Control of vehicular traffic flow via low density autonomous vehicles

Benedetto Piccoli
CNS-1446715

Benjamin Seibold
CNS-1446690

Jonathan Sprinkle
CNS-1446435

Daniel Work
CNS-1446702

The transportation technology landscape

- Classical estimation pre ~2010
  - Dedicated sensors at fixed locations
  - Accurate but sparse coverage
- Modern estimation today
  - Mobile sensing via GPS
  - 1-5% penetration provides global sensor coverage


[Car Connection]


[Yahoo]

- Classical control today
  - Dedicated actuation at fixed locations (e.g., ramp metering)
  - High infrastructure cost
- Future control ~2020+
  - Mobile actuation via autonomous vehicles
  - What can be done when 1-5% of vehicles are autonomous?

[wikimedia]


[Google]

What to expect from a small number of autonomous vehicles (AVs)

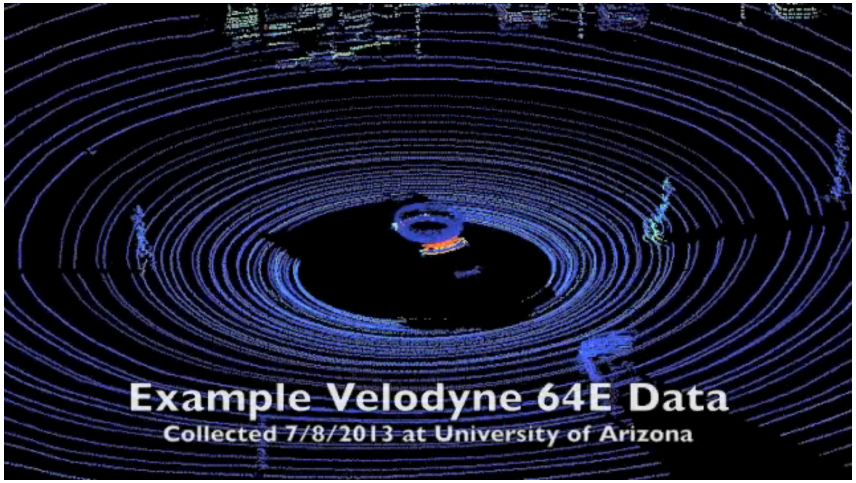
- AVs might not eliminate traffic congestion
  - As long as demand exceeds supply…

- AV's can improve fuel efficiency of *all* drivers
  - Prevent/eliminate dynamically arising traffic waves
  - Locally slow traffic, effectively acting as a variable speed limit without constructing additional infrastructure

Key CPS challenges

- Modeling new traffic dynamics
  - Mix of humans and AVs
  - Micro (Avs)–macro (humans)
- Estimating traffic state via AVs
  - New sensors and data streams
  - New traffic dynamics to track
- Developing control strategies
  - Drive with small deviations from humans, but with large benefits
  - Real-time implementation
- Closing the loop in field experiments
  - Implementable on AV platforms
  - Verification of safety constraints


Arizona autonomous vehicle



And expertise to address them

- Temple (Math)
  - Traffic flow modeling
  - Computational methods



- Illinois (CEE)
  - Estimation
  - Traffic engineering

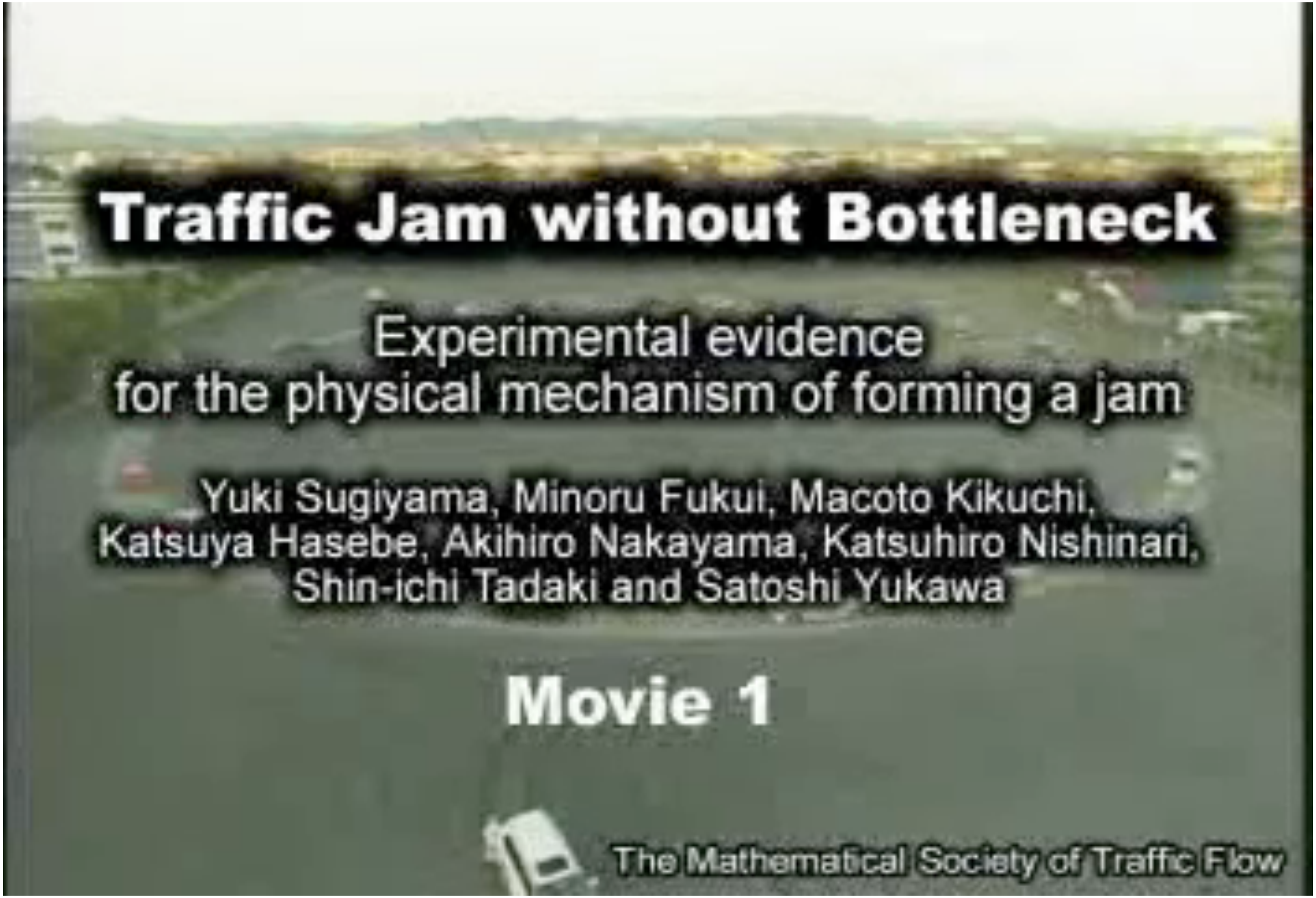

- Rutgers (Math)
  - Mathematical modeling
  - Control theory


- Arizona (ECE)
  - CPS verification and validation
  - Autonomous vehicle development


Stop and go waves generated on freeways

[D. Helbing]

No bottlenecks necessary (human generated)



[Sugiyama et al]

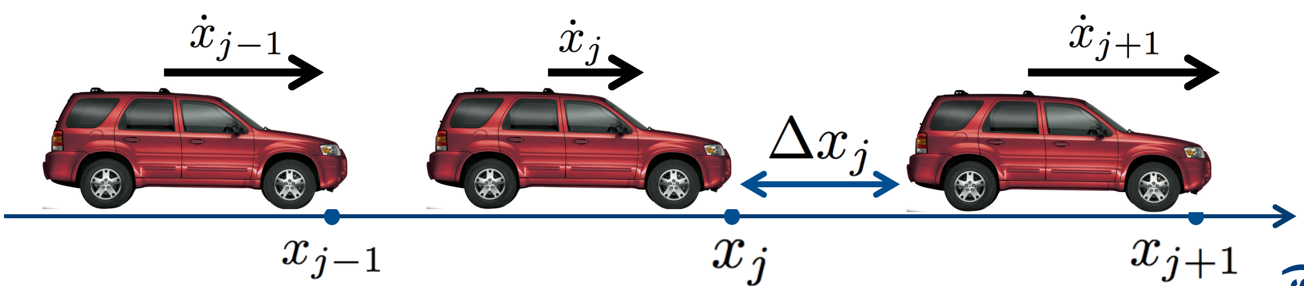
Building a virtual testbed of human drivers

- Model of human drivers
  Acceleration of vehicle j:

$$\ddot{x}_j = a \cdot \left(V\left(\Delta x_j\right) - \dot{x}_j\right) + b \cdot \frac{\dot{x}_{j+1} - \dot{x}_j}{\Delta x_j^2} + \text{noise}$$

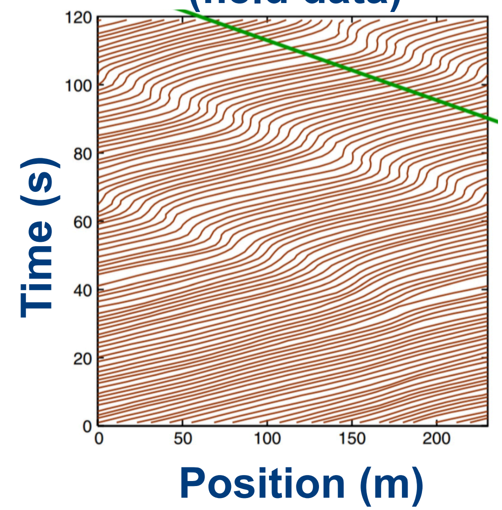
relax towards optimal velocity

relax towards leader's velocity

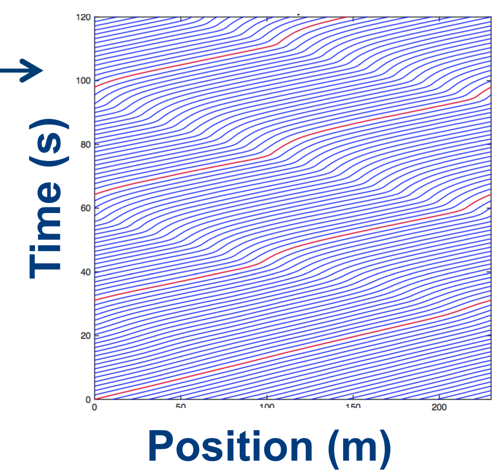


- Calibrated to match experiment
  - Wave speed & growth of waves
  - Average vehicle velocities

Vehicle trajectories (field data)



Vehicle trajectories (simulation)



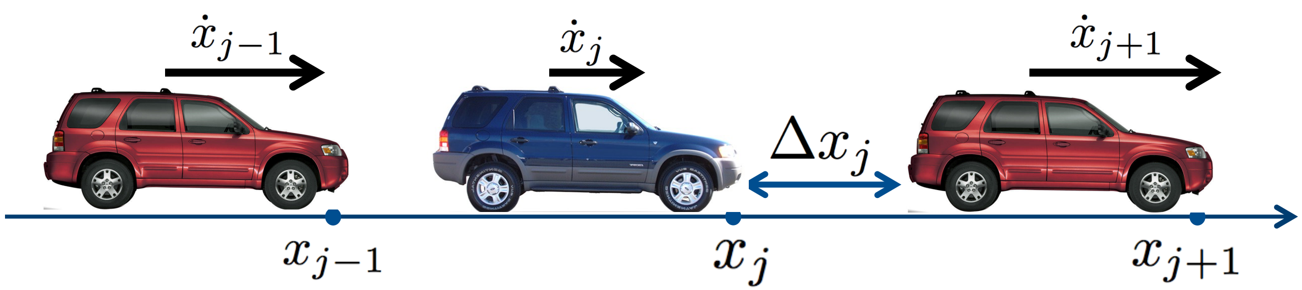
Building a virtual testbed with an AV (first steps)

- Model of an autonomous vehicle

  Acceleration of vehicle j:

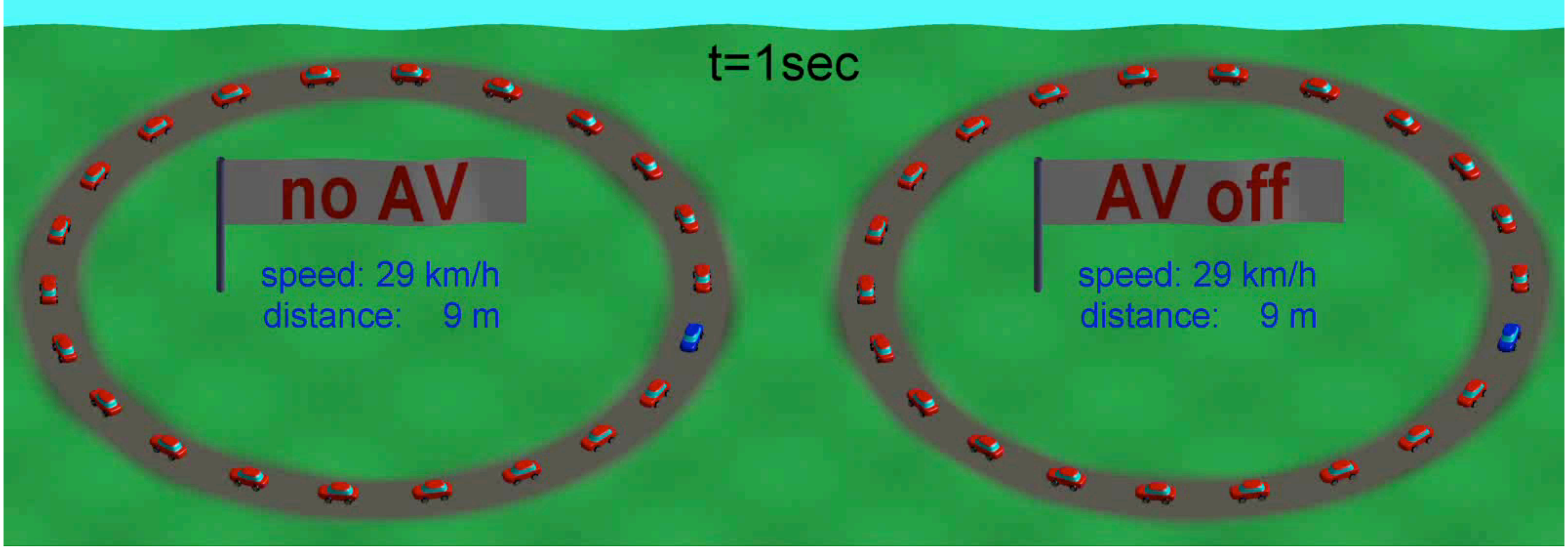
$$\ddot{x}_j = a \cdot \left(V\left(\Delta x_j\right) - \dot{x}_j\right) + b \cdot \frac{\dot{x}_{j+1} - \dot{x}_j}{\Delta x_j^2} + c \cdot \left(u_{\mathrm{eq}} - \dot{x}_j\right)$$

relax towards optimal velocity	relax towards leader's velocity	relax towards equilibrium velocity



- Small deviations from human driving
- Equilibrium velocity must be estimated from human driven vehicles

Virtual testbed in action

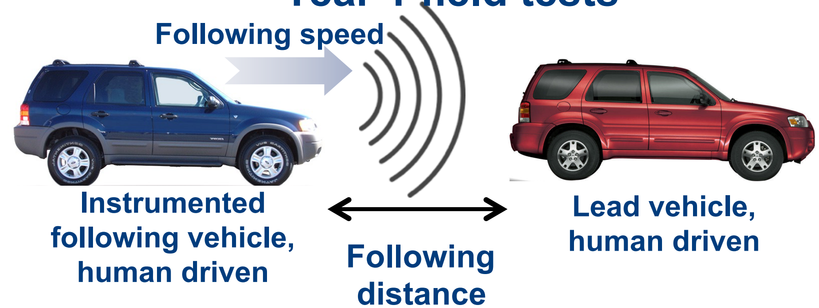


- A single autonomous vehicle
  - Eliminates the stop and go wave
  - Stabilizes the flow & thus increases throughput
- Next steps
  - Controls implementable on an AV
  - Mixed PDE (human drivers) – ODE (AV) controllers

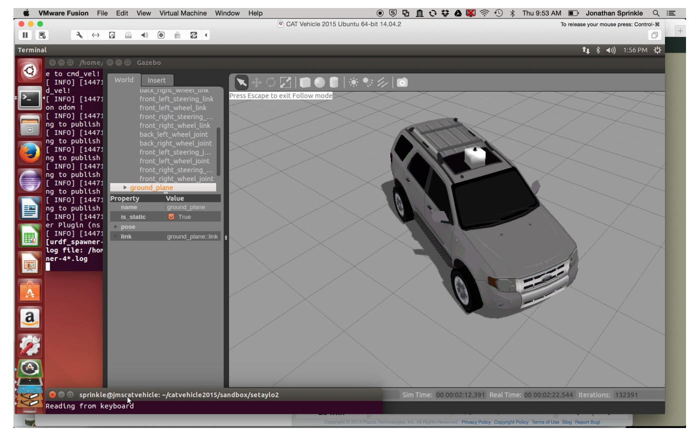
The field tests: Informing and validating the controls

- 2015: data collection
  - Instrumented vehicle, human driven
  - Human model calibration
- 2016: hybrid testing of preliminary control strategies
  - Multi-vehicle tests
  - Realistic communication delays
- 2017: ring road field test
  - Prevent / remove waves in ring road experiment with single AV

Year 1 field tests



Year 2 field tests



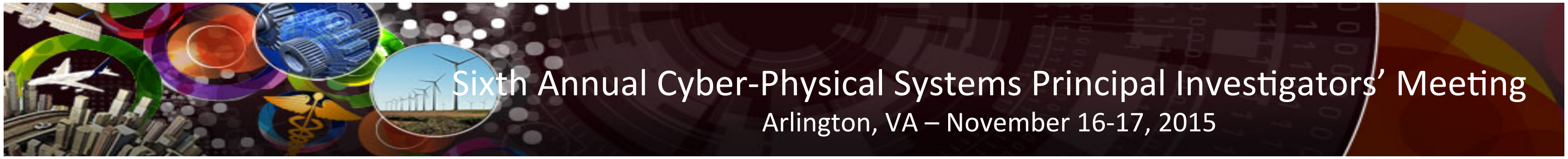
The AV: Down to the wires and back again

- 2008 Ford Escape Hybrid
- Actuated by Torc Robotics
- CAN bus reader with dedicated CompactRIO for control inputs
- 1.2kW power supply based off the Hybrid batter
- Safety features
  - Pause/stop modes for safety
  - Emergency-stop: normally open held closed
  - Dead-man’s switch: executes e-stop when no message received in time frame

Testbed: Over-sampled and over-logged

- 2 MILSPEC machines with dedicated handling for
  - ROS whitepages
  - GPS/INS
- Logging of data to TB++ HDD arrays that rotate out old logs if not claimed
- Dedicated interaction to Velodyne sensor
- 12-18 V DC power supply with 8 output ports (all at same V_0)
- UPS for clean power while driving (uh, clean "ish" power)

Car following using only a smartphone



Project summary: Control of vehicular traffic flow via low density autonomous vehicles (AVs)

Challenge:
- Few AVs will be present in largely human driven traffic
- How to control the traffic using a small number of AVs to reduce fuel consumption of all vehicles?

Solution:
- Verifiably controlling traffic with a small number of AVs existing in the flow
- Controllers drive with small but important distinctions from humans

From stop and go traffic

With all human drivers

To smooth, efficient flow

With human drivers + few autonomous vehicles

Scientific Impact:
- mixed human & AV traffic
  - modeling
  - sensing
  - estimation
  - control
  - field experiments

Broader Impact:
- Fuel consumption reductions by up to 15% of human driven traffic
- Traffic control without dedicated physical control infrastructure
- Applications to control of flows with few mobile actuators

Benedetto Piccoli (Rutgers; CNS-1446715)
Benjamin Seibold (Temple; CNS-1446690)
Jonathan Sprinkle (Arizona; CNS-1446435)
Daniel Work (Illinois; CNS-1446702)