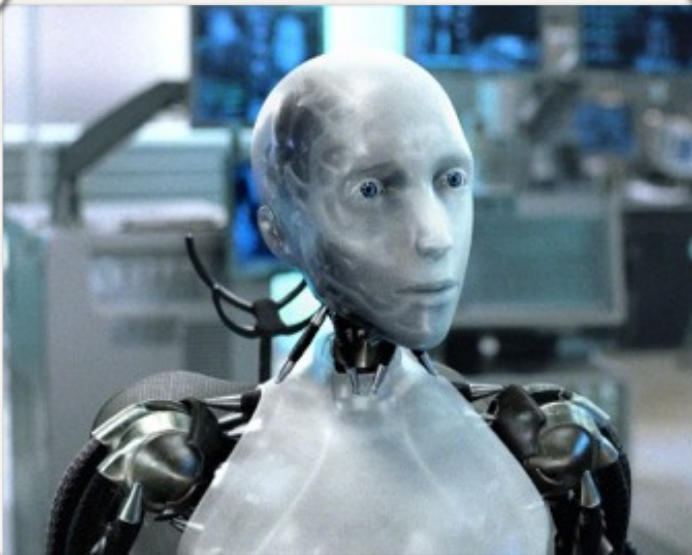
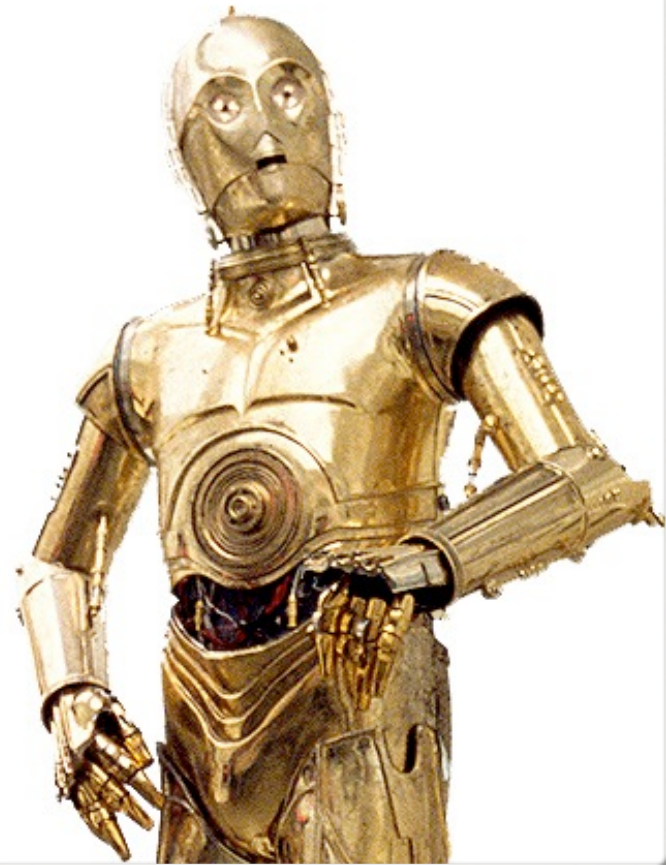
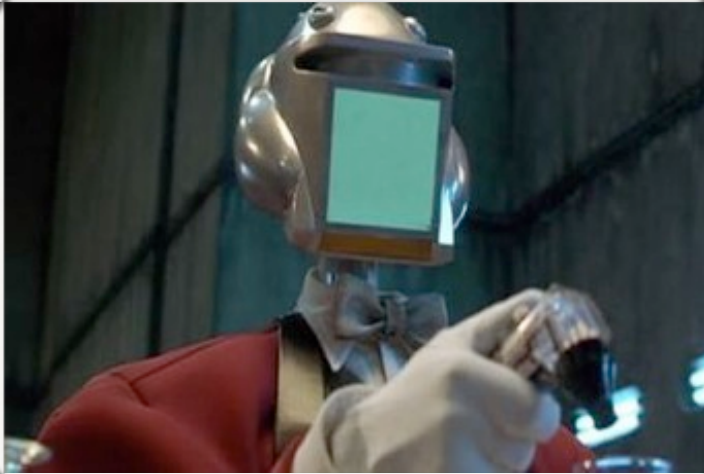


Artificial Intelligence













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

























The Question

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

 **Delay:** increased travel time due to intersection

 **Throughput:** 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

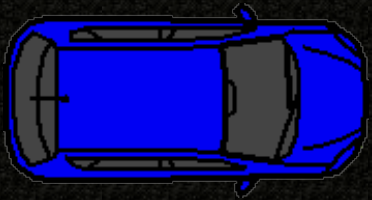
 Point-to-point/broadcast communication

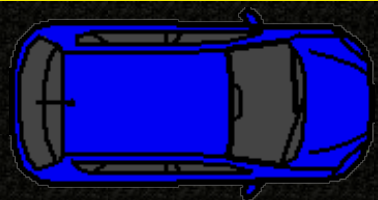
 Vehicle spawned using Poisson process

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
traversal_angle
arrival_time
max_emergency_braking

ACZ_CONFIRM

source_id
destination_id
ticket_number
start_lane
target_lane
acz_distance

ACZ_EXIT

source_id
destination_id

CONFIRM

source_id
destination_id
reservation_id
arrival_id
early_time
late_error
arrival_error
departure_lane
arrival_lane
acz_velocity
acz_distance
accelerations

CANCEL

source_id
destination_id
reservation_id

AWAY

source_id
destination_id

DONE

source_id
destination_id

REJECT

source_id
destination_id
next_communication
reason

ACZ_CANCEL

source_id
destination_id
ticket_number

EMERGENCY_STOP

source_id
destination_id

ACZ_REQUEST

source_id
destination_id
start_lane
target_lane
vehicle_length

ACZ_REJECT






source_id
destination_id
reason

ACZ_ENTERED





source_id
destination_id
ticket_number

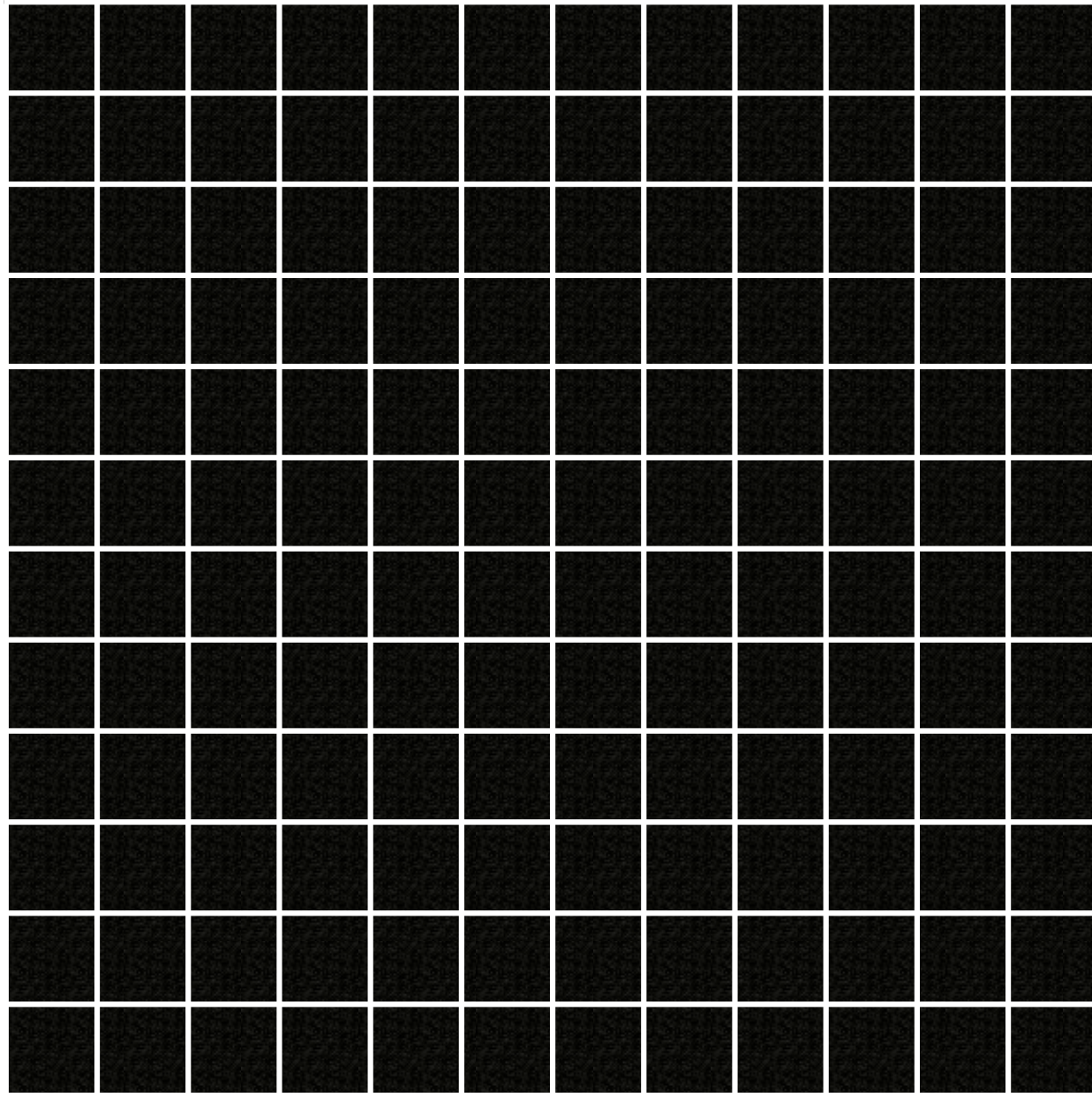
Protocol

The Important Points

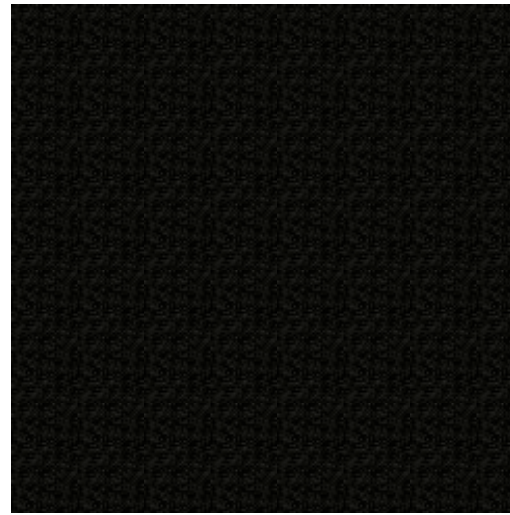
-  Set of messages and rules
-  Digitally signed
-  Agent implementations do not matter
-  Assume communication failure
-  Current mechanisms subsumed

The FCFS Policy

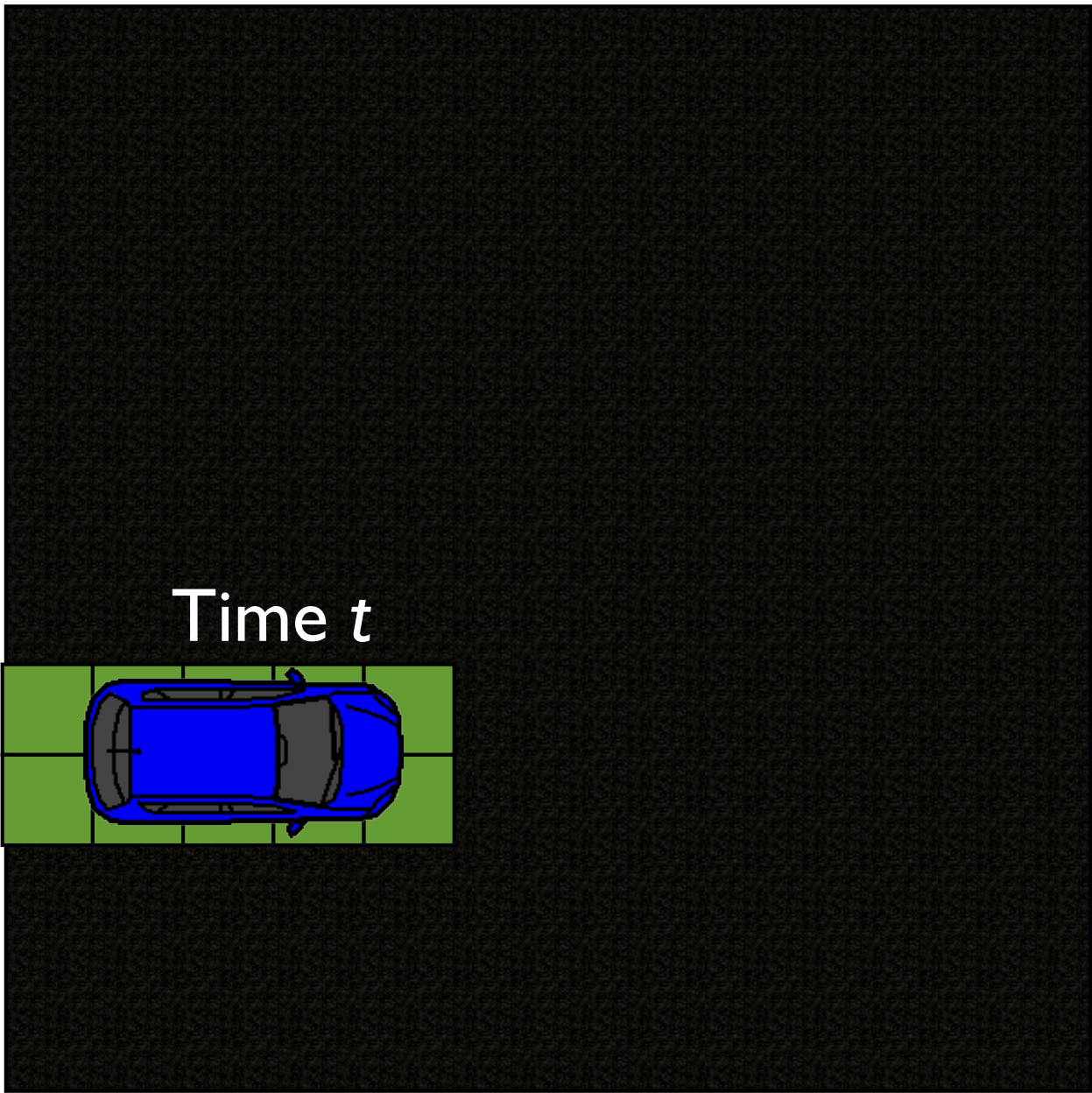
-  “First come, first served”
-  Primary policy
-  Grid of **reservation tiles**
-  **Internal simulation** of vehicles’ trajectories

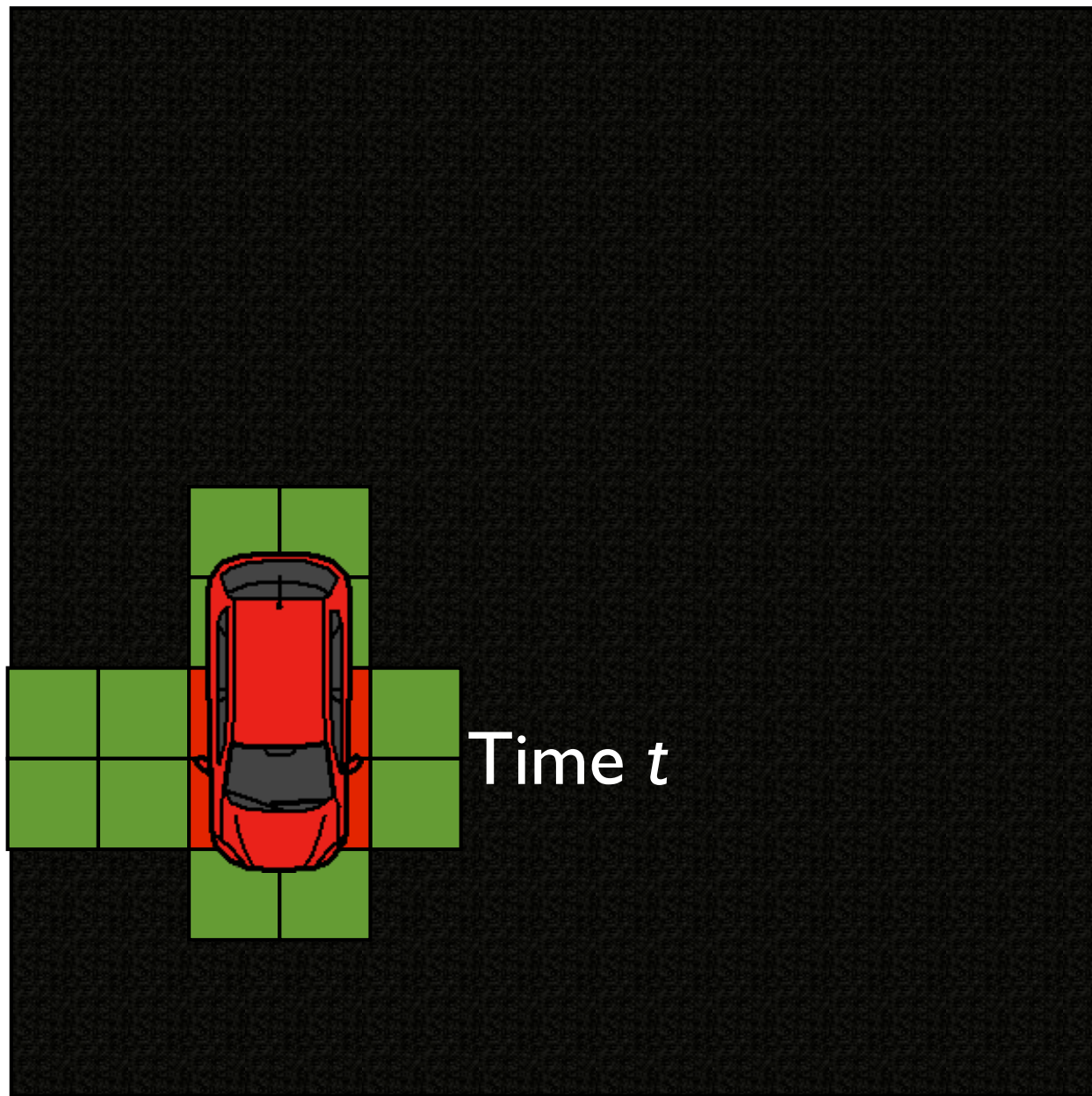


Reservation Tile

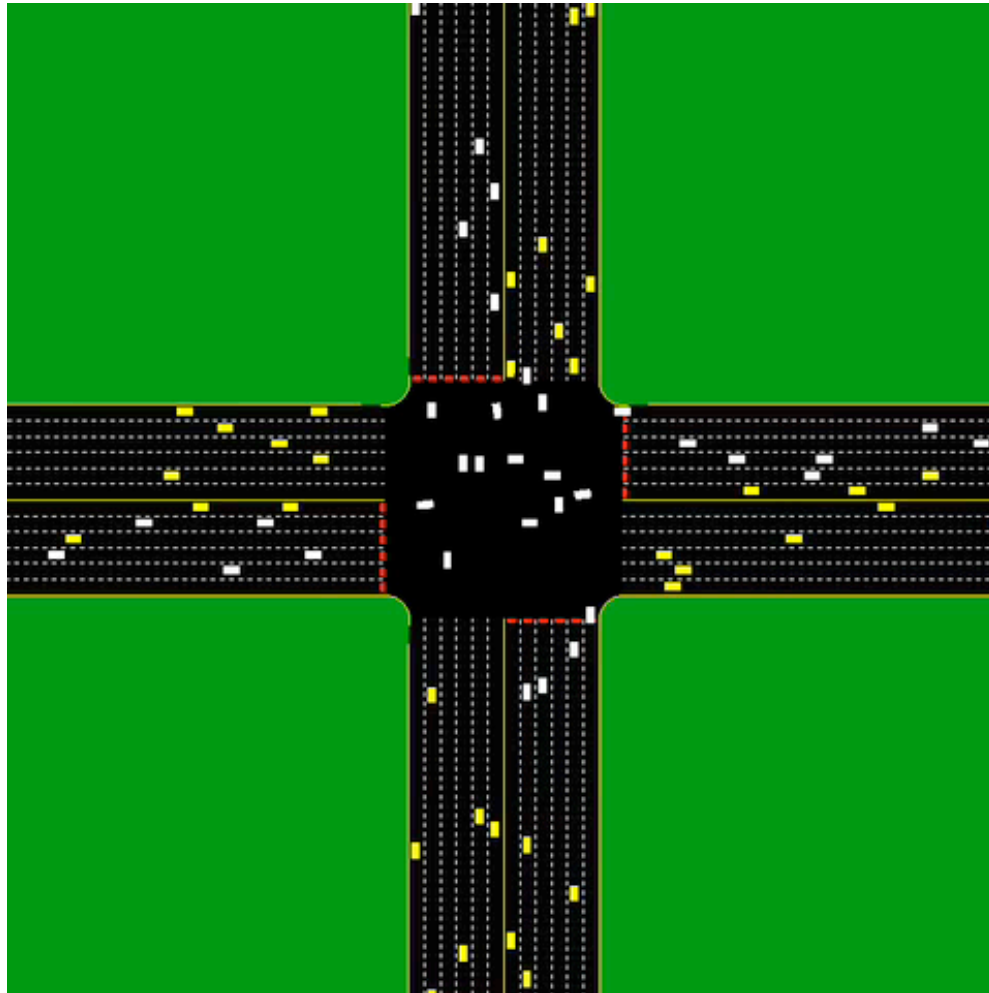


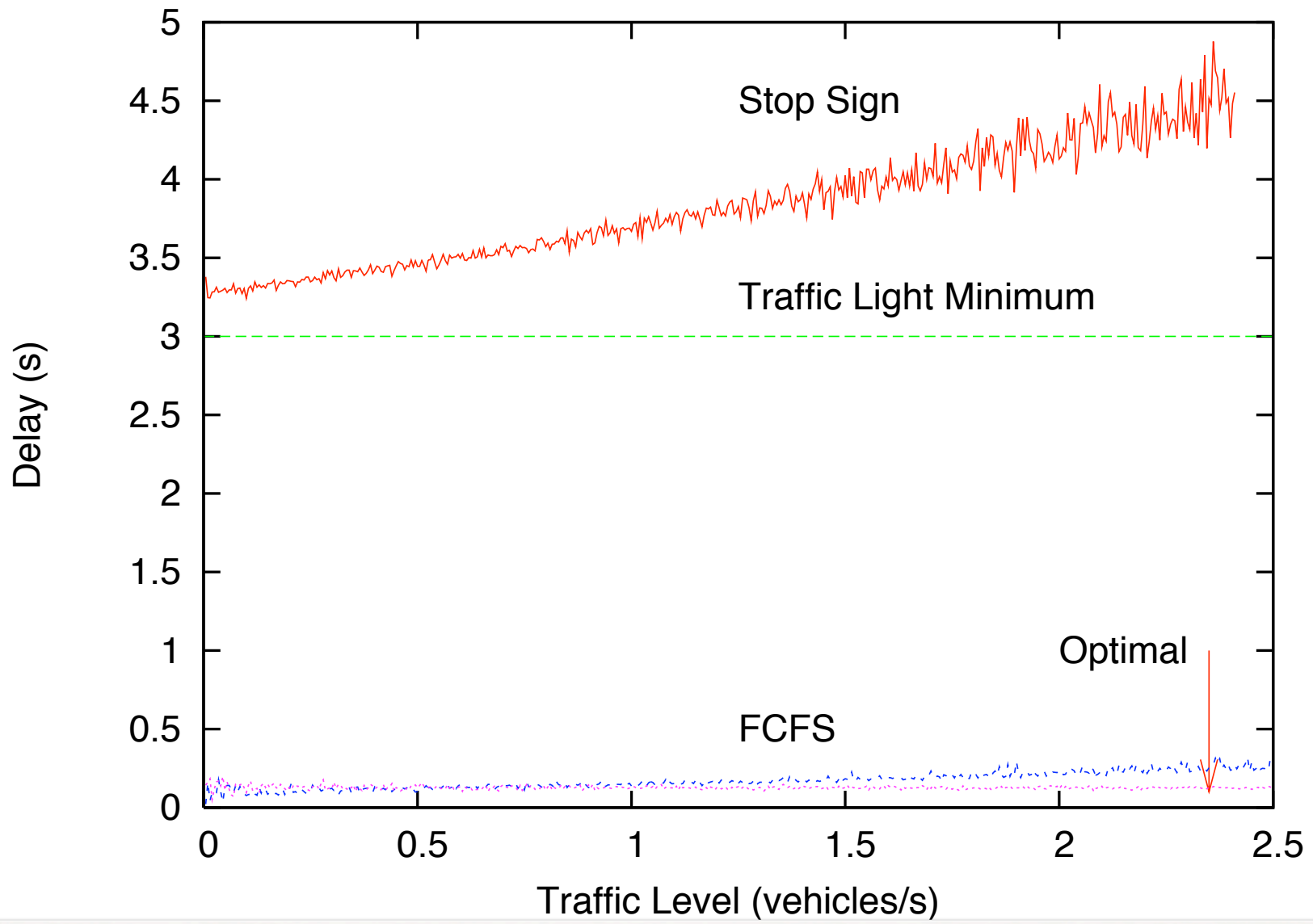
“Granularity”





FCFS Video





Vehicle-to-Vehicle

 Driver agents broadcast a **claim**

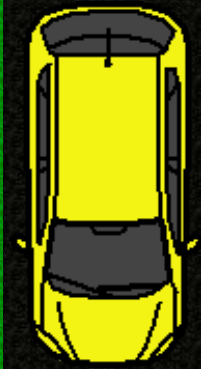
 Define relations over claims:

- ◆ **Conflict**

- ◆ **Priority**

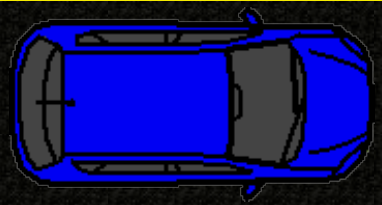
- ◆ **Dominance**

 **Permissibility**



No, *I'm* arriving at time t ...

I'm arriving at time t ...



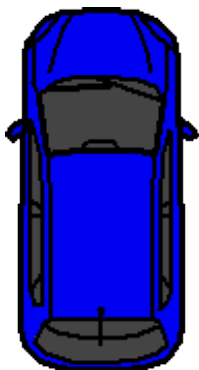
Uh, *I'm* also arriving at time t ...

Time t for me too...



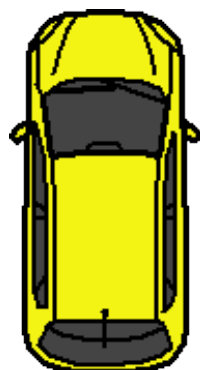
Claim

```
source_id
  1
message_id
 13
  ixn_id
  5
stopped_at_ixn
  false
  arrival_lane
  1
  departure_lane
  2
  arrival_time
 128479
  departure_time
128523
```



Claim

```
source_id
  2
message_id
  6
  ixn_id
  5
stopped_at_ixn
  false
  arrival_lane
  1
  departure_lane
  2
  arrival_time
 128479
  departure_time
128613
```



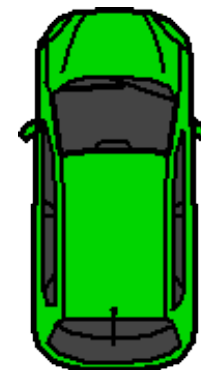
Claim

```
source_id
  3
message_id
 10
  ixn_id
  5
stopped_at_ixn
  false
  arrival_lane
  1
  departure_lane
  2
  arrival_time
 128479
  departure_time
128497
```



Claim

```
source_id
  4
message_id
  4
  ixn_id
  5
stopped_at_ixn
  false
  arrival_lane
  1
  departure_lane
  2
  arrival_time
 128479
  departure_time
128564
```

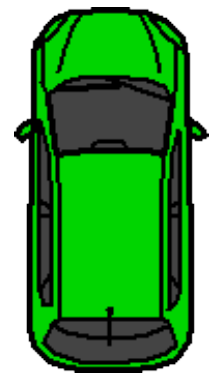
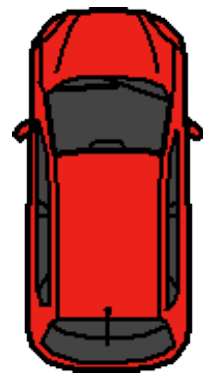
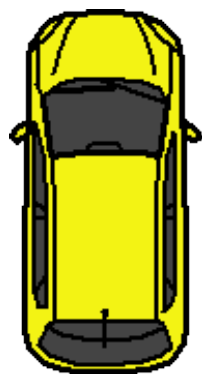
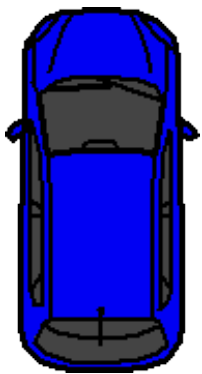
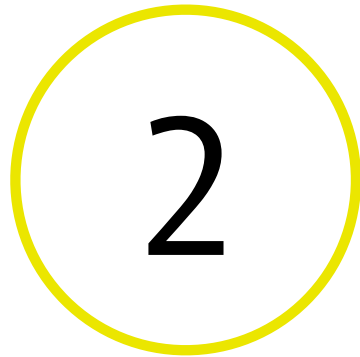
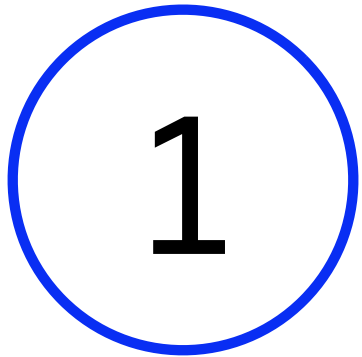


Claim

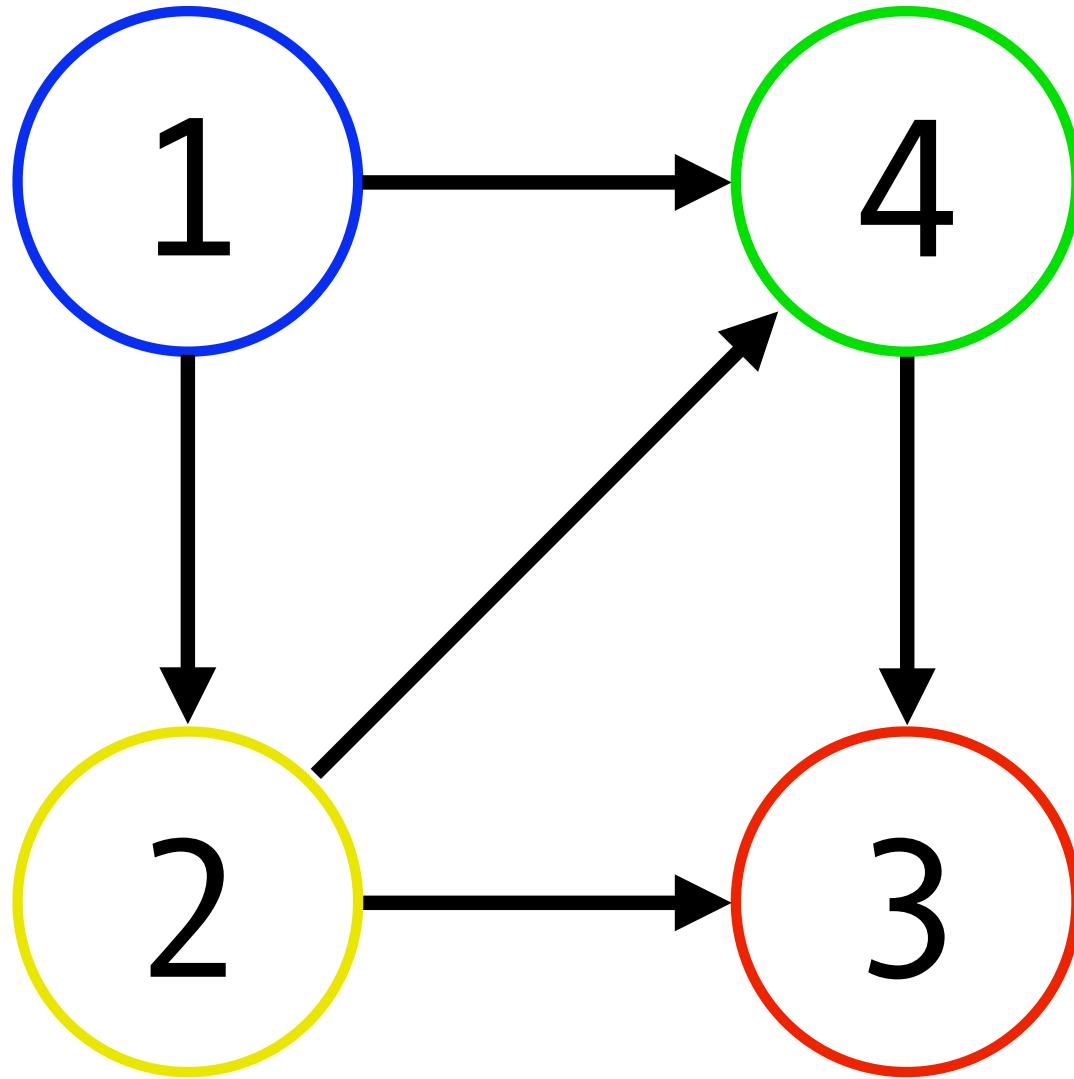
Claim

Claim

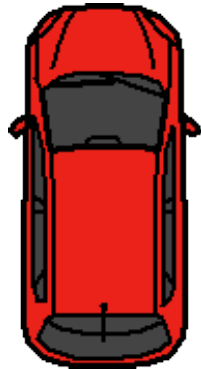
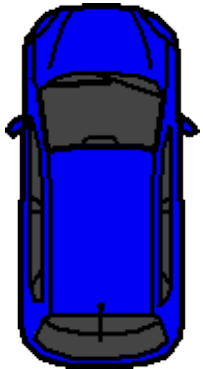
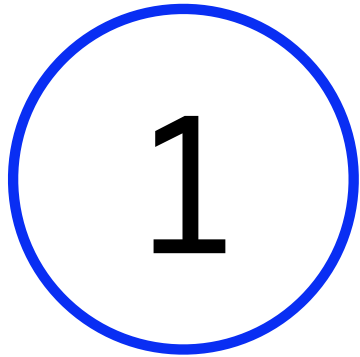
Claim



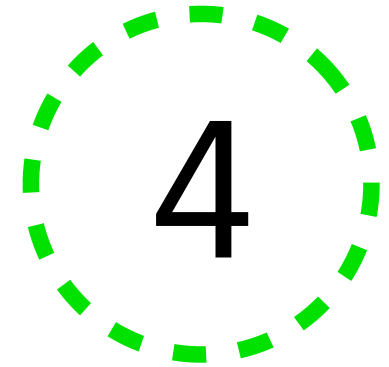
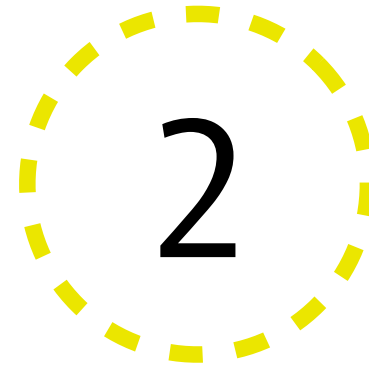
“Dominance”

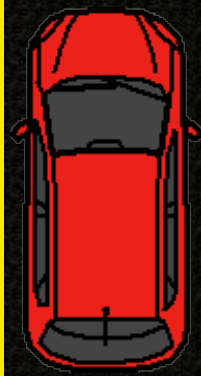
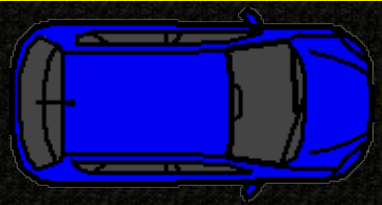
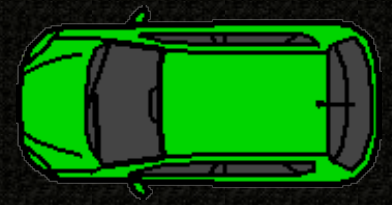
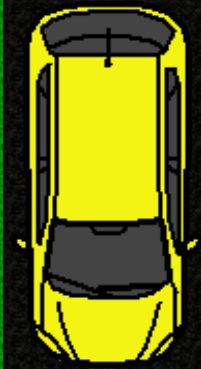


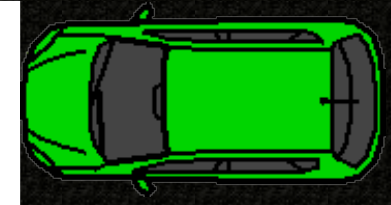
Permissible



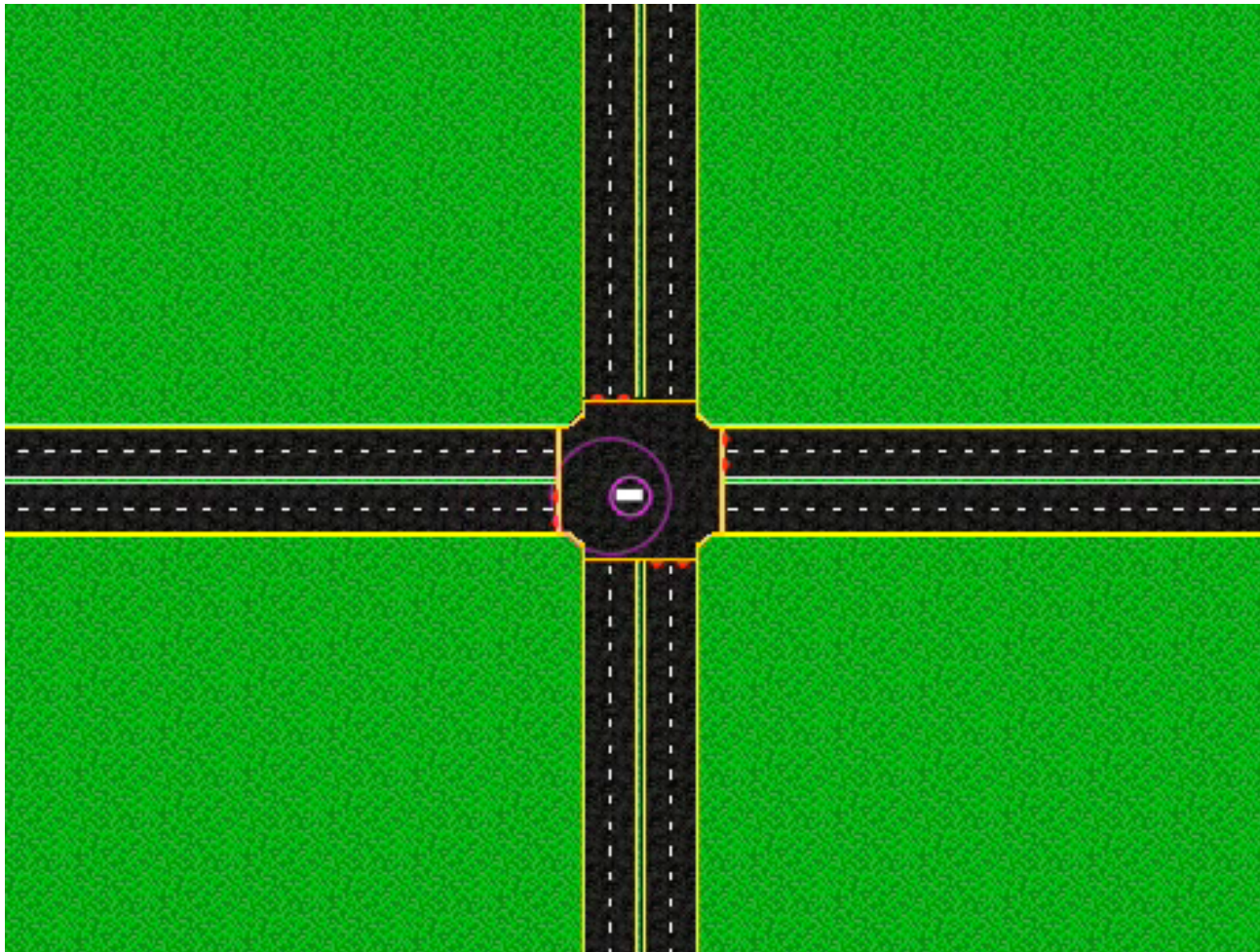
Nonpermissible











V2V Video








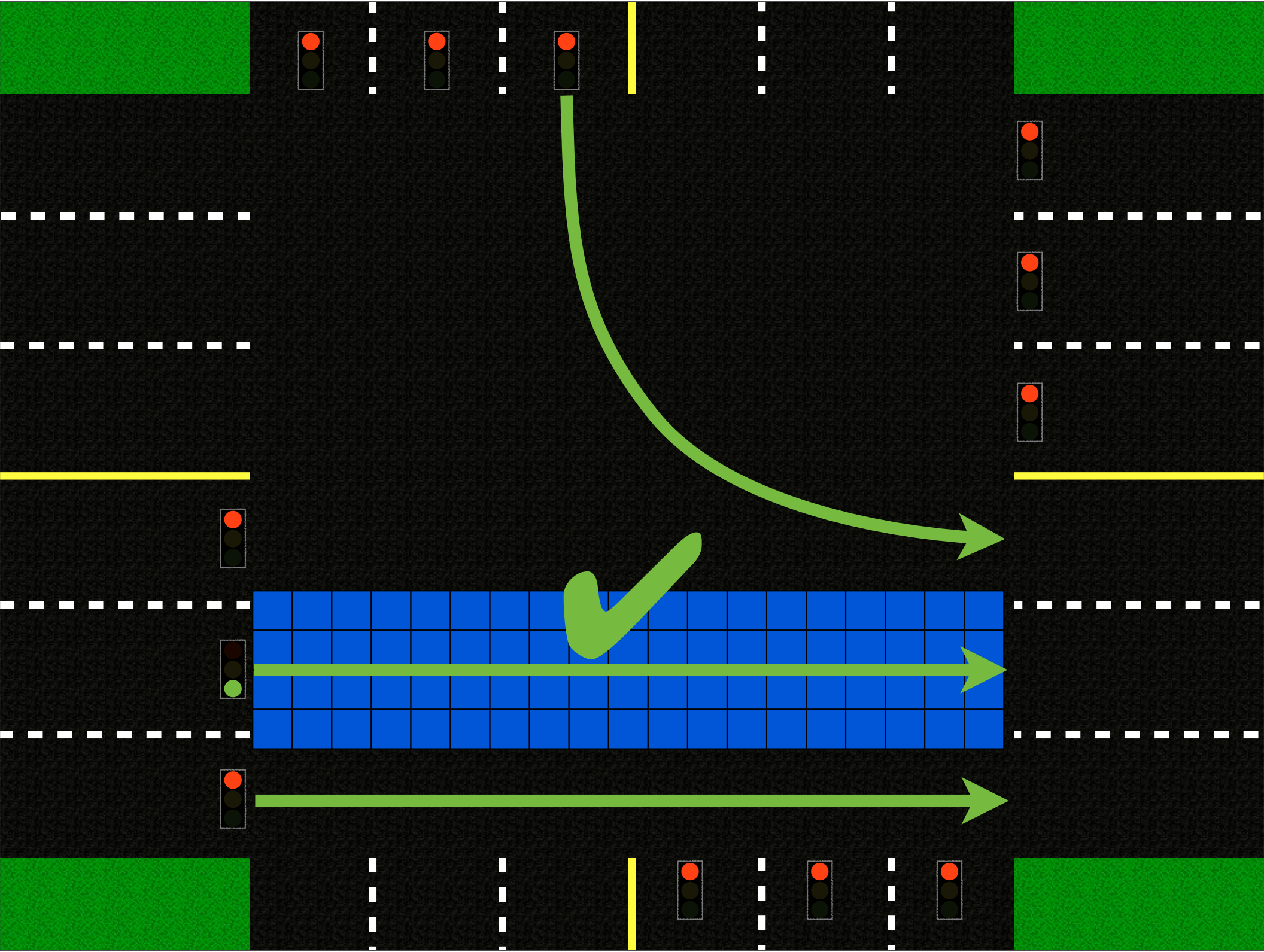
Human Usability

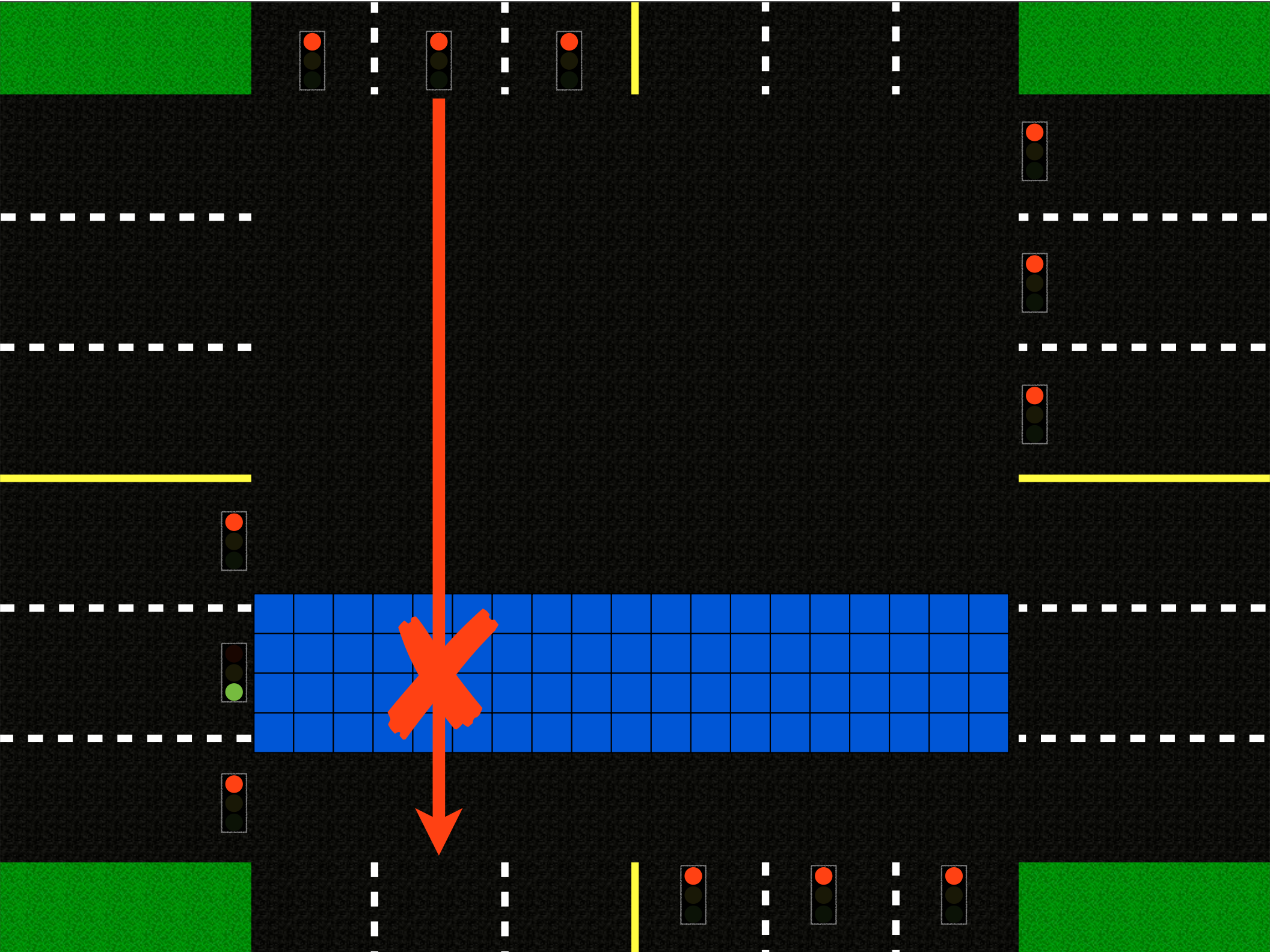
The Benefits

-  Some people enjoy driving
-  Classic cars
-  Transition period
-  Concepts extend to cyclists, pedestrians

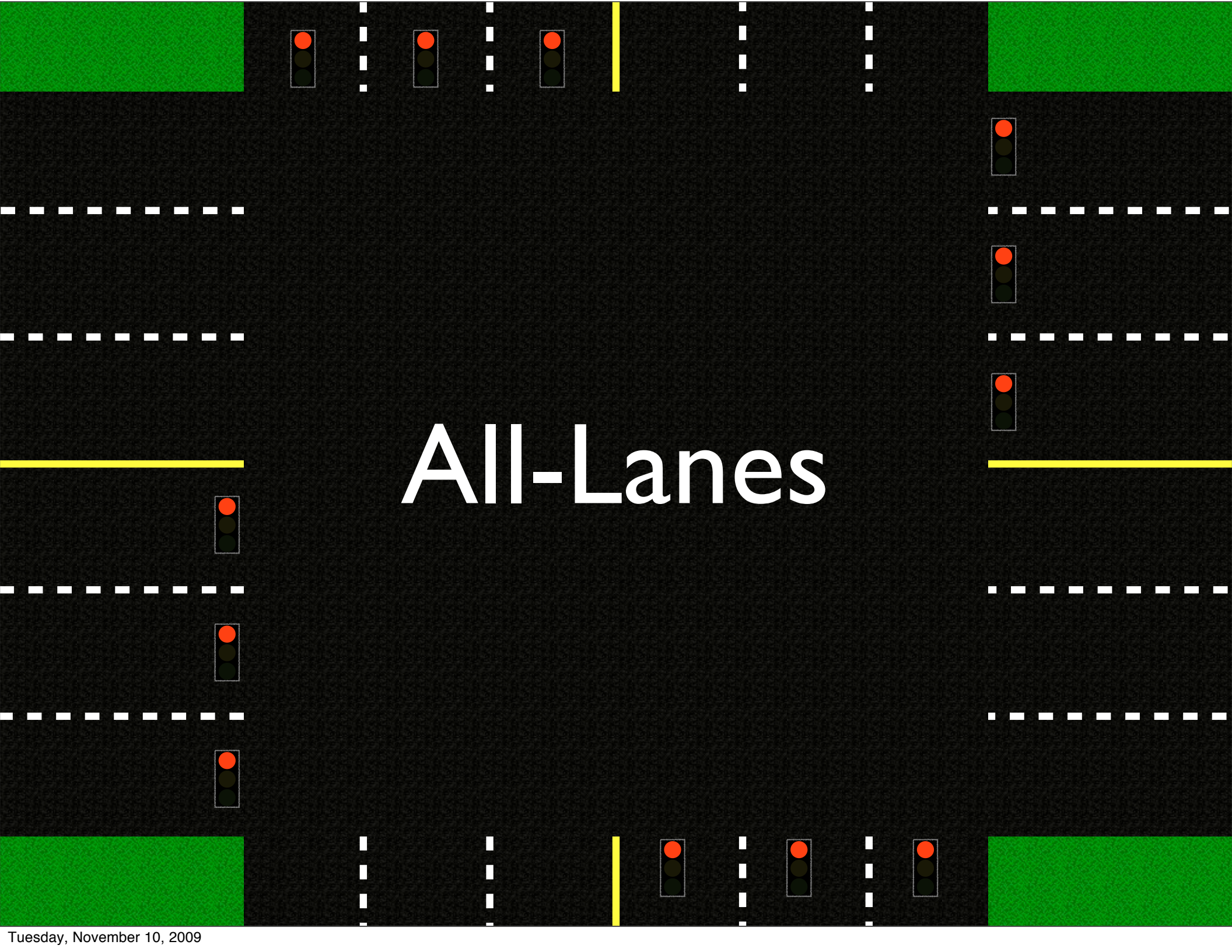
The FCFS-Signal Policy

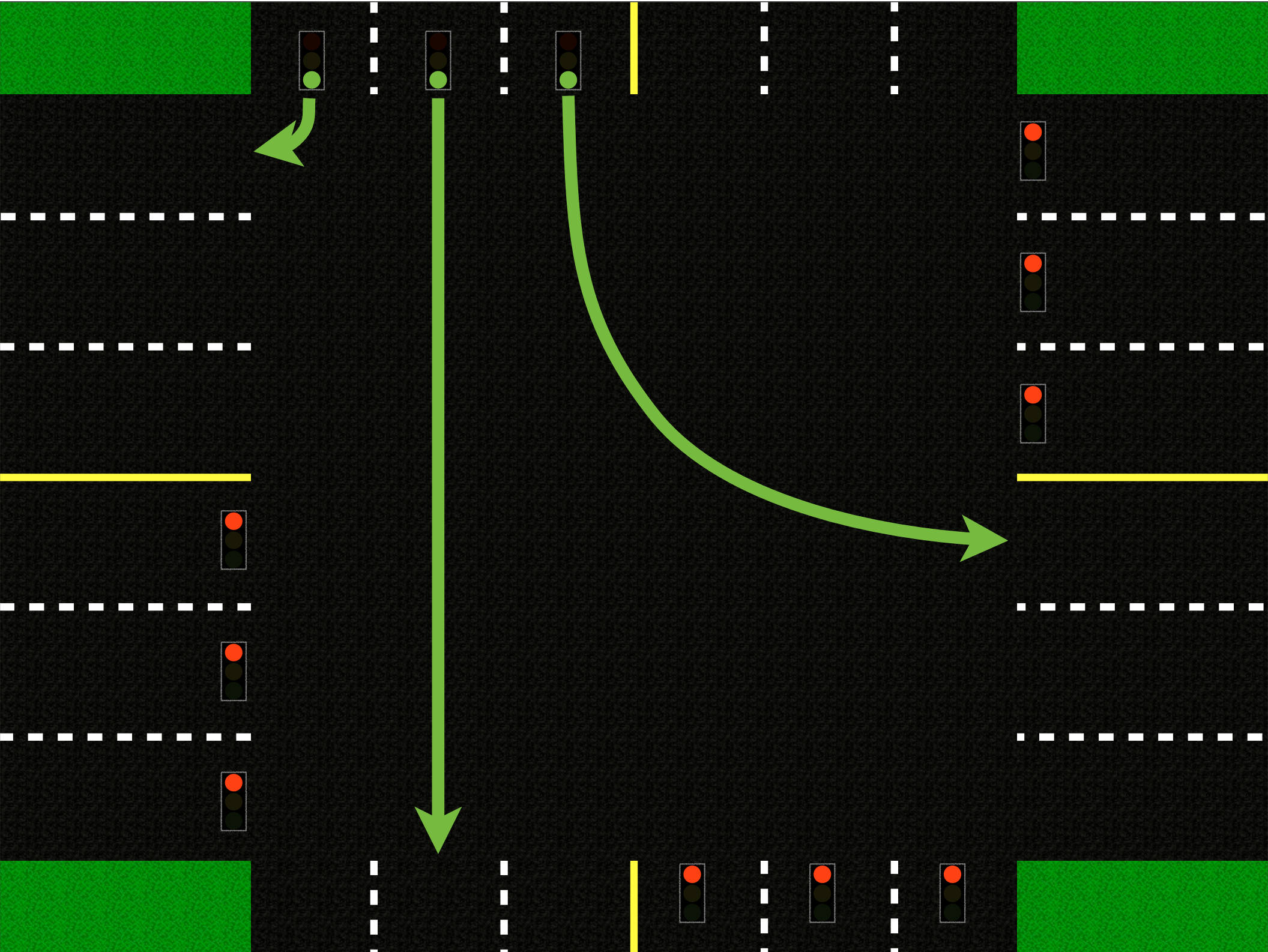
-  Autonomous vehicles use protocol
-  Human-driven vehicles use signals
-  Policy contains a **signal model**
-  Uses state of relevant signal at arrival time:
 - ♦ **Green**: accept
 - ♦ **Yellow**: reject
 - ♦ **Red**: FCFS
-  Set aside **off-limits tiles** during green phases



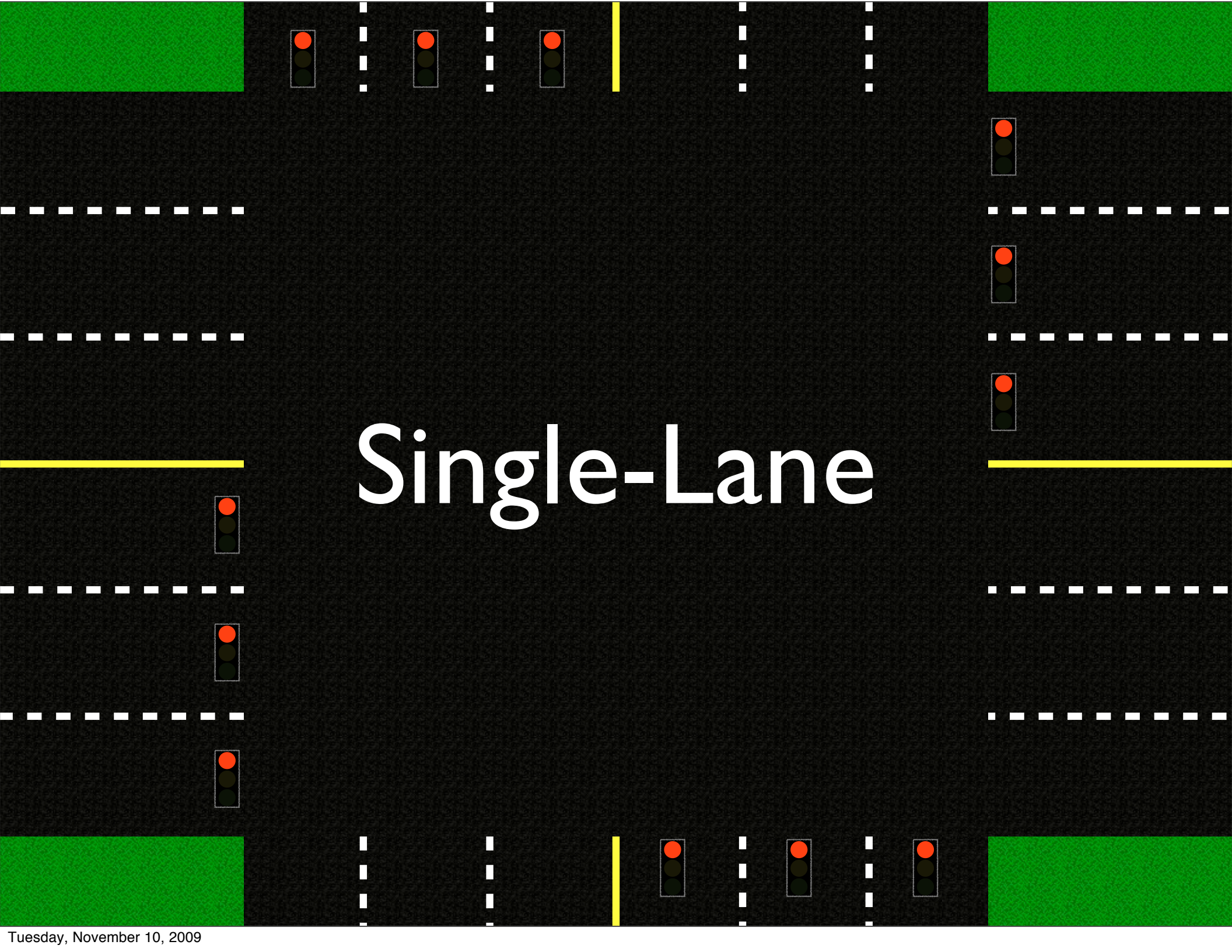


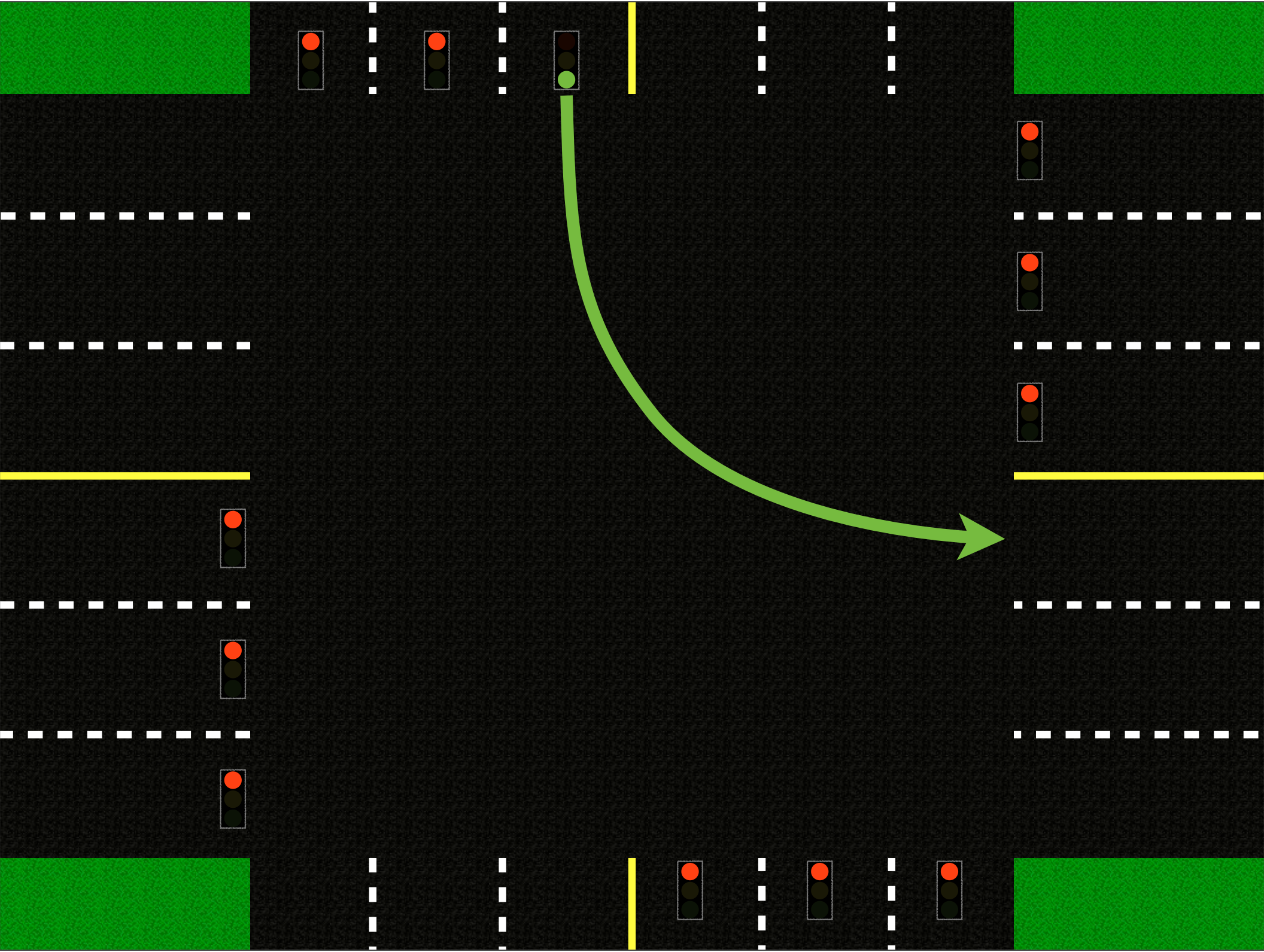
All-Lanes

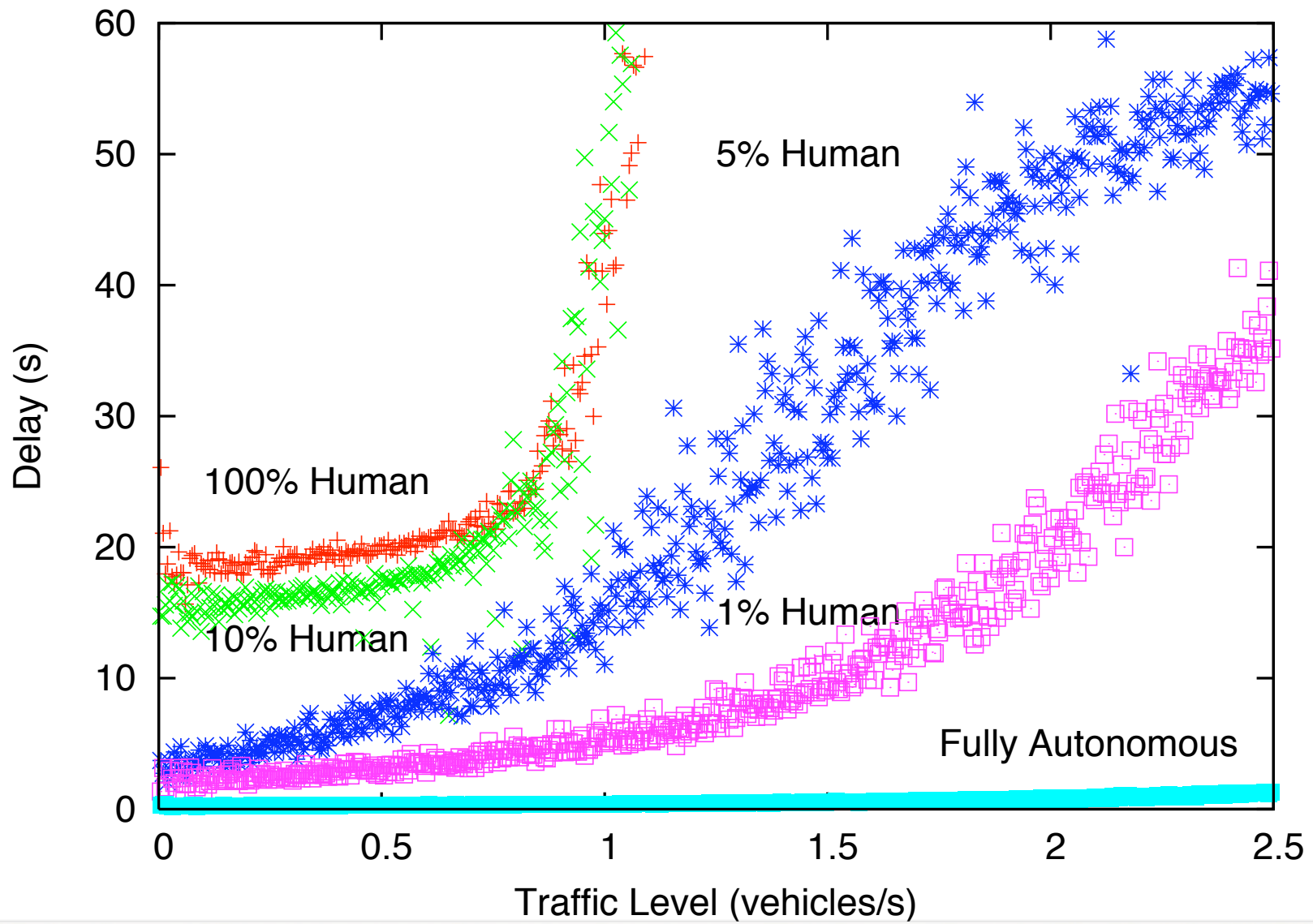







Single-Lane

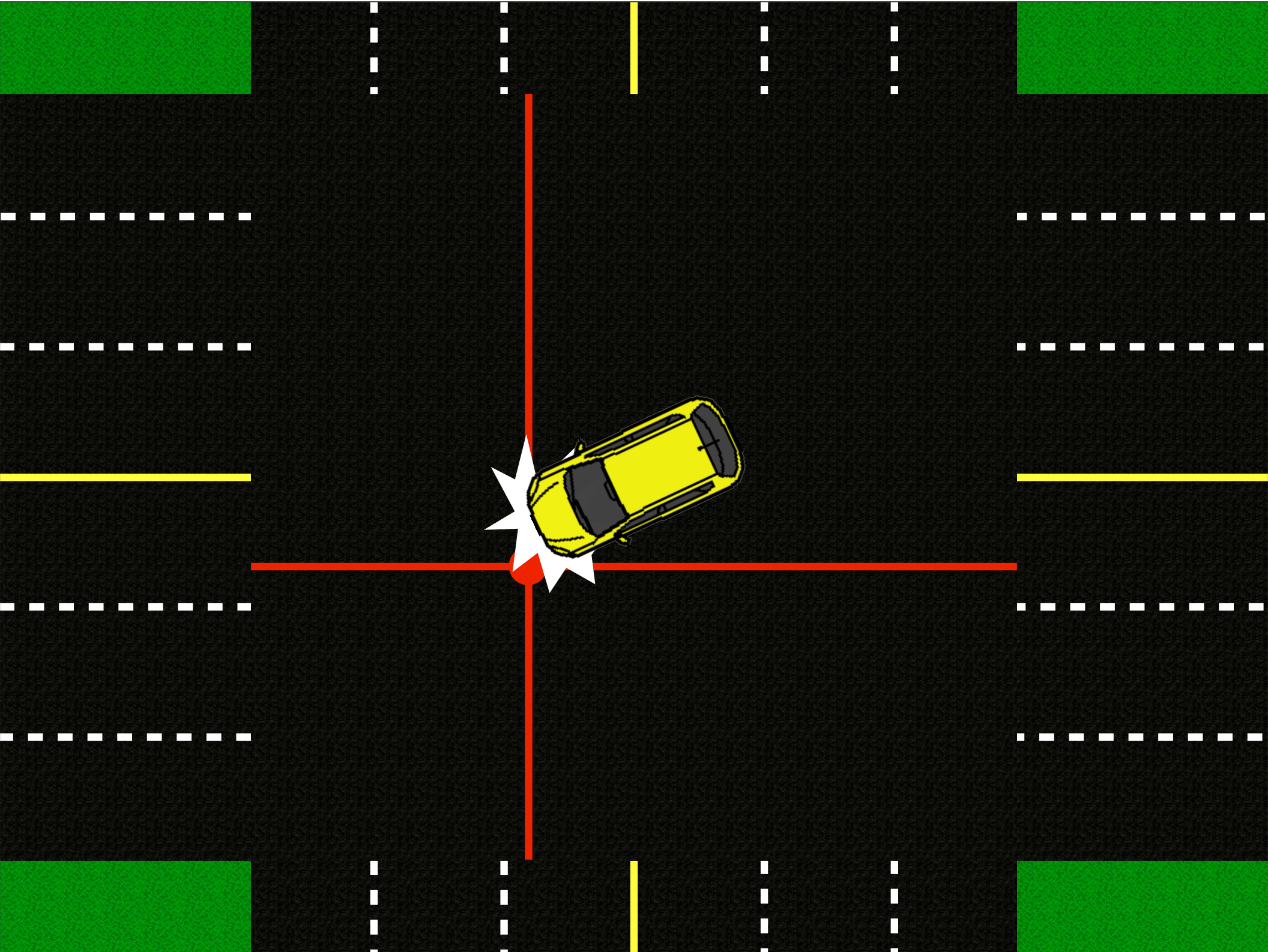


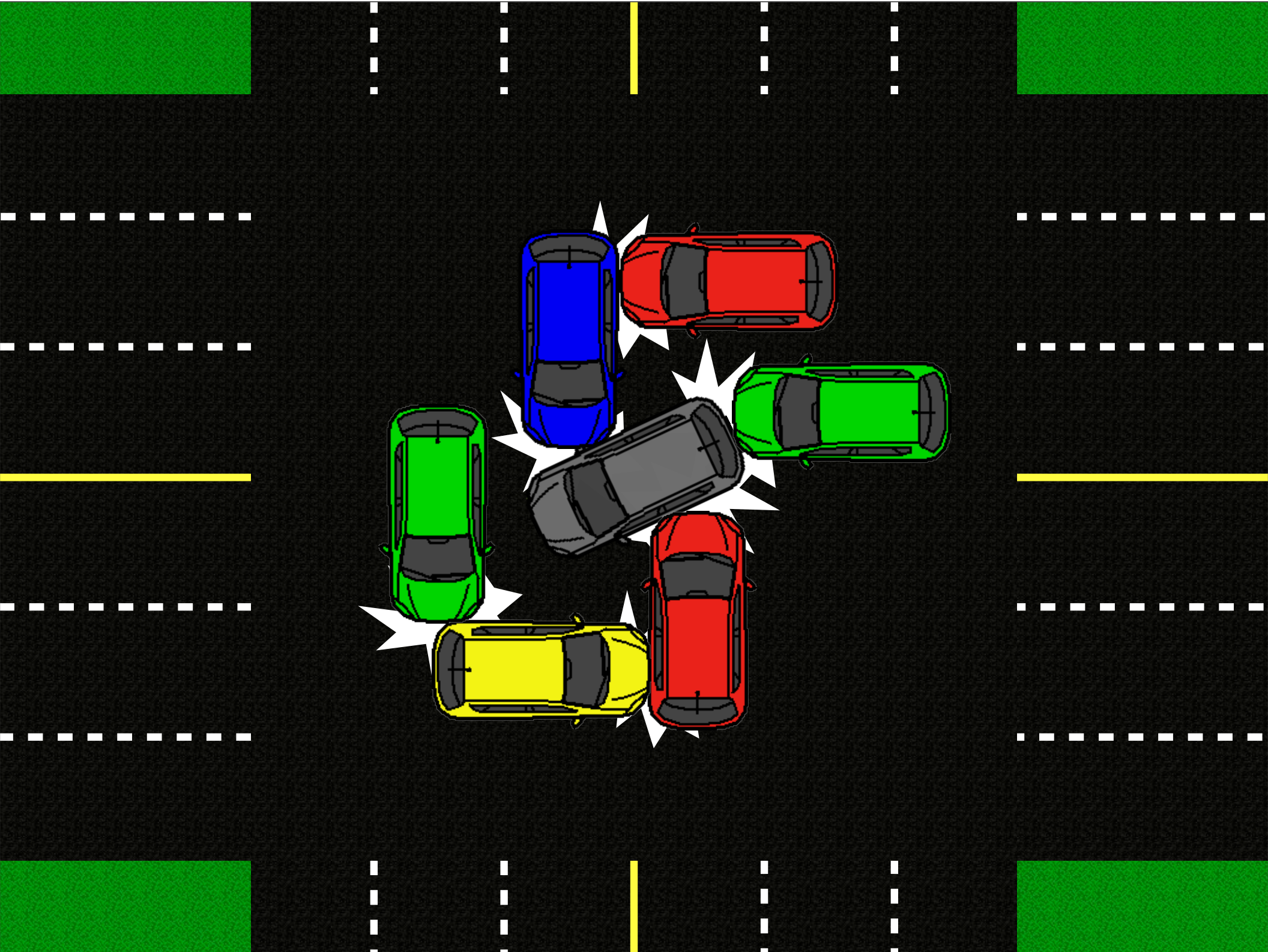


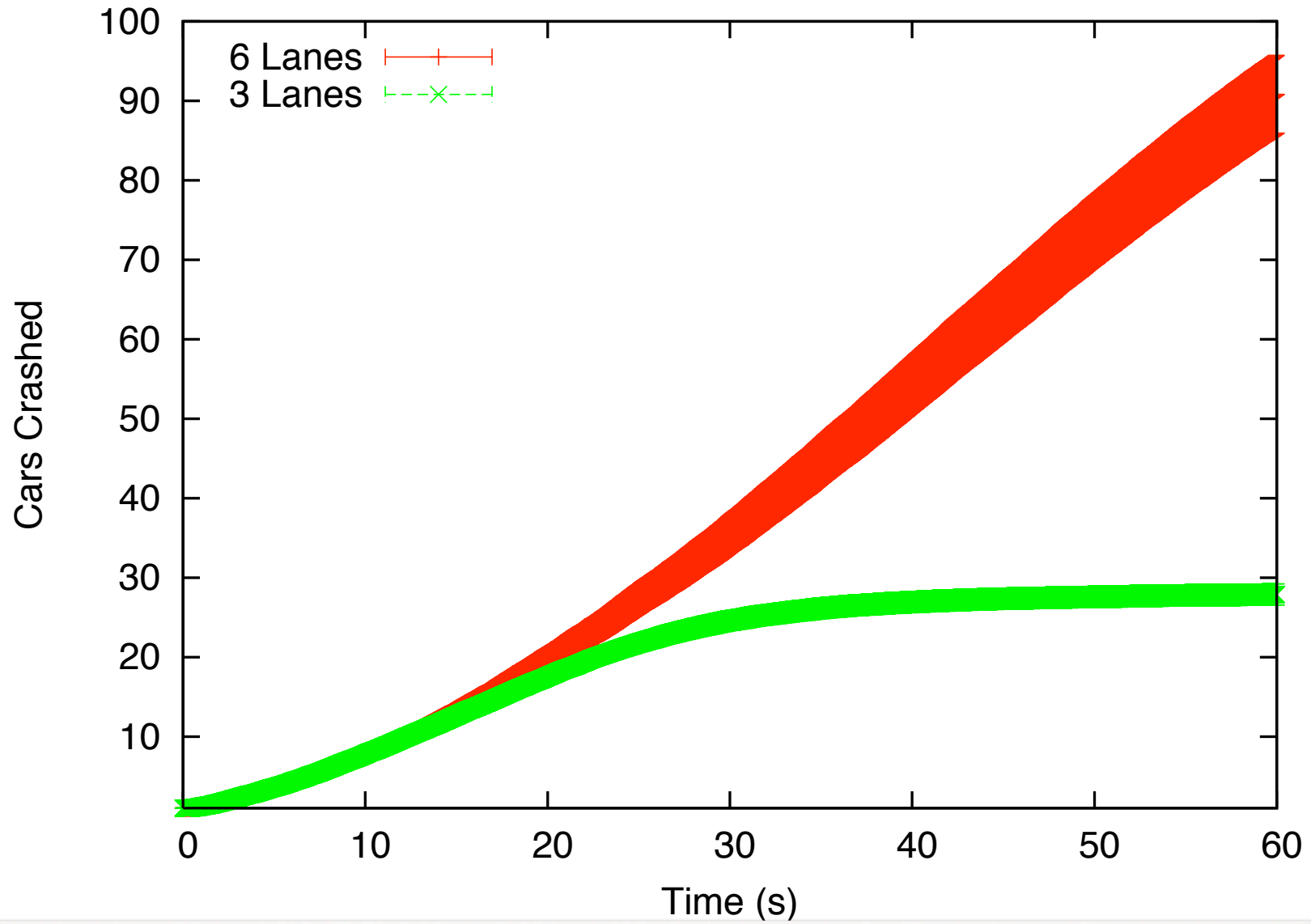


Failure Mode Analysis

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







Mitigating Catastrophe

 Assume intersection manager can **detect**

 Reaction:

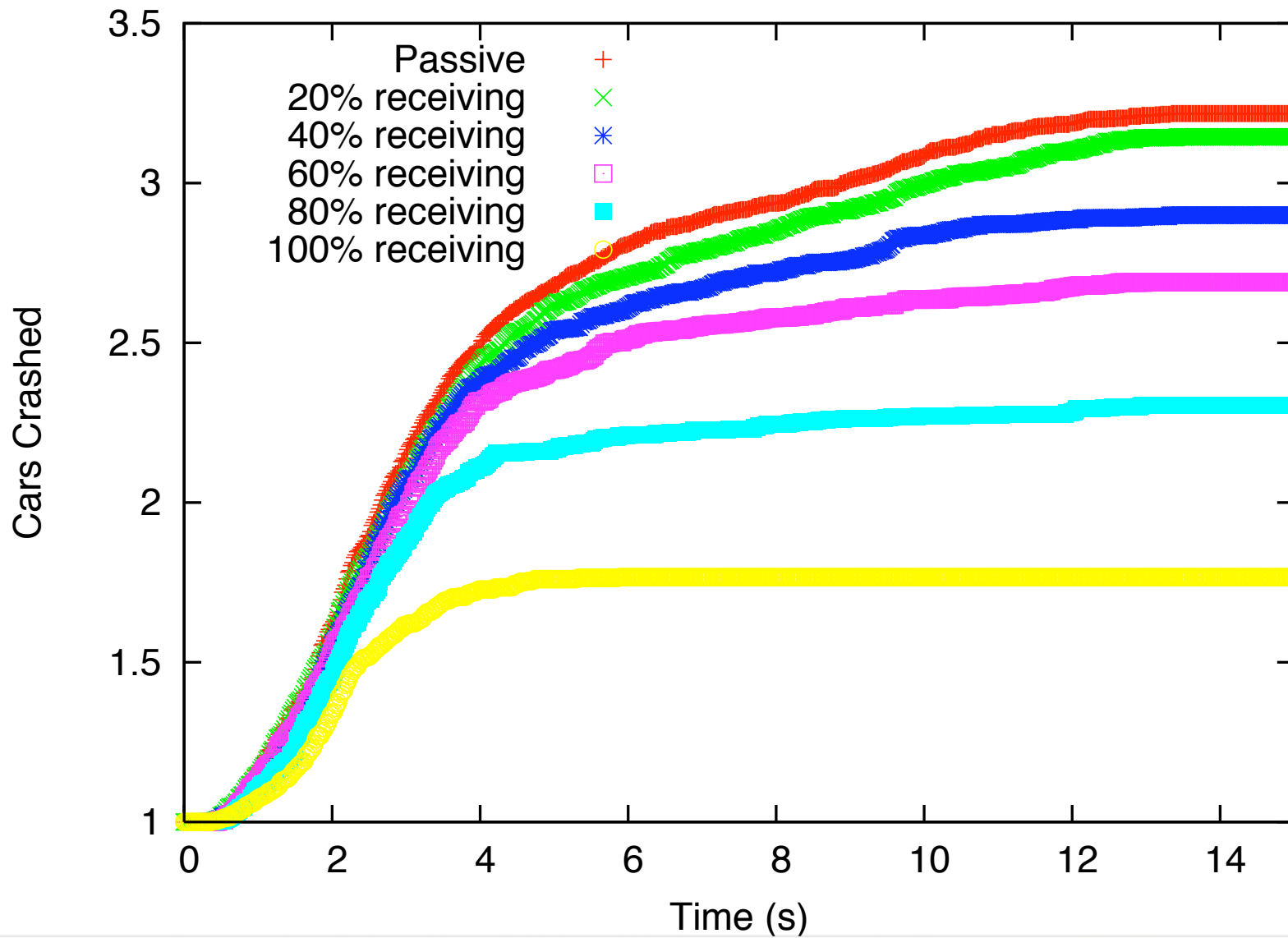
- ◆ Refuse future reservations

- ◆ **Emergency-Stop** message

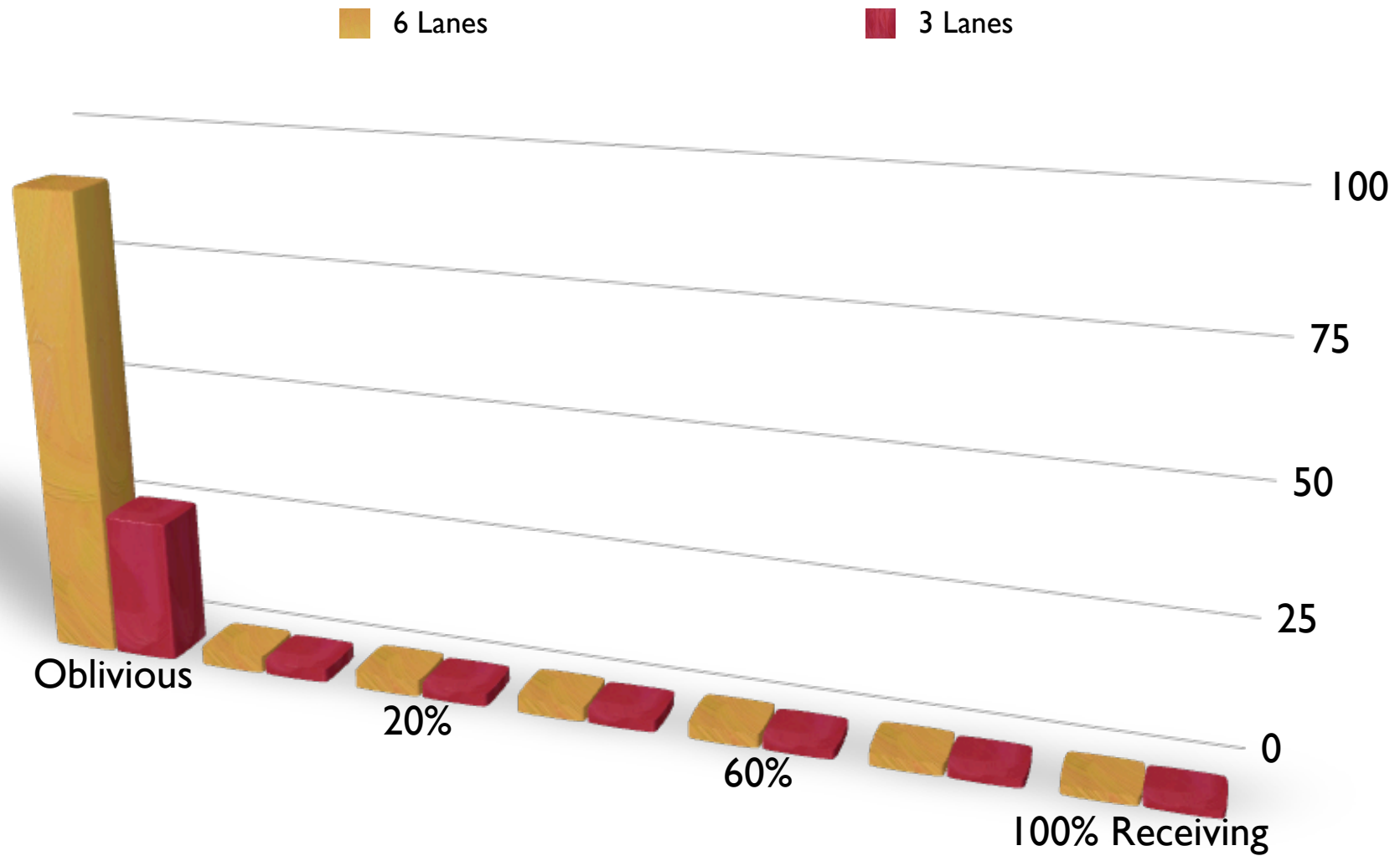
 **Oblivious** vs. **passive** vs. **active**

 What if vehicles do not receive?

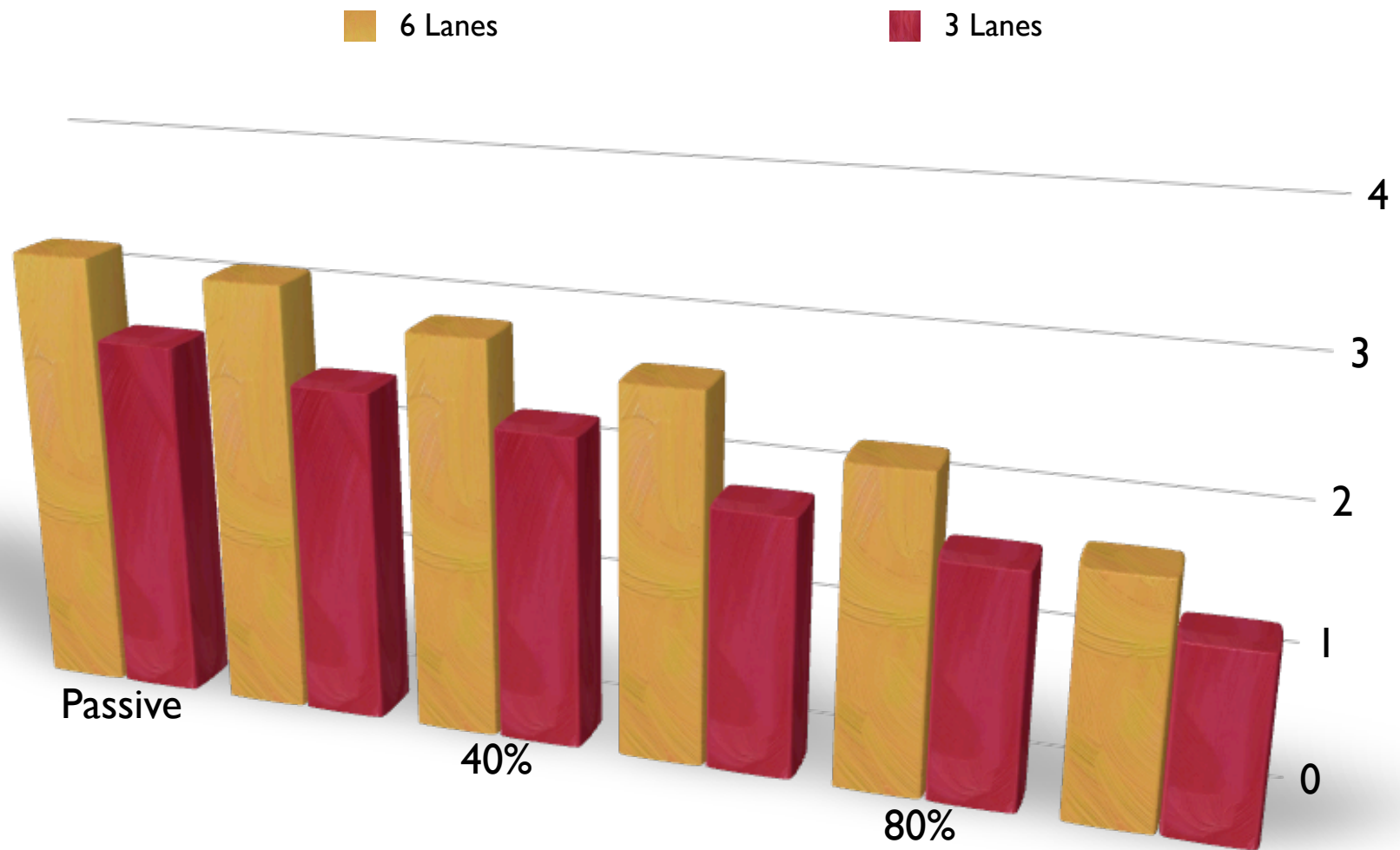




Average Number Of Crashed Vehicles



Average Number Of Crashed Vehicles



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

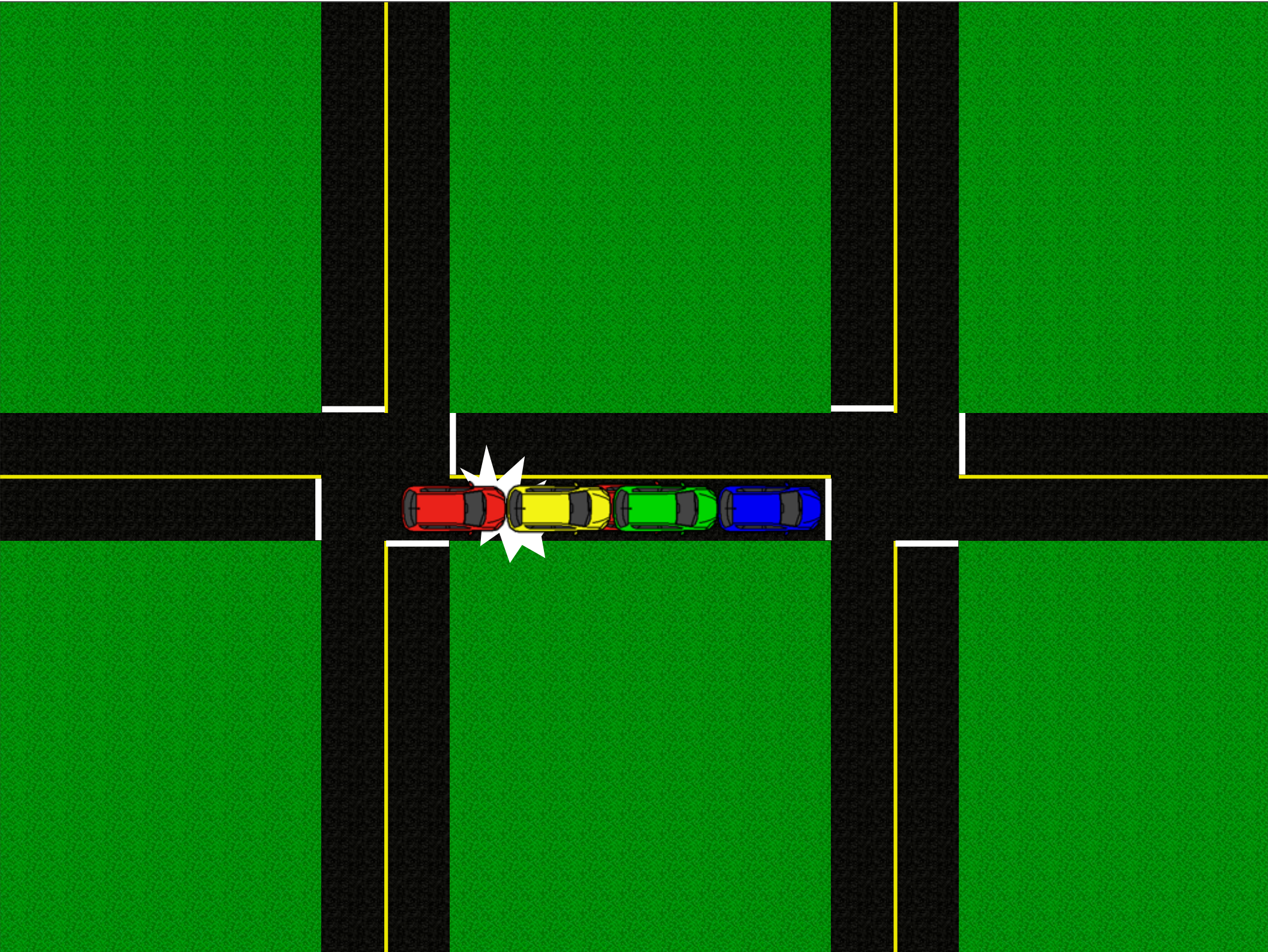
What's The Big Deal?

 Protocol considerations

 Downstream effects

 Driver agent navigation

 Upstream effects



The diagram features a large green rectangular area on the right side, representing the Admission Control Zone (ACZ). A horizontal purple line with vertical end caps spans across the width of this green area. Above this line, the text 'ACZ Distance' is written in purple. Below the green area, the text 'Admission Control Zone (ACZ)' is written in white. The background is black with several yellow and white lines forming a grid-like structure.

ACZ Distance

Admission Control Zone
(ACZ)

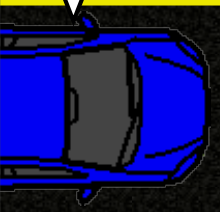
The diagram features a large green rectangular area on the right side of the slide, representing the Admission Control Zone (ACZ). A horizontal yellow line with vertical end caps is positioned above the ACZ, indicating its capacity. The text 'ACZ Capacity' is written in yellow above this line. The background of the slide is black with several green rectangular blocks of varying sizes. A white L-shaped line is visible on the left side of the slide.

ACZ Capacity

Admission Control Zone
(ACZ)

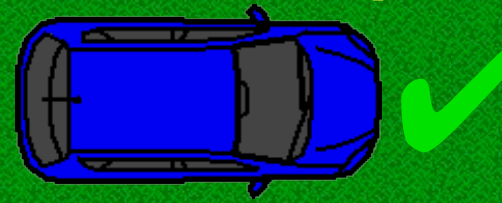
ACZ Capacity

I'm arriving
at time $t...$

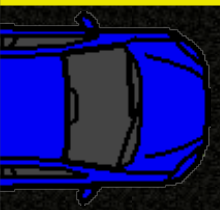


Admission Control Zone
(ACZ)

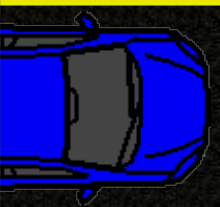
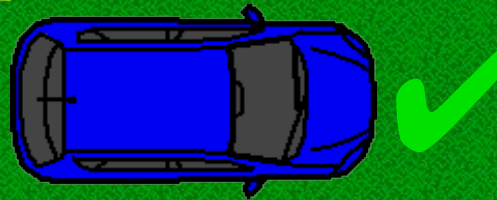
ACZ Capacity



Admission Control Zone
(ACZ)



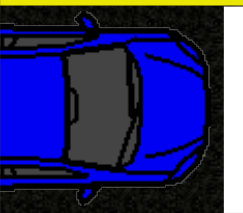
ACZ Capacity



Admission Control Zone
(ACZ)

ACZ Capacity

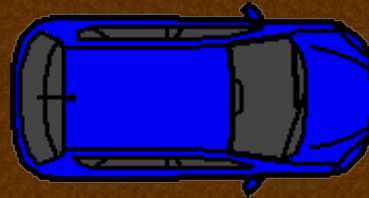
Sounds good to me...



Admission Control Zone (ACZ)

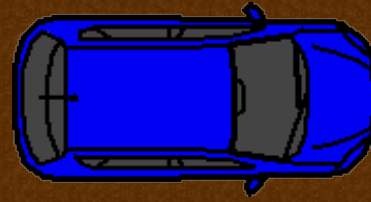
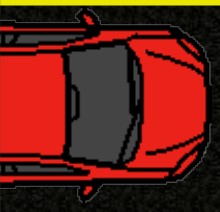
ACZ Capacity

I'm arriving
at time t' ...



Admission Control Zone
(ACZ)

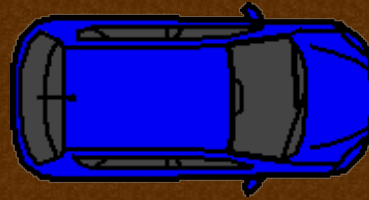
ACZ Capacity



Admission Control Zone
(ACZ)

ACZ Capacity

Sorry! Can't do that!

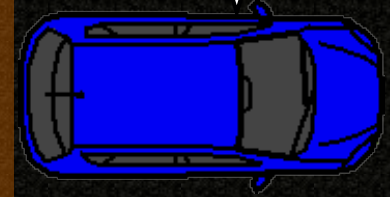


Admission Control Zone
(ACZ)

ACZ Capacity

A yellow horizontal bracket is positioned above a green rectangular area, indicating the width of the Admission Control Zone (ACZ).

I'm away!

A white speech bubble with a black outline and a tail pointing towards a blue car.

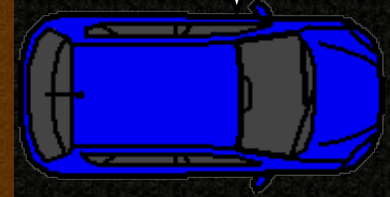
Admission Control Zone
(ACZ)

A brown horizontal bar is located in the center of the diagram, representing the Admission Control Zone (ACZ). It is flanked by green areas above and below it.

ACZ Capacity

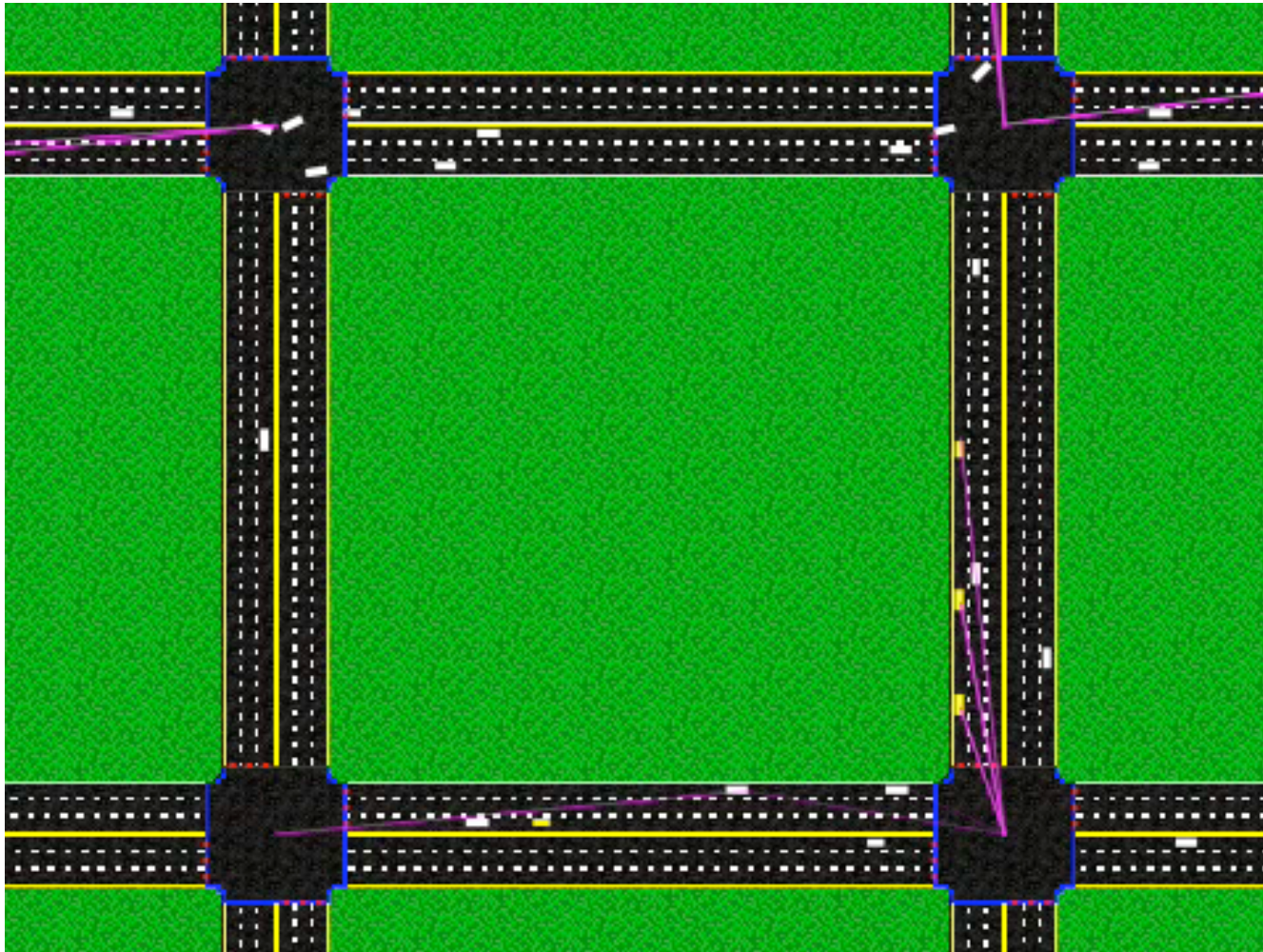


I'm away!



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 (Mählich 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 (Roozemonnd 1999)
-  Q-learning (Abdulhai et al. 2003)
-  Learning Classifier Systems (Bull et al. 2004)
-  MAS + game theory (Bazzan 2005)
-  History-based (Balan and Luke 2006)

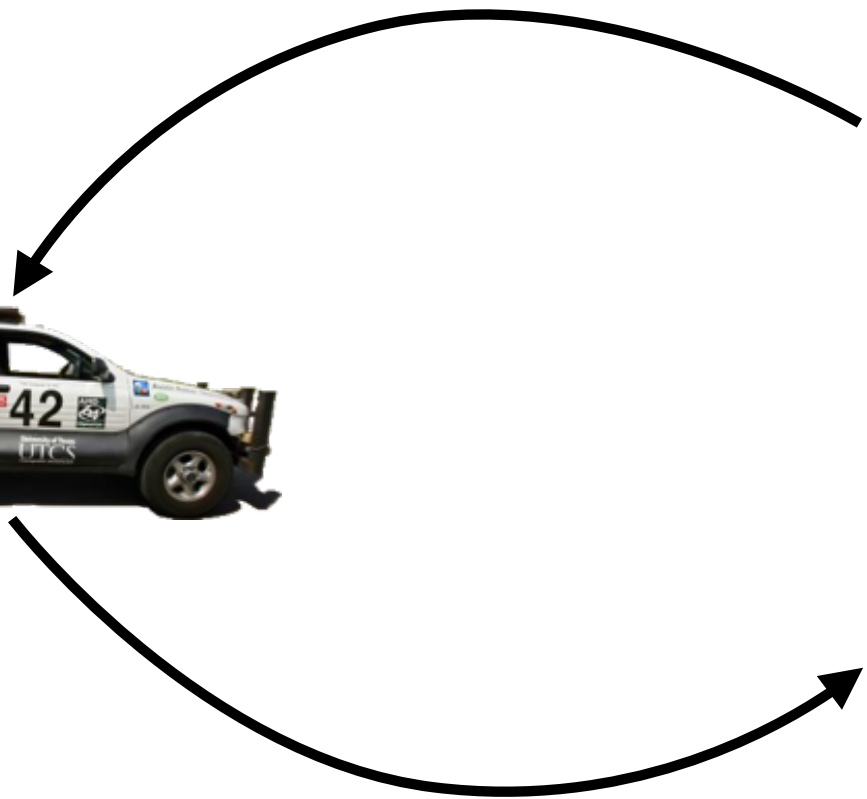
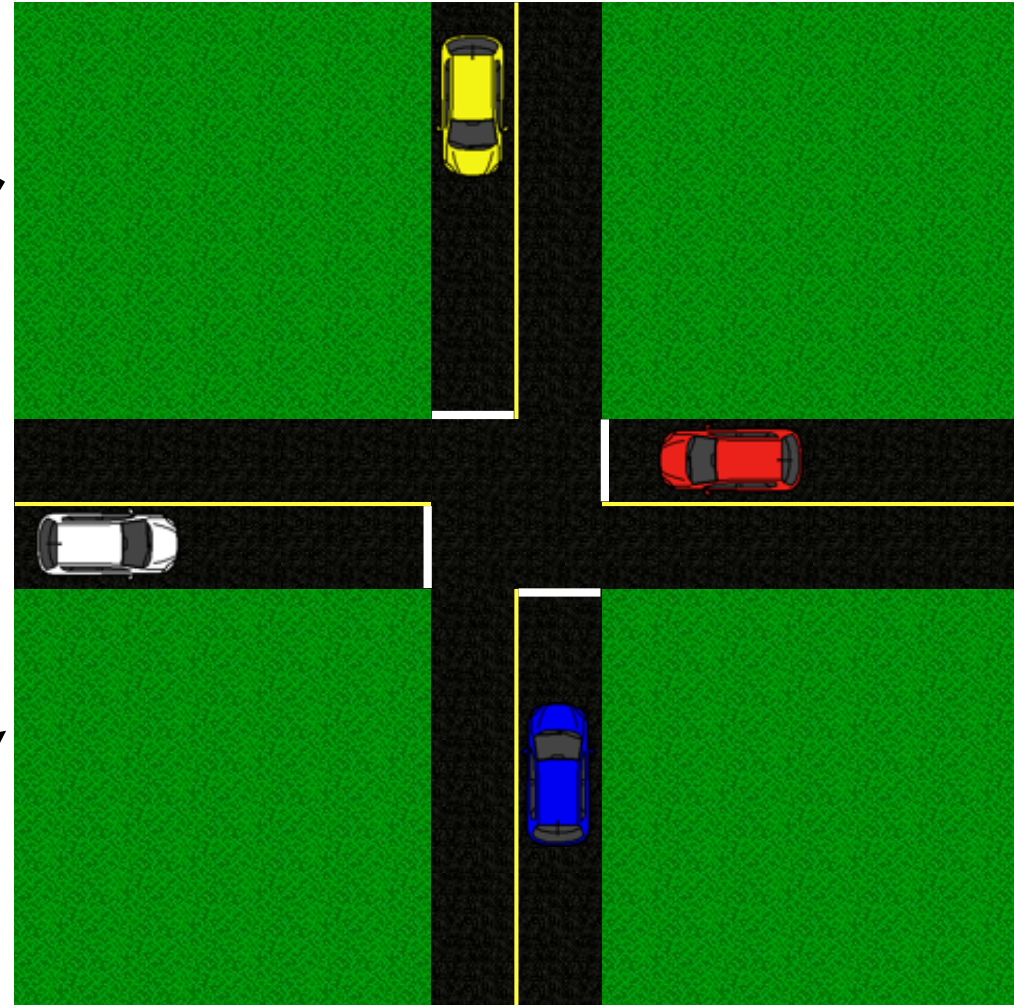
Related Work

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)

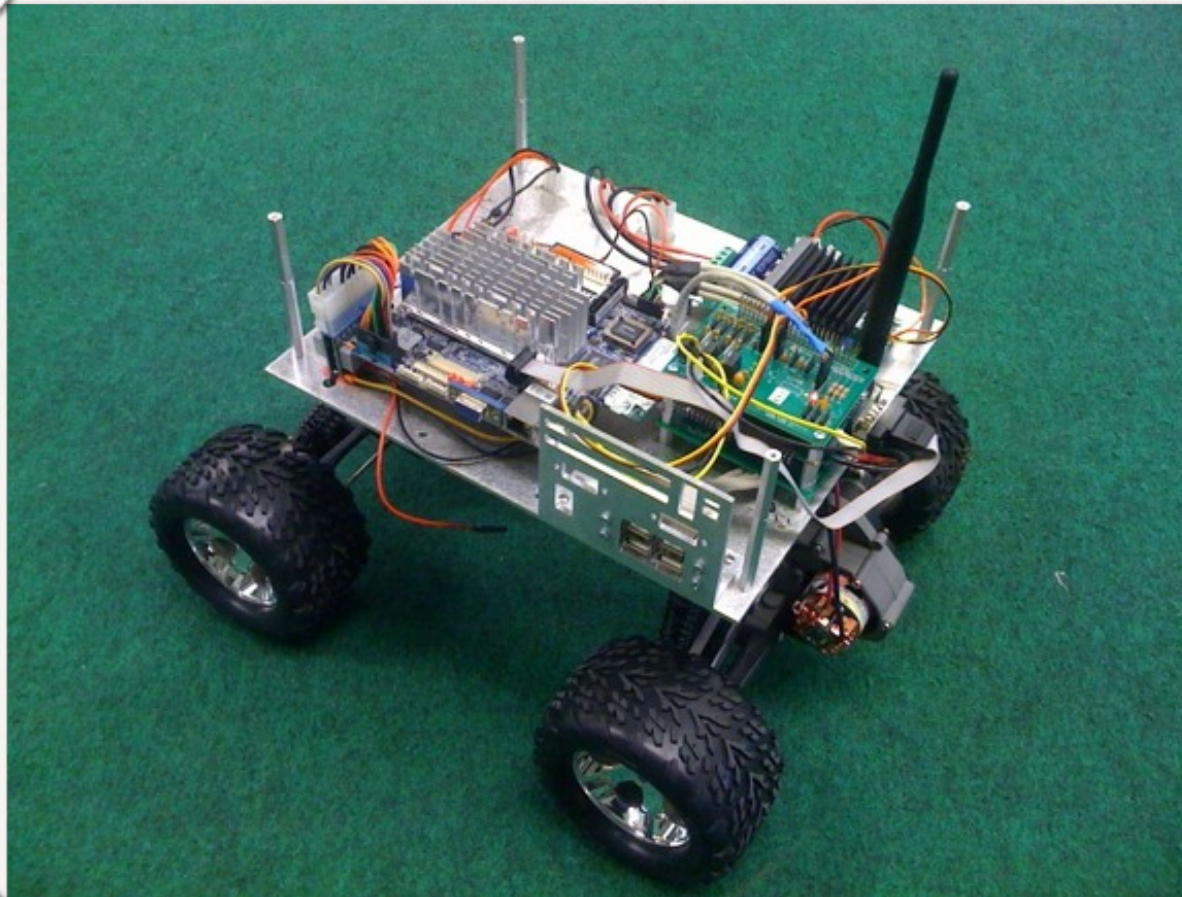
Future Directions

Mixed Simulation



Future Directions

Proteus Robots



Future Directions

Exploring Asynchronicity



Future Directions

Exploring Asynchronicity



Questions?

