

# Intersection Management with Constraint-Based Reservation Systems

Tsz-Chiu Au<sup>2</sup>, Shun Zhang<sup>1</sup>, and Peter Stone<sup>1</sup>

---

<sup>1</sup>Department of Computer Science. The University of Texas at Austin.

<sup>2</sup>School of Electrical and Computer Engineering. Ulsan National Institute of Science and Technology. South Korea.

# Intersection Management: Present and Future

- Today's transportation infrastructure is designed for human drivers.
- In the future: **Autonomous Intersection Management.** Utilize the capacity of autonomous vehicles, as a large multi-robot system, to improve traffic in transportation systems.



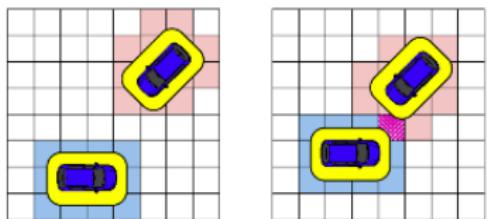
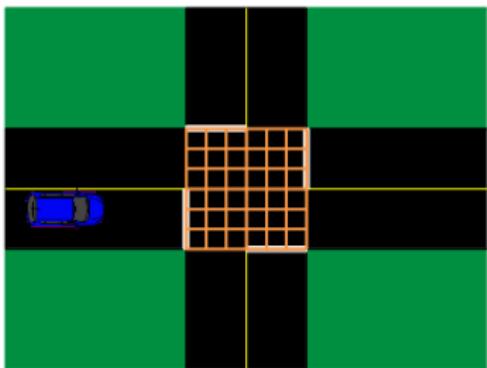
# Previous Work: Autonomous Intersection Management

- Multi-agent approach.  
[Dresner and Stone, 2008].
- First Come First Serve (FCFS). Use Grid-Based Collision Detection.

# Previous Work: Autonomous Intersection Management

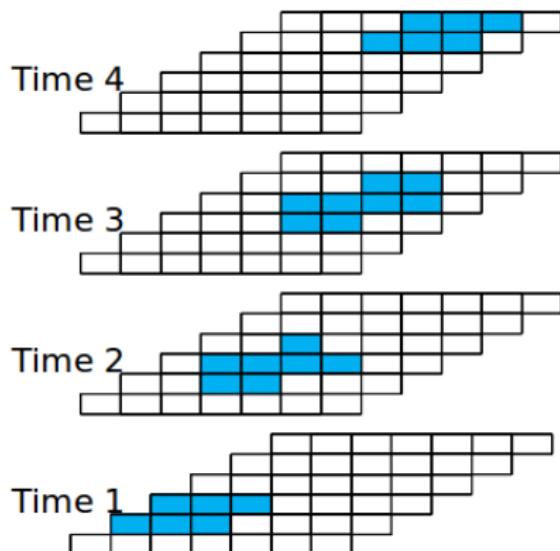
- Multi-agent approach.  
[Dresner and Stone, 2008].
- First Come First Serve (FCFS). Use Grid-Based Collision Detection.
- Dramatically reduce the traffic delay.
- Reduce the overhead of fuel consumption by approximately two thirds.

# Grid-Based Collision Detection



Accept

Reject

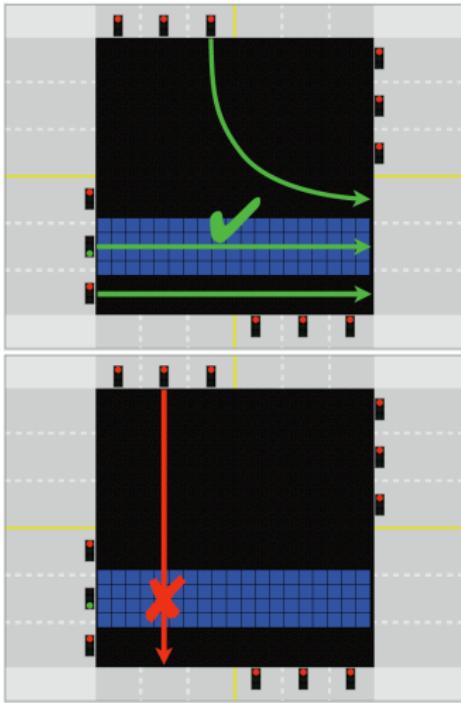


# Sharing the Road with Human Drivers

- AIM is designed for the time when vehicles are autonomous.
- Autonomous vehicles won't displace manual-controlled vehicles in one day. Some people enjoy driving.

# Sharing the Road with Human Drivers

- AIM is designed for the time when vehicles are autonomous.
- Autonomous vehicles won't displace manual-controlled vehicles in one day. Some people enjoy driving.
- One solution: FCFS-Signal = First-Come First-Served Policy + Traffic Signals  
[Dresner and Stone, 2008]



# Observation

- This ignores the possible equipments of human-driven vehicles (e.g. cruise control).
- The desirable performance is reached when 90% of the vehicles are fully autonomous.

# Observation

- This ignores the possible equipments of human-driven vehicles (e.g. cruise control).
- The desirable performance is reached when 90% of the vehicles are fully autonomous.
- **Goal:** find a way to make all types of vehicles to achieve the benefits (better than traffic signal, may not be as good as 100% fully autonomous vehicles).

# Definition

**Semi-autonomous vehicles:** vehicles with limited autonomous driving and wireless communication capabilities.

# Definition

**Semi-autonomous vehicles:** vehicles with limited autonomous driving and wireless communication capabilities.

They are able to follow a *limited number* of predictable trajectories at intersections more precisely than human drivers.

# Set of Equipments

- **Communication Device (Com)**: a component in a vehicle's on-board electronic system that enables the vehicle to wirelessly communicate with the transportation infrastructure including the IM.

# Set of Equipments

- **Communication Device (Com)**: a component in a vehicle's on-board electronic system that enables the vehicle to wirelessly communicate with the transportation infrastructure including the IM.
- **Simple Cruise Control (CC)**: An optional speed control subsystem in vehicles' drivetrain that automatically controls the vehicle speed by taking over the throttle of the vehicles.

# Set of Equipments

- **Communication Device (Com)**: a component in a vehicle's on-board electronic system that enables the vehicle to wirelessly communicate with the transportation infrastructure including the IM.
- **Simple Cruise Control (CC)**: An optional speed control subsystem in vehicles' drivetrain that automatically controls the vehicle speed by taking over the throttle of the vehicles.
- **Adaptive Cruise Control (ACC)**: an advanced cruise control system that automatically adjusts the speed of a vehicle in order to maintain a certain distance from vehicles ahead.

# Type of Semi-Autonomous Vehicles

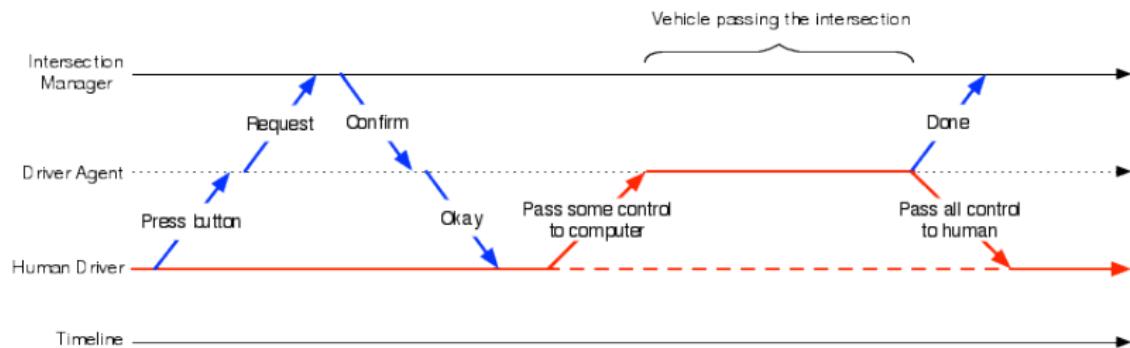
Vehicle Type	Communication Device	Cruise Control	Adaptive Cruise Control
SA-ACC	X	X	X
SA-CC	X	X	
SA-Com	X		

# Interaction Model

For safety, we need to define a simple and clean interface between the human driver and the vehicle.

# Interaction Model

For safety, we need to define a simple and clean interface between the human driver and the vehicle.



# Constraint-Based Reservation

We turn AIM into a *constraint-based reservation system*, which allows vehicles to make reservations in terms of constraints over

- their driving profiles such as their arrival time and arrival velocity
- the relationships with other vehicles.

# Basic Elements

- **Intention:** The direction in which the vehicle intends to move.

# Basic Elements

- **Intention:** The direction in which the vehicle intends to move.
- **Vehicle Type:** The type of vehicle.

# Basic Elements

- **Intention:** The direction in which the vehicle intends to move.
- **Vehicle Type:** The type of vehicle.
- **Entry Condition:** The condition under which the vehicle will enter the intersection.

# Basic Elements

- **Intention:** The direction in which the vehicle intends to move.
- **Vehicle Type:** The type of vehicle.
- **Entry Condition:** The condition under which the vehicle will enter the intersection.
- **Acceleration Profile List:** The list of possible acceleration schedules from among which the vehicle will choose one to follow during the traversal of the intersection.

# Constant-Velocity Request

- Intent =  $(I_1 \vee I_2 \vee \dots \vee I_n)$  in which  $I_i$  is a possible lane from which the vehicle exits the intersection;
- Type is the vehicle type;
- Entry =  $((I'_1 \vee I'_2 \vee \dots \vee I'_n), [t_1, t_2], [v_1, v_2])$  is the entry statement; and
- AP =  $(\langle(t_1, 0)\rangle)$

For the performance of Simple Cruise Control.

# Whole-Row Request

- Intent =  $(I_1 \vee I_2 \vee \dots \vee I_n)$   $I_i$  is a possible lane from which the vehicle exits the intersection;
- Type is the vehicle type;
- Entry =  $((I'_1 \vee I'_2 \vee \dots \vee I'_n), [t_1, t_2], [v_1, v_2])$  is the entry statement; and
- AP is the acceleration profile list, and may not be provided.

For the performance of Communication Device.

# Anchor Request

Semi-autonomous vehicles with adaptive cruise control can use a special constraint-based request called *anchor requests* to make reservations.

# Anchor Request

Semi-autonomous vehicles with adaptive cruise control can use a special constraint-based request called *anchor requests* to make reservations.

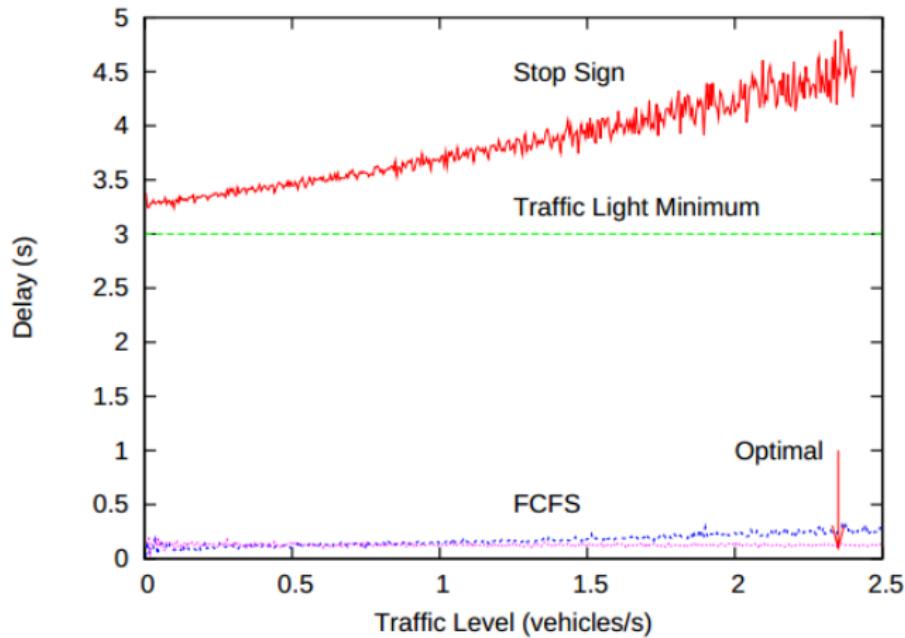
An anchor request is  $\langle \text{Type}, \text{vin}, d \rangle$

# A General Request

In Lisp syntax,

```
(cc-profile (v verror angle)
  (is-auto-speed-control)
  (not is-auto-steering)
  (< velocity (+ v verror))
  (> velocity (- v verror))
  (< steer-angle angle) (> steer-angle -angle))
```

## Evaluation on AIM (Previous Work)



[Dresner and Stone, 2008]

# Goal

Recall, our **goal**:

# Goal

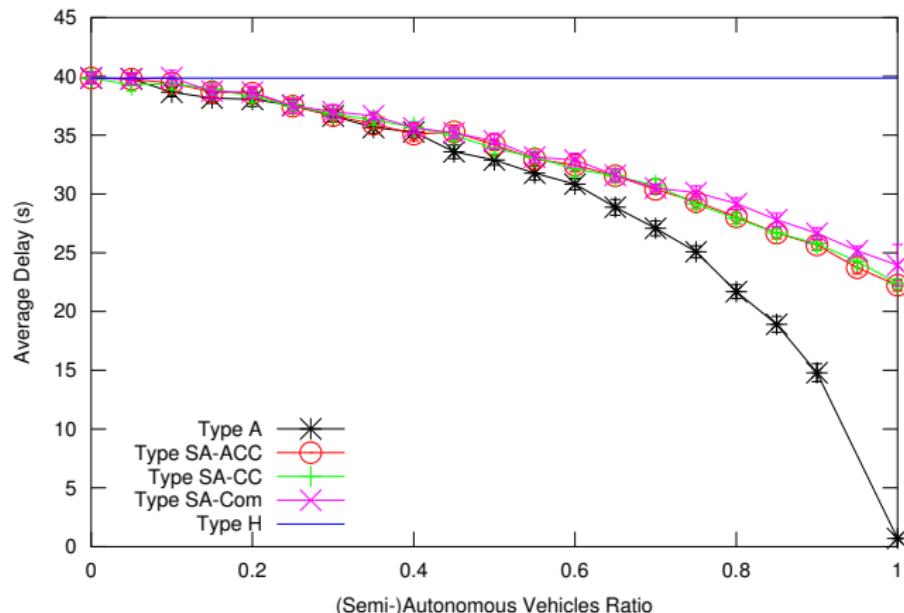
Recall, our **goal**: find a way to make all types of vehicles to achieve the benefits (better than traffic signal, may not be as good as 100% fully autonomous vehicles).

# Implementation

Vehicle Type	Communication Device	Cruise Control	Adaptive Cruise Control
SA-ACC	X	X	X
SA-CC	X	X	
SA-Com	X		

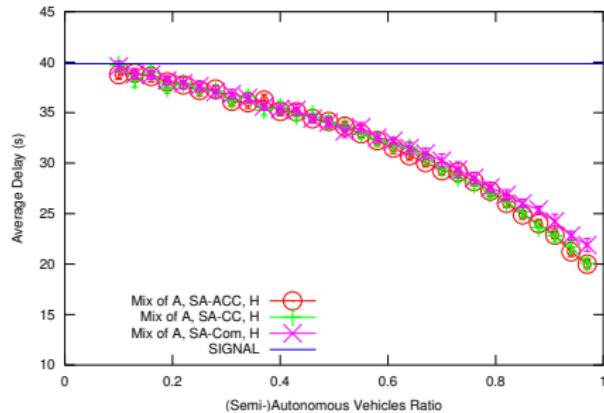
For each type of vehicle - always try the most *advanced* type of request first.

# Evaluation on SemiAIM



(Semi-)Autonomous vehicles vs. Human-Driven vehicles. Traffic level = 360 vehicles/lane/hour.

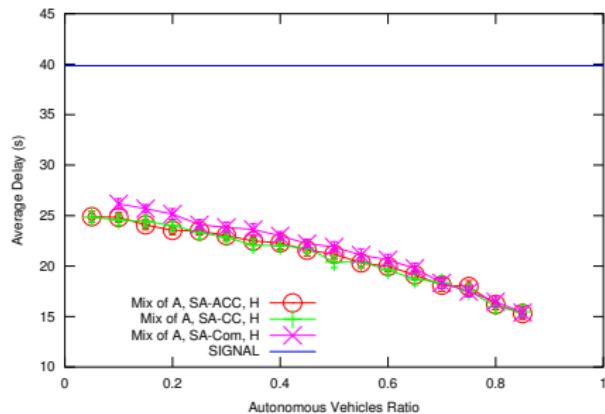
# Evaluation on SemiAIM



Type H	SemiAuto	Type A
90%	9%	1%
87%	11%	2%
84%	13%	3%
...	...	...
0%	69%	31%

The average delay according to a deployment schedule. Traffic level = 360 vehicles/lane/hour.

# Evaluation on SemiAIM



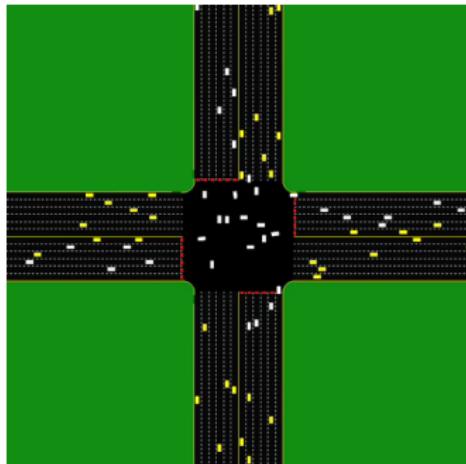
Type H	SemiAuto	Type A
10%	85%	5%
10%	80%	10%
10%	75%	15%
...	...	...
10%	5%	85%

The average delay according to a deployment schedule. Traffic level = 360 vehicles/lane/hour.

## Related Works

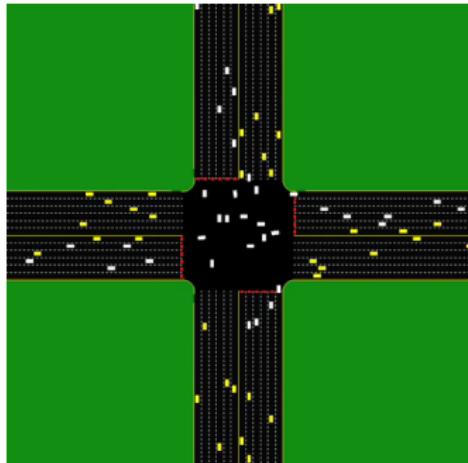
- The main context of our work is an extension to the FCFS policy proposed by Dresner and Stone [Dresner and Stone, 2008].
- Similar to the analysis of adaptive cruise control performance by Jerath and Brennan [Jerath and Brennan, 2010].
- Part of a series of robotic car competitions such as the *DARPA Grand Challenges* [DAR, ].
- Jointly optimizing autonomous vehicles and road infrastructure, for example, the PATH program [Shladover et al., 1991].
- Vehicle-to-Vehicle (V2V) forms of autonomous intersection management [Naumann and Rasche, 1997, VanMiddlesworth et al., 2008].

# Conclusion



- SemiAIM is the first multiagent protocol to enable smooth interactions between human-driven, fully autonomous, and semiautonomous vehicles.

# Conclusion



- SemiAIM is the first multiagent protocol to enable smooth interactions between human-driven, fully autonomous, and semiautonomous vehicles.
- Our experiments showed that our system can greatly decrease traffic delay when most vehicles are semiautonomous, even when few (if any) are fully autonomous.

# Bibliography

-  **DARPA grand challenge.**  
[http://en.wikipedia.org/wiki/DARPA\\_Grand\\_Challenge](http://en.wikipedia.org/wiki/DARPA_Grand_Challenge).
-  **Dresner, K. and Stone, P. (2008).**  
A multiagent approach to autonomous intersection management.  
*Journal of Artificial Intelligence Research (JAIR)*.
-  **Jerath, K. and Brennan, S. N. (2010).**  
Adaptive cruise control: Towards higher traffic flows, at the cost of increased susceptibility to congestion.  
In *AVEC'10*.
-  **Naumann, R. and Rasche, R. (1997).**  
Intersection collision avoidance by means of decentralized security and communication management of autonomous vehicles.  
In *Proceedings of the 30th ISATA - ATT/IST Conference*.
-  **Shladover, S., Desoer, C., Hedrick, J., Tomizuka, M., Walrand, J., Zhang, W.-B., McMahon, D., Peng, H., Sheikholeslam, S., and McKeown, N. (1991).**  
Automated vehicle control developments in the path program.  
*IEEE Transactions on Vehicular Technology*, 40(1):114–130.
-  **VanMiddlesworth, M., Dresner, K., and Stone, P. (2008).**  
Replacing the stop sign: Unmanaged intersection control for autonomous vehicles.  
In *AAMAS Workshop on Agents in Traffic and Transportation*, pages 94–101, Estoril, Portugal.