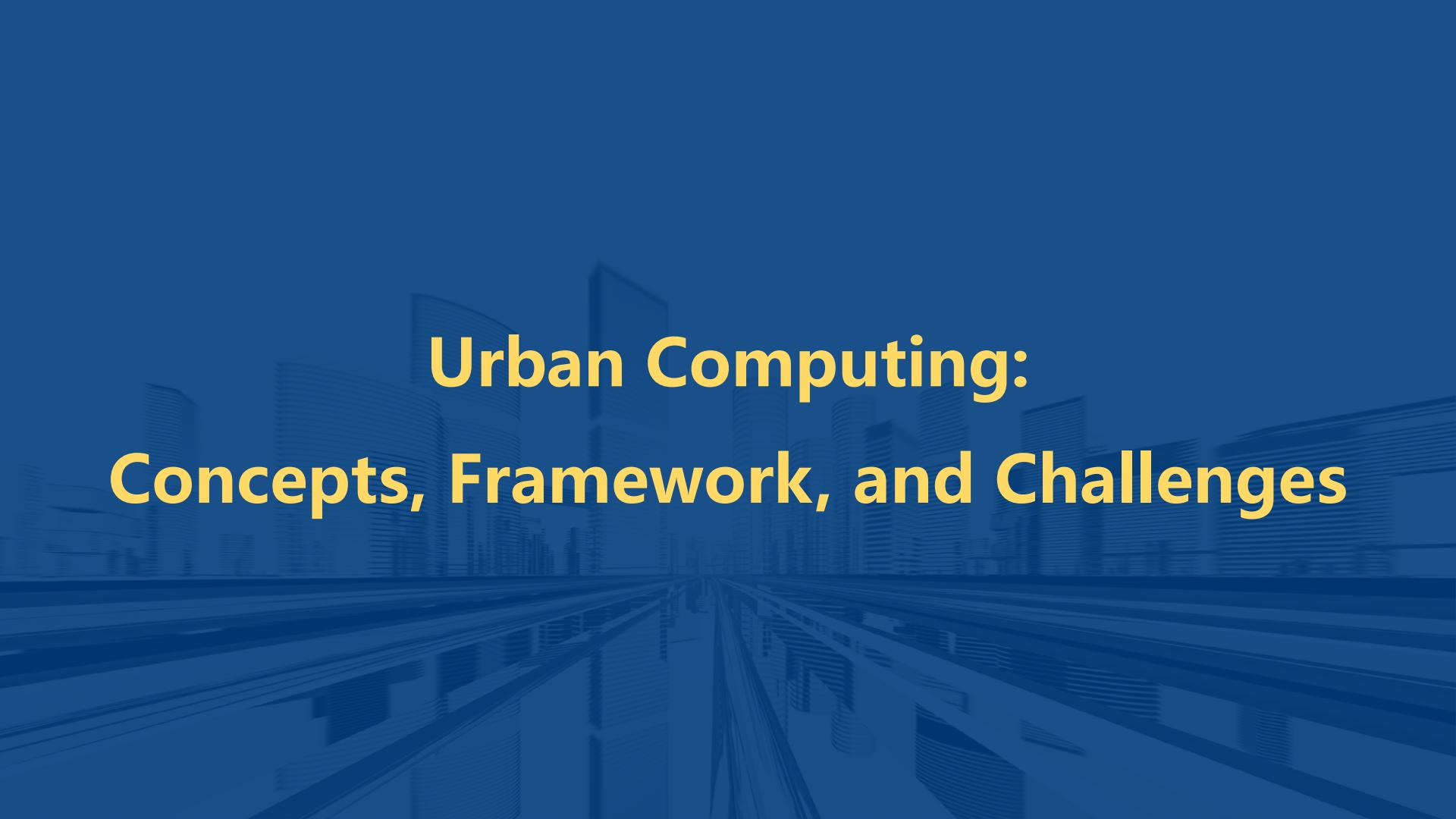
Taxi flows



Crime hotspots



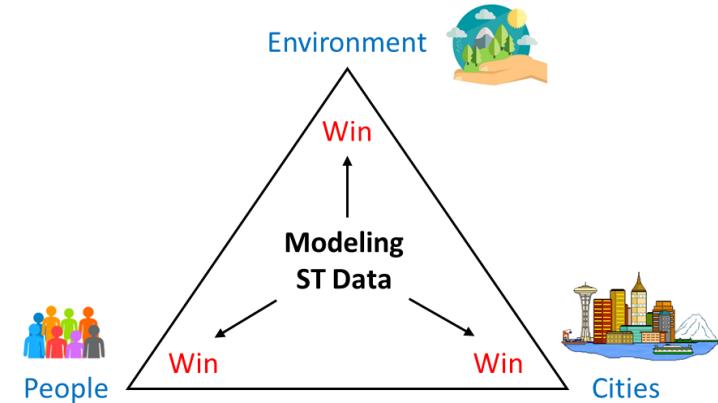
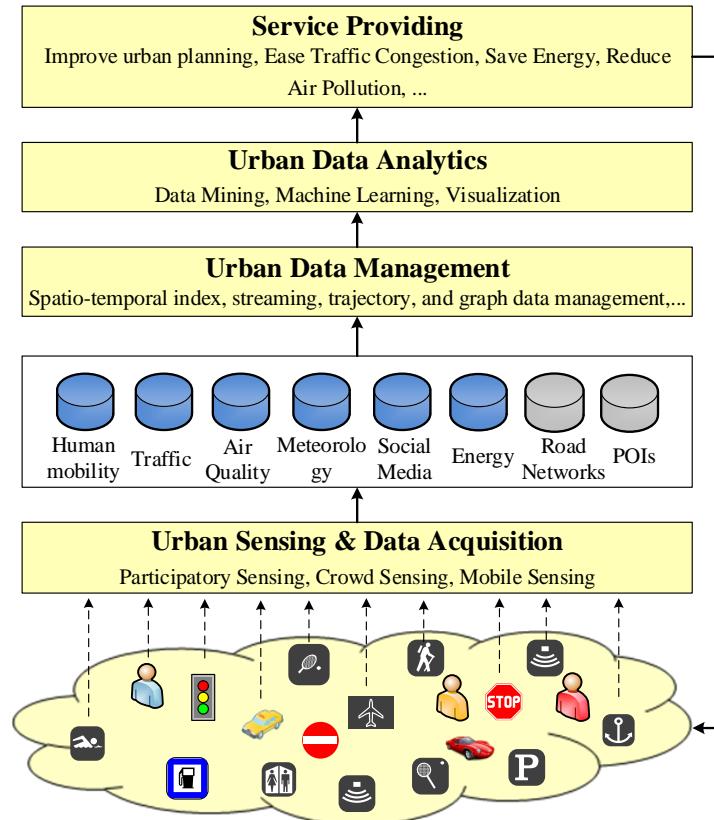
Bike-sharing demands



# **Urban Computing: Concepts, Framework, and Challenges**



# Framework



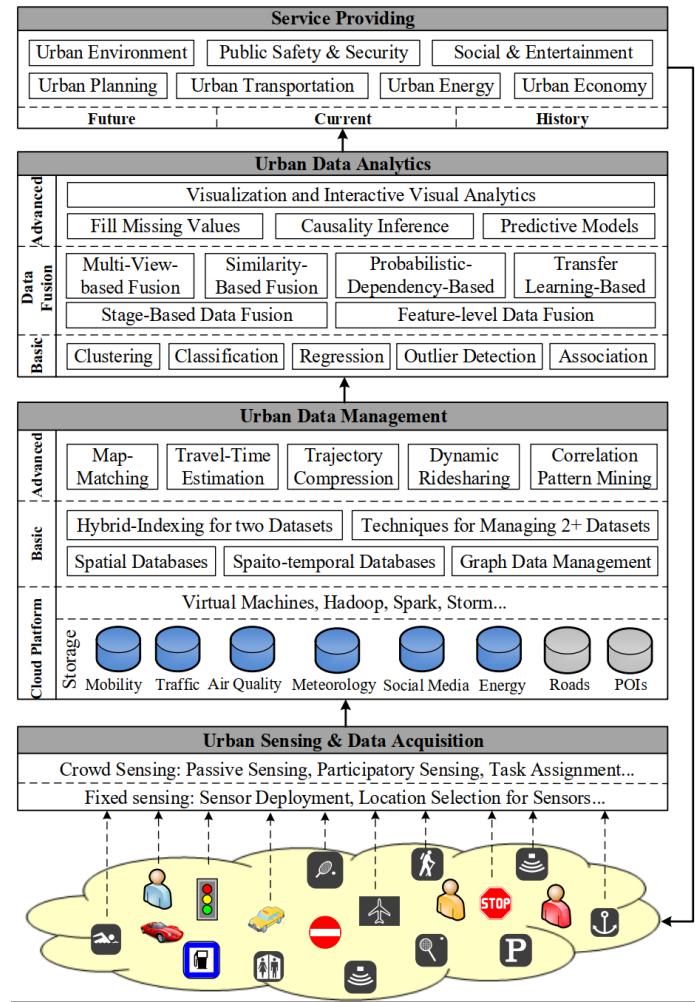
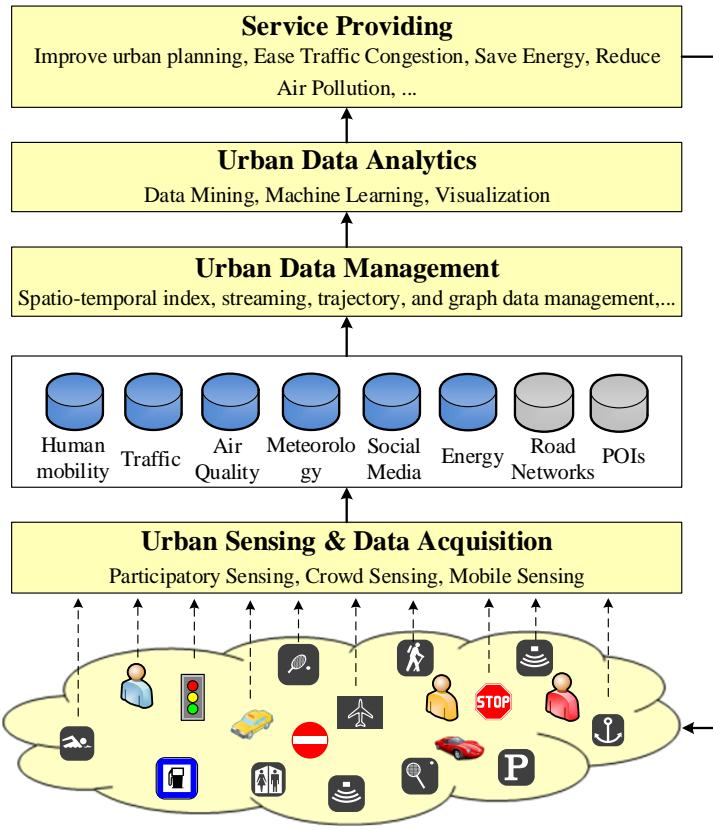
*Tackle the Big challenges*

*in Big cities*

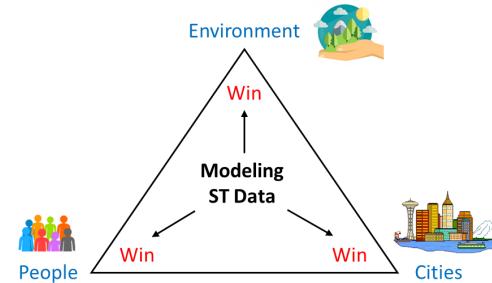
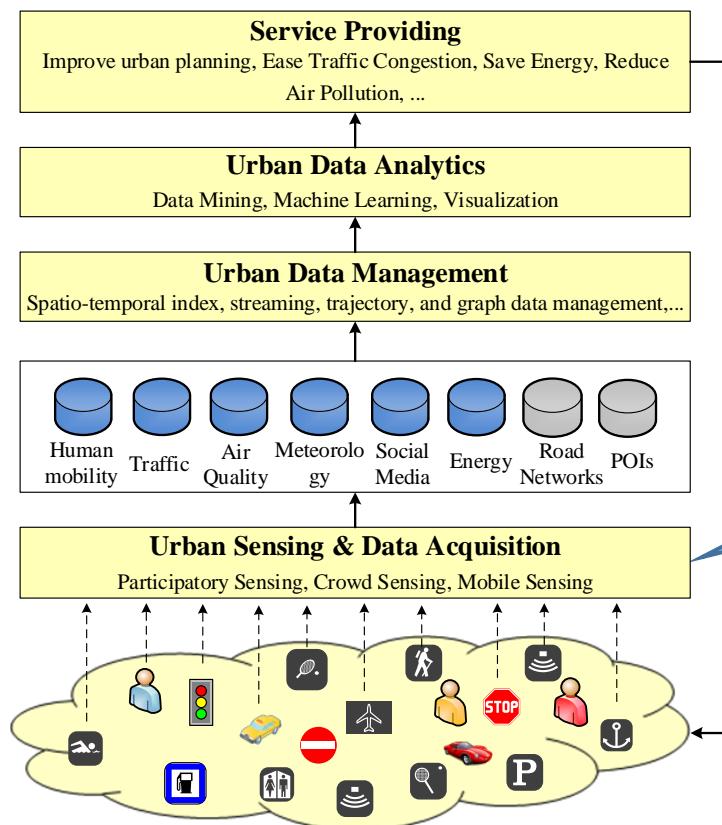
*using Big data!*

**Urban Computing: concepts, methodologies, and applications.**

Zheng, Y., et al. *ACM transactions on Intelligent Systems and Technology*.

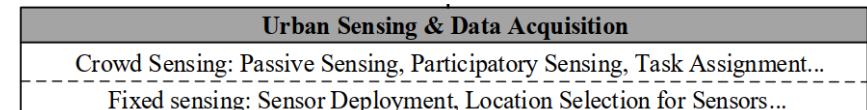


# 1<sup>st</sup> Stage: Urban Sensing & Data Acquisition



Collecting urban data through

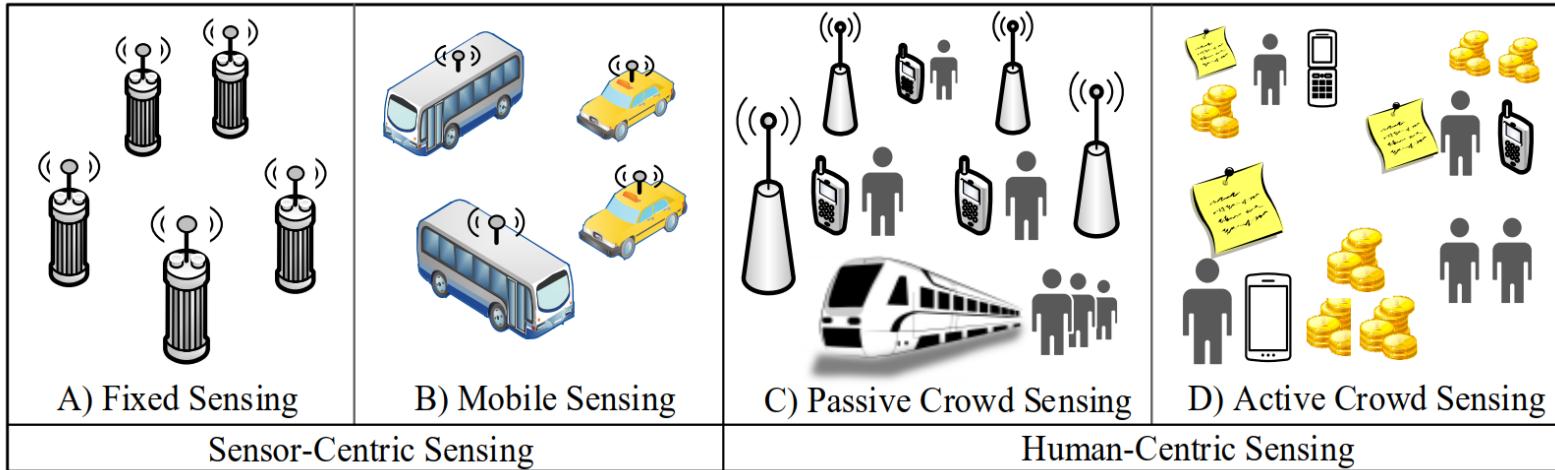
- Sensor-centric sensing
- Human-centric sensing



# Spatio-Temporal Sensing Modes

- Sensor-centric sensing
  - Fixed (location) sensing
  - Mobile (objects) sensing

- Human-centric sensing
  - Passive crowd sensing
  - Active crowd sensing



# 城市感知的内容

感知内容的标准化



人流量

- 交通枢纽人流量
  - 地铁人流
  - 公交人流
  - 机场人流
- 职住场所人流
  - 社区人流
  - 酒店人流
  - 园区人流
- 公共区域人流
  - 商圈人流
  - 景区人流
- 重大活动人流
  - 出入口人流



交通流

- 公共交通
  - 公交车
  - 地铁
  - 轻轨
  - 高铁
  - 飞机
- 私人交通
  - 共享单车
  - 出租车
  - 网约车
  - 专车
  - 私家车
- 运输
  - 物流车
  - 垃圾车
  - 危化品车
- 特种运输
  - 救护车
  - 警车
  - 消防车
  - ...



环境

- 空气质量
  - SO<sub>2</sub>、CO、O<sub>3</sub>
  - PM10、PM2.5
- 气象
  - 温度、湿度
  - 降水
    - 雨
    - 雪
  - 风
    - 风向
    - 风速
- 水质
  - 含氧量
  - 含氯量
  - PH值
- 遥感
  - 噪声
  - 土壤
  - 垃圾

公共安全

- 自然灾害
  - 台风
  - 洪水
  - 地震
  - 积水
  - 干旱
  - 高温
  - 积雪
- 人为灾害
  - 偷窃
  - 抢劫
- 意外风险
  - 地面塌陷
  - 火灾
  - 积水
  - 井盖是否盖住
- 舆情
  - 热点事件
  - 民众投诉
  - 政策评价



能耗

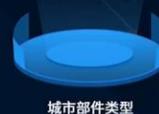
- 水
  - 居民用水
  - 企业用水
- 电
  - 家庭用电
  - 照明用电
  - 工业用电
- 气
  - 居家燃气
  - 交通加气
  - 企业用气
- 热
  - 居民家庭供暖
  - 写字楼供暖
  - 企业功能
  - 学校供暖
- 油
  - 汽油
  - 柴油
  - 煤油
- 消费
  - 线上购物
  - 生鲜
  - 粮油
  - 家电
  - ...
- 线下消费
  - 商超
  - 文旅
  - 医疗
  - ...
- 税收
  - 个人所得税
  - 消费税
  - 增值税
  - 关税
  - 房产税
  - ...
- 产值
  - 企业产量
  - 物品销量

...

## 城市部件覆盖总量

126种

1071999个



## 各区城市部件数量统计

单位: 件

500000

400000

300000

200000

100000

0

崇川区 395000 件

港闸区 345000 件

开发区 225000 件



100万IOT设备

10万摄像头

以传感器为中心的固定感知  
知



# 交通一张图



全行业数据“汇一图” 全时空监测“看一图” 全样本决策“用一图”

100万IOT设备  
10万摄像头

9356 出租车、卡车、网约车  
11,675 船舶

以传感器为中心的固定感知

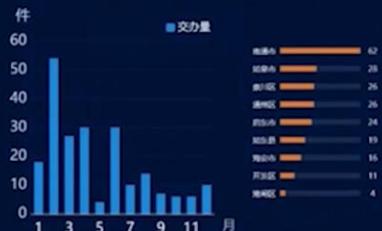
以传感器为中心的移动感知

# 市域治理现代化指挥平台 - 社情民意一张图

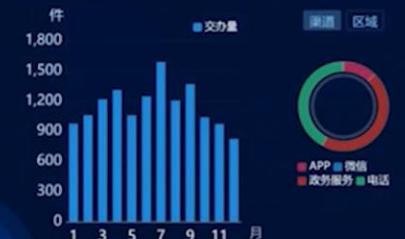
上级交办

上级交办总量 14066 件

国家交办(当日)	0 件
国家交办(累计)	148 件
互联网+督查	68 件
国务院服务	216 件



省平台交办(当日)	3 件
省平台交办(累计)	13734 件



广纳民声

聚焦民意

响应民情

惠及民心

网络渠道

网络汇聚总量 5758 件

本年度上报总量 1053578 件

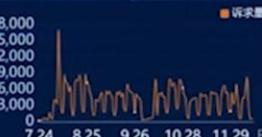
联动上报

联动上报总量 1033754 件

部门联动平台

部门联动平台上报总量 709004 件

当日上报量 638 累计上报量 580133



上报详情 时间

- |   |           |       |
|---|-----------|-------|
| 3 | 草坪里有黄色塑料袋 | 12/14 |
| 4 | 农家庭检查     | 12/14 |
| 5 | 交通标志牌脱落   | 12/14 |
| 6 | 绿化维护      | 12/14 |

政务热线平台

政务热线上报总量 324311 件

887 / 322612

12345服务【当月/累计量】

5,000

4 / 1499

直接整合热线【当月/累计量】

3,000

0 / 0

并联整合热线【当月/累计量】

1,000

上报详情 时间

- |   |            |       |
|---|------------|-------|
| 3 | 咨询贵阳停电何时来电 | 12/14 |
| 4 | 咨询恒大什么时候来电 | 12/14 |
| 5 | 关于地铁施工的问题  | 12/14 |
| 6 | 关于噪音扰民的问题  | 12/14 |

紧急联动平台

紧急联动平台上报总量 439 件

110热线

当日

2

累计量

439

119热线

当日

0

累计量

120热线

当日

0

累计量

100万 IOT 设备  
10万 摄像头

以传感器为中心的固定感知

9356 出租车、卡车、网约车  
11,675 船舶

以传感器为中心的移动感知

7万+ 网格员  
数十万居民主动上报

以人为中心的主动感知

南通百通 APP

微渠道

APP 服务量 (件)

微博 (件)

146

426

网站 (件)

好差评 (件)

59

116

网络话题

正面

【时来运转】泥料：家藏老紫泥 容量：280cc 此...

2020-12-14 10:09:47

来源：新浪微博

正面

【苏州东吴医院】「苏州肠道病医院」「苏州肛肠...

2020-12-14 10:09:42

来源：新浪微博

正面

#网上重走长征路# 在教学中坚持把“四史”教育...

2020-12-14 10:09:41

来源：新浪微博

正面

【湖北12条新政优化高新区企业认定服务 全时受理企...

2020-12-14 10:09:28

来源：新浪微博

负面

#江西服装学院##江歌小青马# 2020年12月14日 ...

2020-12-14 10:10:10

来源：新浪微博

负面

//@如皋发布:#带着微博去如皋# Welcome to Ru...

2020-12-14 10:10:09

来源：新浪微博

负面

昨晚还在刷微博，看见别人买东西卡在里面，然后...

2020-12-14 10:10:09

来源：新浪微博

负面

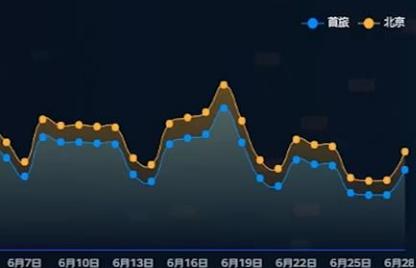
转最近2号线尹山湖站保利悦都招租一个半月可续...

2020-12-14 10:10:08

来源：新浪微博

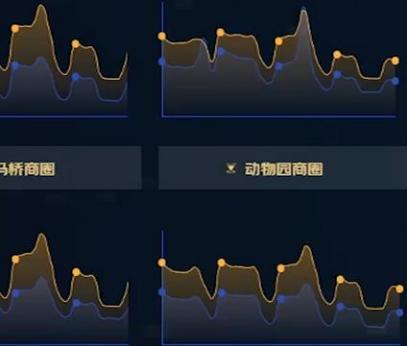
⑦

度与北京市人口活跃度对比



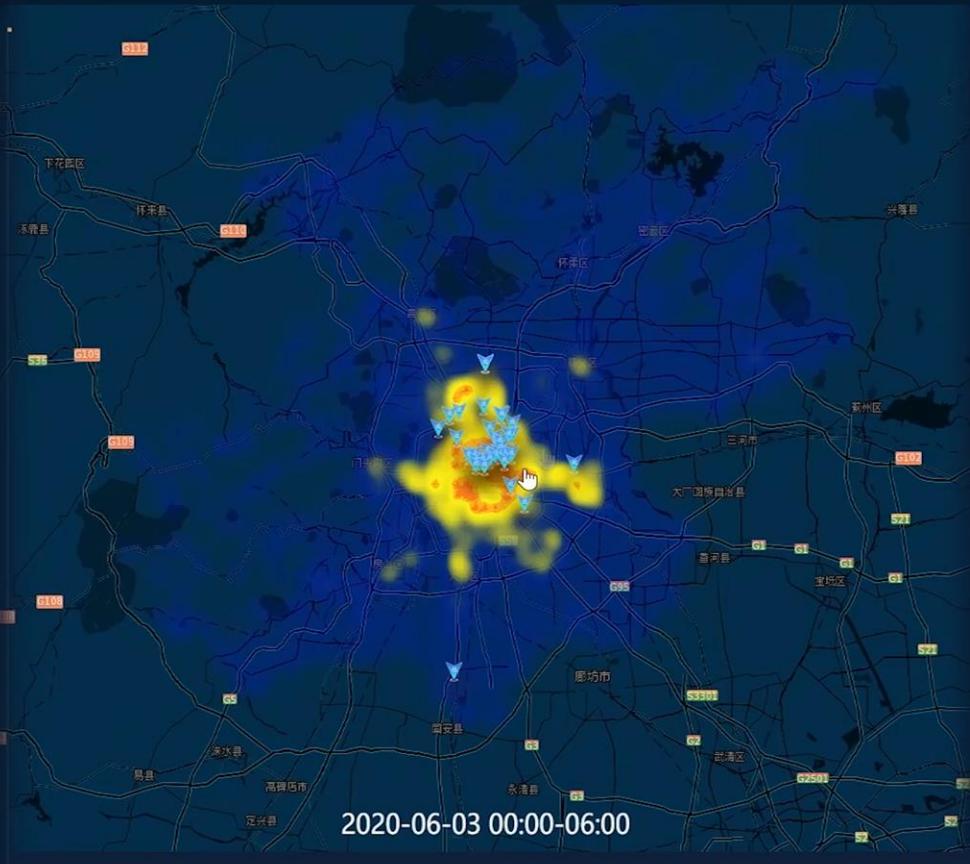
商圈

王府井商圈



商圈

动物园商圈



100万IOT设备  
10万摄像头

以传感器为中心的固定感知

9356 出租车、卡车、网约车  
11,675 船舶

以传感器为中心的移动感知

7万+ 网格员  
数十万居民主动上报

以人为中心的主动感知

800万居民手机信令  
社交媒体

以人为中心的被动感知

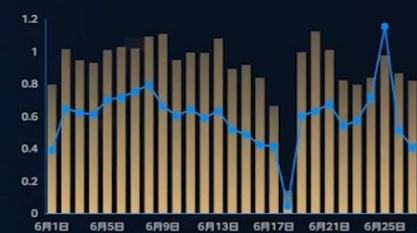
客群消费力指数 (%)



客群消费力

客群消费能力

客群信用水平指数 (%)

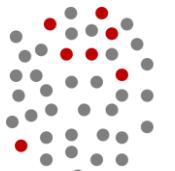


客群信用

北京市客群信用水平

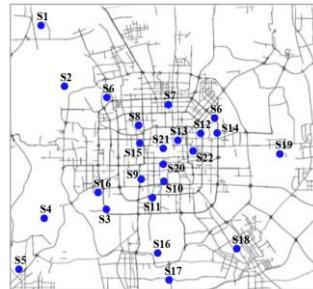
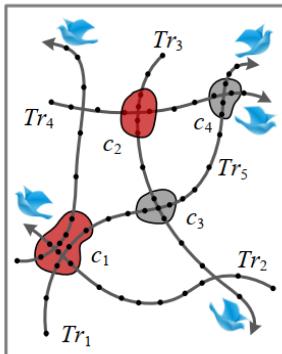
客群消费力指数

# Challenges of Urban Sensing

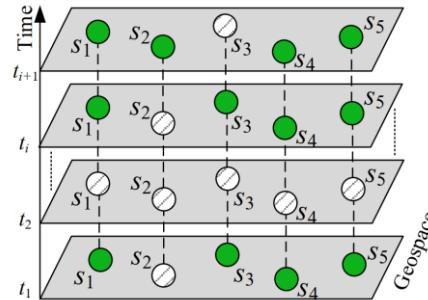


- Samples
- Other points

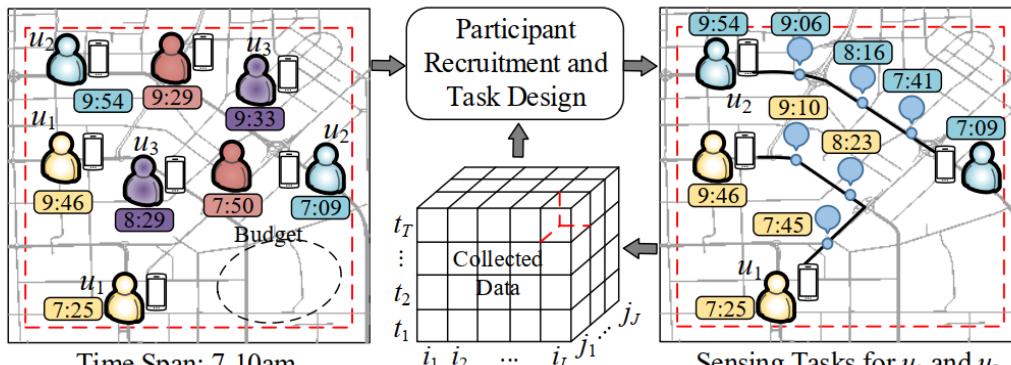
## Biased distribution



## Data sparsity



## Data missing



## Resource deployment

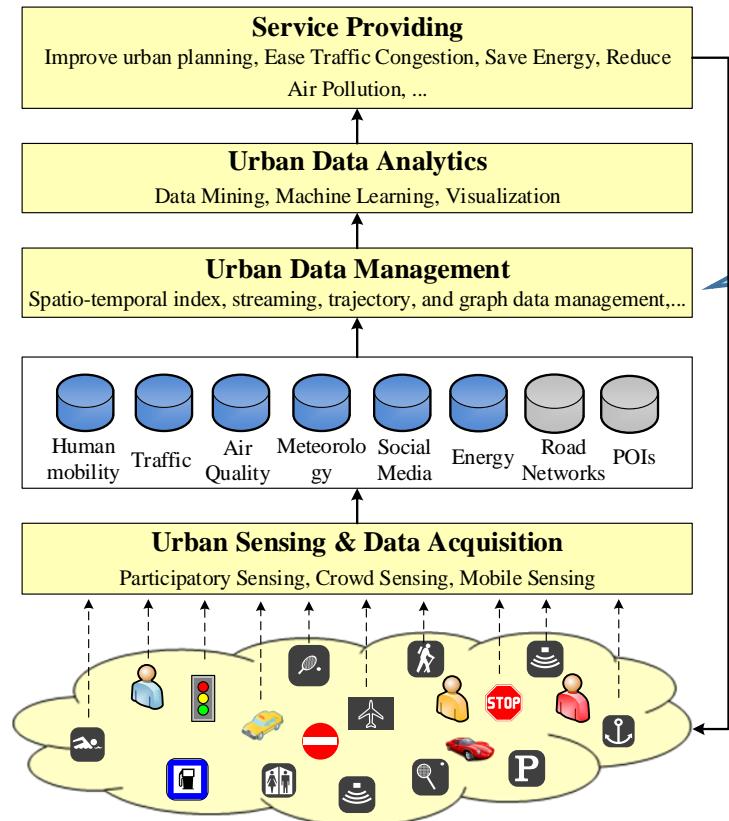
# Target Venues



- Journals
  - IEEE Transactions on Mobile Computing (TMC)
  - The Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies (IMWUT)
  - IEEE Transactions on Intelligent Transportation Systems (TITS)
  - IEEE Transactions on Knowledge and Data Engineering (TKDE)
- Conferences
  - KDD, WWW, Ubicomp, MobiCom, Infocom
  - ICDM, CIKM, WSDM, ECML-PKDD

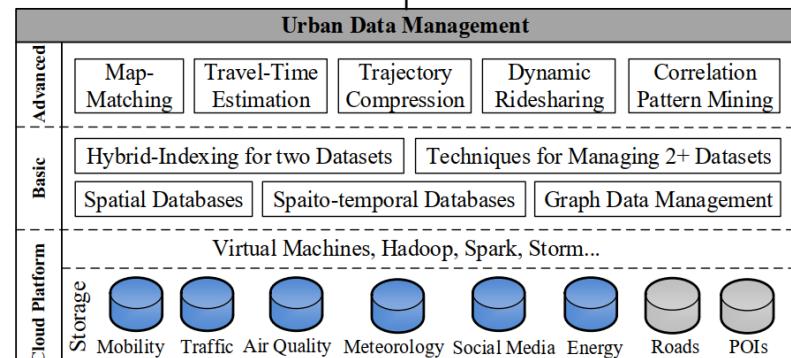


# 2<sup>nd</sup> Stage: Urban Data Management



Manage cross-domain spatio-temporal data using

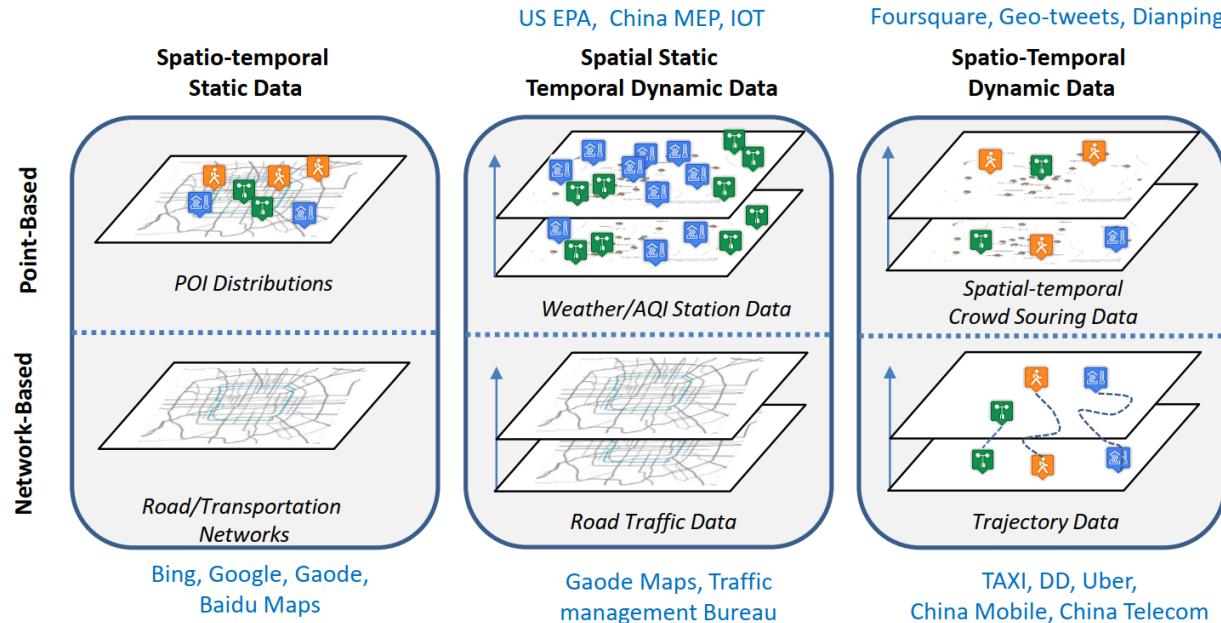
- Data: ST properties
- Indexing and retrieval algorithms
- Cloud computing platforms





# Spatio-Temporal Big Data

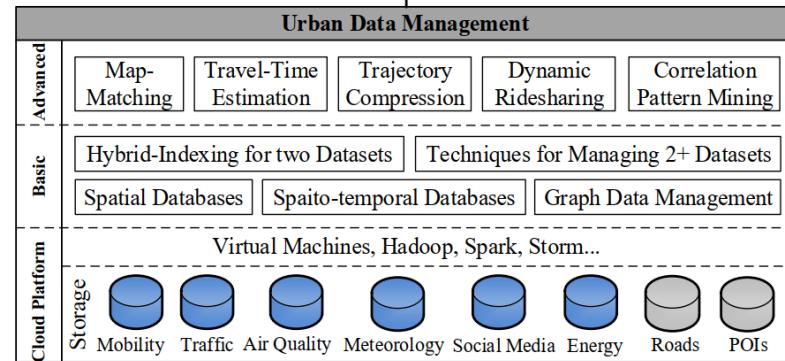
- Data Structures
- Spatio-Temporal (ST) Properties



# Spatio-Temporal Data Management



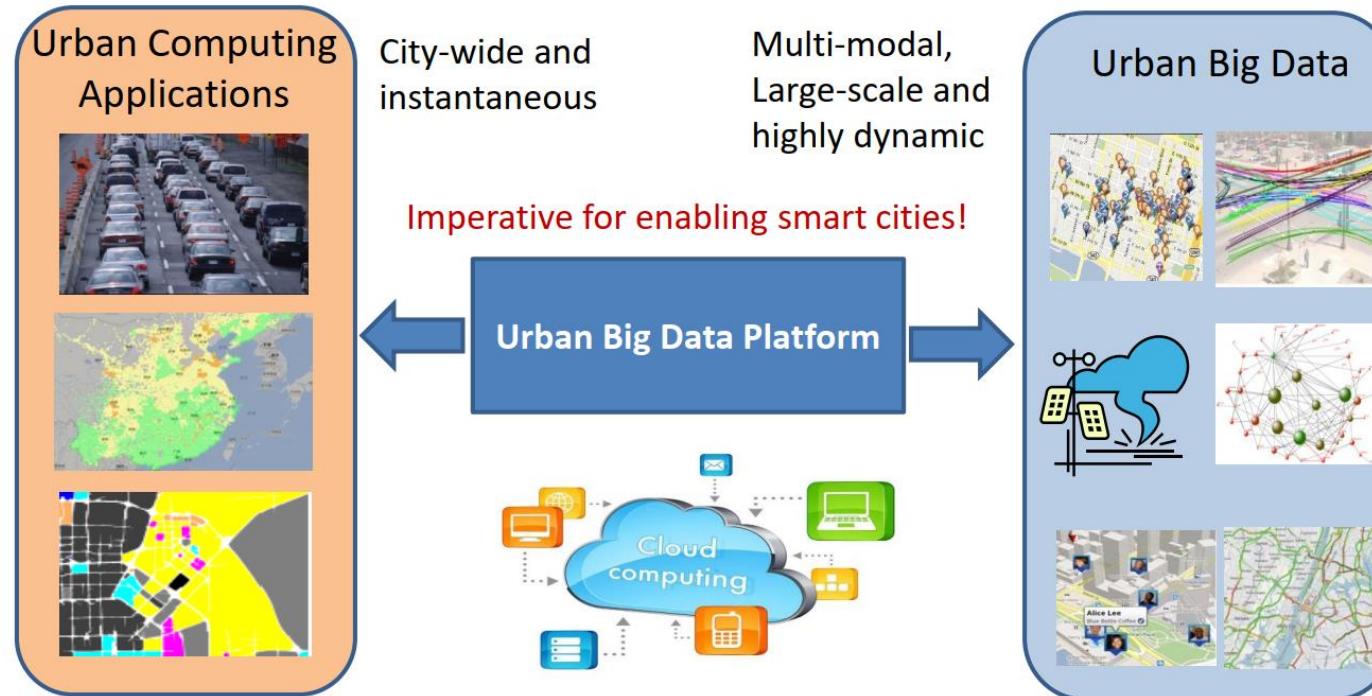
- Basic data management techniques
  - Spatial databases
  - Spatio-temporal databases
- Applications
  - Map matching
  - Trajectory compression
  - Large-scale dynamic ridesharing
  - ...
- Cloud computing platforms
- Managing spatio-temporal data on the cloud





# Why ST Big Data Platform?

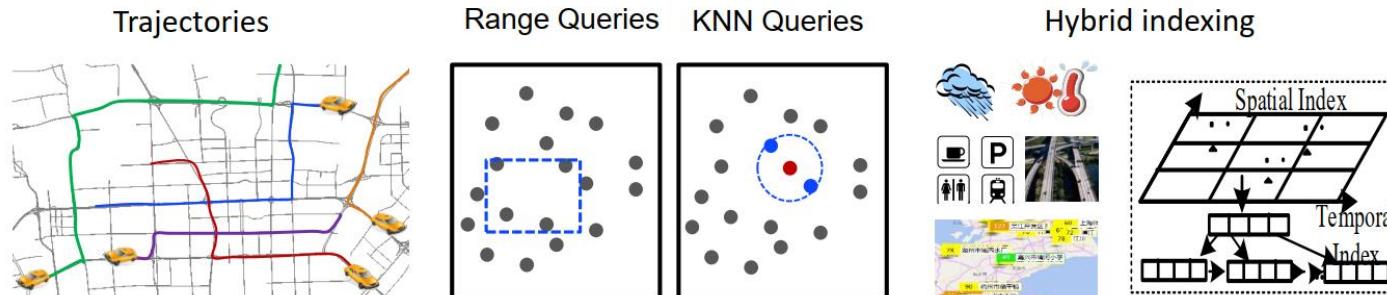
- Bridge the gap between ST big data and real-world applications





# Difficulties in Managing Urban Big Data

- Large-scale and highly dynamic → cloud computing
- Cloud computing platforms do not support ST data well
  - Unique ST data structures: trajectories (the most complex ST Data)
  - Unique queries: ST-Range queries and KNN queries rather than key words
  - Data across different domains: Hybrid indexing for managing multi-modality data





# Detecting Vehicle Illegal Parking Events using Sharing Bikes' Trajectories

Tianfu He, Jie Bao, Ruiyuan Li, Sijie Ruan, Yanhua Li, Chao Tian, Yu Zheng

*Harbin Institute of Technology; Urban Computing B.U., JD Finance;  
Worcester Polytechnic Institute; Beijing Mobike Technology; Xidian University*



京东金融  
JD Finance

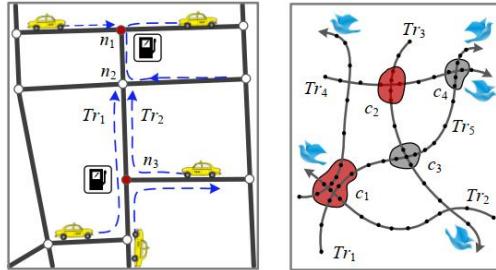
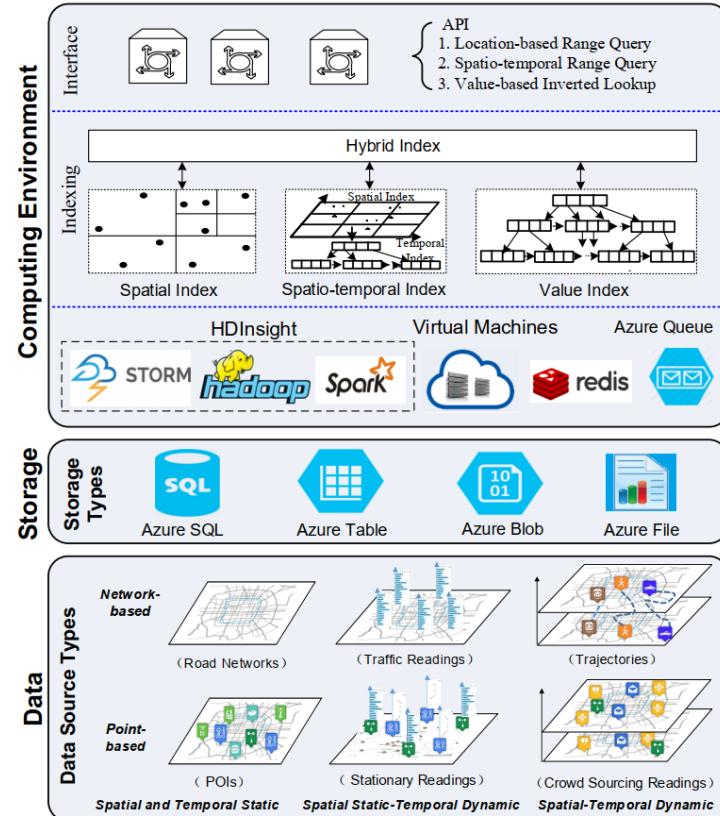


mobiKE  
摩拜单车

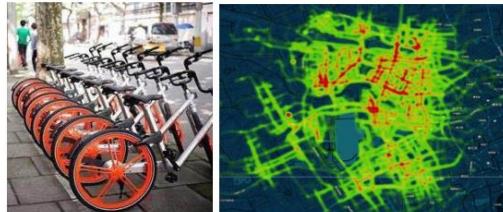




# Cloud Computing for ST Data



Y. Li, J. Bao, Y. Li, Z. Gong, **Y. Zheng**.  
[Mining the Most Influential k-Location Set From Massive Trajectories.](#)  
 IEEE Transactions on Big Data. 2017

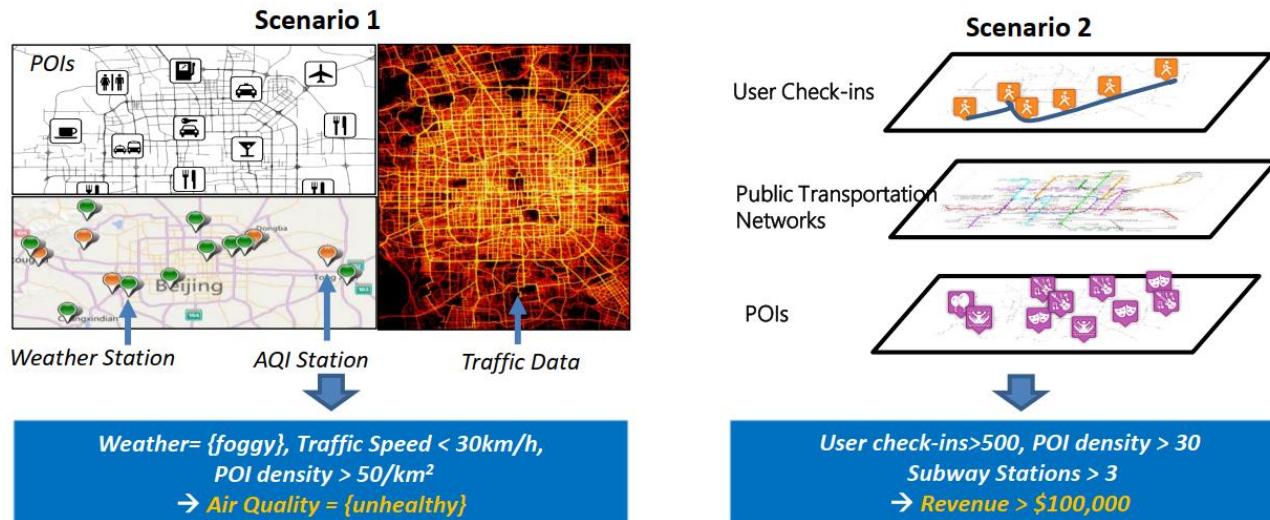


J. Bao, T. He, S. Ruan, Y. Li, and Y. Zheng et al.  
[Planning bike lanes based on Sharing-bike's trajectories,](#)  
 KDD 2017



# Urban Data Management: Examples

- Mining Cross-Domain Correlation Patterns from multiple ST datasets
  - Hybrid indexing structures
  - Group query technology
  - Interactive visual data analytics based on cloud computing

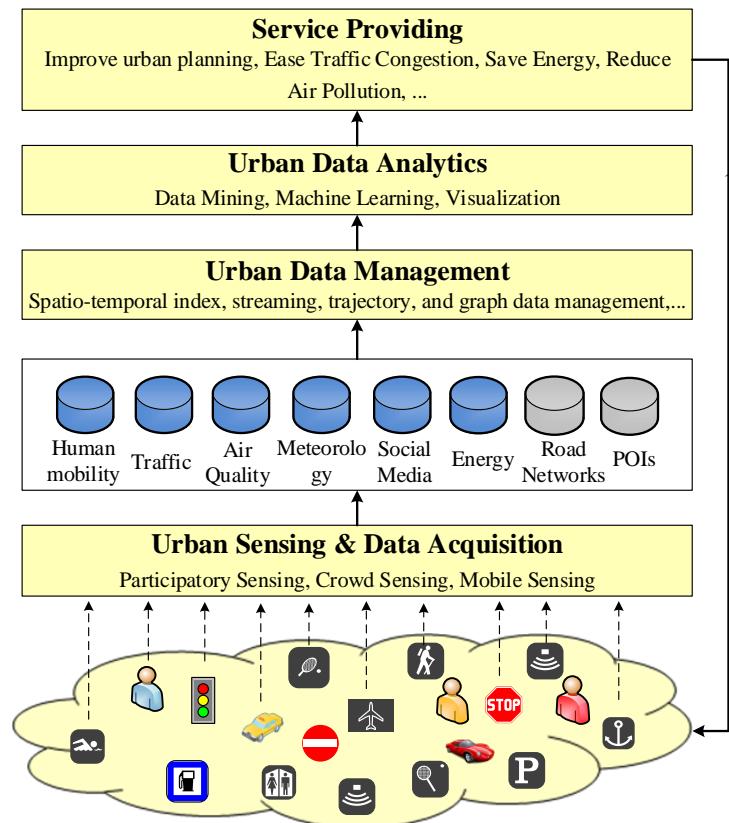


# Target Venues



- Journals
  - IEEE Transactions on Knowledge and Data Engineering (TKDE)
  - The VLDB Journal
  - ACM Transactions on Database Systems (TOIS)
- Conferences
  - KDD, SIGMOD, VLDB, ICDE,
  - ICDM, CIKM, WSDM, ECML-PKDD

# 3<sup>rd</sup> Stage: Urban Data Analytics



- Texts and images → spatio-temporal data
- A single data source → cross-domain data sources
- Separate data mining algorithms → ML + data management
- Visual and interactive data analytics

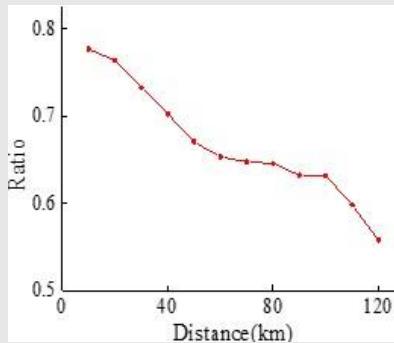
Urban Data Analytics				
Basic				
Data Fusion	Advanced			
	Fill Missing Values	Causality Inference	Predictive Models	Transfer Learning-Based
Multi-View-based Fusion	Similarity-Based Fusion	Probabilistic-Dependency-Based	Stage-Based Data Fusion	Feature-level Data Fusion
Clustering	Classification	Regression	Outlier Detection	Association



# Spatio-Temporal Data is Unique

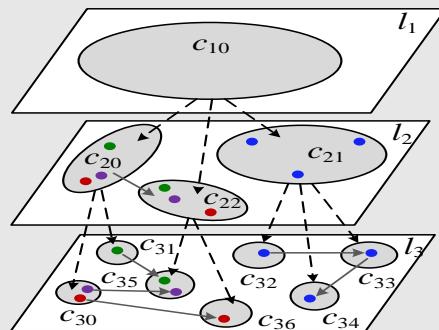
- Spatial property

## Spatial closeness



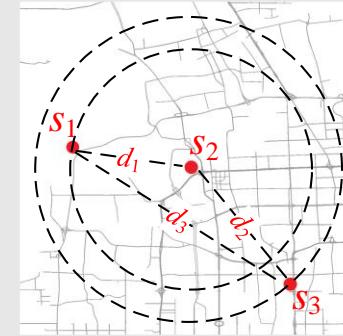
Describing correlations

## Spatial hierarchy



Structural constraints between  
different spatial granularity

## Spatial distance



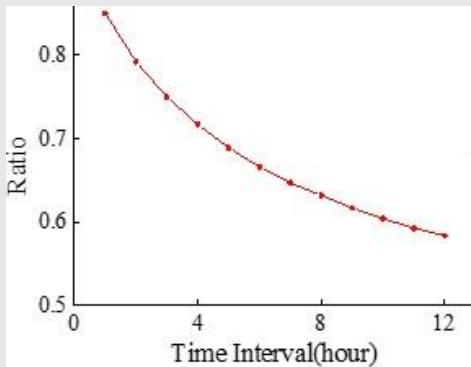
Triangle inequality:  
 $|d_1 - d_2| \leq d_3 \leq |d_1 + d_2|$



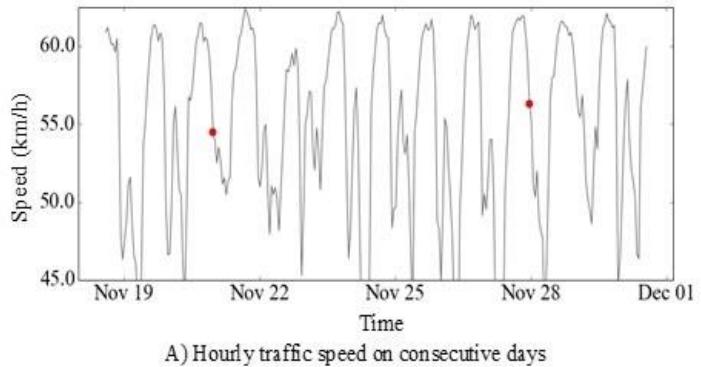
# Spatio-Temporal Data is Unique

- Temporal property

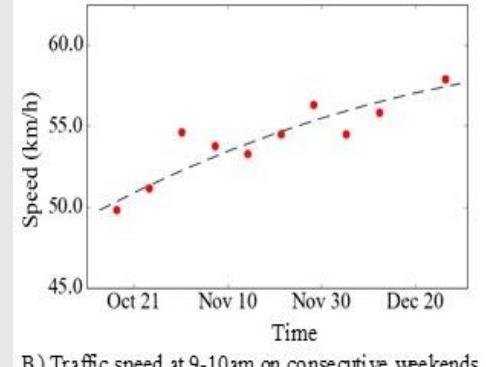
## Closeness



## Periodicity



## Trend





# Cross-Domain Data Fusion

- Case 1: Unlock the power from multiple (**sparse**) data across **different domains**



Meteorology



Traffic



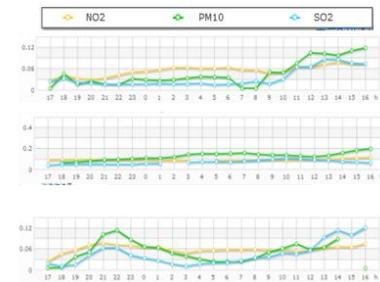
Human Mobility



POIs



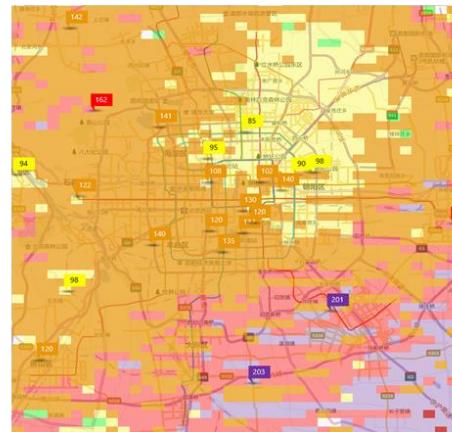
Road networks



Historical air quality data



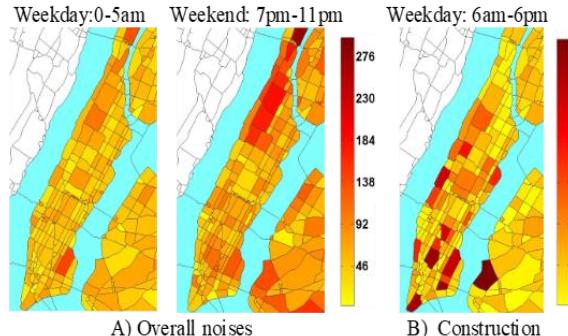
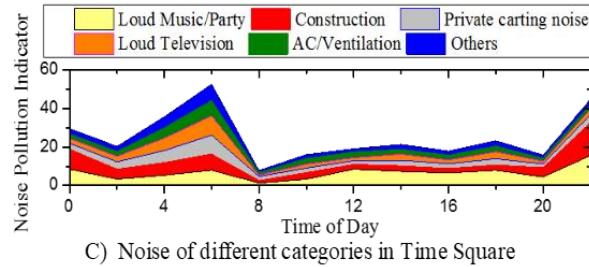
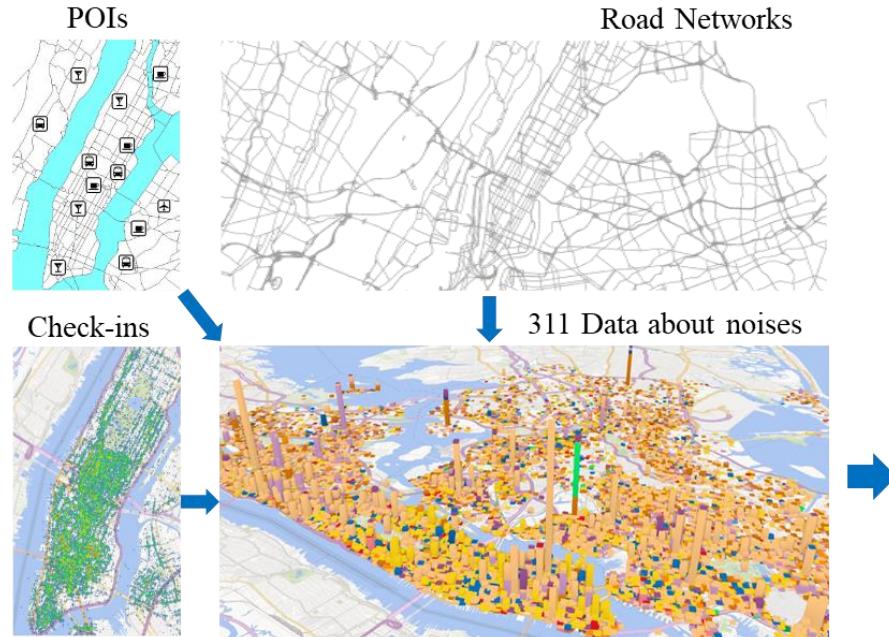
Real-time air quality reports





# Cross-Domain Data Fusion

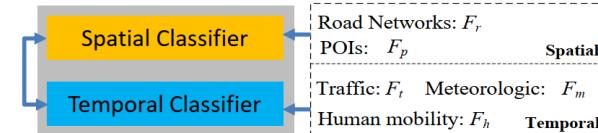
- Case 2: Unlock the power from multiple (**sparse**) data across **different domains**



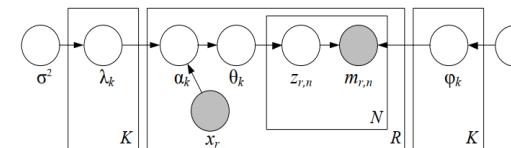


# Methodologies for Cross-Domain Data Fusion

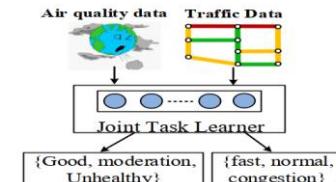
- Stage-based data fusion
- Feature-level-based data fusion
  - Feature concatenation + regularization
  - DNN-based
- Semantic meaning-based fusion
  - Multiple-view-based: like co-training
  - Similarity-based: Coupled matrix factorization
  - PGM-based
  - Transfer learning-based



Multi-view learning (Co-training)



Pro. dependency-based (Topic Models)



Transfer Learning-based

$$Y \iff X \iff Z$$

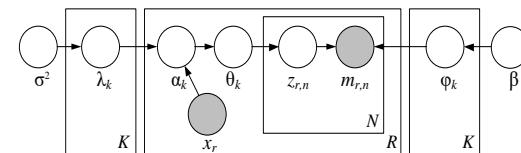
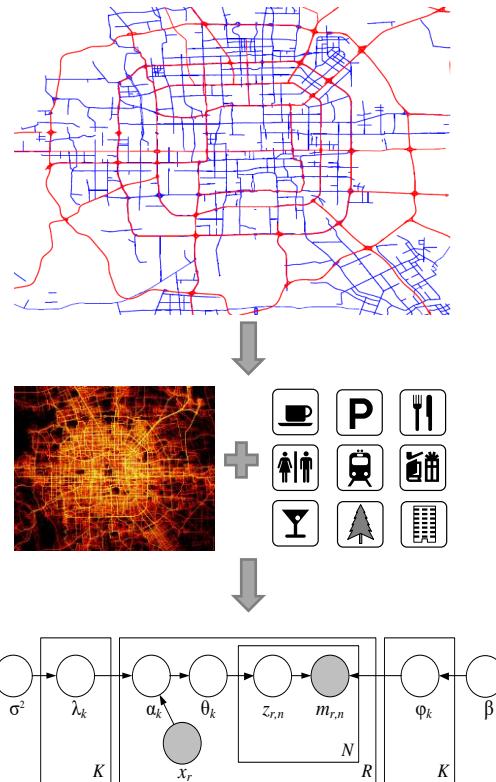
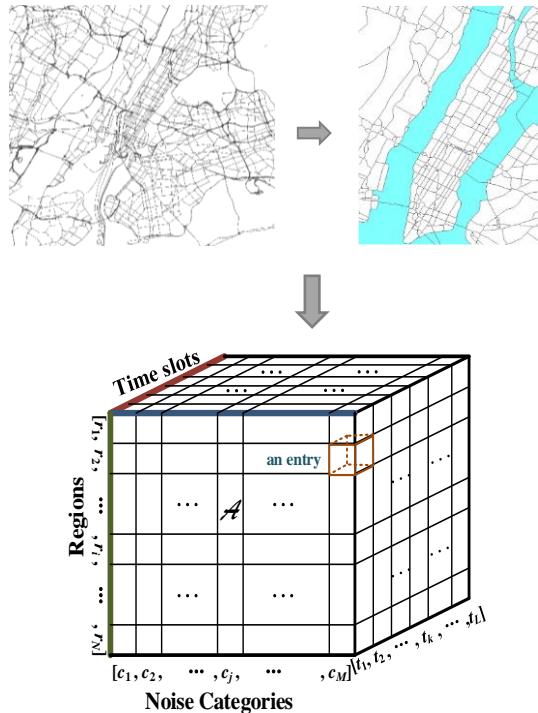
$$Y = \begin{bmatrix} g_1 & g_2 & \cdots & g_{16} \\ M'_G & & & M_G \end{bmatrix}, \quad X = \begin{bmatrix} r_1 & r_2 & \cdots & r_n \\ M'_r & & & M_r \end{bmatrix}, \quad Z = \begin{bmatrix} f_1 & f_2 & \cdots & f_k \\ r_1 & & & f_g \\ r_2 & & & f_p \\ \vdots & & & \vdots \\ r_n & & & f_g \end{bmatrix}$$

Similarity-based (matrix factorization)

# Methodologies for Cross-Domain Data Fusion



- Stage-based fusion





# Methodologies for Cross-Domain Data Fusion

- Feature-level-based data fusion



Meteorology



Traffic



Human Mobility



POIs



Road networks

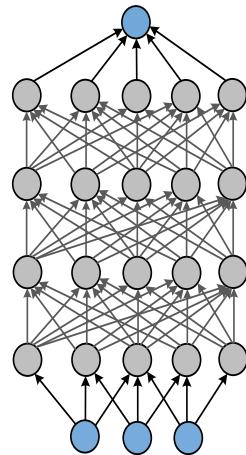


Black Box  
DNN, Classifiers

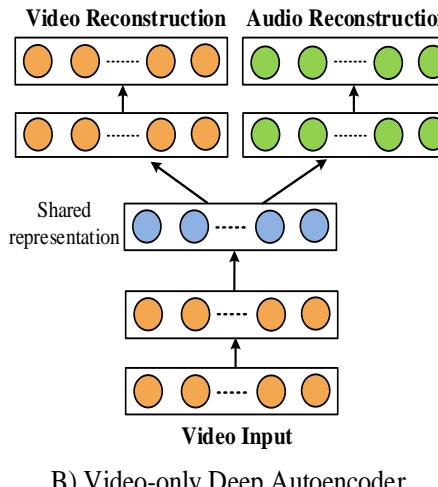
# Methodologies for Cross-Domain Data Fusion



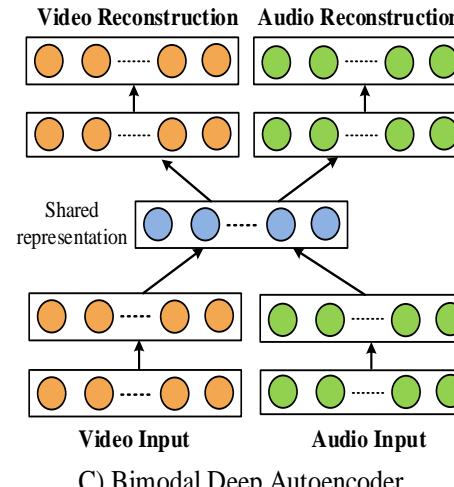
- Feature-level-based data fusion



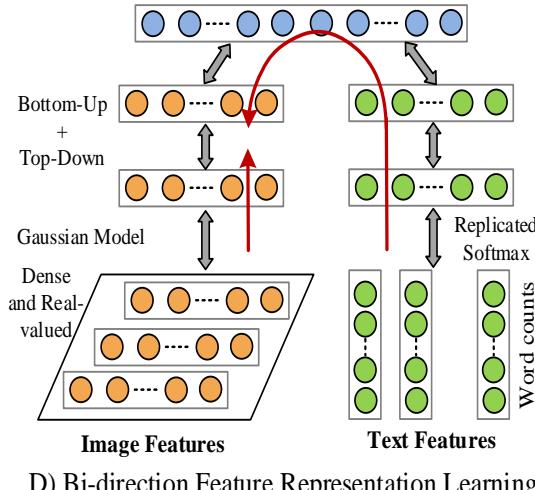
A) DNN



B) Video-only Deep Autoencoder



C) Bimodal Deep Autoencoder

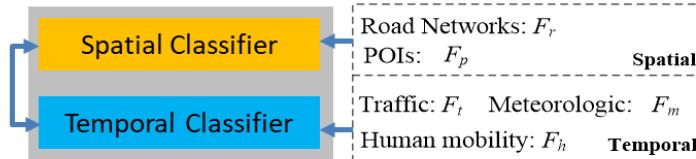


D) Bi-direction Feature Representation Learning

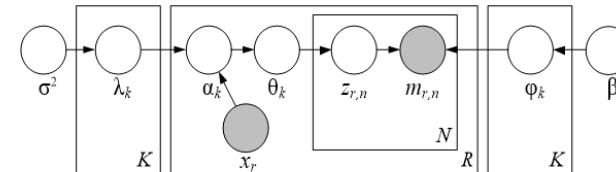


# Methodologies for Cross-Domain Data Fusion

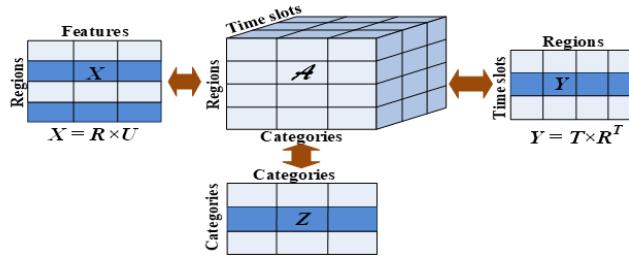
- Semantic meaning-based Data Fusion



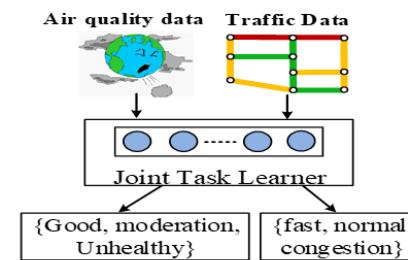
Multi-view learning (Co-training)



Pro. dependency-based (Topic Models)



Similarity-based (matrix factorization)

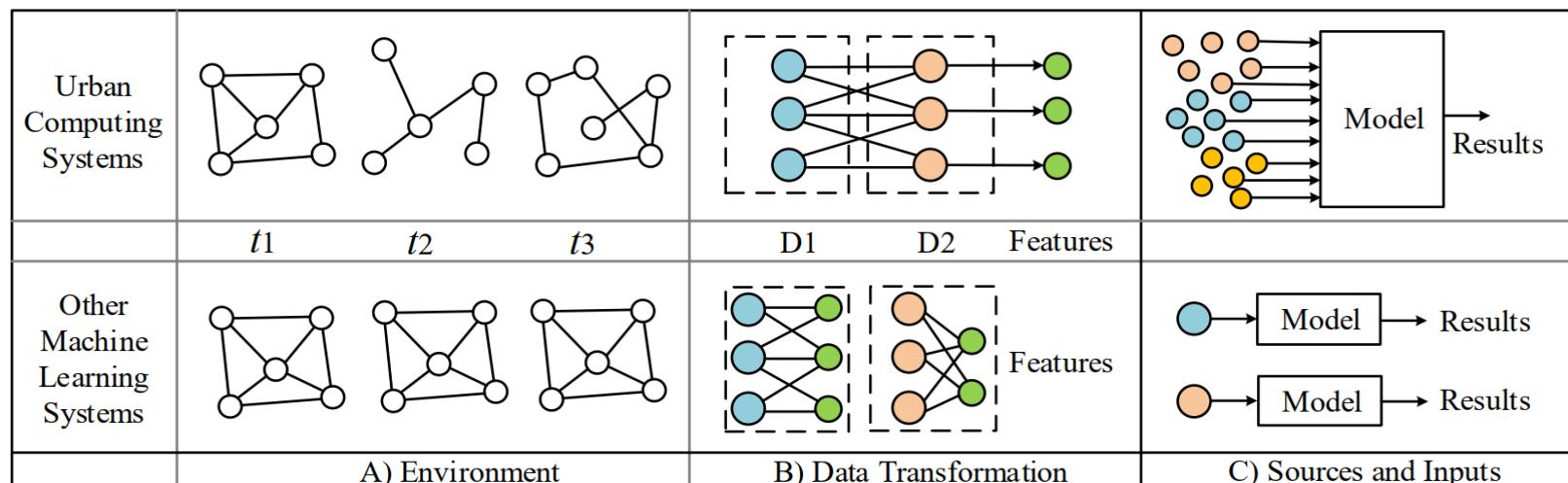


Transfer Learning

# Combining Databases with Machine Learning



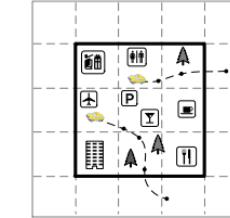
- Dynamic environment
- Complex data transformation
- Citywide and multi-source input



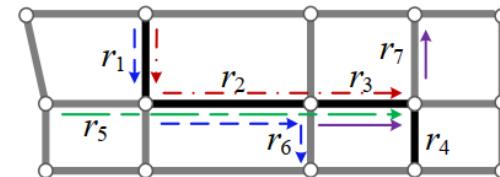


# Combining Databases with Machine Learning

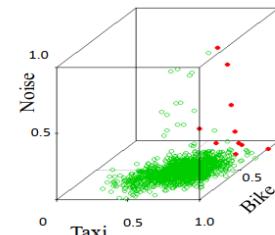
- Design spatial and spatio-temporal indexing structures to expedite the information retrieval and feature extraction process for machine learning algorithms
- Use database techniques to generate candidates to scale down the computing space of a complex learning algorithm
- Derive upper/lower bounds to prune the computing spaces of machine learning algorithms



Air quality  
Inference  
(KDD 2013)



Travel time estimation (KDD 2014)



Collective  
anomalies  
(GIS 2015)



# Current Trend: Emergence of Deep Learning

- Great Success of AI



AlphaGo beats Go  
human chap



ResNet outperforms humans  
in image classification



DouZero wins humans in  
斗地主



DeepStack beats  
professional poker players

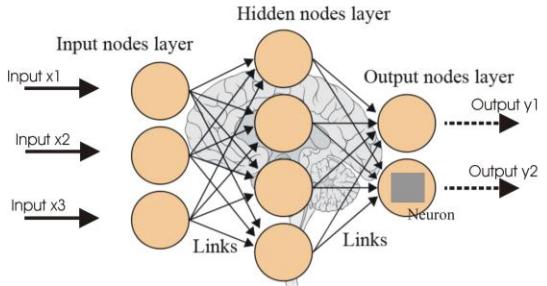


Computer out-plays  
humans in Doom

# Criteria for Success of AI



# Big Data



# Algorithms



## Clean Data



# Computing Resources



# Vertical (Narrow) Domain

# Big AI Opportunity





# Spatio-Temporal AI

General AI



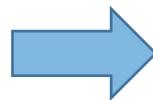
Face recognition



Audio recognition



Machine  
translation



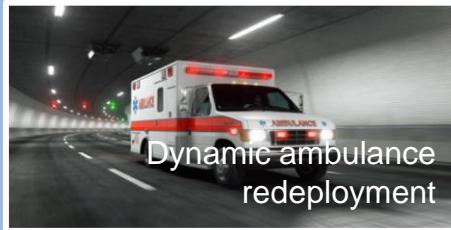
ST data science (oriented to ST data)



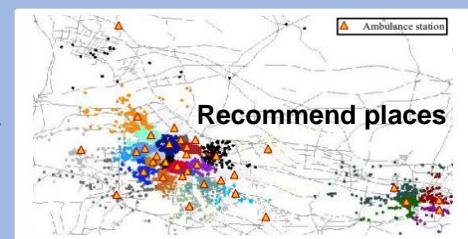
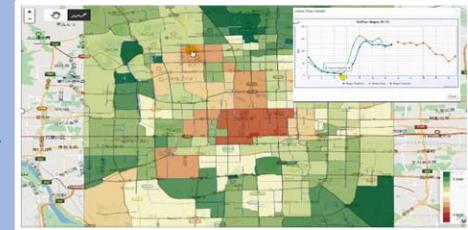
Traffic prediction



Fire risk early warning



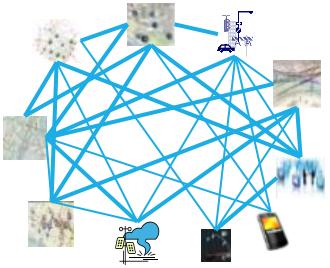
Dynamic ambulance  
redeployment



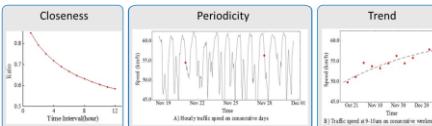
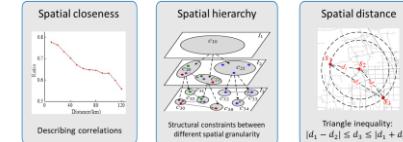
Ambulance station

Recommend places

## Big ST Data



## Spatio-Temporal Data Science



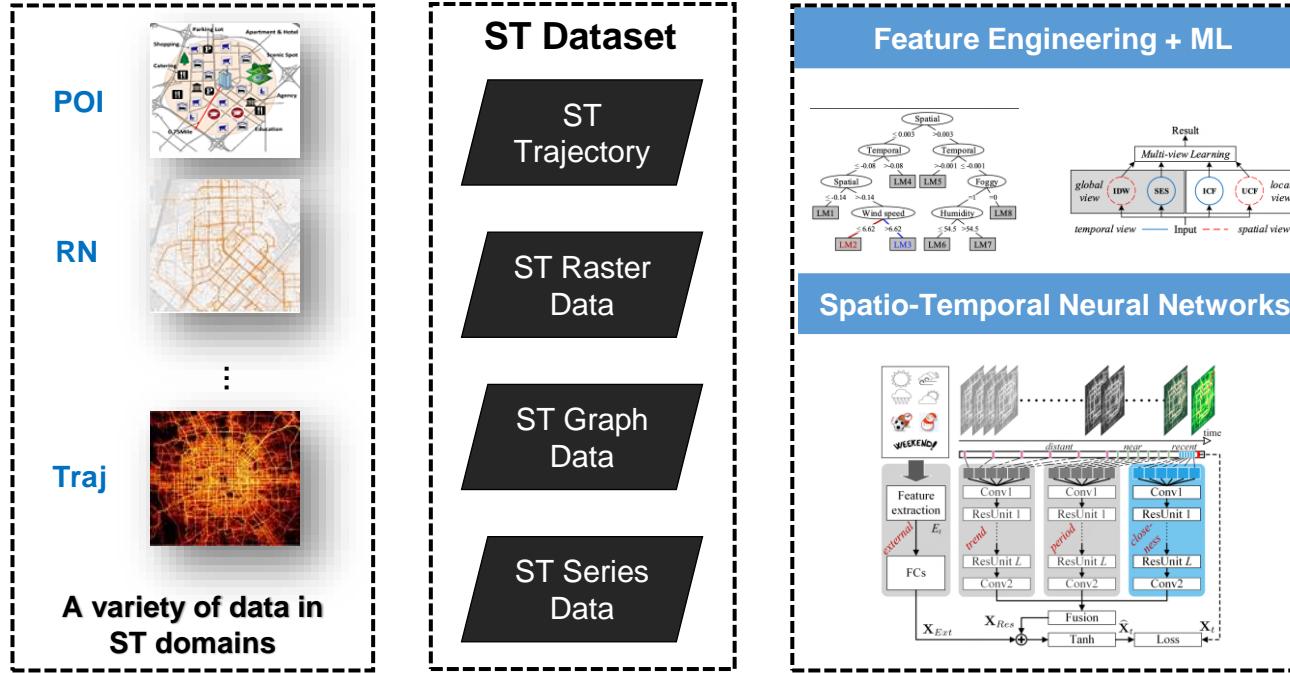
## Smart Cities



## Domain Knowledge



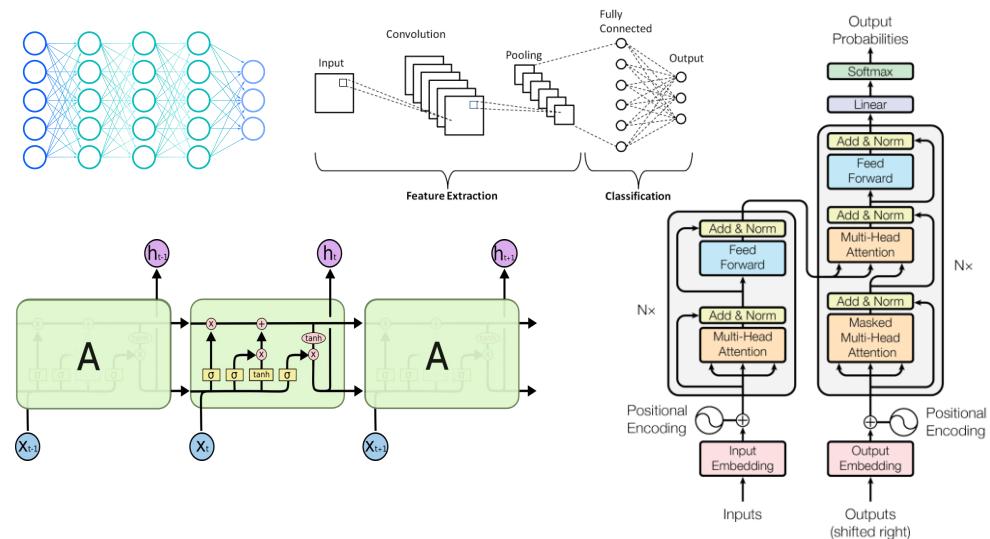
# Modeling Pipeline of Spatio-Temporal AI



# Deep Spatio-Temporal Neural Networks



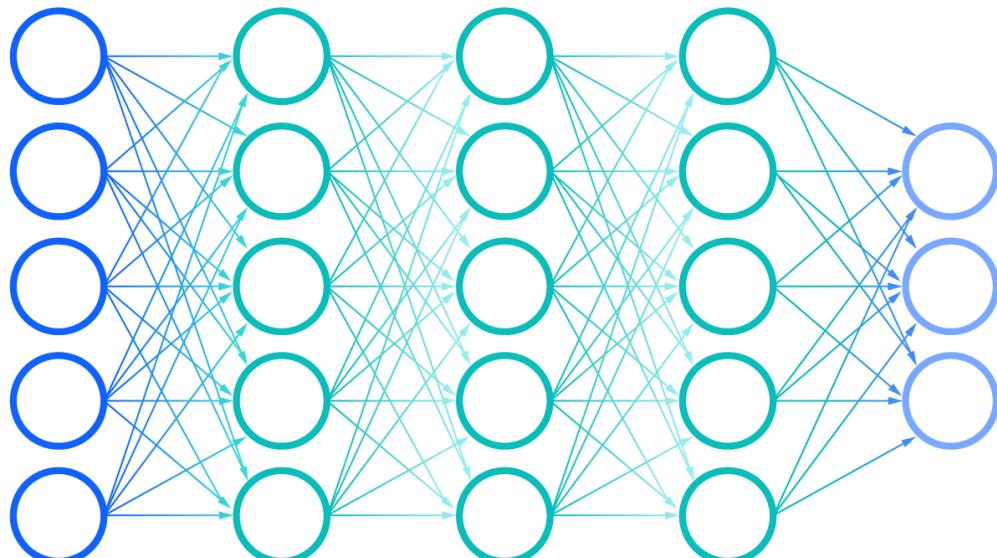
- Advantages beyond traditional ML methods
  - Larger capacity
  - Automatic feature extraction
  - Friendly to cross-domain data fusion, e.g., considering external factors
- Basic building blocks
  - Multi-layer perceptron (MLP)
  - Convolutional neural networks (CNN)
  - Recurrent neural networks (RNN)
  - Attention models, e.g., Transformers
  - Graph neural networks (GNNs)



# Multi-Layer Perceptron (MLP)



- Input layers
- Hidden layers
- Output layers



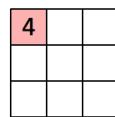


# Convolutional Neural Networks (CNN)

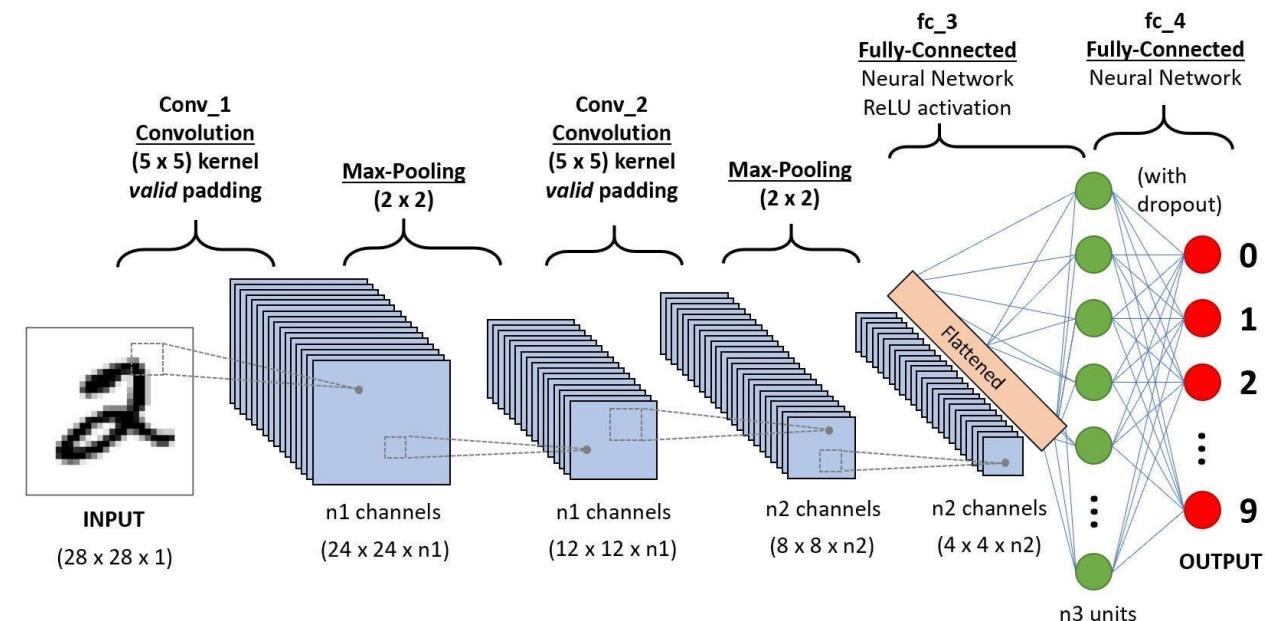
- Convolution
- Max-pooling
- FC/MLP

1	1	1	0	0
0	1	1	1	0
0	0	1	1	1
0	0	1	1	0
0	1	1	0	0

Image

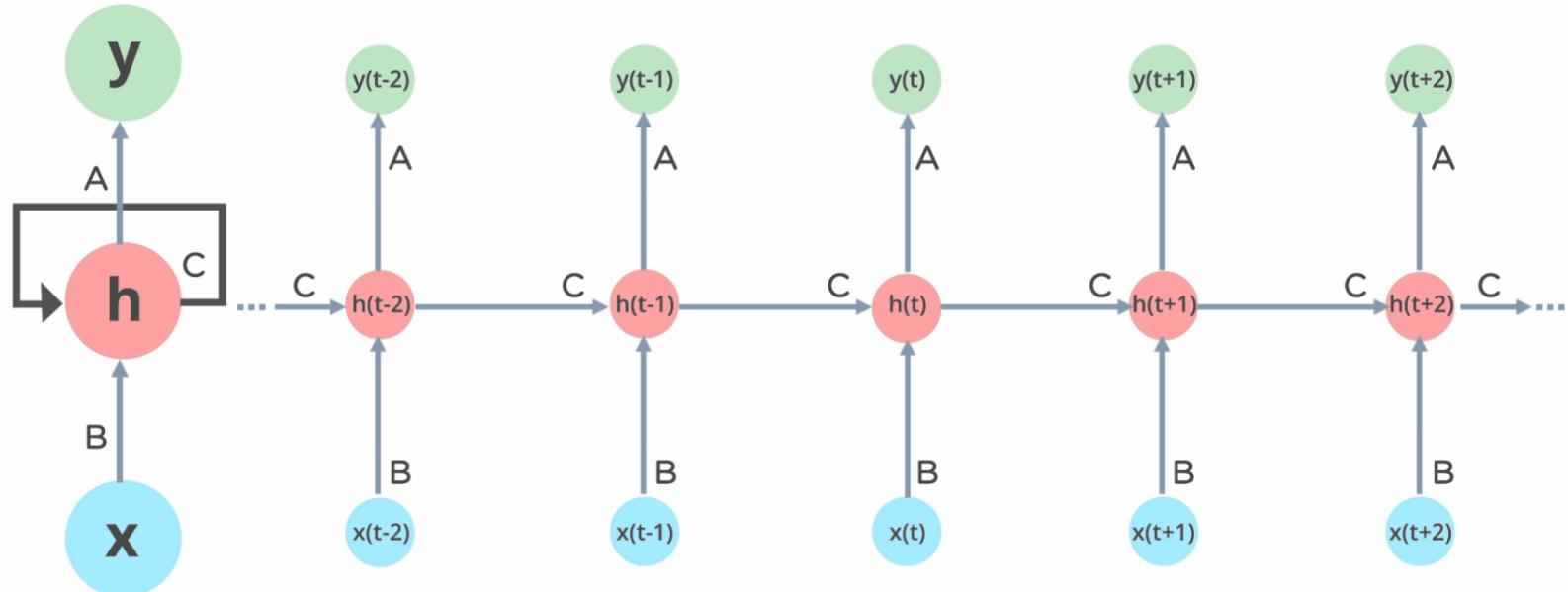


Convolved Feature





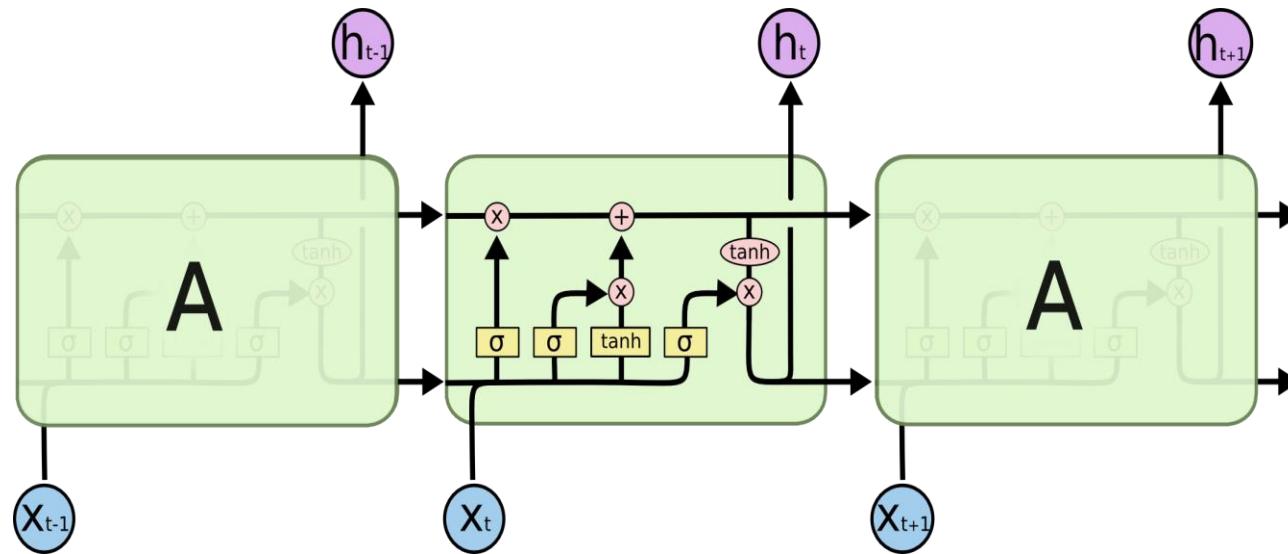
# Recurrent Neural Networks (RNN)





# Long Short-Term Memory (LSTM)

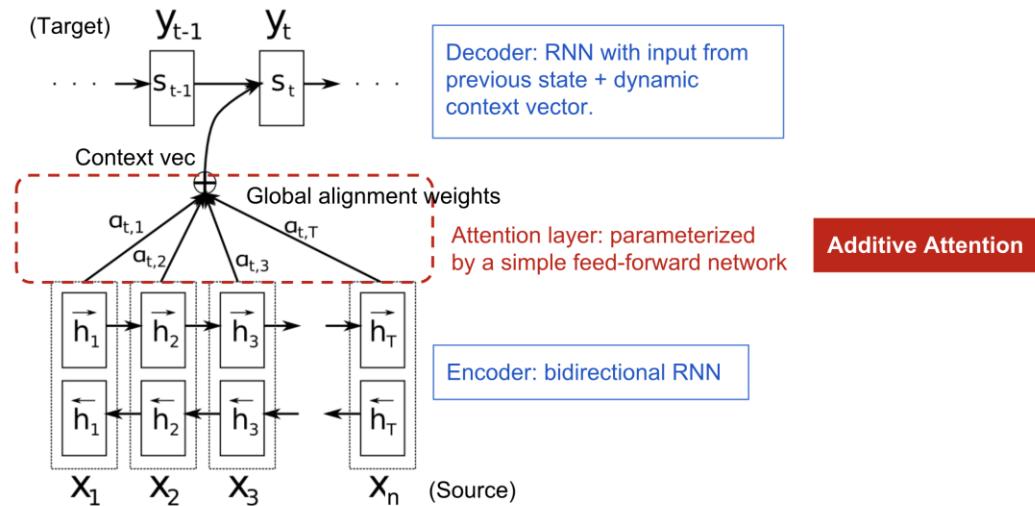
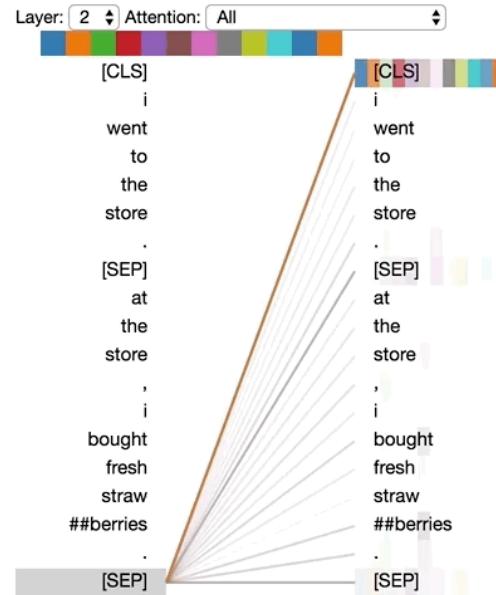
- Avoiding gradient explosion and vanishing





# Attention Mechanism

- Born for machine translation [Bahdanau et al. 2013]

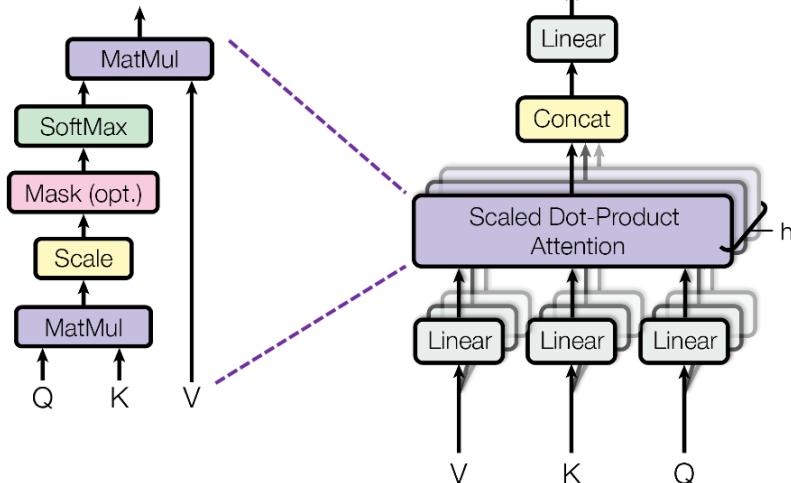




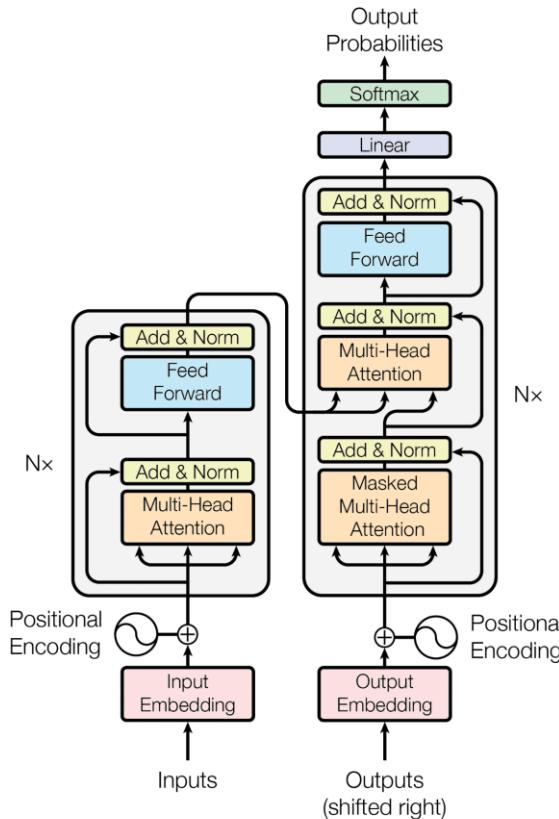
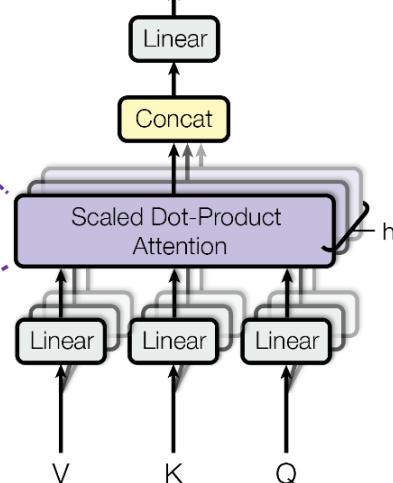
# Transformers (Self-Attention)

- Attention is all you need

Scaled Dot-Product Attention



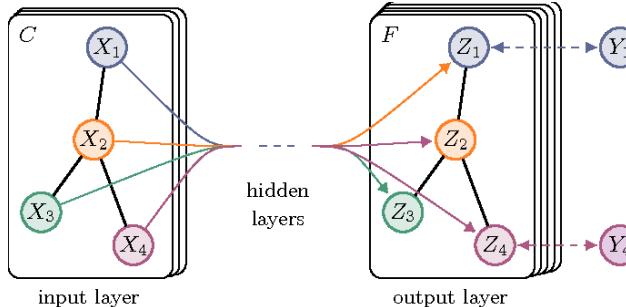
Multi-Head Attention



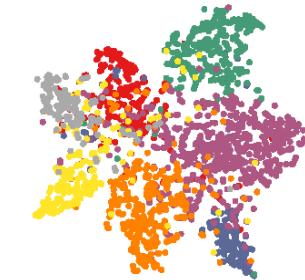
# Graph Neural Networks (GNN)



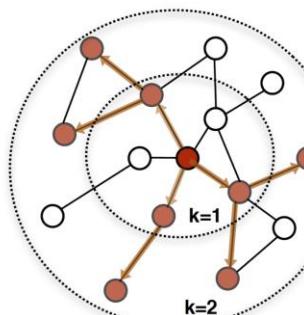
- Spectral-based GNNs
- Spatial-based GNNs



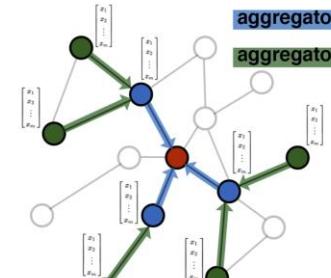
(a) Graph Convolutional Network



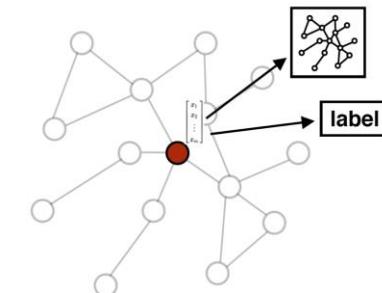
(b) Hidden layer activations



1. Sample neighborhood



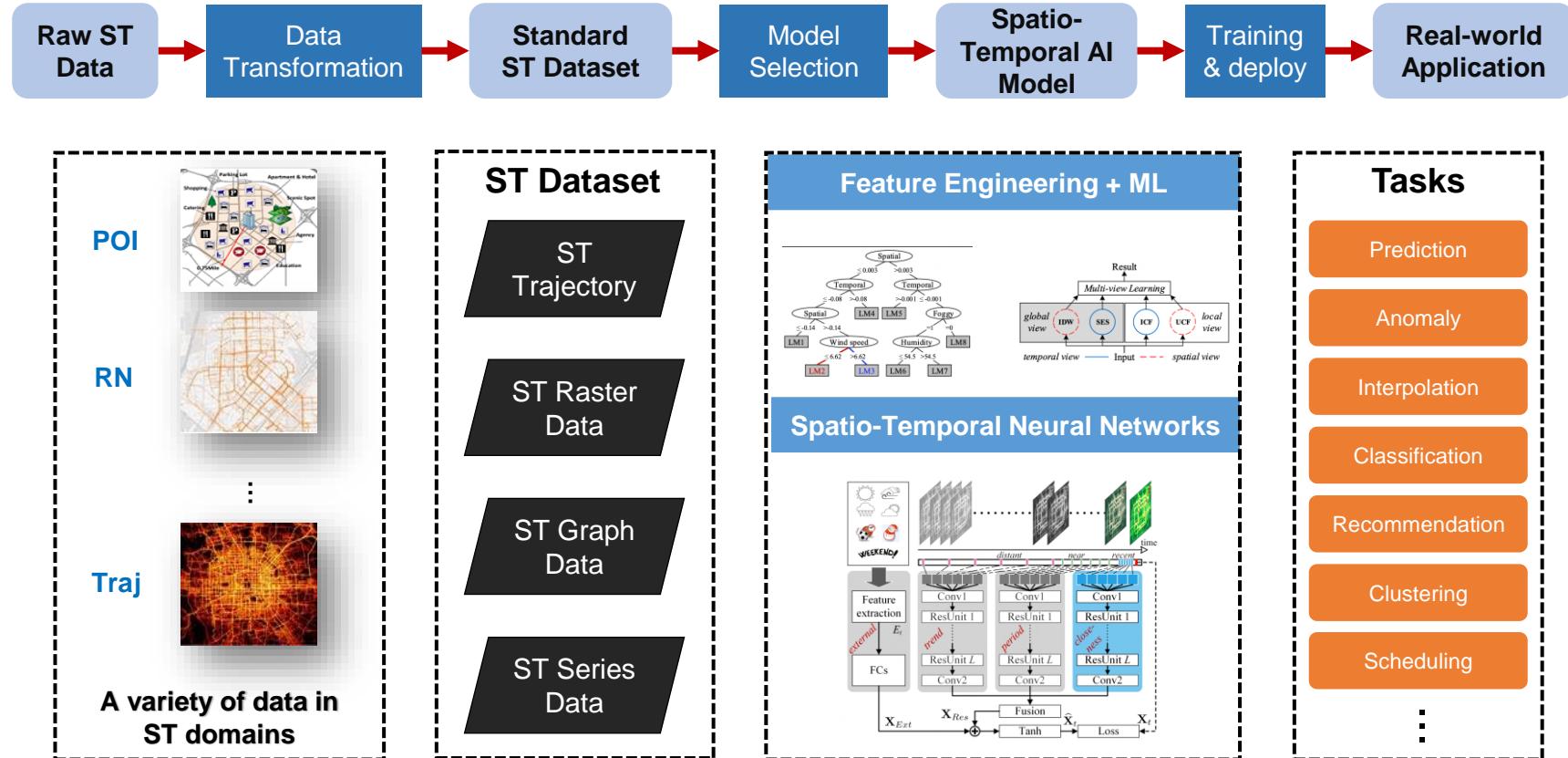
2. Aggregate feature information from neighbors



3. Predict graph context and label using aggregated information



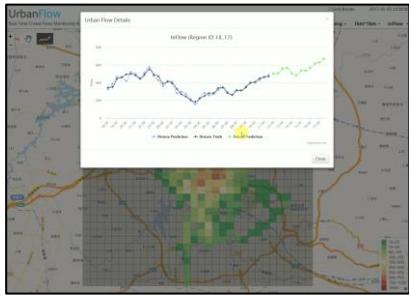
# Modeling Pipeline of Spatio-Temporal AI



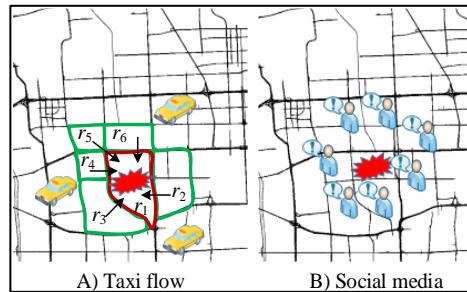


# Popular Tasks in Spatio-Temporal AI

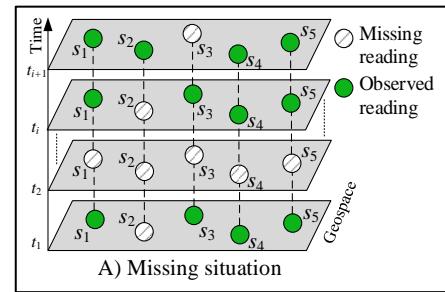
## ST Prediction



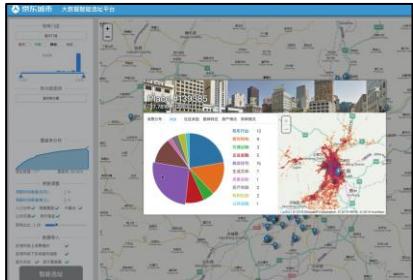
## Anomaly Detection



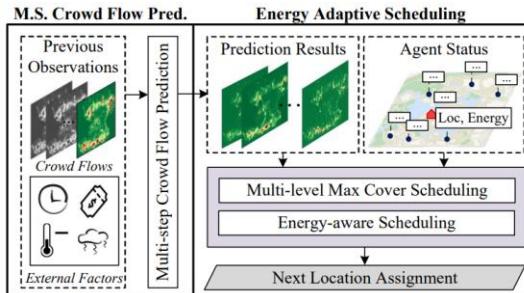
## ST Interpolation



## ST Recommendation



## Scheduling



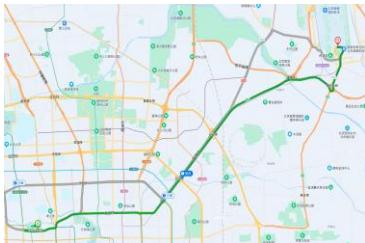
## Classification





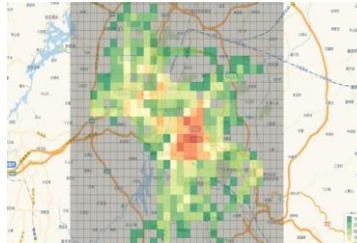
# Our Methodologies & Applications

Modeling ST Trajectory



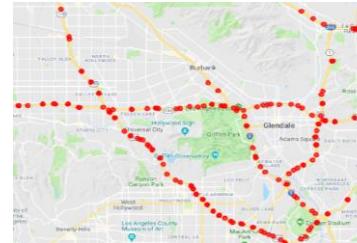
TrajODE [IJCAI'21]

Modeling ST Rasters



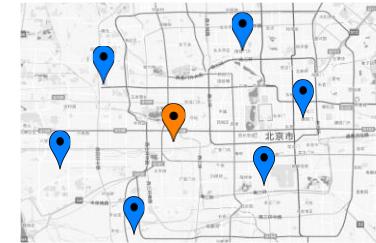
STRN [WWW'21]

Modeling ST Graphs



ST-MetaNet [KDD'19]

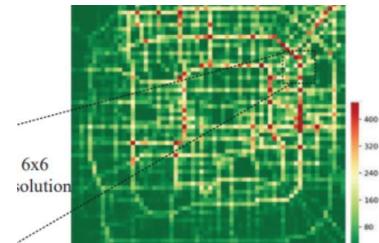
Modeling ST Series



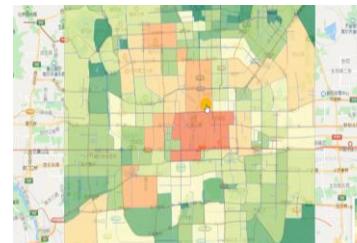
GeoMAN [IJCAI'18]



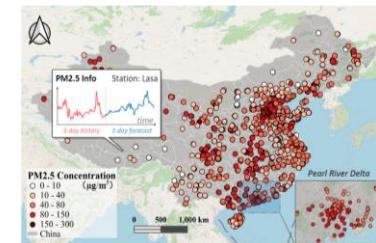
TrajFormer [CIKM'22]



UrbanFM [KDD'19]



MixRNN [TKDE'22]

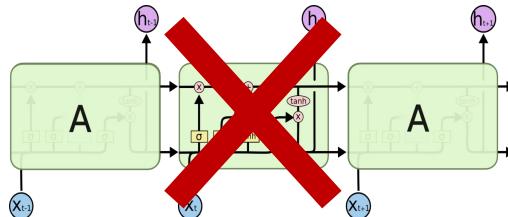


AirFormer [AAAI'23]

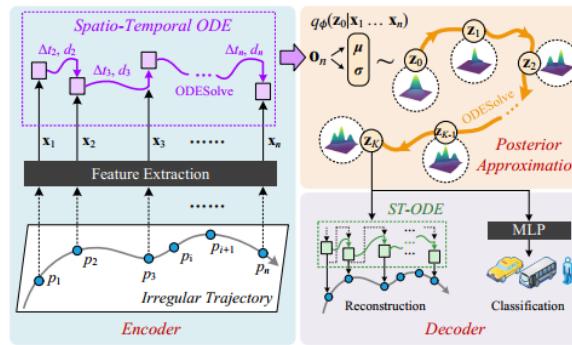


# Our Exploration on ST Trajectories

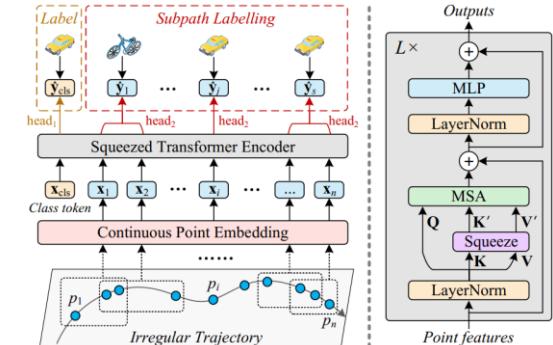
- Existing AI approaches for CV/NLP are NOT always good choices for modeling trajectories
- Capturing the **irregularity** of trajectories is of great importance to trajectory modeling
- We demonstrate how to encode the domain knowledge (i.e., irregularity) into existing AI methods, including RNNs and Transformers



Classic RNNs



Continuous trajectory modeling



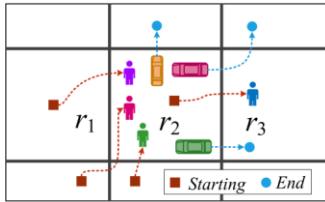
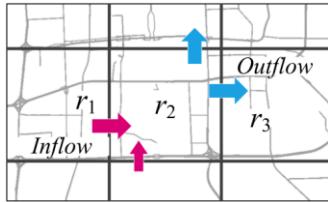
Efficient trajectory modeling



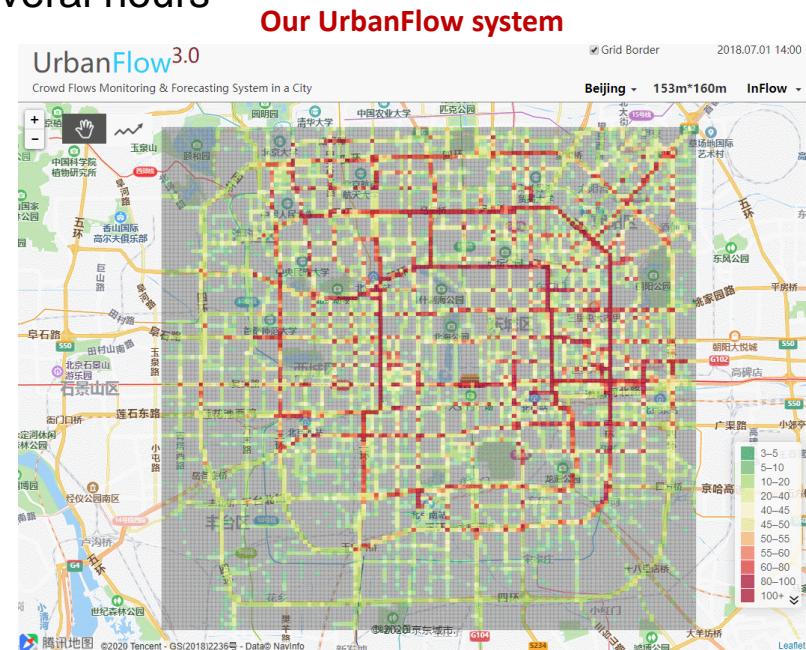
# Our Exploration on ST Raster Data

## An Example: Grid-based citywide crowd flow prediction

- Predicting the inflow/outflow of **every region** in several hours



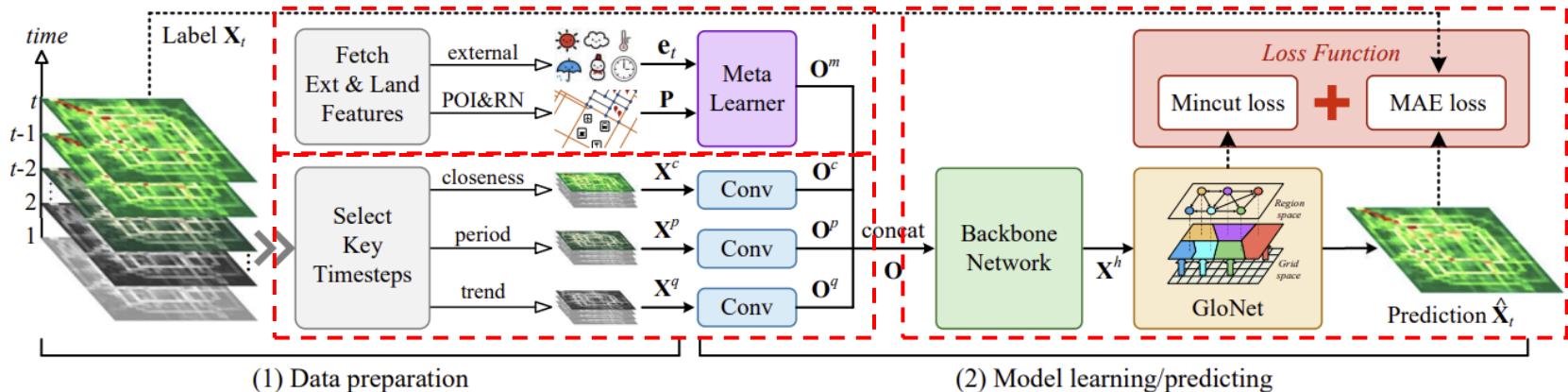
- It can provide insights to
  - Traffic control, risk assessment
- Challenges
  - Complex ST dependencies
  - External factor influence





# Sample Solution: STRN Framework

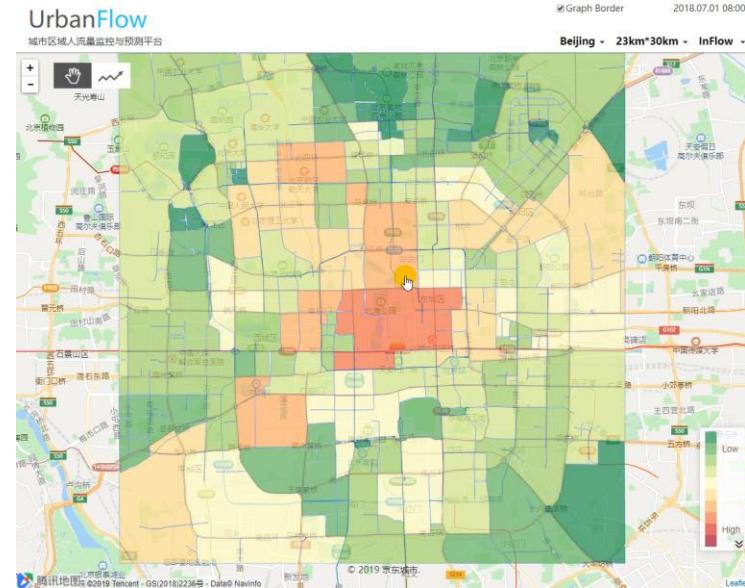
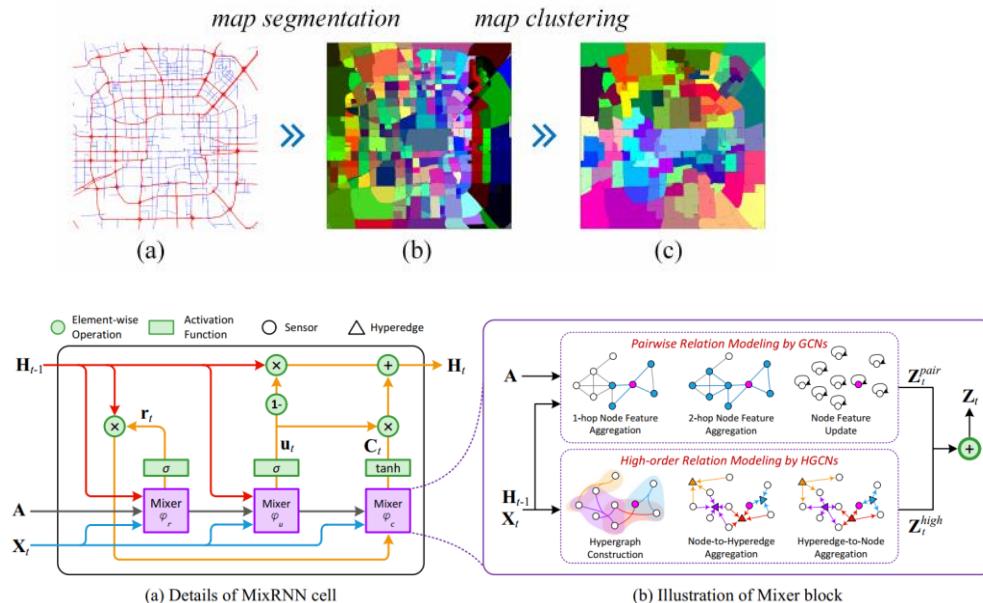
- Spatio-Temporal Relation Network (STRN)
  - Modeling temporal properties: closeness, periodicity, trend
  - Learning the impact of external factors
  - Learning local and global spatial dependencies





# Our Exploration on ST Graphs

- Prior works mainly focused on predicting the crowd flows in regular gridded regions
- We can also predict on irregular regions

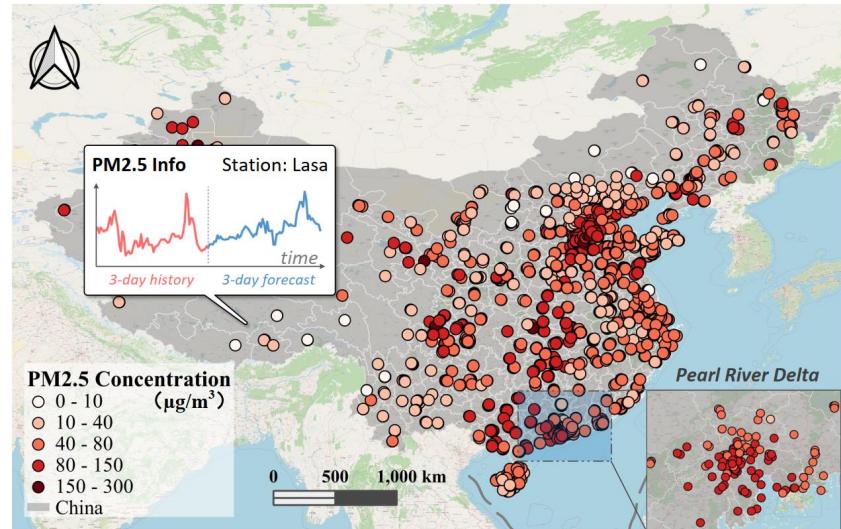




# Our Exploration on ST Series

## An Example: Nationwide Air Quality Prediction in China

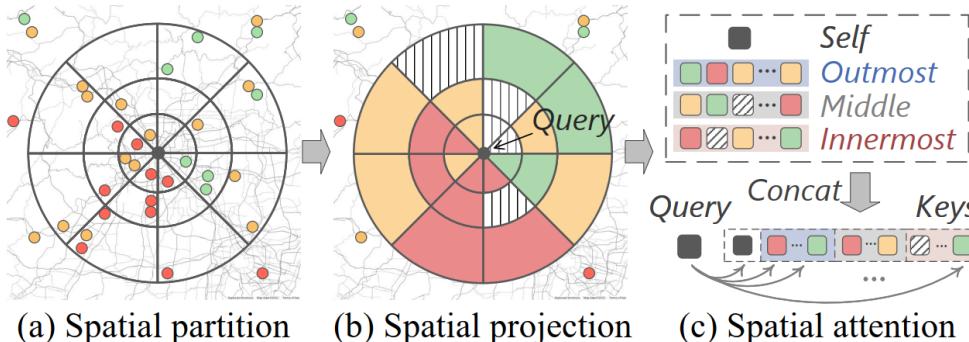
- We present the first attempt to *collectively* predict air quality in the Chinese mainland with an **unprecedented fine spatial granularity**, covering 1,000+ stations.
- Benefits of nationwide prediction
- To capture dynamic spatial correlations
  - Using **self-attention mechanism**
  - Challenge: **quadratic complexity w.r.t #locations**





# Dartboard Spatial-MSA (DS-MSA)

- Considering the spatial correlations among nearby locations are often stronger than those far away, we devise DS-MSA to **efficiently capture spatial relations**
  - Insight: as its name suggests, each location attends to its close surroundings at a fine granularity and faraway stations at a coarse granularity
  - Pipeline: see the following figure
  - Result: DS-MSA only takes **linear complexity** w.r.t the number of stations.



$\mathcal{O}(N^2C)$  MSA  
Reduced  
 $\mathcal{O}(NM C)$  our DS-MSA

$N$ : #stations  
 $M$ : #regions

# Target Venues



- Journals
  - IEEE Transactions on Knowledge and Data Engineering (TKDE)
  - Artificial Intelligence (AI)
  - IEEE Transactions on Mobile Computing (TMC)
  - IEEE Transactions on Pattern Analysis and Machine Intelligence (TPAMI)
- Conferences
  - KDD, SIGMOD, VLDB, ICDE, NeurIPS, ICLR, ICML, AAAI, IJCAI
  - ICDM, CIKM, WSDM, ECML-PKDD, ECAI

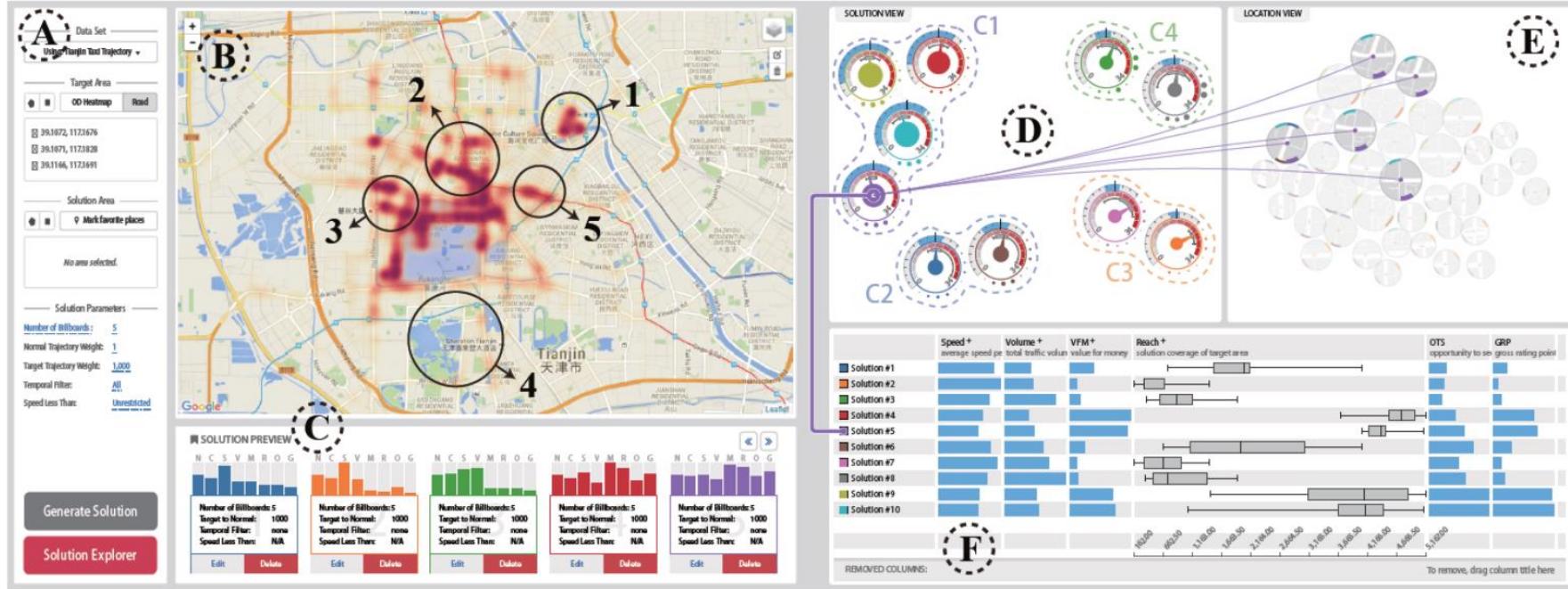
# Visual and Interactive Data Analytics



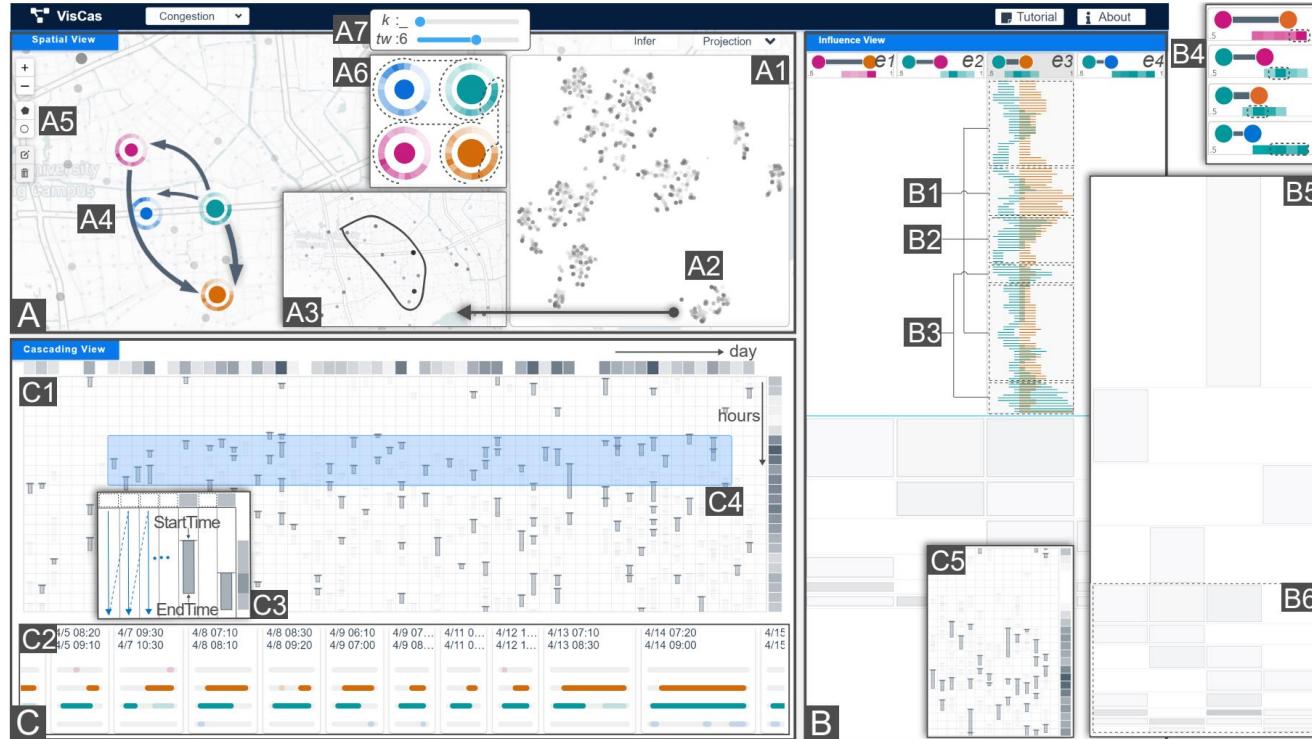
- Human + Machine intelligence
- Domain knowledge + Data Science
- Visualization + Data Mining



# Selecting Billboard Locations using Taxi Trajectories



# Visual Cascade Analytics of Large-scale ST Data





# Target Venues

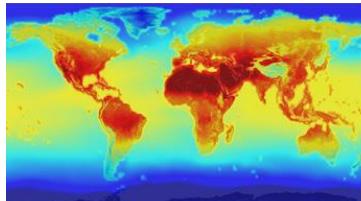


- Journals
  - IEEE Transactions on Visualization and Computer Graphics (TVCG)
  - ACM Transactions on Graphics (TOG)
- Conferences
  - VIS, SIGGRAPH, MM

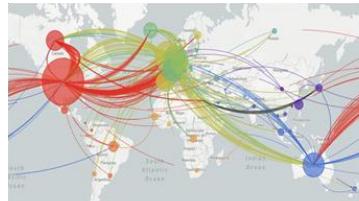


# Future Research Topics

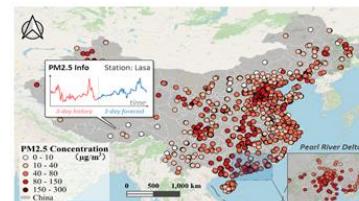
- Towards a long-term goal of *developing effective and efficient AI algorithms to address the challenges of modeling complex dependencies within ST data*
  - **Novel interdisciplinary research:** big ST data + rich scenarios + domain knowledge



Climate



Epidemiology



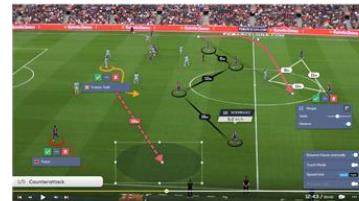
Environment



Social Science



Transportation

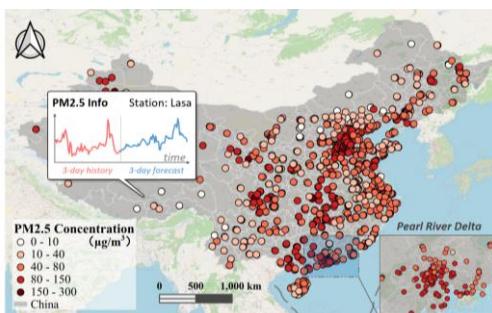
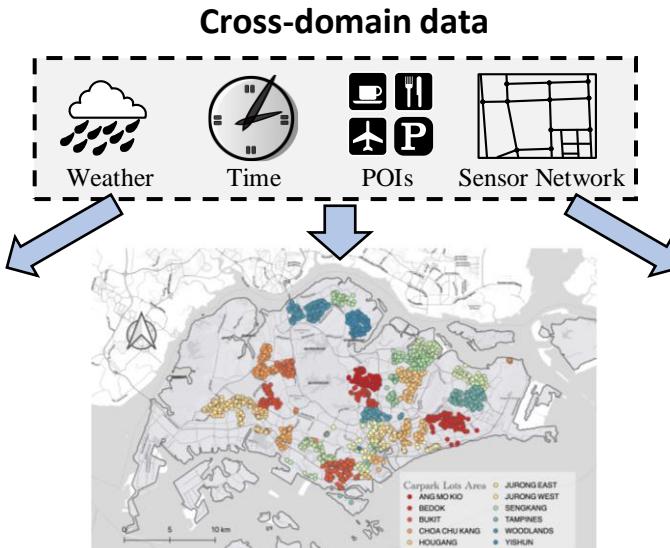


Sports Analysis



# Future Research Topics

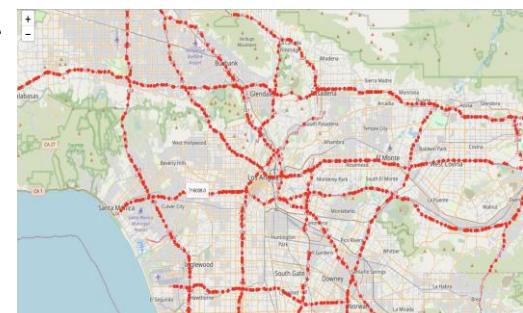
- **Efficient AI for large-scale ST Applications**
  - Produce new benchmarks for the community: large-scale ST data + external factors
  - Designing scalable AI methods



Air quality data in China  
(~2,000 stations)

Carpark availability data in  
Singapore (~2,000 carparks)

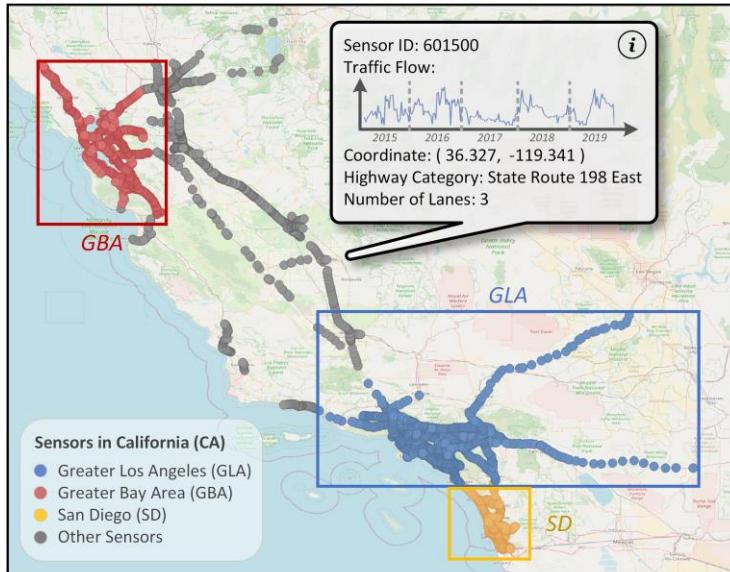
Datasets	#Sensors	#Edges
PeMSD7(M)	228	1132
PeMSD7(L)	1026	10150
PeMS03	358	547
PeMS04	307	340
PeMS07	883	866
PeMS08	170	295





# LargeST: a Large-Scale Traffic Dataset

- We crawled, processed, and released a large-scale traffic dataset
  - Scalability, Generalizability, Robustness, etc.



Dataset	Nodes	Edges	Degree	Meta	Time Range	Frames	Data Points
PeMSD7(M)	228	1,664	7.3	6	05/01/2012 – 06/30/2012	12,672	2.89M
PeMSD7(L)	1,026	14,534	14.2	0	05/01/2012 – 06/30/2012	12,672	13.00M
METR-LA	207	1,515	7.3	3	03/01/2012 – 06/27/2012	34,272	7.09M
PEMS-BAY	325	2,369	7.3	3	01/01/2017 – 06/30/2017	52,116	16.94M
PEMS03	358	546	1.5	1	09/01/2018 – 11/30/2018	26,208	9.38M
PEMS04	307	338	1.1	0	01/01/2018 – 02/28/2018	16,992	5.22M
PEMS07	883	865	1.0	0	05/01/2017 – 08/06/2017	28,224	24.92M
PEMS08	170	276	1.6	0	07/01/2016 – 08/31/2016	17,856	3.04M
CA	8,600	201,363	23.4	9	01/01/2017 – 12/31/2021	525,888	4.52B
GLA	3,834	98,703	25.7	9	01/01/2017 – 12/31/2021	525,888	2.02B
GBA	2,352	61,246	26.0	9	01/01/2017 – 12/31/2021	525,888	1.24B
SD	716	17,319	24.2	9	01/01/2017 – 12/31/2021	525,888	0.38B



香港科技大学(广州)  
THE HONG KONG  
UNIVERSITY OF SCIENCE AND  
TECHNOLOGY (GUANGZHOU)



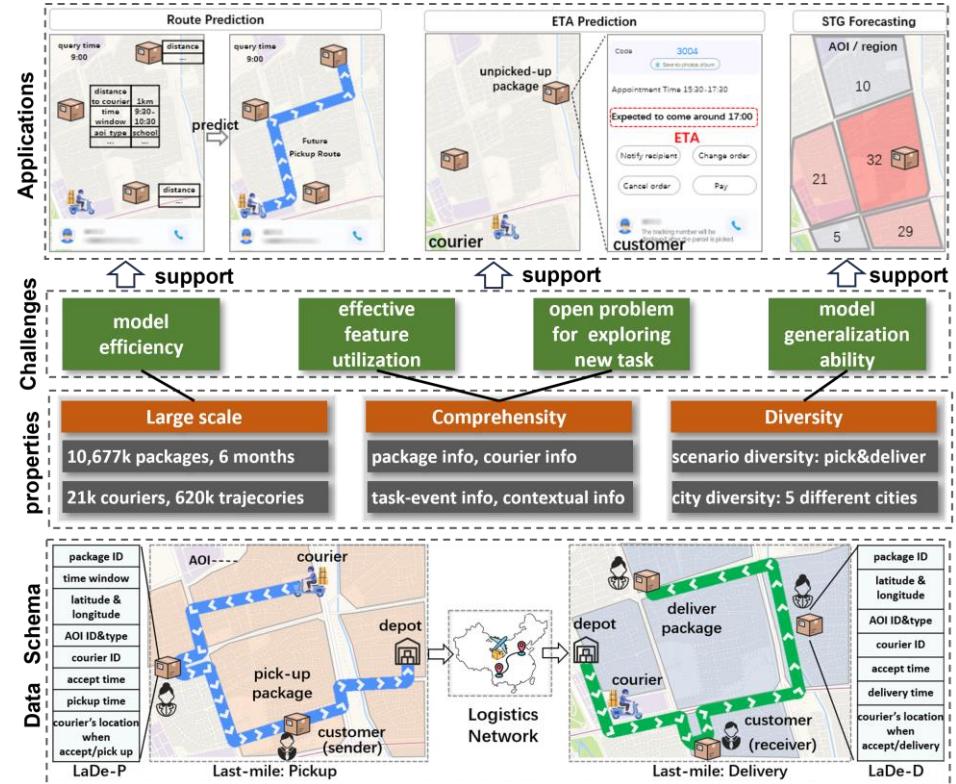
# LaDe Dataset

- We released **The First Last-Mile Delivery Dataset from Industry**
  - Large scale
  - Comprehensivity
  - Diversity

CAI  
NIAO 菜鸟



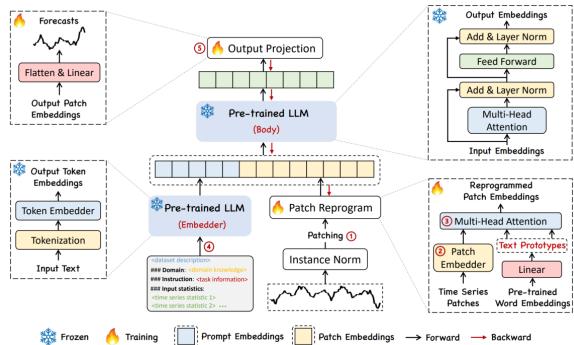
香港科技大学(广州)  
THE HONG KONG  
UNIVERSITY OF SCIENCE AND  
TECHNOLOGY (GUANGZHOU)



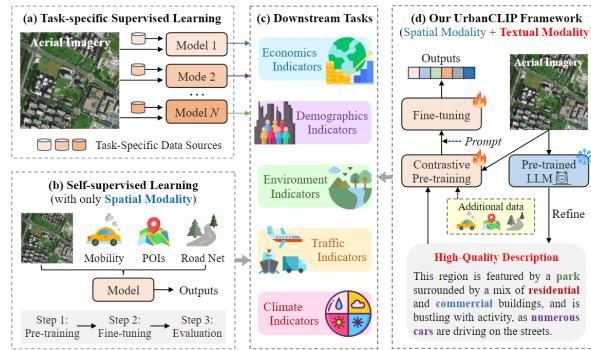


# Future Research Topics

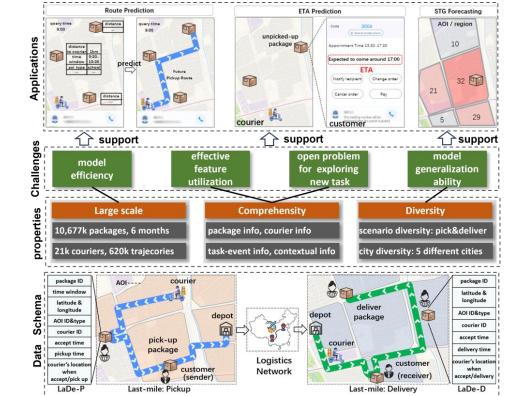
- Our group has been investigating **Large Language Models (LLMs)** for learning spatio-temporal data



Time-LLM



Urban-LLM



Logistic-LLM



# Time-LLM: LLM for Time Series

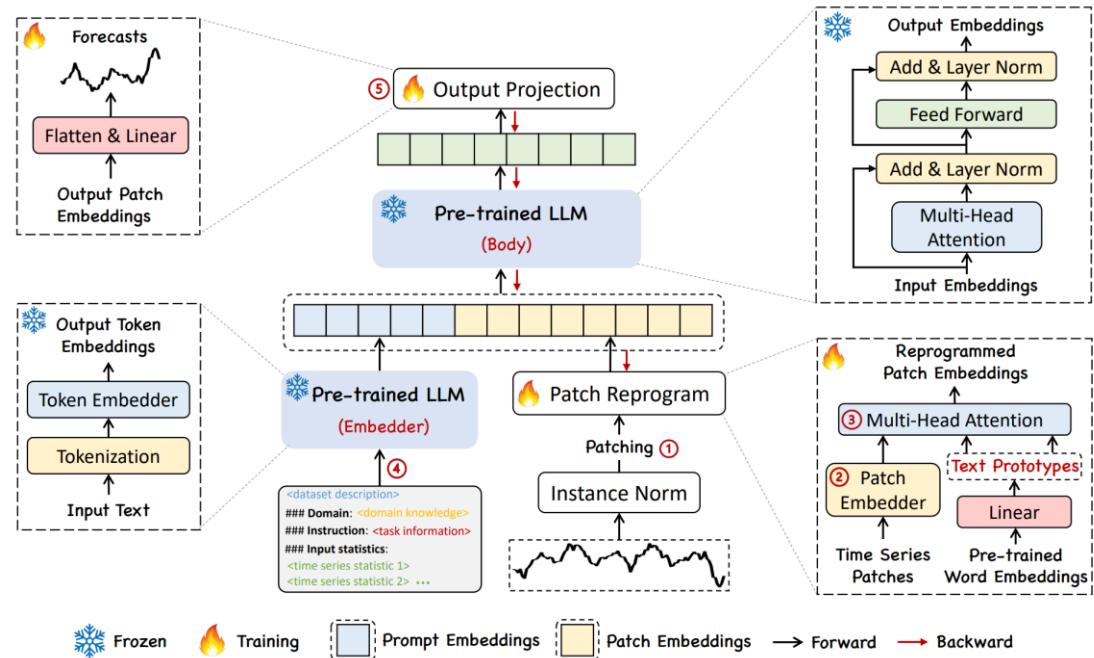
- Time-LLM supports general time series analysis

The Electricity Transformer Temperature (ETT) indicates the electric power long-term deployment. Each data point consists of the target oil temperature and 6 power load features ...  
Below is the information about the input time series:

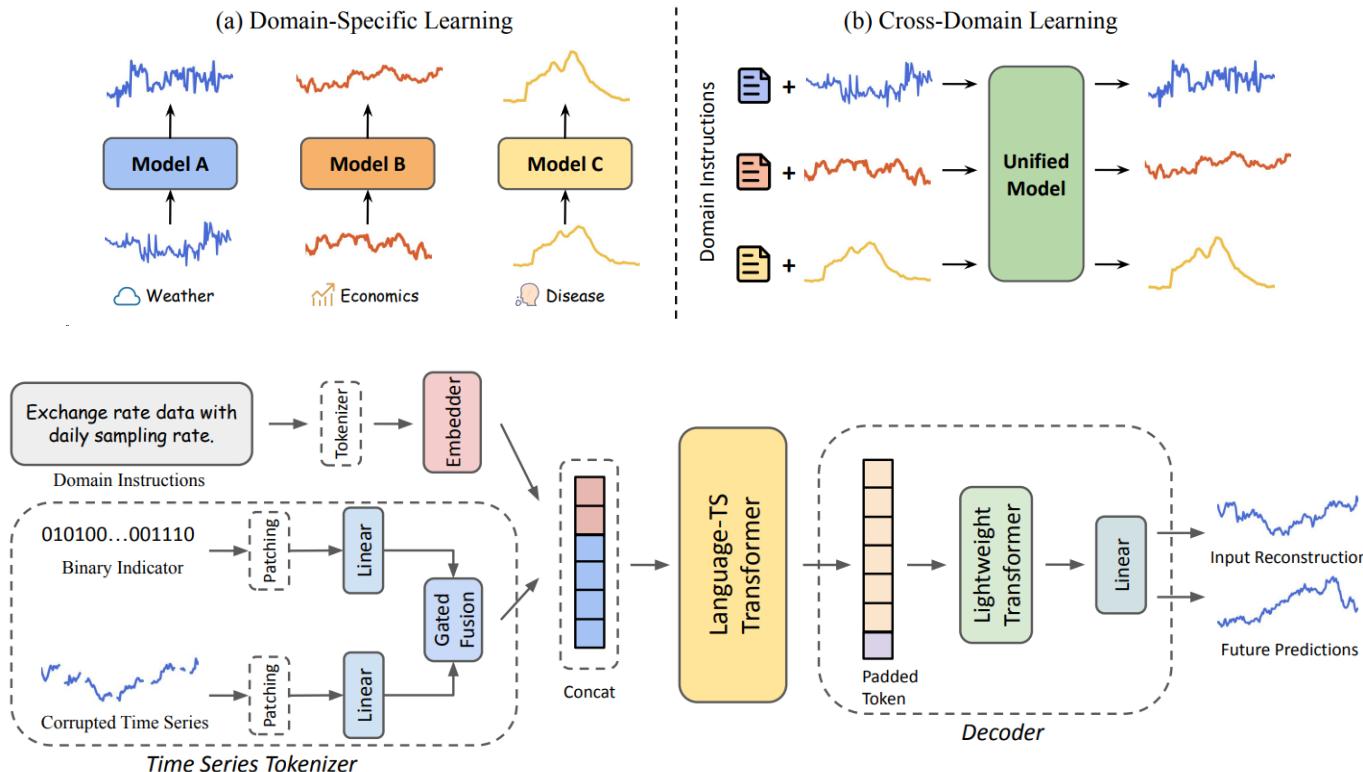
**[BEGIN DATA]**

\*\*\*  
**[Domain]:** We usually observe that electricity consumption peaks at noon, with a significant increase in transformer load  
\*\*\*  
**[Instruction]:** Predict the next `<H>` steps given the previous `<T>` steps information attached  
\*\*\*  
**[Statistics]:** The input has a minimum of `<min_val>`, a maximum of `<max_val>`, and a median of `<median_val>`. The overall trend is `<upward or downward>`. The top five lags are `<lag_val>`.

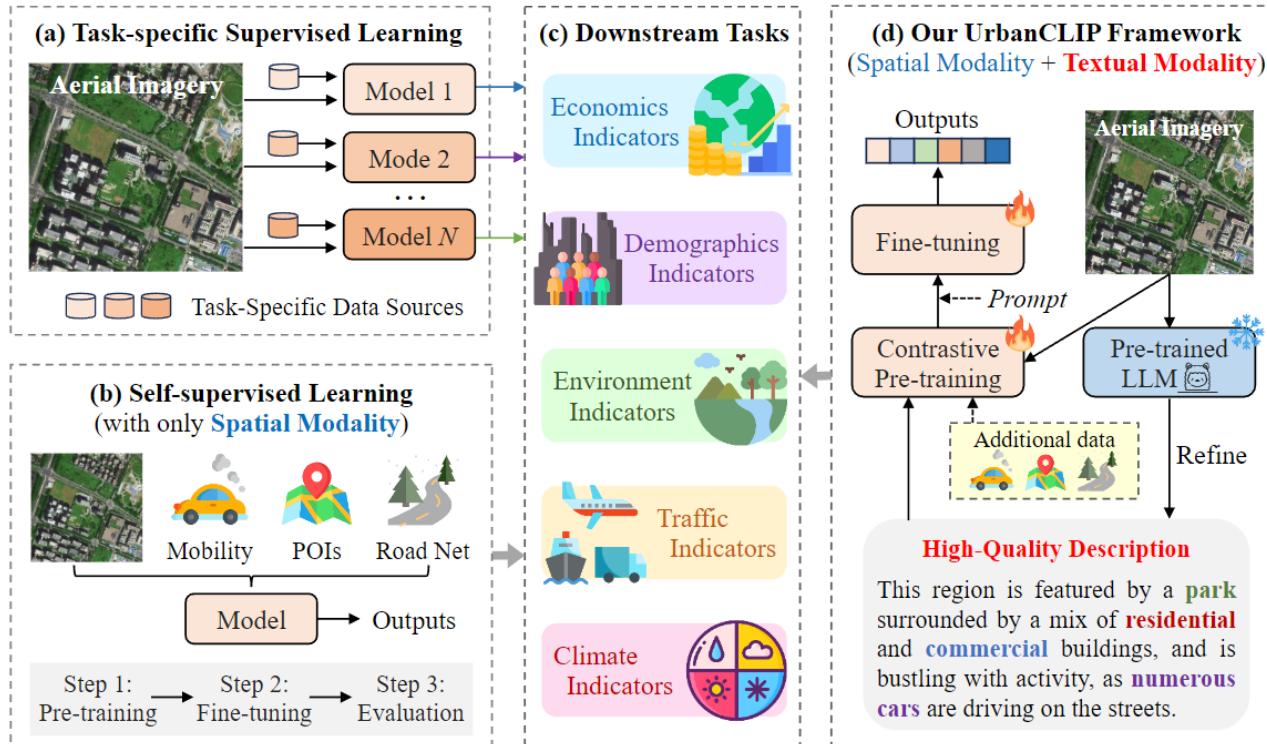
**[END DATA]**



# UniTime: LLM for Cross-Domain Time Series



# Urban LLM



# Demo



## Urban Insights

— LLM-Integrated Urban Indicator System. —

Select City Map Styles Reset Zoom Research Homepage

Search here ...

Region #1254, Beijing

Carbon: 4810.82 tons Population: 9337 units GDP: 99798.54 million

**Text Description:** The satellite image presents an urban landscape with a major thoroughfare, intersecting roads, variously sized buildings, and interspersed green spaces including a central park or garden.

This is a 1km x 1km region centered around coordinate (116.407°E, 39.904°N)

Popular POIs: Beijing Hospital, Dongdan Park, Dongdan Sports Center etc.

300米

mapbox

© Mapbox © OpenStreetMap Improve this map © Maxar

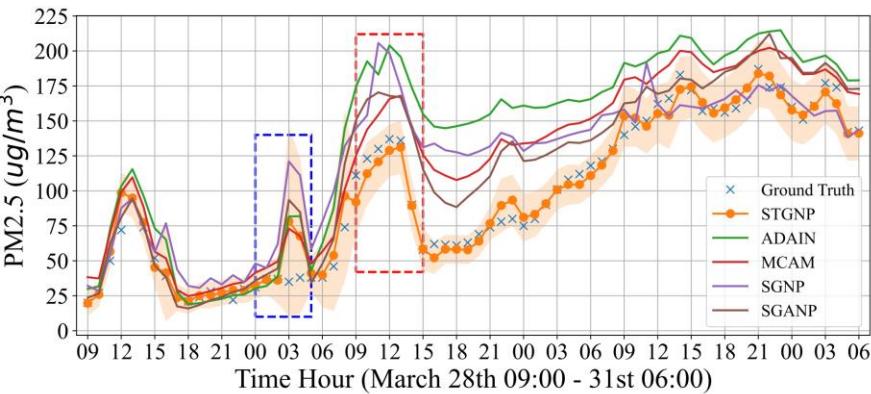
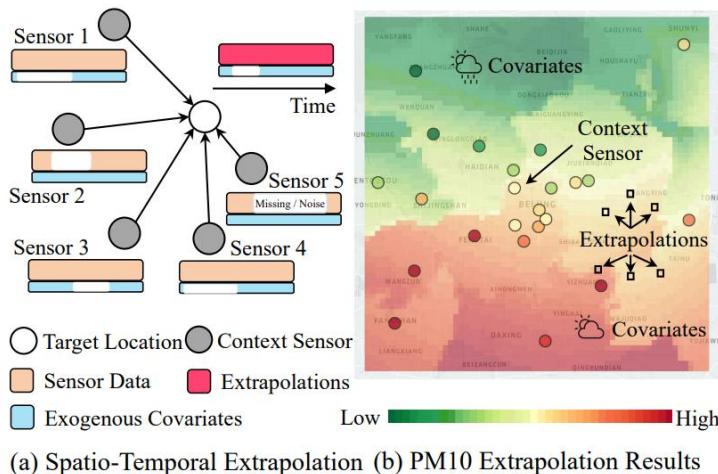
# Future Research Topics



- Towards a long-term goal of *developing effective and efficient AI algorithms to address the challenges of modeling complex dependencies within ST data*
  - Novel Interdisciplinary Research: big ST data + rich scenarios + domain knowledge
  - Efficient AI for large-scale ST Applications
    - Produce new benchmarks for the community: large-scale ST data + external factors
    - Designing scalable AI methods
  - Leveraging the power of Large Language Models for ST data
  - Uncertainty-Aware Generative Modeling for ST Data

# Generative Modeling (NP) for ST Graphs

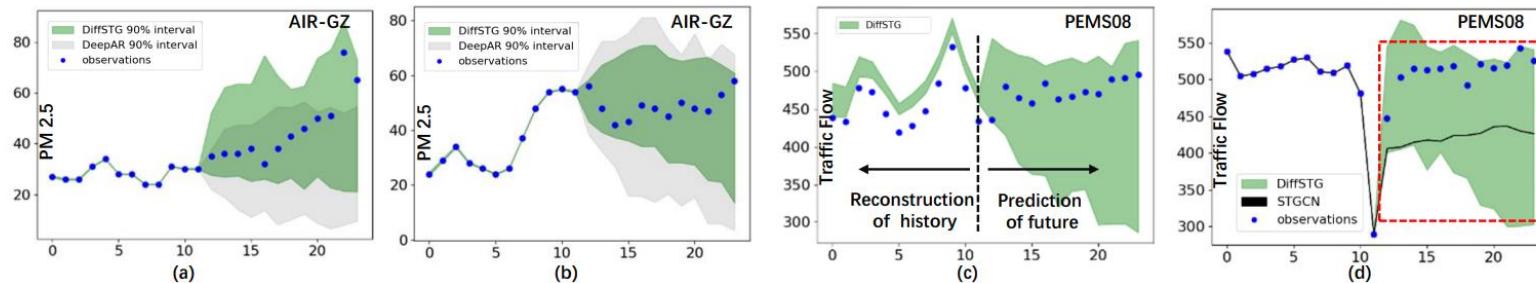
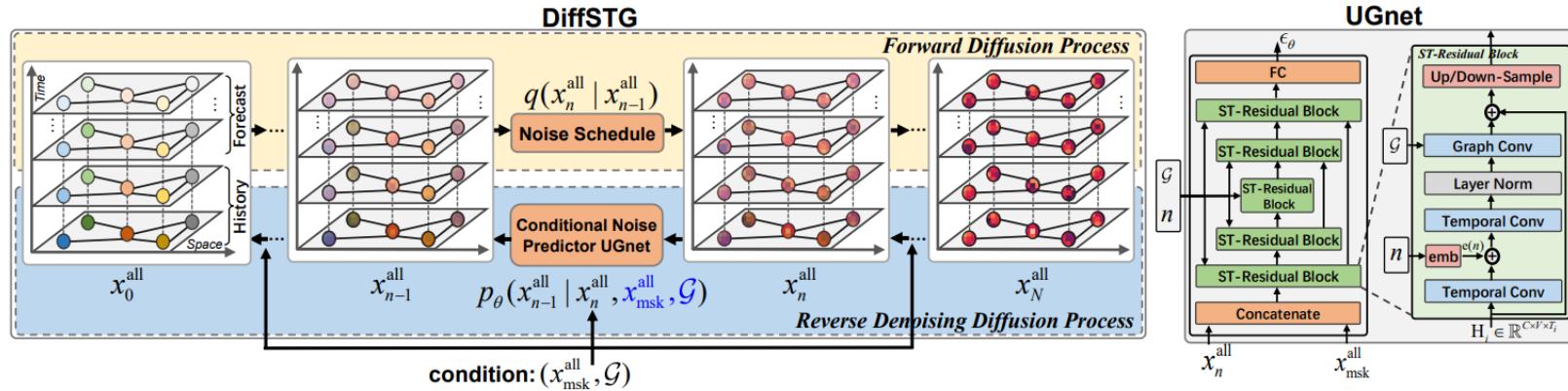
- Uncertainty-aware ST modeling



(a) Spatio-Temporal Extrapolation (b) PM10 Extrapolation Results



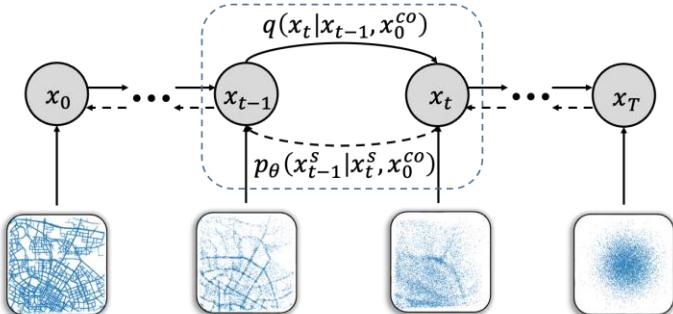
# Generative Modeling (DDPM) for ST Graphs



# Generative Modeling (DDPM) for Trajectories



- Using real-world human trajectories usually has privacy concerns
  - Protect users' privacy
  - DDPM outperforms GAN and VAE



Same origin and destination



Different origin and destination

# Future Research Topics

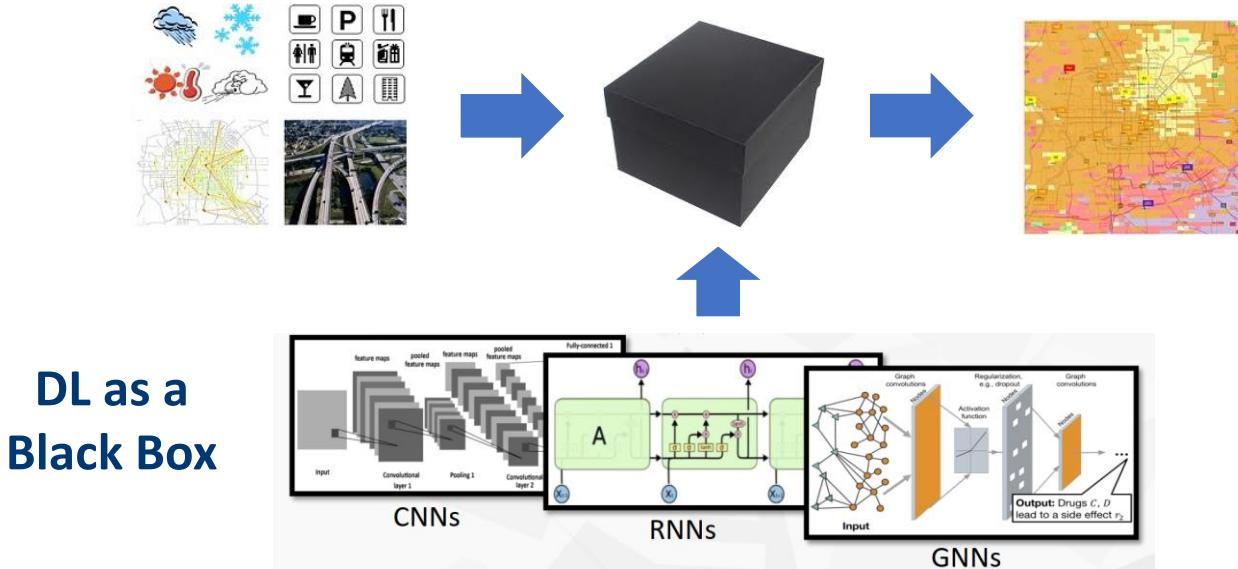


- Towards a long-term goal of *developing effective and efficient AI algorithms to address the challenges of modeling complex dependencies within ST data*
  - Novel Interdisciplinary Research: big ST data + rich scenarios + domain knowledge
  - Efficient AI for large-scale ST Applications
    - Produce new benchmarks for the community: large-scale ST data + external factors
    - Designing scalable AI methods
  - Leveraging the power of Large Language Models for ST data
  - Uncertainty-Aware Generative Modeling for ST Data
  - Explainable AI for ST data

# Future Trends – Towards Explainable AI for STDMA



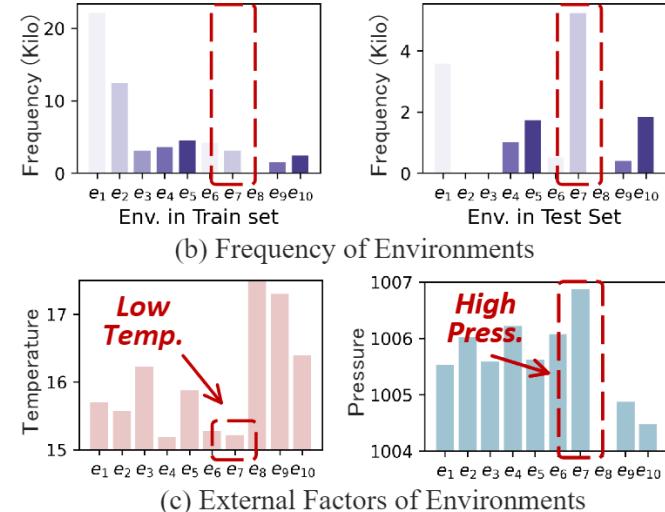
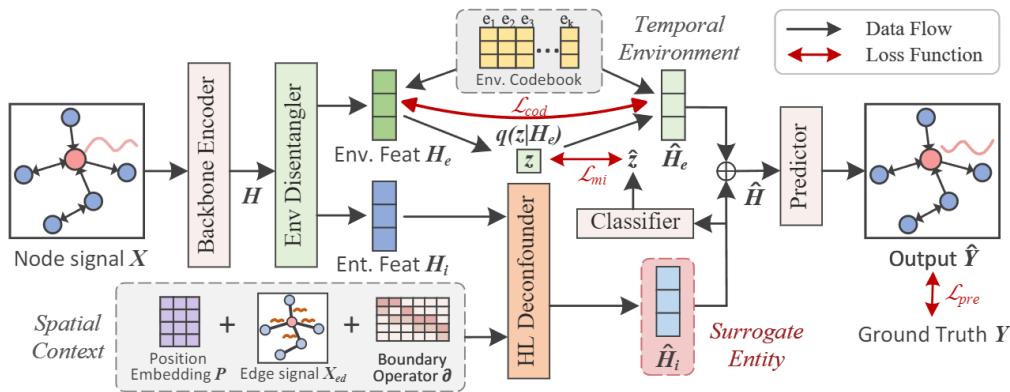
- The current generation of DL-based ST systems
  - They offer tremendous benefits
  - But may make occasional BIG mistakes, limiting its effectiveness & application



# Future Trends – Towards Explainable AI for STDMA

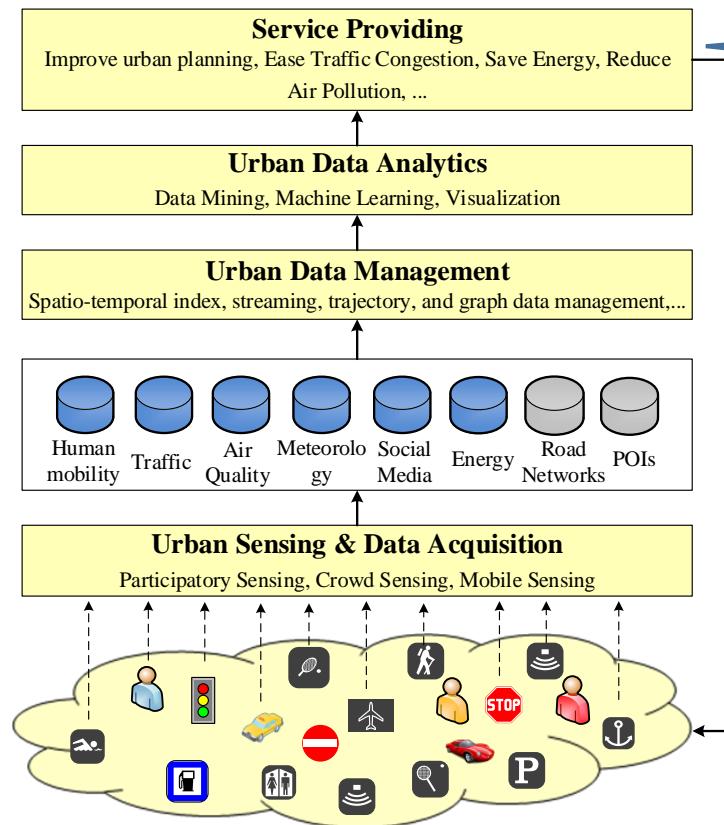


- Explainable AI for ST Data Science
  - Causal inference
  - Gradient-based approaches

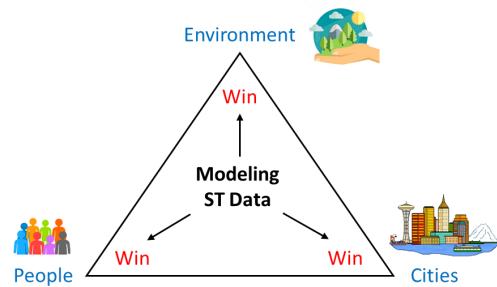
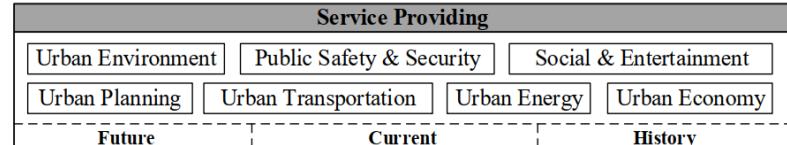




# 4<sup>th</sup> Stage: Service Providing



- Citywide, Dynamic, Decision making
- Current, future and history



# Service Providing



Future	Current	Historical
<p>Forecast and prediction:</p> <ul style="list-style-type: none"><li>– Air quality</li><li>– Traffic of vehicles and people</li><li>– ...</li></ul> <p>Intervention-based services:</p> <ul style="list-style-type: none"><li>– What if we build a new road or subway line?</li><li>– What if we do a traffic control to lower the air pollution?</li><li>– ...</li></ul>	<ul style="list-style-type: none"><li>• Ridesharing</li><li>• Logistics industries</li><li>• Trip planning and navigation</li><li>• Fine-grained air quality monitor</li></ul> <p>...</p>	<ul style="list-style-type: none"><li>• What is the root cause of air pollution?</li><li>• What is the percentage of PM2.5 from vehicle emission?</li><li>• Why Beijing's traffic is so congested?</li></ul> <p>...</p>
<b>Citywide! Dynamic! Decision-making!</b>		

# An Example from JD.COM

城市操作系统



# 智慧城市 城市数据一网共享

# 城市大数据



# 城市数据 一网共享



# 城市感知的内容

感知内容的标准化



人流量

- 交通枢纽人流量
  - 地铁人流
  - 公交人流
  - 机场人流
- 职住场所人流
  - 社区人流
  - 酒店人流
  - 园区人流
- 公共区域人流
  - 商圈人流
  - 景区人流
- 重大活动人流
  - 出入口人流



交通流

- 公共交通
  - 公交车
  - 地铁
  - 轻轨
  - 高铁
  - 飞机
- 私人交通
  - 共享单车
  - 出租车
  - 网约车
  - 专车
  - 私家车
- 运输
  - 物流车
  - 垃圾车
  - 危化品车
- 特种运输
  - 救护车
  - 警车
  - 消防车
  - ...



环境

- 空气质量
  - SO<sub>2</sub>、CO、O<sub>3</sub>
  - PM10、PM2.5
- 气象
  - 温度、湿度
  - 降水
    - 雨
    - 雪
  - 风
    - 风向
    - 风速
- 水质
  - 含氧量
  - 含氯量
  - PH值
- 遥感
  - 噪声
  - 土壤
  - 垃圾

公共安全

- 自然灾害
  - 台风
  - 洪水
  - 地震
  - 积水
  - 干旱
  - 高温
  - 积雪
- 人为灾害
  - 偷窃
  - 抢劫
- 意外风险
  - 地面塌陷
  - 火灾
  - 积水
  - 井盖是否盖住
- 舆情
  - 热点事件
  - 民众投诉
  - 政策评价



能耗

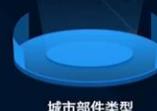
- 水
  - 居民用水
  - 企业用水
- 电
  - 家庭用电
  - 照明用电
  - 工业用电
- 气
  - 居家燃气
  - 交通加气
  - 企业用气
- 热
  - 居民家庭供暖
  - 写字楼供暖
  - 企业功能
  - 学校供暖
- 油
  - 汽油
  - 柴油
  - 煤油
- 消费
  - 线上购物
  - 生鲜
  - 粮油
  - 家电
  - ...
- 线下消费
  - 商超
  - 文旅
  - 医疗
  - ...
- 税收
  - 个人所得税
  - 消费税
  - 增值税
  - 关税
  - 房产税
  - ...
- 产值
  - 企业产量
  - 物品销量

...

## 城市部件覆盖总量

126种

1071999个



## 各区城市部件数量统计

单位: 件

500000
400000
300000
200000
100000
0

崇川区 395000 件  
港闸区 345000 件  
开发区 215000 件

## 按类型统计部件数量

市容环卫设施: 11967 交通设施: 54759

园林绿化设施: 327014

1071999 件

总数量

公用设施: 655327

其他部件: 22932

100万IOT设备  
10万摄像头

以传感器为中心的固定感知

## 部件统计

部件图层

公用设施

报刊亭

变压器箱

不明井盖

不明立杆

充电桩

地灯

电话亭

电缆井盖

电力井盖

电力立杆

电力设施

电视井盖

电信交接箱

电信井盖

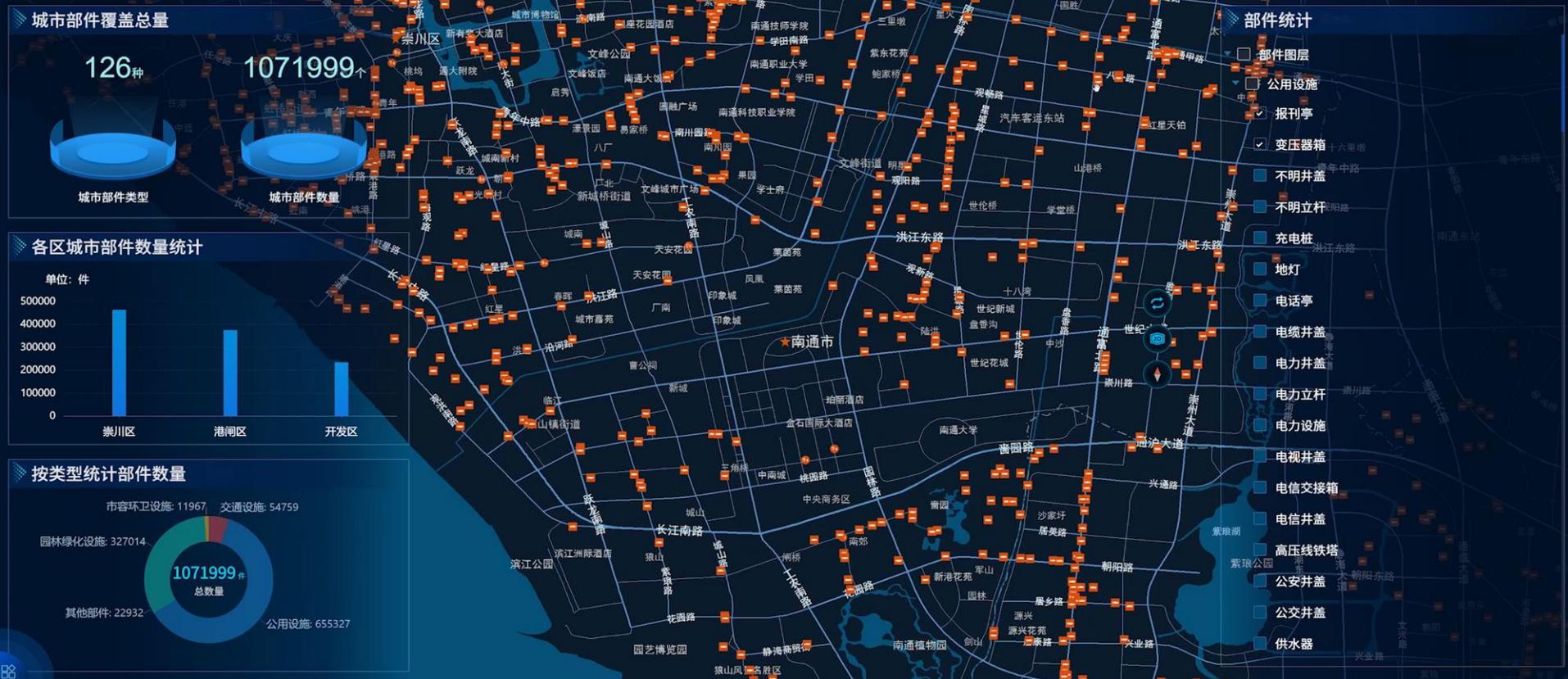
高压线铁塔

紫琅公园

公安井盖

公交井盖

供水器



# 交通一张图



全行业数据“汇一图” 全时空监测“看一图” 全样本决策“用一图”

100万IOT设备  
10万摄像头

9356 出租车、卡车、网约车  
11,675 船舶

以传感器为中心的固定感知

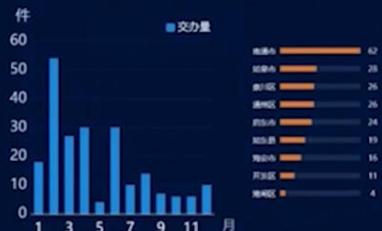
以传感器为中心的移动感知

# 市域治理现代化指挥平台 - 社情民意一张图

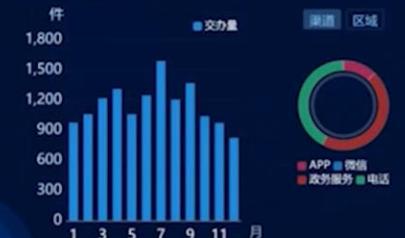
上级交办

上级交办总量 14066 件

国家交办(当日)	0 件
国家交办(累计)	148 件
互联网+督查	68 件
国务院服务	216 件



省平台交办(当日)	3 件
省平台交办(累计)	13734 件



100万IOT设备  
10万摄像头

以传感器为中心的固定感知

广纳民声

聚焦民意

响应民情

惠及民心

网络渠道

网络汇聚总量 5758 件

本年度上报总量 1053578 件

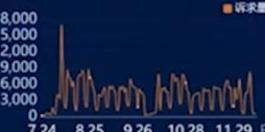
联动上报

联动上报总量 1033754 件

部门联动平台

部门联动平台上报总量 709004 件

当日上报量 638 累计上报量 580133



其他部门

上报详情 时间

- |             |       |
|-------------|-------|
| 3 草坪里有黄色塑料袋 | 12/14 |
| 4 农家宴检查     | 12/14 |
| 5 交通标志牌脱落   | 12/14 |
| 6 绿化维护      | 12/14 |

政务热线平台

政务热线上报总量 324311 件

887 / 322612

12345服务

【当月/累计量】

5,000

4,000

3,000

2,000

1,000

0 / 0

并联整合热线【当月/累计量】

上报详情 时间

- |              |       |
|--------------|-------|
| 3 咨询贵阳停电何时来电 | 12/14 |
| 4 咨询恒大什么时候来电 | 12/14 |
| 5 关于地铁施工的问题  | 12/14 |
| 6 关于噪音扰民的问题  | 12/14 |

紧急联动平台

紧急联动平台上报总量 439 件

110热线

当日

累计量

439

119热线

当日

0

累计量

120热线

当日

0

累计量

0

9356 出租车、卡车、网约车

11,675 船舶

以传感器为中心的移动感知

7万+ 网格员  
数十万居民主动上报

以人为中心的主动感知

网络渠道

网络汇聚总量 5758 件

南通百通APP

微渠道

APP服务量(件)  
146

微信(件)  
4855

微博(件)  
426

全媒体

网站(件)  
59

邮件(件)  
8

短信(件)  
148

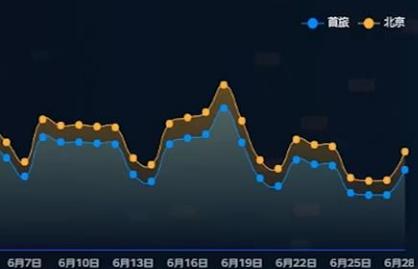
好差评(件)  
116

网络话题

正面	【时来运转】泥料：家藏老紫泥 容量：280cc 此...
正面	2020-12-14 10:09:47 来源：新浪微博
正面	【苏州东吴医院】「苏州肠道病医院」「苏州肛肠...
正面	2020-12-14 10:09:42 来源：新浪微博
正面	#网上重走长征路# 在教学中坚持把“四史”教育...
正面	2020-12-14 10:09:41 来源：新浪微博
正面	【湖北12条新政优化高新区企业认定服务 全时受理企...
正面	2020-12-14 10:09:28 来源：新浪微博
负面	#江西服装学院##江歌小青马# 2020年12月14日 ...
负面	2020-12-14 10:10:10 来源：新浪微博
负面	//@如皋发布:#带着微博去如皋# Welcome to Ru...
负面	2020-12-14 10:10:09 来源：新浪微博
负面	昨晚还在刷微博，看见别人买东西卡在里面，然后...
负面	2020-12-14 10:10:09 来源：新浪微博
负面	转最近2号线尹山湖站保利悦都招租一个半月可续...
负面	2020-12-14 10:10:08 来源：新浪微博

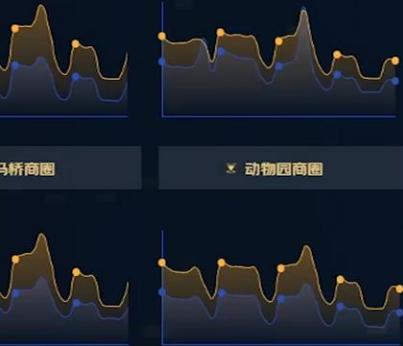
⑦

度与北京市人口活跃度对比

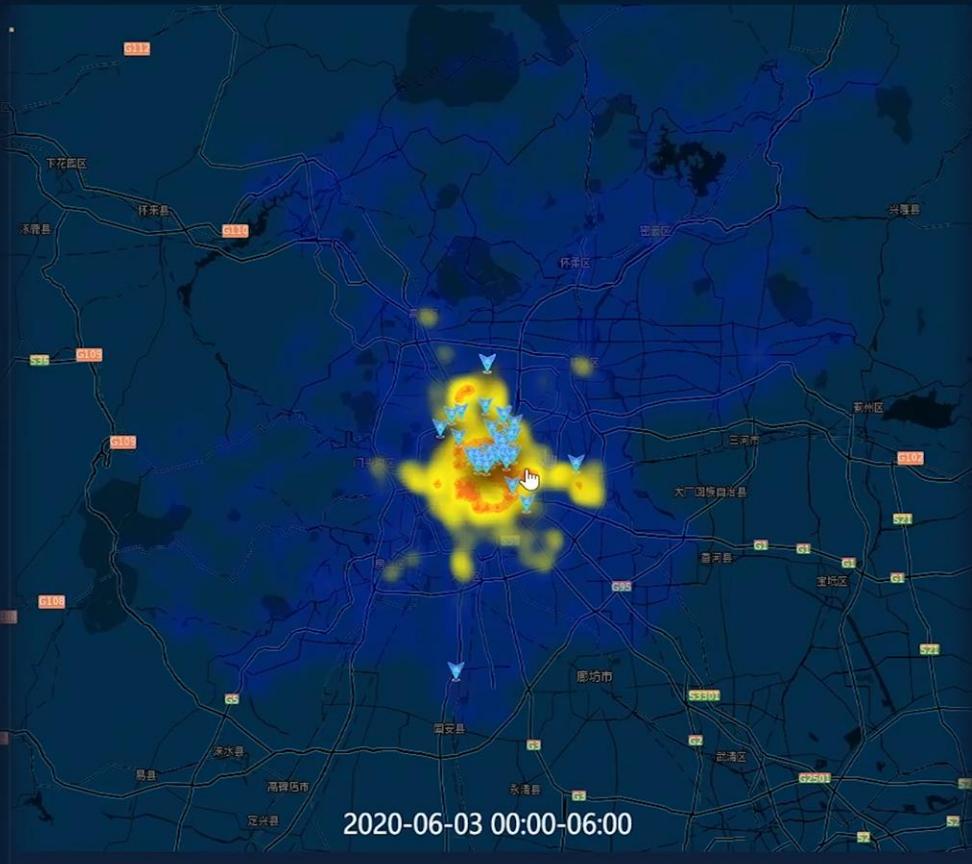


商圈

王府井商圈



动物园商圈



100万IOT设备  
10万摄像头

以传感器为中心的固定感知

9356 出租车、卡车、网约车  
11,675 船舶

以传感器为中心的移动感知

7万+ 网格员  
数十万居民主动上报

以人为中心的主动感知

800万居民手机信令  
社交媒体

以人为中心的被动感知

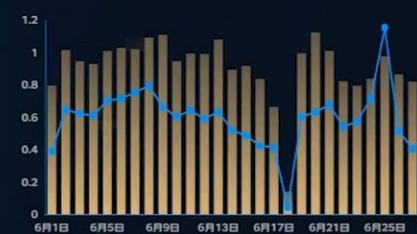
客群消费力指数 (%)



客群消费力

客群消费能力

客群信用水平指数 (%)



客群信用

北京市客群信用水平

客群消费力指数

# 城市数据一网共享 的机遇和价值



新型数据孤岛突显



赋能支撑不足



生态化缺失

城市数据极大丰富、政府需要管理和利用好数据生产要素

数据被列为第五种生产要素  
(土地、劳动力、资本、技术)



我们不是脑和中枢

# 智慧城市操作系统

我们不是云

我们不是系统集成



## 全域感知

搭建全域数据感知的高速通道、实现**复杂网络**下，**多源异构**数据的**实时汇聚**，全域感知。



## 高效管理

以六种时空数据模型、归类万千数据，**100+倍**时空数据查询管理效率，快速捕获数据信息。



## 智能引擎

归纳应用背后**智能因子**、沉淀城市独特的**时空算法模块**，感知城市运行状况，预测城市未来。

# 智能城市操作系统

城市操作系统是一个开放的、组件化的、标准化的集采集、存储、管理、挖掘、分析、可视化于一体的智能城市大数据AI使能平台。



## 互联互通

打破数据融合壁垒，实现数据不出门情况下的联合建模，实现知识共享、互联互通。

## 数字孪生

物理世界的**精准还原**、数据的**实时映射**、数据**分析后的指导现实世界的决策**



**应用程序**



**操作系统**



**硬件基础操作**

**PC机**



**智慧城市操作系统**



**云基础设备**



# 城市操作系统

城市操作系统是一个开放的、组件化的、标准化的智慧城市大数据AI使能平台。依托操纵系统，感知城市全域数据、打造数字孪生城市基底，赋能智慧城市生态应用，实现城市运行状态特征的全面监测和城市资源的智能配置。



## 全域感知

搭建全域数据感知的高速通道、实现复杂网络下，多源异构数据的实时汇聚，全域感知。



## 互联互通

打破数据融合壁垒，实现数据不出门情况下的联合建模，实现知识共享、互联互通。



## 高效管理

以六种时空数据模型、归类万千数据，100+倍时空数据查询管理效率，快速捕获数据信息。



## 智能引擎

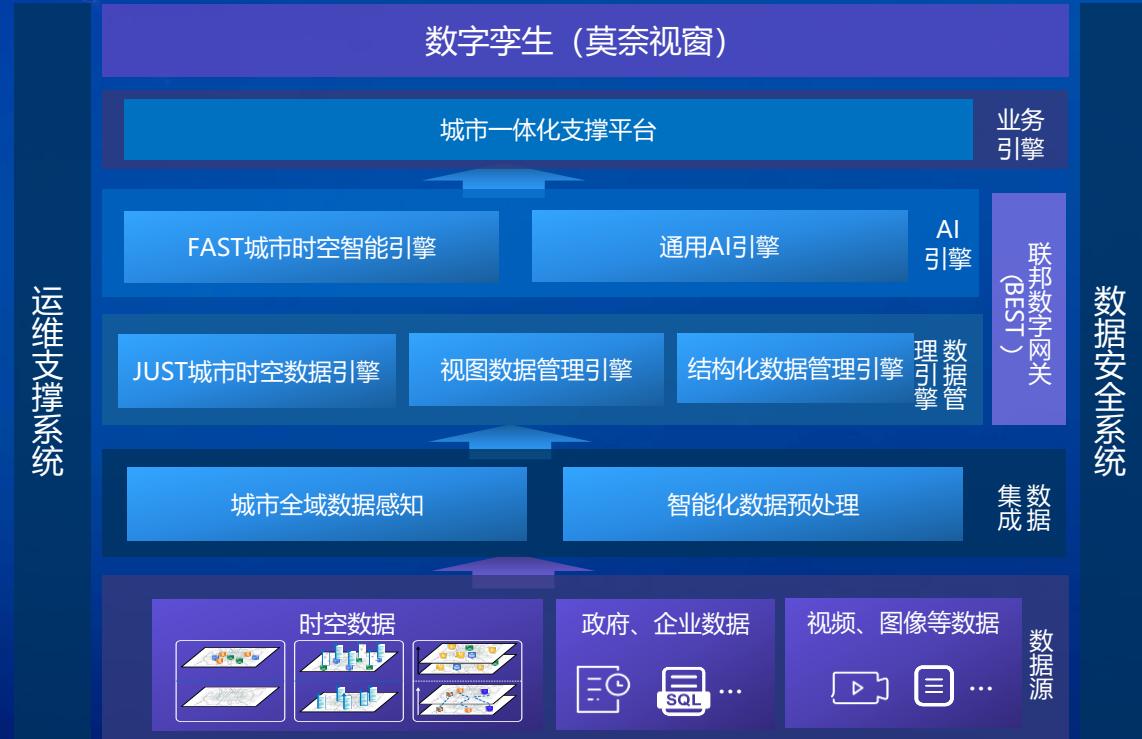
归纳应用背后智能因子、沉淀城市独特的时空算法模块，感知城市运行状况，预测城市未来。



## 生态开放

构建共性支撑平台、助力第三方开发者快速搭建业务应用，共建共性应用，助力操作系统不断迭代。

运维支撑系统





# What is a GOOD research in MobilDL



- Should be in the scope of human mobility data
- Go beyond accuracy, but consider problems of robustness and scalability
- Care about explainability, fairness, and privacy
- Support users, offer insights and solutions
- Provide a new perspective to solve a problem or study a novel problem
- Lead a new era or area (although very hard ☺)

# Objective of This Course



- To Introduce
  - The concepts of Spatio-Temporal (ST) data, especially human mobility data
  - The rich and exciting areas of ST data mining and analytics research
  - The recent advances in research and applications
  - The future research trends
  - Hands-on exercises using real-world datasets
- Modes of Assessment
  - Paper reading and presentation
  - Question-answering
  - Reports (of publishable quality) and Project

# Key Course Information



- Lessons: Tuesday, 18:00-20:50 (Rm 202, E3)
- **Presentation & QA (40%)**
  - Each person to present 1-2 papers
  - Each person to be assigned papers to ask good questions
  - It starts in Week 2, to present 1~2 papers per week
- **Project (60%)**
  - Topic: an open project on a MobiDL topic
  - Design Report (10%)
  - System Report + Demo + Presentation (50%)



# Course Schedule

- The first half

	Date	Lecture/Tutorial Topics	Pre	Remarks
1	2 Sep	L1: Overview and Introduction		
2	9 Sep	L2: Tutorials on Deep Learning	✓	Introduce foundations in deep learning techniques, such as CNN, RNN, GNN, Transformer, etc.
	16 Sep	No lecture		Mid-Autumn Festival
3	23 Sep	L3: Spatio-Temporal Data Sensing and Management	✓	To form team (2 people)
4	30 Sep	L4: Cross-Domain Data Fusion and Multimodal Learning	✓	
	7 Oct	No lecture		National Day
5	14 Oct	L5: Location Embedding and Urban Region Profiling	✓	Meeting 1: Submit 1-page plan for project (by 14 Oct @ 23:59)
6	21 Oct	L6: Learning Spatio-Temporal Trajectory Data	✓	

# Course Schedule



- The second half

7	28 Oct	L7: Learning Spatio-Temporal Raster Data	✓	Submit Design Report (by 28 Oct @ 23:59)
8	4 Nov	L8: Open Course for Project Discussion	✓	
9	11 Nov	L9: Learning Spatio-Temporal Graph Data	✓	Meeting 2: Finalize designs & applications
10	18 Nov	L10: Advanced Topics in Human Mobility Analytics	✓	
11	25 Nov	L11: Large Language Models for Human Mobility Analytics	✓	
12	2 Dec	L12: Summary and Future Trends	✓	* Project presentation * Submit Systems Report & Codes (by 9 Dec @ 23:59)

# Presentation & QA



## Presentation (30%)

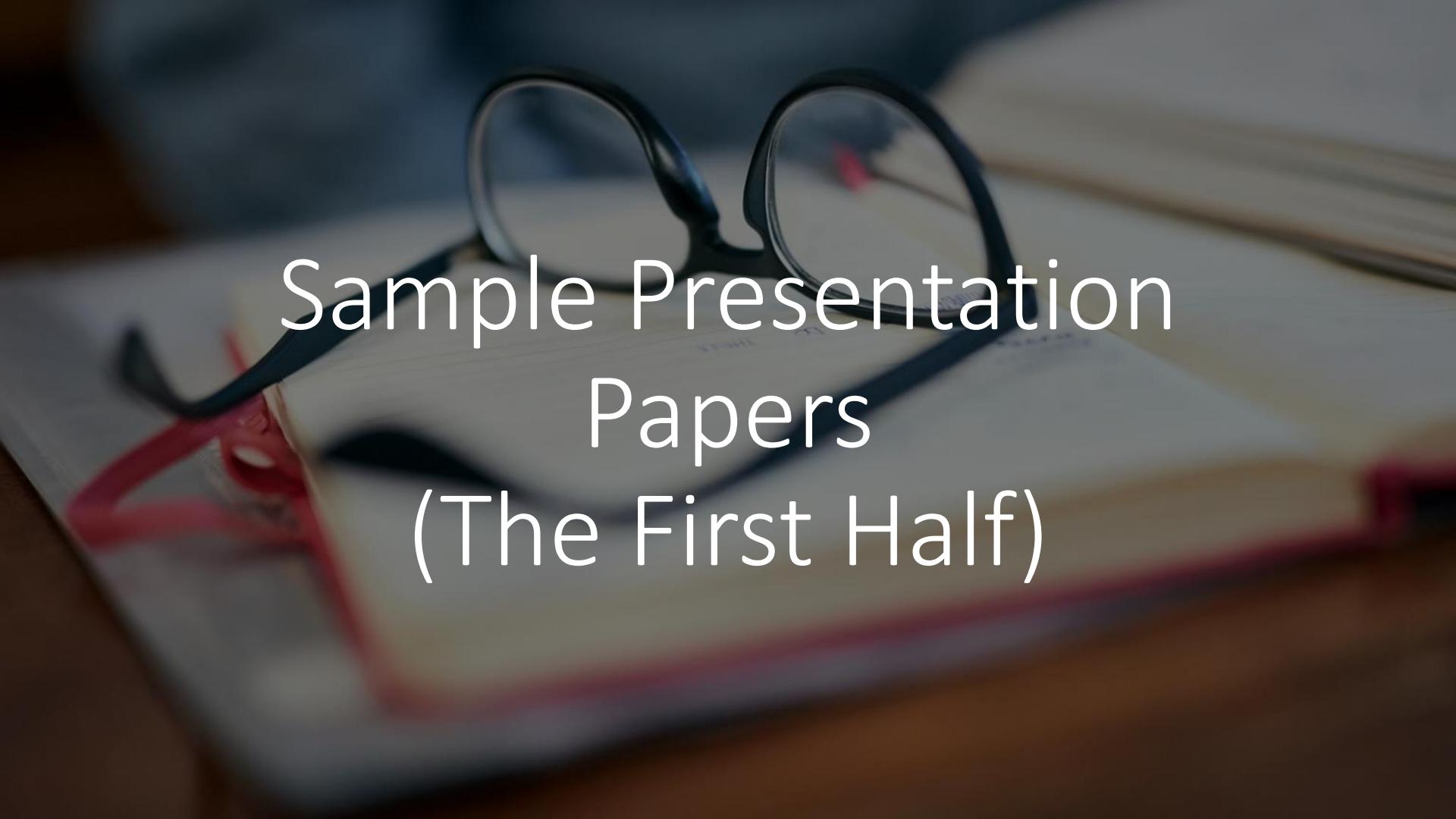
- **To cover 2 assigned papers**
  - May use other materials to supplement the materials
  - Max: 20 mins (learn to say what you have to say concisely in 15 mins, followed by 5-min QA)
- Presentation should cover:
  - Objectives of paper (including clear statement of problem solved)
  - Literature reviews (cover what has been done, limitations and gaps)
  - The basis of design in the target paper
  - Key summary of innovation and solution (must clearly highlight innovation)
  - Results and how the authors validate the solutions
  - The future trends
- Important notes: Must clearly explain innovation and why in design/implementation

# Presentation & QA



## Questioning (10%)

- To be assigned several papers to ask questions
  - **May be assigned on the spot**, so be prepared at all time
  - Ask 2-3 questions – should have good depth and help to uncover insights of papers
  - Could be asked to explain why these questions
- Open questioning by all

A stack of several books is shown in a slightly blurred background. A pair of dark-rimmed glasses lies horizontally across the top of the stack. The books have various colored spines, including blue, red, and yellow. The overall lighting is soft and warm.

# Sample Presentation Papers (The First Half)

# Week 2-3: ST Data Sensing and Management



- Data Sensing
  - Dynamic Public Resource Allocation based on Human Mobility Prediction. Ubicomp 2020.
  - Urban Sensing for Multi-Destination Workers via Deep Reinforcement Learning. ICDE 2024.
- Spatial & Spatio-temporal database
  - TraSS: Efficient Trajectory Similarity Search Based on Key-Value DataStores, ICDE 2022
- Advanced applications
  - Map matching
    - DeepMM: Deep Learning based Map matching with Data Augmentation, TMC
    - Transformer-based map-matching model with limited labeled data using transfer-learning approach, TRC
  - Large-Scale Dynamic Ridesharing
    - T-share: A large-scale dynamic taxi ridesharing service, ICDE 2013
  - Learning to generate maps from trajectories, AAAI 2020

# Week 4: Cross-Domain Data Fusion and Multimodal Learning



- Stage-based
  - Discovering Regions of Different Functions in a City using Human Mobility and POIs, KDD 2012
- Feature concatenation
  - Sparse Real Estate Ranking with Online User Reviews and Offline Moving Behaviors. ICDM 2014
- Semantic-based
  - U-Air: When Urban Air Quality Inference Meets Big Data, KDD 2013 (not mobility-related)
- Deep Learning
  - Deep Spatio-Temporal Residual Networks for Citywide Crowd Flows Prediction, AAAI 2017
  - GeoMAN: Multi-level Attention Networks for Geo-sensory Time Series Prediction, IJCAI 2018

# Week 5: Location Embedding and Urban Region Profiling



- Beyond the First Law of Geography: Learning Representations of Satellite Imagery by Leveraging Point-of-Interests, WWW 2022
- Unifying inter-region autocorrelation and intra-region structures for spatial embedding via collective adversarial learning, KDD 2019
- Urban Region Profiling With Spatio-Temporal Graph Neural Networks, TCSS
- Unsupervised Learning of Disentangled Location Embeddings, IJCNN 2020
- When Urban Region Profiling Meets Large Language Models, WWW 2024
- UrbanCross: Enhancing Satellite Image-Text Retrieval with Cross-Domain Adaptation. MM 2024.

# Week 6: Learning Spatio-Temporal Trajectory Data



- Learning trajectory representations
  - TrajFormer: Efficient Trajectory Classification with Transformers, CIKM 2022
  - Modeling Trajectories with Recurrent Neural Networks, IJCAI 2017
  - Modeling Trajectories with Neural Ordinary Differential Equations, IJCAI 2021
- Learning for DB tasks
  - Deep Representation Learning for Trajectory Similarity Computation, ICDE 2018
  - Mtrajrec: Map-constrained trajectory recovery via seq2seq multi-task learning, KDD 2021
- Novel applications
  - Detecting Vehicle Illegal Parking Events using Sharing Bikes' Trajectories, KDD 2020
  - Detecting Loaded Trajectories for Hazardous Chemicals Transportation, KDD 2022

# Presentation Assignment (The First Half)



- Please fill in the assignment sheet [\[link\]](#)
- Deadline: Sep 8, 2024

A	B	C	D	E	F	G	H	I
	Topic	Order	Paper Title	Paper URL	Venue	Year	Institution (the first one)	Presenter
1	Overview and Introduction	1	U-Air: When Urban Air Quality Inference Meets Big Data <a href="#">[This is a Sample Row!!!]</a>	<a href="#">Link</a>	KDD	2013	MSRA	Yuxuan LIANG
2	Tutorials on Deep Learning	1						
		2						
	Spatio-Temporal Data Sesning and Management	1						
3		2						
		3						
4	Cross-domain Data Fusion and Multimodal Learning	1						
		2						
		3						
5	Location Embeddings and Urban Region Profiling	1						
		2						
		3						
6	Learning Spatio-Temporal Trajectory Data	1						
		2						
		3						

# Reports + Projects



- Topic: An Open Project on Deep Learning for Human Mobility Analytics
- Team of 1 or 2 students:
  - To form team by **23 Sep. @ 23:59**
  - To decide topic by **14 Oct. @ 23:59**
  - Sending the team members to my email
  - Aim: **To produce a publishable paper & prototype by end of course**

# Reports + Projects



Design Paper (**10%**) – Deadline: **28 Oct @ 23:59**

- To write the outline of paper without results
  - To cover: objective (why this topic); review (what has been done and what new problems to solve); analysis of problem; proposed solutions (what are the innovative aspects, and why it works); possible limitation.
  - Not more than 8 pages in ACM 2-column format
- Grading consideration:
  - Cover all above points clearly with good justifications
  - Well written, clear and easy to read

# Reports + Projects



Final Paper + Codes (**30%**) – Deadline: **9 Dec @ 23:59**

- To extend design paper into a publishable paper
  - To refine what has been written
  - To include more details of systems design, implementation issues and key innovative functions of the final system
  - To include results ,ablation studies, insights and analysis.
  - Not more than 8 pages in ACM 2-column format
  - Grading criteria: whether it is ready for publication

# Reports + Projects



System and Demo (20%) – Deadline for submission of Codes: **9 Dec @ 23:59**

- Final Presentation and Demo – general
  - Cover key essence of work
  - PPT presentation to cover the usual what (what problems), why (literature review part); how (your design and innovation), and why (innovations and justifications); plus results and analysis
  - Demo: show the key innovative parts of work; to highlight main features of system
- Presentation and Demo to class
  - To present within 15 mins
  - Peer voting of top 5 works
- Final Presentation and Demo to me
  - To present within 20 mins (ppt presentation < 10 mins, demo < 5 mins)
  - QA

# Any Questions?



- From the second week, **3 papers will be presented each course**
  - I will give 90-120 mins overview and introduction of topic
  - followed by 3 presentations of 60 mins (15-min Pre + 5-min QA) each
- **Timing control for presentation will be very strict!!!**



# Thanks!

CityMind Lab



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