Intersections of the Future: Using Fully Autonomous Vehicles

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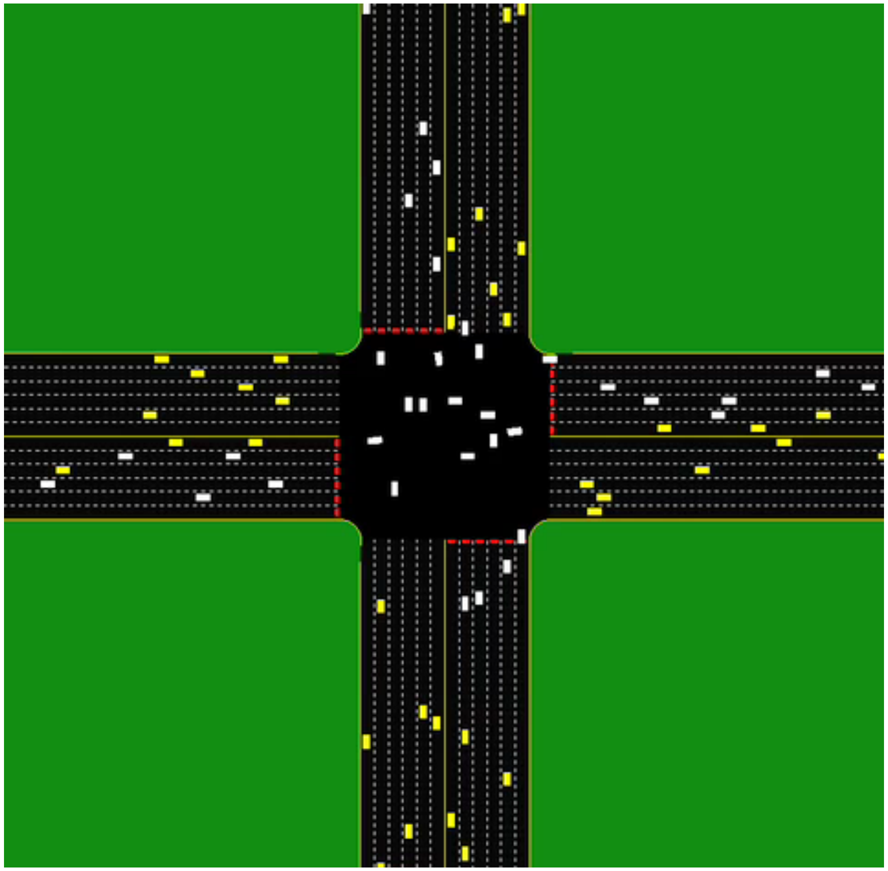
Transportation Infrastructure: Present and Future

- Today's transportation infrastructure is designed for human drivers.
- In the future:
  Autonomous Traffic Management
  - Utilize the capacity of autonomous vehicles to improve traffic in transportation systems.
  - Highly Efficient
    - ➔ Less fuel consumption
    - ➔ Less emissions
    - ➔ Sustainable society

aim

autonomous intersection management

Autonomous Intersection Management

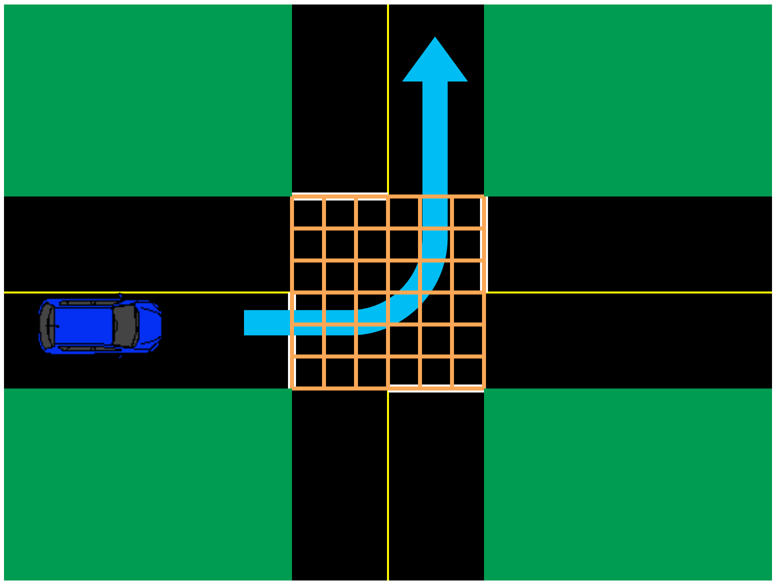


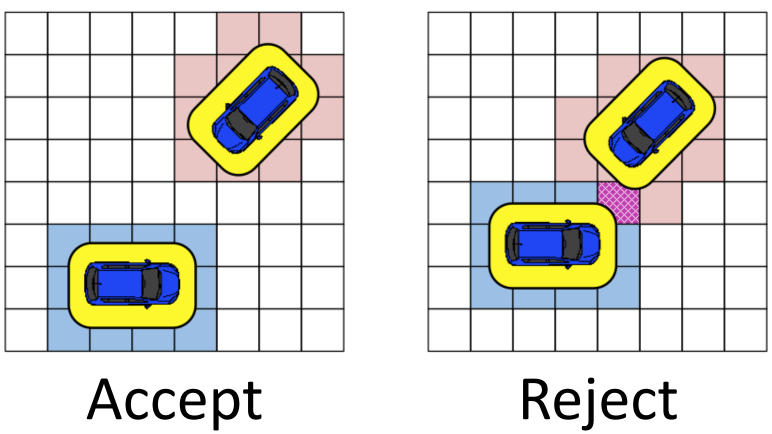
- Dramatically reduce the traffic delay.
- Reduce the overhead of fuel consumption by approximately two thirds.

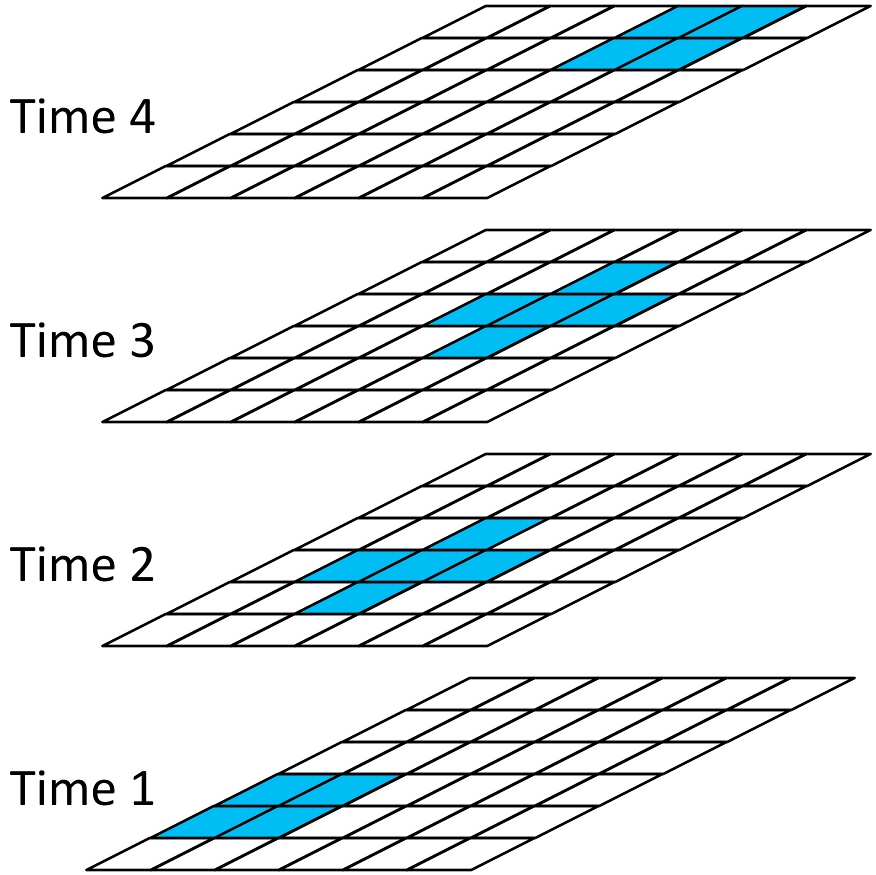
Kurt Dresner and Peter Stone. A Multiagent Approach to Autonomous Intersection Management. *JAIR* 2008.

D. Fajardo, T.-C. Au, S. T. Waller, P. Stone, and D. Yang. Automated Intersection Control: Performance of a Future Innovation Versus Current Traffic Signal Control. In *Transportation Research Record : Journal of the Transportation Research Board,* 2011.

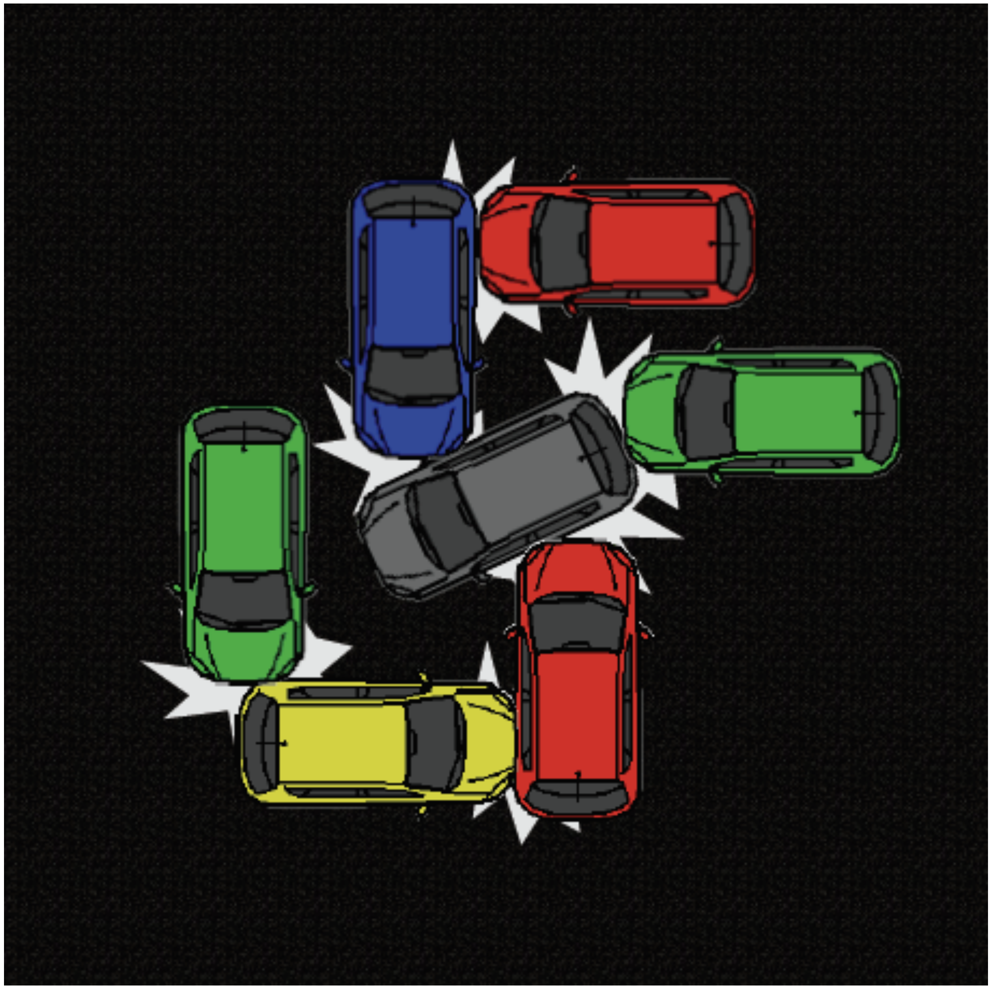
Grid-Based Collision Detection



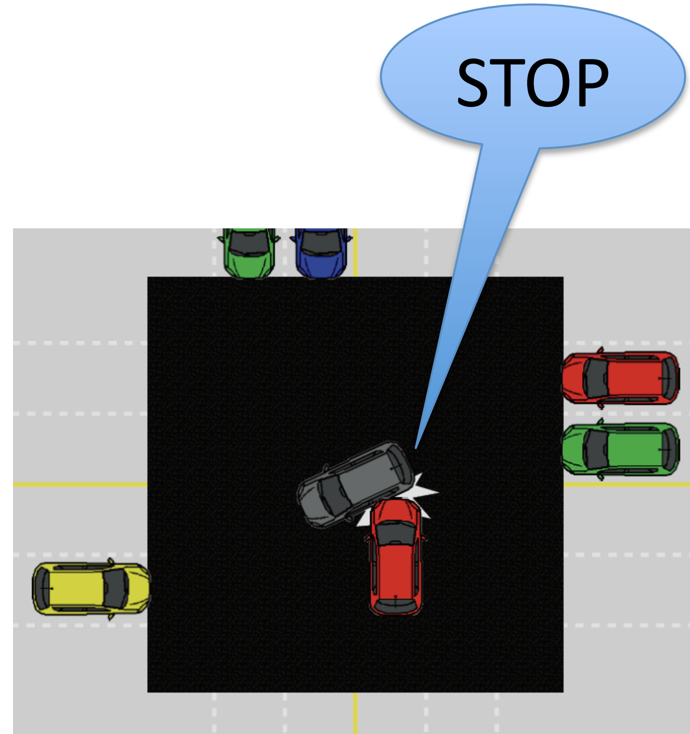




Is the protocol safe?



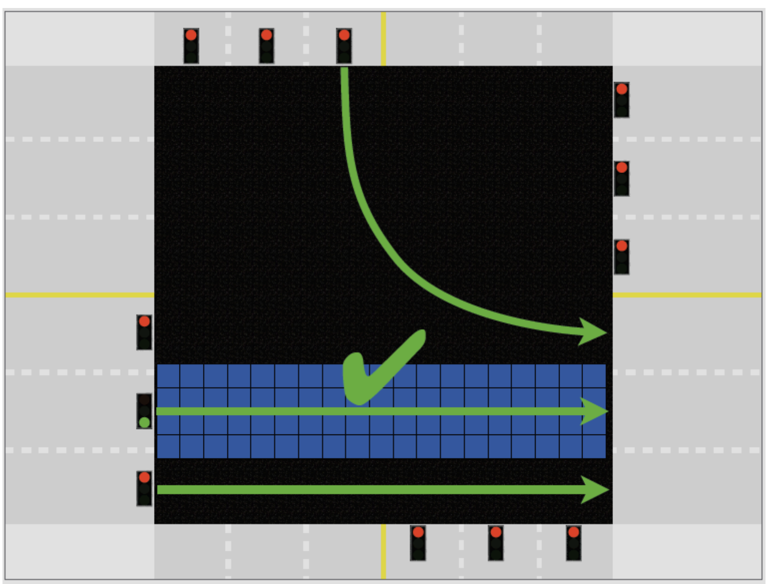
Safety Measures

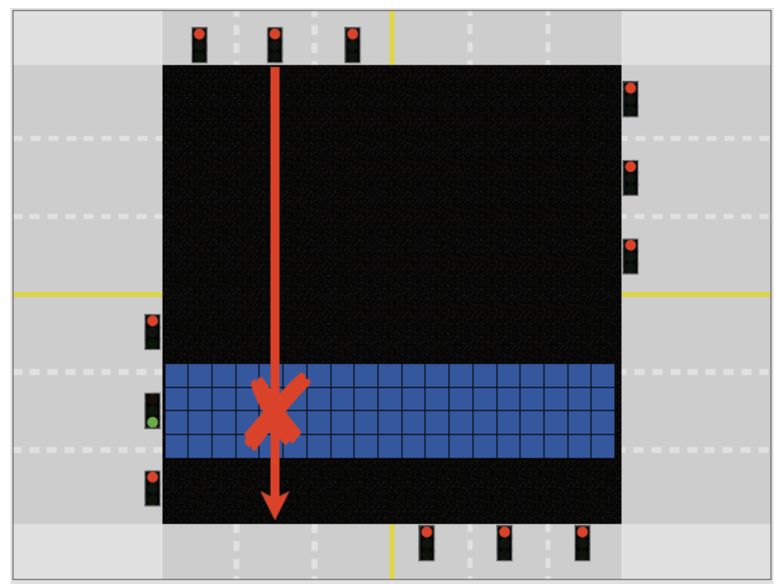


- Buffer
- The protocol is fail-safe in the event of message dropping
  - If all autonomous vehicles follow the protocol, guarantee no collisions.
- When a crash occurs, sends **STOP** messages to all vehicles nearby.
  - Avoid most collisions. But some are unavoidable.

Sharing the Road with Human Drivers

- Autonomous vehicles won't displace manual-controlled vehicles in one day.
- Some people enjoy driving.
- FCFS-signal = First-Come, First-Served Policy + Traffic Signals

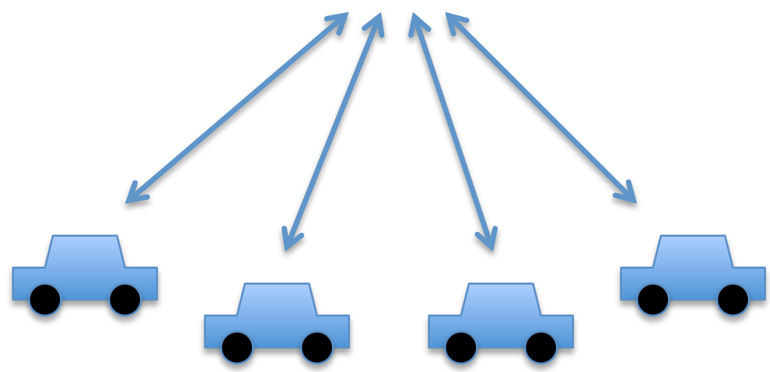




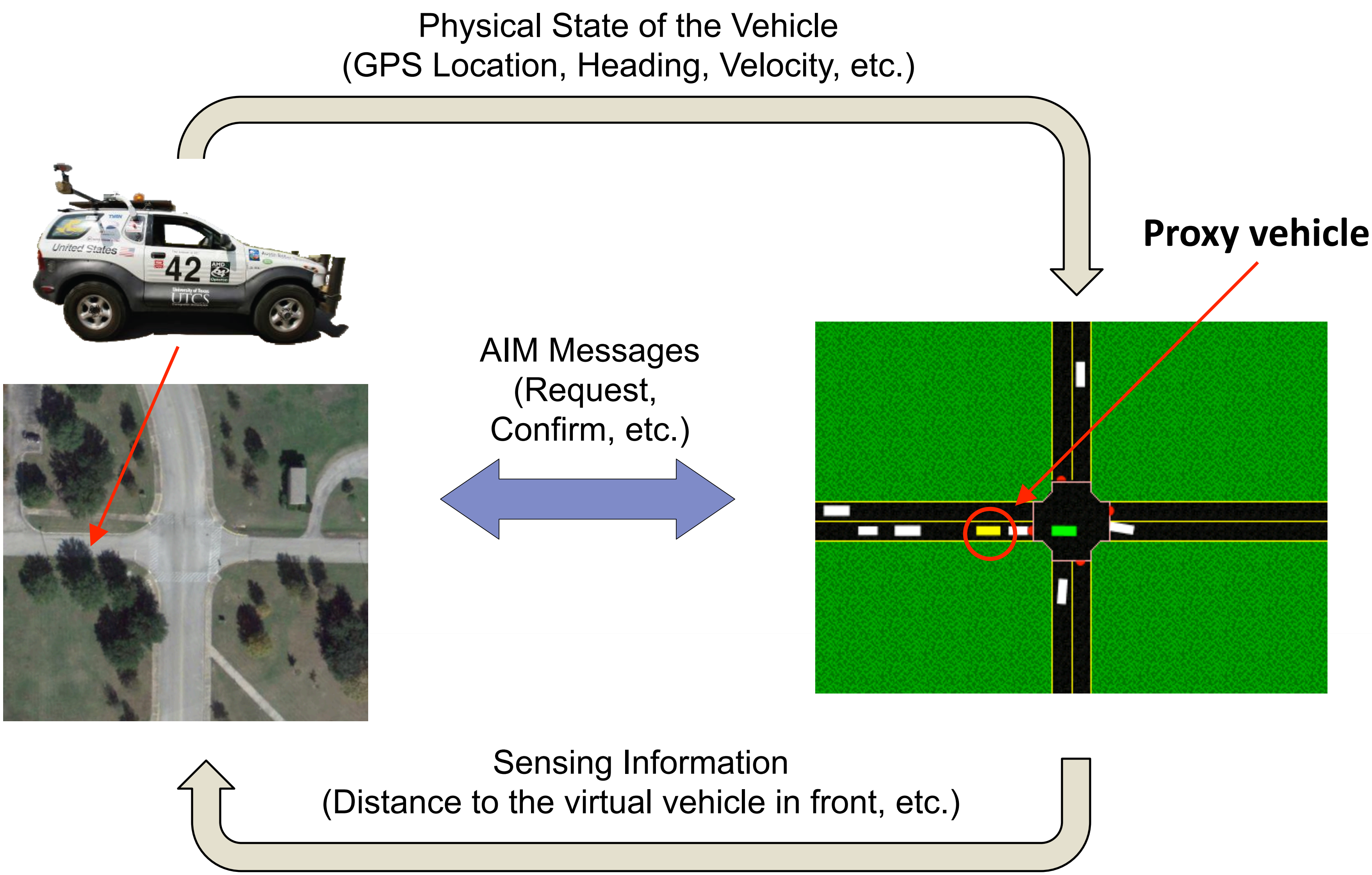
Evaluating AIM with Real Autonomous vehicles

- Completely testing AIM on real hardware requires a fleet of autonomous vehicles
  - Expensive and dangerous!
- We implemented a **mixed reality platform**
  - Testing a single real autonomous vehicle that interacts with many virtual (or simulated) vehicles.

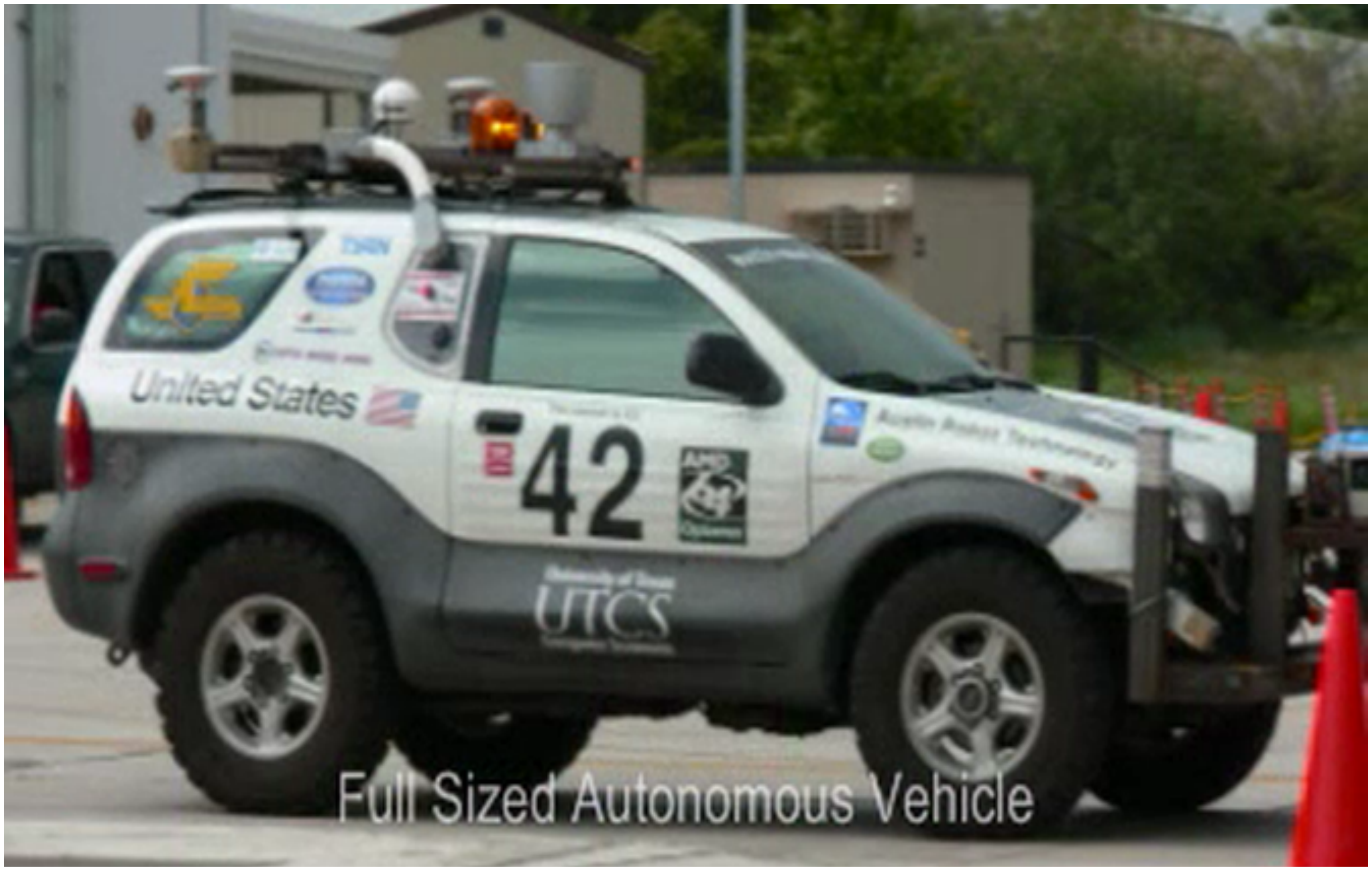
Marvin – our autonomous vehicle



Mixed Reality Platform



Mixed Reality in Action



Outline

- Introduction to AIM
- Autonomous Traffic Management for Road Networks
- Innovative Traffic Controls
- Future Directions

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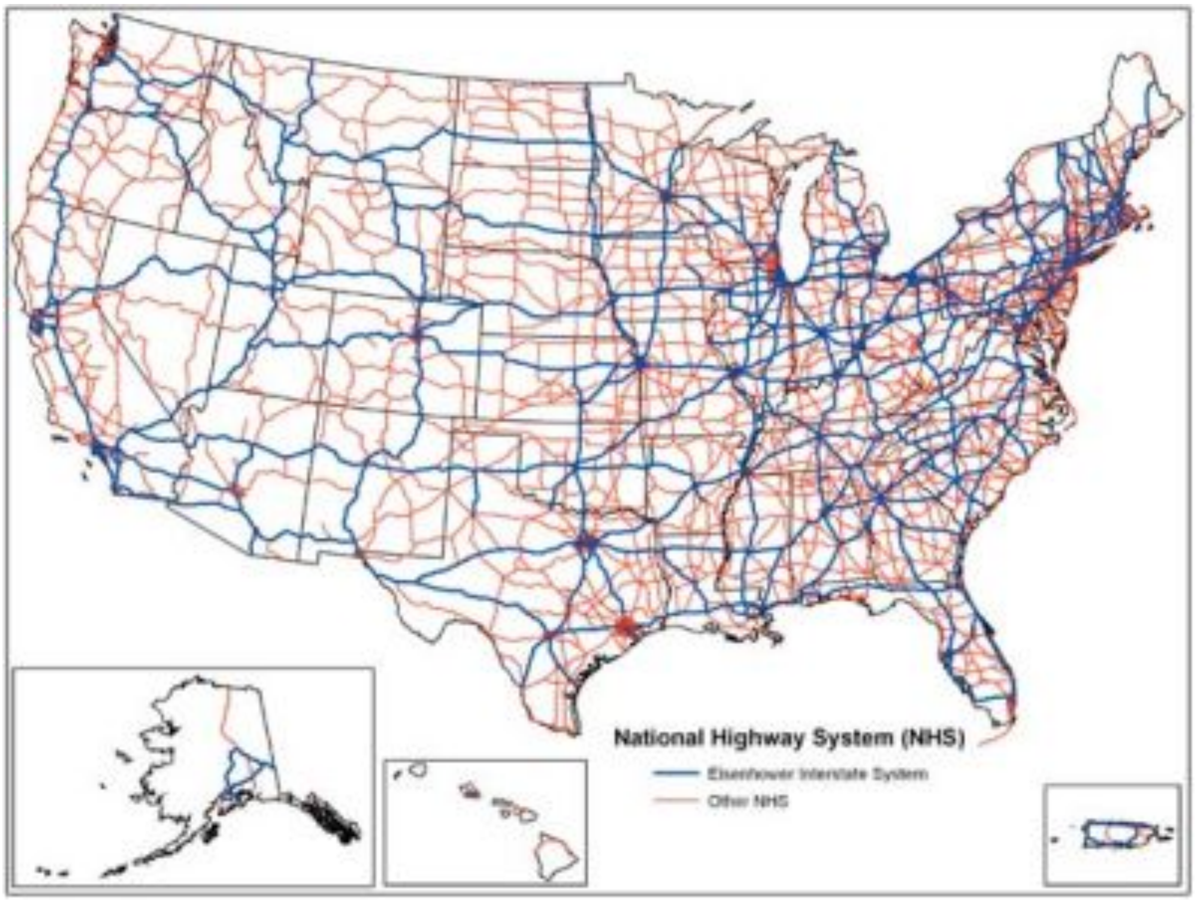
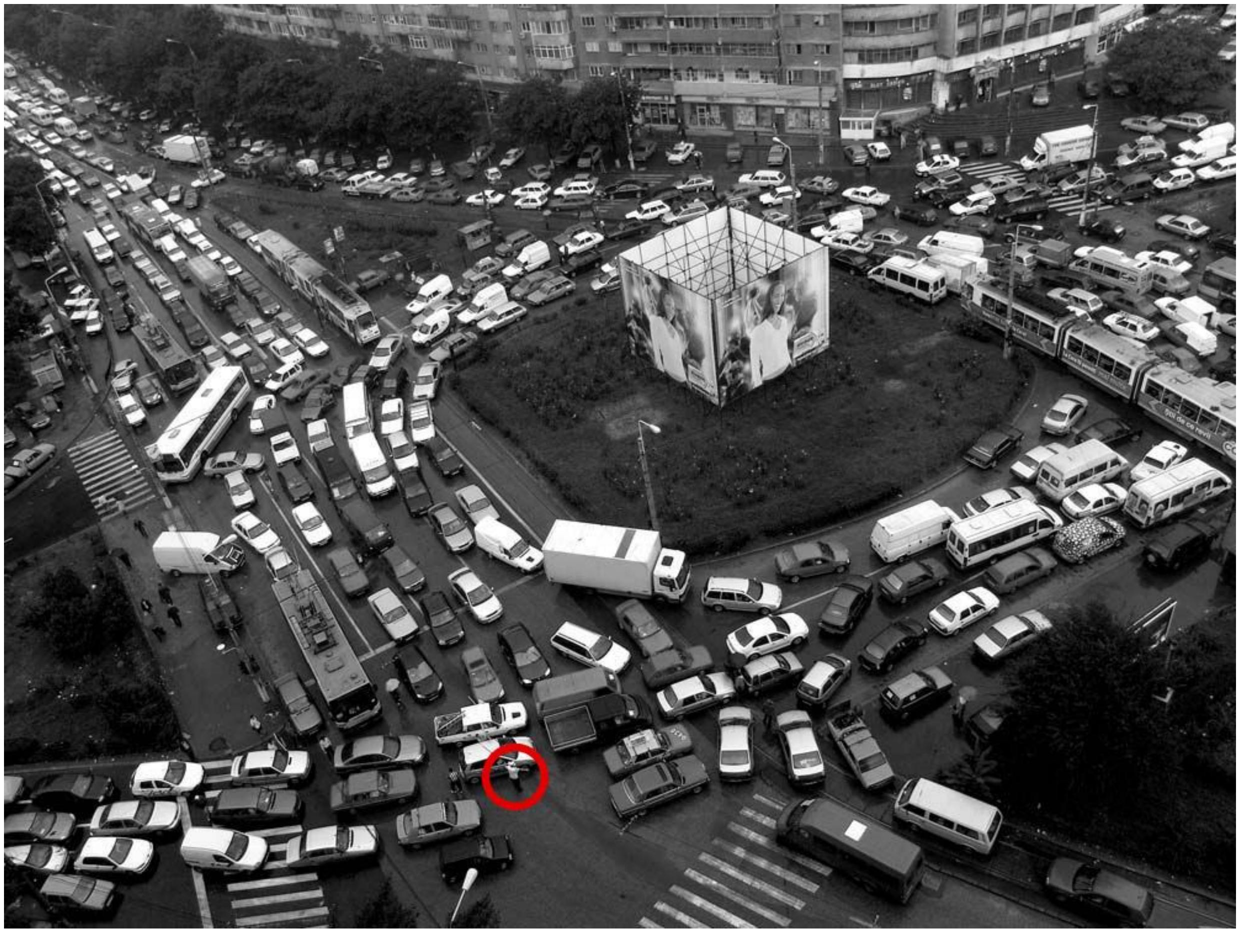
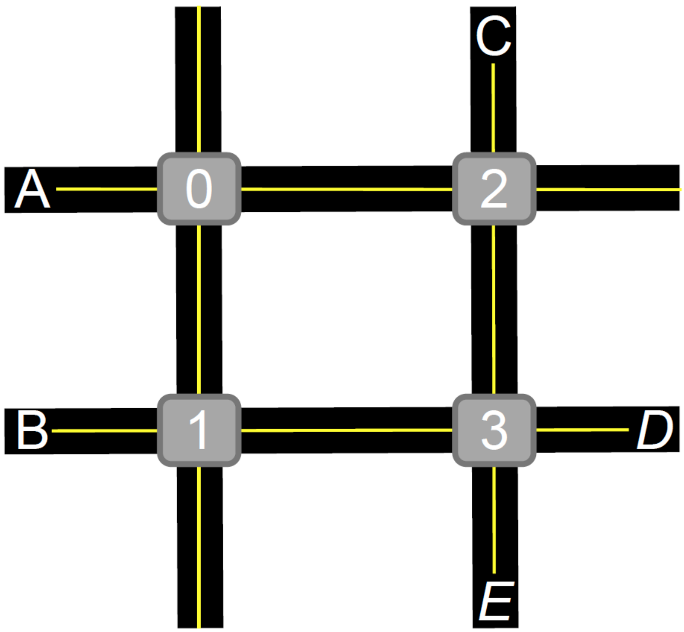
Autonomous Traffic Management in Road Networks

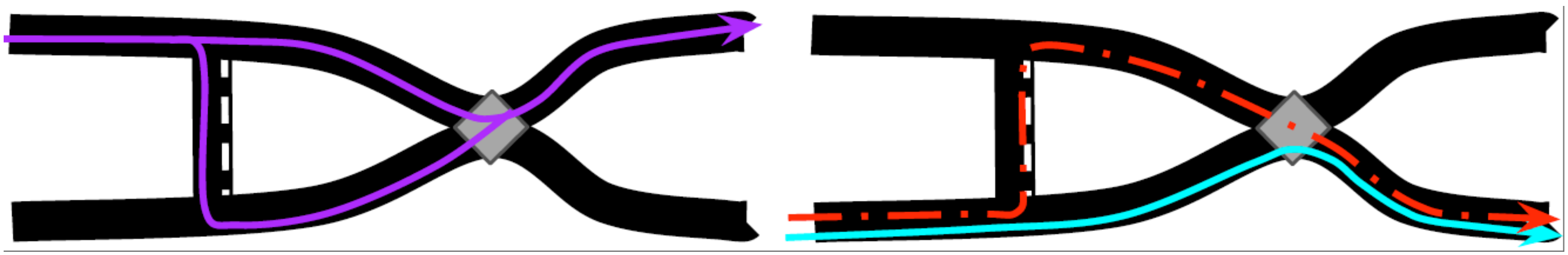




Dynamic Route Planning

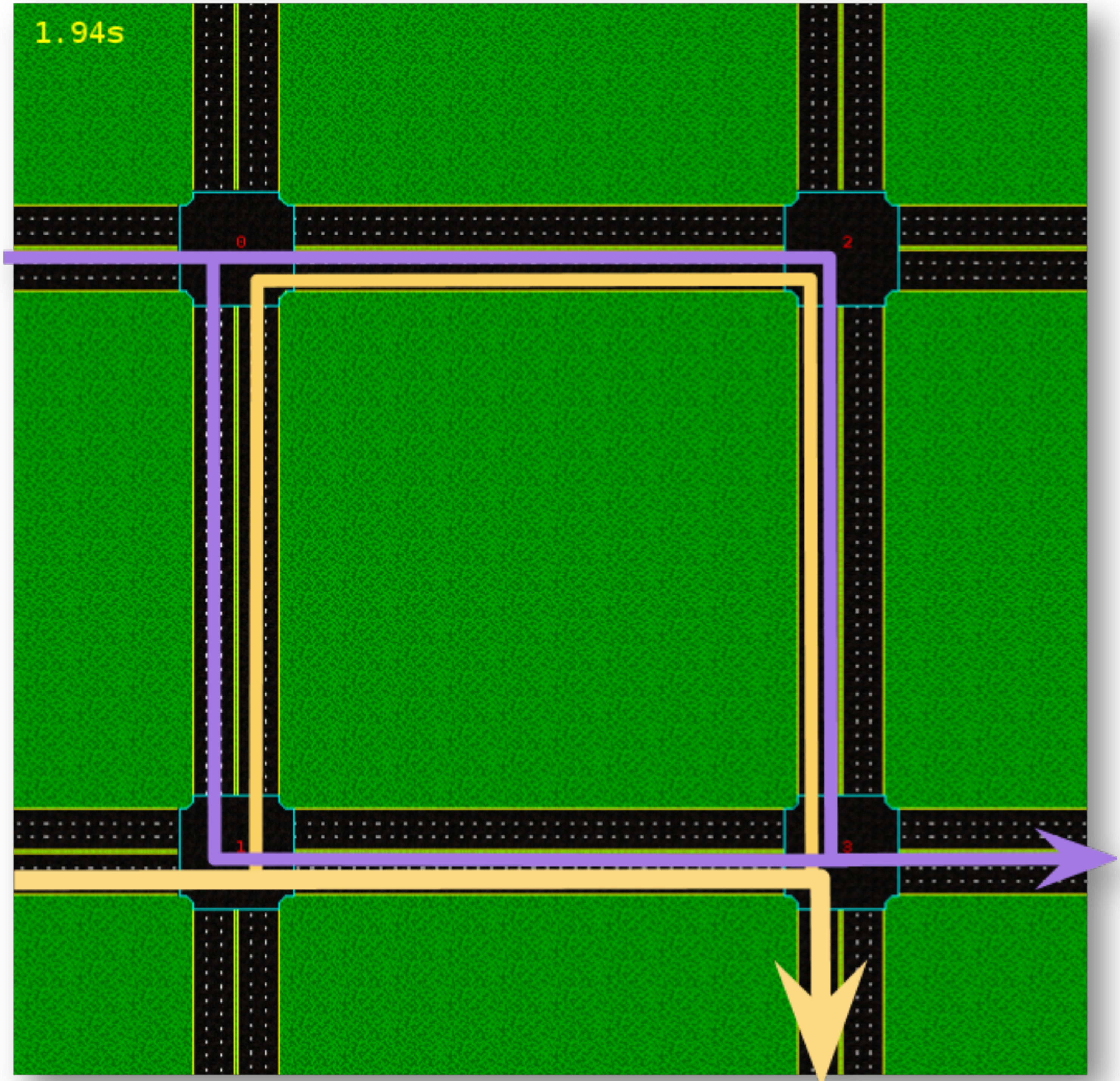
- Examined different navigation policies by which autonomous vehicles can dynamically alter their planned paths
- Braess' paradox





Braess' Paradox

Phenomenon in which adding additional capacity to a network, when moving entities selfishly choose their routes, results in reduced overall performance.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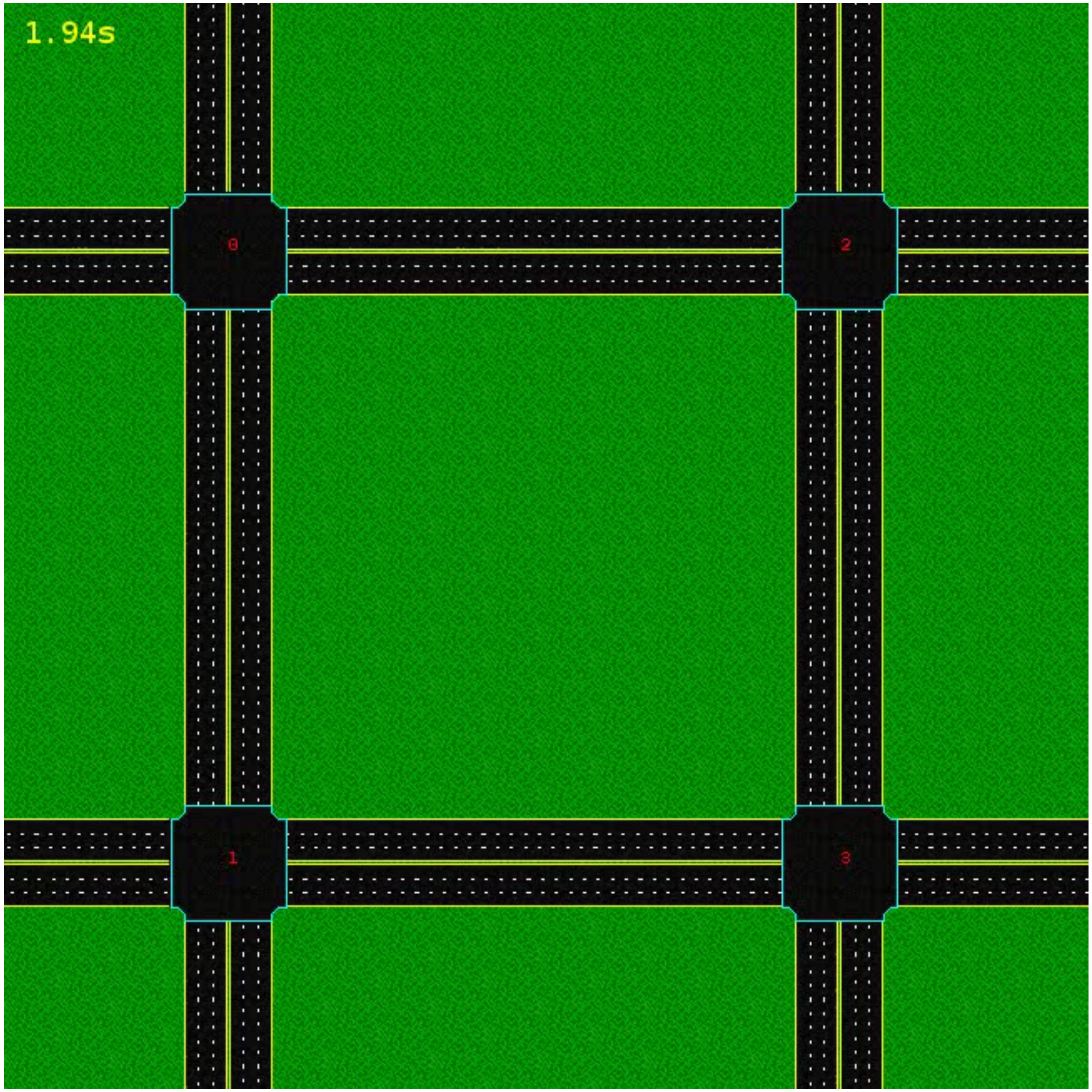
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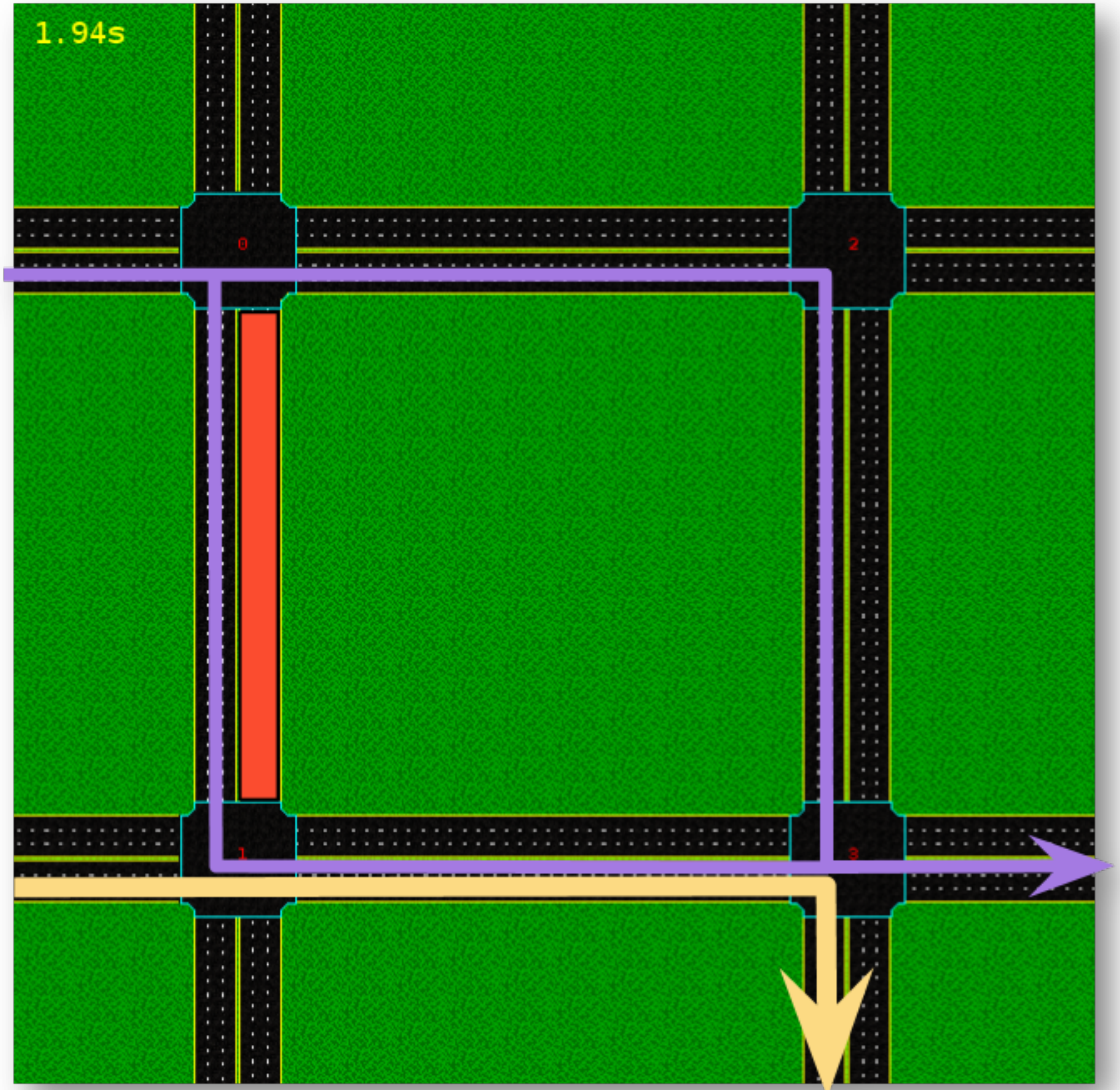
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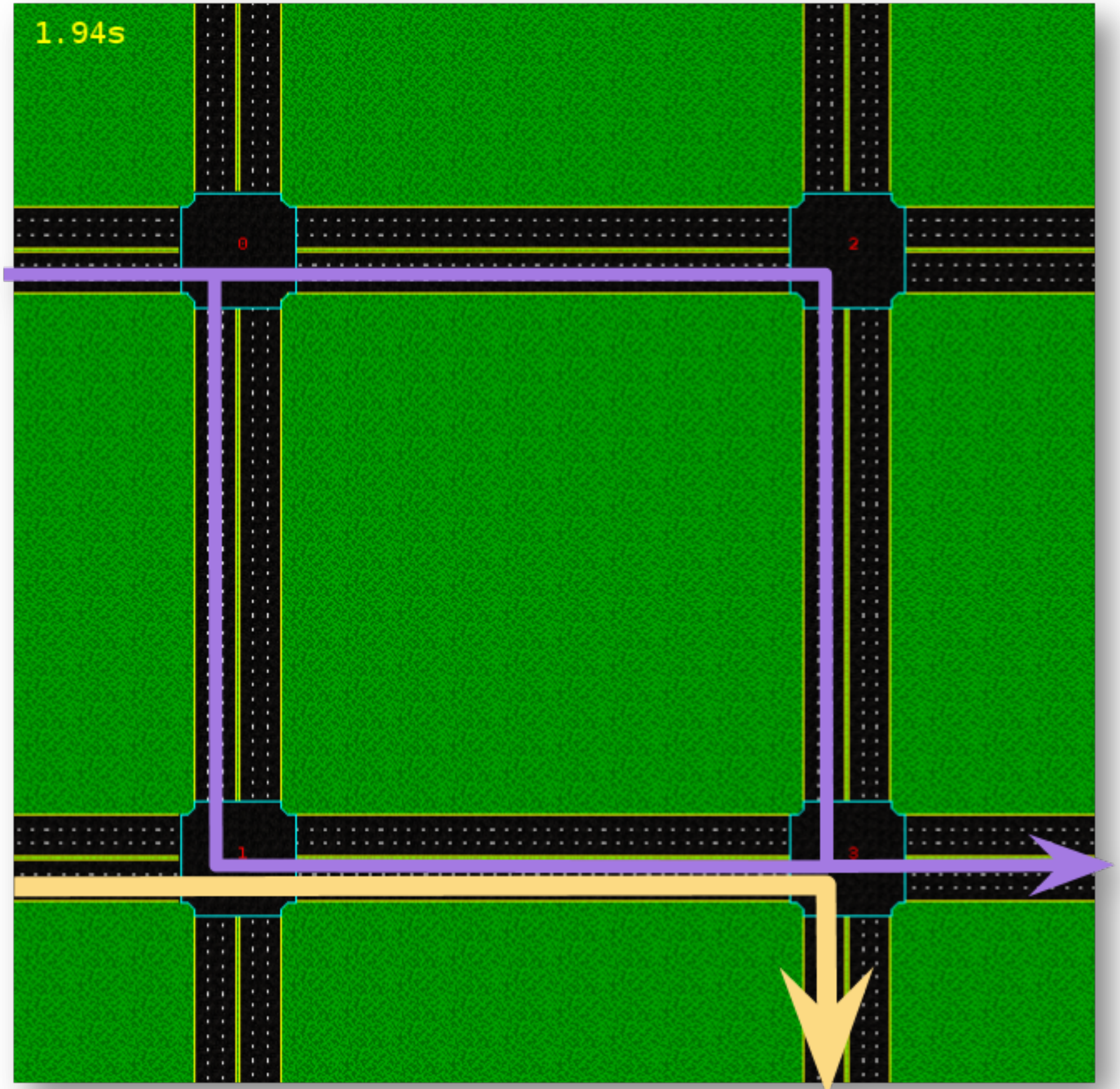

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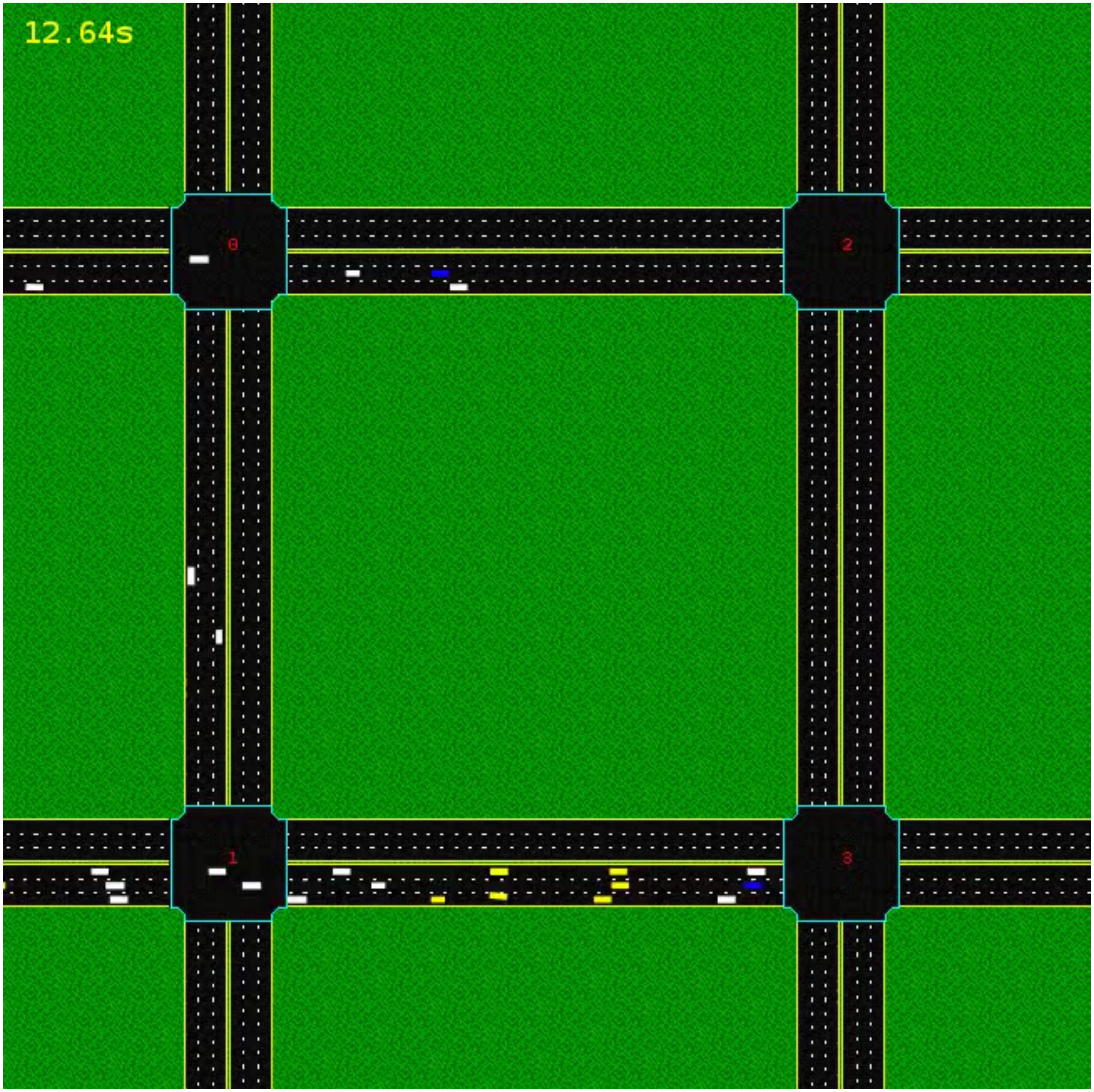

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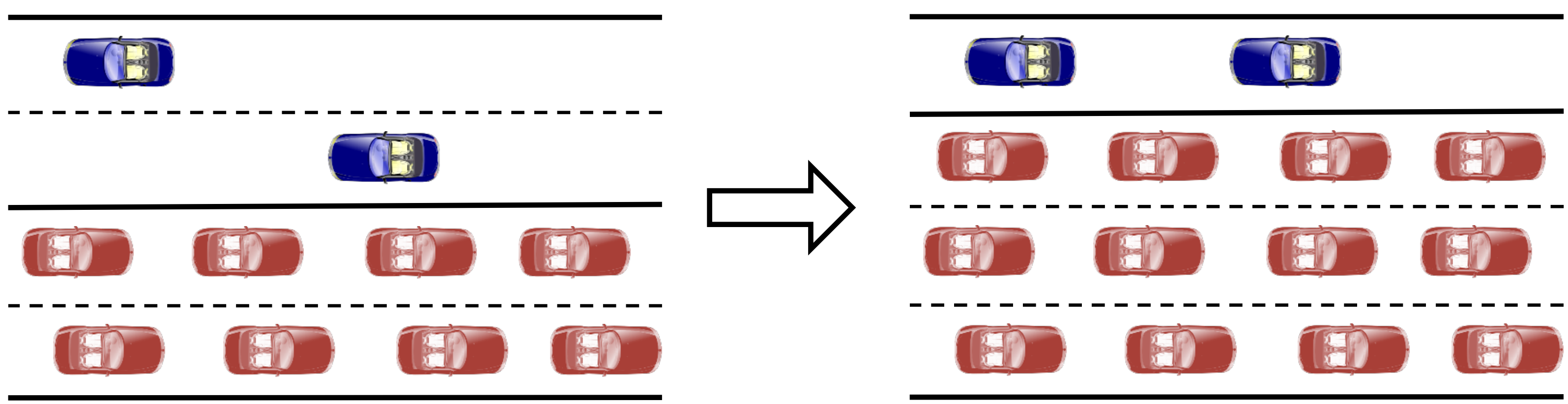
Contraflow Lane Reversal



- Increase the capacity of roads without increasing land use for transportation.
- Mainly use to control traffic during rush hour and emergency evacuation

Existing Hardware for Lane Reversal

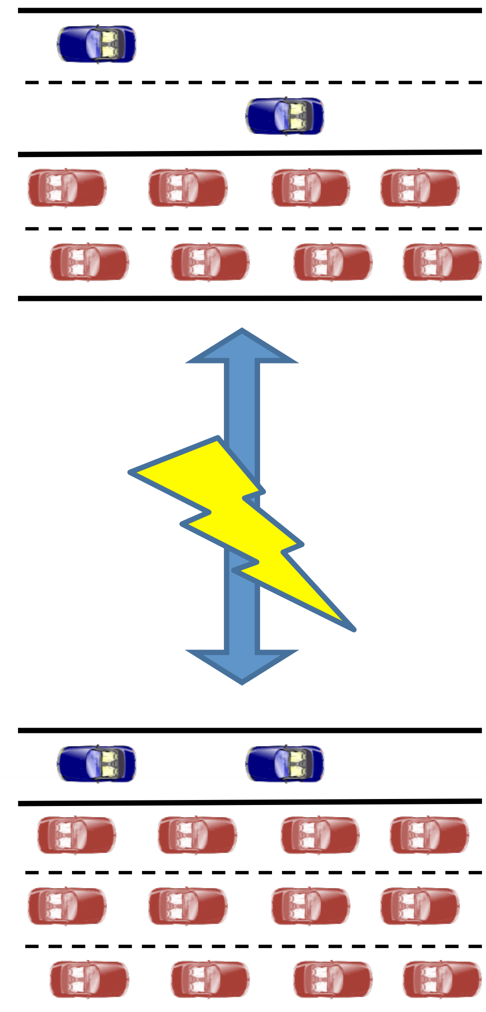
Signals of lane direction

Zipper machines

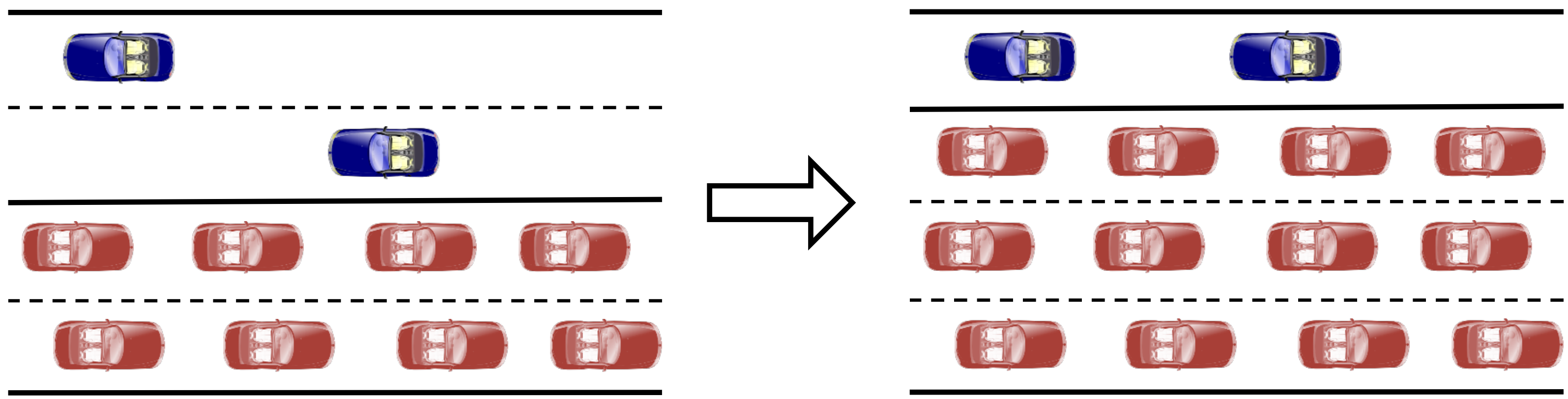
- Limitations:
  - for certain hours and locations only
  - must carefully plan ahead
- Can we do better?

Dynamic Lane Reversal

- Yes, we can do better.
- Dynamic Lane Reversal
  – Safely and quickly change lane directions at a much smaller timescale
  – Fast update of contraflow strategies for a road network
- Benefits
  – adapt to the changing traffic conditions

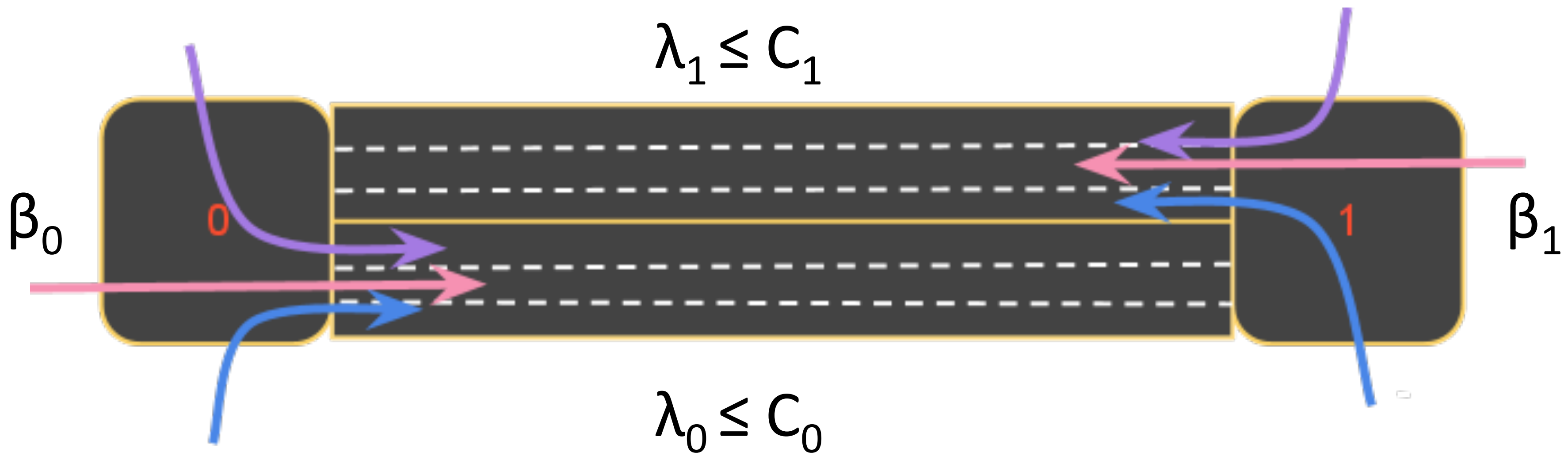


Conditions For Lane Reversal



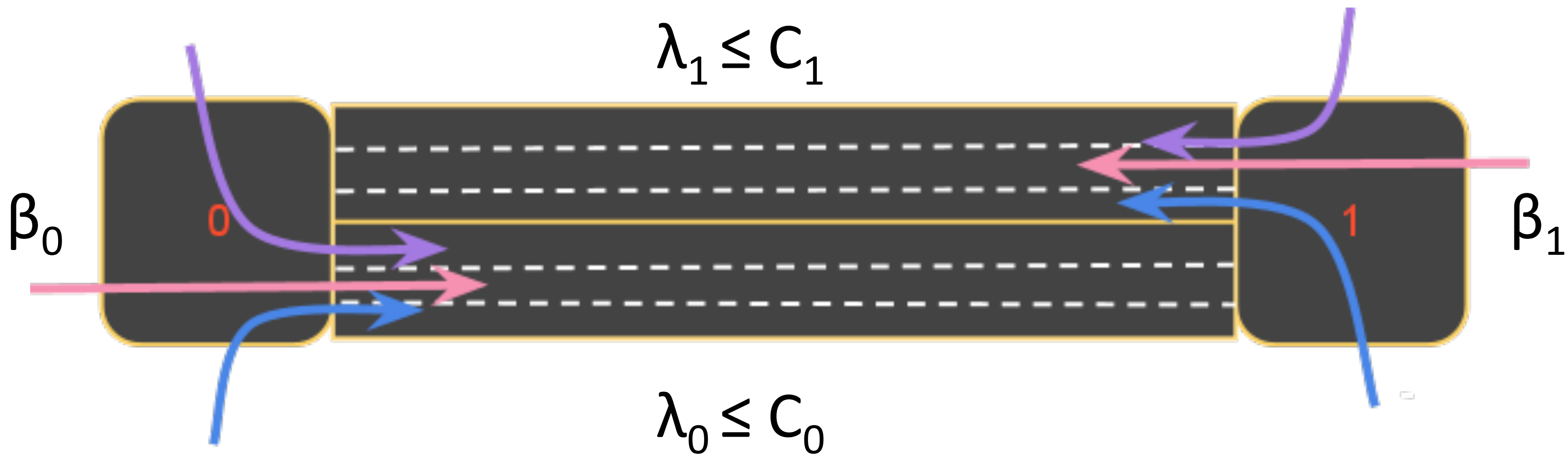
- Under what conditions would contraflow lane reversal would be beneficial?
  - A road
  - An intersection
  - A road network

Lane Reversal for a Road



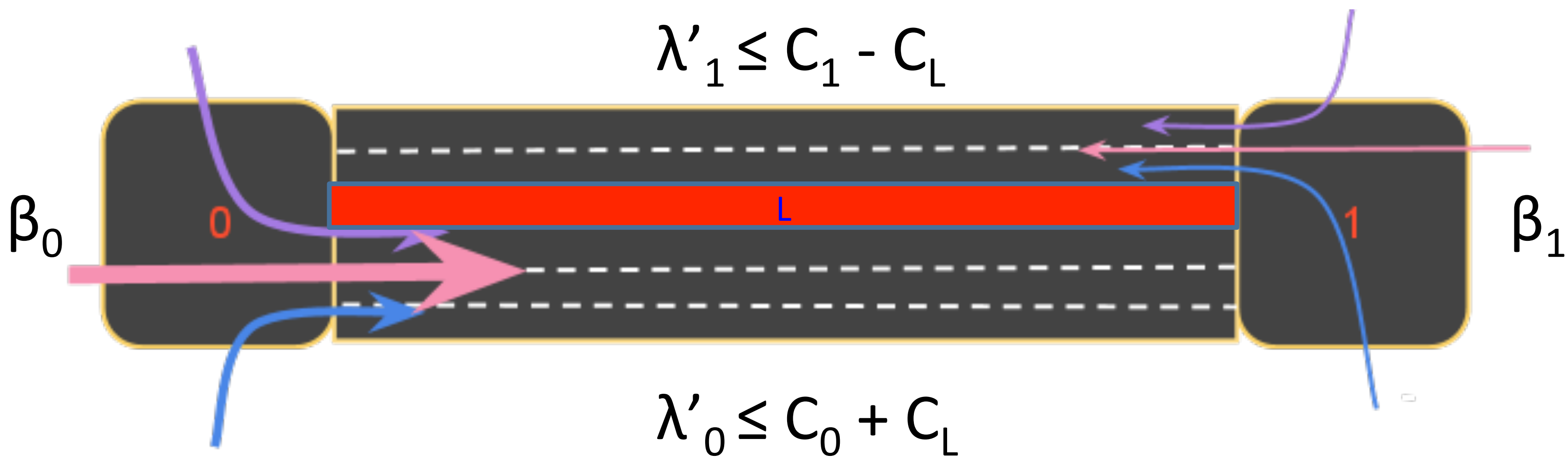
- Capacity: C_0 and C_1
- Target traffic rates: β_0 and β_1
- Effective traffic rates: $\lambda_0 = \min(\beta_0, C_0)$ and $\lambda_1 = \min(\beta_1, C_1)$
- Throughput of the road: $\lambda_0 + \lambda_1$

Saturation of a Road

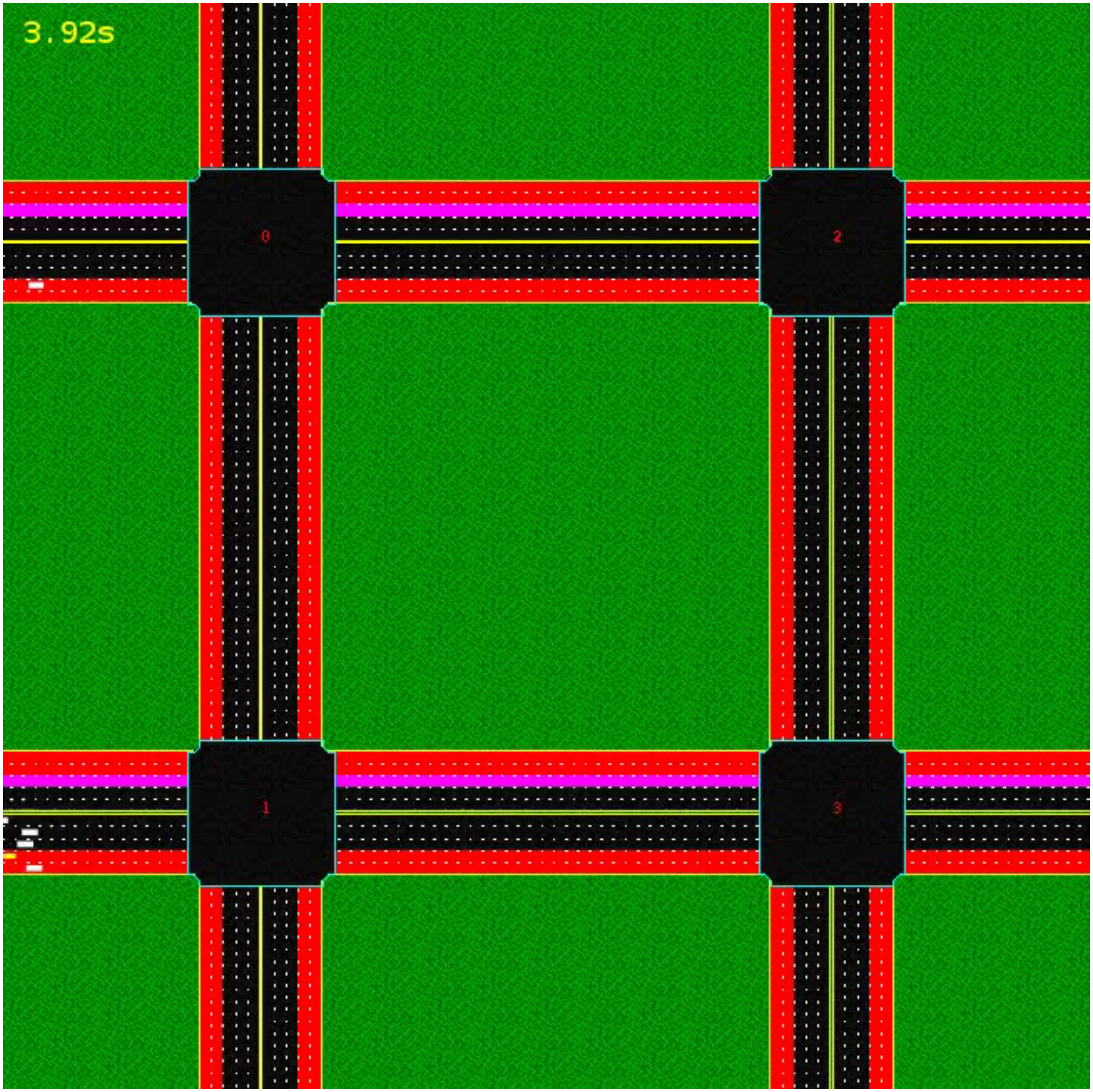


- If $\beta_0 > c_0$, the eastbound lanes are **oversaturated**.
- If $\beta_0 < c_0$, the eastbound lanes are **undersaturated**.
- If $\beta_0 = c_0$, the eastbound lanes are **saturated**.

Necessary and Sufficient Conditions for Lane Reversals for a Road



- Criterion: $\lambda_0 + \lambda_1 < \lambda'_0 + \lambda'_1$
- Lane reversal is beneficial if and only if the eastbound lanes are oversaturated by δ_0 while the westbound lanes are undersaturated by δ_1
  - $\max(C_L - \delta_1, 0) < \delta_0$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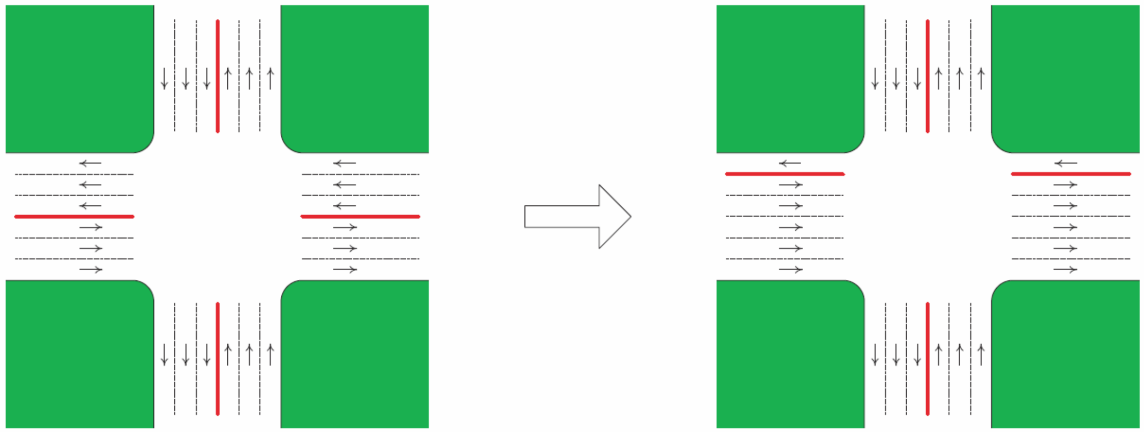
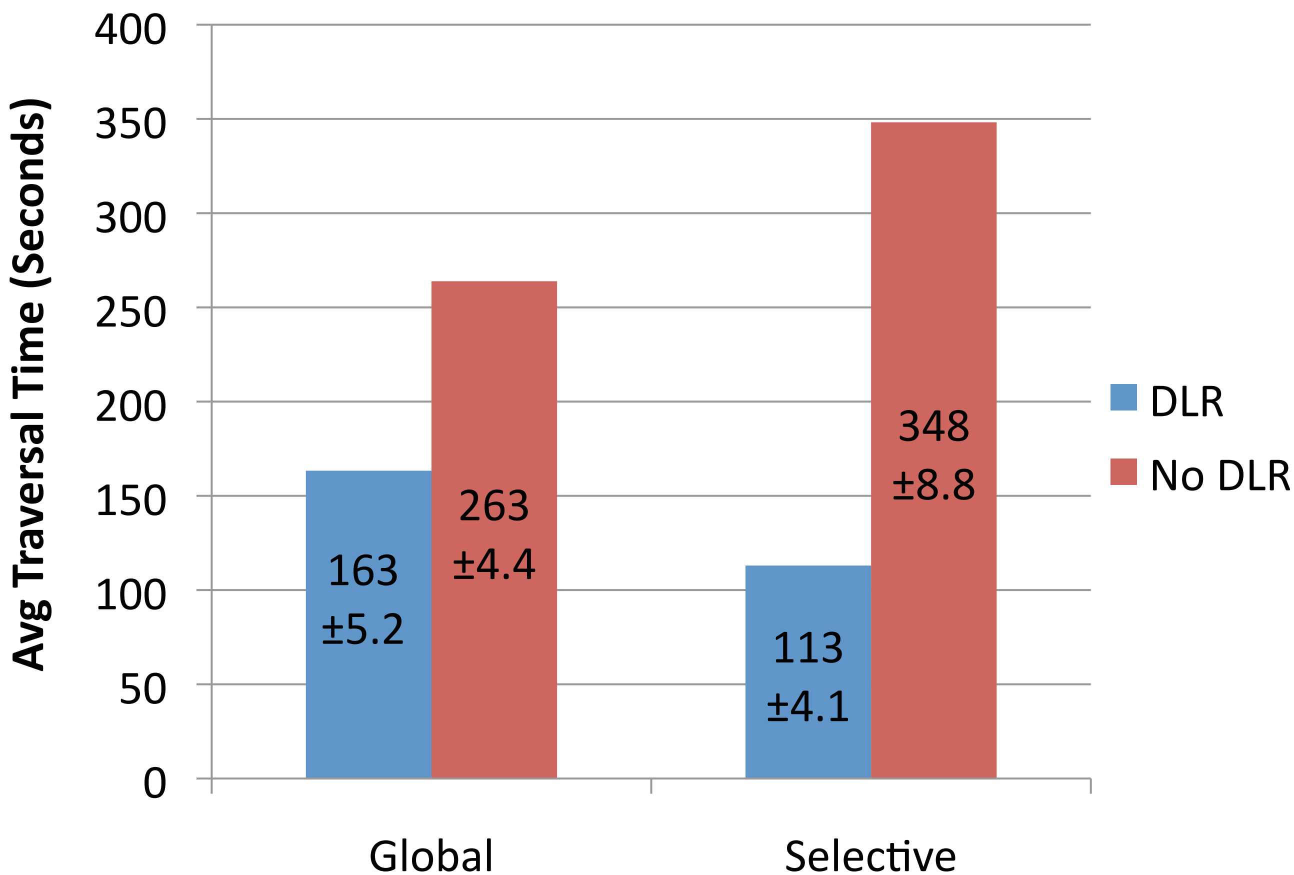
Lane Reversal for an Intersection controlled by Traffic Signals



	Before reversal	After reversal	Change
Eastbound road	4618.5 ± 8.8	5228.0 ± 12.2	13.2%
Westbound road	1184.5 ± 14.1	1124.7 ± 9.6	−5.0%
Northbound road	1711.6 ± 11.3	1700.6 ± 13.6	−0.6%
Southbound road	1712.8 ± 13.8	1714.6 ± 12.1	−0.1%
Intersection	9183.3 ± 32.4	9775.8 ± 26.6	6.5%

- Number of Trials: 30
- 1 hour of simulations in each trials

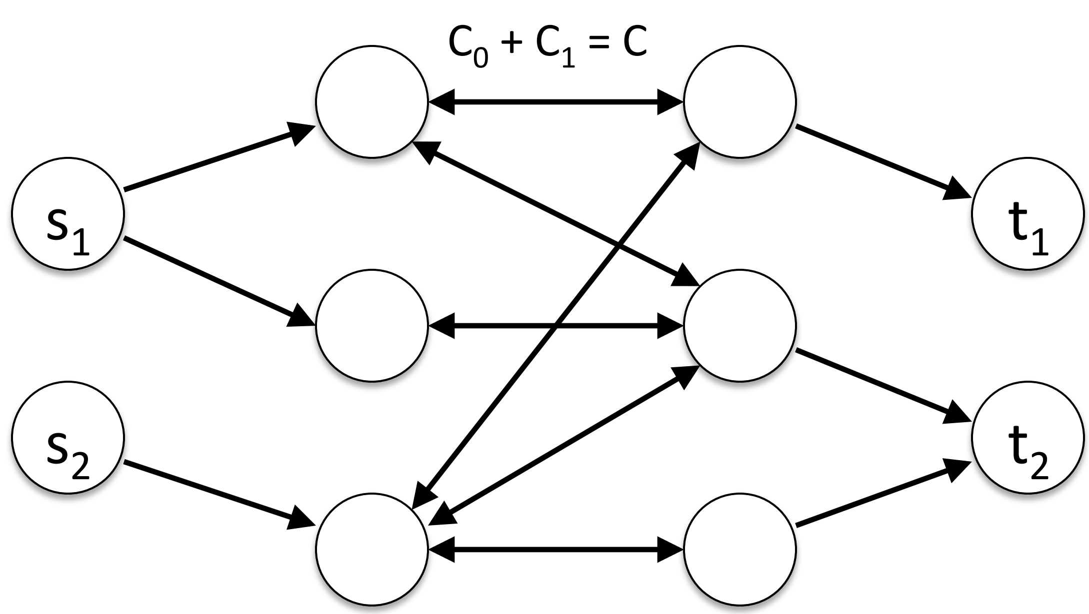
Dynamic Lane Reversal (DLR)



Experimental results averaged over 30 trials – each 1000 seconds.

Multicommodity Flow Problem

- A generalization of maximum flow problem
- An NP-hard problem
- Capacity constraint on each directed edges



Bi-Level Programming Formulation

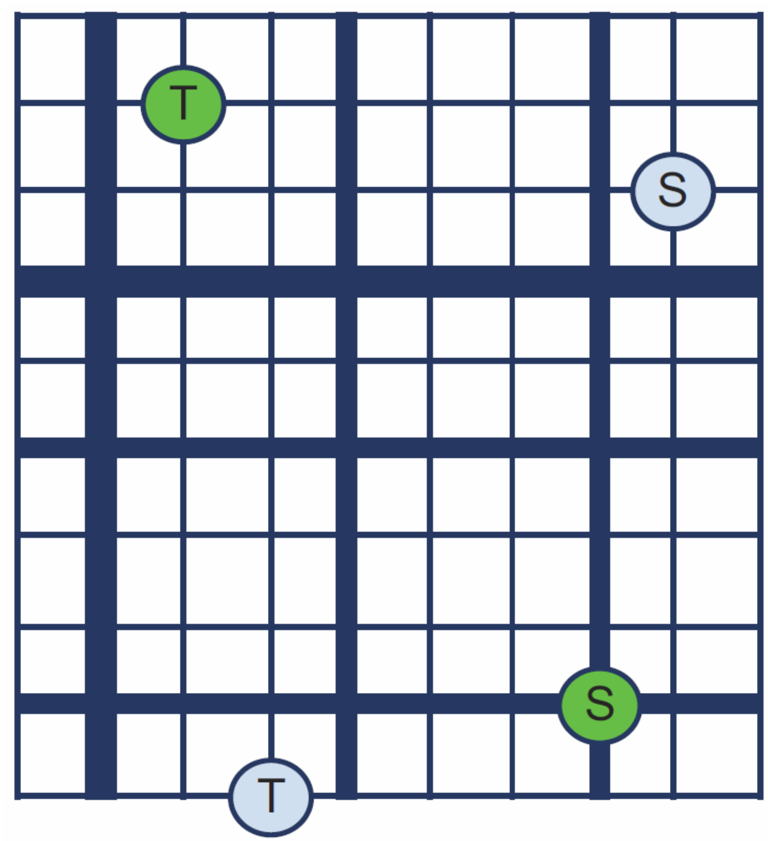
- Upper level: Allocation of capacity to each direction of all roads
- Lower level: Solve the classic User Equilibrium model by Wardrop.
- Genetic Algorithms (GAs)
  - A gene represents the capacity of each direction of roads.

Maximum Flow vs. User Equilibrium

- The maximum flow problem has a unique solution that is independent of vehicles' behavior.
- But drivers are self-interested – they do not cooperate to achieve the maximum flow
- User equilibrium – the system behavior when each drivers minimizes their travel times.

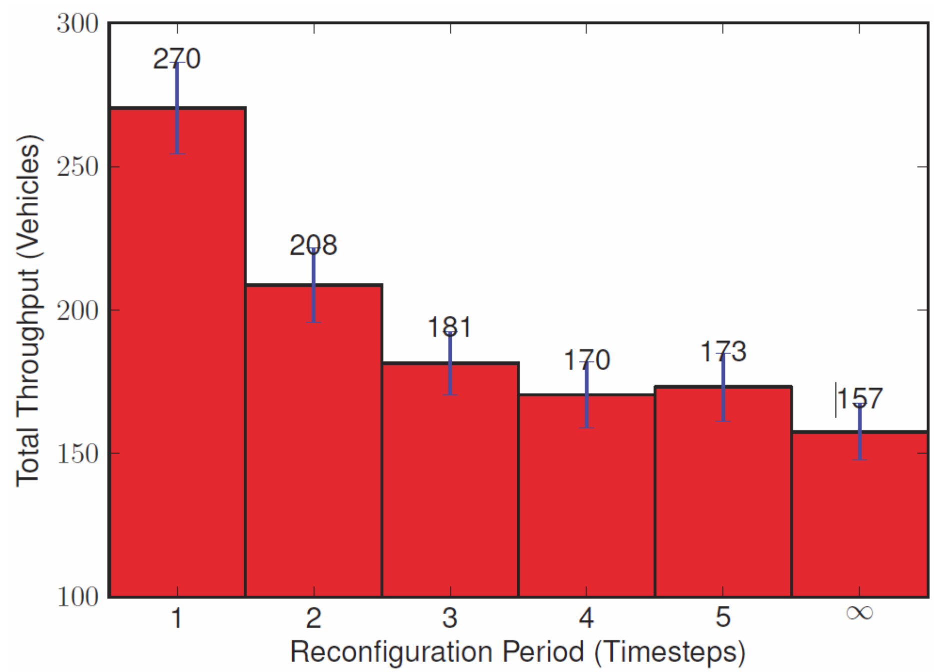
Random Road Network

- Road network on a planar grid
- Three types of roads:
  - Street (89%)
  - Arterial road (10%)
  - Main road (1%)
- Flows are generated by selecting source and sink randomly.



Experimental Results with ILP

- 34 different networks
  - 10 × 10 intersections
- 10 hours of simulations
- 4 random flows per hour
- Reconfiguration period
- Hourly reconfiguration vs. static configuration
  - 72% increase in throughput



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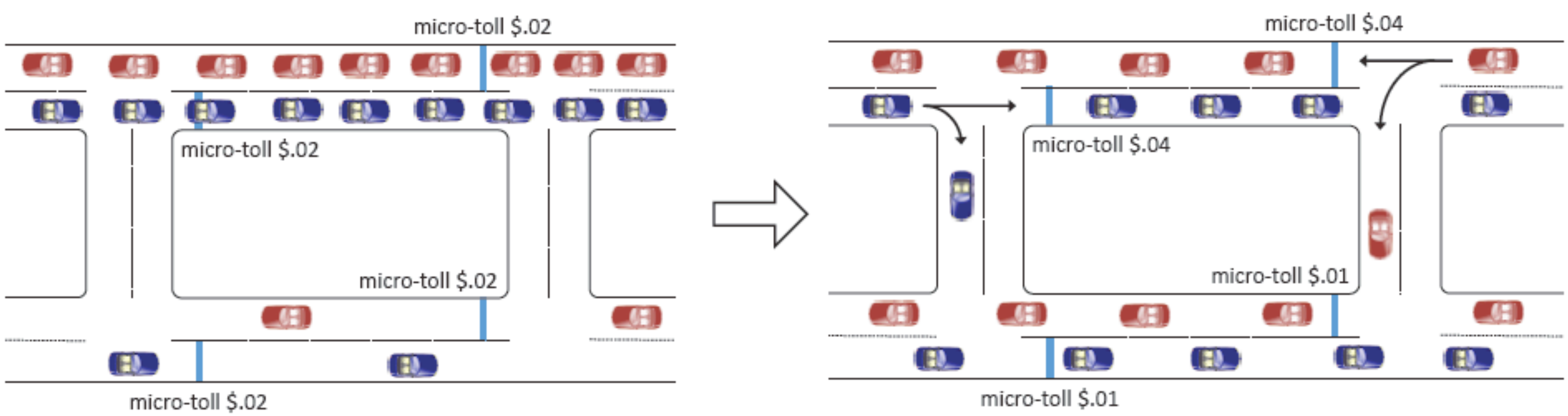
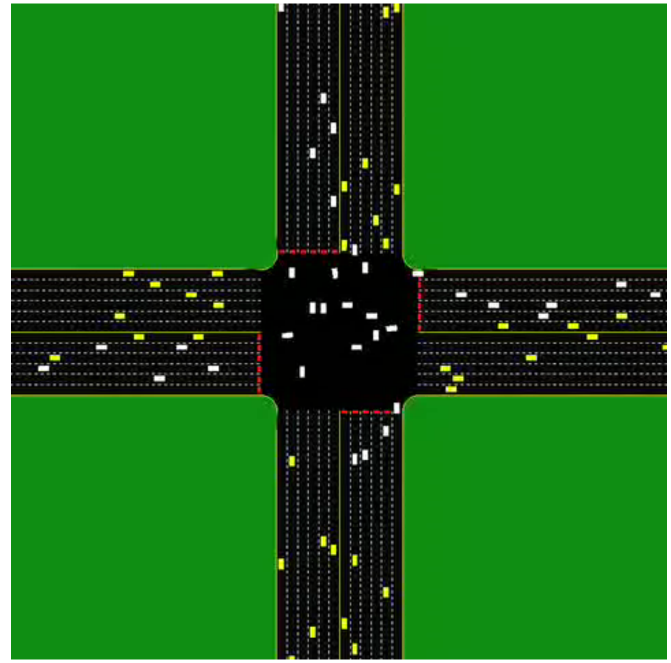
Micro-tolling

- Congestion pricing at a very fine-grained level via auction or dynamic road/intersection pricing.
- Incentivize cars to adjust their routes based on dynamically changing tolls.
- Challenges: predict how the rerouting strategy actually affects the equilibrium after prices are changed.



Conclusions and Future Work

- It is possible to make modern transportation systems much more efficient.
- Autonomous Driving
- Mixed Reality Simulation Platform
- Autonomous Intersection Management
- Traffic management for road networks
- Contraflow lane reversal
- In the future
  - More efficient transportation infrastructure to cope with increasing demand for transport



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