Artificial Intelligence
Driving Is Easy

- Eating, phone calls, texting, sleeping
- Drunk driving
- Aggressive driving
Driving Is Hard!

- Distance and velocity estimation
- Physical dexterity
- Piloting vs. navigating
- Split-second reactions
To what extent and how can a multiagent intersection control mechanism take advantage of the capabilities of autonomous vehicles in order to make automobile travel safer and faster?
Desiderata

- Autonomy
- Low communication complexity
- Sensor model realism
- Protocol standardization
- Deadlock/starvation avoidance
- Incremental deployability
- Safety
- Efficiency
Measuring Efficiency

Metrics

 HttpResponseMessage: increased travel time due to intersection

HttpResponseMessage: total vehicles/time/lane
Simulator

“aim3”  http://code.google.com/p/aim3

~20K lines of Java

Discrete time (0.02 s)

Non-holonomic vehicle motion

Point-to-point/broadcast communication

Vehicle spawned using Poisson process
Vehicle-to-Intersection

- **Driver agents** call ahead to reserve a region of space-time.
- **Intersection manager** approves or denies based on an intersection control policy.
- Vehicles may not enter the intersection without a reservation.
- **Driver agents** trust the intersection manager in the intersection.
I’m arriving at time t...
Sounds good to me!
Protocol

REQUEST
source_id
destination_id
vehicle_length
vehicle_width
maximum_acceleration
minimum_acceleration
minimum_velocity
front_wheel_displacement
rear_wheel_displacement
max_steering_angle
max_turn_per_second
emergency
traversal_proposals
arrival_time
arrival_velocity
maximum_velocity

CANCEL
source_id
destination_id
reservation_id

DONE
source_id
destination_id

AWAY
source_id
destination_id

ACZ_REQUEST
source_id
destination_id
start_lane
target_lane
vehicle_length

ACZ_CONFIRM
source_id
destination_id
ticket_number
start_lane
target_lane
acz_distance

ACZ_EXIT
source_id
destination_id

ACZ_CANCEL
source_id
destination_id
ticket_number

ACZ_ENTERED
source_id
destination_id
ticket_number

_EMERGENCY_STOP
source_id
destination_id

ACZ_REJECT
source_id
destination_id
ticket_number

REJECT
source_id
destination_id
next_communication
reason

CONFIRM
source_id
destination_id
reservation_id
arrival_time
early_error
late_error
arrival_lane
departure_lane
arrival_velocity
acz_distance
accelerations
Protocol

The Important Points

- Set of messages and rules
- Digitally signed
- Agent implementations do not matter
- Assume communication failure
- Current mechanisms subsumed
The FCFS Policy

“First come, first served”
Primary policy
Grid of reservation tiles
Internal simulation of vehicles’ trajectories
Reservation Tile

“Granularity”
Time $t$
FCFS Video
Vehicle-to-Vehicle

- Driver agents broadcast a claim
- Define relations over claims:
  - Conflict
  - Priority
  - Dominance
- Permissibility
I’m arriving at time $t$...

Uh, I’m also arriving at time $t$...

I’m arriving at time $t$...

Time $t$ for me too...

No, I’m arriving at time $t$...

Uh, I’m also arriving at time $t$...
<table>
<thead>
<tr>
<th>Source ID</th>
<th>Message ID</th>
<th>IXN ID</th>
<th>Stopped at IXN</th>
<th>Arrival Lane</th>
<th>Departure Lane</th>
<th>Arrival Time</th>
<th>Departure Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>13</td>
<td>5</td>
<td>False</td>
<td>1</td>
<td>2</td>
<td>128479</td>
<td>128523</td>
</tr>
<tr>
<td>2</td>
<td>6</td>
<td>5</td>
<td>False</td>
<td>1</td>
<td>2</td>
<td>128479</td>
<td>128613</td>
</tr>
<tr>
<td>3</td>
<td>10</td>
<td>5</td>
<td>False</td>
<td>1</td>
<td>2</td>
<td>128479</td>
<td>128497</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>5</td>
<td>False</td>
<td>1</td>
<td>2</td>
<td>128479</td>
<td>128564</td>
</tr>
</tbody>
</table>
V2V Video
Human Usability
The Benefits

- Some people enjoy driving
- Classic cars
- Transition period
- Concepts extend to cyclists, pedestrians
The FCFS-Signal Policy

- Autonomous vehicles use protocol
- Human-driven vehicles use signals
- Policy contains a signal model
- Uses state of relevant signal at arrival time:
  - **Green**: accept
  - **Yellow**: reject
  - **Red**: FCFS
- Set aside off-limits tiles during green phases
Single-Lane
Failure Mode Analysis

- Enable collision detection
- Trigger incidents, examine aftermath
- Construct crash log
Mitigating Catastrophe

Assume intersection manager can detect

**Reaction:**
- Refuse future reservations
- **Emergency-Stop** message

**Oblivous vs. passive vs. active**

**What if vehicles do not receive?**
Average Number Of Crashed Vehicles

- 6 Lanes
- 3 Lanes

- Passive
  - 40%
  - 80%

Tuesday, November 10, 2009
best case # of cars today: 1
worst case # of cars involved: 4.5
accidents due to driver error: ~96%

1 - (4.5 * 0.04) : 82%
Multiple Intersections
What’s The Big Deal?

- Protocol considerations
- Downstream effects
- Driver agent navigation
- Upstream effects
Admission Control Zone (ACZ)
Admission Control Zone (ACZ) Capacity
I’m arriving at time $t$...
Admission Control Zone (ACZ)
Sounds good to me...
I’m arriving at time $t'$...
Admission Control Zone (ACZ)
Admission Control Zone (ACZ)

I'm away!

Tuesday, November 10, 2009
Admission Control Zone

ACZ Capacity

I'm away!

Admission Control Zone (ACZ)
Multi-intersection Video
Other Results

- Effects of multiple intersections
- Emergency vehicles
- On-the-fly policy switching
- Learning policy selection
Related Work
Intelligent Vehicles

Object detection and tracking
- Stereo far-IR/fusion (Mählisch et al. 2005)
- Gray-valued video (Gepperth et al. 2005)

Lane following
- NN for Road Departure Warning (Kohl et al. 2006)
- “No Hands Across America” (Pomerleau 1995)
- Robust to lighting/road conditions (Watanabe and Nishida 2005)
- Unmarked roads (Ramström and Christensen 2005)

Adaptive cruise control (Jaguar, Honda, BMW, Nissan, Toyota)
Related Work
Traffic Signals

- TRANSYT (Robertson 1969)
- SCOOT (Hunt et al. 1981)
- Cooperative traffic signals (Roozemond 1999)
- Q-learning (Abdulhai et al. 2003)
- Learning Classifier Systems (Bull et al. 2004)
- MAS + game theory (Bazzan 2005)
Related Work

Autonomous Vehicles at Intersections

- “Potential collision points” (Rasche and Naumann 1998)
- Steering algorithms/collision avoidance (Reynolds 1999)
- Platoons (Clement 2002, Hallé and Chaib-draa 2005)
- Physical robots (Kolodko and Vlacic 2003)
Future Directions
Mixed Simulation
Future Directions
Proteus Robots
Future Directions
Exploring Asynchronicity
Future Directions
Exploring Asynchronicity