Planning under uncertainty with sensor occlusions in urban driving scenarios

Offline and online planning approaches for solving the occluded crosswalk problem

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Motivation

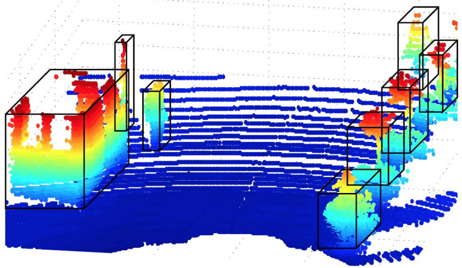
Need safe and efficient planning for autonomous vehicles in urban scenarios

Even with perfect sensors, **sensor occlusions lead to planning uncertainty**

- Static occlusions (buildings, signs, trees)
- Dynamic occlusions (other traffic participants)

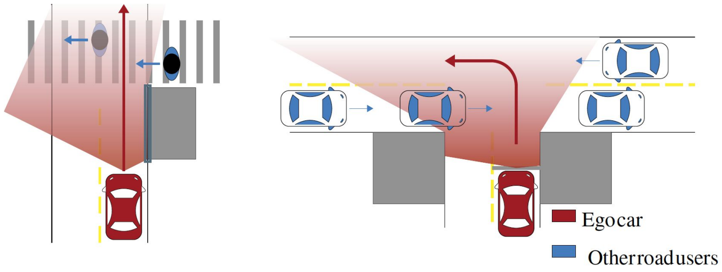
Common occlusion scenarios

- *Occluded crosswalk*
- Occluded unsignalized T-intersection
- Occluded overtaking (rural!)



Ideal detection result from LIDAR

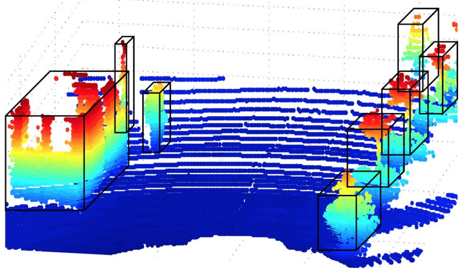
S. D. Pendleton *et al.*, "Perception, planning, control, and coordination for autonomous vehicles," *Machines*, vol. 5, no. 1, pp. 1–54, 2017.



Common occlusion scenarios

M. Bouton, A. Nakhaei, K. Fujimura, and M. J. Kochenderfer, "Scalable Decision Making with Sensor Occlusions for Autonomous Driving," *2018 IEEE Int. Conf. Robot. Autom.*, pp. 2076–2081, 2018.

Motivation



Ideal detection result from LIDAR

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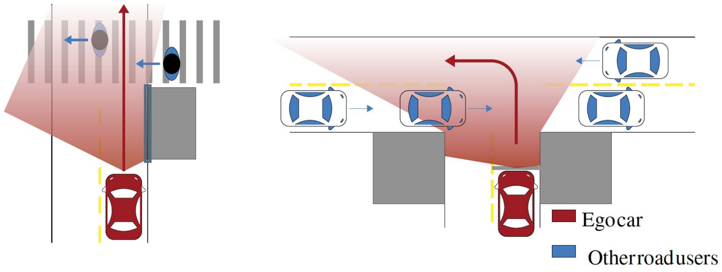
To achieve safe and efficient planning, other traffic participants need to be reasoned about and **sensor uncertainty and sensor occlusions need to be accounted for**

Occluded crosswalk is a good initial problem



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Related Work

Pedestrian avoidance	(Kapania, 2019); (Pusse, 2019)
Sensor occlusions	
Crosswalk, static & dynamic occlusion	(Bouton, 2018); (Schratter, 2019)
Crosswalk, dynamic occlusion	(Thornton, 2018)
Risk quantification	(Yu, 2018)
Field-of-view propagation	(Hubmann, 2019)
Intention-aware planning	
Pedestrians	(Bai, 2015); (Luo, 2018); (Cai, 2019)
Drivers	(Sunberg, 2017)

Problem Setting

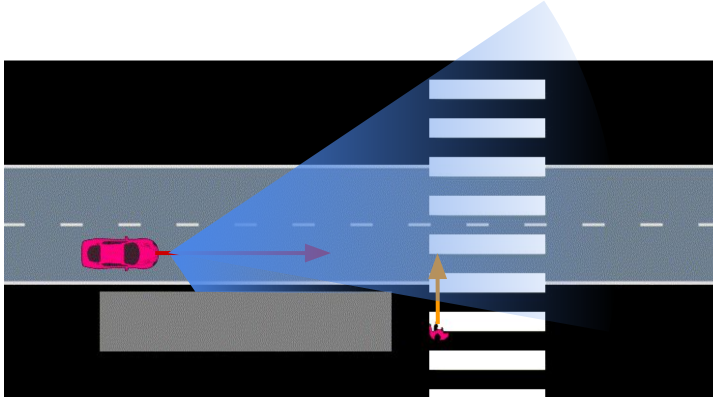
Occluded crosswalk POMDP

Ego vehicle ($\cdot_{ego}$) and pedestrian ($\cdot_{ped}$)

s: position

v: velocity

a: acceleration



Occluded crosswalk scenario with ego vehicle and one pedestrian

2D continuous reduced spaces

S: $(s_{ego}, v_{ego}) \times (s_{ped}, v_{ped}) \ldots \times_i (s_{ped}, v_{ped})_i$

A: a_{ego}

O: $(s_{ego}, v_{ego}) \times (s_{ped}, v_{ped}) \ldots \times_i (s_{ped}, v_{ped})_i$

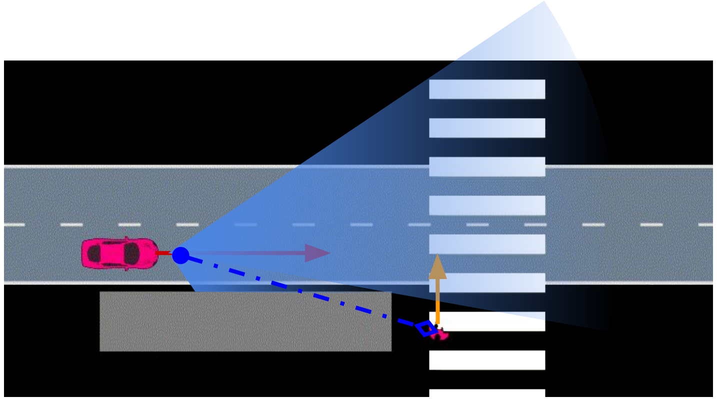
Options to discretize spaces, extend number of traffic participants

Problem Setting

Occluded crosswalk POMDP

Transition, reward, and observation models

- T: linearized vehicle dynamics w/noise
  linearized pedestrian dynamics w/noise
- R: -1 for collision with pedestrian,
  +1 for reaching roadway end
- O: fully-observable ego vehicle
  partially-observable pedestrian



Occluded crosswalk scenario with ego vehicle and one pedestrian

Reach end of roadway without collision as quickly as possible using finite-horizon discounting

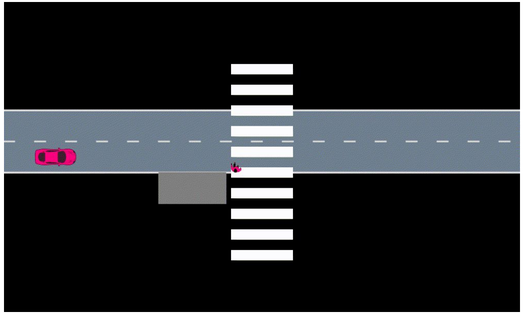
Obstacle prevents even partial observability of pedestrian

Progress & Future Work

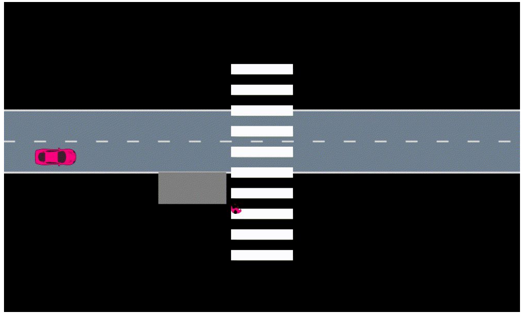
`POMDPs.jl` & `AutomotivePOMDPs.jl`

1.	**`SingleOCPOMDP`**	**crosswalk**	**ego, one pedestrian**
2.	**`OCPOMDP`**	**crosswalk**	**ego, multiple pedestrians**
3.	`UrbanPOMDP`	urban intersection	ego, multiple pedestrians, multiple cars

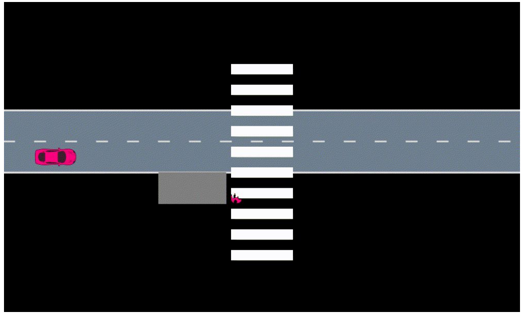
Examine performance of offline solvers



Random policy simulation



QMDP policy simulation



SARSOP policy simulation

Progress & Future Work

Examine effects of:

- discretization (continuous v. discrete, discrete resolution)
- sensor types (Gaussian sensor, LIDAR sensor)

Metrics & results

- Success rate
- Crossing time (≈ reward)
- Computation time & bound convergence
- Policy & history visualizations

Offline approaches will likely become intractable in more complex scenarios, so **explore online approaches in the OCPOMDP scenario**

```
Loading the model ...
  input file   : model.pomdpx
  loading time : 261.95s

SARSOP initializing ...
  initialization time : 297.29s

-------------------------------------------------------------------------------
 Time   |#Trial |#Backup |LBound    |UBound    |Precision  |#Alphas |#Beliefs
-------------------------------------------------------------------------------
 297.29  0       0        -8.33525e-05 0.238063   0.238147    4        1
 343.25  3       50       0.107623   0.234757   0.127134    52       26
 392.92  8       103      0.140963   0.230195   0.0892325   100      49
 441.26  11      155      0.146635   0.22927    0.0826354   148      64
 482.68  15      200      0.161548   0.229001   0.0674531   183      78
 528.84  18      250      0.162559   0.227923   0.0653644   227      92
 573.68  22      300      0.172311   0.225924   0.0536128   273      110
 619.98  26      350      0.172311   0.222978   0.0506668   311      125
-------------------------------------------------------------------------------

SARSOP finishing ...
  Preset timeout reached
  Timeout     : 600.000000s
  Actual Time : 619.980000s

-------------------------------------------------------------------------------
 Time   |#Trial |#Backup |LBound    |UBound    |Precision  |#Alphas |#Beliefs
-------------------------------------------------------------------------------
 619.98  26      350      0.172311   0.222978   0.0506668   311      125
-------------------------------------------------------------------------------

Writing out policy ...
  output file : policy.out
```