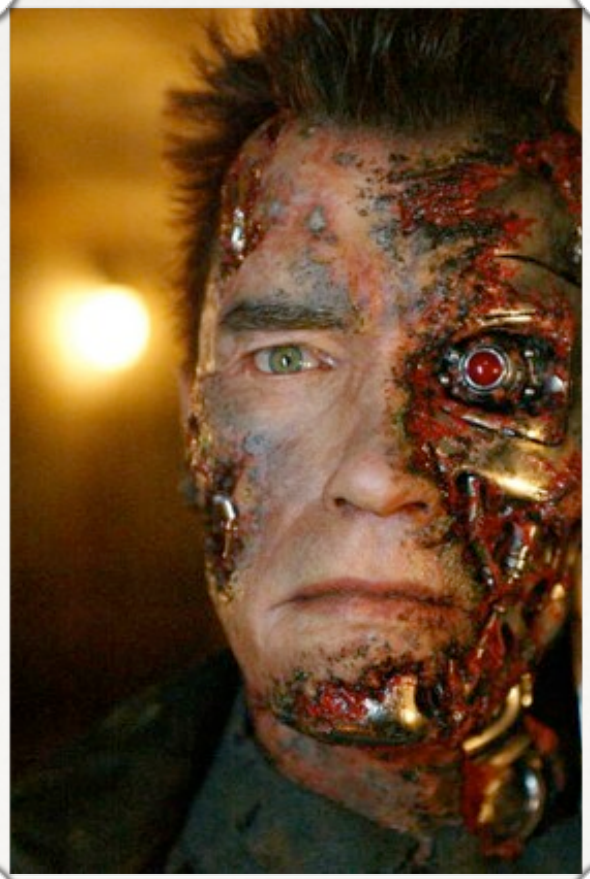
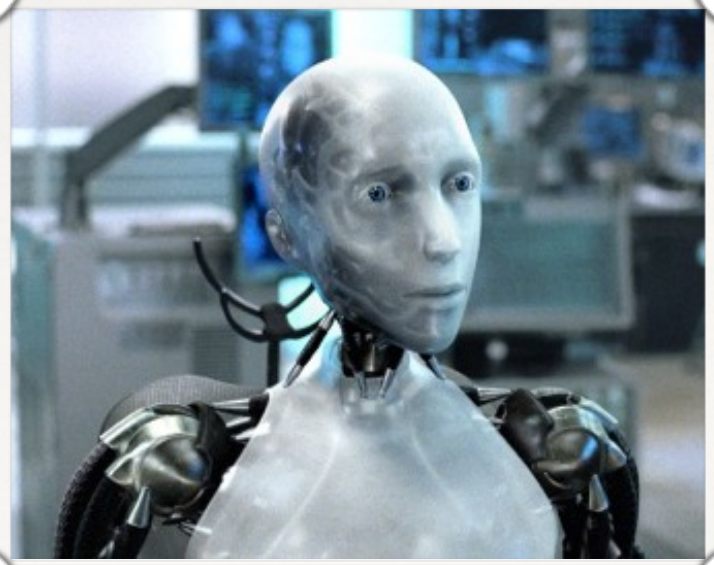
Artificial Intelligence





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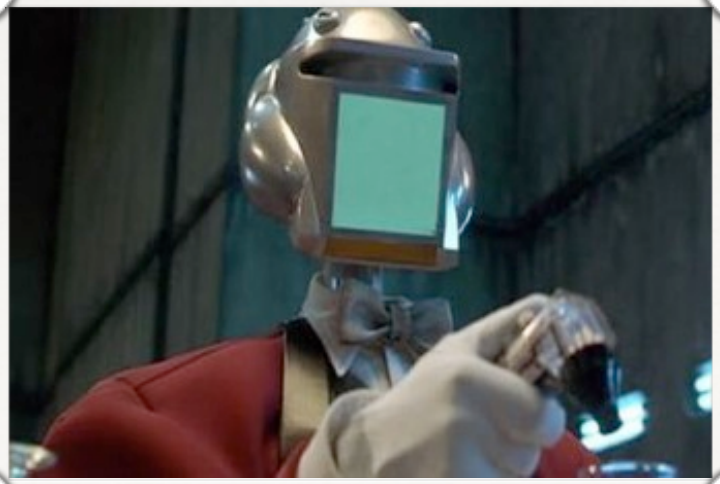

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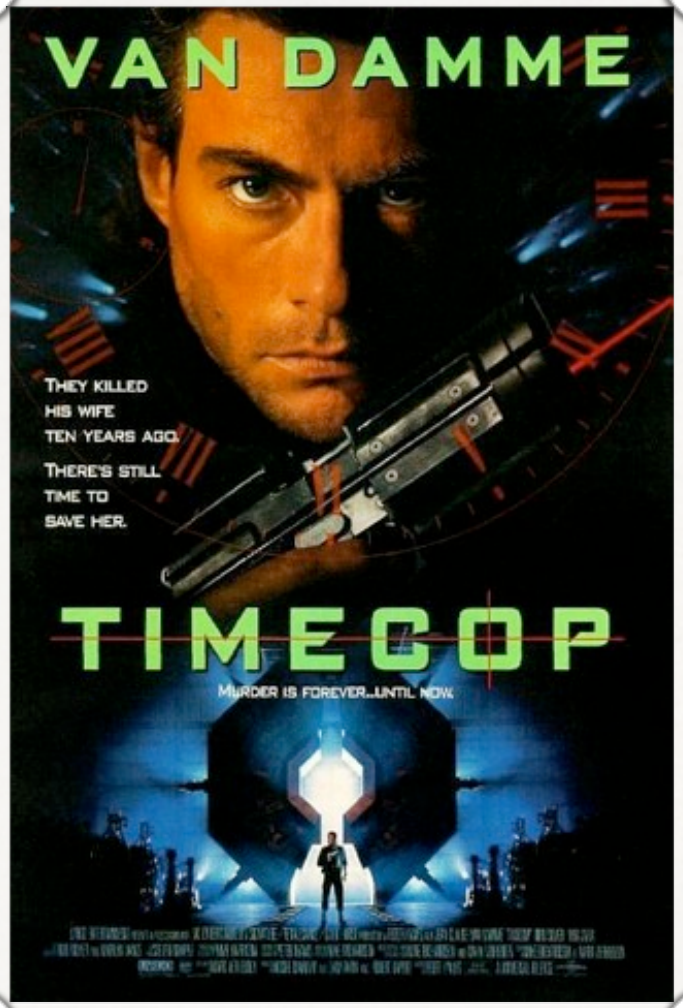

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Driving Is Easy

- Eating, phone calls, texting, sleeping
- Drunk driving
- Aggressive driving

Driving Is Hard!

- Distance and velocity estimation
- Physical dexterity
- Piloting vs. navigating
- Split-second reactions

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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

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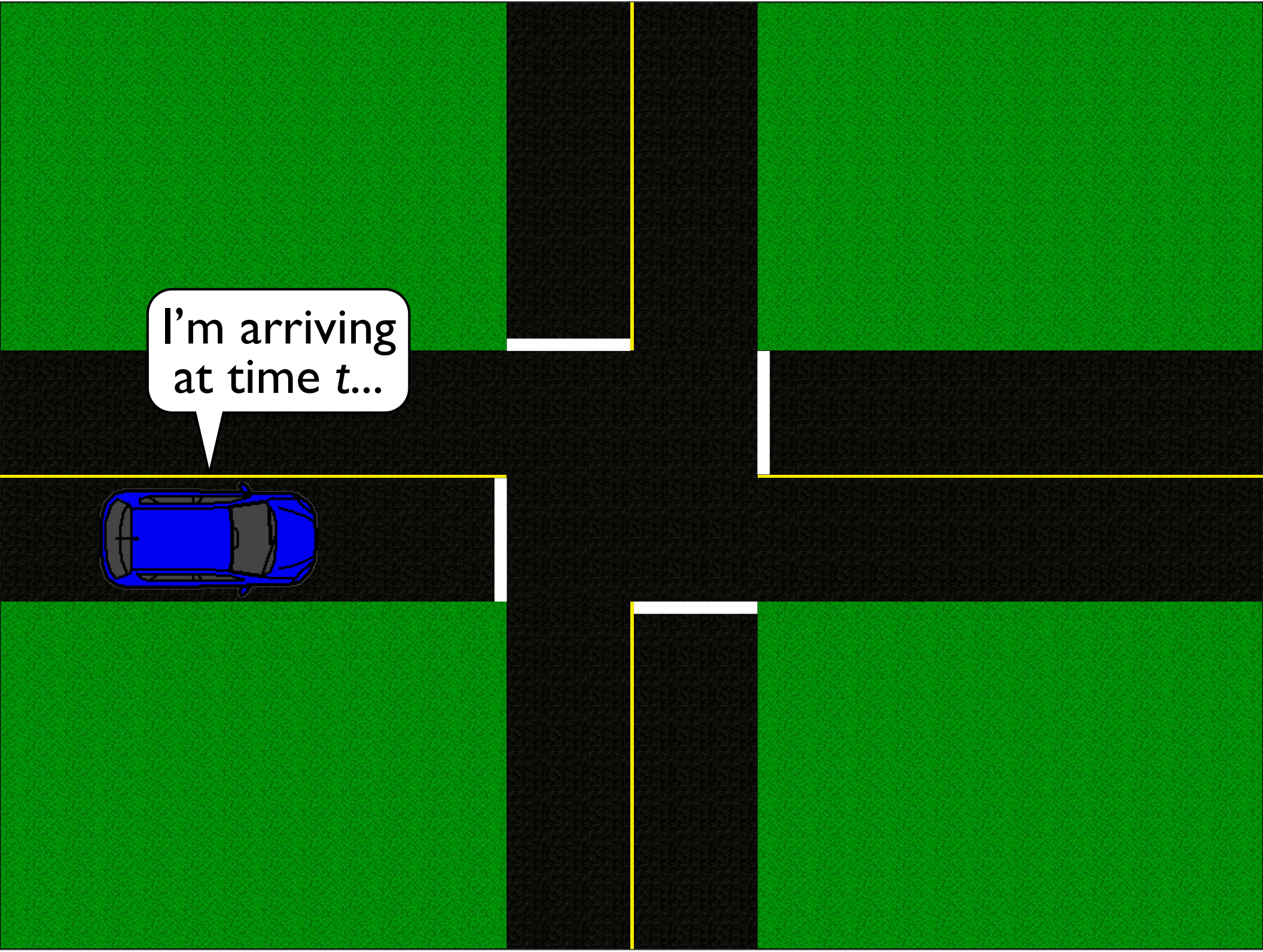
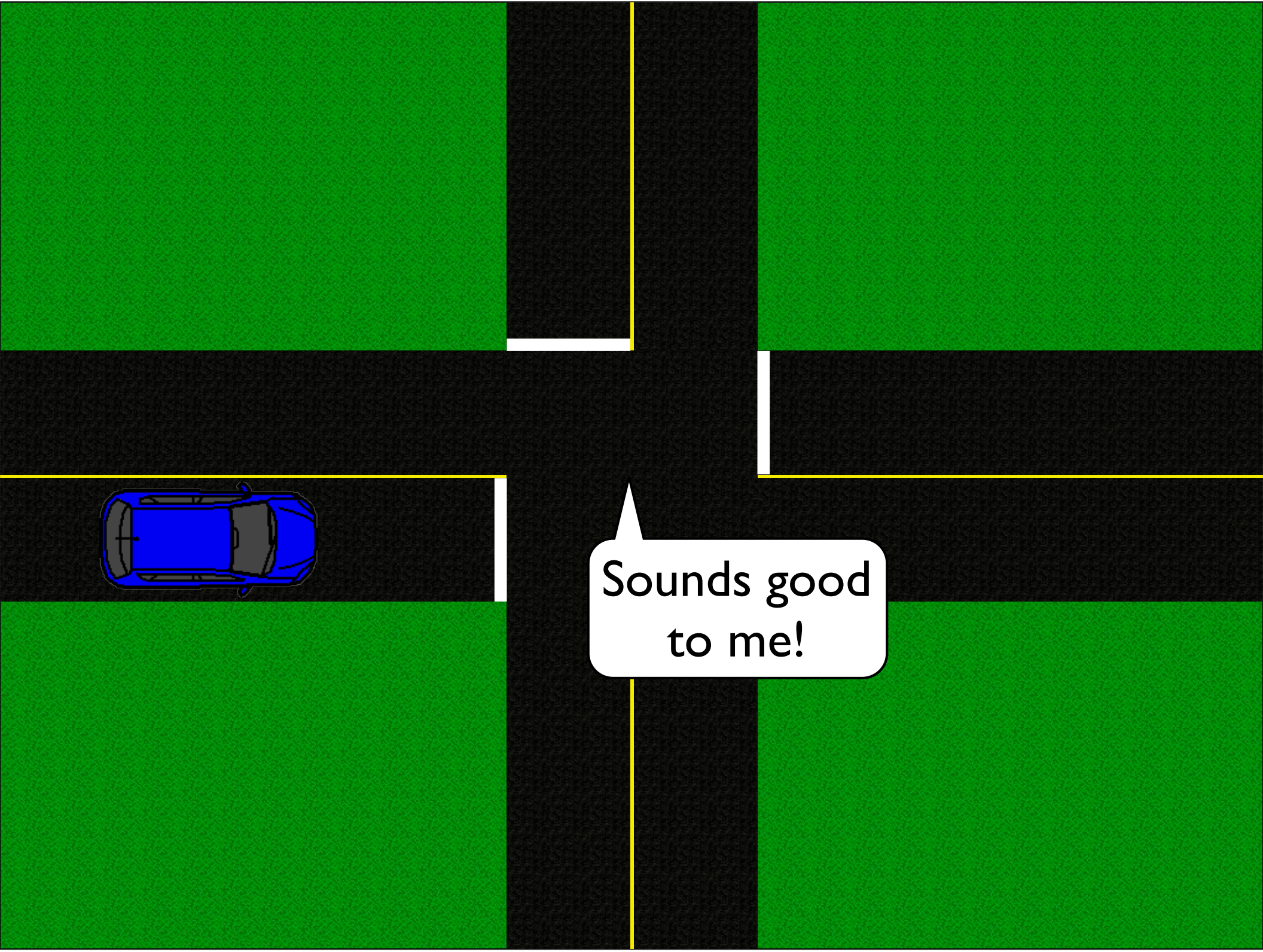
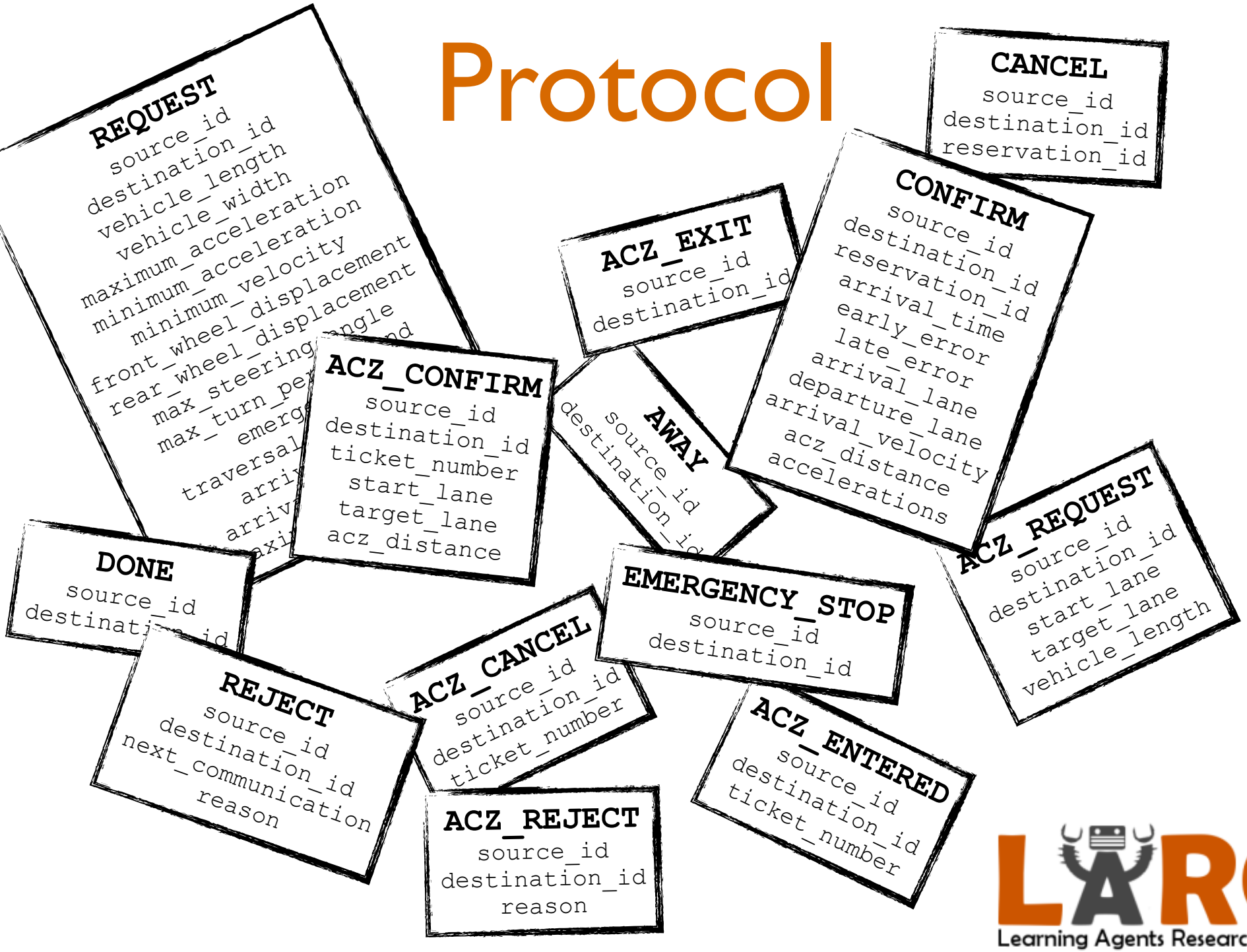
Vehicle-to-Intersection

- 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



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Protocol

The Important Points

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

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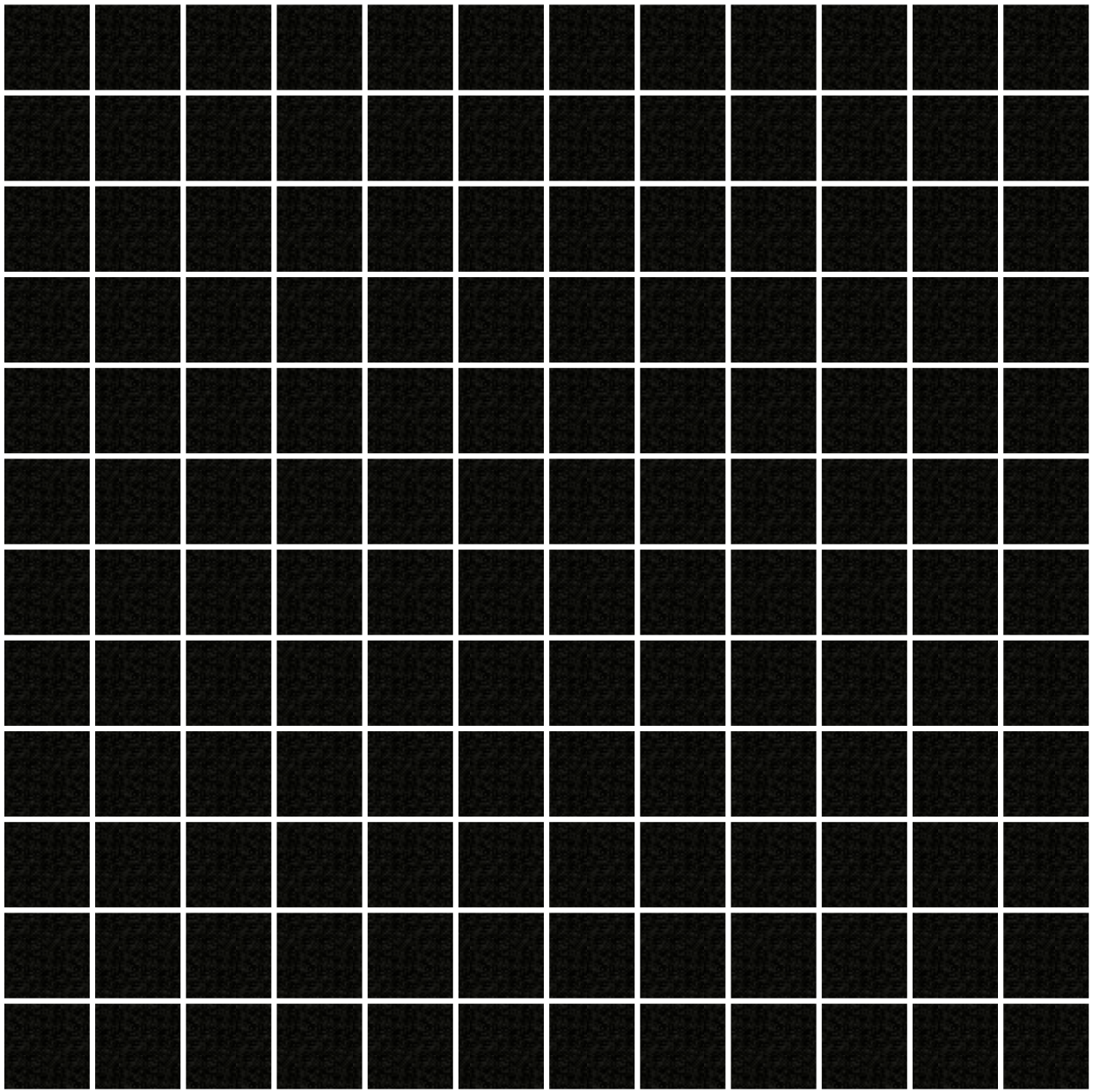
The FCFS Policy

- "First come, first served"
- Primary policy
- Grid of reservation tiles
- Internal simulation of vehicles' trajectories



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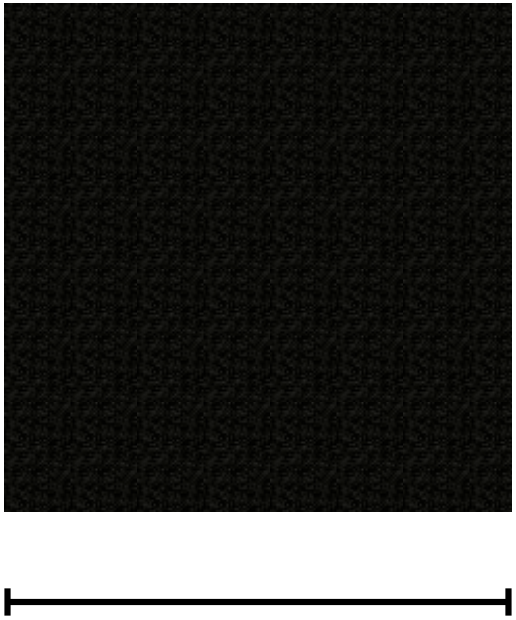
Reservation Tile



"Granularity"

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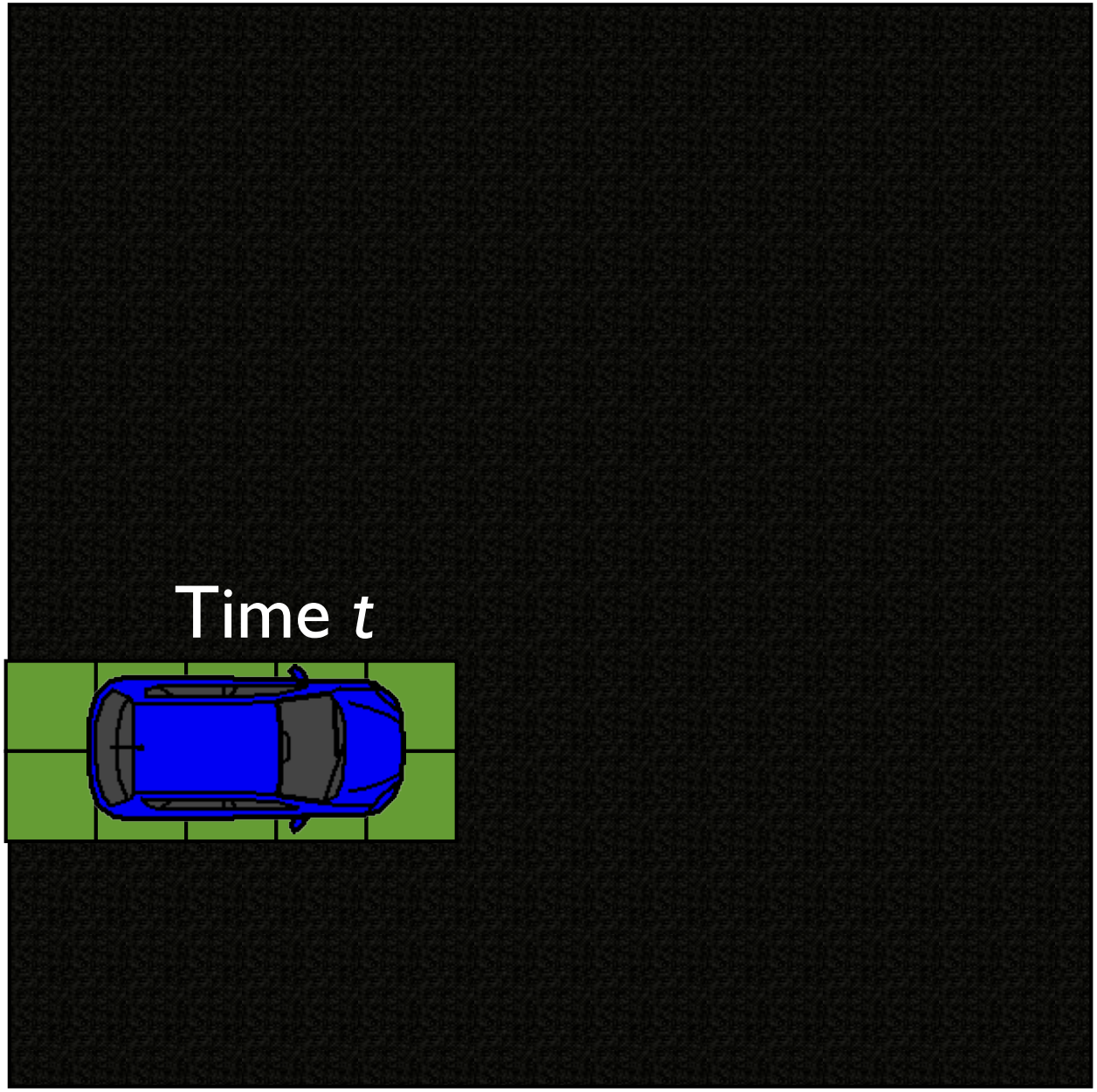

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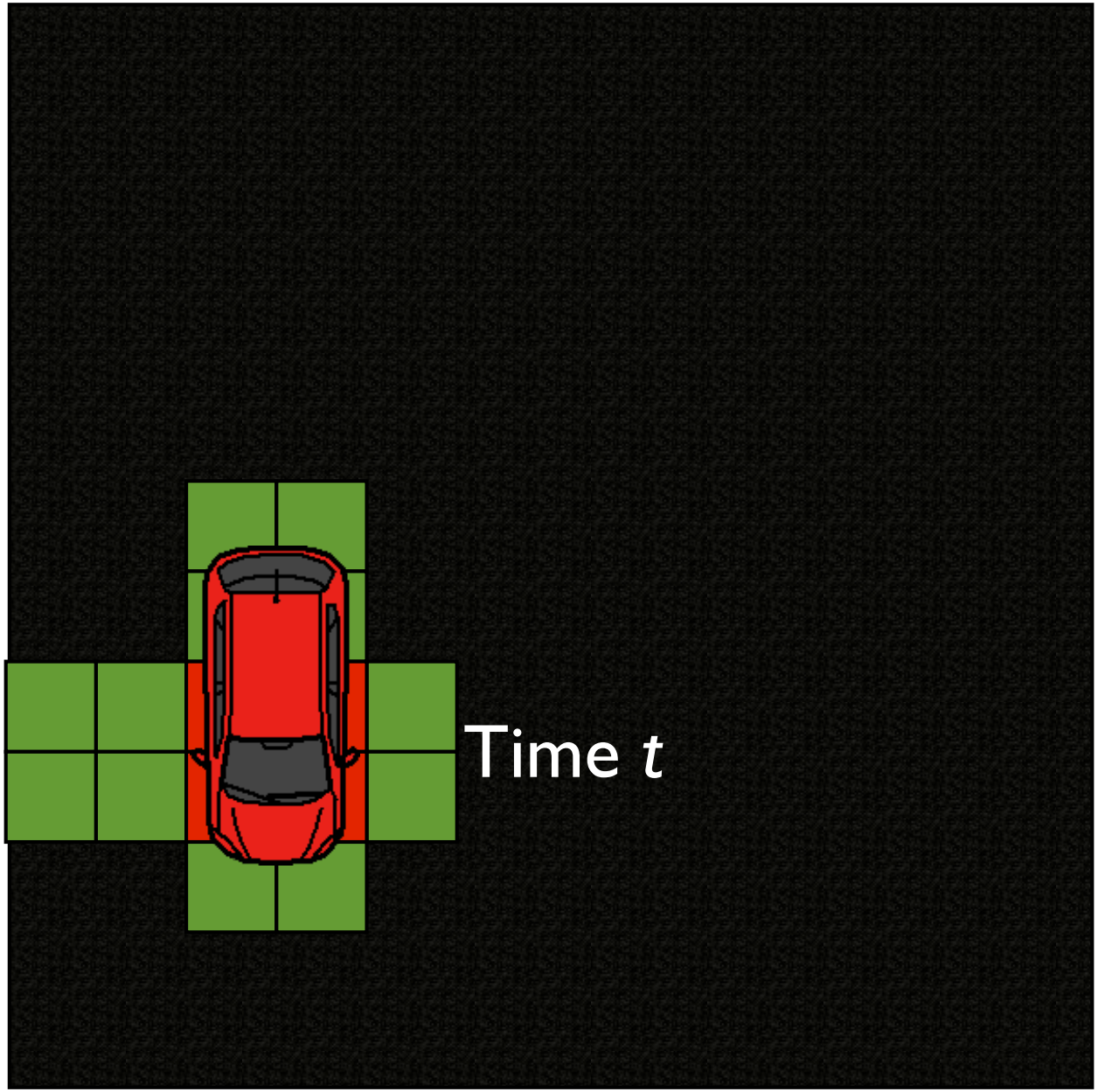

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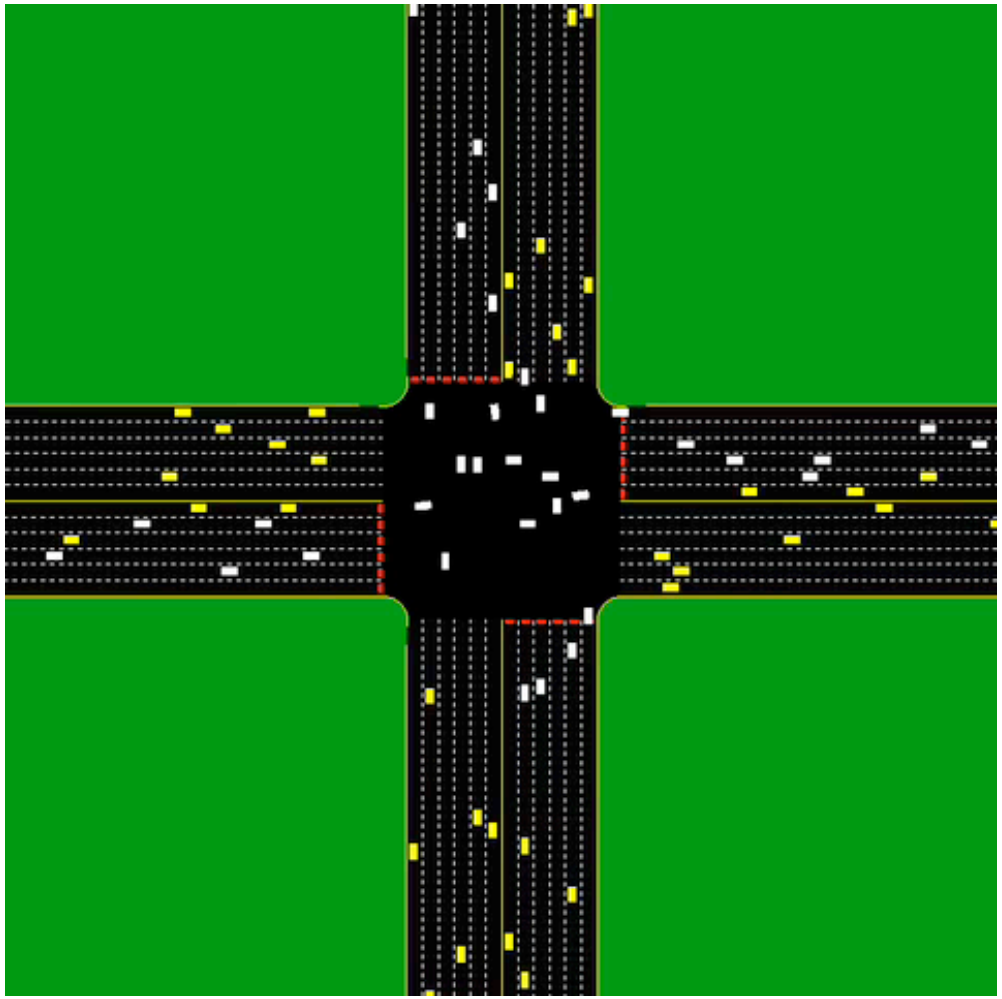
FCFS Video



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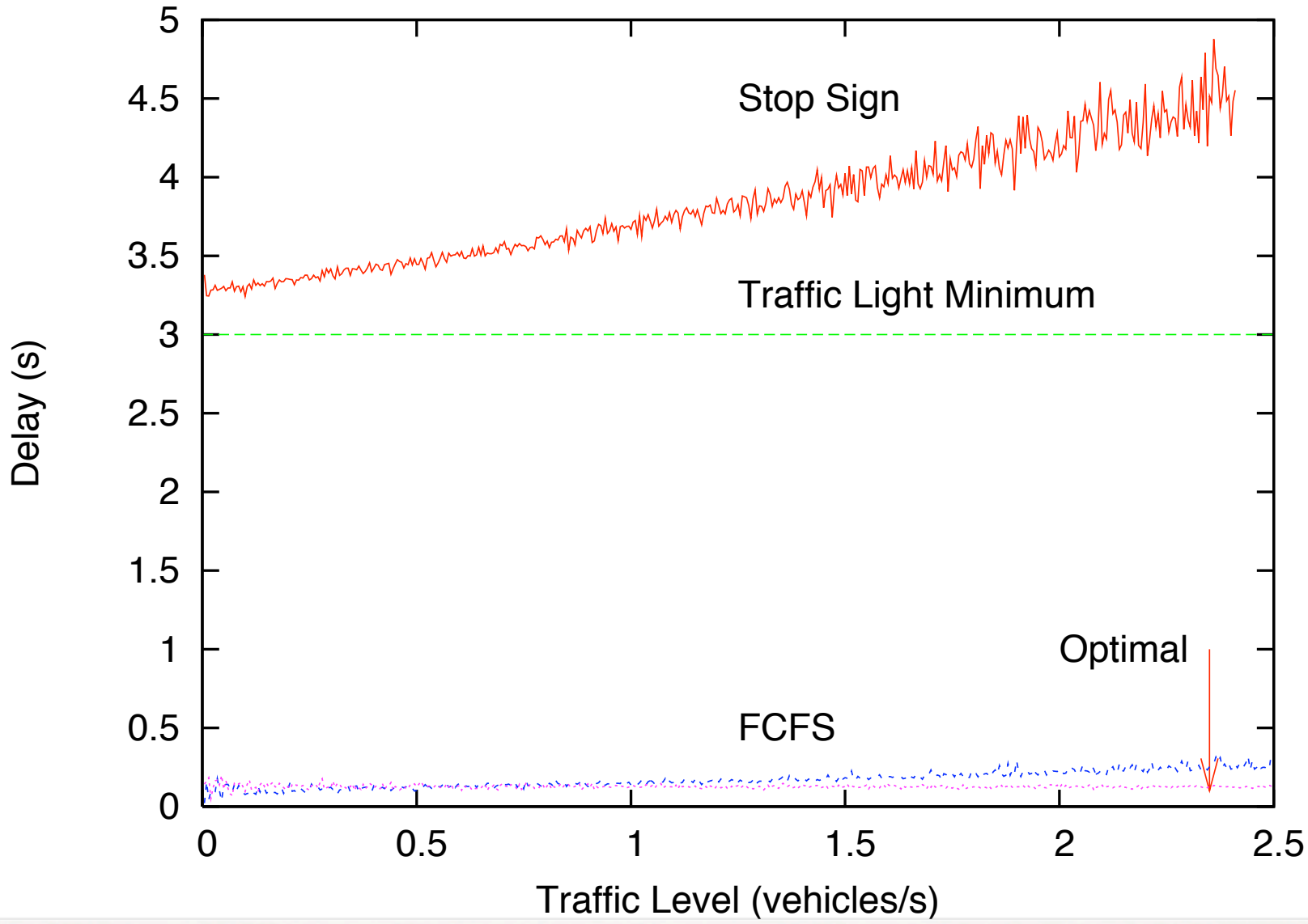

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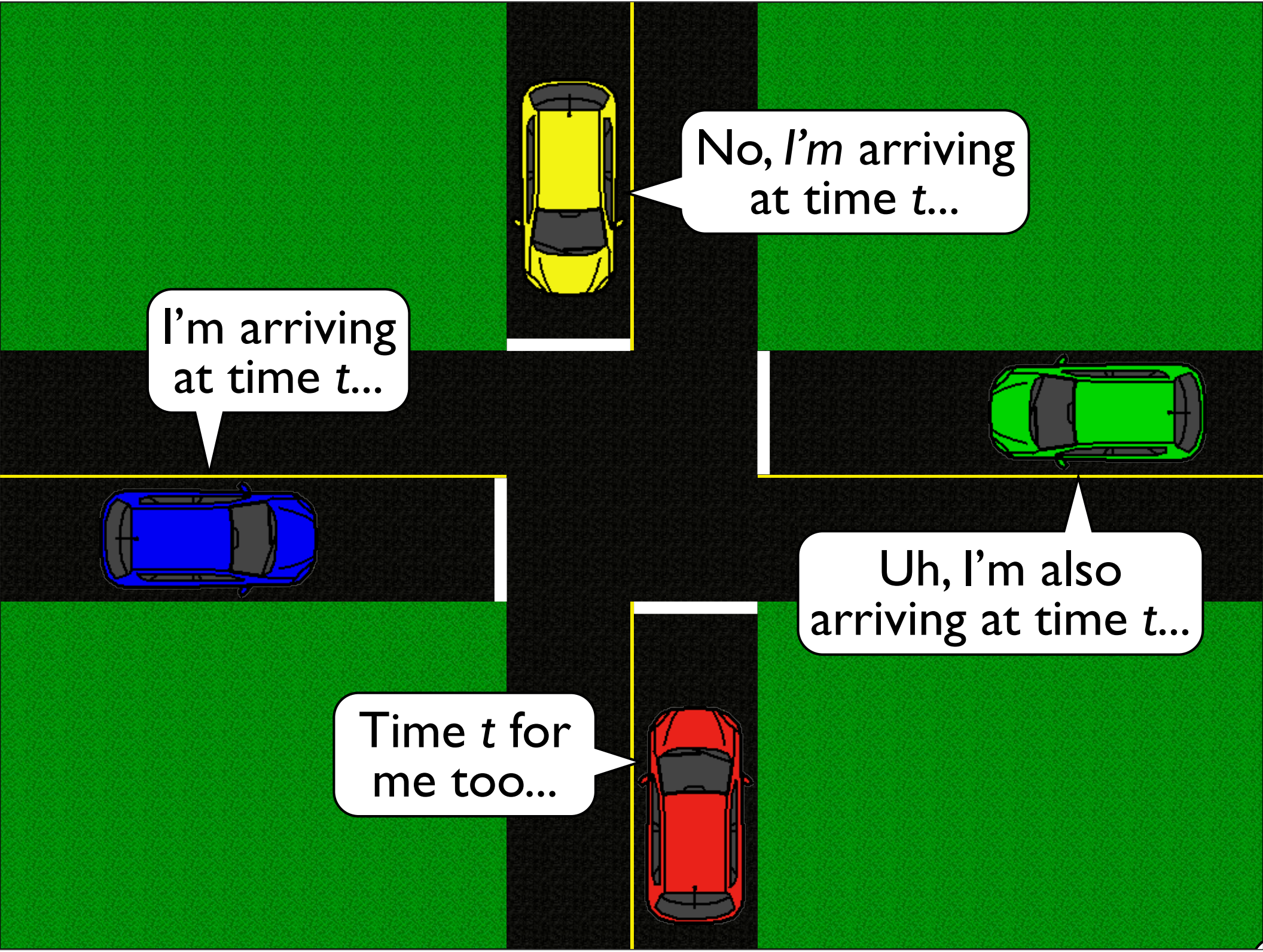
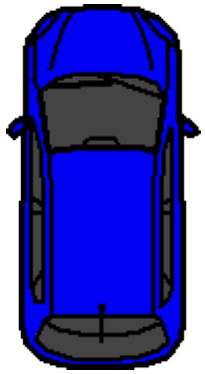
Vehicle-to-Vehicle

- 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

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2
message_id
6
ixn_id
5
stopped_at_ixn
false
arrival_lane
1
departure_lane
2
arrival_time
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departure_time
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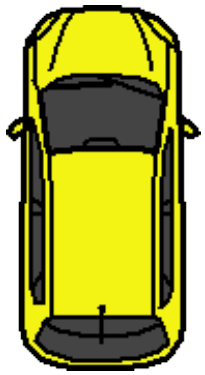

Claim

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message_id
10
ixn_id
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departure_lane
2
arrival_time
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departure_time
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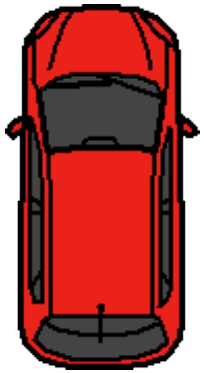

Claim

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message_id
4
ixn_id
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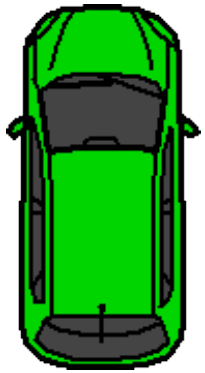

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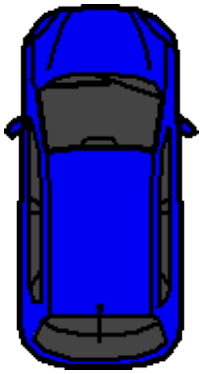
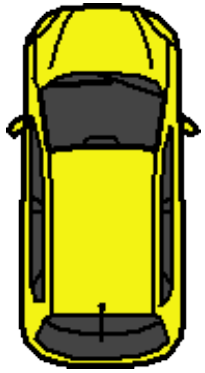
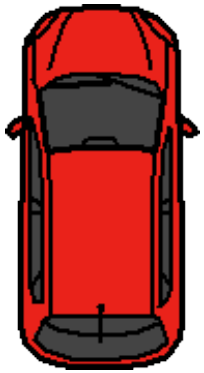
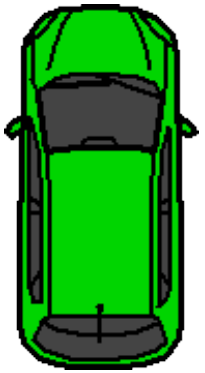
Claim Claim Claim Claim

1 2 3 4

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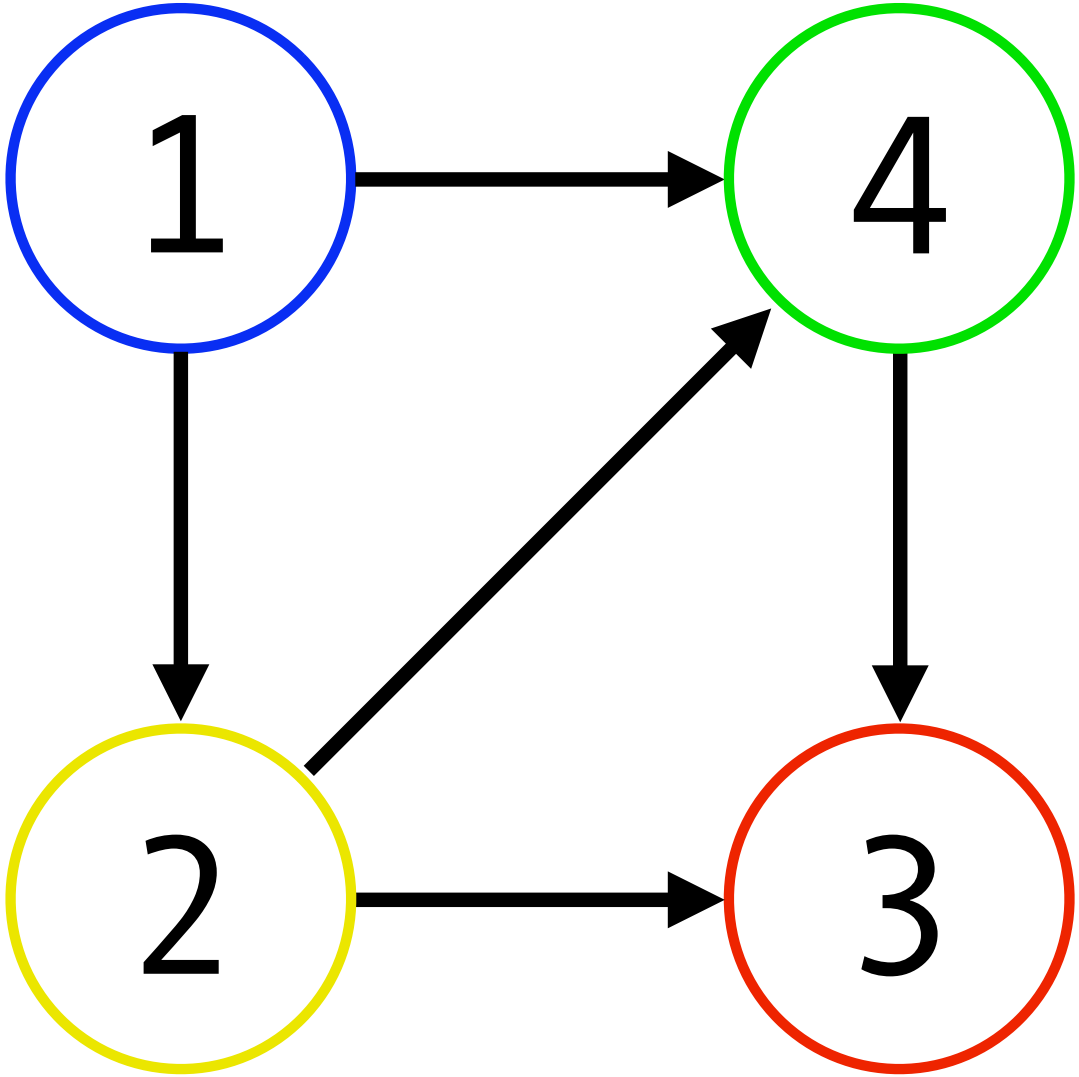
“Dominance”



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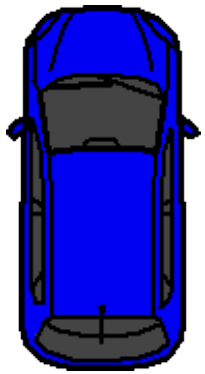
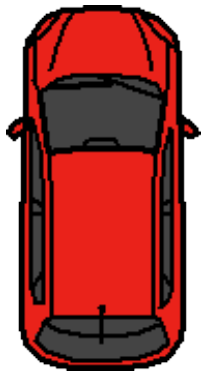
Permissible

1

3





Nonpermissible

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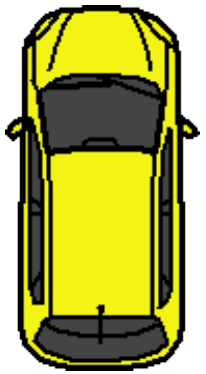
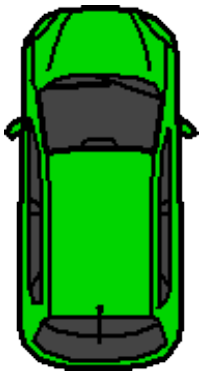
4





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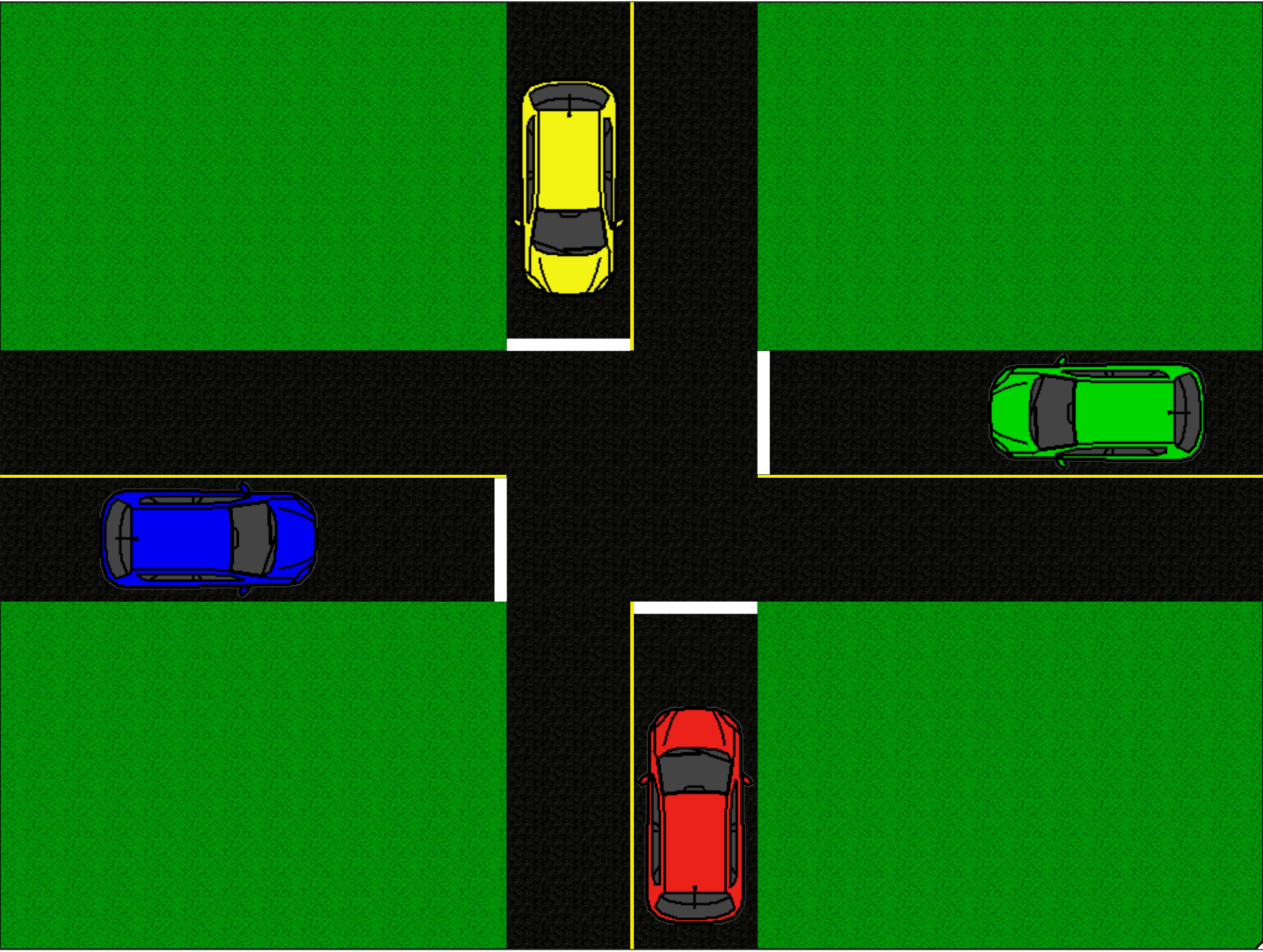

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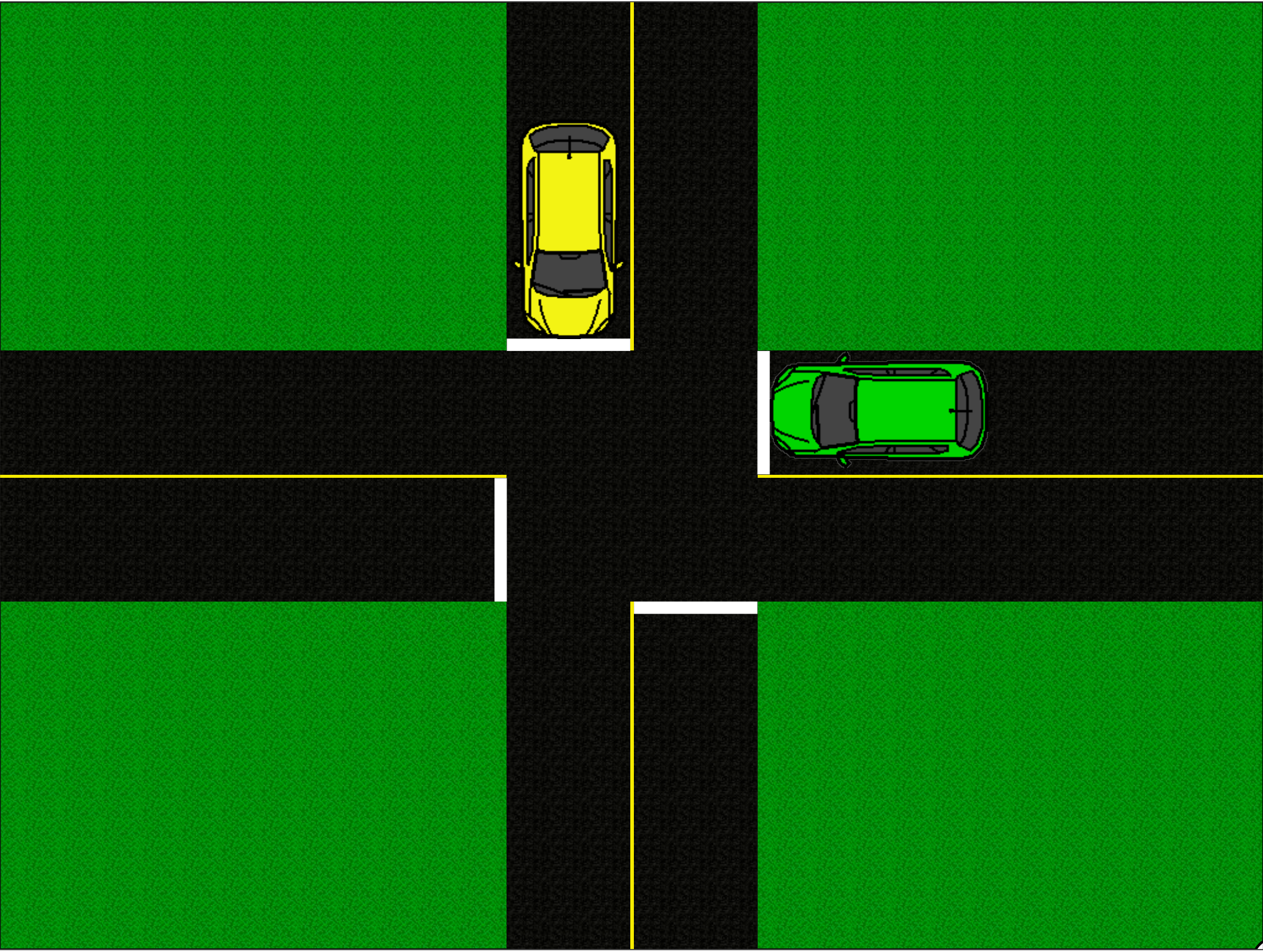

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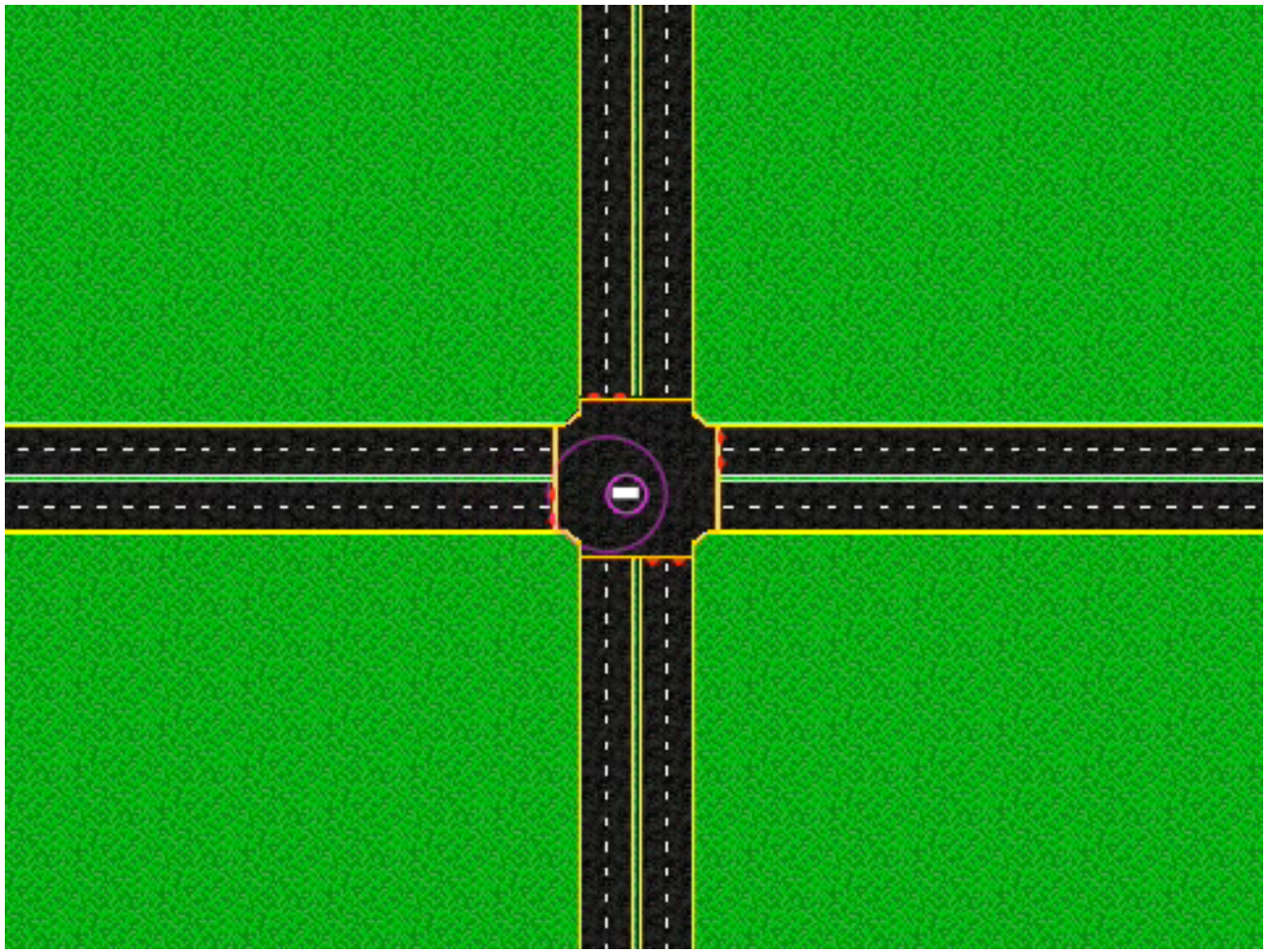
V2V Video



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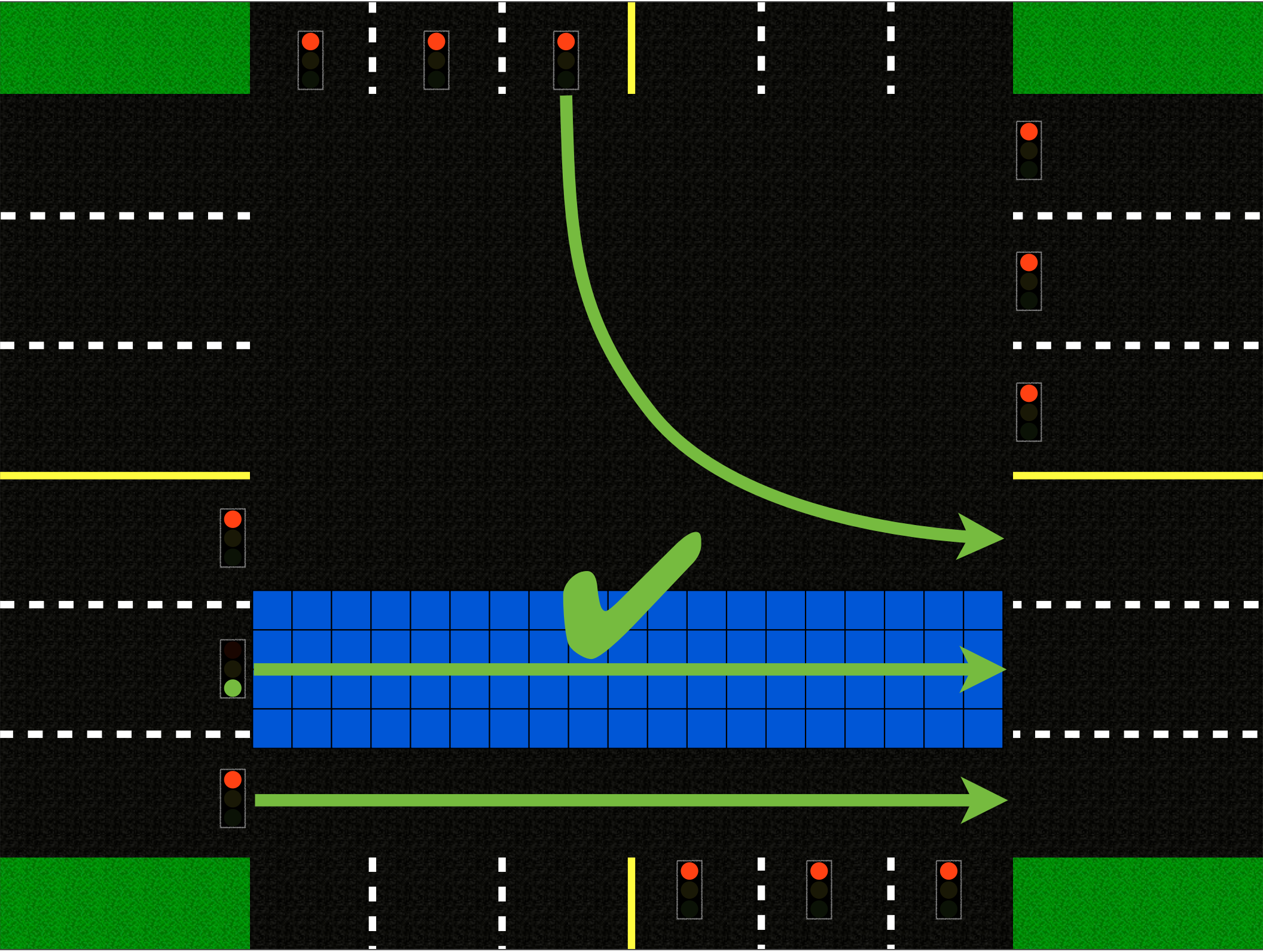
Human Usability

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



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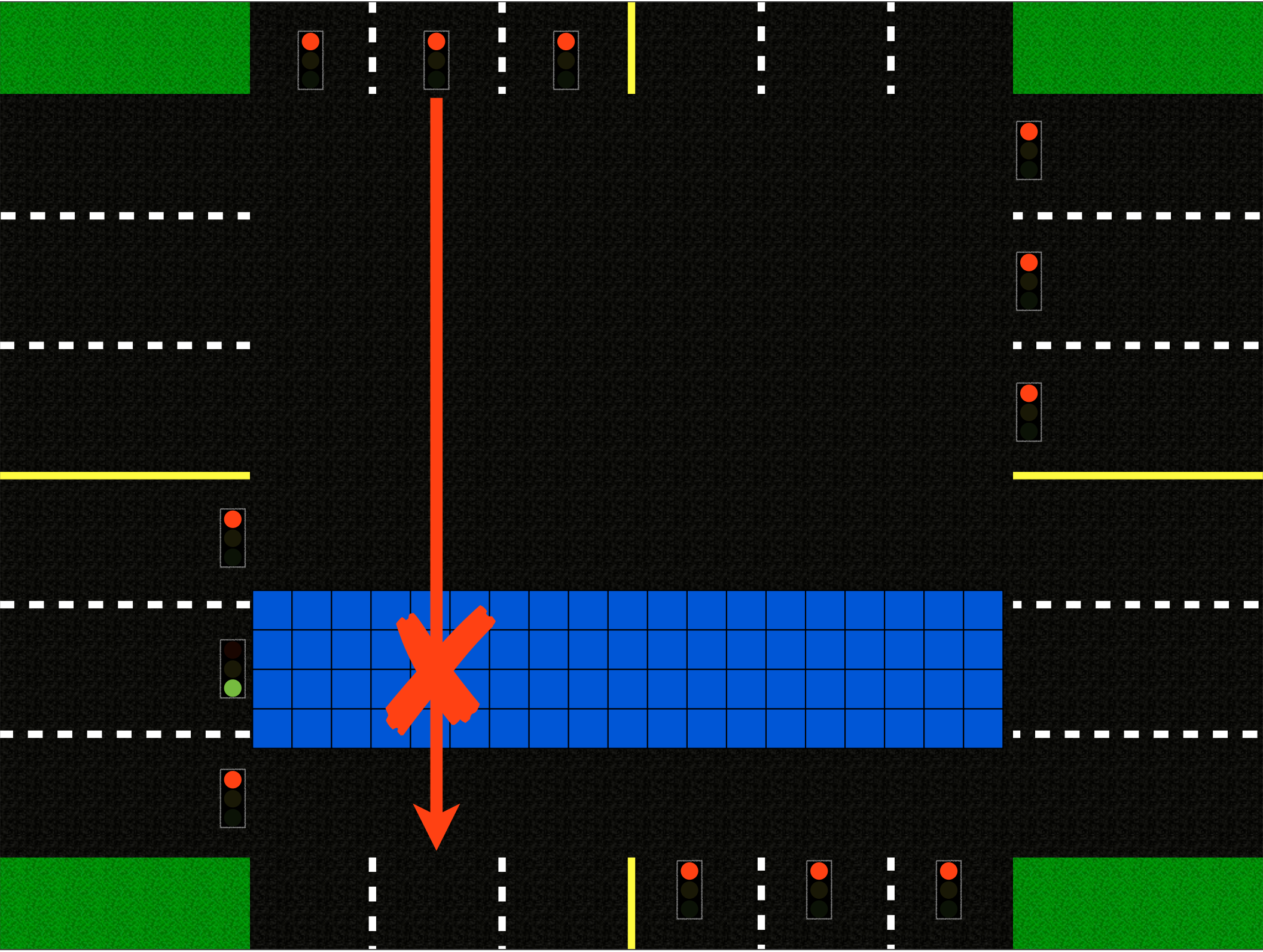

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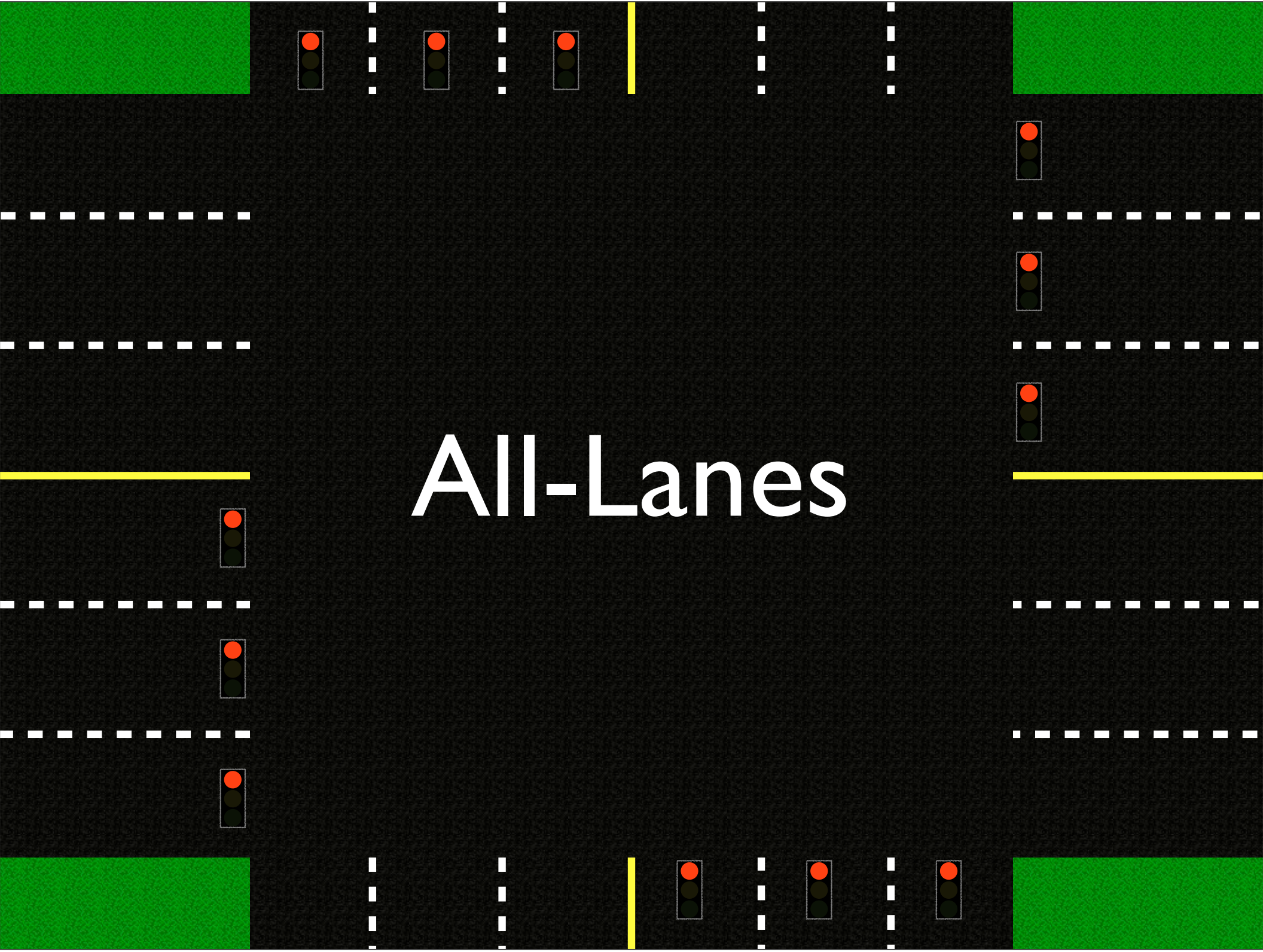
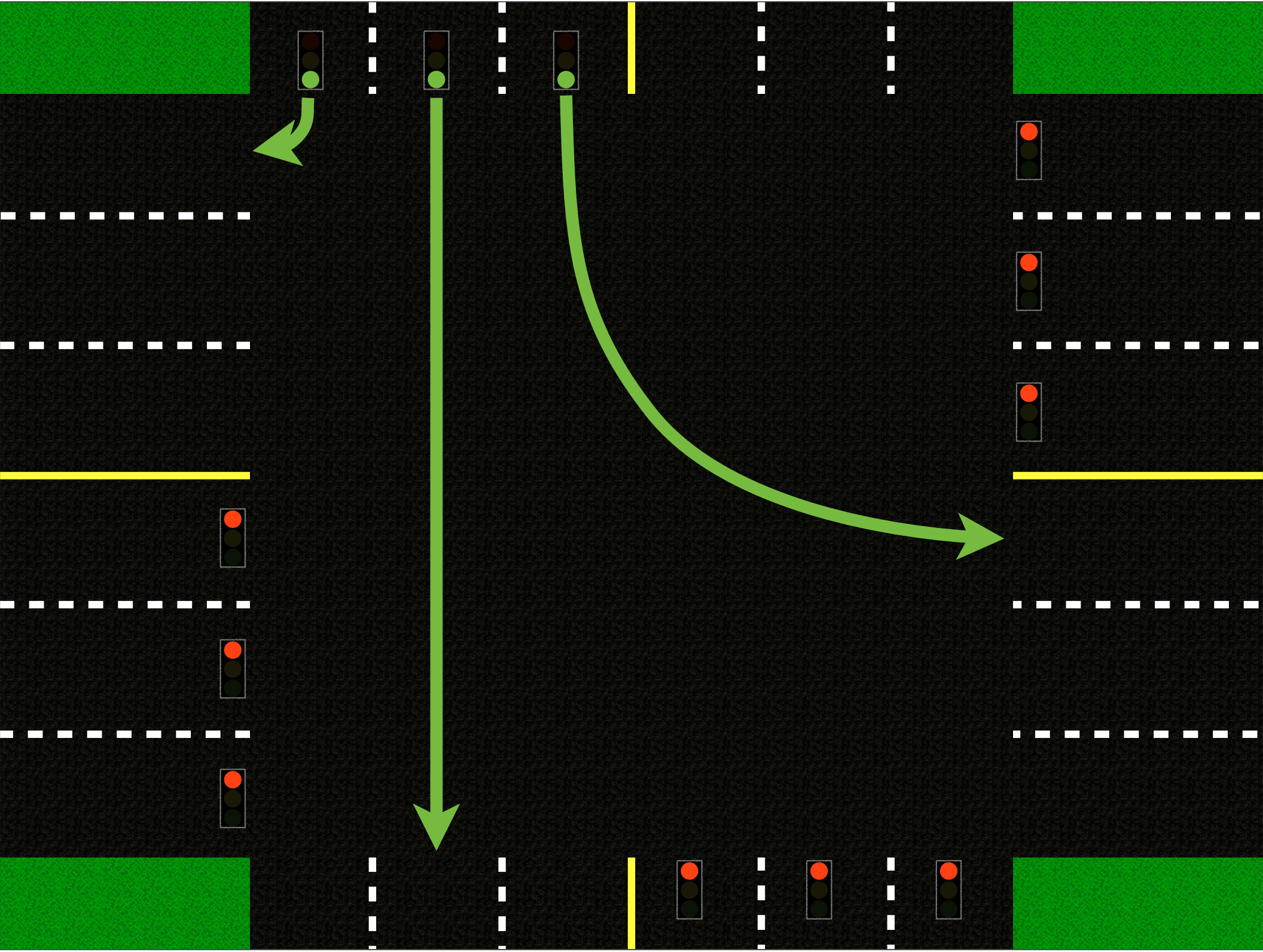

All-Lanes



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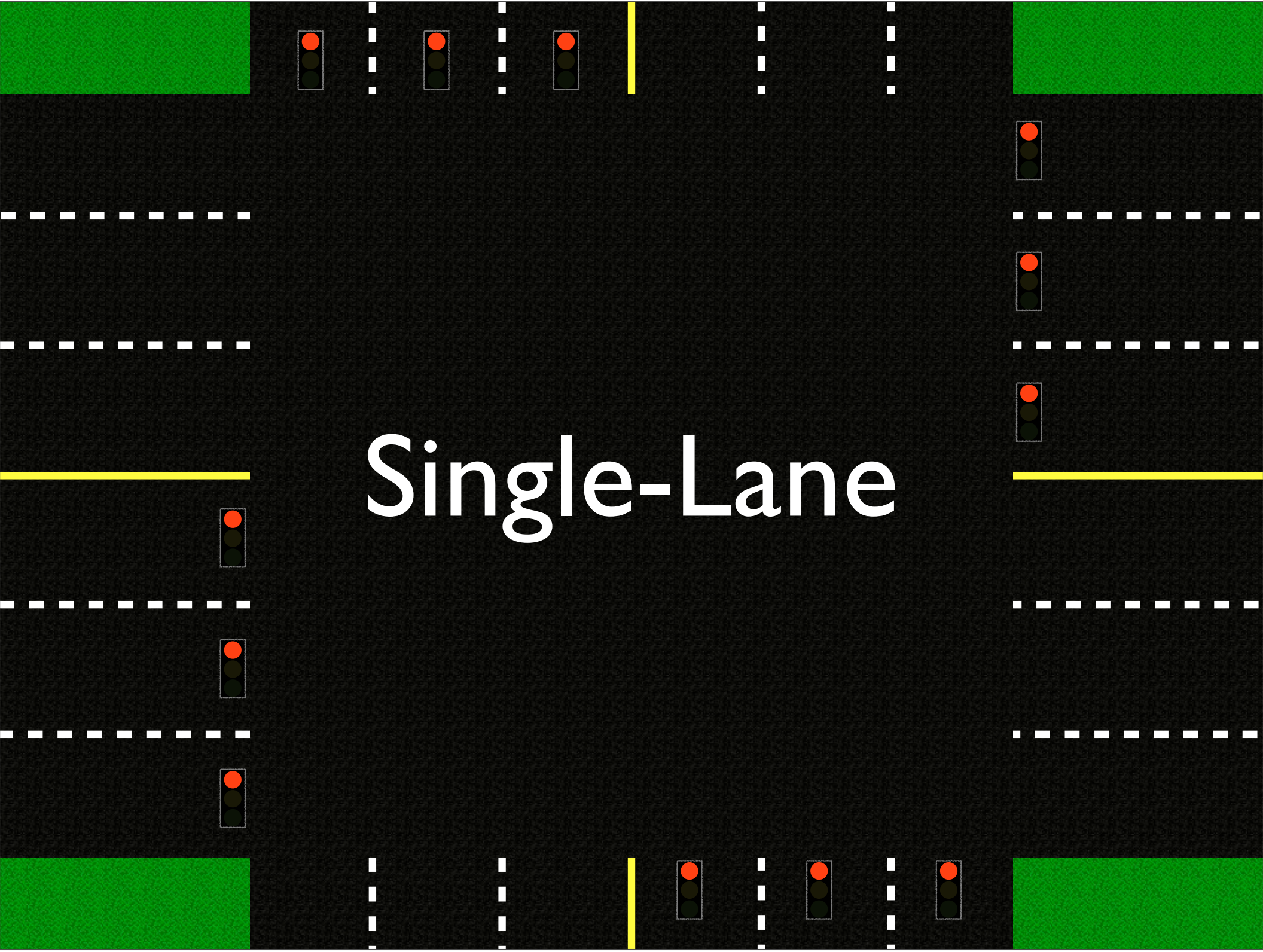
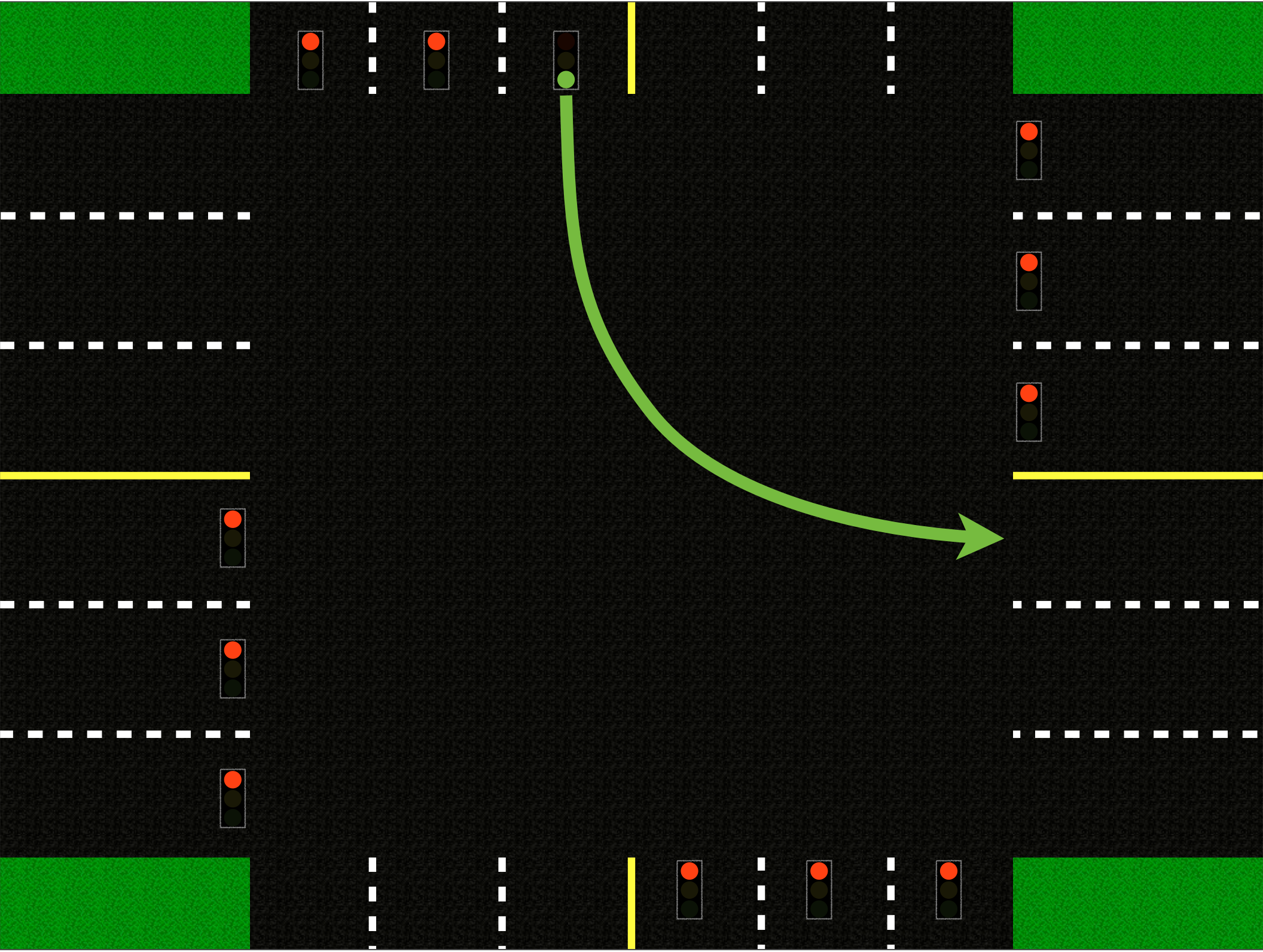

Single-Lane



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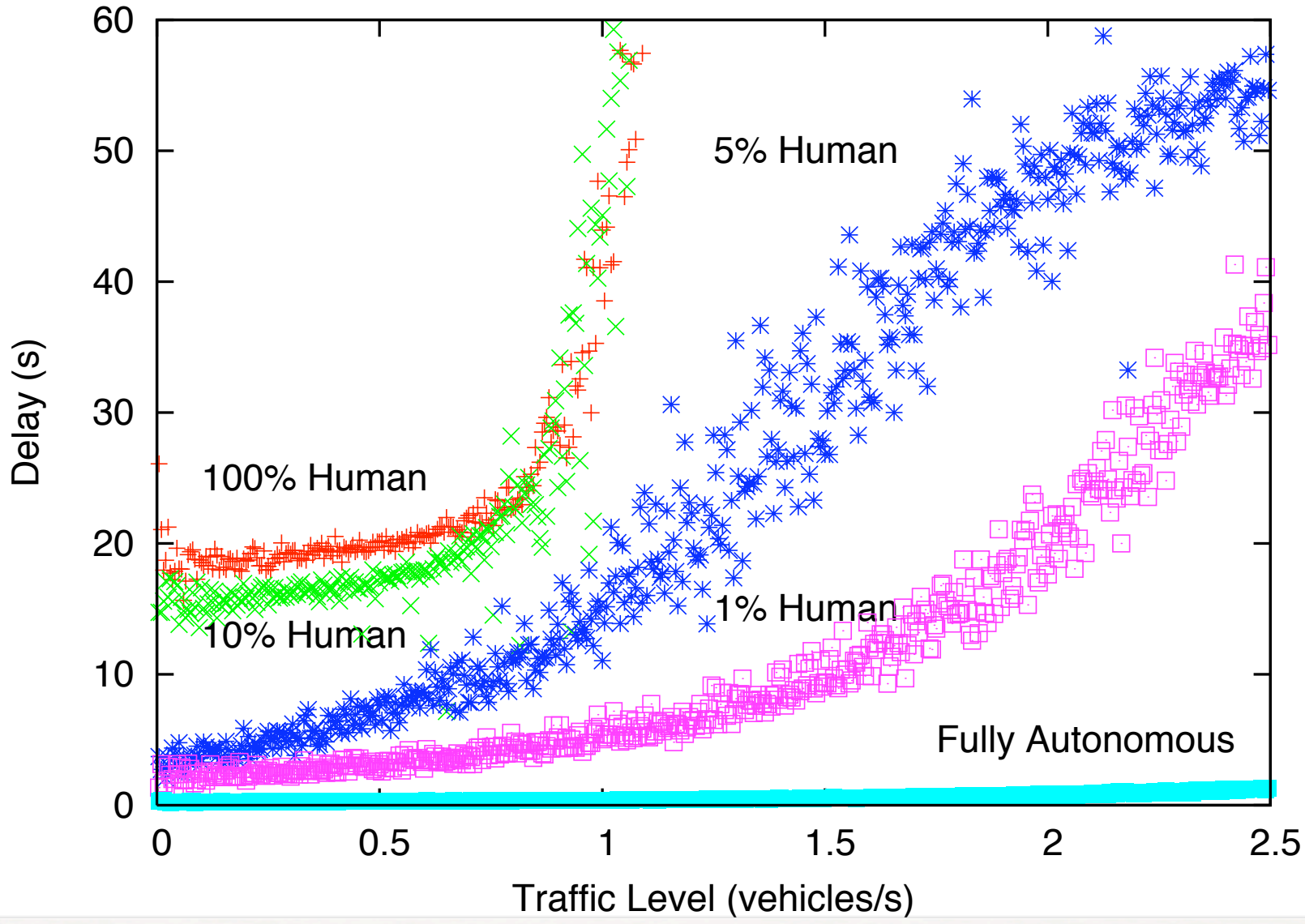

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Failure Mode Analysis

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

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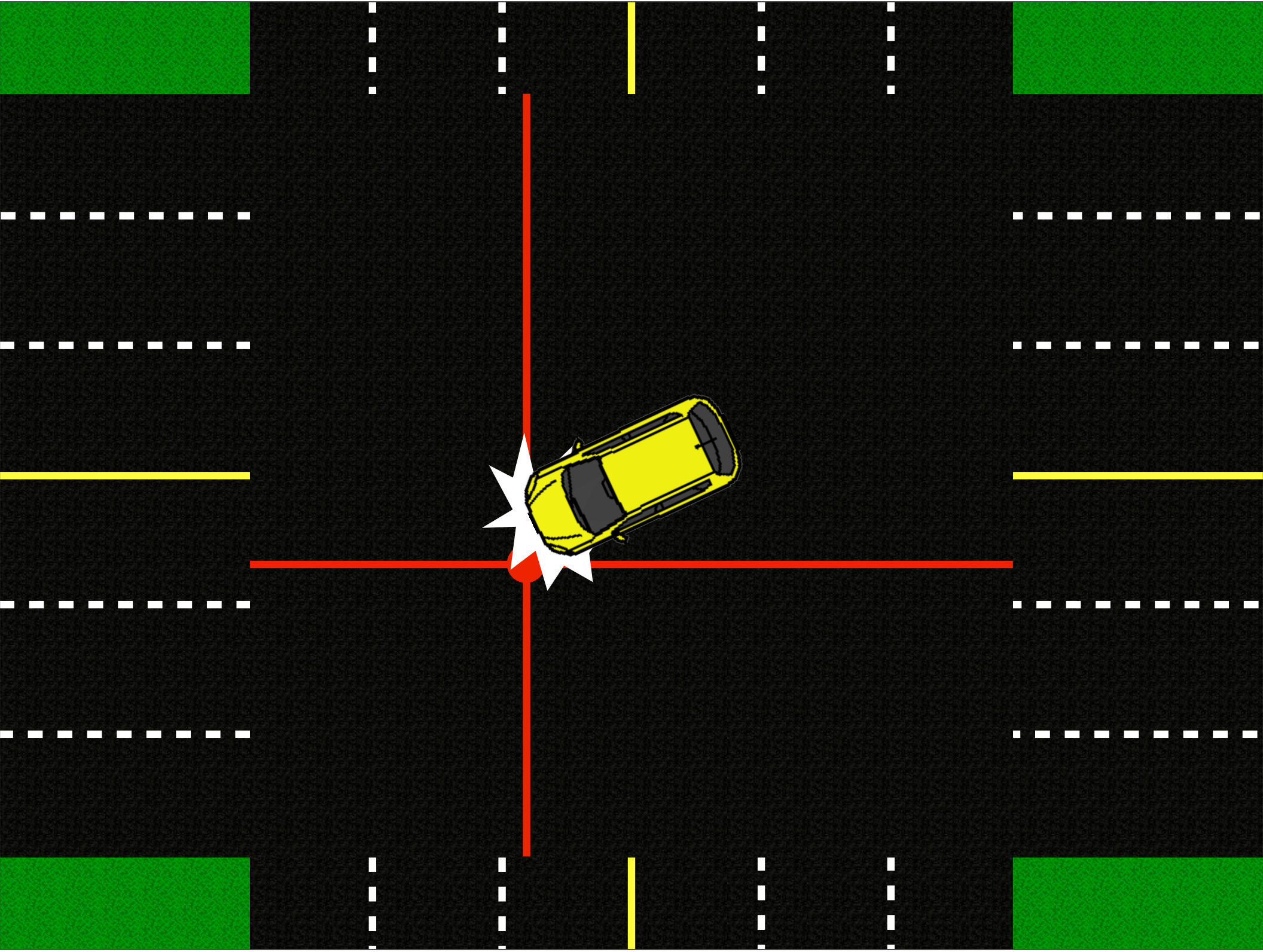

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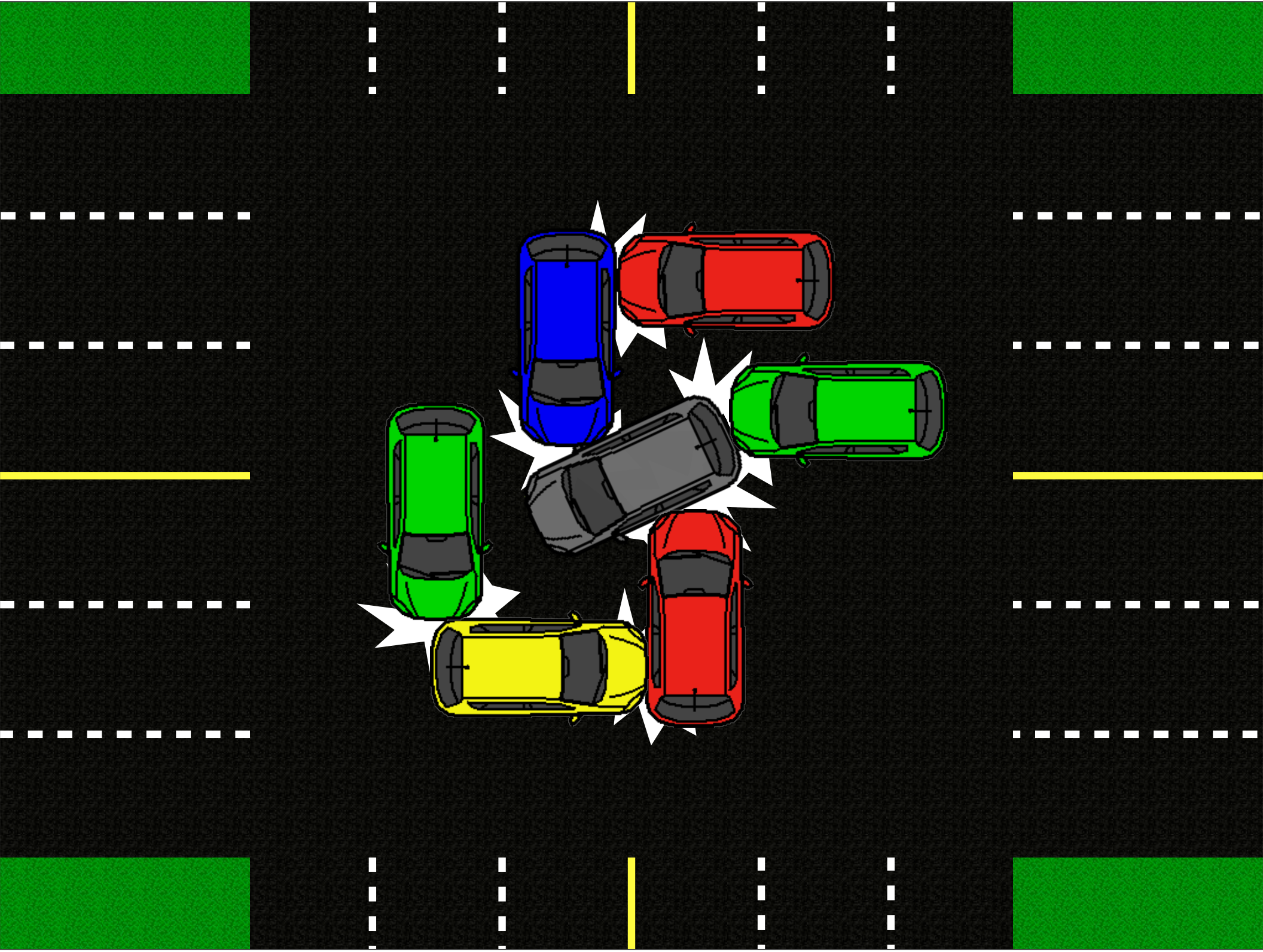

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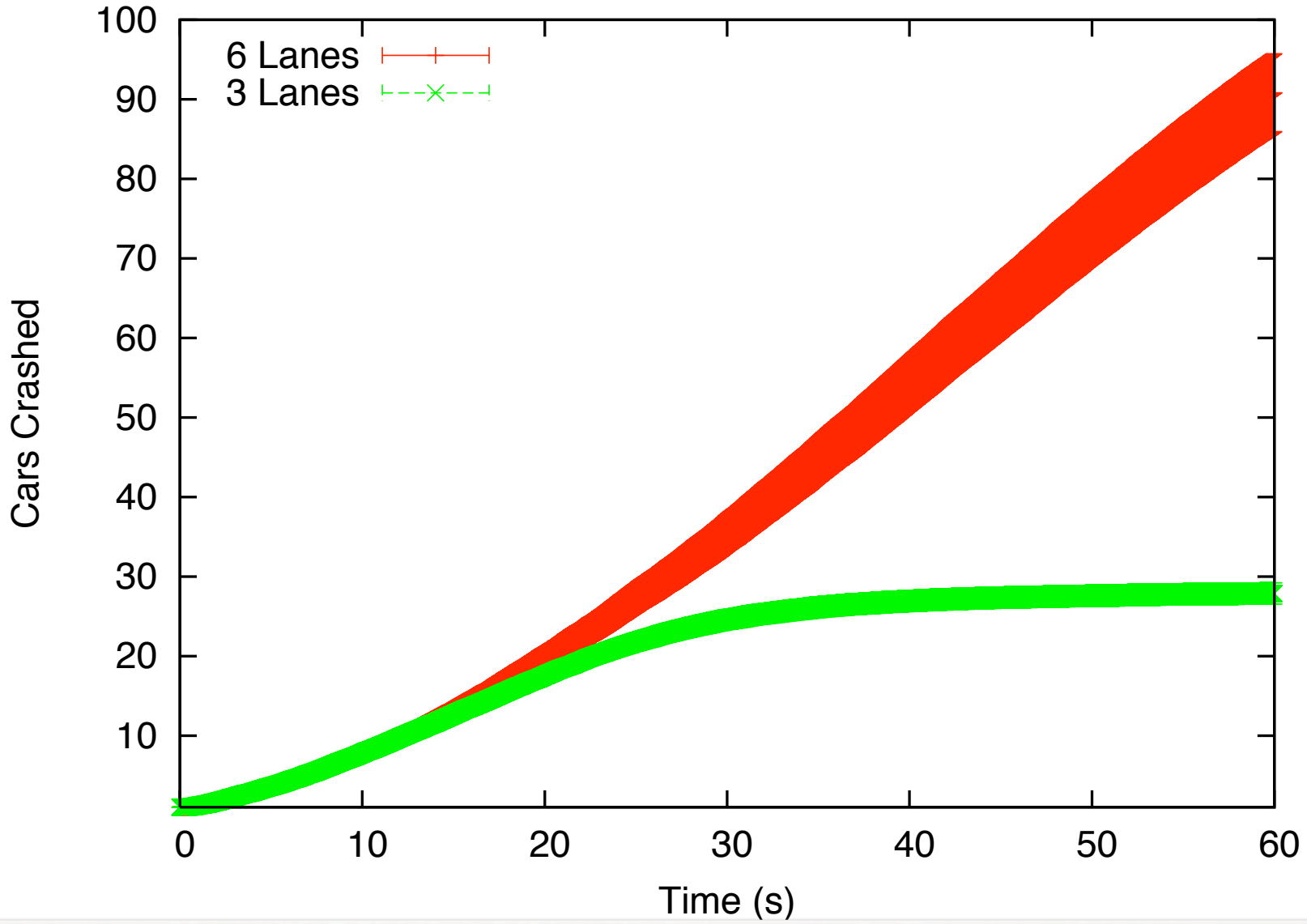

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Mitigating Catastrophe

- Assume intersection manager can detect
- Reaction:
  - Refuse future reservations
  - Emergency-Stop message
- Oblivous vs. passive vs. active
- What if vehicles do not receive?

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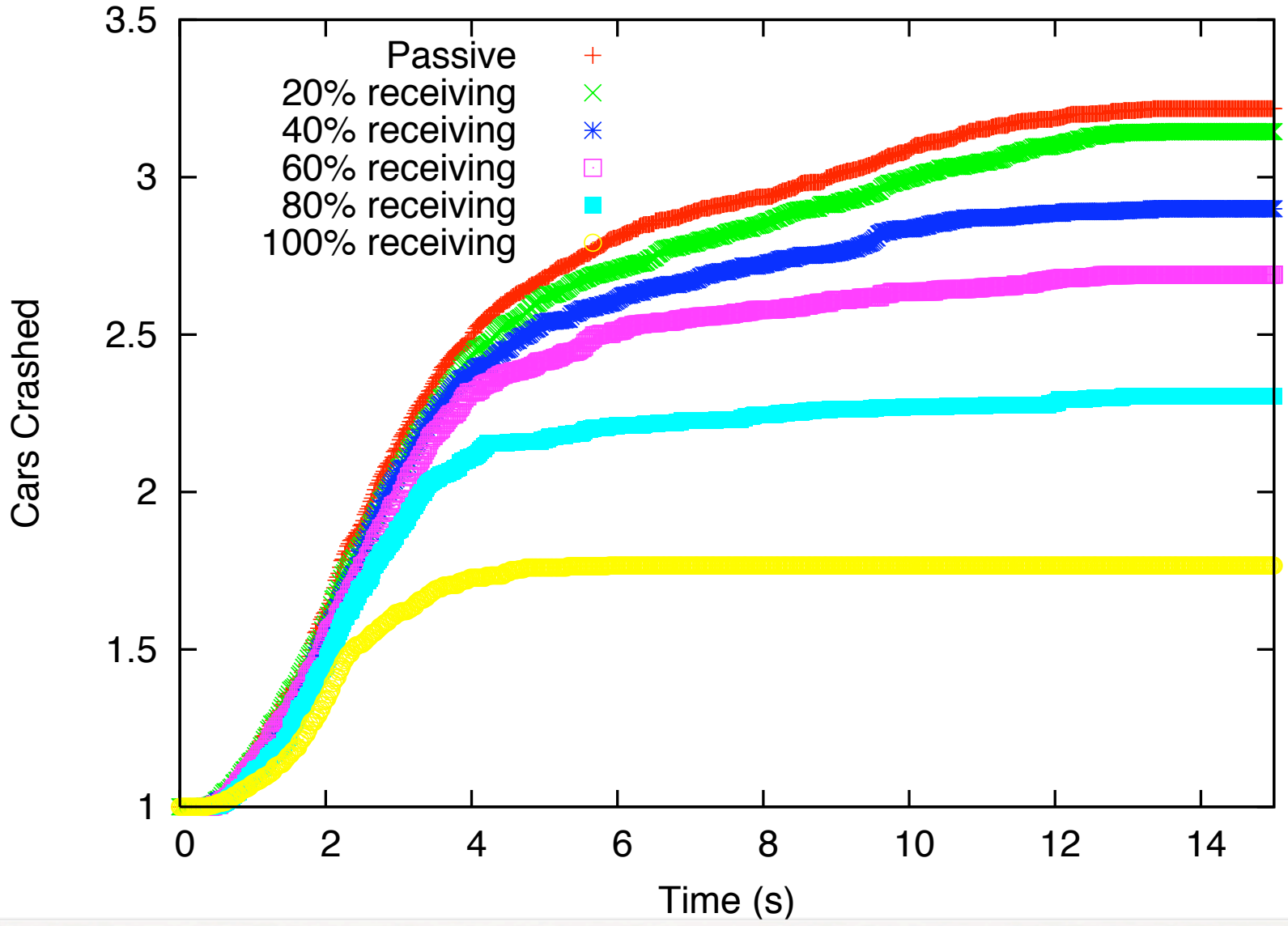

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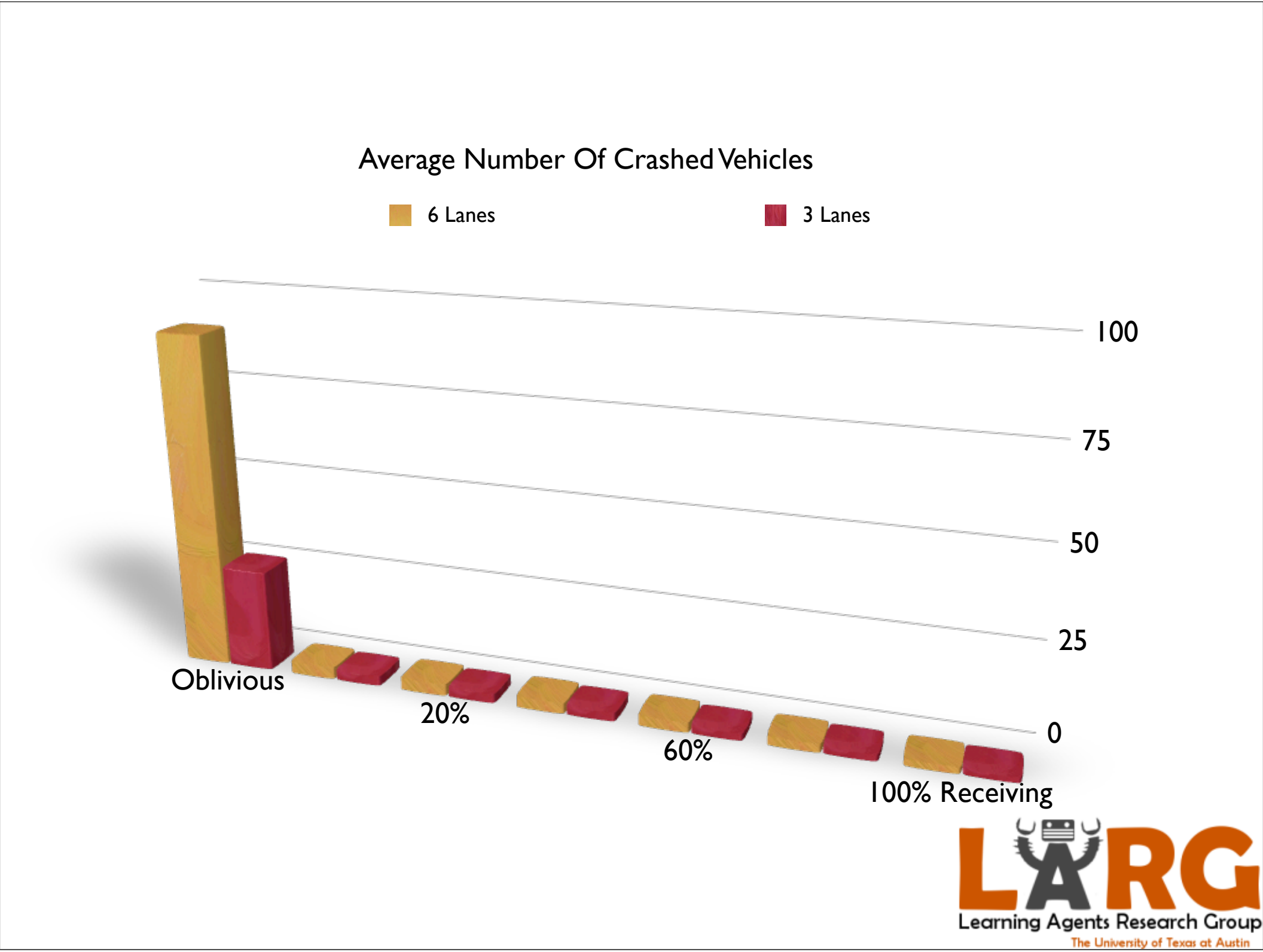

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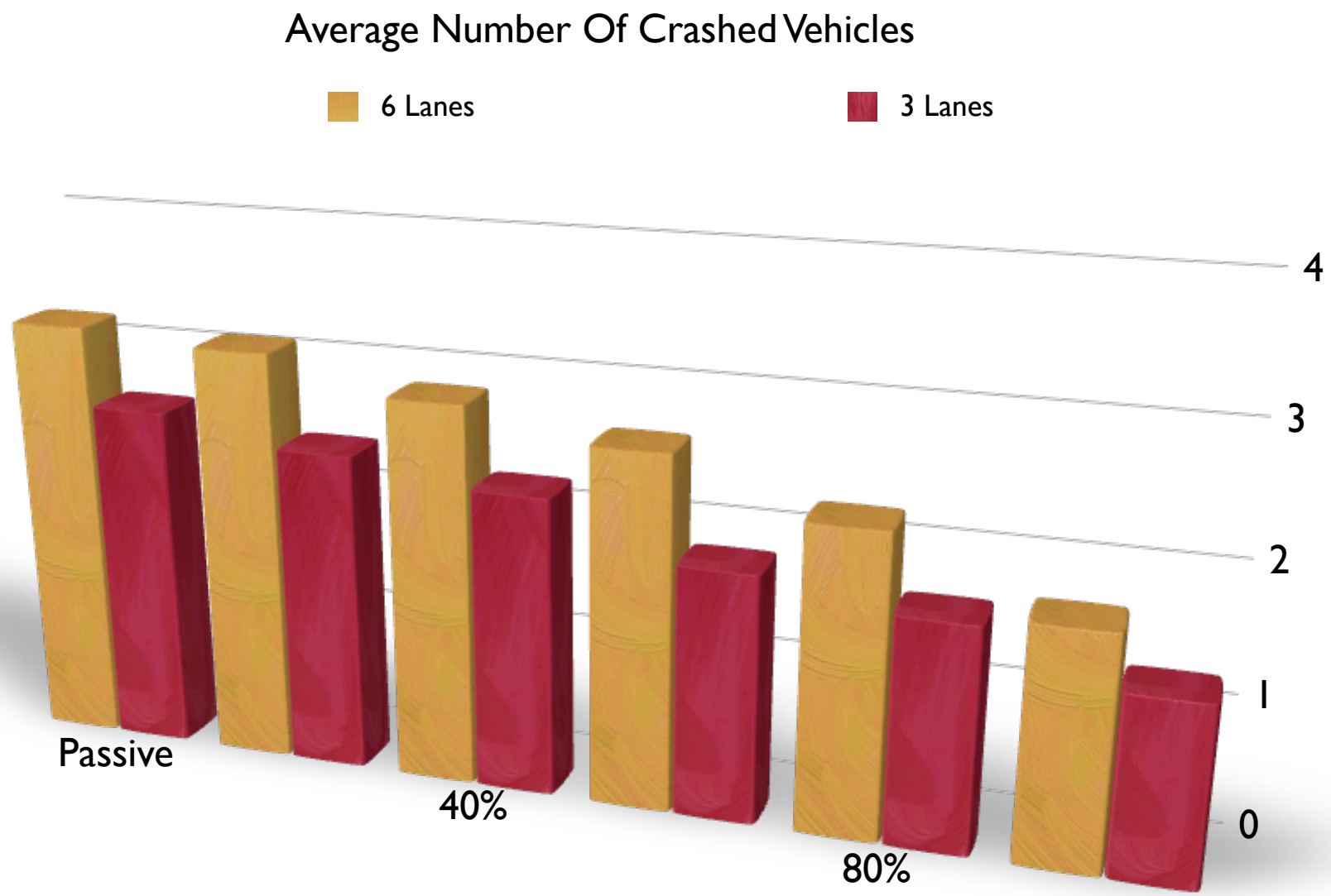

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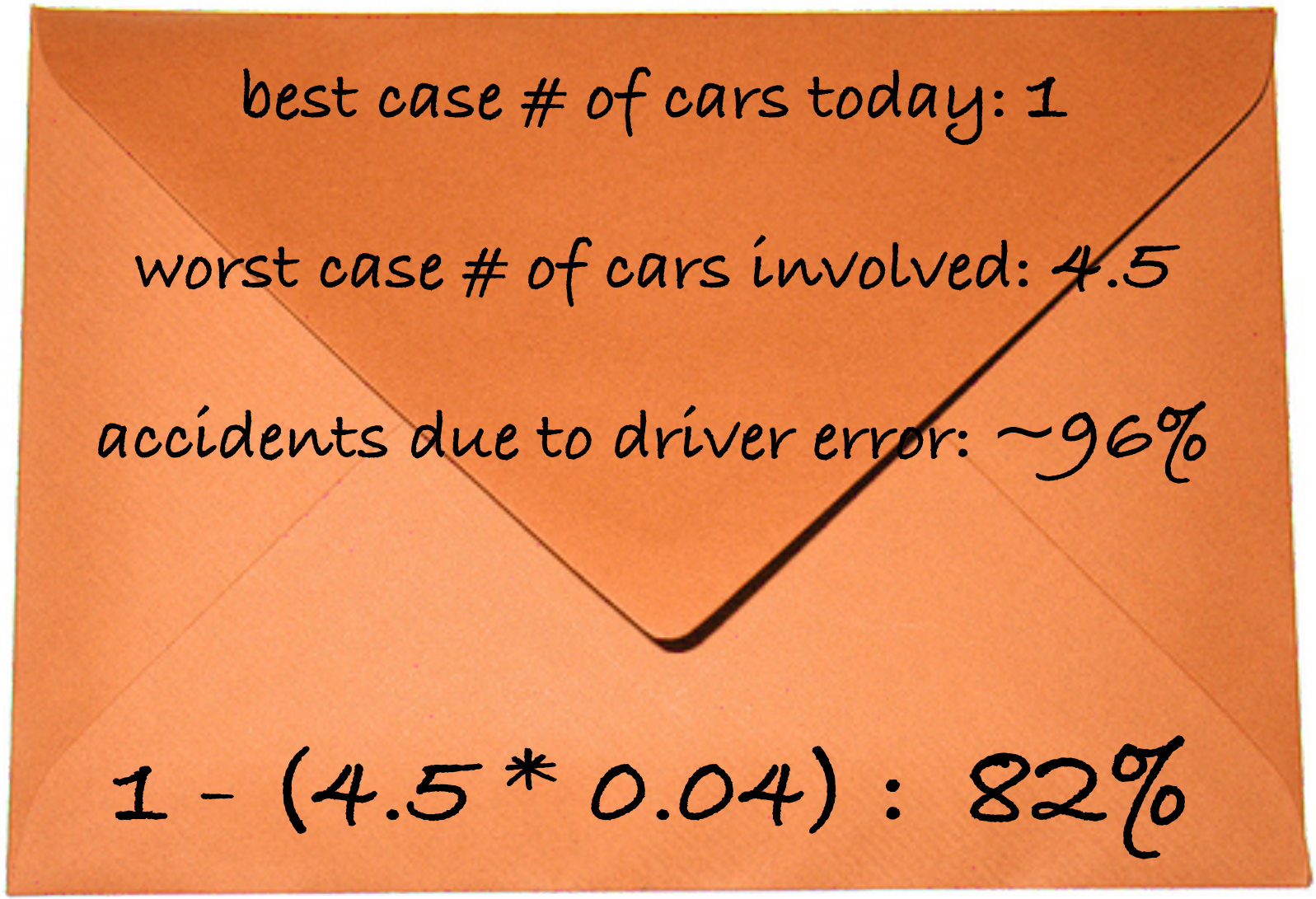

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Multiple Intersections

What's The Big Deal?

- Protocol considerations
- Downstream effects
- Driver agent navigation
- Upstream effects

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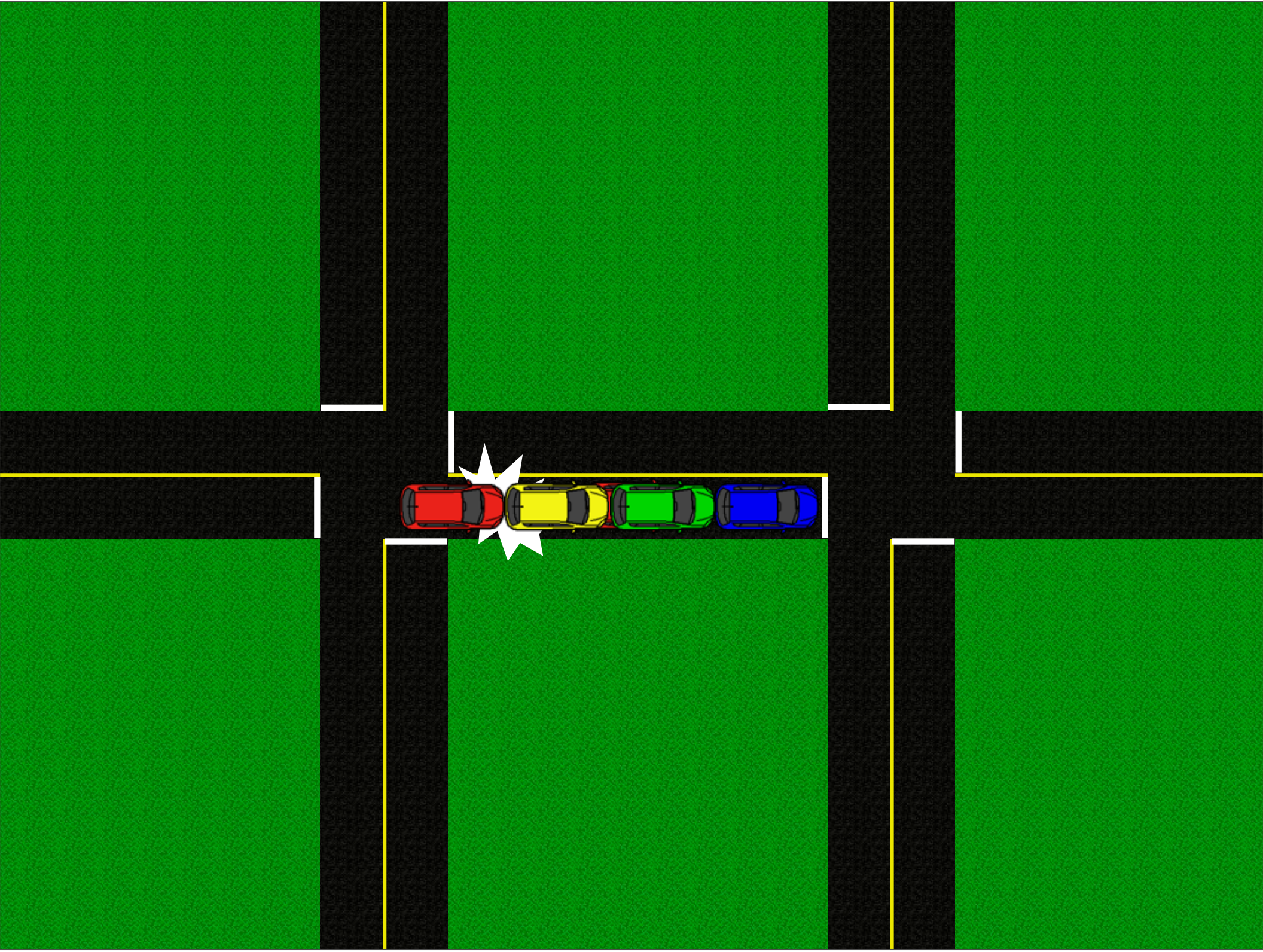

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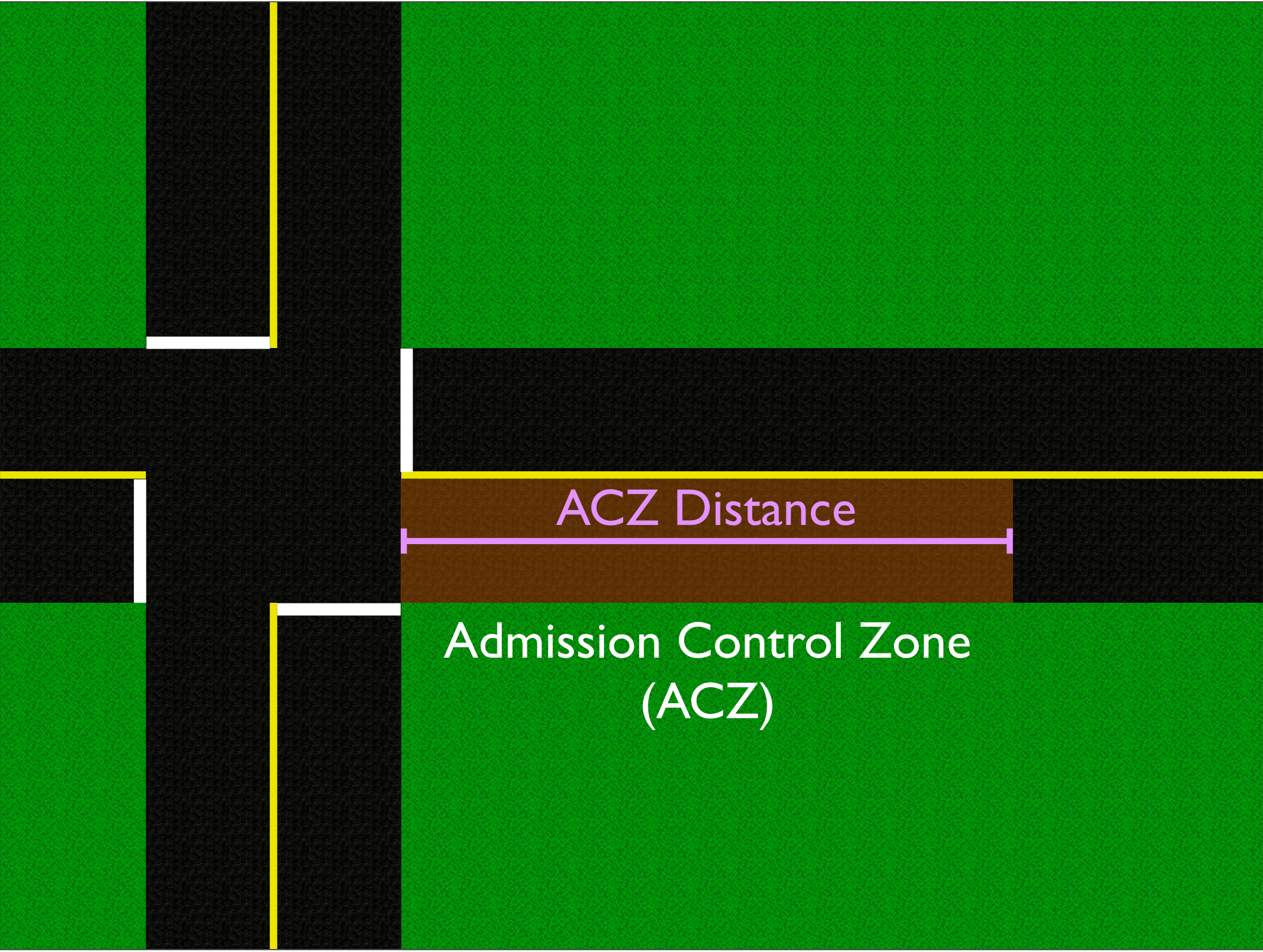
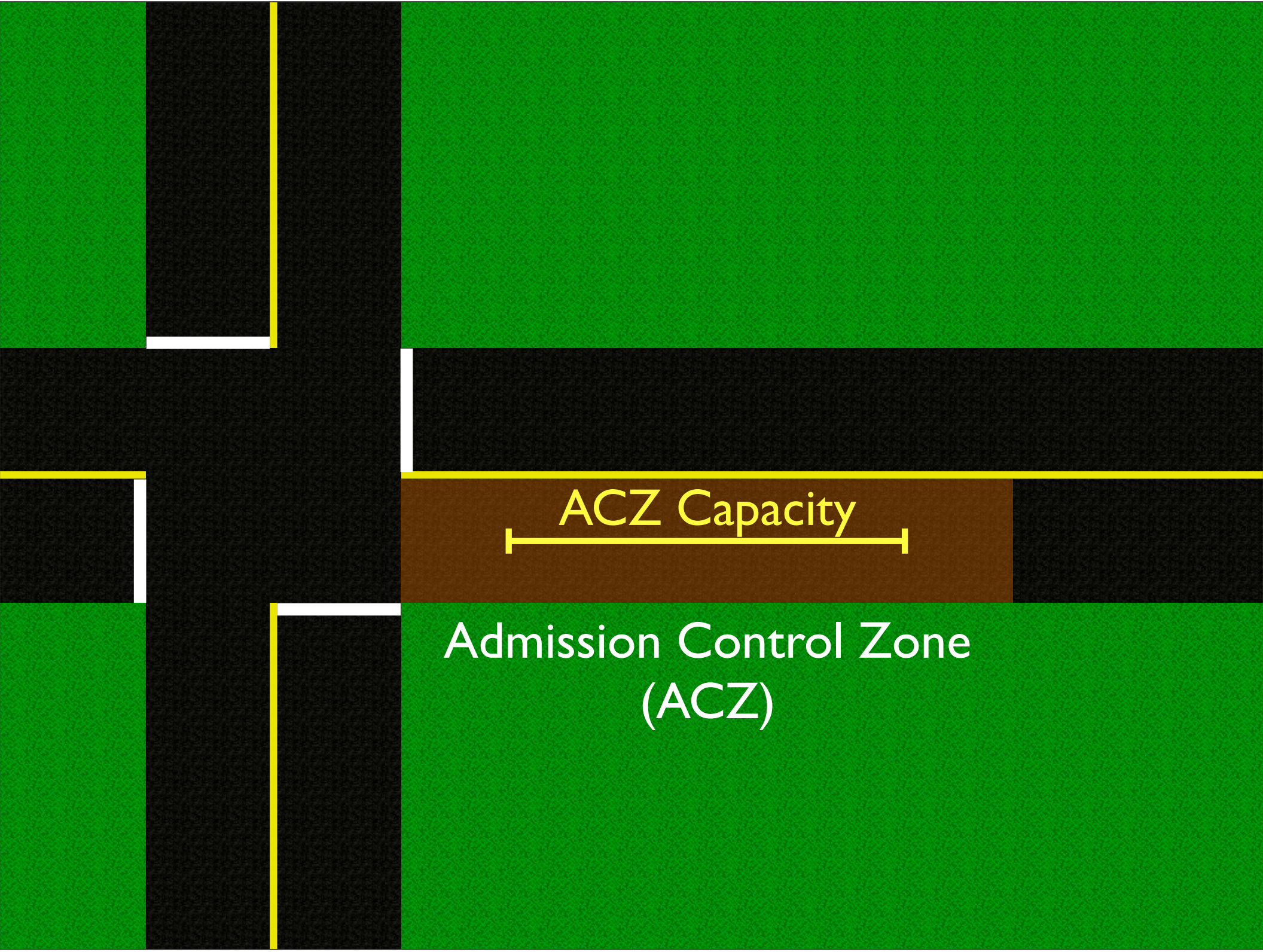
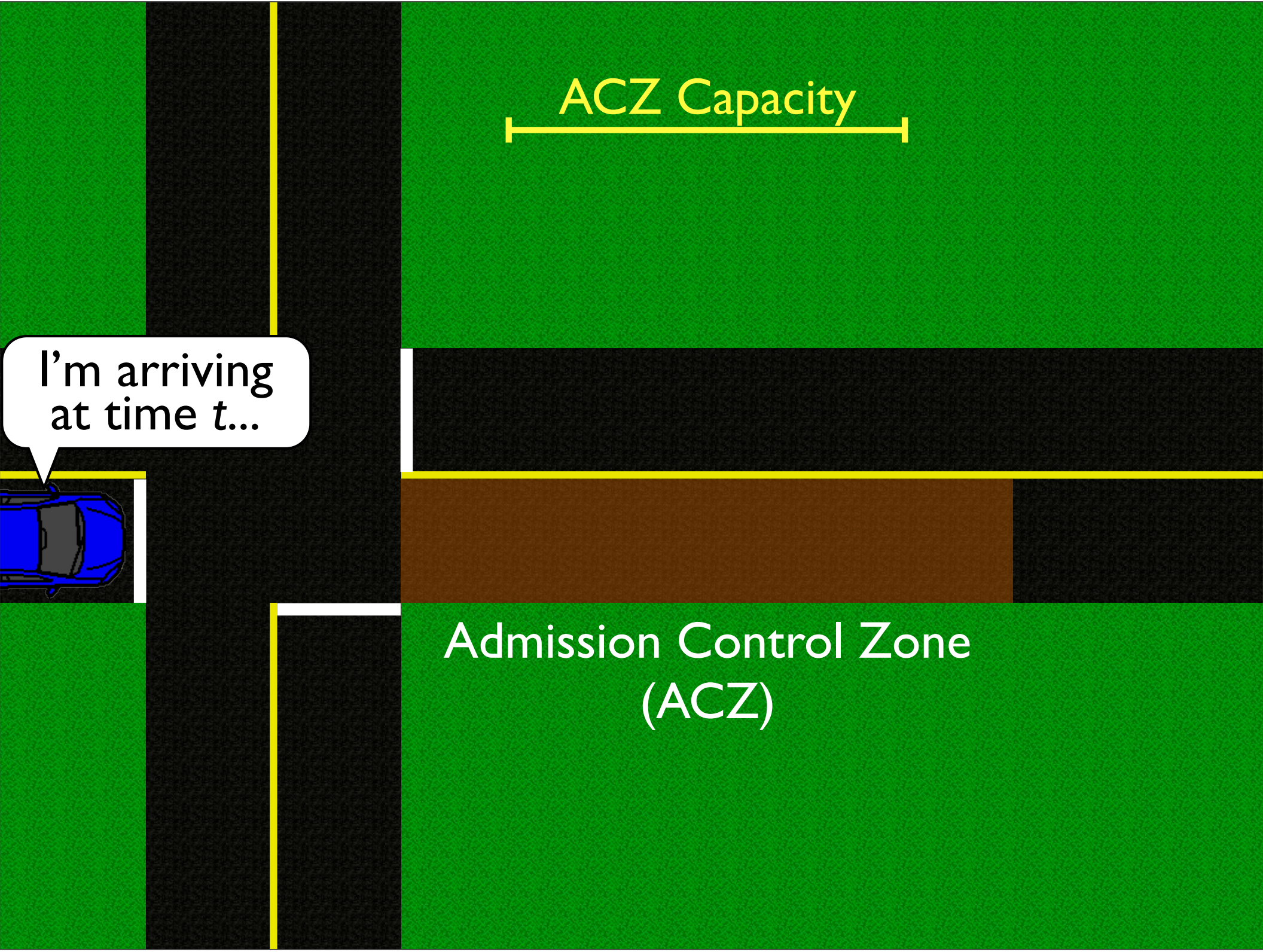
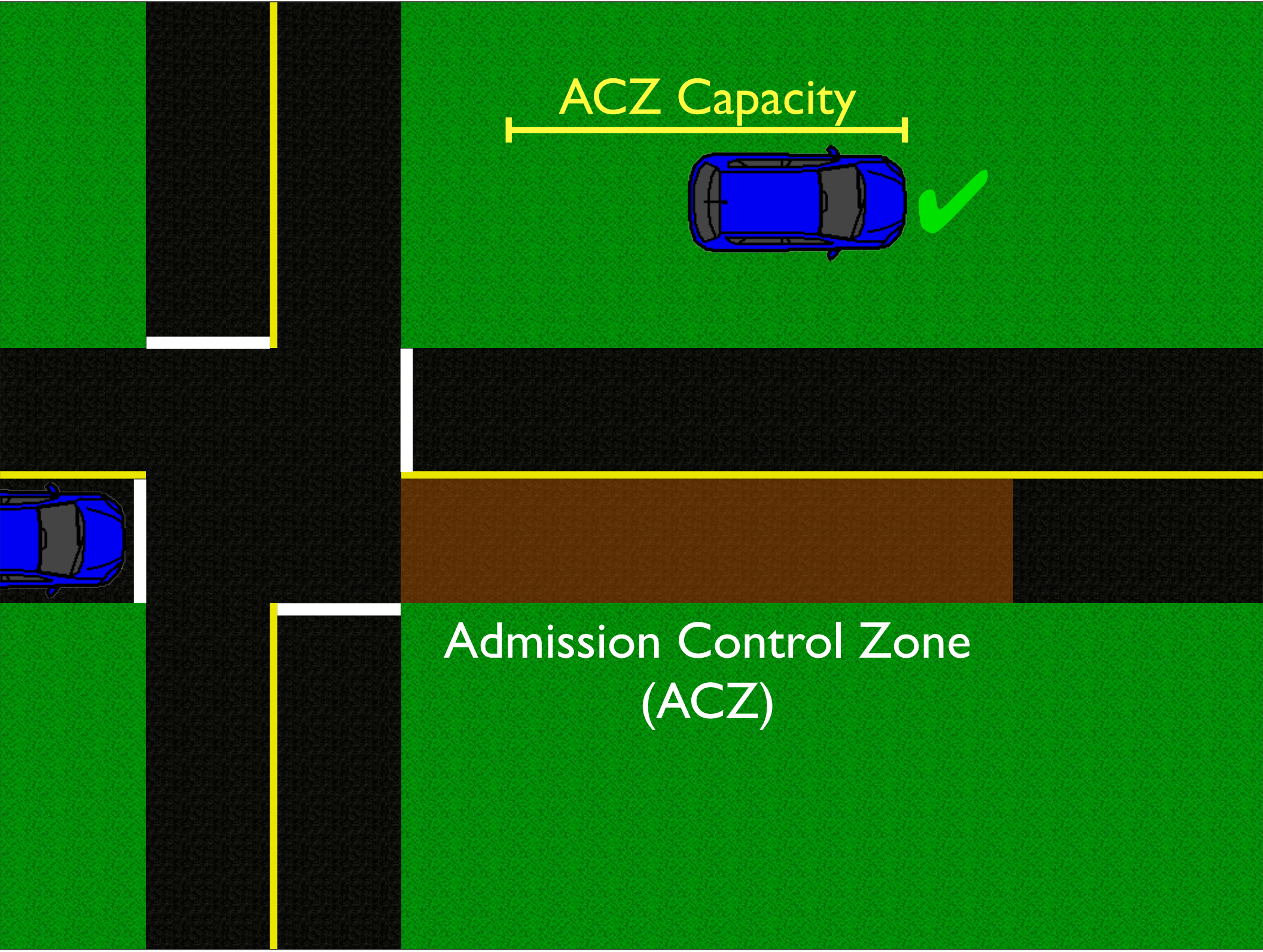
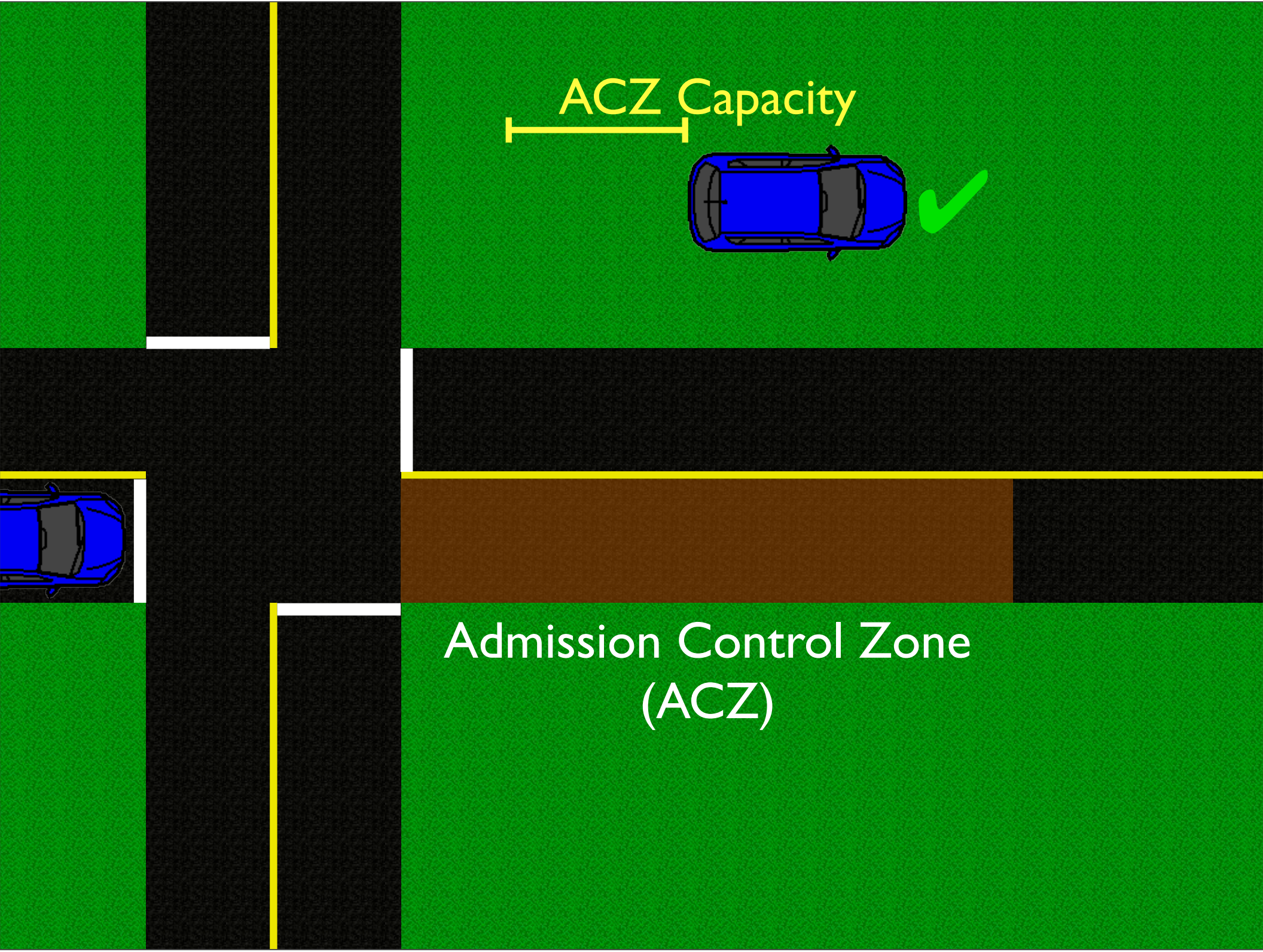
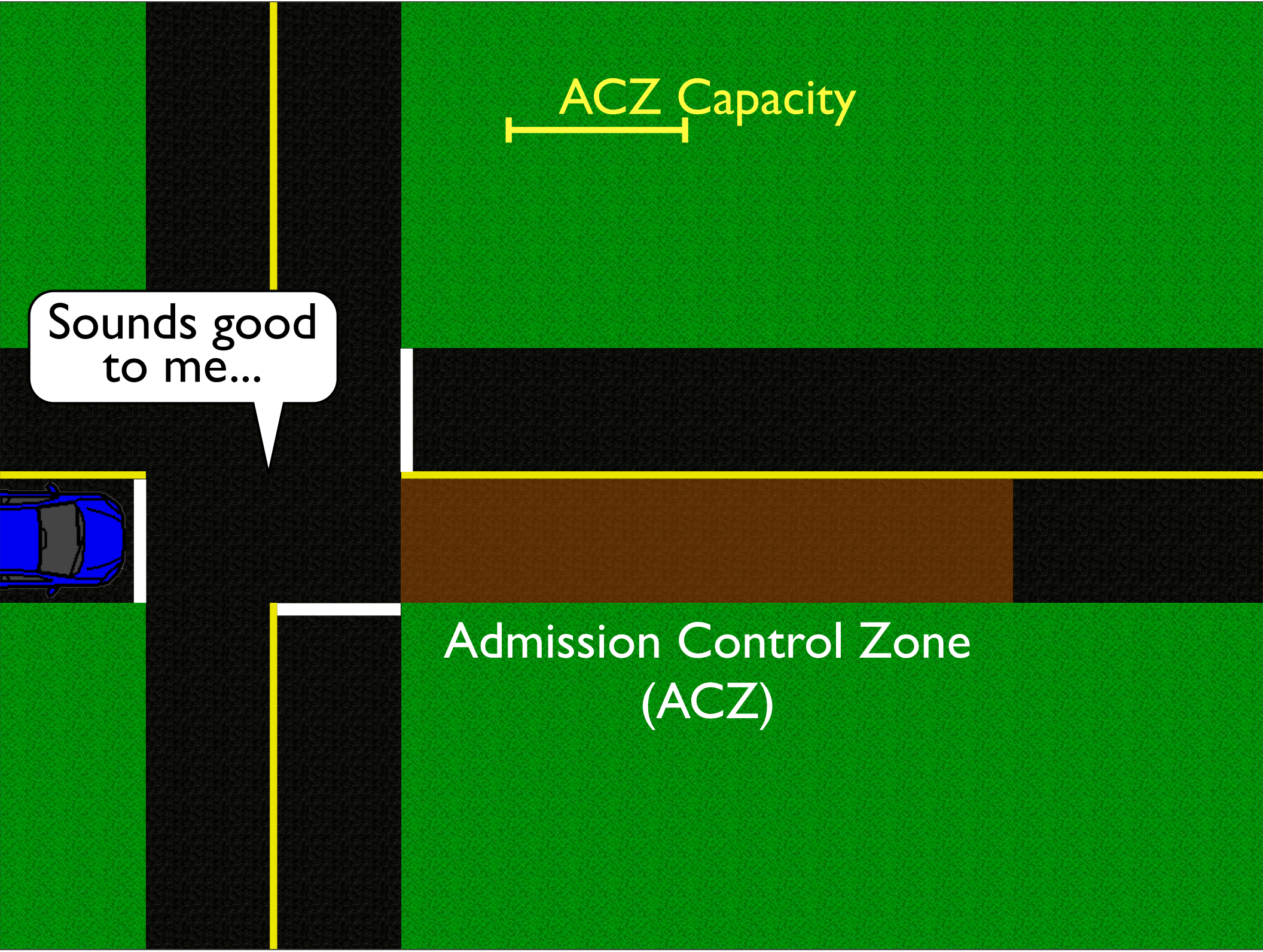

ACZ Distance
Admission Control Zone
(ACZ)

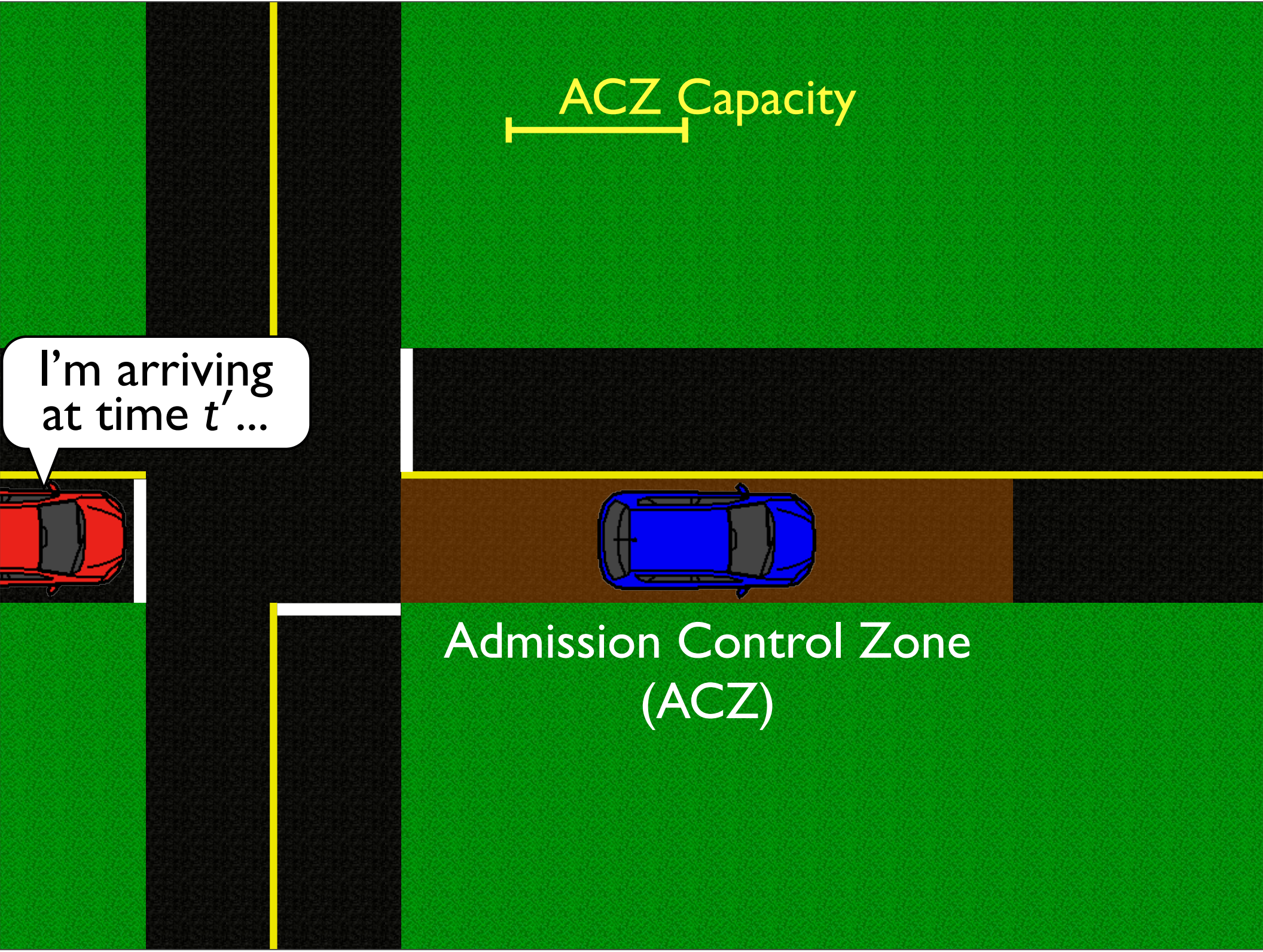

ACZ Capacity
Admission Control Zone
(ACZ)

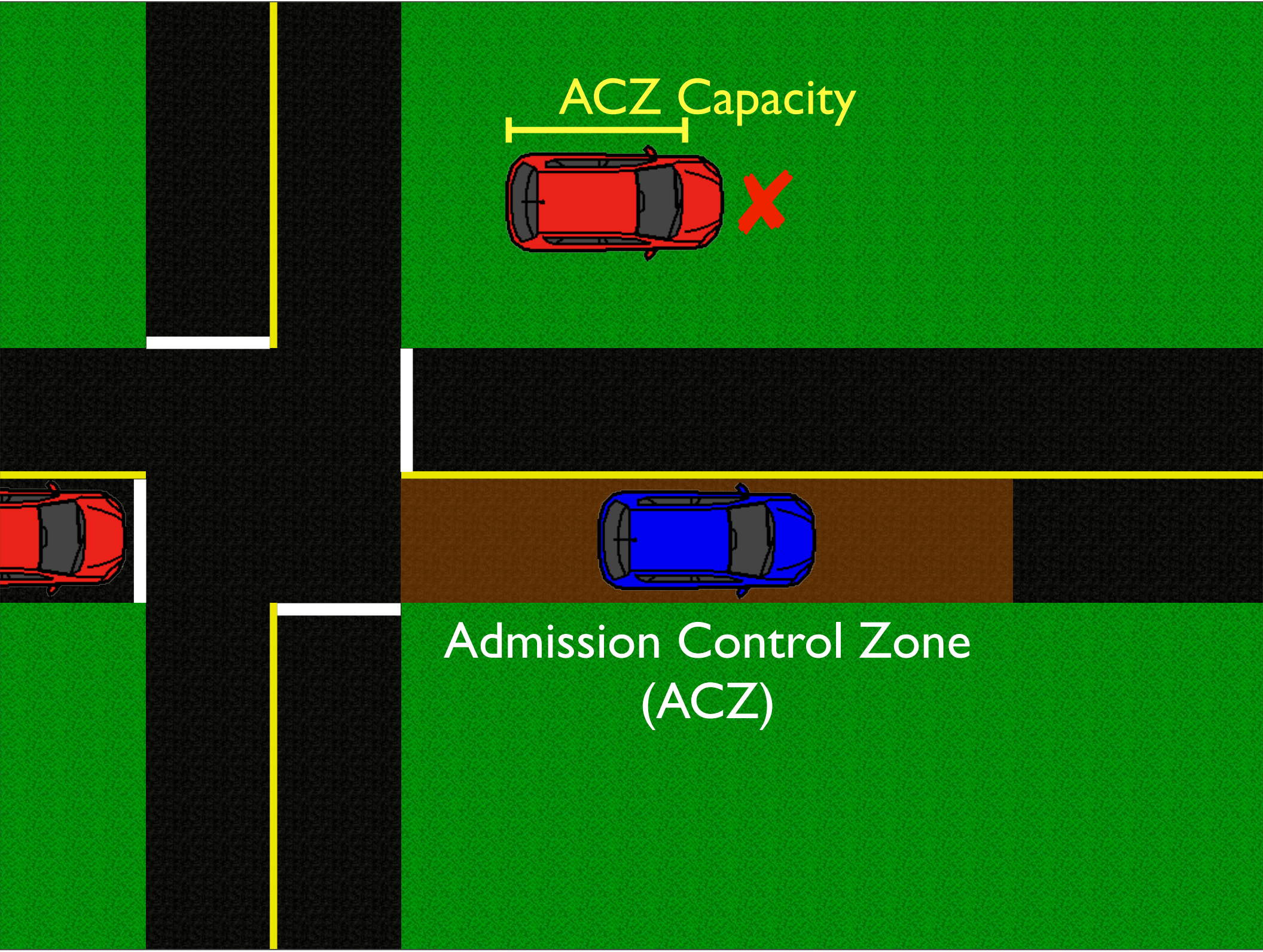

ACZ Capacity
I'm arriving at time t...
Admission Control Zone (ACZ)

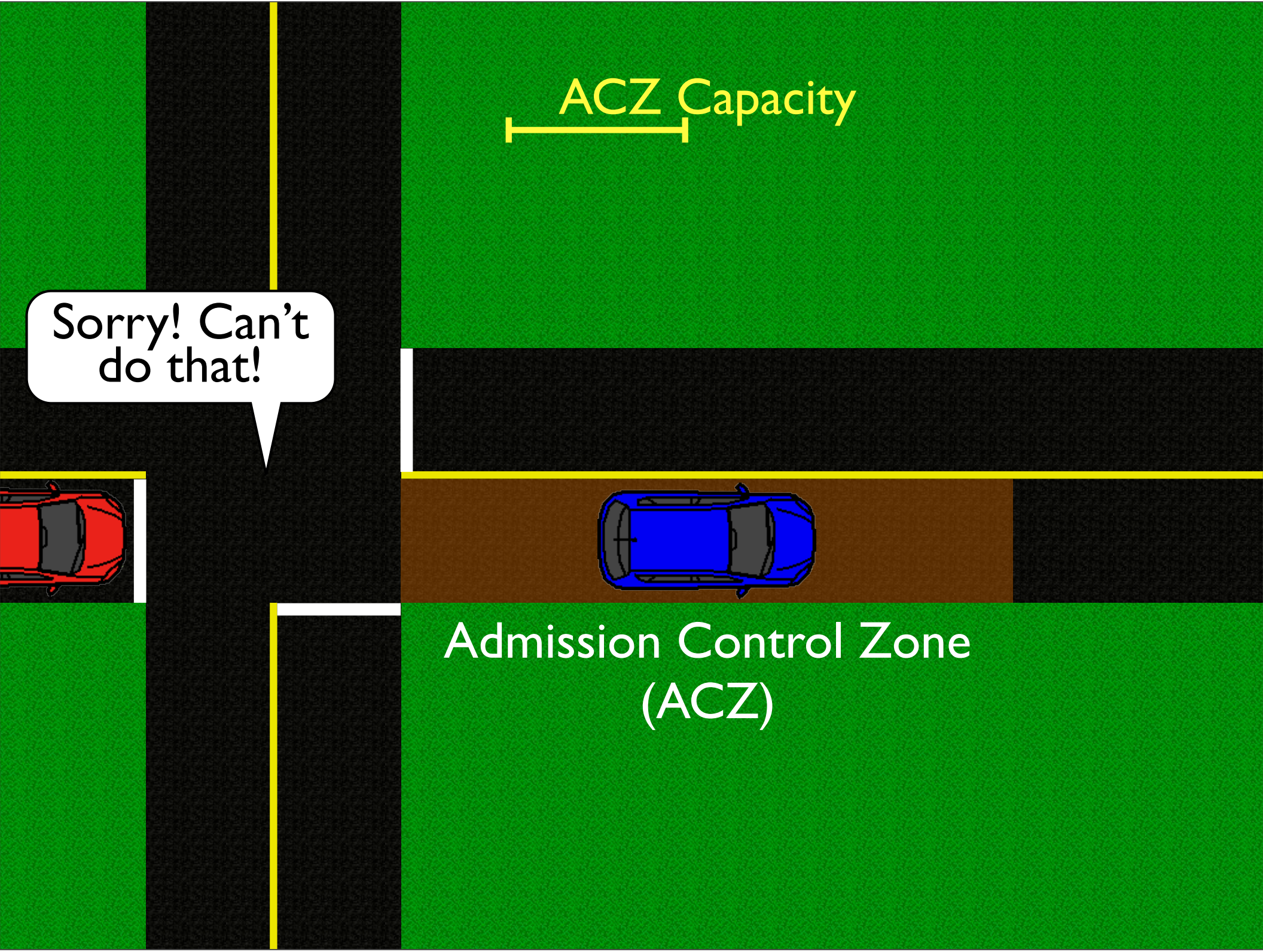

ACZ Capacity
Admission Control Zone
(ACZ)

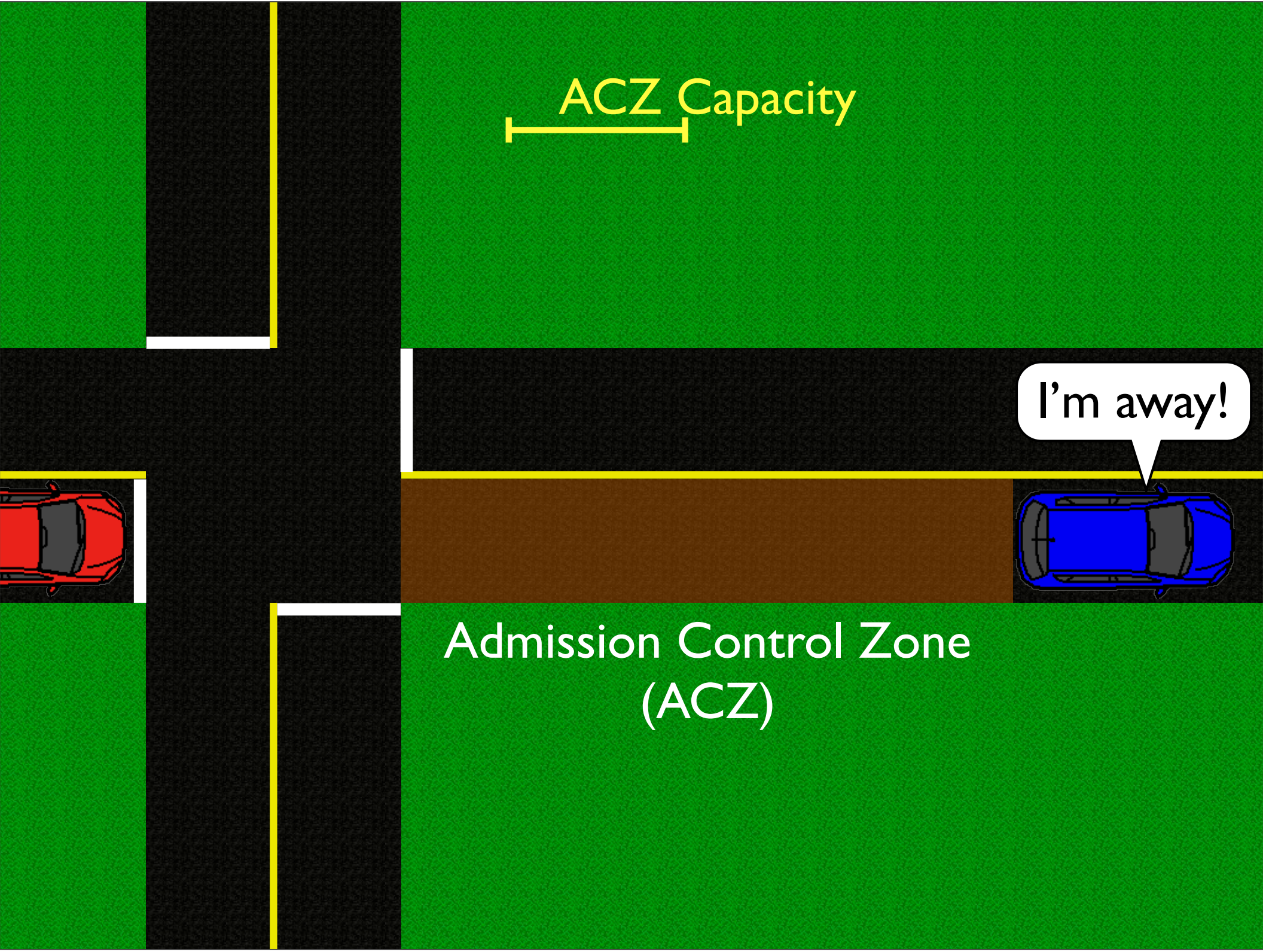

ACZ Capacity
Admission Control Zone
(ACZ)

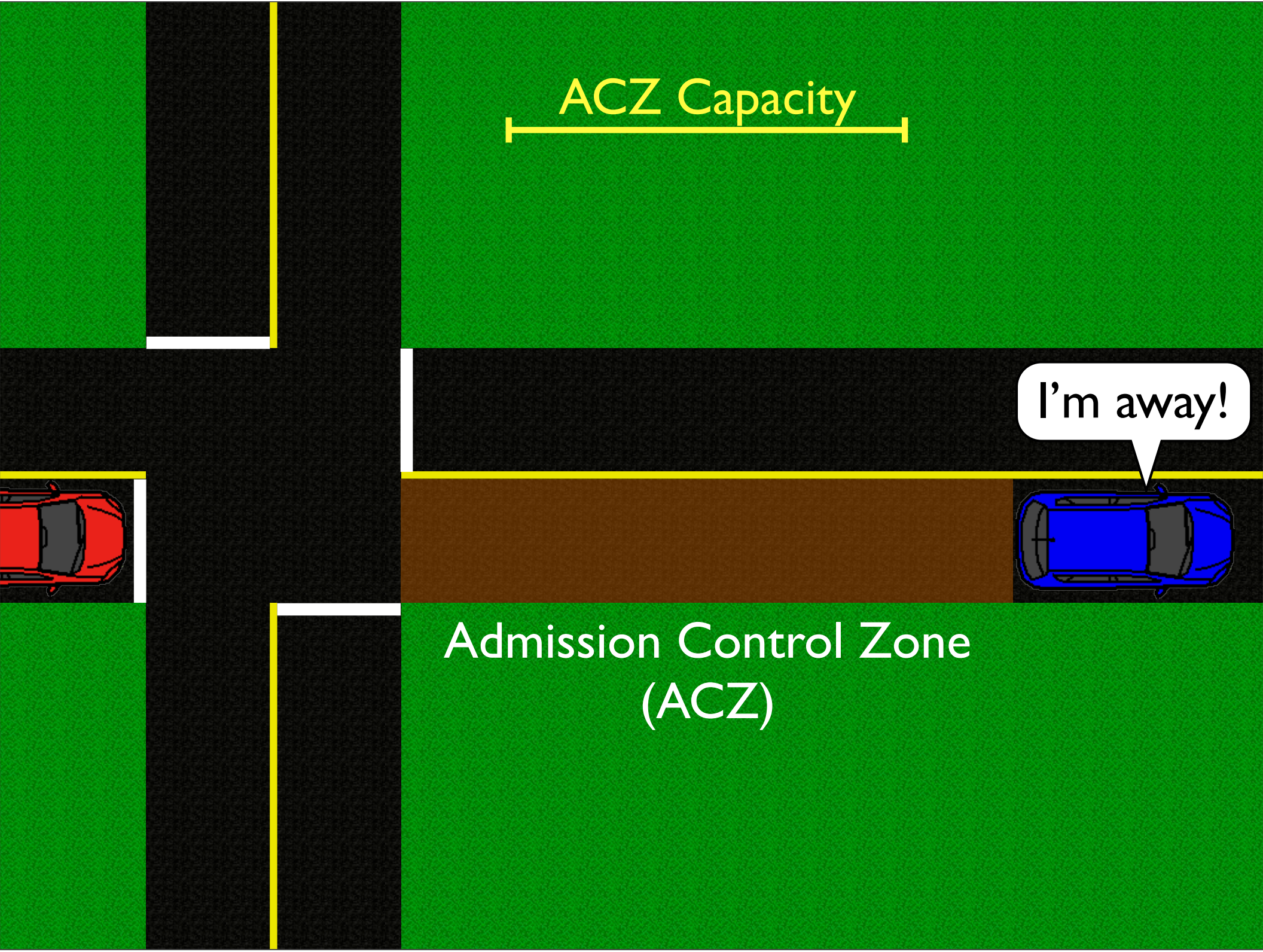

ACZ Capacity
Sounds good to me...
Admission Control Zone (ACZ)


ACZ Capacity
I'm arriving at time t'...
Admission Control Zone (ACZ)

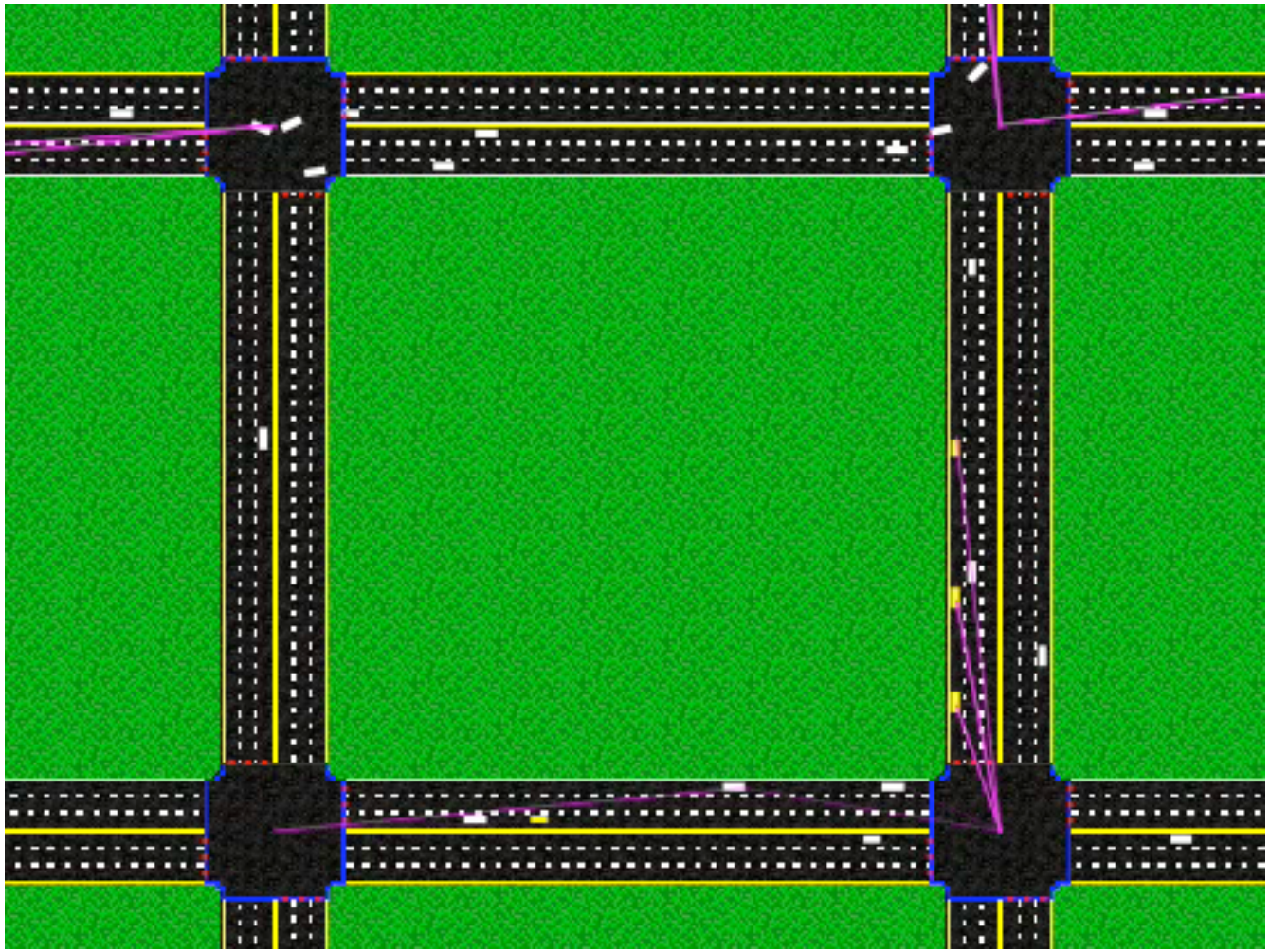

ACZ Capacity
Admission Control Zone
(ACZ)


ACZ Capacity
Sorry! Can't do that!
Admission Control Zone (ACZ)


ACZ Capacity
I'm away!
Admission Control Zone
(ACZ)


ACZ Capacity
I'm away!
Admission Control Zone
(ACZ)

Multi-intersection Video



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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)
- History-based (Balan and Luke 2006)

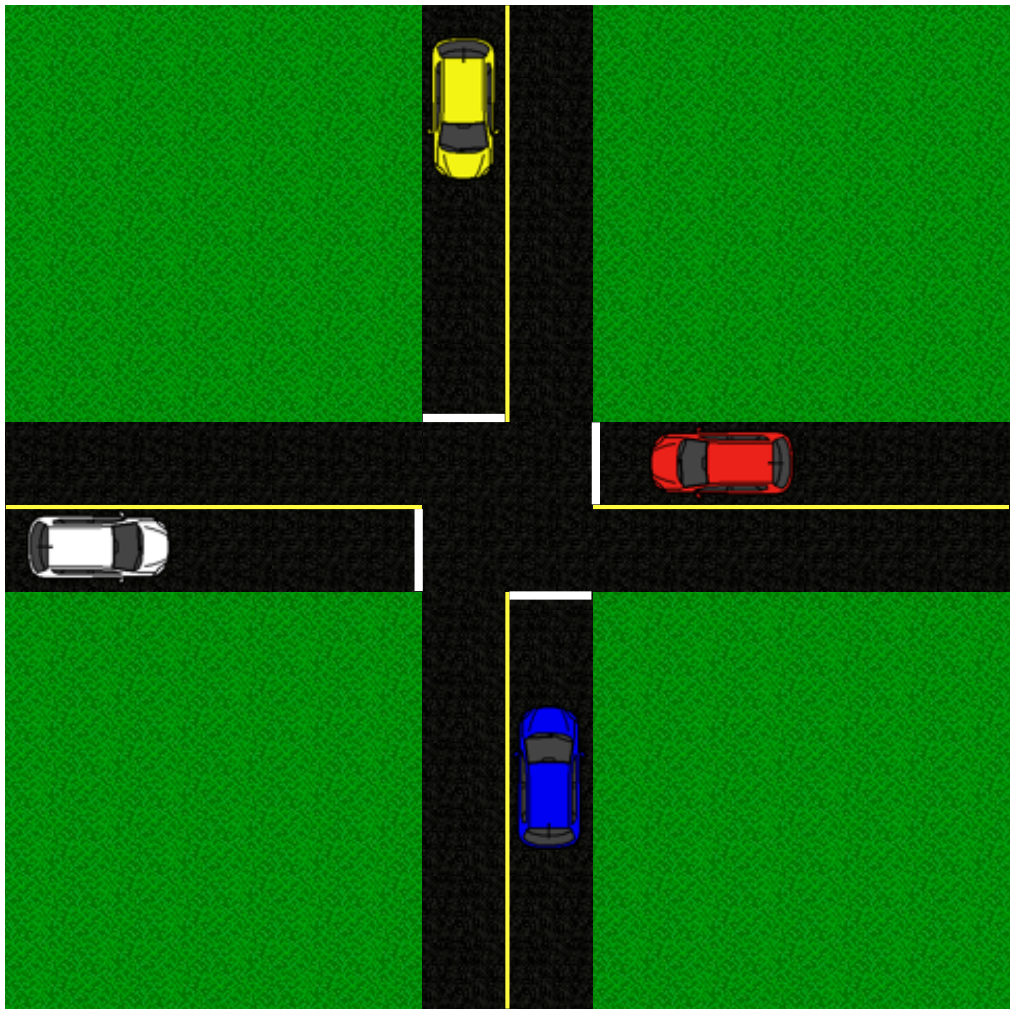
Related Work

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



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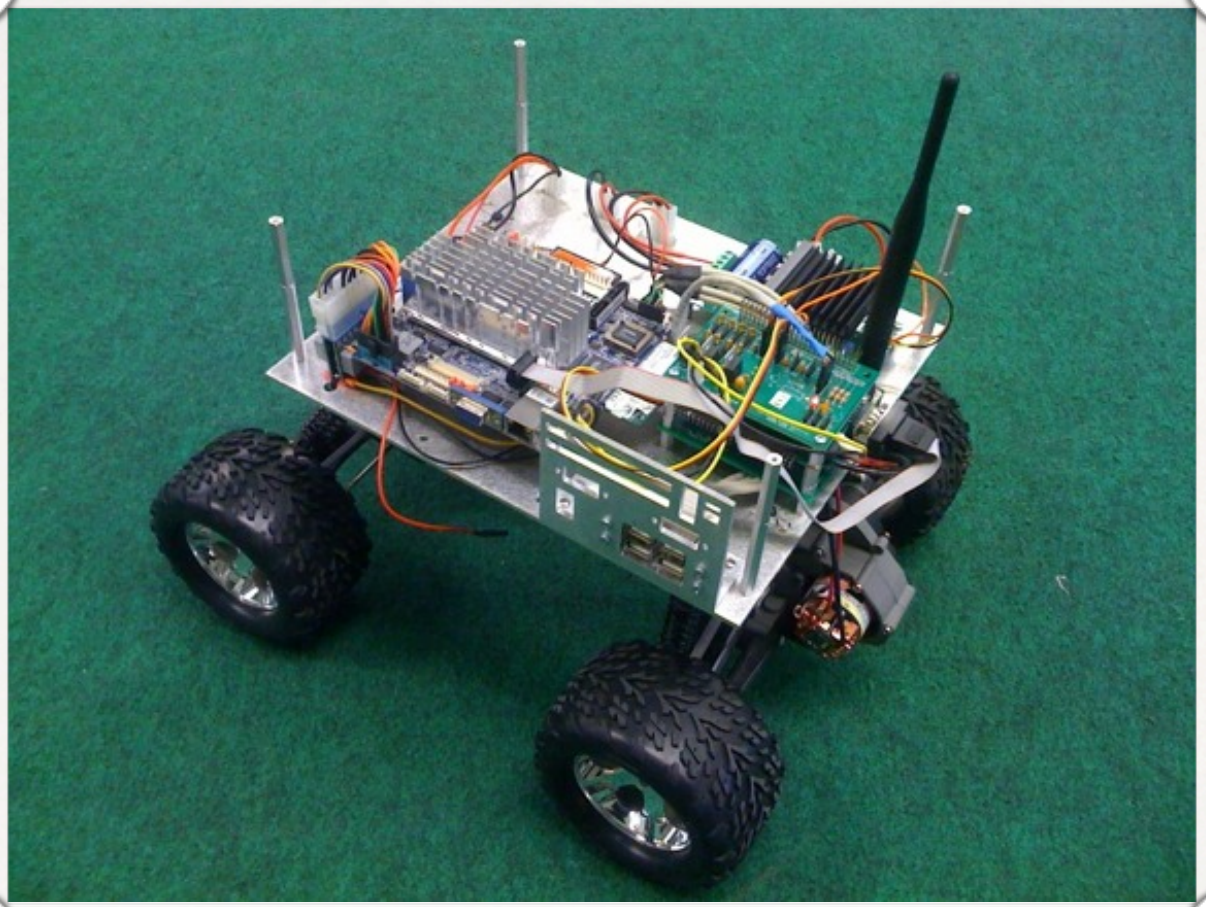
Future Directions

Proteus Robots



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Future Directions

Exploring Asynchronicity

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Future Directions

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Questions?

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