High-resolution Ubiquitous Traffic Sensing with Autonomous Vehicles

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Autonomous Vehicles

Autonomous Vehicles can:

- Improve safety and mobility
- Reduce fuel consumption and emission
- Redefine the civil infrastructure systems
  - Intersections
  - Parking spaces
  - Public transit systems

A Missing Piece in Traffic Management with AVs

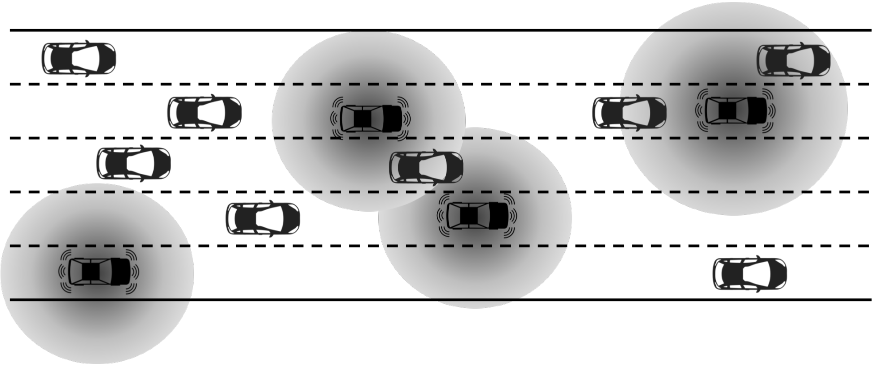
AVs as controllers:

- Mixed traffic (AVs + Human-driven vehicles)
- Traffic state information is still required as input for management models
- Conventional traffic sensing methods: fixed traffic sensors
- Traffic state data: low-frequency and sparse

AVs as moving observers

Our proposal:

- AVs: sensors, moving observers
- Perception capabilities → Traffic sensing ability
- Cost-effective



Comparison with other moving observers

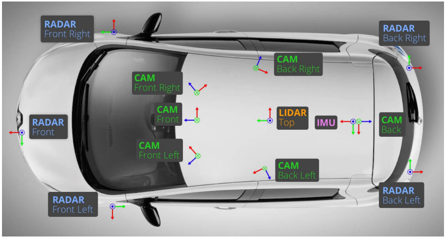
New challenges to traditional Traffic State Estimation (TSE) methods:

- **Originally defined moving observer.** Counting the vehicles that overtake and are overtaken by the moving observer.
- **PVs (Probe Vehicles).** The PVs refer to all the vehicles that can be geo-tracked. Speed estimation ✓, density estimation ✗.
- **UAVs (Unmanned Aerial Vehicle).** Scan a continuous segment of road or even the entire network ✓, costly ✗
- **AVs.** Can be geo-tracked. Scan a continuous segment of road or even the entire network ✓, cost effective ✓, constrained vision ✗

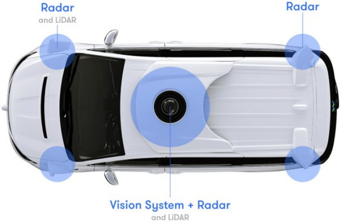
Research Question

In the mixed traffic networks, especially with **low AV market penetration rate**, is it possible to estimate the high-resolution **traffic states**, namely flow, density and speed using the massive data collected by AVs?

Sensors on AVs



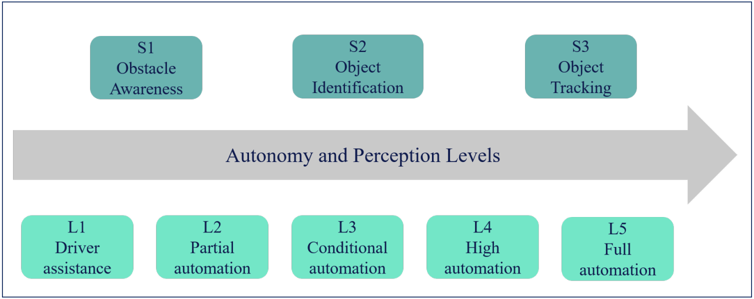
(a) nuScenes



(b) Waymo

Sensors	Usage	Range
Camera	Surrounding vehicle detection/tracking, lane detection	20 ∼ 60 meters
Stereo vision camera	Surrounding vehicle detection/tracking, 3D mapping	20 ∼ 60 meters
LiDAR	Surrounding vehicle detection/tracking, 3D mapping	30 ∼ 150 meters
Long-range radar	Preceding vehicle detection	150 meters

Levels of Perception



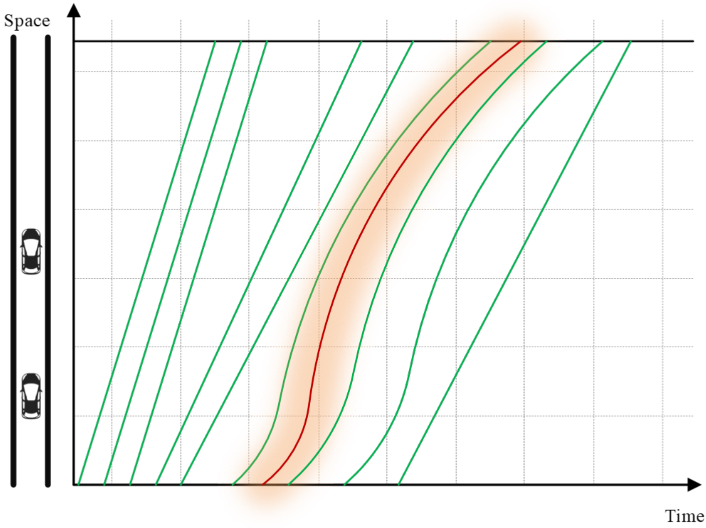
- S_1: tacking the preceding vehicle, adaptive cruise control (ACC).
- S_2: detecting and locating surrounding vehicles.
- S_3: tracking every single vehicle in the detection area, hence the location and speed of each vehicle is monitored.

Traffic Sensing Framework

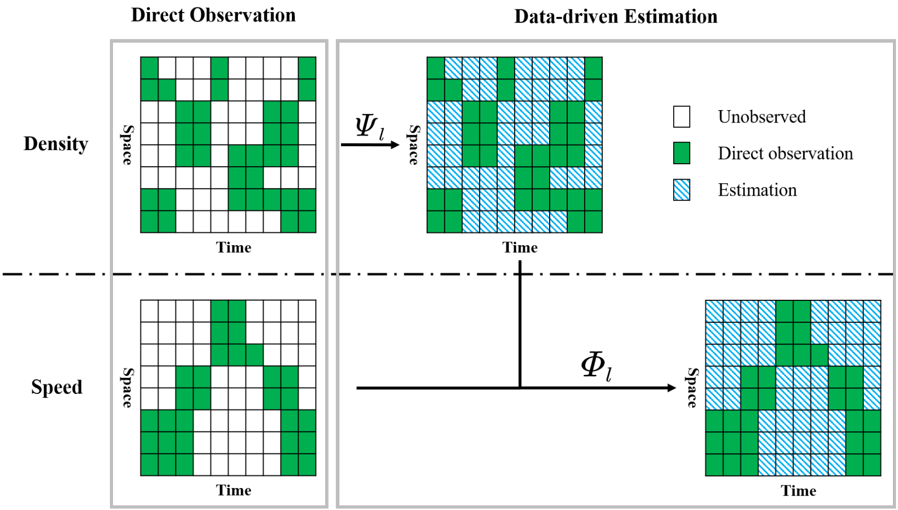
Two-step Framework:

- Direct Observation by AVs
- Data-driven estimation for unobserved traffic states

Time-space region

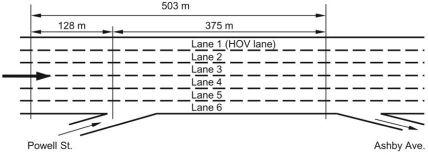


Traffic Sensing Framework

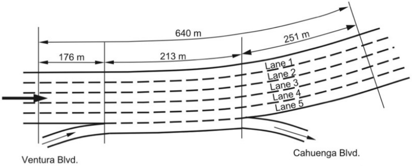


Numerical Experiments

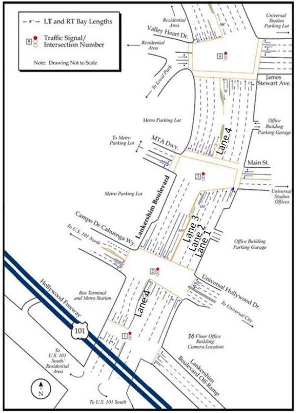
The Next Generation Simulation (NGSIM) dataset



I-80



US-101



Lankershim Boulevard

Numerical Experiments

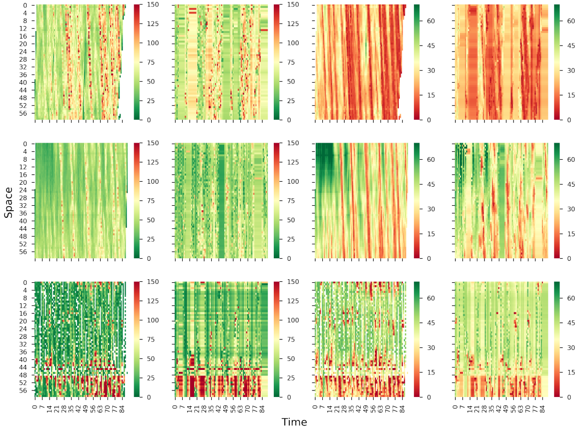
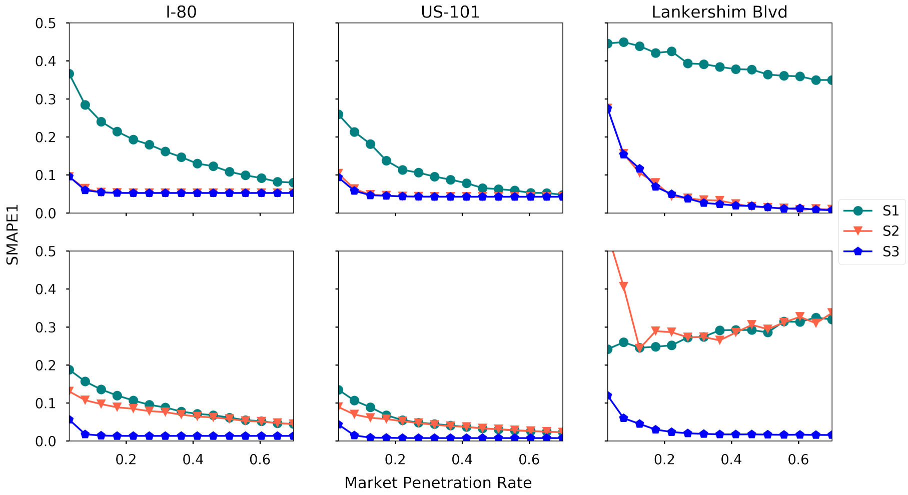
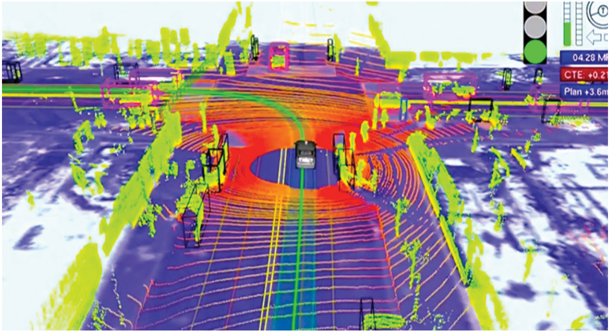


Figure 3: True and estimated density and speed for lane 2 (first row: I-80, second row: US-101. third row: Lankershim Blvd; first column: ground true density, second column: estimated density, third column: ground true speed, fourth column: estimated speed; density unit: veh/km, speed unit: km/hour).

Numerical Experiments



Community Sensing



- Any object in public space can be detected: vehicles by vehicle classifications, parked vehicles, pedestrians, cyclists, signage
- On-street parking management, curb management, infrastructure inventory and management
- Promote collaborations between public agencies and private sectors

Takeaways

- *Moving observer:* AVs are the moving observers on the roads.
- *Perception levels:* The sensing power of AVs can be categorized into three levels of perception based on autonomy levels.
- *Strong AV sensing power*: High estimation accuracy can be achieved with even 5% market penetration rate.
- *Community sensing.* Ubiquitous sensing of all objects.

Thanks! Questions and comments?

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