Mixed-autonomy traffic

IEEE UPP Leaders Summit

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Optimization & algorithms

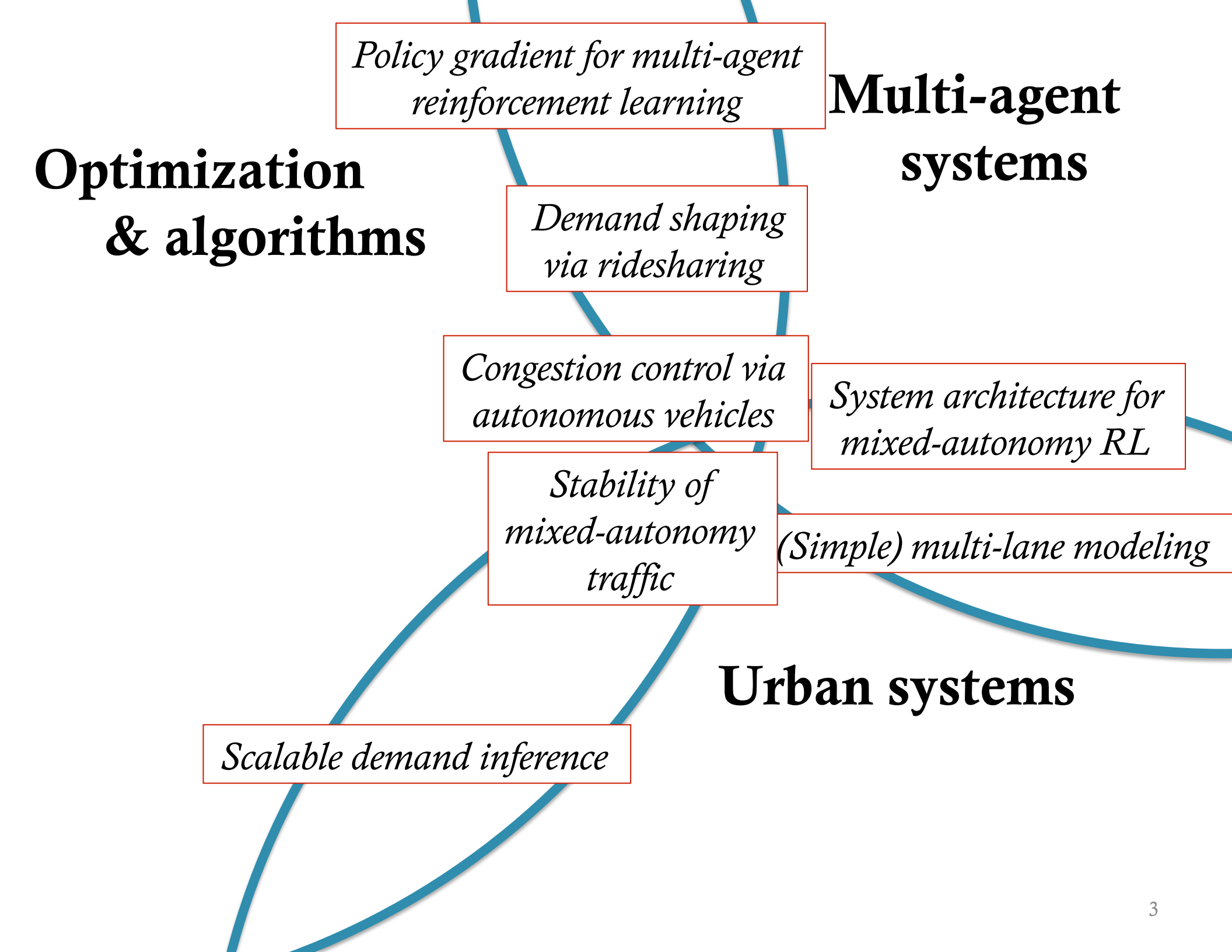
Convex optimization
Combinatorial optimization
Machine learning
Control theory
Reinforcement learning

Multi-agent systems

Modeling framework
Goals & incentives
Learning

Urban systems

Mobility
Energy, water, waste
Urban planning
CityOS, IoT

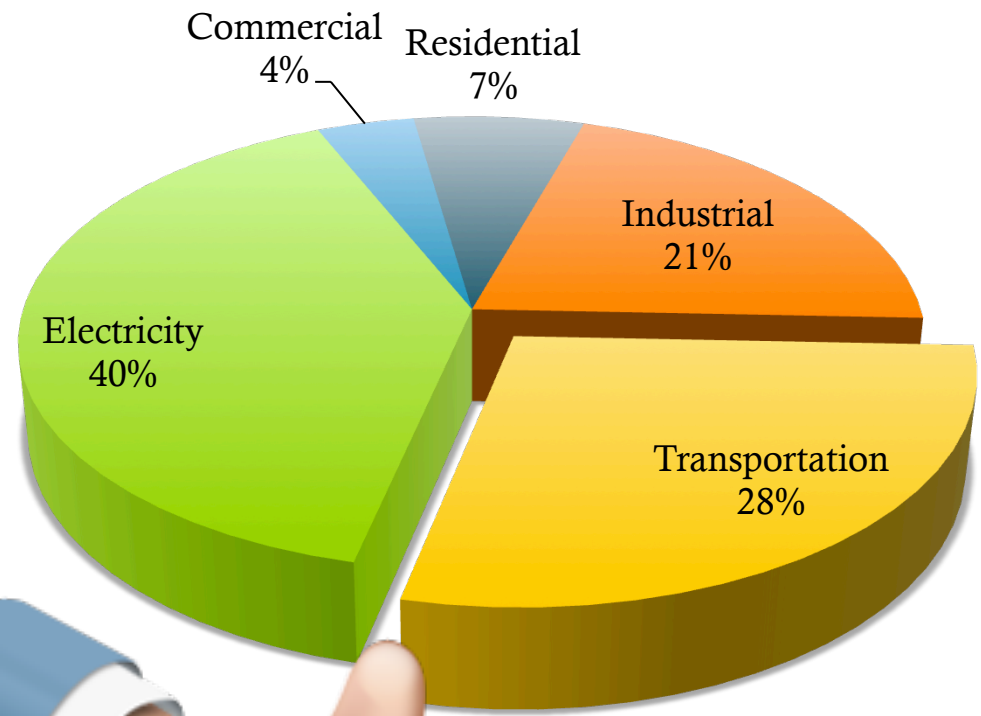

Policy gradient for multi-agent reinforcement learning
Multi-agent systems
Optimization & algorithms
Demand shaping via ridesharing
Congestion control via autonomous vehicles
System architecture for mixed-autonomy RL
Stability of mixed-autonomy traffic
(Simple) multi-lane modeling
Urban systems
Scalable demand inference

MOTIVATION

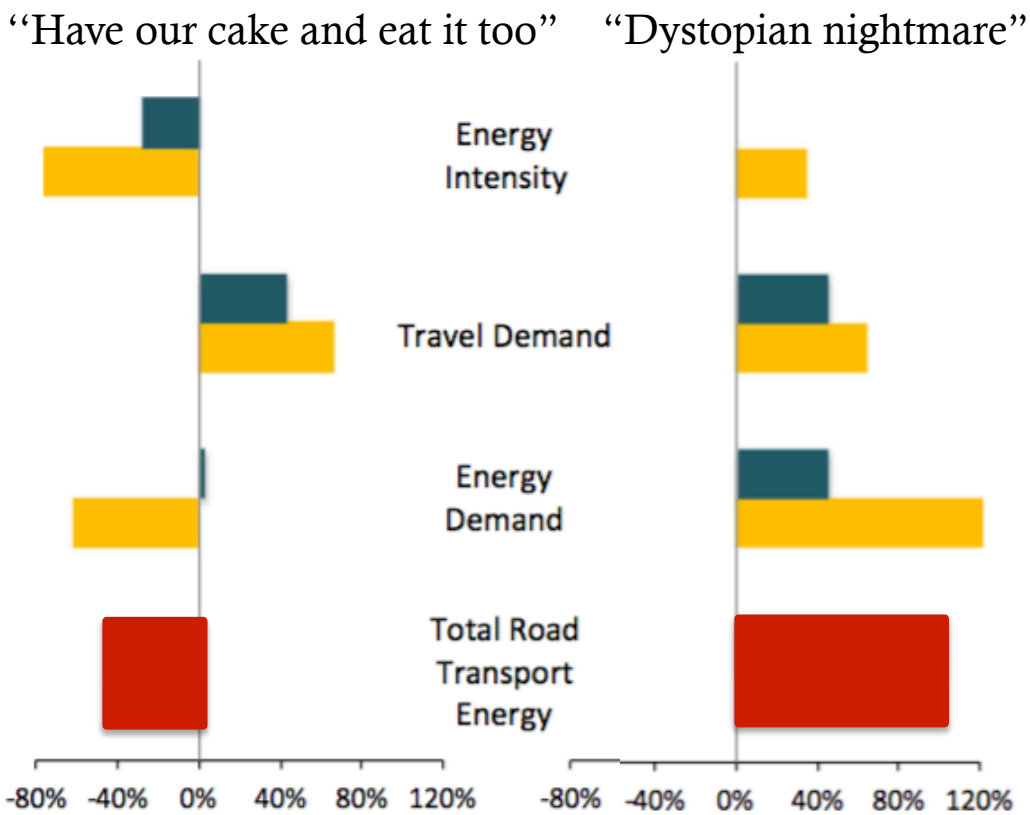
Energy impacts of vehicle automation

Setting: now, no automation

US Energy Consumption by Sector

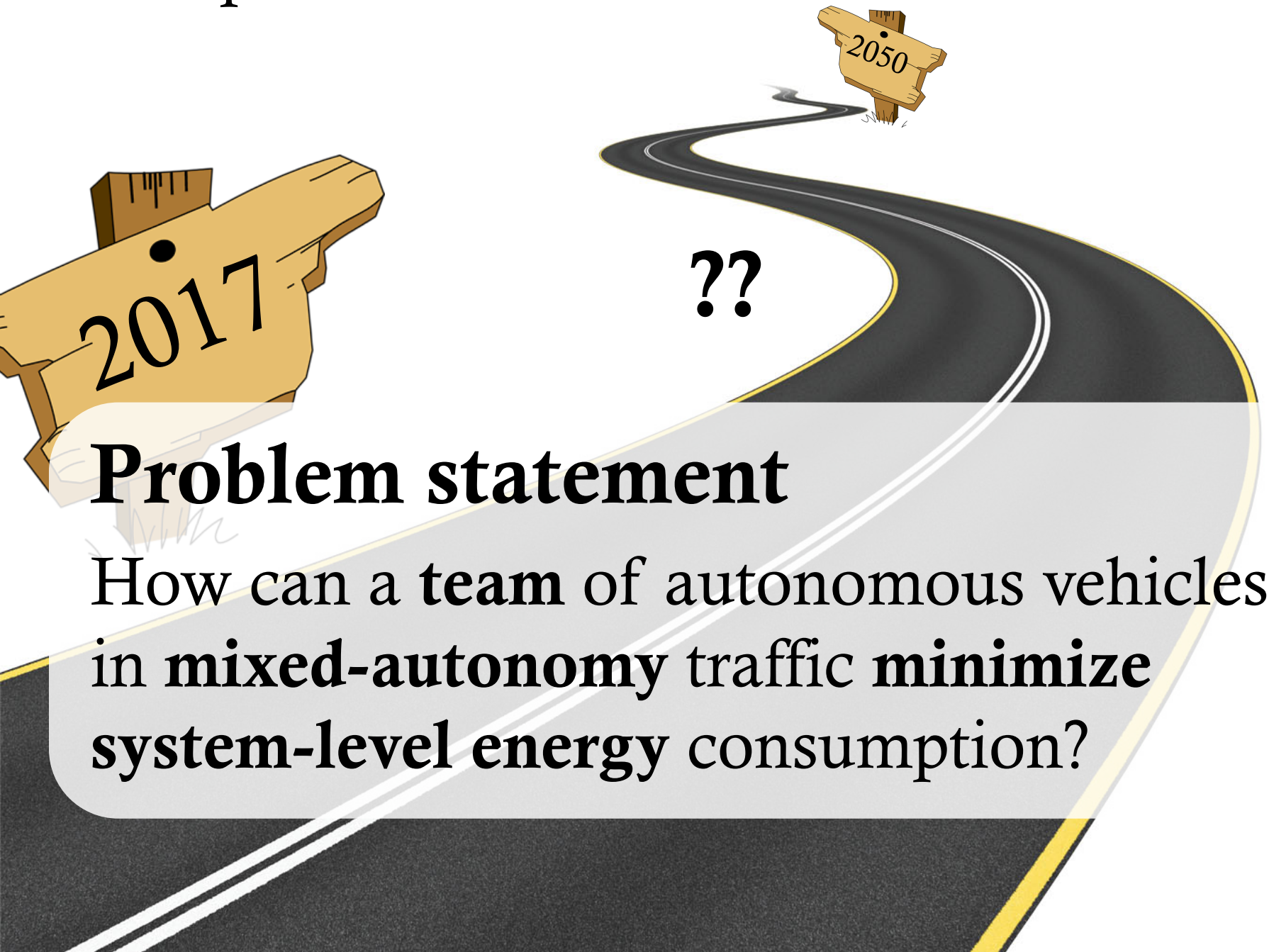


Setting: 2050, full automation



[US Energy Information Agency; Wadud et al., 2016]

What happens **between 0% and 100%** penetration of autonomous vehicles?

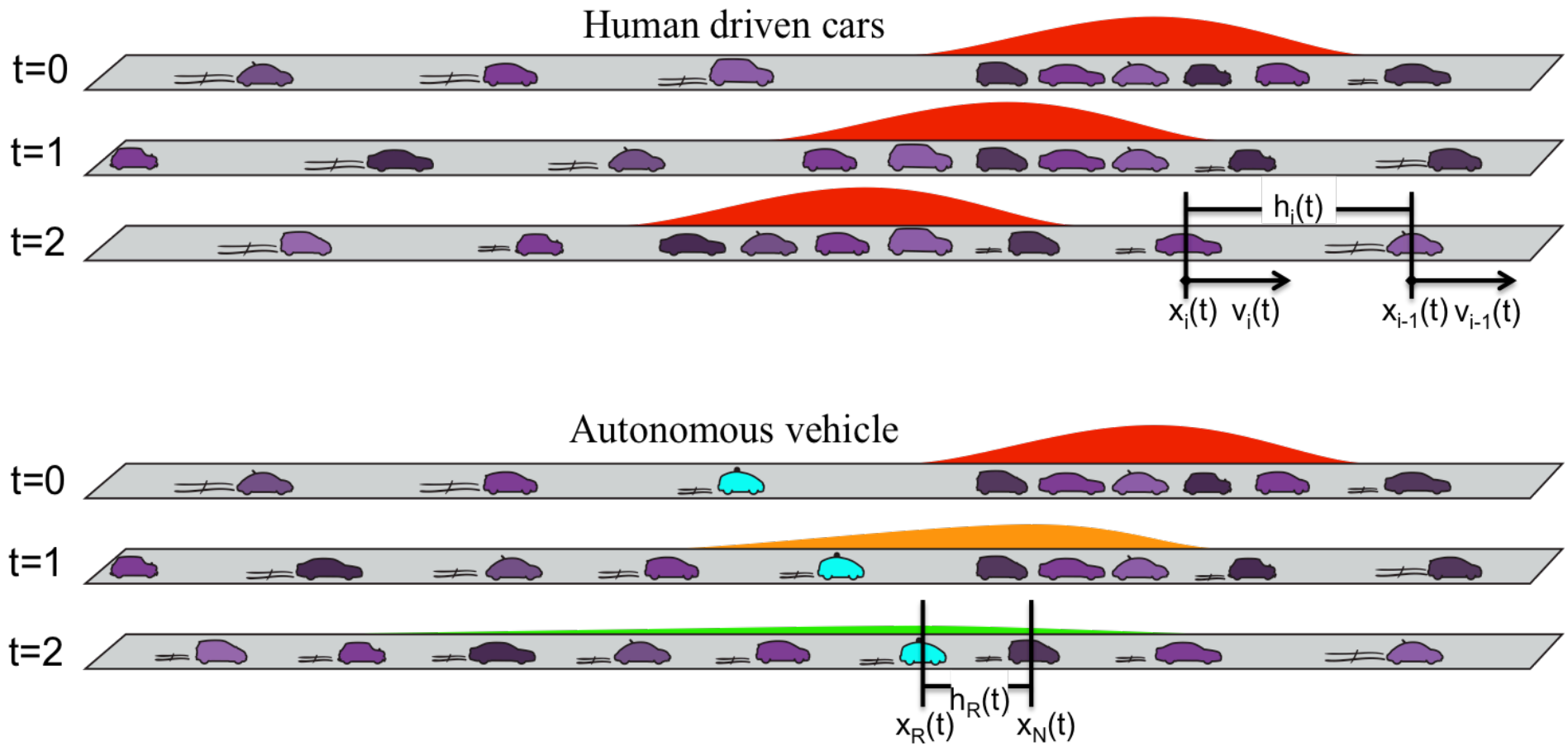


Problem statement

How can a **team** of autonomous vehicles in **mixed-autonomy** traffic **minimize system-level energy** consumption?


2008
The Mathematical Society of Traffic Flow

Problem setup



Linear dynamics: $\ddot{\tilde{x}}_i = k_p(\tilde{x}_{i-1} - \tilde{x}_i) + k_d(\dot{\tilde{x}}_{i-1} - \dot{\tilde{x}}_i) - k_v(\dot{\tilde{x}}_i)$

Robot control: $\ddot{\tilde{x}}_i = k_{p_r}(\tilde{x}_{i-1} - \tilde{x}_i) + k_{d_r}(\dot{\tilde{x}}_{i-1} - \dot{\tilde{x}}_i) - k_{v_r}(\dot{\tilde{x}}_i)$

[Wu et al., In submission, 2017]

Image credit: Florian Brown-Altvater

Stability for mixed-autonomy traffic

Motivation: Stability is a useful property for understanding energy use.

Goal: How many vehicles can one autonomous vehicle stabilize?

Related work: Infinite (realistically, 40) [Cui, et al., IV, 2017]

Contributions:

- Additionally considers safety and efficiency.
- Optimization procedure for studying single-lane mixed-autonomy traffic while maintaining safety, efficiency, and stability.
- Derivation of safety condition.
- Frequency domain analysis of stability and safety.

Definition (String stability)

A system $T(\cdot)$ is **string stable** if and only if $|T(j\omega)| \leq 1, \forall \omega$. Equivalently, $\|T(j\omega)\|_\infty \leq 1$.

[Wu et al., In submission, 2017]

Frequency domain analysis

Stability condition:

$$\left\|\prod_i T_i(\cdot)\right\|_\infty \leq 1$$

$$\Longrightarrow \; n_{stable} = \min_\omega -\frac{\log|T_R(j\omega)|}{\log|T_H(j\omega)|}$$

Safety/performance condition:

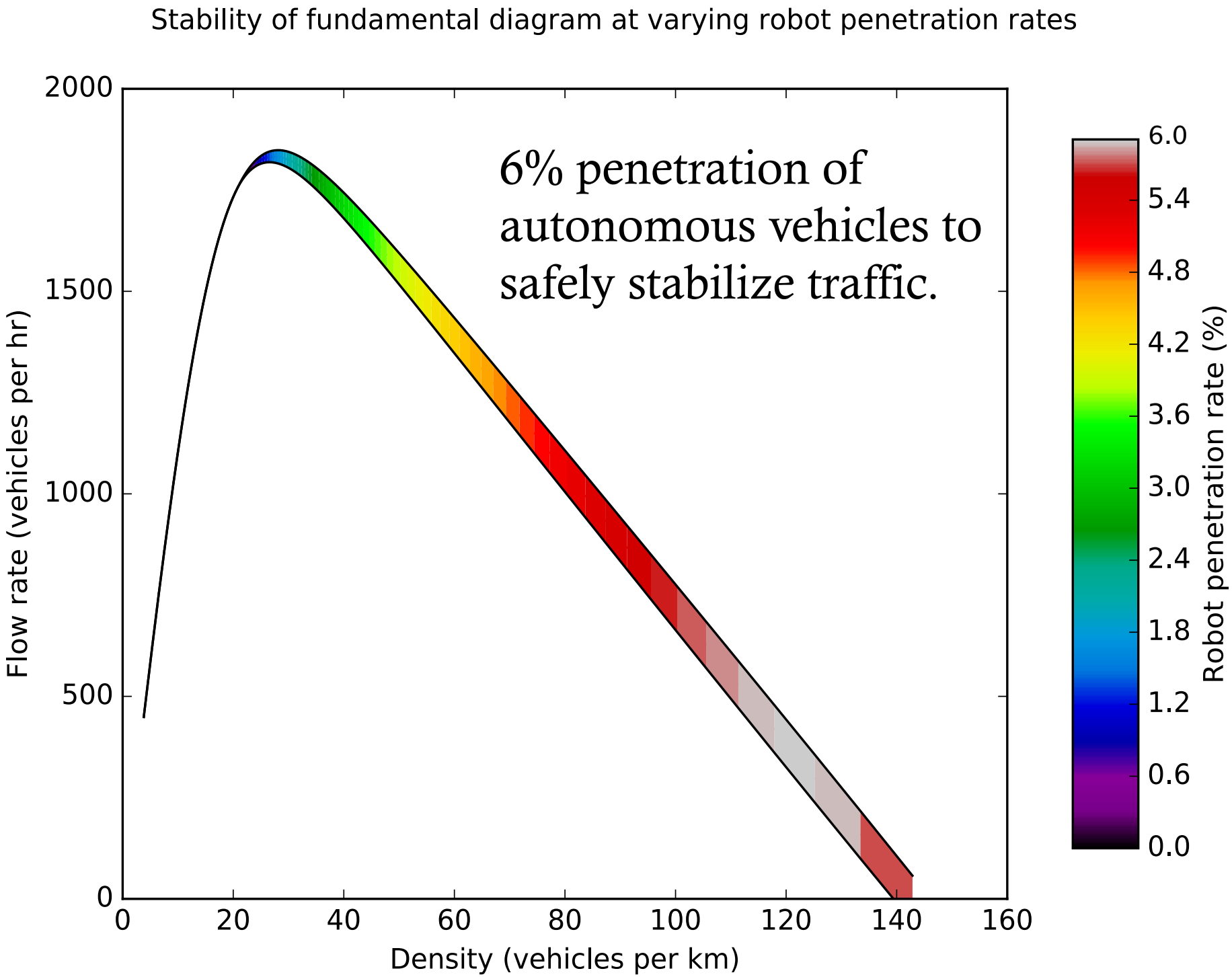
$$\Delta_- < h_R(t) < \Delta_+, \; \forall t > 0$$

$$\Longrightarrow \; n_{safe} = \min_\omega \frac{\log\eta - \log|1 - T_R(j\omega)|}{\log|T_H(j\omega)|}$$

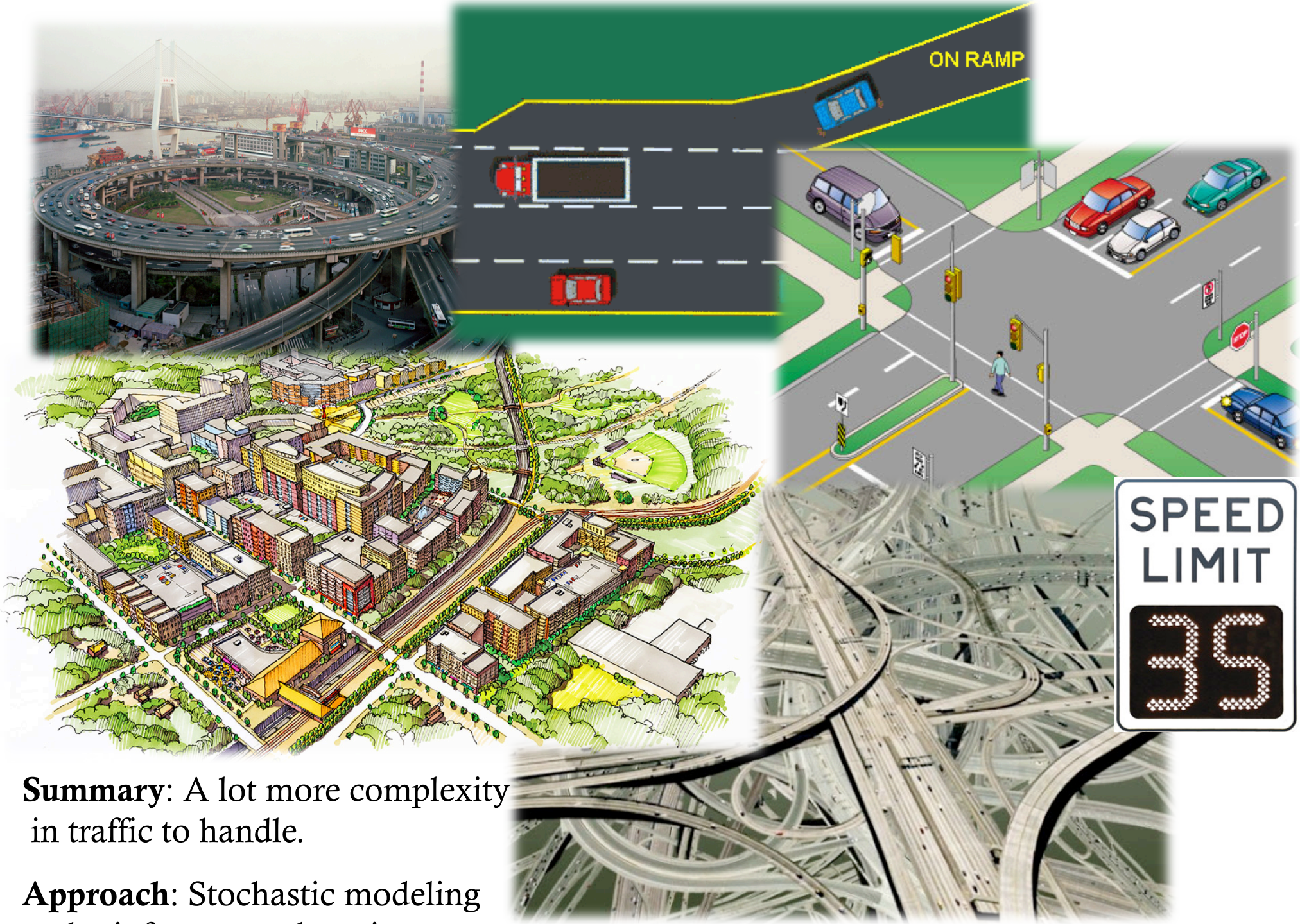
Overall optimization problem

$$\begin{aligned} n^* &= \max_{T_R} \min(n_{stable}, n_{safe}) \\ \text{s.t.} \quad T_R(s) &= \frac{k_{d_r} s + k_{p_r}}{s^2 + (k_{d_r} + k_{v_r})s + k_{p_r}} \end{aligned}$$

[Wu et al., In submission, 2017]



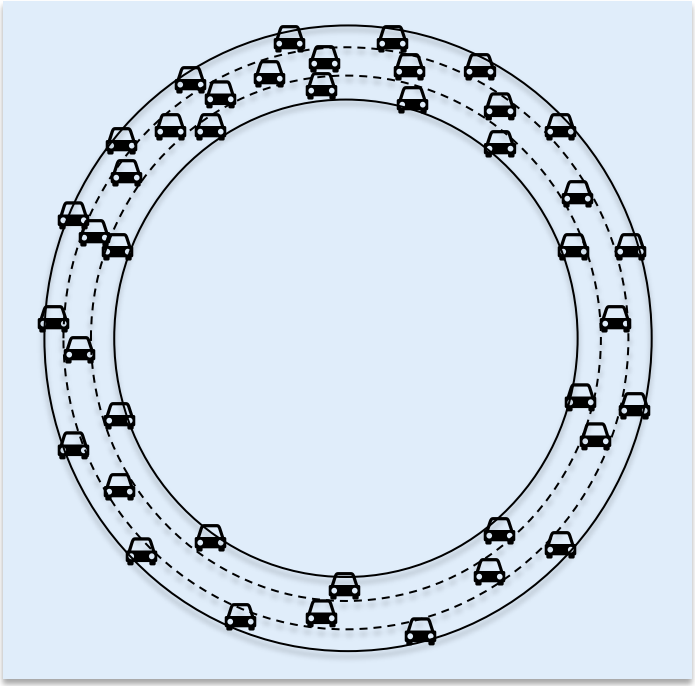
[Wu et al., In submission, 2017]



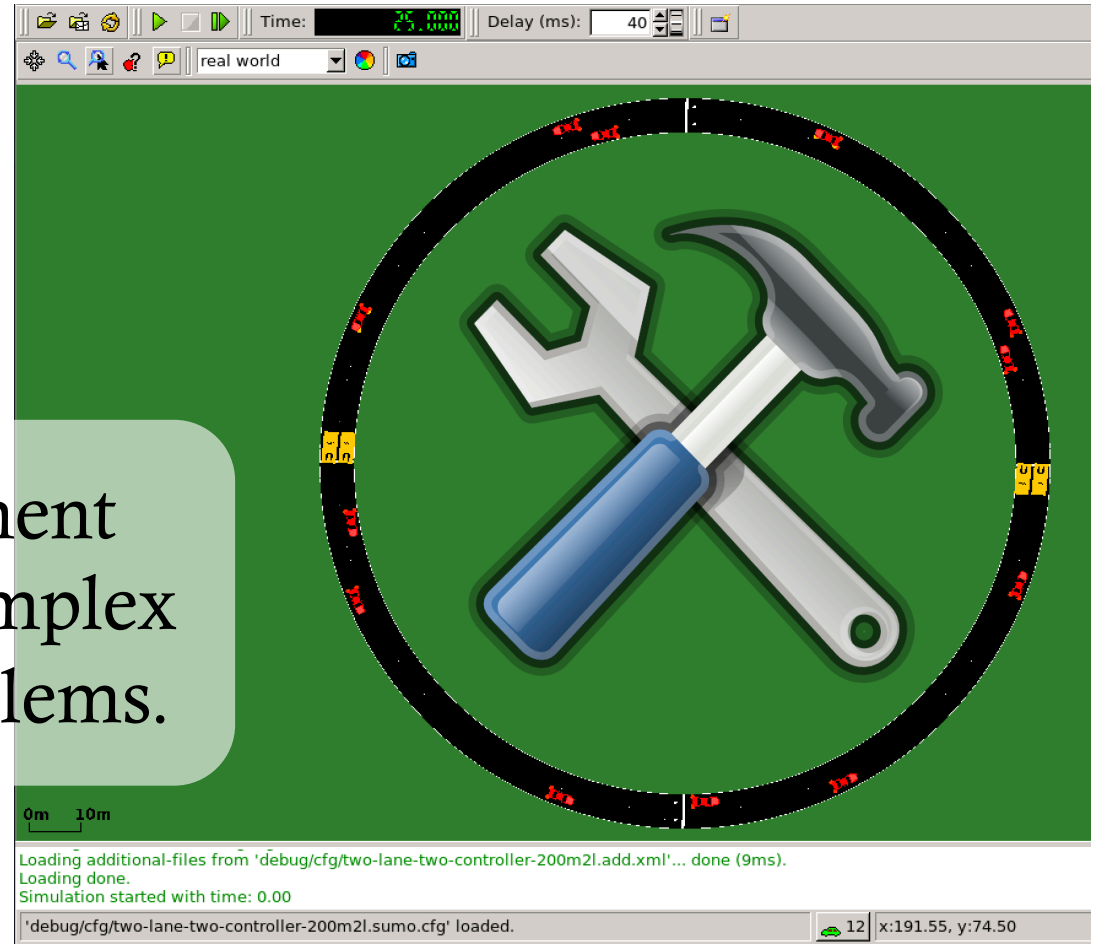
Summary: A lot more complexity in traffic to handle.

Approach: Stochastic modeling and reinforcement learning.

Recent and ongoing work



Goal: Model and understand the effect of lane changes on congestion and energy consumption.



Goal: Enable reinforcement learning for studying complex traffic optimization problems.

Image credit: Florian Brown-Altvater