

A RESEARCH VISION:

# “Human Mobility Sensing and Analytics in Connected Vehicles for Social Good”

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# My Personal Journey:

## ➤ **Academia** (15 years)

- Carnegie Mellon University
  - Computer Aided Design
  - Computer Architecture

## ➤ **Industry** (15 years)

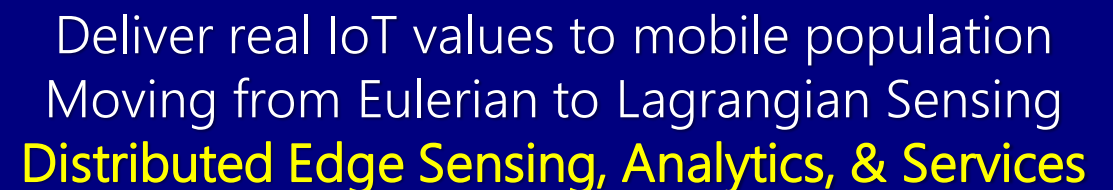
- Intel, Research Lab
  - Superscalar/Multicore Processors
- Nokia, Research Center
  - Mobile/Cloud Computing Systems

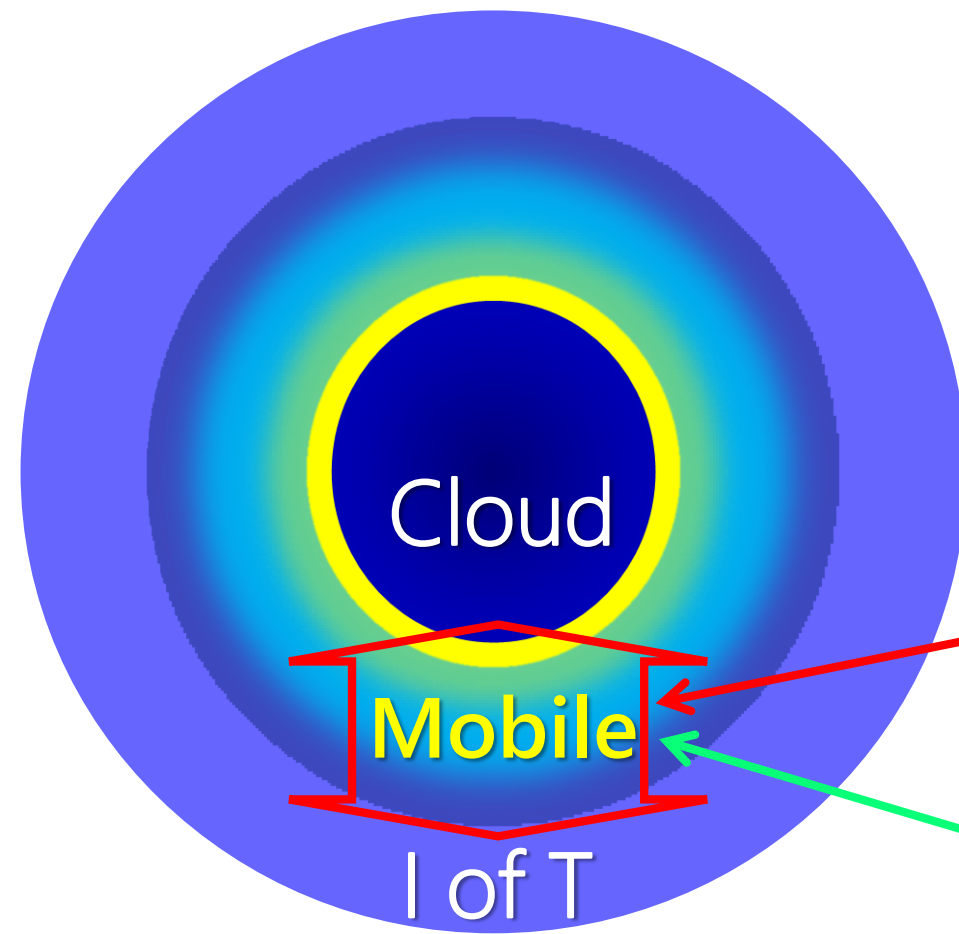
## ➤ **Academia** (2015-present)

- Carnegie Mellon University (Silicon Valley Campus)
  - Data Analytics & Societal Services
  - FCT funded CMU-Portugal Program (Prof. Joao Claro & Prof. Jose Moura)



**A Workshop Offered by the MuSyC and GSRC FCRP Research Centers**

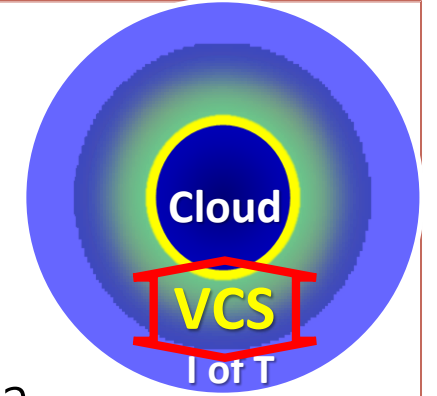




**Connected Vehicles**

**Edge Sensing & Analytics**

# ➤ Vehicular Computing Systems (VCS)



## ➤ General Purpose Programmable VCS:

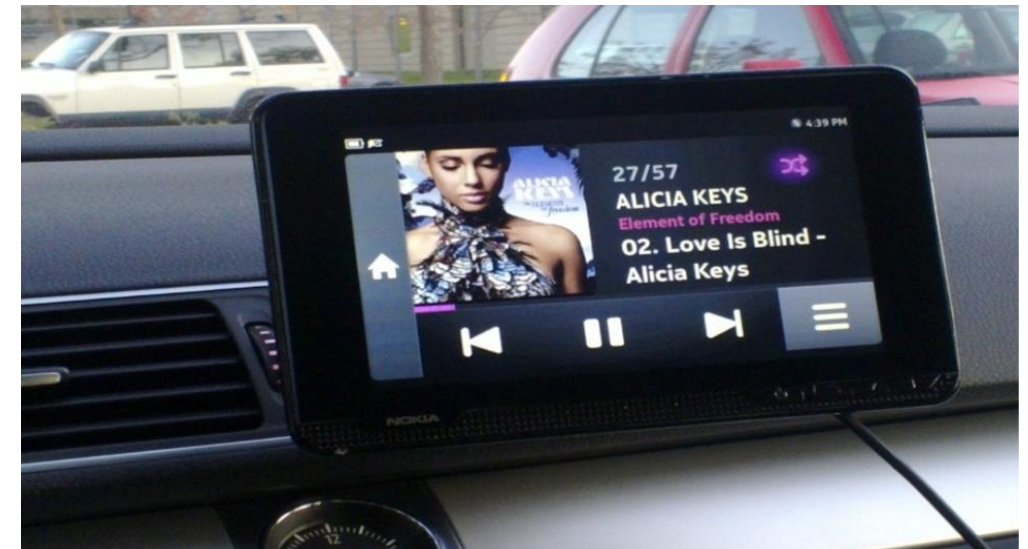
- Performance/Power Efficiency: improve from 1 GF/W to 10 GF/W will enable a Terascale ( $10^{12}$  FLOPS, TBs) mobile supercomputer with a 100W power budget.
- Extreme Form-Factor Integration: 3D TSV stacking of diverse dies: heterogeneous processors, high-BW DRAMs and SSDs, FPGA, antenna, power delivery, & cooling.

## ➤ Potential Compelling Applications:

- Mobile Cloud Edge Servers
- Edge Sensing/Analytics Platforms
- Mobile 5G Picocell Base Stations

## ➤ Anticipated Industry Evolutions:

- Special Purpose → General Purpose systems
- Vertical → Horizontal ecosystems
- Enterprise → Consumer adoptions





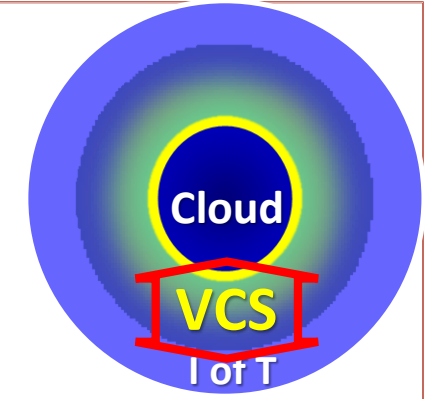
# Intel Compute Sticks as Wireless Cluster Nodes



**Intel Compute Sticks: (2015, 2016)**

Bay Trail SOC, Quad-core Atom Processor, 32GB storage, Wi-fi, BT

Skylake Core m5 Dual-core Processor, vPro, 64GB storage, Wi-Fi, BT



## ➤ VCS Research Areas:

### ➤ Wireless Cluster Interconnect

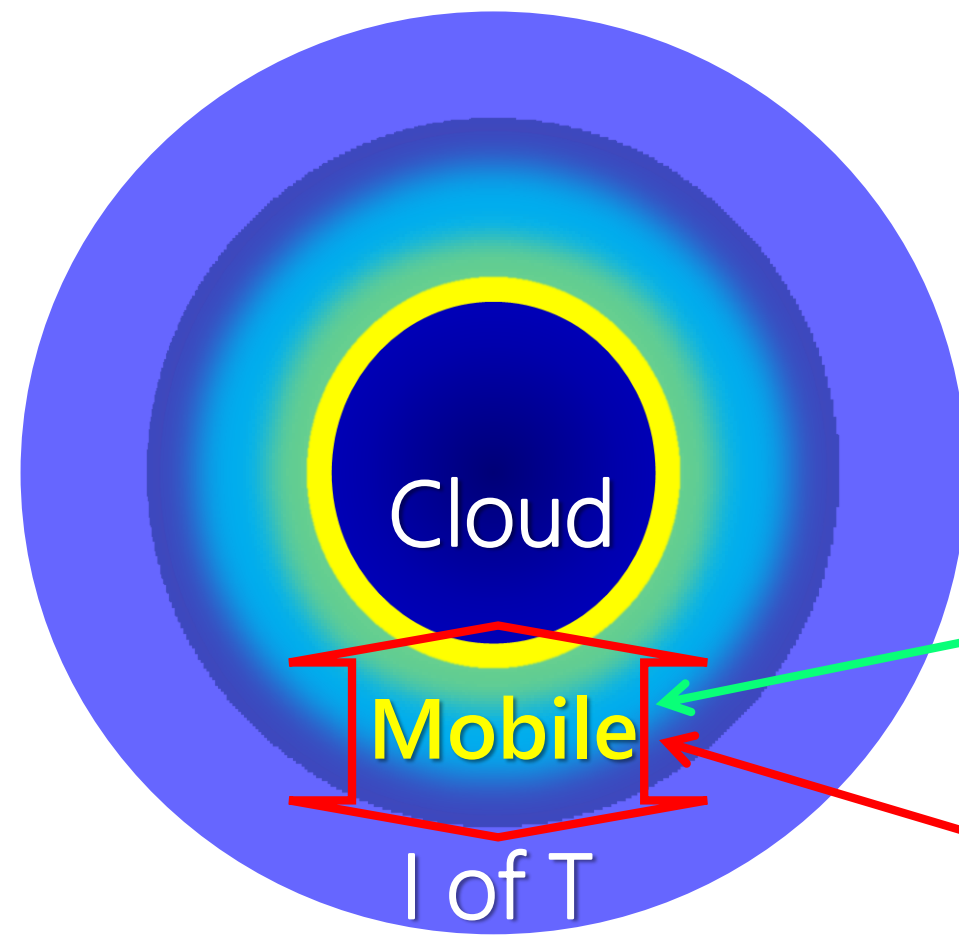
- Evolution of commodity Wi-Fi Direct for cluster interconnect.
- Tradeoffs to achieve short range, high bandwidth, and low power.
- Cluster-level antenna system as the new wireless backplane/hub.

### ➤ Compute & Storage Architecture

- Physical System Design: modular, ease of maintenance, ease of upgrade.
- Heterogeneous Computing Cores: types, mix, coherence, memory model.
- Memory/Storage (SSD) Hierarchy: new bandwidths and latencies at all levels.

### ➤ End-to-End Software Architecture

- Leverage existing cluster software systems for quick porting to wireless cluster.
- Identify potential killer apps for the VCS platform in connected vehicles.
- Edge (in-situ) sensing and analytics with seamless interface to remote cloud.

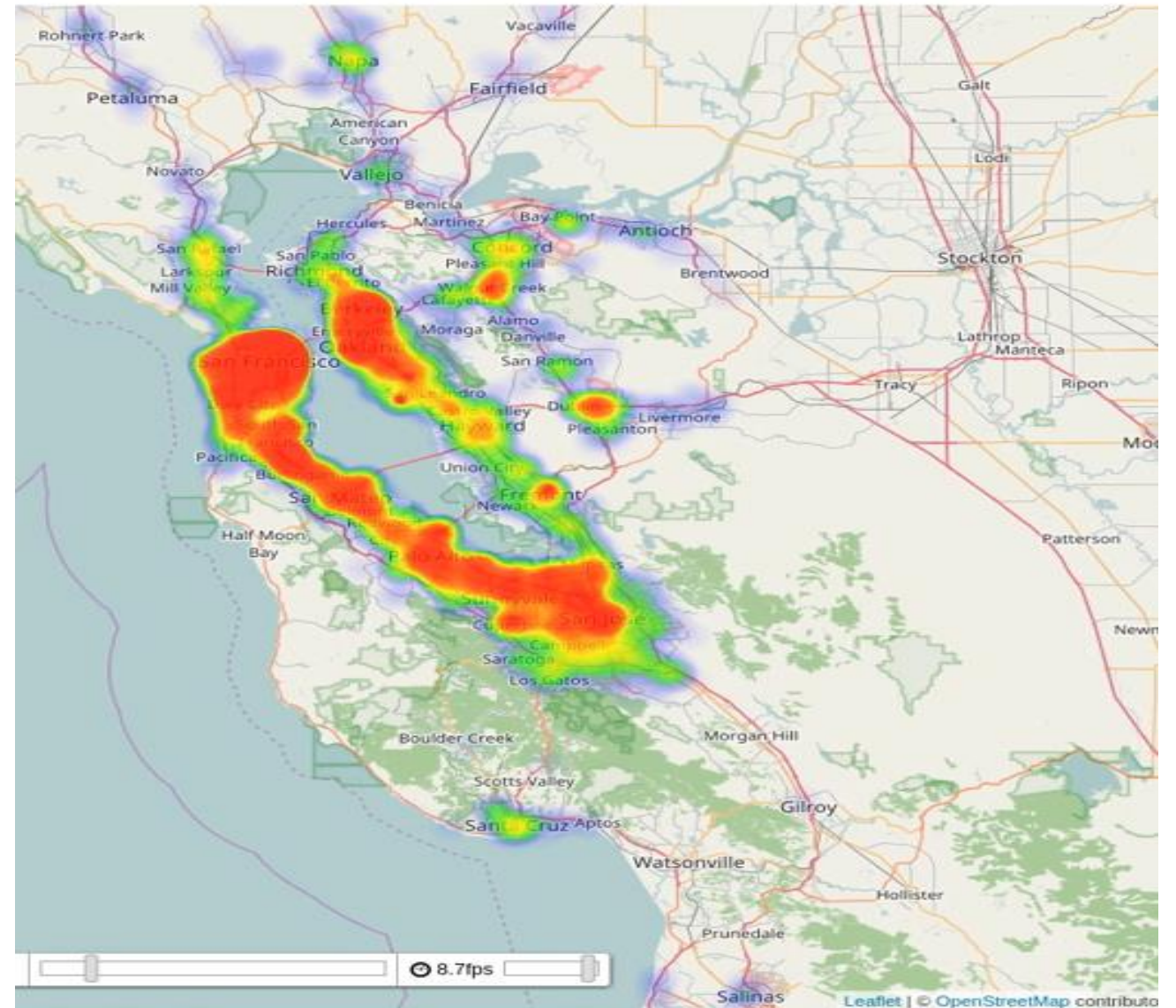
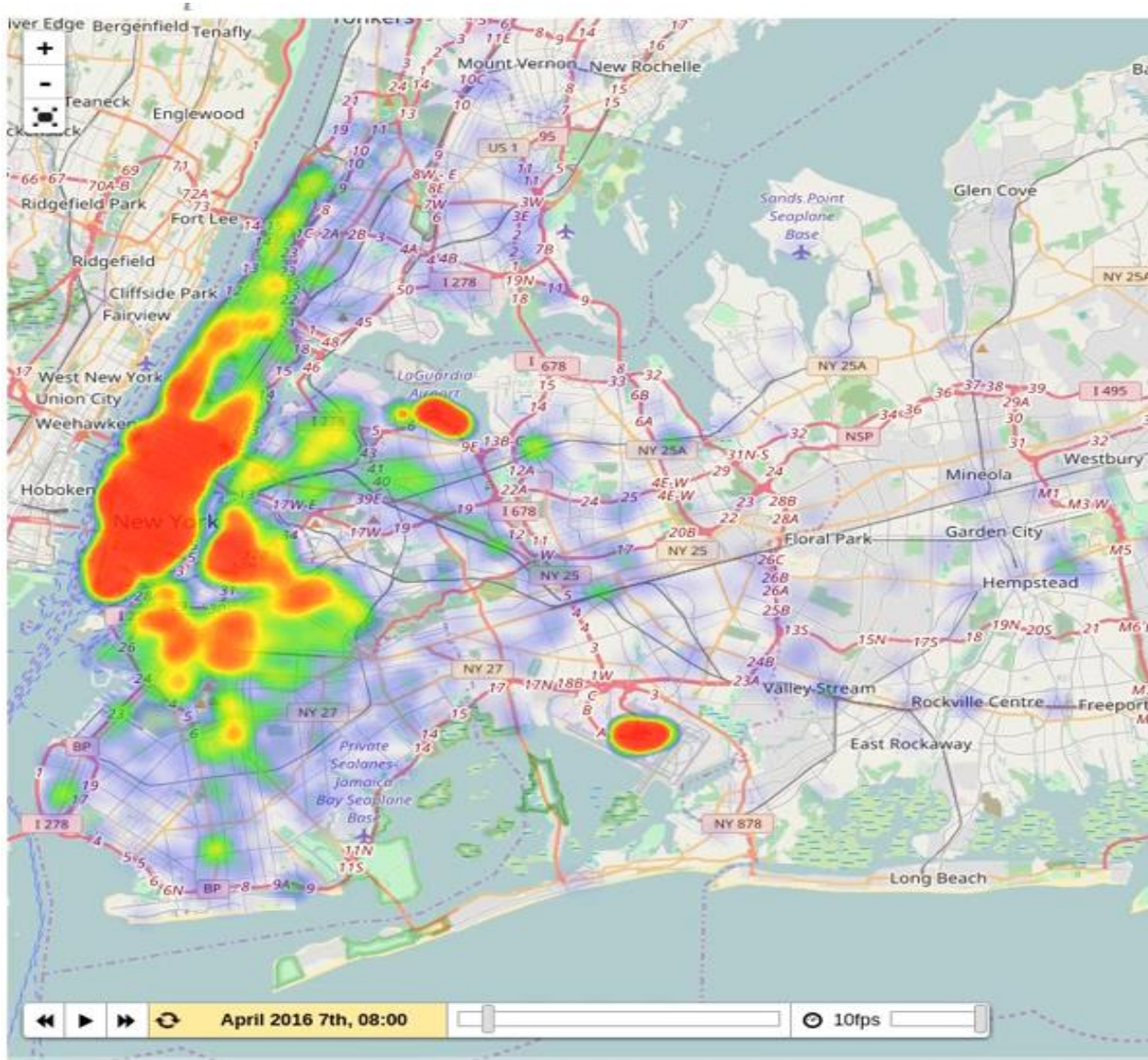




# Unprecedented Digital Landscape

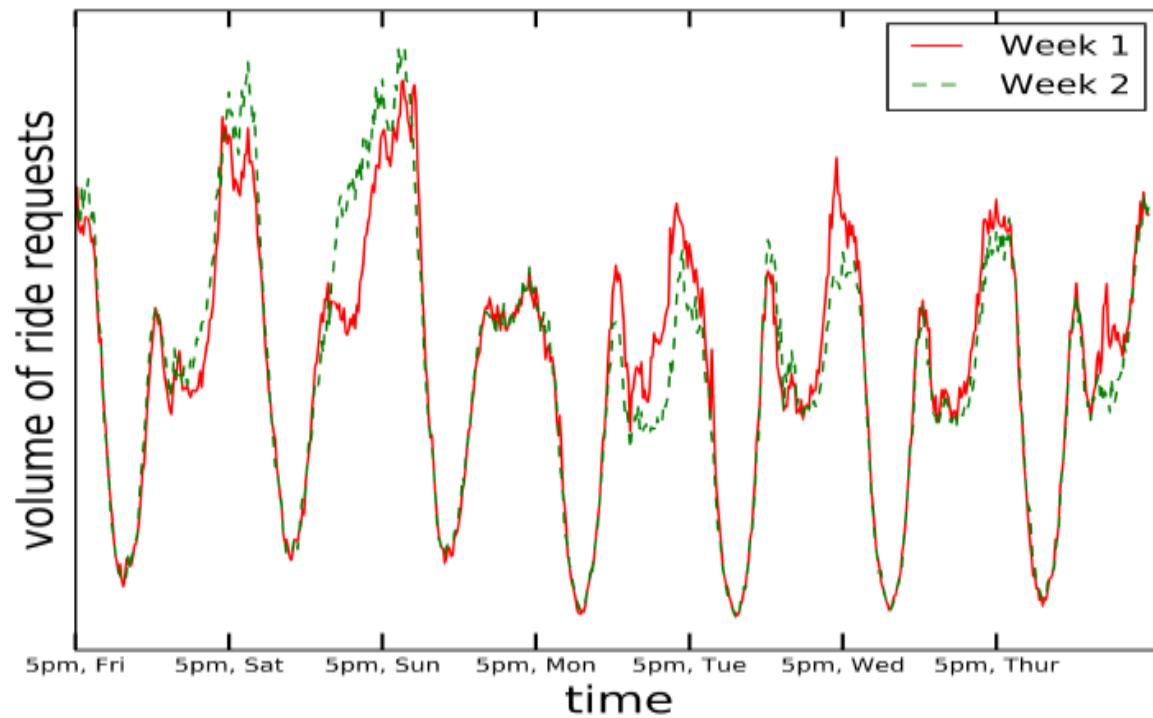
- Global coverage of cellular connectivity.
- Global availability of mobile devices.
- Global presence of ride-sharing services.
- Global problem of human urban mobility.

# Data Sets of Ride Requests (NY & SF)

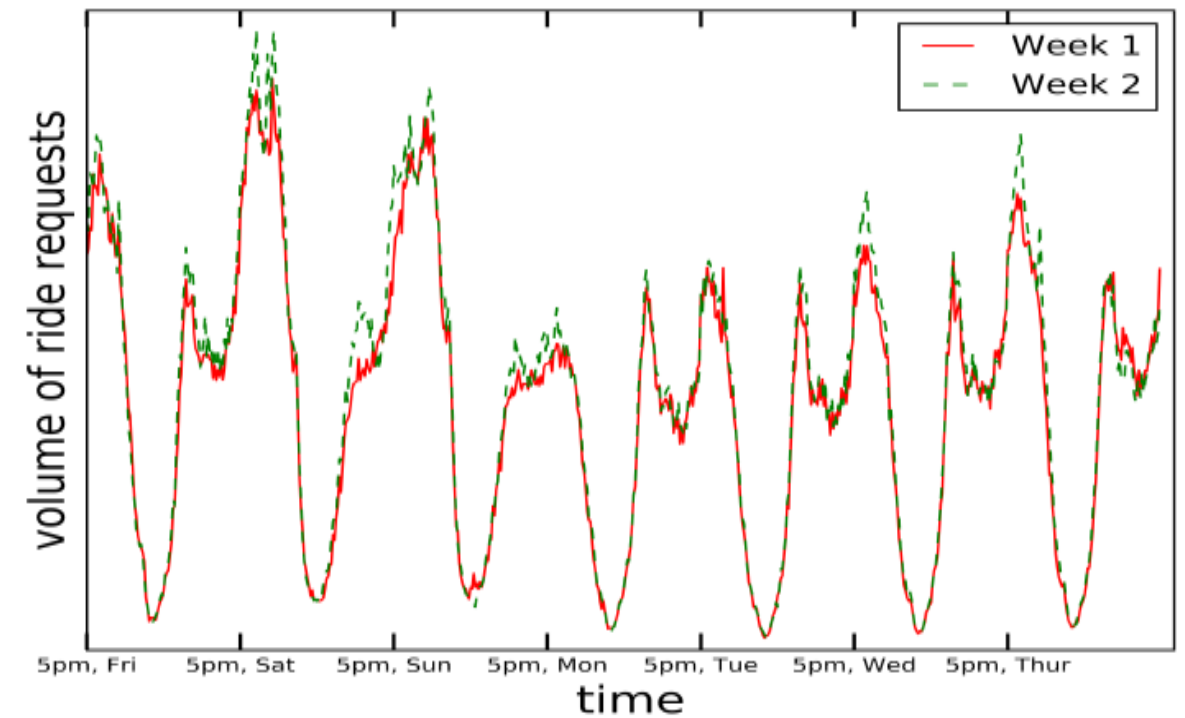




# Weekly Pattern of Ride Requests (NY & SF)

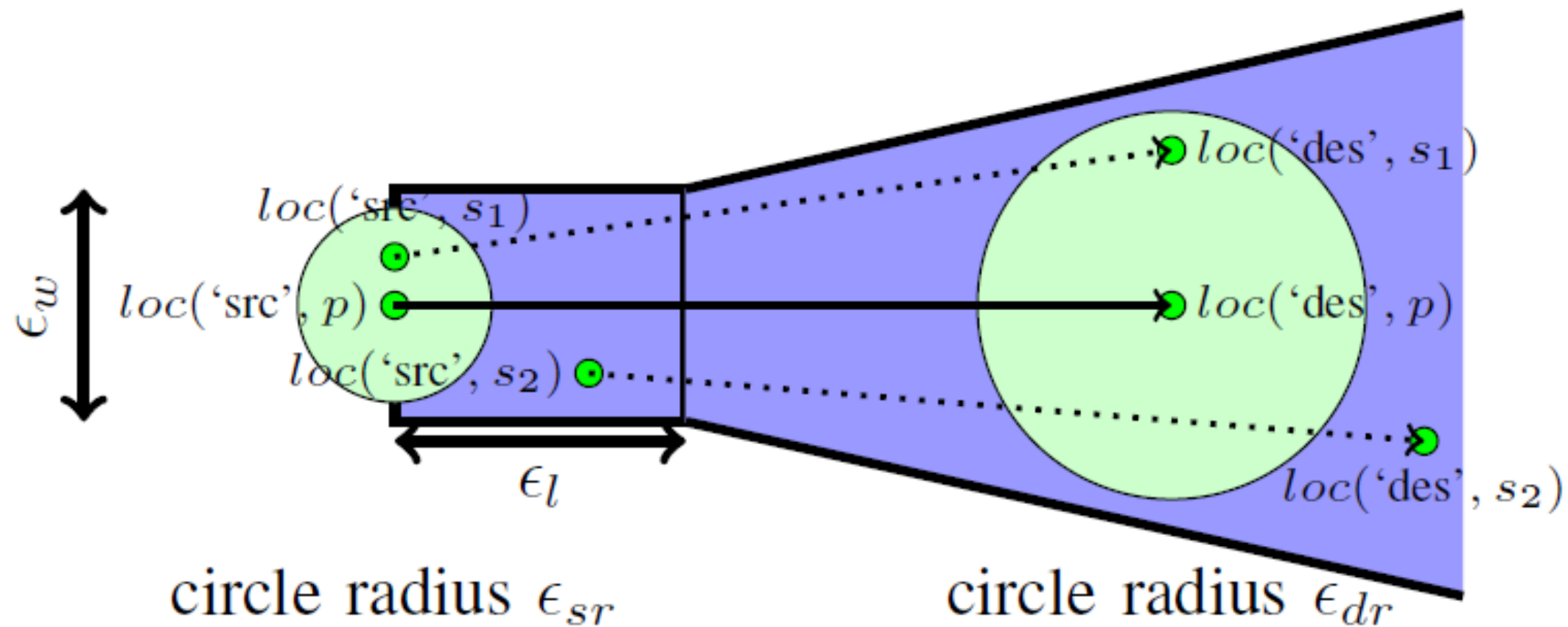


(a) New York



(b) San Francisco

# Dynamic Ride Pooling Method

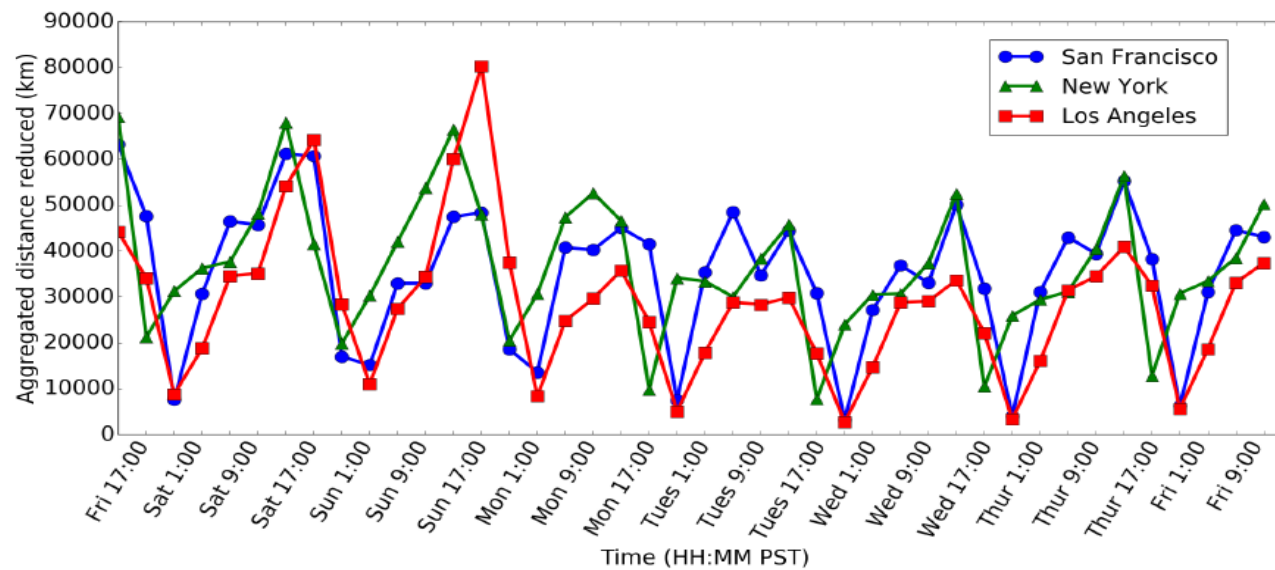




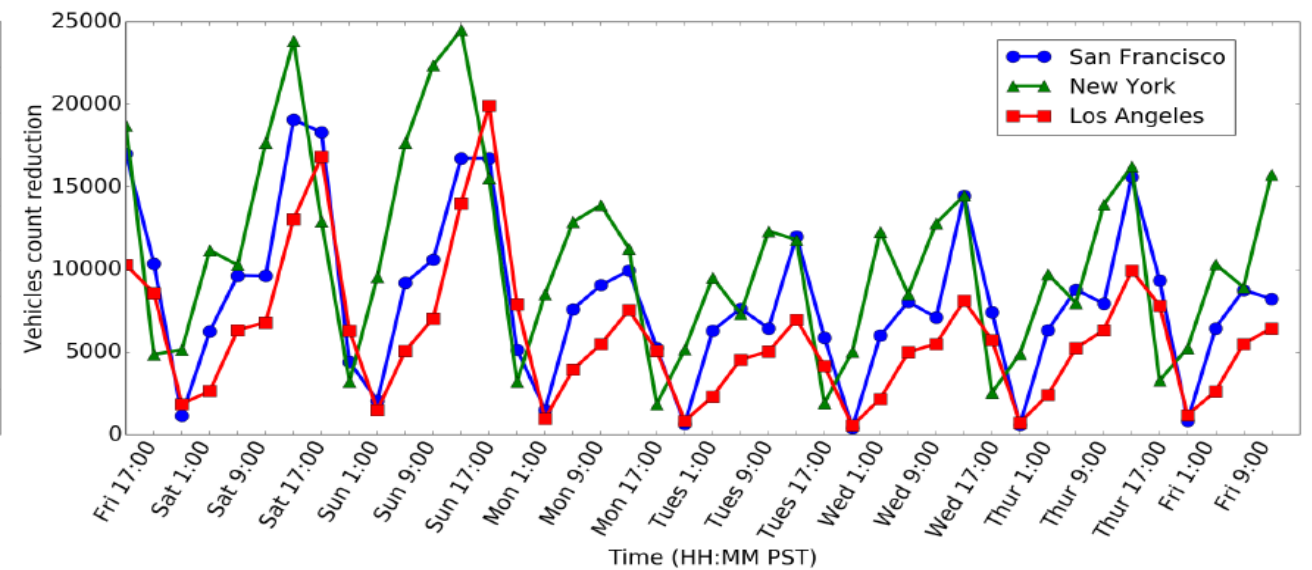
# Dynamic Ride Pooling Metrics

1. Total Travel Distance Reduction (%)
2. Total Vehicle Count Reduction (%)
3. Average Ride Request Poolability (%)
4. Average Trip Time Penalty (sec)

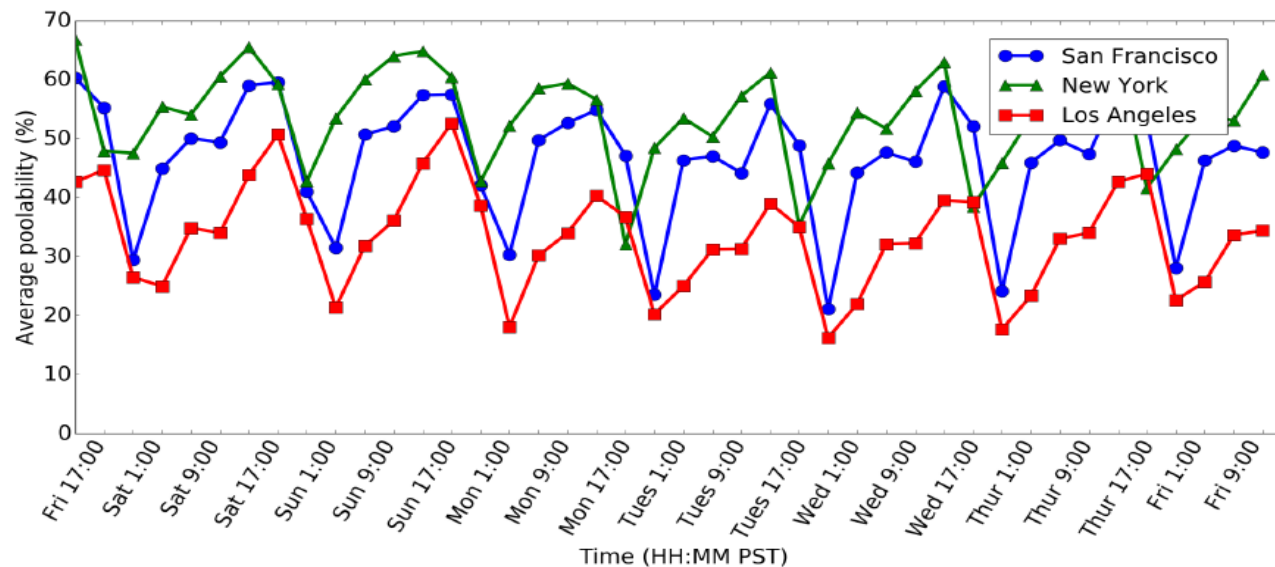
# Dynamic Ride Pooling Benefits and Cost



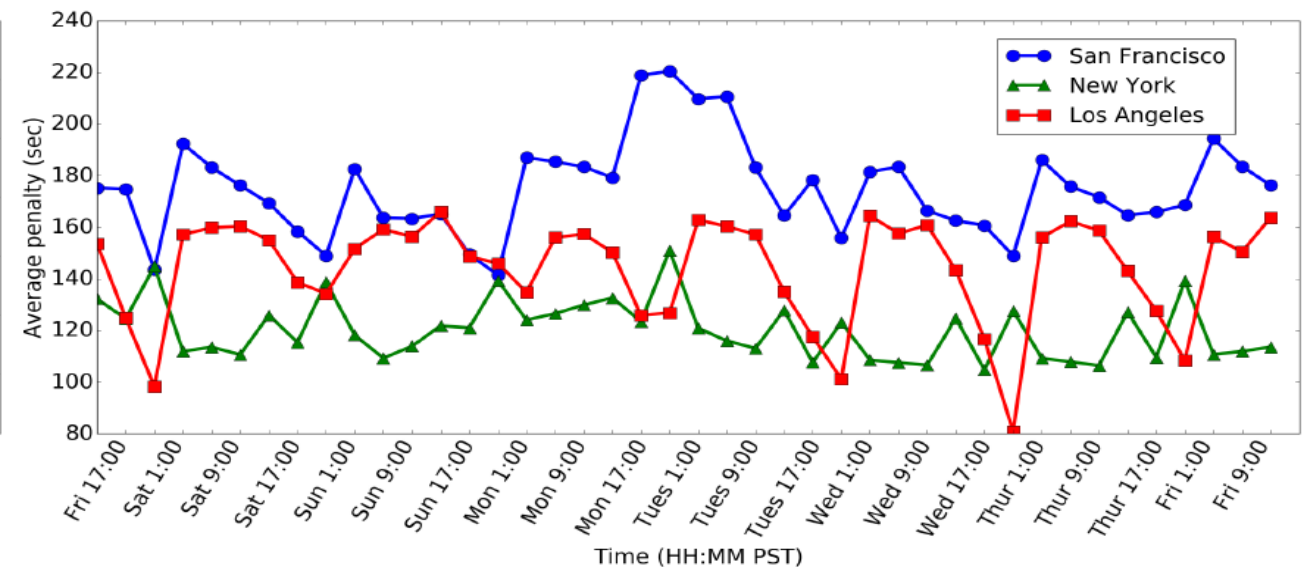
(1) Total Travel Distance Reduction.



(2) Total Vehicle Count Reduction.



(3) Average Ride Request Poolability (%).



(4) Average Trip Time Penalty (sec).

# Societal Benefits of Dynamic Ride Pooling

Total Travel Distance Saving: 15.76%

Total Vehicle Count Reduction: 31.22%

Average Rider Trip Time Penalty: 135.84 sec.

## Win-Win-Win Research Strategy:

Leverage private enterprises to achieve societal good, benefiting all parties: companies, people, and society.





## Bay Area Fair Value Commuting: Project Summary

An FTA MoD Sandbox Demonstration Project



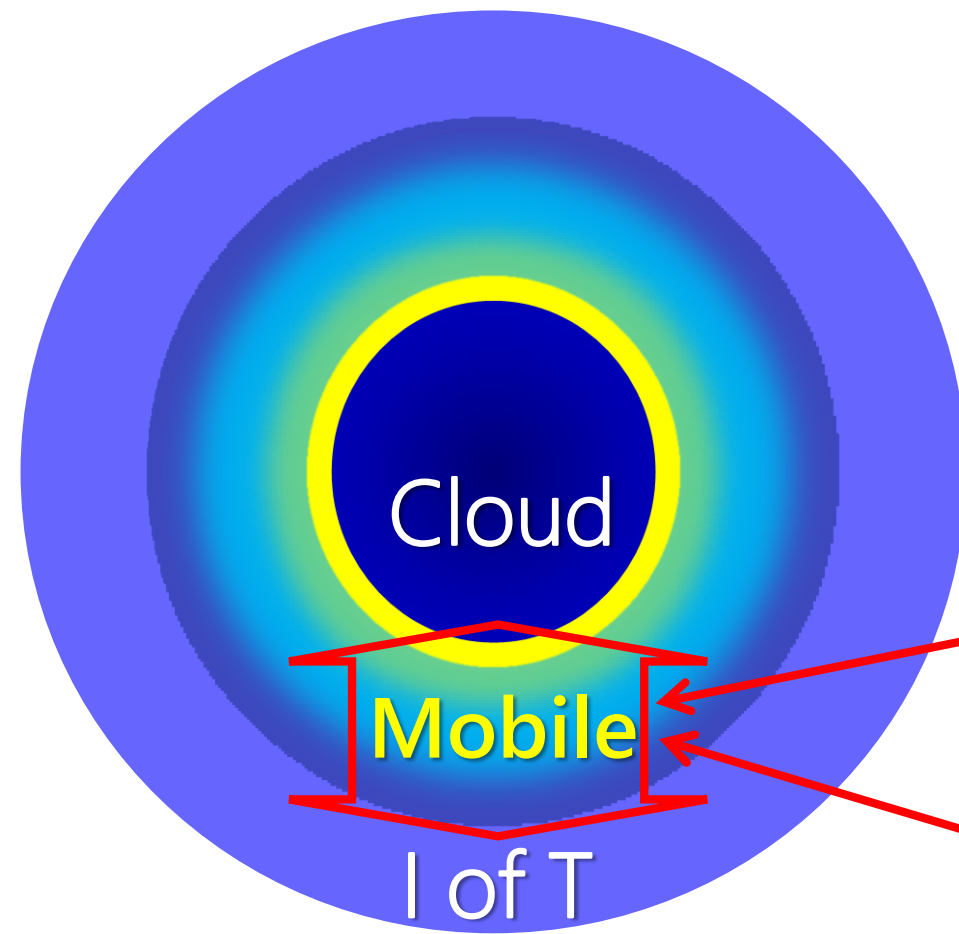
Link to this google doc: <http://bit.ly/FVCsummary>

**WHY:** In pursuit of climate protection and traffic congestion relief, state/regional/local objectives have converged for 15% per-capita VMT reduction and 2X transit/biking.

**WHAT:** In pursuit of regional objectives, our solution has the potential to reduce Bay Area SOV commute share from 75% to 50%. Our technology/policy solution is called Fair Value Commuting (FVC) and consists of five components:

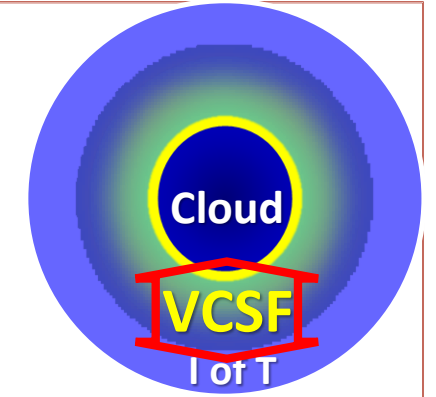






**Connected Vehicles**

**Edge Sensing & Analytics**



## ➤ Roaming VCS Fleets (VCSF)

### ➤ VCS-equipped Connected Vehicles:

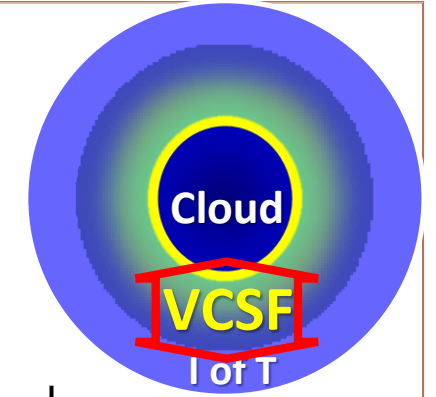
- Mobile Programmable Supercomputers: Powerful compute/storage clusters.
- Integration with Other On-board Systems: Diverse sensing platforms, including image, radar, audio, vehicle, environment etc.; Mobile 5G picocell base station.

### ➤ Mobile (Lagrangian) Sensing Platform:

- Dynamic and adaptive Lagrangian sensing.
- Naturally correlate with human mobility.

### ➤ Distributed (In-situ) Analytics Platform:

- Facilitate highly distributed local data analytics in real time.
- Enable distributed continuous learning for deep learning models.
- Provide secured, local, low latency: sensing, analytics, and services.



## ➤ VCS Fleets Research Ideas:

### ➤ Real-Time Environment Sensing and Processing

- Highly mobile and autonomous real-time data collection, analytics, and inferences, without reliance on some remote cloud infrastructure.
- Example: real-time traffic and street views, human mobility monitoring.

### ➤ Localized Cloud Services for Mobile Population

- Context aware cognitive assistance; Continuous map generation and update.
- Mixed reality live cyber habitat with intuitive spatial and temporal navigation.

### ➤ Mobile, Dynamic, Adaptive Cloud Edge Infrastructure

- A roaming VCS Fleet can become a highly distributed platform/infrastructure for facilitating city-scale Sensing, Analytics, and Services.
- Trusted VCS Fleets can become a new global-scale computing and communication infrastructure to enable a new wave of innovations and services.

# Revisit “City Scene” Project [Nokia, 2010-2012]

- Natural augmentations of urban imagery require an understanding of the 3D structure of the scene
- Semantic segmentation of the model enables intuitive touch UI and content placement
- Accurate, well registered geometry can be used for photorealistic image-based rendering of transitions



In Nokia App Store  
Oct 2011 (for N9)

Available on WP8 as  
part of Nokia Maps



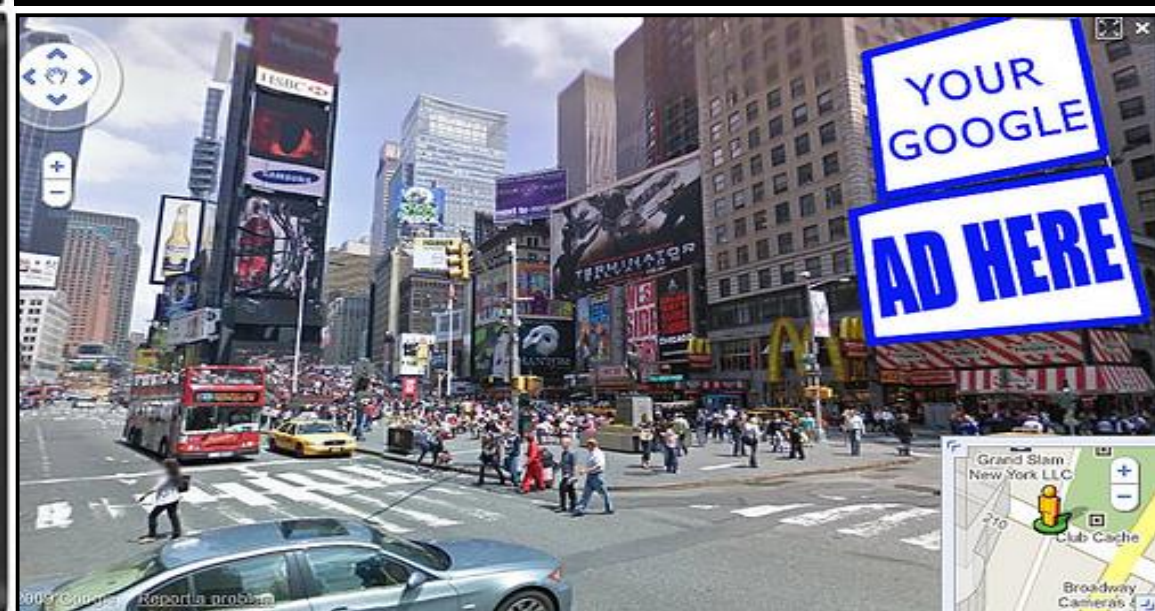
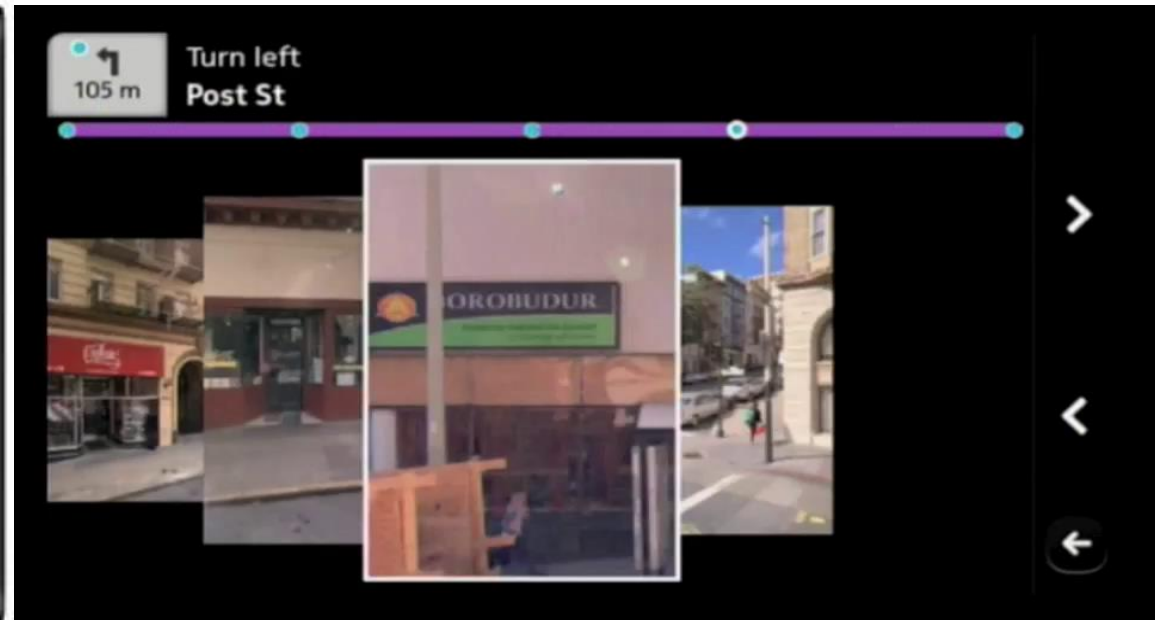
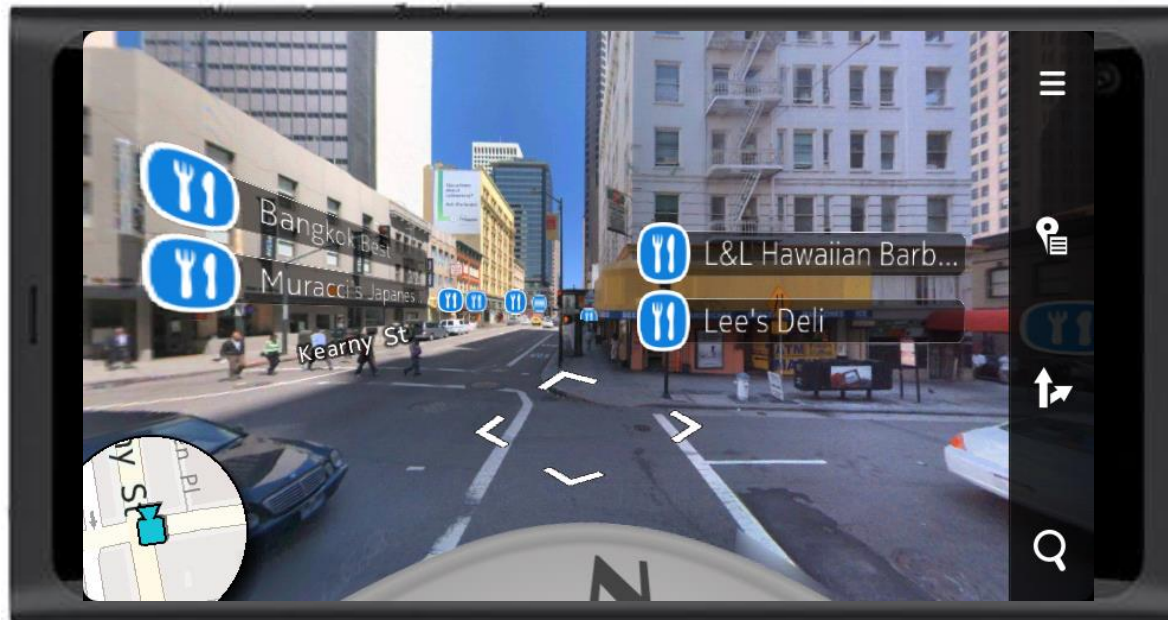
# "City Scene" Data Set Collection & Processing

- Data for downtown San Francisco
- 23 drives
- 180,000 panoramas
- More than 6TB of LIDAR data



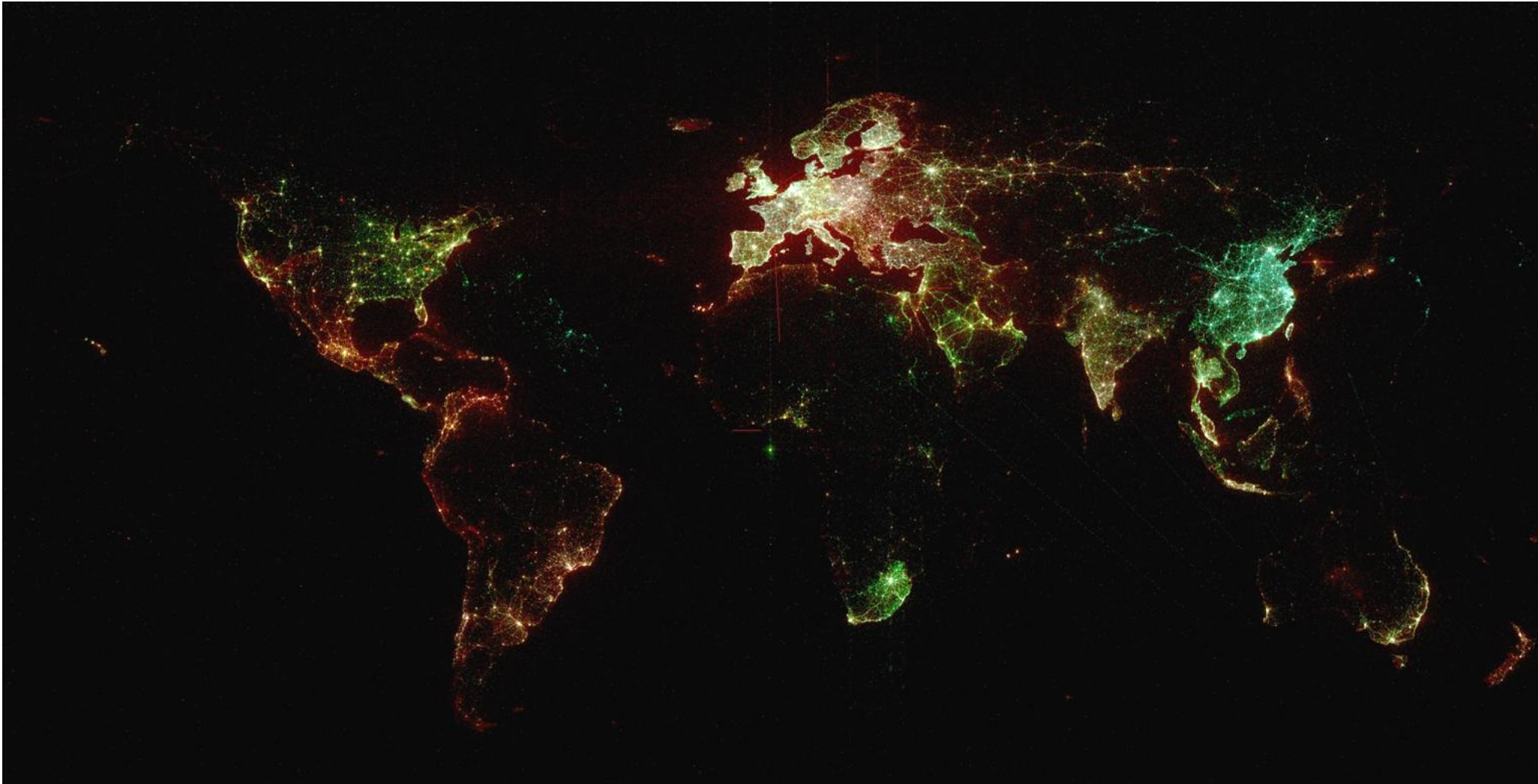


# “Live City Scene” → New 3D Cyber Habitat ?





# A New Global-Mobile Digital Infrastructure



Research Tool for Computer/Data/Social Scientists