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
Autonomous Intersection Management

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


Grid-Based Collision Detection

Accept

Reject
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.
Mixed Reality Platform

Physical State of the Vehicle
(GPS Location, Heading, Velocity, etc.)

Sensing Information
(Distance to the virtual vehicle in front, etc.)

AIM Messages
(Request, Confirm, etc.)

Proxy vehicle
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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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: $\beta_0$ and $\beta_1$
- 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

\[ \lambda'_1 \leq C_1 - C_L \]

\[ \lambda'_0 \leq C_0 + C_L \]

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

- 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

\[ C_0 + C_1 = C \]
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 driver 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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