A Multiagent Approach to Autonomous Intersection Management

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Outline

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Background

- Autonomous Robots — A popular goal in AI
- Already exist for complex tasks
  - Soccer Robots
  - Navigating the Desert
- 2007 DARPA Urban Challange (DARPA, 2007)
  - Do not need to sense traffic signals or signs
  - Work in sparse traffic
  - *Suburban* rather than dense, urban setting

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Motivation for Automated Drivers

- Traffic and Automobile collisions are a significant cost to society
  - Loss of life
  - Damaged property
  - Loss of time and productivity
- Some statistics[1] from USA
  - 46 hours — annual time spent waiting in traffic per capita (2004)
  - 21.2 billion litres — fuel used per year by engines idling
  - US$63 billion — annual financial cost of traffic congestion (2002)
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Requirements of an Automated Driver

- Obey speed limit and other road rules
- Detect and track pedestrians
- Stay in the appropriate lane
- Navigate to the destination
- Park (parallel, perpendicular, angle, etc.)

Features already developed and deployed to production vehicles

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Intersection Management

- On the open road, autonomous drivers have less of a challenge
  - Simple, reactive behaviour — keep the vehicle in the lane, maintain safe distances, avoid obstacles
- If most drivers on the road are automated, current intersection management systems are horribly inefficient
- A new system can leverege the new or improved abilities of automated drivers
- **Intersection Management** — focus of this paper

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Intersections

- Many vehiclies coming from different directions
- Vehicle paths frequently cross
  - Collisions between vehicles moving in different directions often lead to greater damage or injury
- Between 25% and 45% of collisions happen at intersections
  - Intersections make up a very small portion of roadways

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Existing Systems

Uncontrolled Intersections

Image from `http://www.mto.gov.on.ca/english/dandv/driver/handbook/section2.4.0.shtml`

Stop/Yield Signs

Image from `http://flickr.com/photos/nep/307553468/`

Traffic Lights

Image from http://flickr.com/photos/photopia/1500098646/

Roundabouts

Image from `http://www.ellemosh.com/wp-content/uploads/2008/02/magic_roundabout.jpg`

Interchanges

Image from http://commons.wikimedia.org/wiki/Image:Viaduct_in_Puxi,_Shanghai.jpg

Existing Systems

- Coordinated by several factors
  - Laws
  - Signs & signalling systems
  - Small variations between provinces/states
  - Larger variations between countries
- Safety buffers compensate for human limitations
  - Street signs are large, simple, brightly coloured (easy to see and understand)
  - Periods where all traffic lights are red (slow rection time, impatient drivers)
  - Following distances to allow for slow reaction times
  - Speed limits to ensure drivers have time to react
- Fundamentally designed for human drivers — if all drivers are automatic, mechanism is inefficient. It is working with agents for which it wasn't designed.

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New Systems

- Use automated drivers' increased precision of control and sensing
- New options for communication between vehicles enterings and traversing an intersection
  - Drivers can call ahead to let the intersection know which direction they will go
  - If only a single vehicle wishes to use the intersection, it should not have to wait
  - If no vehicles cross paths, none should have to wait
- Sophisticated, two-way communication is not feasible with human drivers
  - Too much communication under tight time constraints
  - Humans are likely to make mistakes

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New Systems

- Single-agent solution is not viable
  - Single point of failure, with drastic consequences for failure
  - Enormous computational and communication requirements
  - Drivers sometimes have conflicting objectives
- Each car/driver is an agent
  - Self-interested – wants to minimise travel time, travel distance and fuel consumption
- Extensions
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- Sensor Model Realism
- Protocol Standardisation
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- Incremental Deployability
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Outline

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- Central idea of the solution in this paper
- Much like reserving a hotel room
  - Visitor makes a request for a room with conditions
  - If exact conditions can not be met, hotel may supply a counter offer
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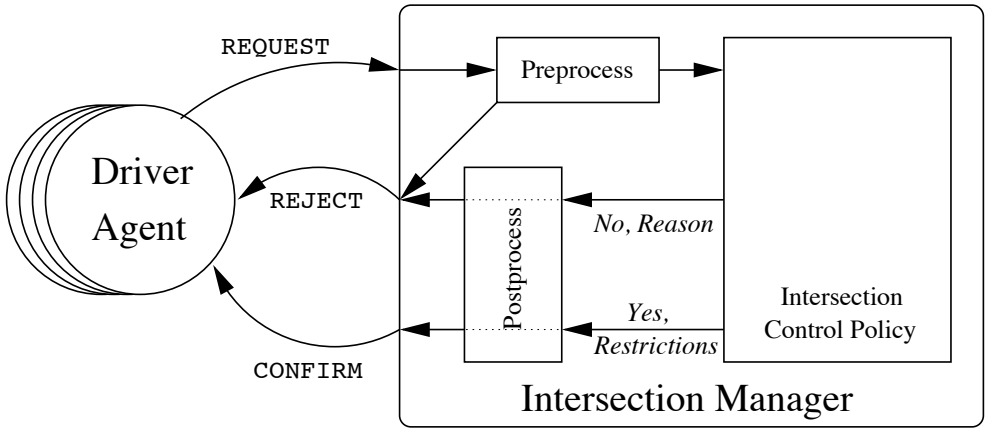

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  - Drivers call ahead to the intersection manager
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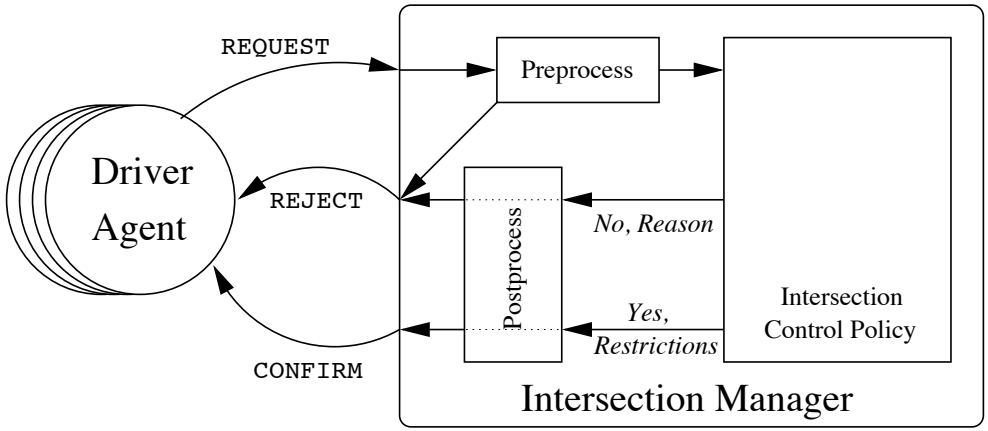

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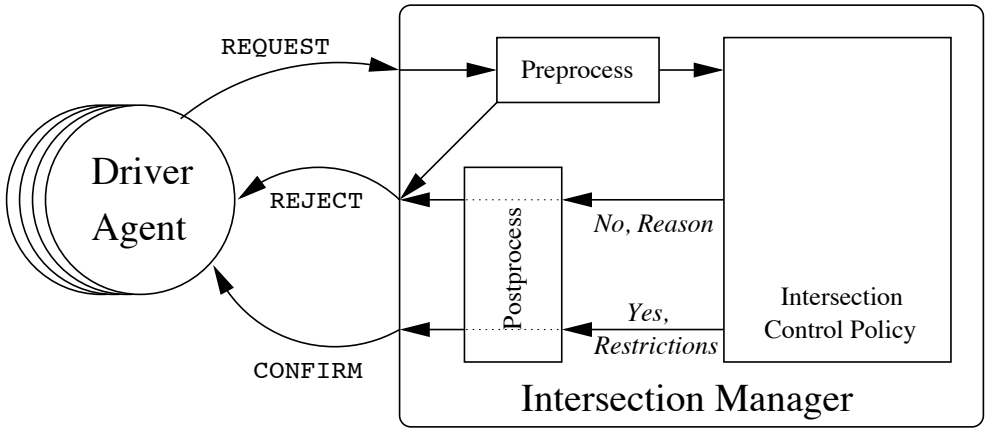

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- Four-way, multi-lane intersection (right-hand traffic simulated, but not required)
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  - Maximum vehicle-detection sensor range
- Drivers can read sensors
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- All information between agents and the intersection goes through a single, monitorable channel
- Limited number of message types
  - Drivers have REQUEST, CHANGE-REQUEST, CANCEL, DONE
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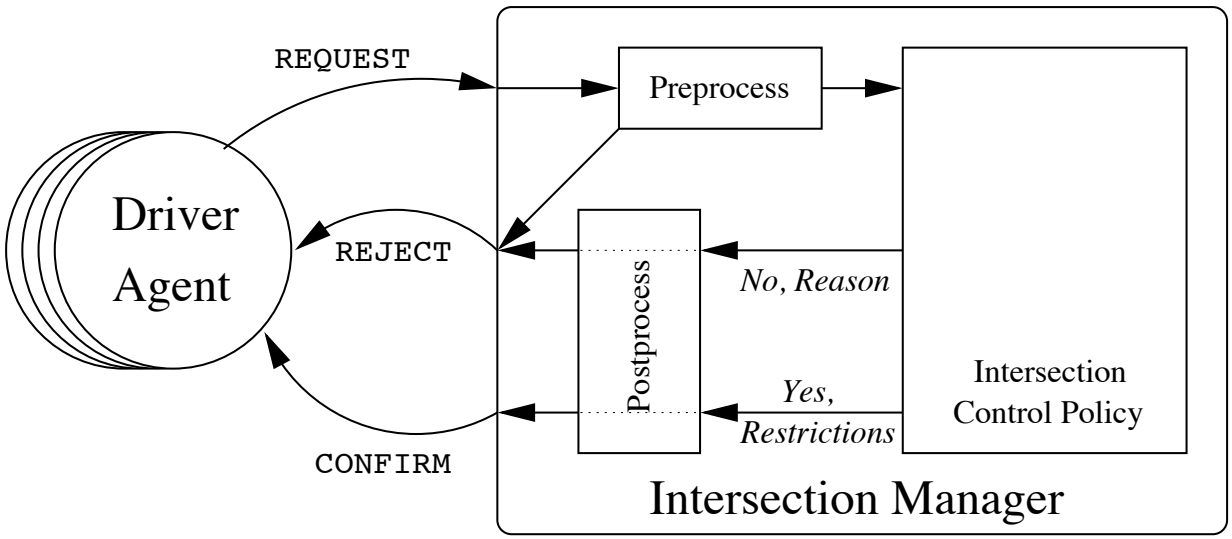
Intersection Policies

- The "brains" of the system



(Dresner and Stone, 2008)

The First Come First Served Policy

- Intersection is divided into a grid of reservable tiles
- Driver approaching intersection issues request
- Intersection manager runs internal simulation of driver in intersection
  - If car will occupy a reserved tile, then reject policy
  - Otherwise reserve appropriate tiles at appropriate times and accept reservation.
- Simple
- Early trials led to modifications to improve safety, efficiency and reliability.

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Improvements:

- Intersection determines the outbound lane
- Put limits on acceleration in the intersection
  - Either maximum acceleration or no acceleration
- No vehicle gets a reservation unless vehicle in front has one
  - Estimate position using vehicle's reported velocity and ETA.
  - Maintain estimate of front-most vehicle in each lane with a rejected request
  - Reject request if vehicle is behind this estimate
  - Otherwise, process normally. If rejected, update cut-off distance, otherwise reset distance to infinity.

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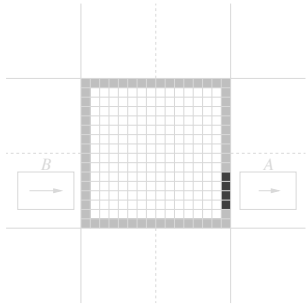
Improvements:

- Timeouts after rejected requests
- Static & dynamic buffers around vehicles
- Edge Tiles – Safety buffer for cars leaving intersection

(a) A turns right in front of B.

(b) B cannot stop in time.



(c) B must slow down preemptively.

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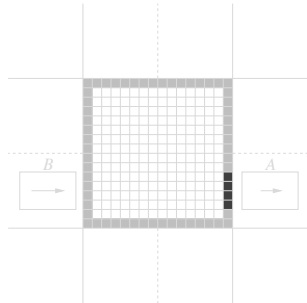

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(Dresner and Stone, 2008)

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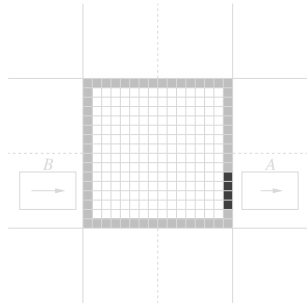

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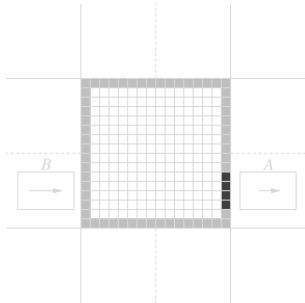

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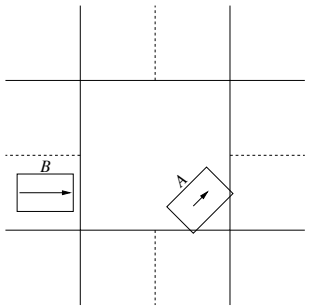

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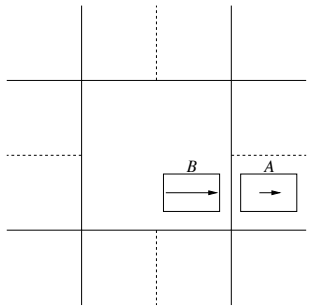

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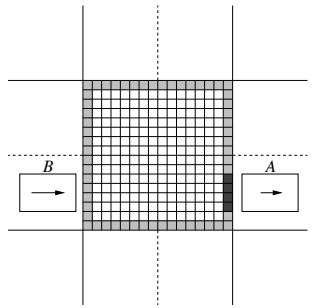

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- Extend existing infrastructure – traffic lights
- Assume there is a human driver everywhere one *could* be
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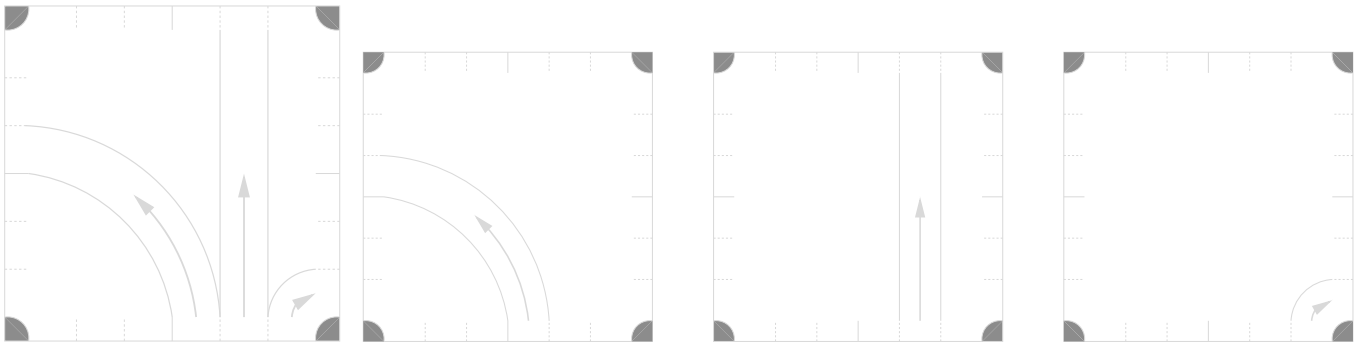

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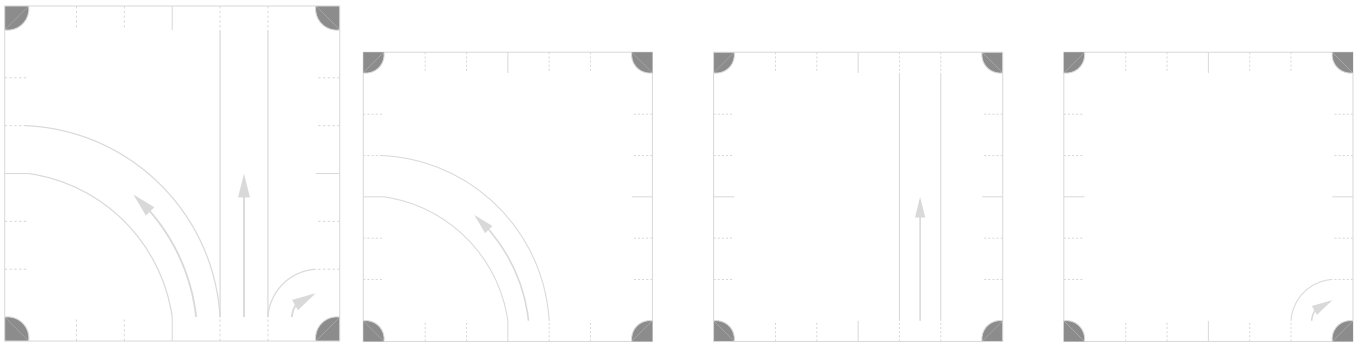

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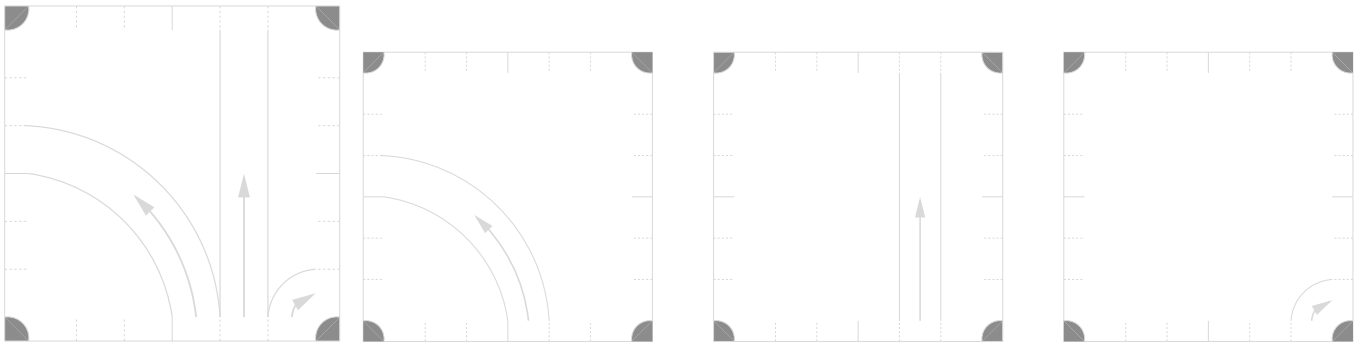

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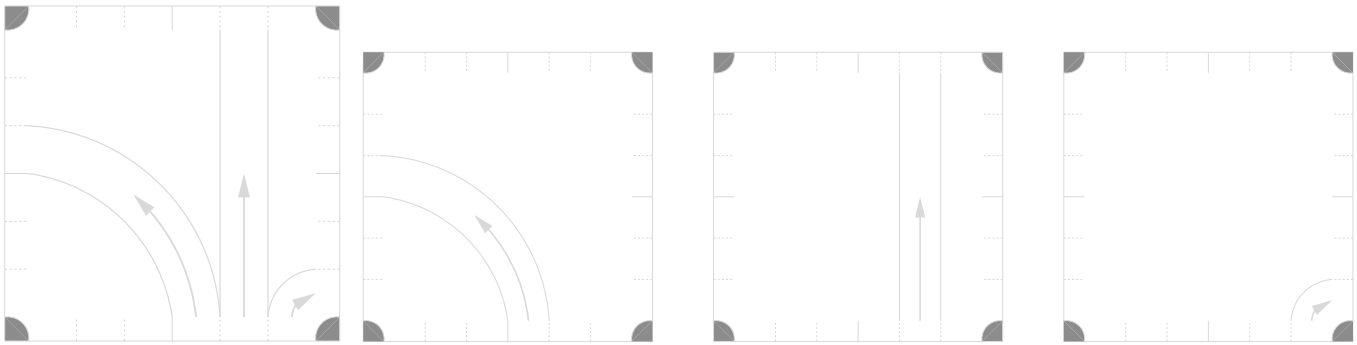

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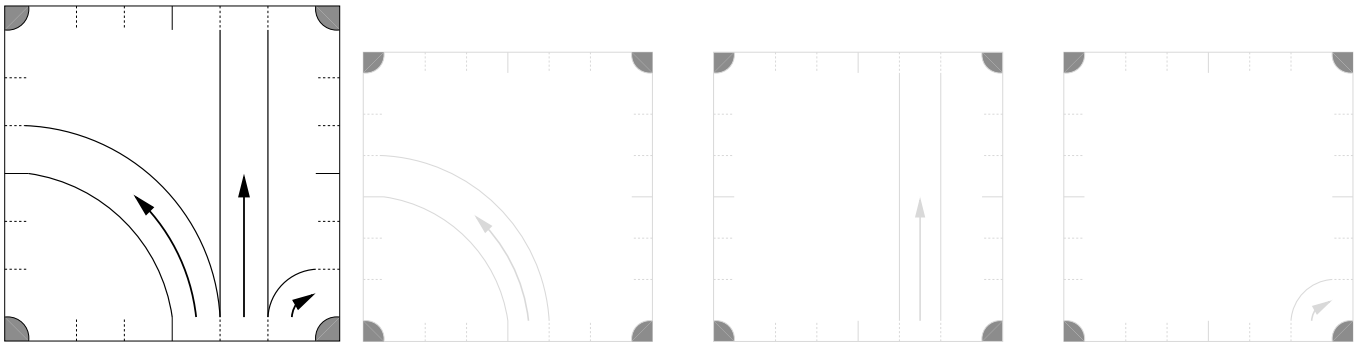

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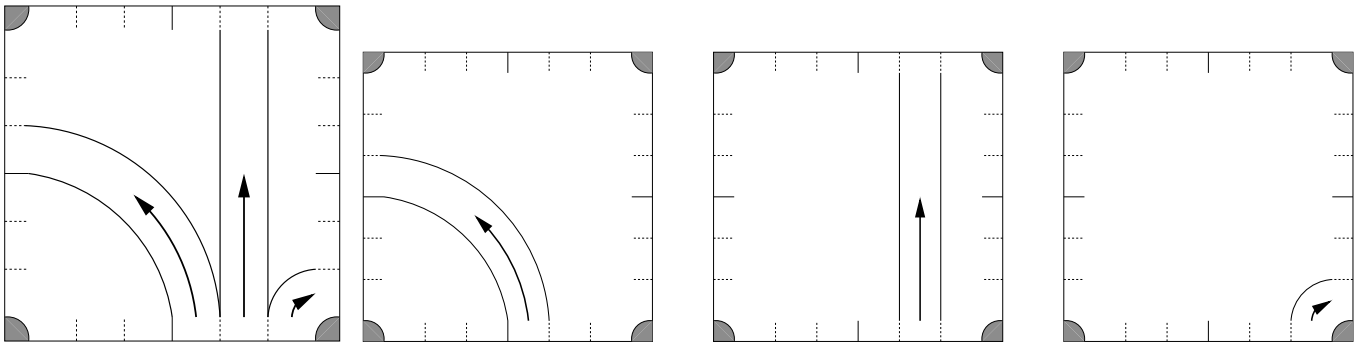

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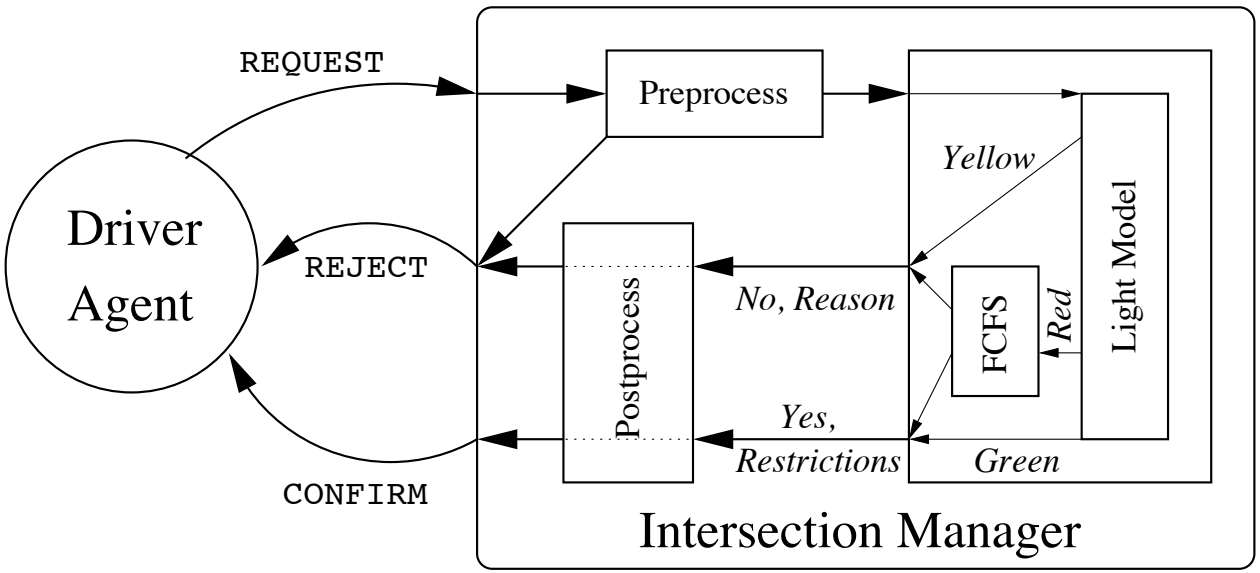

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Emergency Vehicles

- If an emergency vehicle is approaching the intersection, only accept requests from vehicles in that lane.
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- Simulation adds "Emergency Vehicle" flag
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Outline

Comparison to existing systems

Reduce delay by up to two orders of magnitude against traffic lights

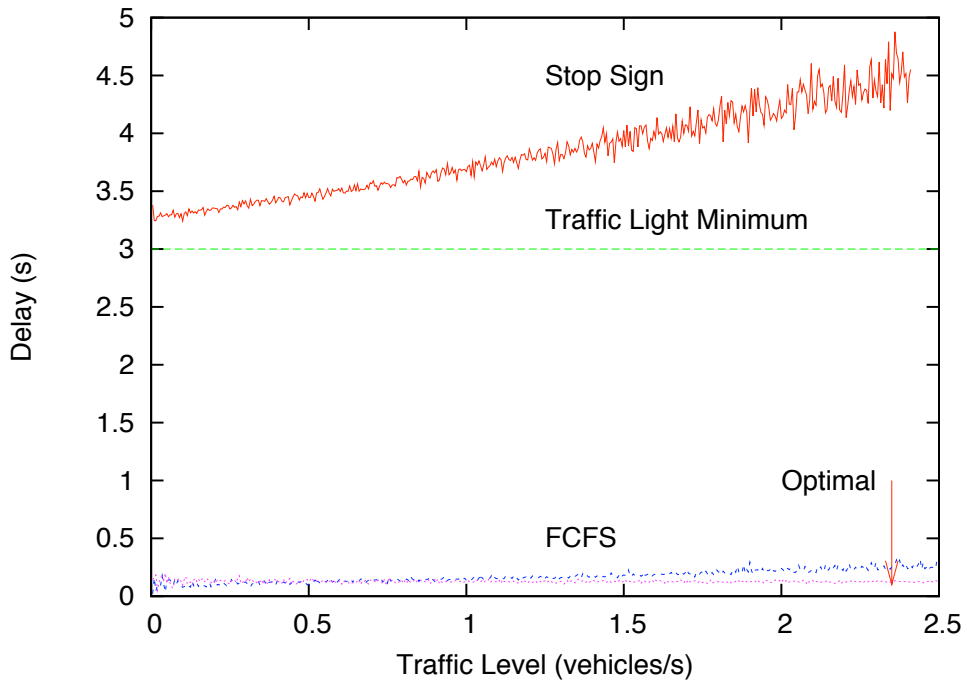

Figure: FCFS policy (100% autonomous drivers)

(Dresner and Stone, 2008)

Incremental Deployment

- At each point there is always incentive to upgrade
  - Intersections have lower delay for all drivers
  - Automated drivers have lower delay than human drivers
- When population of automated drivers increases, there is incentive to upgrade policy from ALL-LANES to SINGLE-LANE

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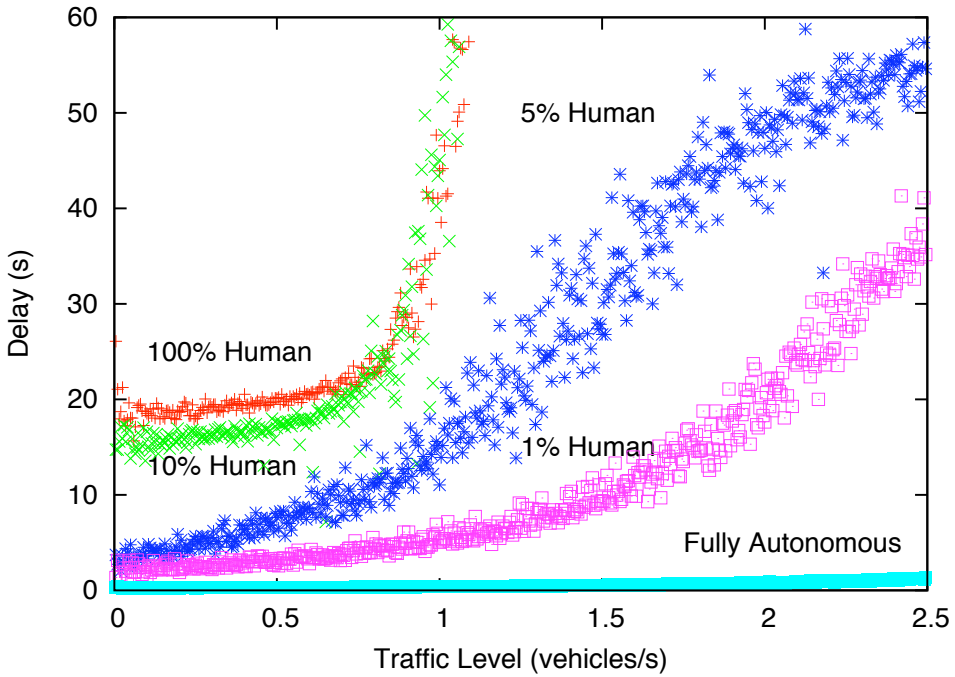

Figure: ALL-LANES light model ($\geq$ 10% Human), SINGLE-LANE ($<$ 10% Human)

(Dresner and Stone, 2008)

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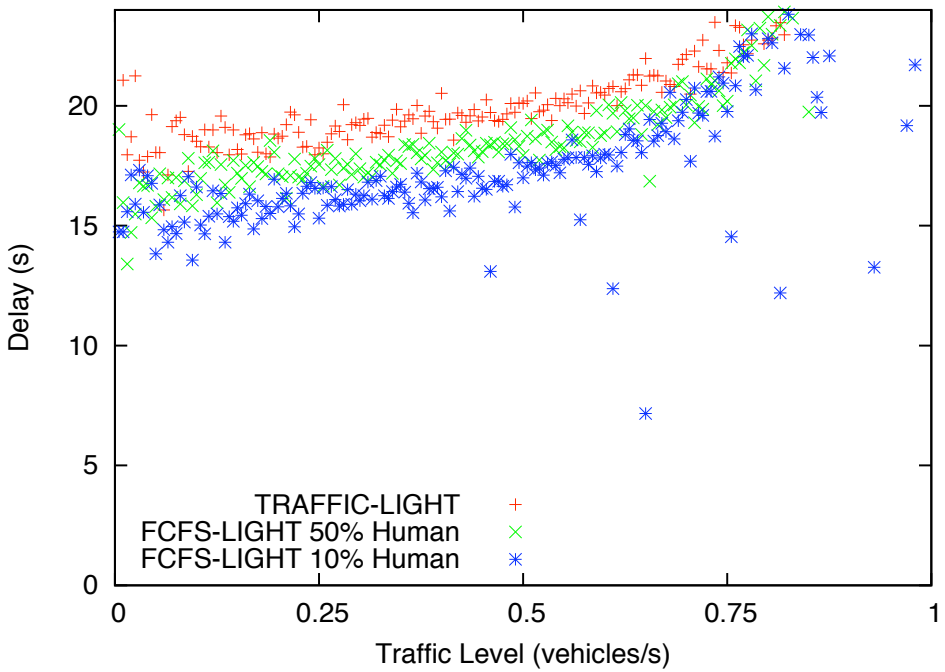

Figure: ALL-LANES light model. TRAFFIC-LIGHT is equivalent to 100% human drivers

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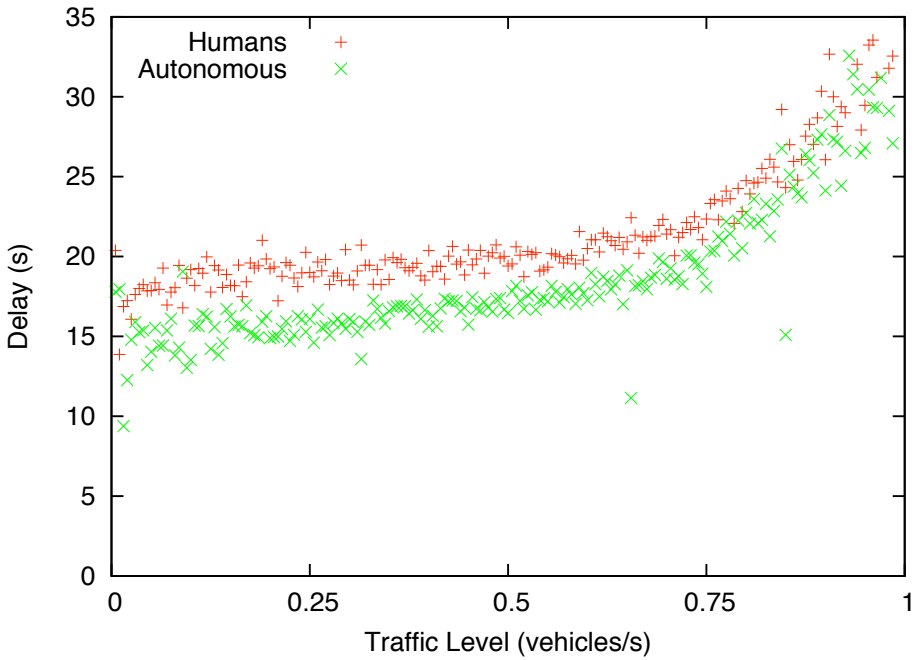

Figure: ALL-LANES light model. 50% human drivers

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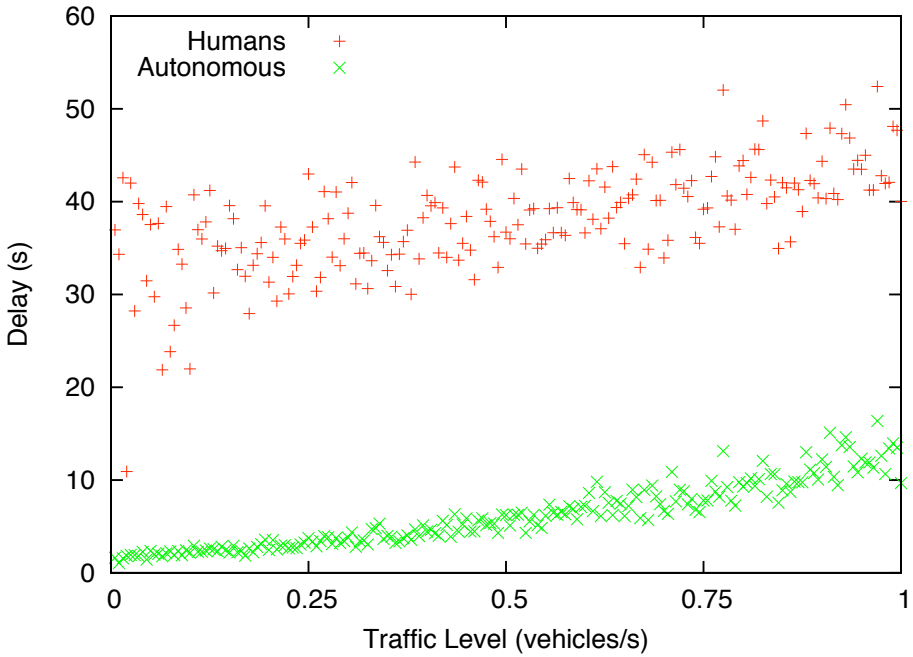

Figure: SINGLE-LANE light model. 5% human drivers

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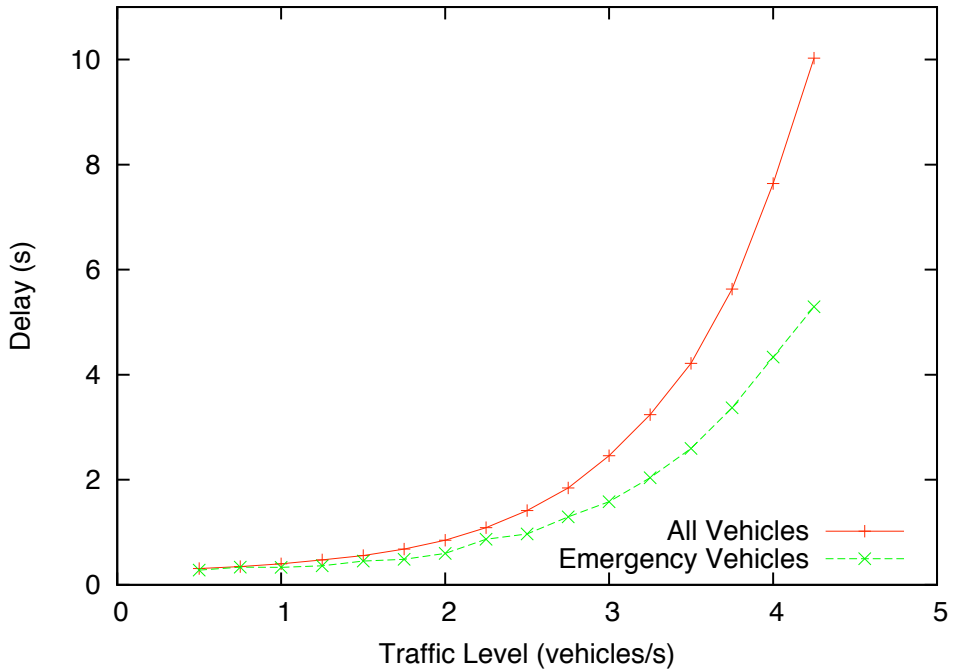
Emergency Vehicles

Emergency vehicles benefit most when traffic is heavy



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Outline

Summary

- Provided an intersection management system that meets the desiderata
- Always provides incentive to upgrade & incrementally deployable
- Benefits increase as number of automated vehicles increase
- Emergency vehicles have lower delay
- Can reduce the number and severity of collisions

Pros and Cons

Pros

- Simulations well designed and detailed
- Solution is simple and effective
- Always an incentive to see implementation through to completion
- No reliance on un-invented sensor/communication technology.

Cons

- Traffic spawned randomly, not according to any patterns
- "ALL-LANES" Traffic light system doesn't match real traffic lights

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Future Work

- Real world tests
- More sophisticated simulator physics
  - Non-level, non-square intersections
  - Potholes, debris, oil
  - Weather conditions (rain, snow, ice)
- Detailed safety studies
- More sophisticated intersection policies
- Sensors to detect human-driven vehicles (induction loops already used at traffic lights)
- Malicious agents

Outline

References

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- K. Dresner and P. Stone (2008). A Multiagent Approach to Autonomous Intersection Management. In *Journal of Artificial Intelligence Research*, Vol 31, pp. 591-656.
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Any Questions?