Intention-Aware Online POMDP Planning for Autonomous Driving in a Crowd

Bai, Haoye, et al. ICRA 2015

TaeHyoung Kim(김태형)

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Review

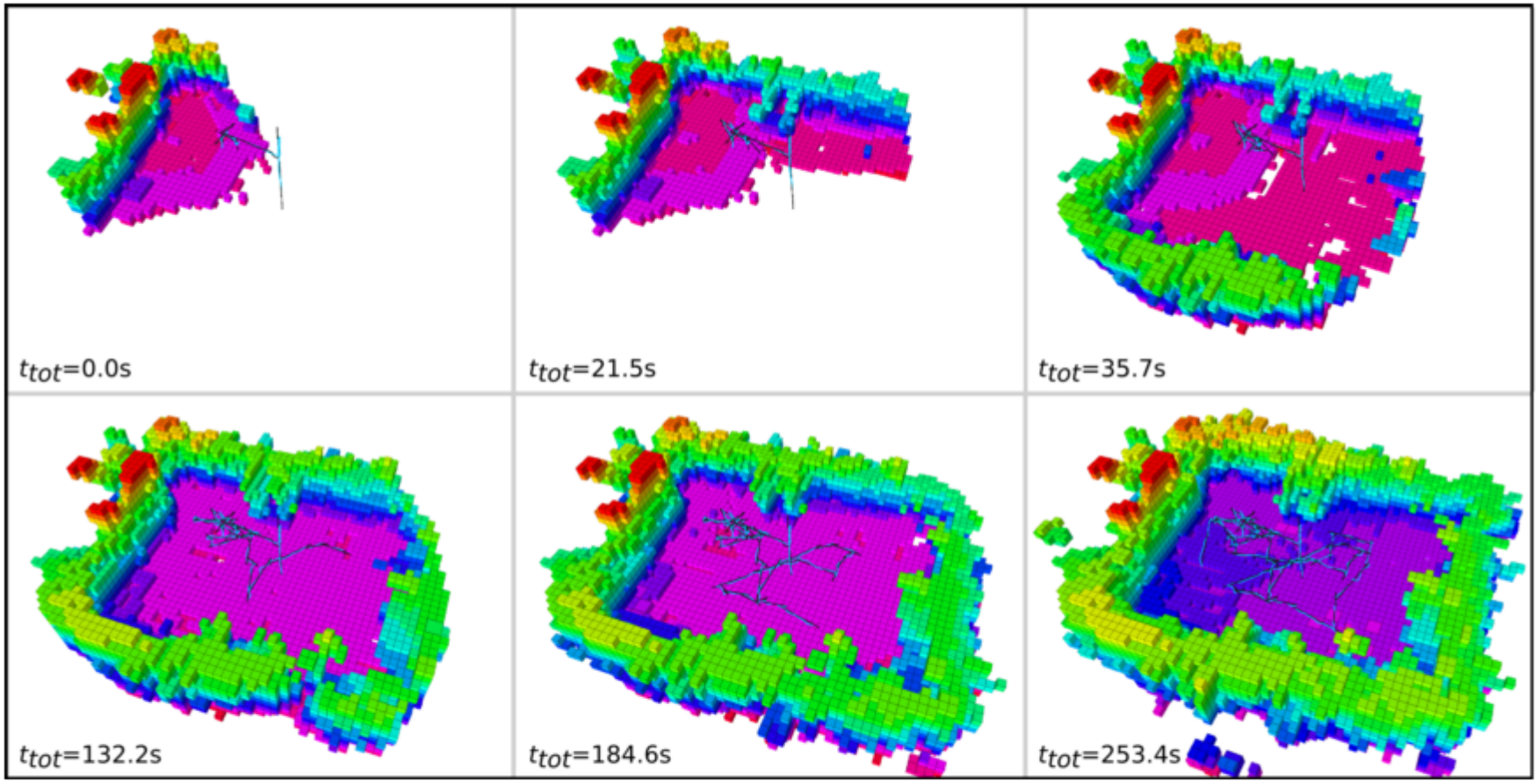

Fig. 8: The exploration experiment in a closed room is depicted. The colored voxels represent occupied parts of the occupancy map (colored according to height) while the computed path is given in black and the vehicle response in light blue. The initial phase of the exploration mission is dominated by yawing motions to maximize exploration without traveling large distances. Subsequently the MAV explores regions further away, to eventually accomplish its mission.

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Abstract

- **Goal: Autonomous driving among many pedestrians effectively and safely.**

- **Main contribution:**
  - **Online planning**
  - **Consider long-term effect of action**

    C.f.) Reactive control

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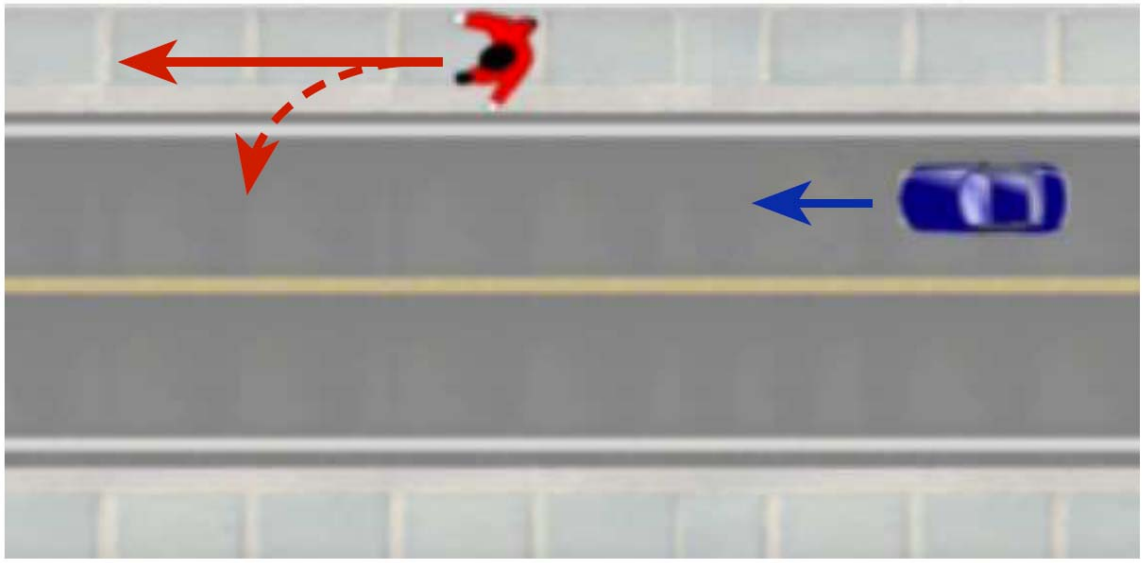
Reactive controller

Reactive Control

- **Two state for pedestrian behavior**
  - **Stays on side walk**
  - **Crosses the road**



Bai, Haoyu, et al. "Intention-aware online POMDP planning for autonomous driving in a crowd." *Robotics and Automation (ICRA), 2015 IEEE International Conference on*. IEEE, 2015.

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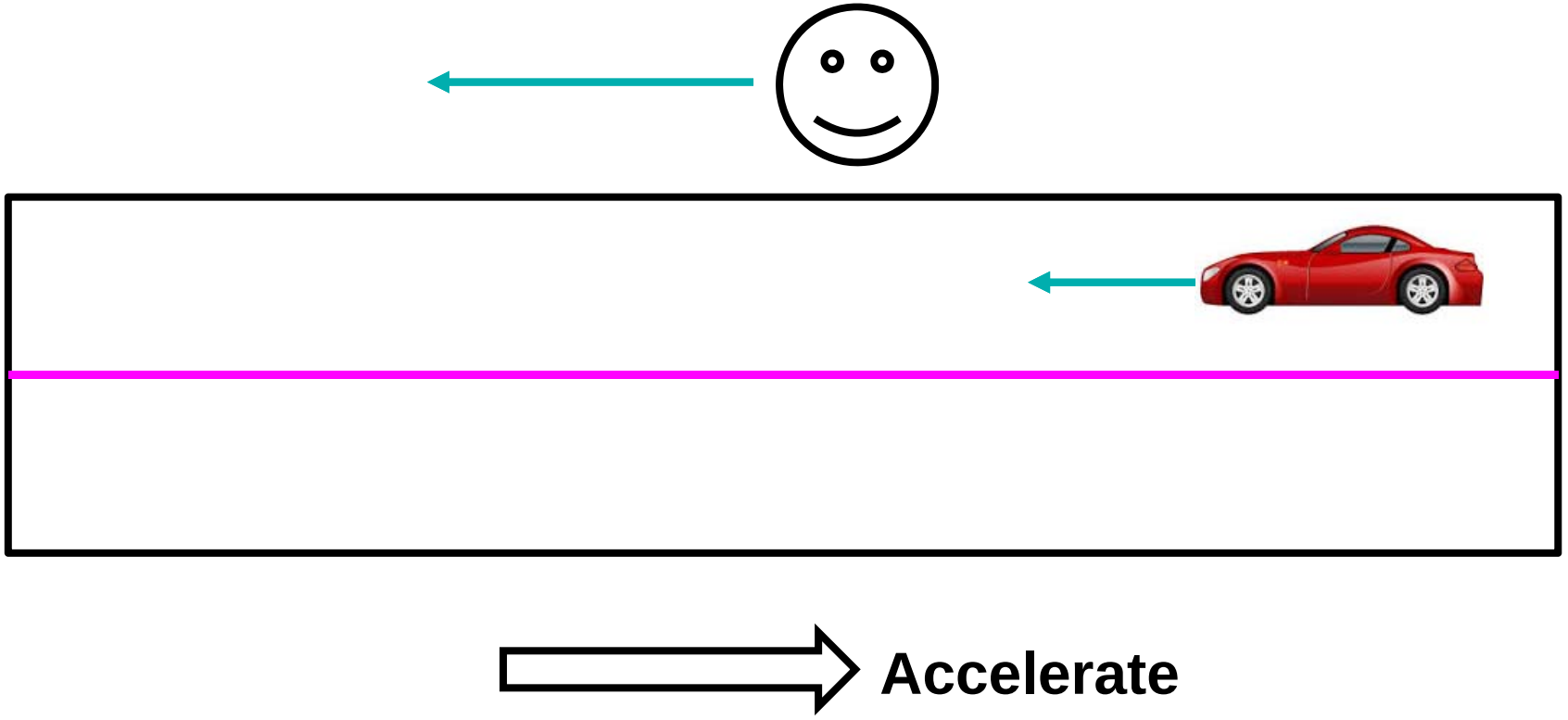
Reactive Control

- For time n, Belief~(0.51,0.49)



Reactive Control

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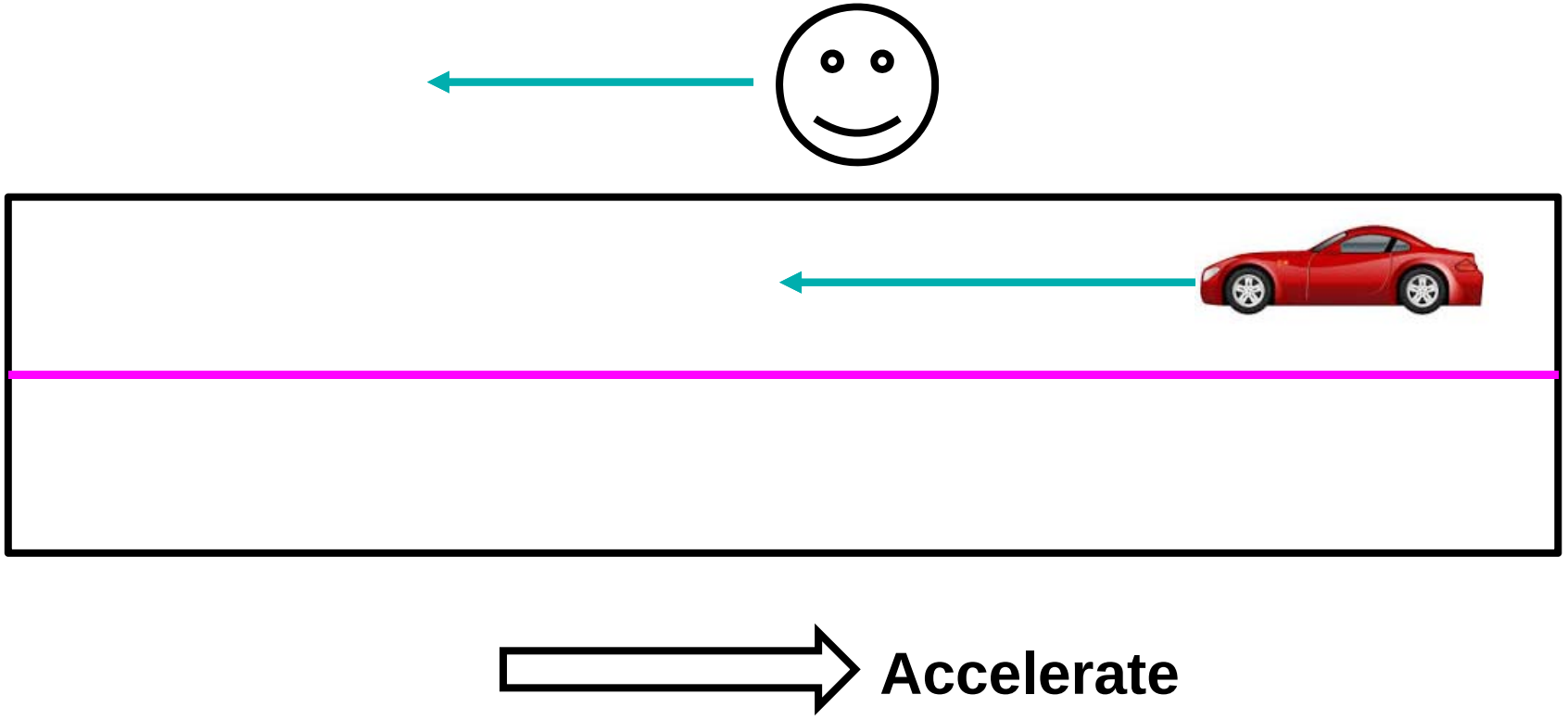
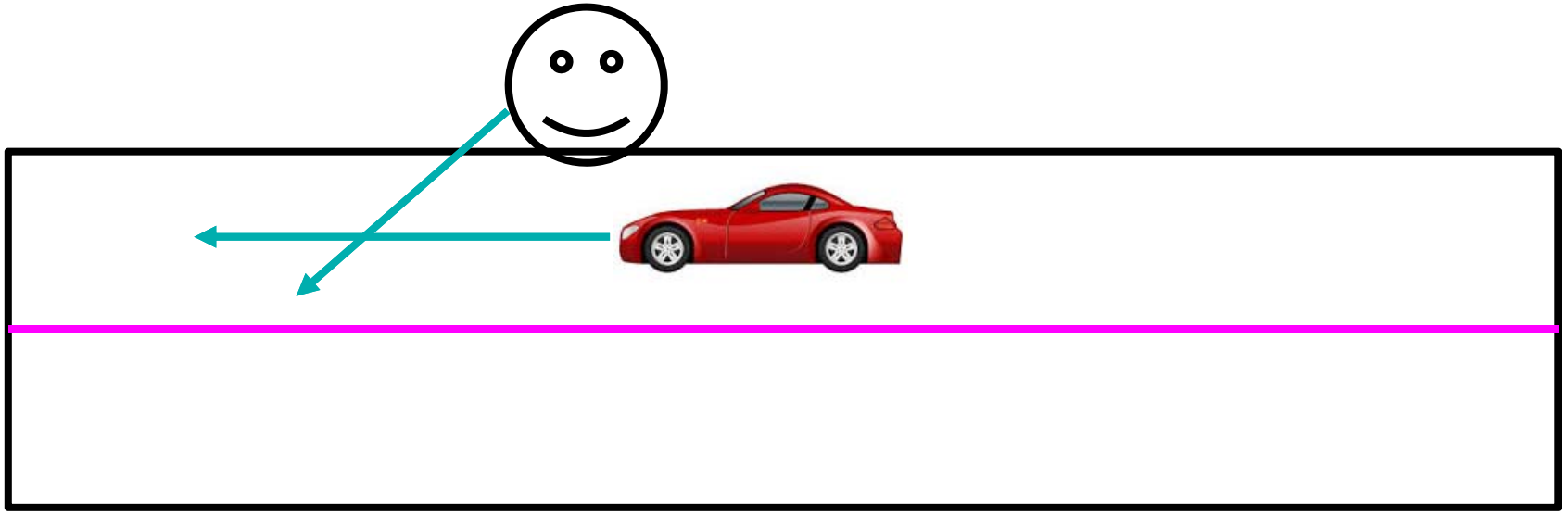
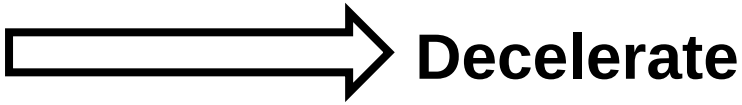


Reactive Control

- For time n+1, Belief~(0.35,0.65)





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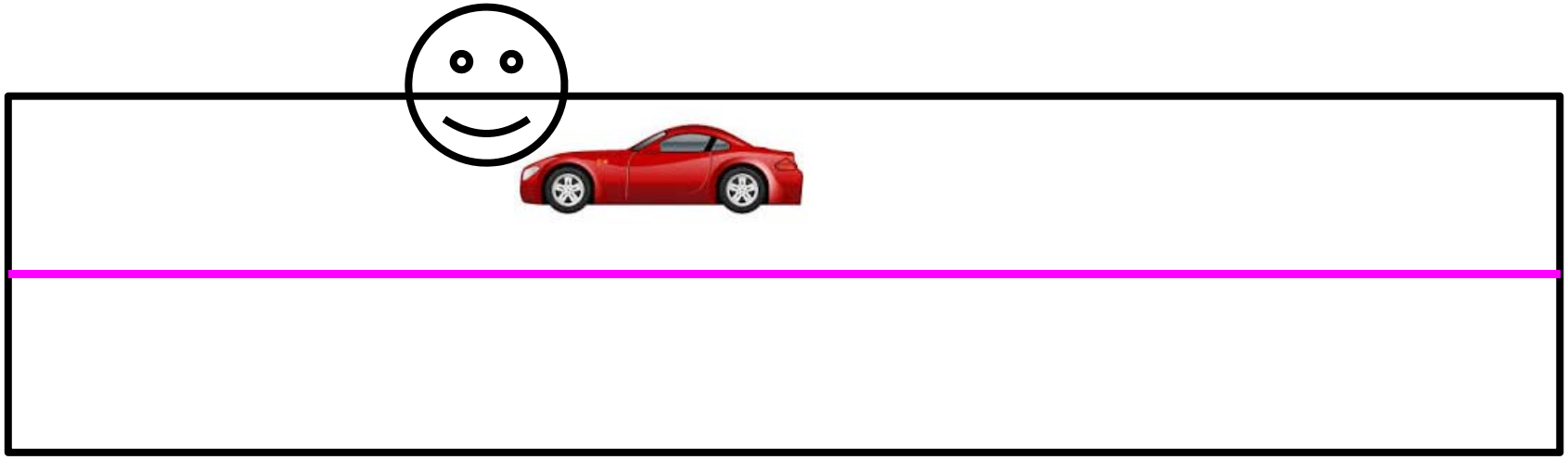
Reactive Control

- For time n+1, Belief~(0.35,0.65)



Too late..

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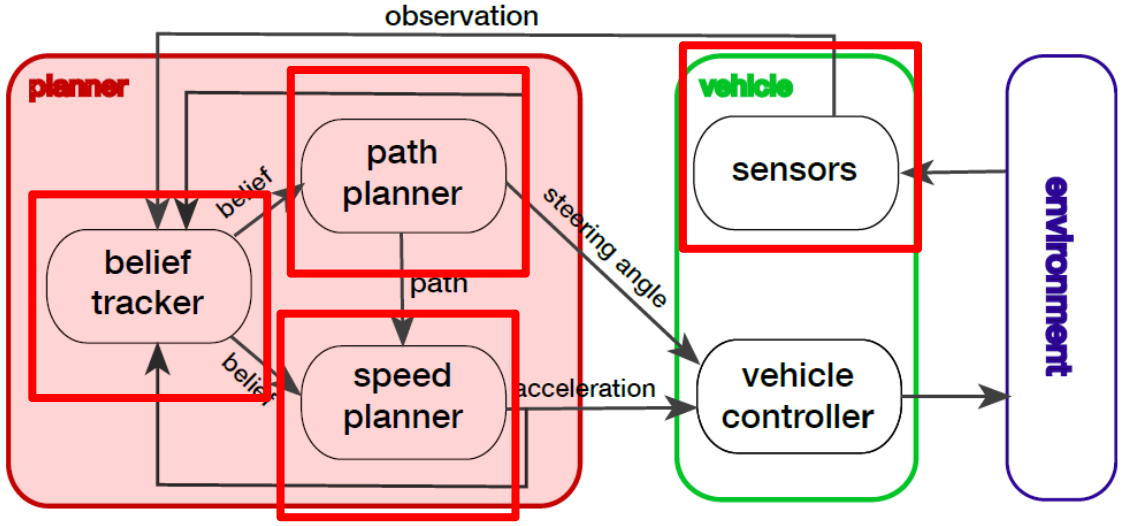
System overview

System models

- **Vehicle Model**
  - Position (x, y)
  - Orientation θ
  - Instantaneous speed v
- **Pedestrian Model**
  - Position (x_i, y_i)
  - Instantaneous speed v_i
  - Goal g_i (intention - Explained later)
- **Sensor Model**
  - Vehicle position, speed
  - Positions of all pedestrians

System Overview

- **For every time step,**
  - **Belief tacking**
  - **Path planning**
  - **Speed planning**



Bai, Haoyu, et al. "Intention-aware online POMDP planning for autonomous driving in a crowd." *Robotics and Automation (ICRA), 2015 IEEE International Conference on*. IEEE, 2015.

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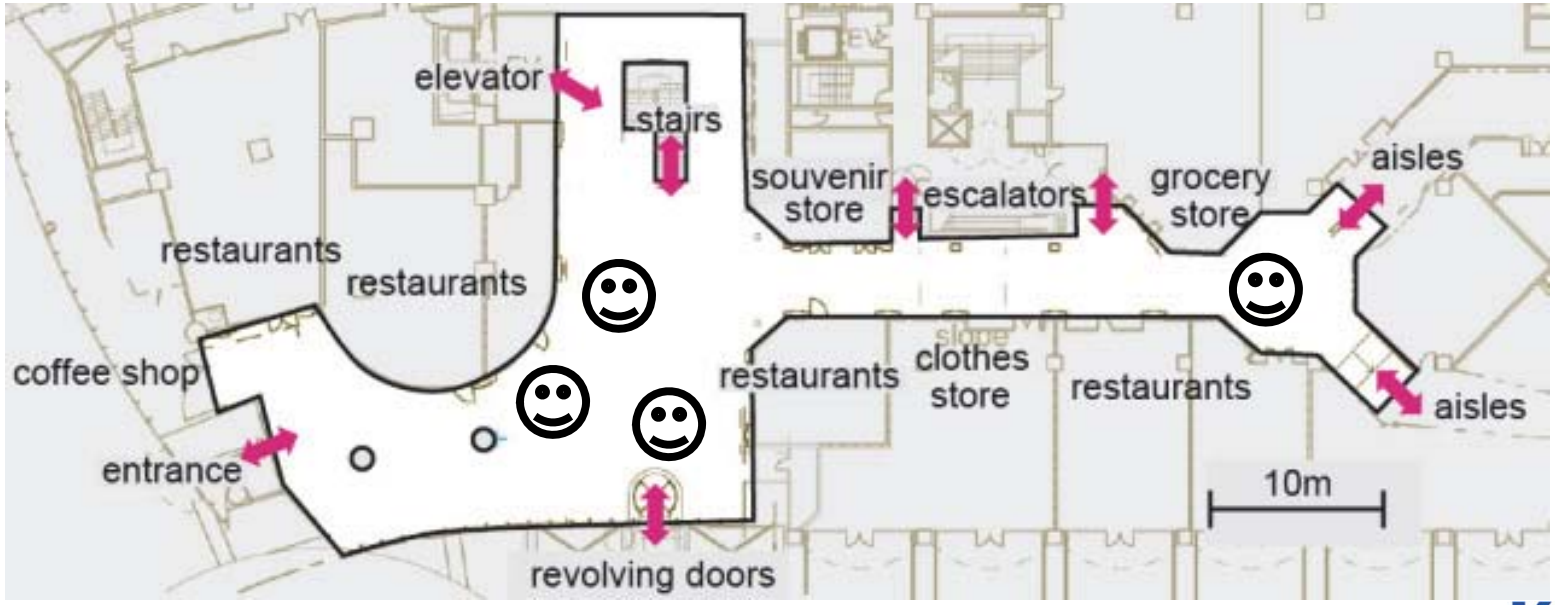
Belief Tracker

Sub-goal Concept

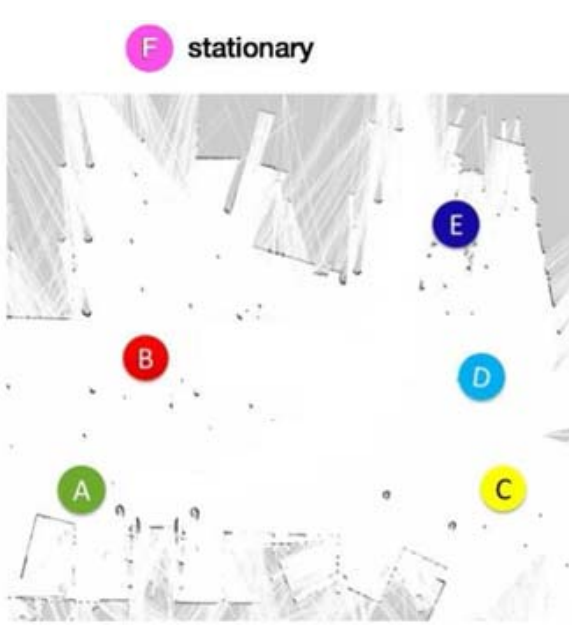
- From human science studies.
- Sub-goal
  - points in a space that pedestrians are walking toward
  - landmarks of environment

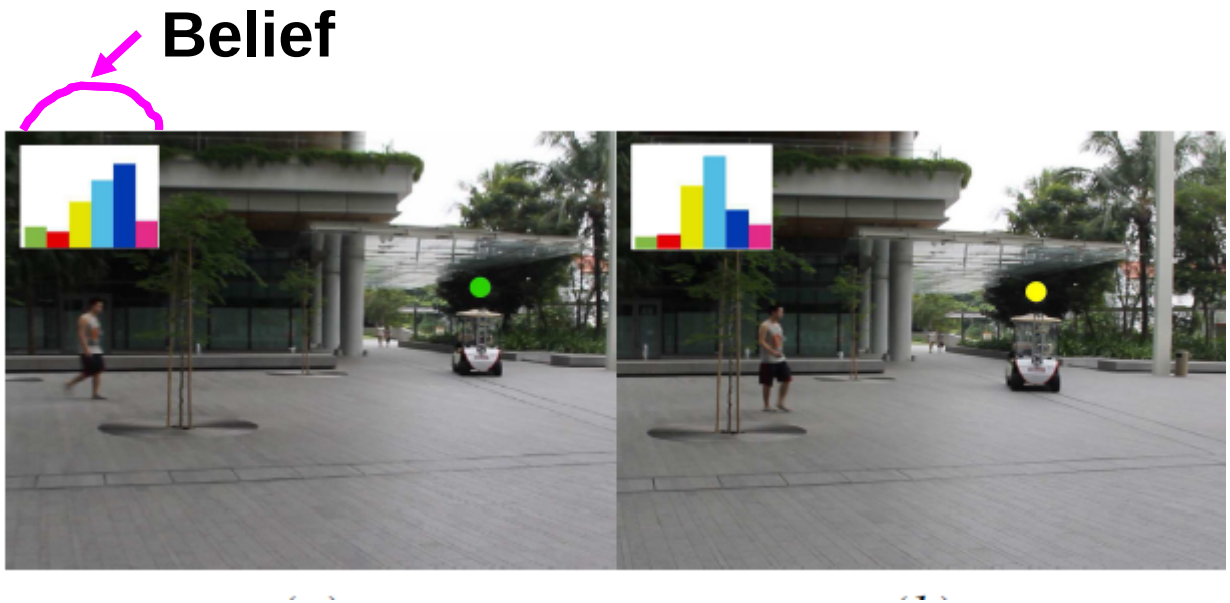


Ikeda, Tetsushi, et al. "Modeling and prediction of pedestrian behavior based on the sub-goal concept." *Robotics* (2013): 137.

Belief of Pedestrians' intention

- **Belief of Pedestrians' intention**
  - **Probability distribution for each sub-goals**





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Pedestrian model

- **Pedestrian Model**
  - **Position** (x_i, y_i)
  - **Instantaneous velocity,** v_i
  - **Goal** g_i

The Highest possible sub-goal position in Belief

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Belief Tracker

- **Using observed pedestrian's movement**
  - **Bayer's rule**

New belief

Previous position

$$b'(g) = \eta p(x', y' | x, y, v, g) b(g)$$

Current position

Velocity, goal

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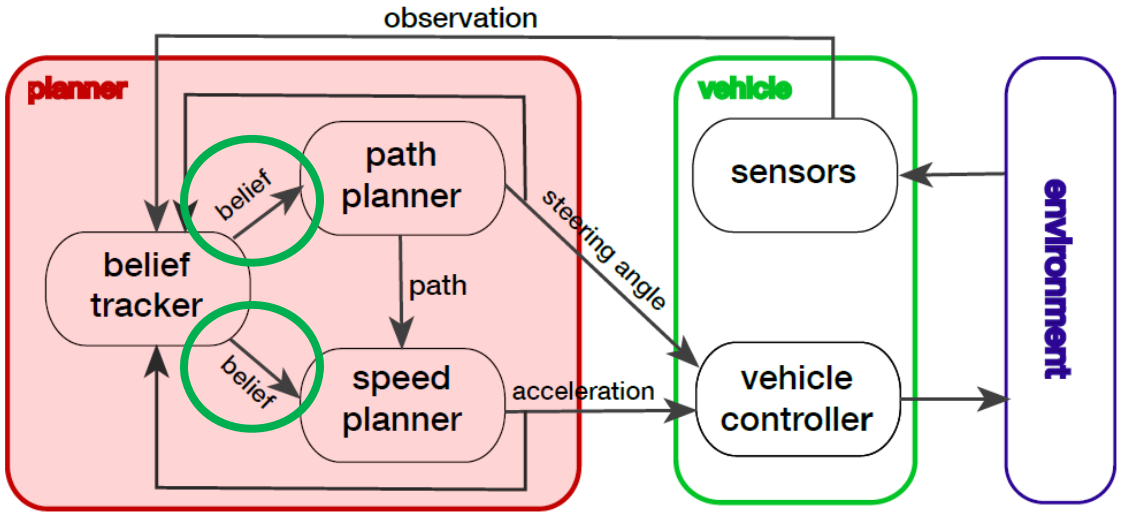
Belief Tracker

- **Use Belief**
  - **Utilized in path planning & speed planning**
  - **Up to 7 Pedestrians**



Bai, Haoyu, et al. "Intention-aware online POMDP planning for autonomous driving in a crowd." *Robotics and Automation (ICRA), 2015 IEEE International Conference on*. IEEE, 2015.

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Path Planning

Path planning

- **Grid World + Grid search**
  - **Path, ρ: $(x_0, y_0) - (x_1, y_1) - (x_2, y_2)$ …**
  - **Path cost, $C(\rho)$**

$$C(\rho) = \sum_{i=0}^{n} \lambda^i C_{\text{st}}(x_i, y_i) + \sum_{i=0}^{n} \lambda^i C_{\text{ped}}(x_i, y_i) + \sum_{i=1}^{n-1} \lambda^i C_{\text{sm}}(\rho, i)$$

Static obstacle **Pedestrians** **Smoothness**

Potential Field

λ: ***discount constant***

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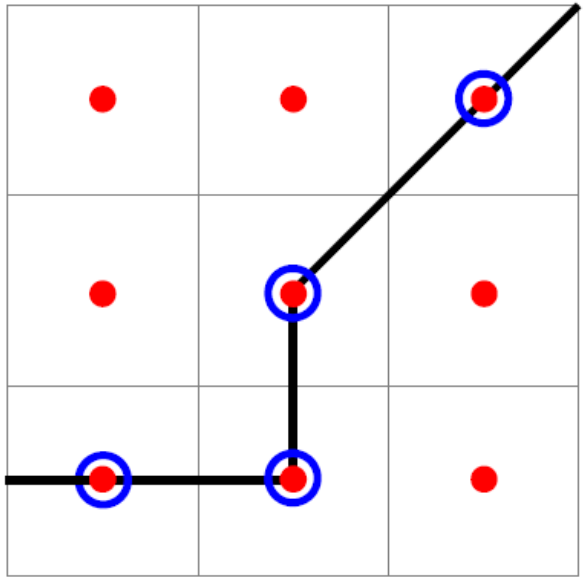
Path Planning – Grid Search

- **Grid Search**
  - **Regular A***
    - **Does not consider non-holonomic constraint**



Petereit, Janko, et al. "Application of Hybrid A* to an autonomous mobile robot for path planning in unstructured outdoor environments." *Robotics; Proceedings of ROBOTIK 2012; 7th German Conference on*. VDE, 2012.

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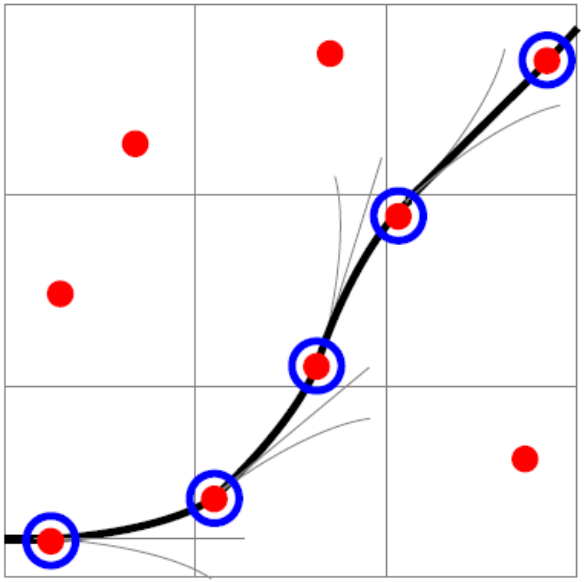
Path Planning – Hybrid A*

- **Hybrid A***
  - **For each cell, also contains continuous position.**



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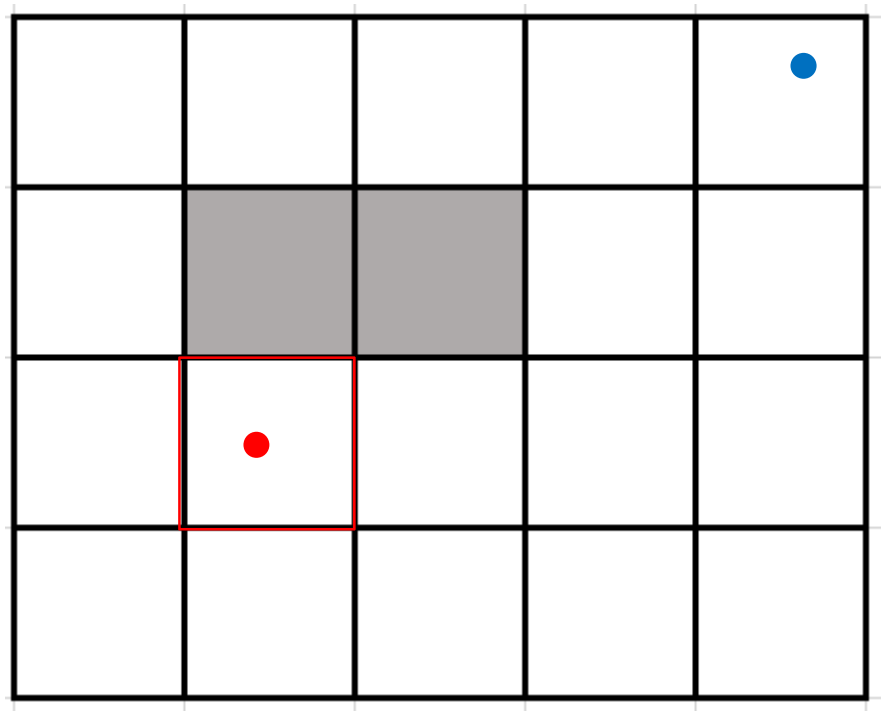
Path Planning – Hybrid A* detail

- In detail procedure

- Open set
- Close set



Initial situation

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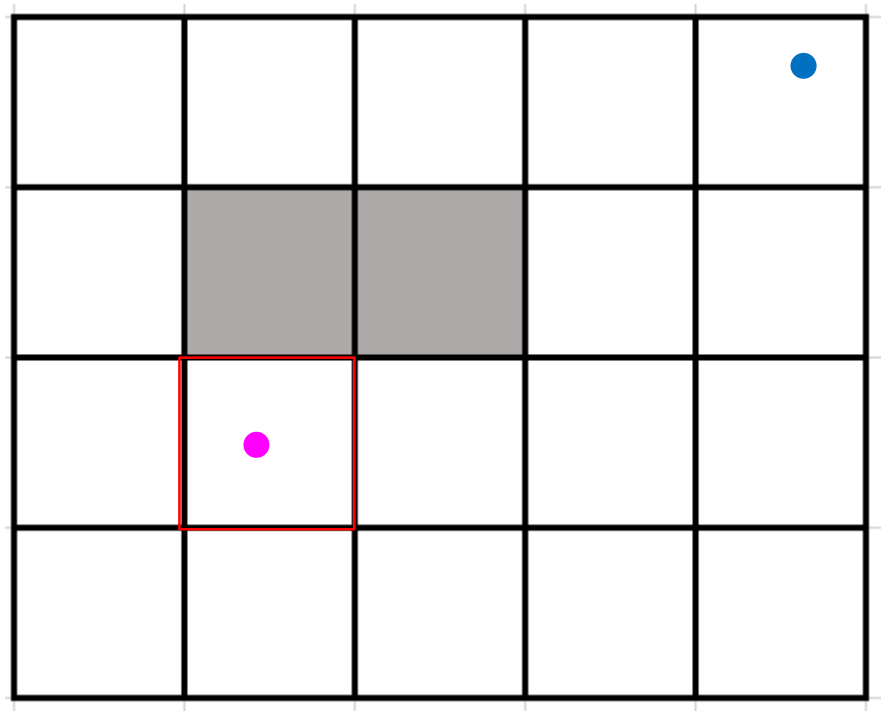
Path Planning – Hybrid A* detail

- In detail procedure

- Open set
- Close set



Select node from open set to expand

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Path Planning – Hybrid A* detail

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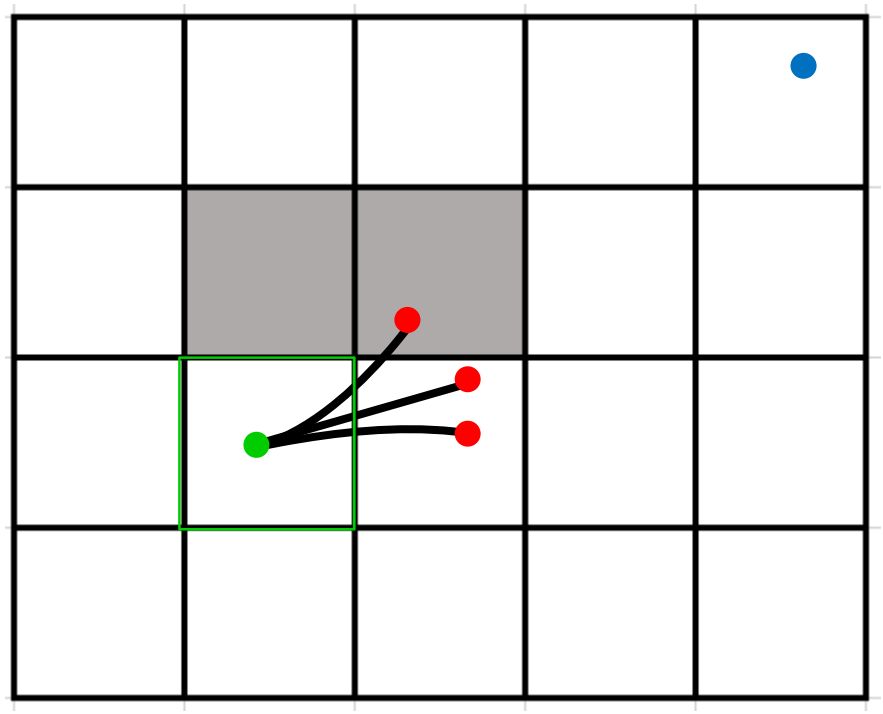

Expand node

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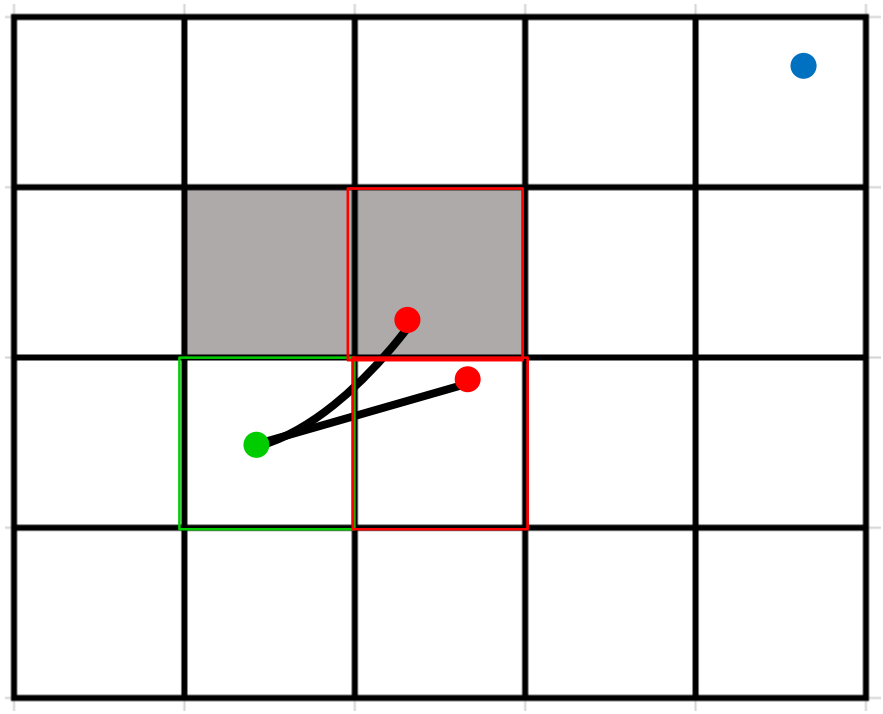
Path Planning – Hybrid A* detail

- **In detail procedure**

- **Open set**
- **Close set**



Select one point in each cell

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Path Planning – Hybrid A* detail

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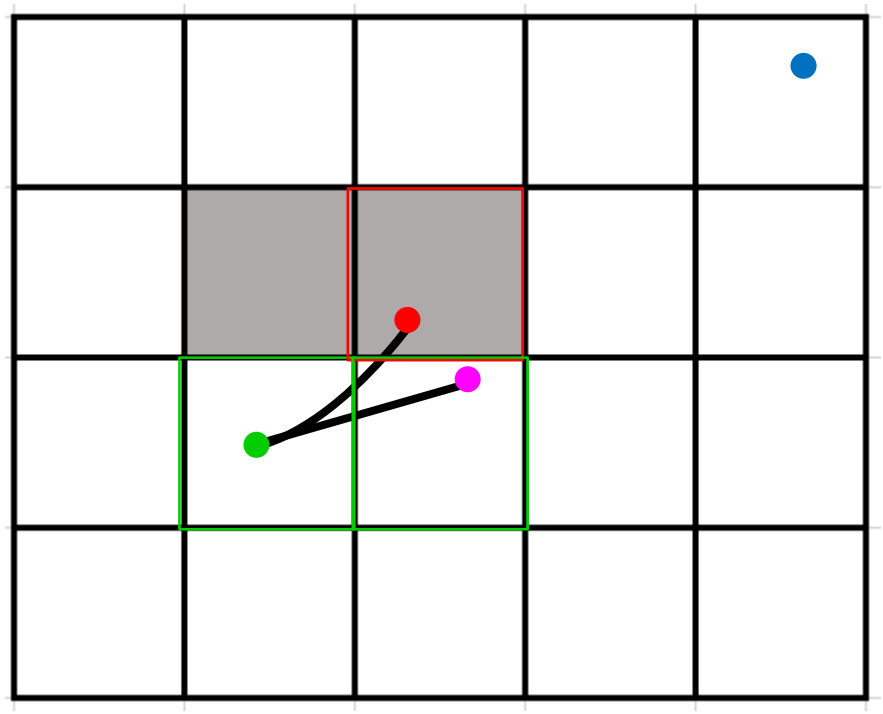

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Path Planning – Hybrid A* detail

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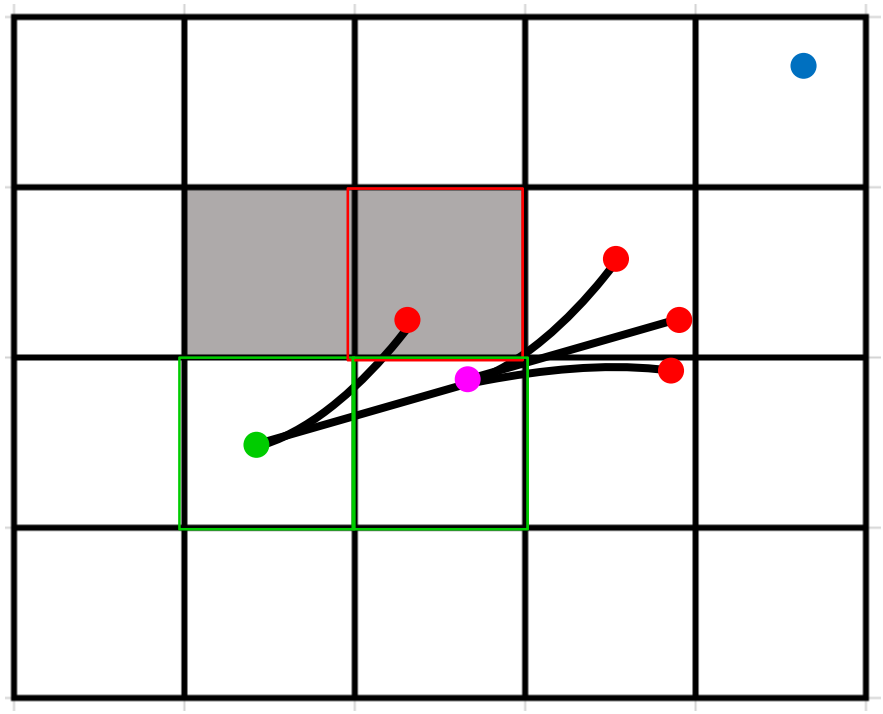

Expand node

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Path Planning – Hybrid A* detail

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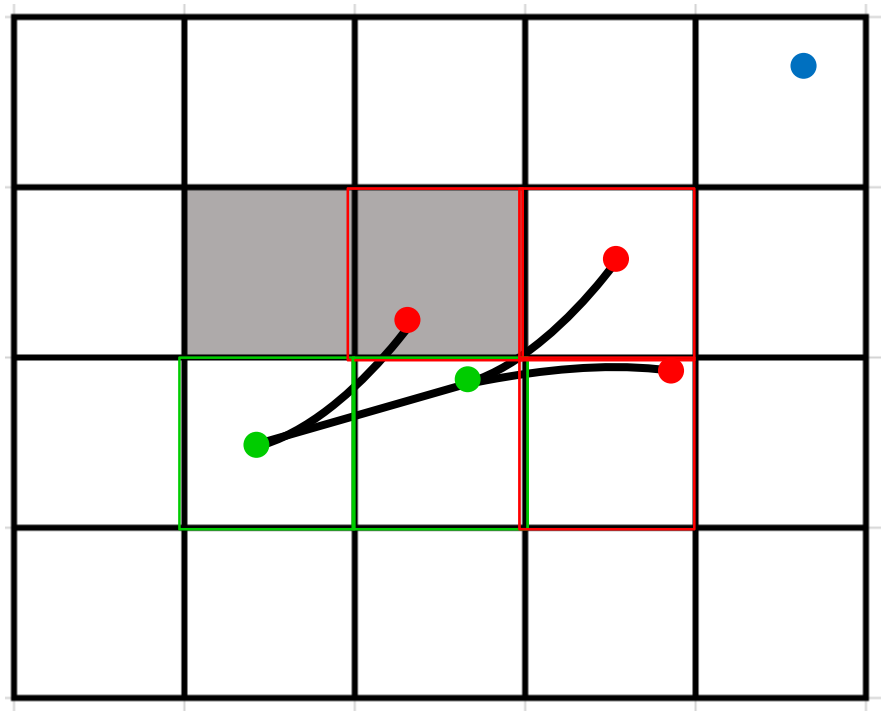

Select one point in each cell

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Path Planning – Hybrid A* detail

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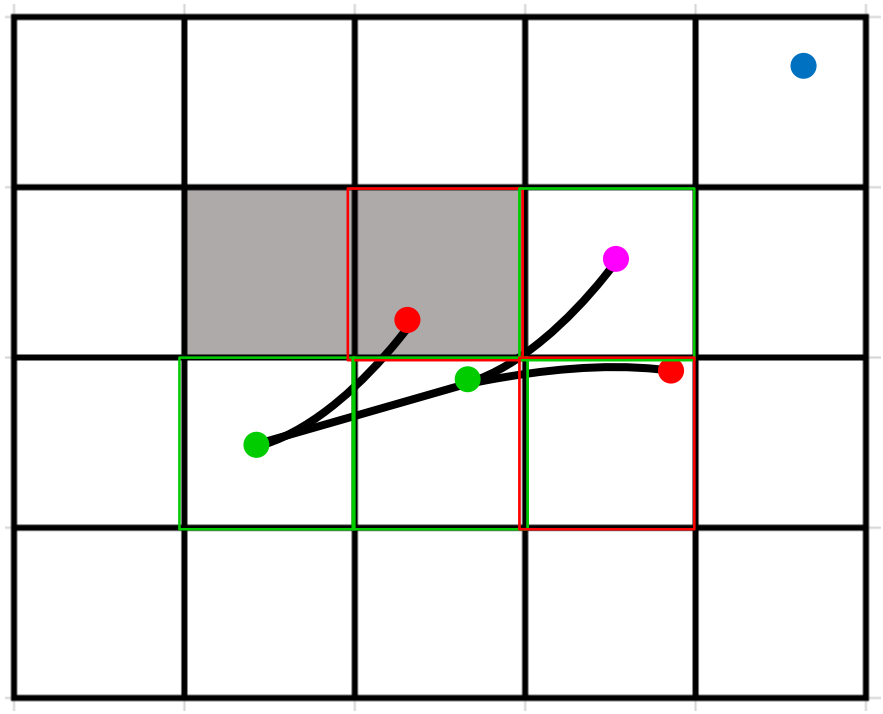

Select node from open set to expand

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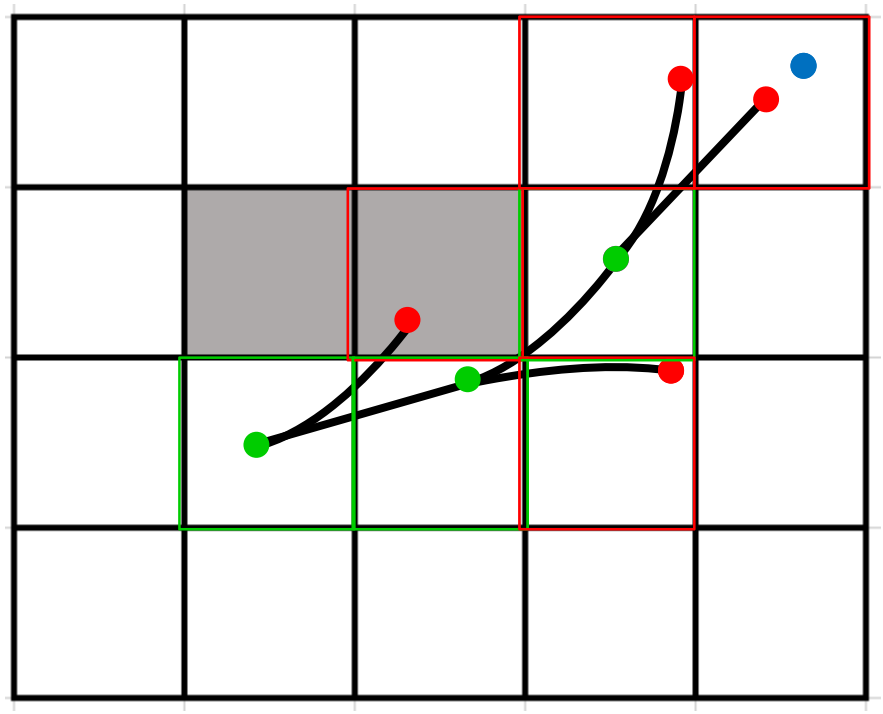
Path Planning – Hybrid A* detail

- **In detail procedure**

- **Open set**
- **Close set**



Expand & Select one point in each cell

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Path Planning – Hybrid A* detail

- In detail procedure

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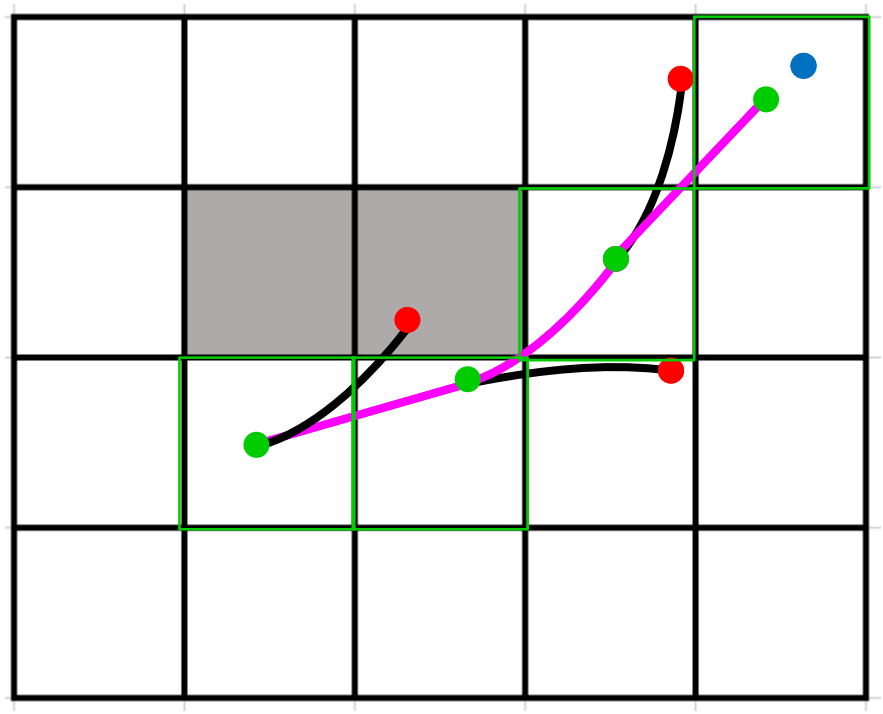
- Close set



Find continuous path

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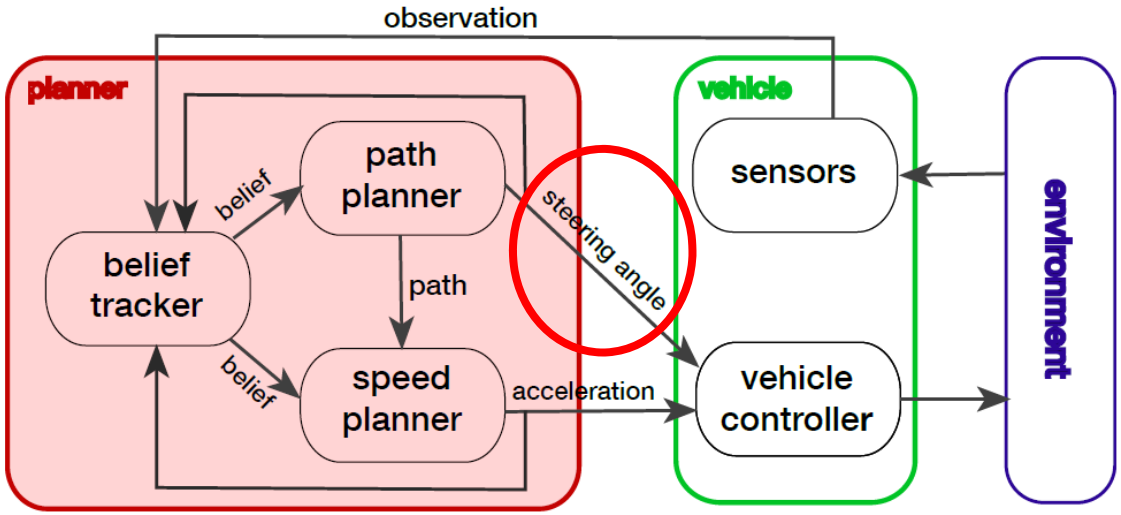
Path Planning

- Set **current** steering angle
  - Situation is continuously **changing**



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Speed Planner

- Collision Avoidance

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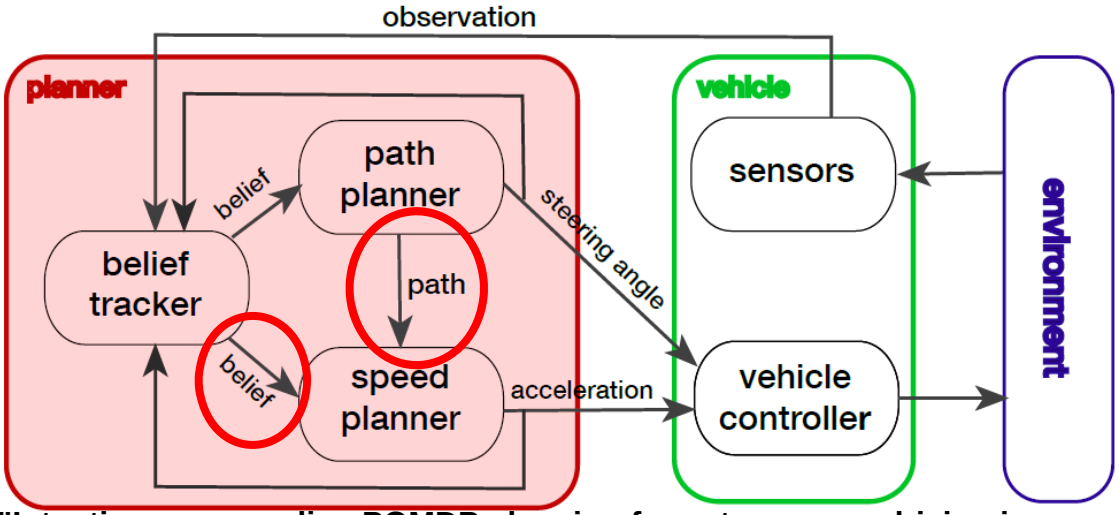
Speed planning

- **Assumption**
  - **Pedestrian walks toward it’s goal**
  - **Pedestrian speed is constant during planning cycle**
  - **Perfect sensor**

Collision Avoidance

- **Select Acceleration**
  - **Action: ACCEL. / MAINTAIN / DECEL.**

- **Utilize**
  - **Path from path planner**
  - **Belief from belief tracker – For penalty**



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Framework – Online POMDP

- **POMDP model**
  - **Vehicle(x, y, θ, v)**
  - **Pedestrians(x_i, y_i, g_i, v_i) up to 7**
  - **Sensor model: discretized values**
  - **Action: Acceleration**
    - **(ACCELERATE, MAINTAIN, DECELERATE)**
  - **Rewards & Penalties: Next Page…**

Current situation

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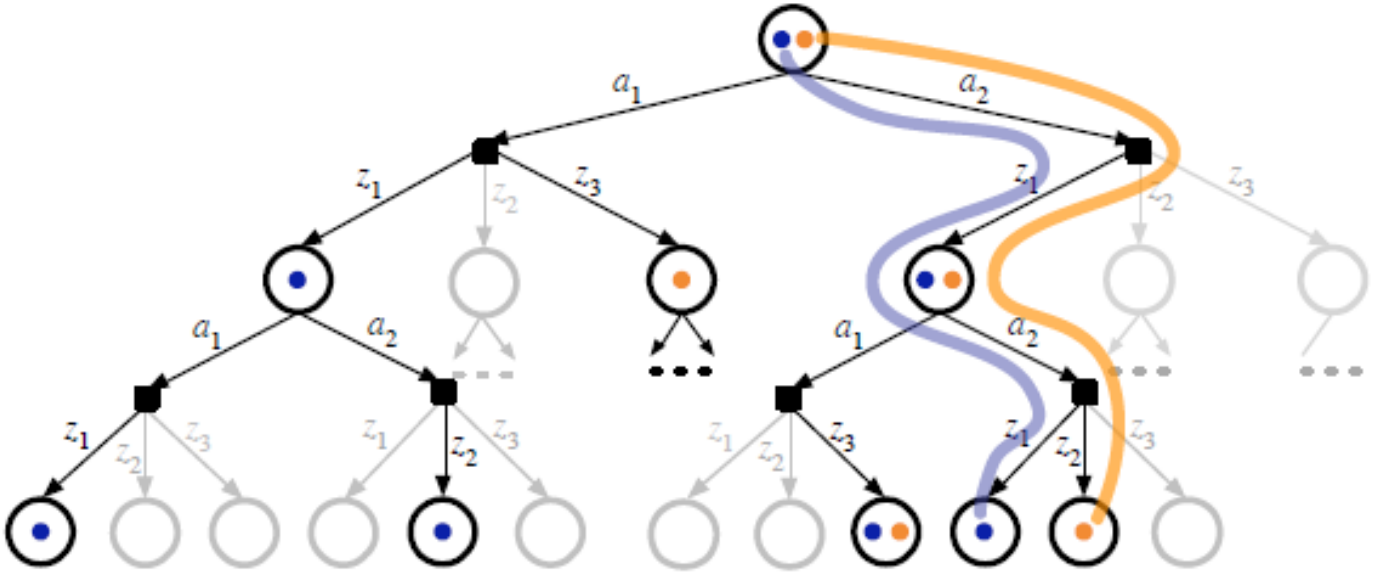
Framework – Online POMDP

- **Reward**
  - **Large reward around Goal**
    → **to reach the destination**

- **Penalties**
  - **Large penalty for approaching the pedestrians**
    → **for safe**
  - **Slow speed**
    → **For driving at a higher speed**
  - **Accelerate and Decelerate actions**
    → **For smooth driving**

Framework – Online POMDP

- **Online POMDP**
  - **Only finite horizon**
  - **Scenario sampling**



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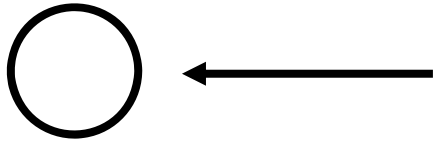
Framework – Online POMDP

- **Online POMDP procedure**



Current belief
: vehicle state,
pedestrian beliefs

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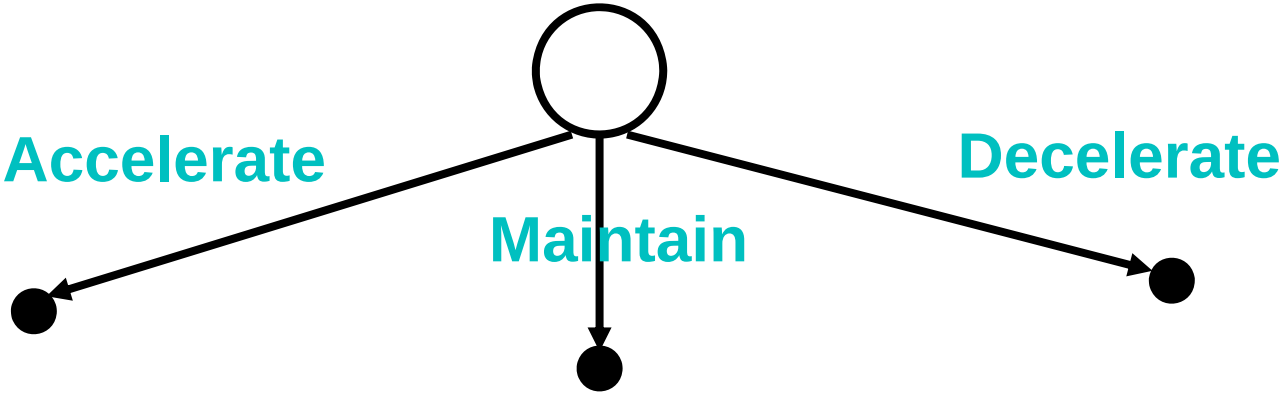
Framework – Online POMDP

- **Online POMDP procedure**



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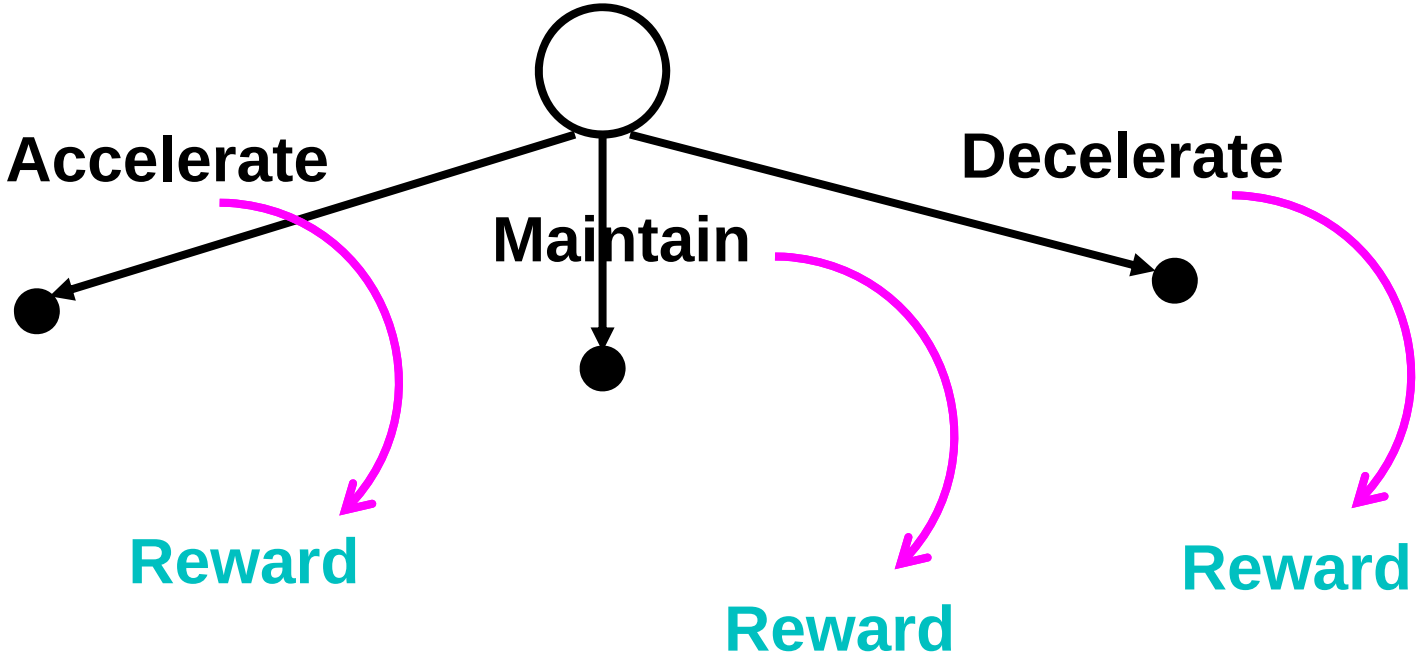
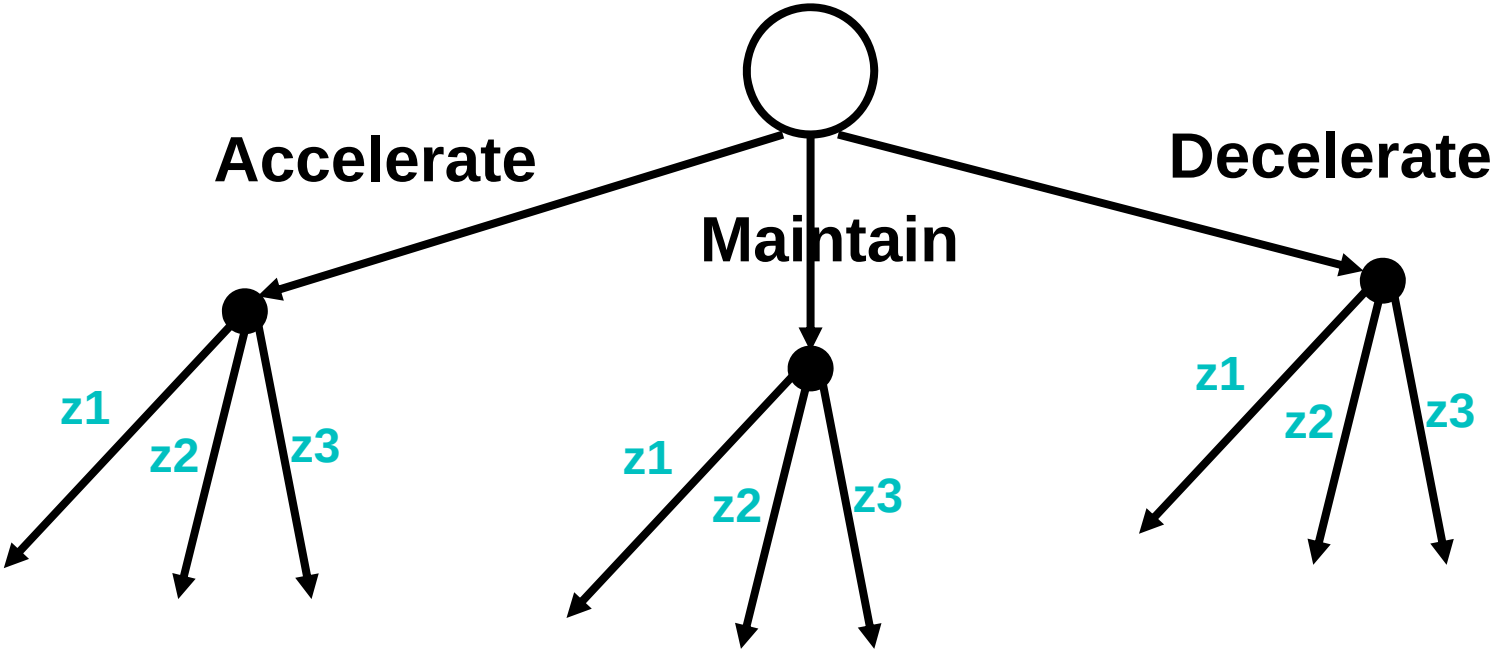
Framework – Online POMDP

- **Online POMDP procedure**



Framework – Online POMDP

- **Online POMDP procedure**



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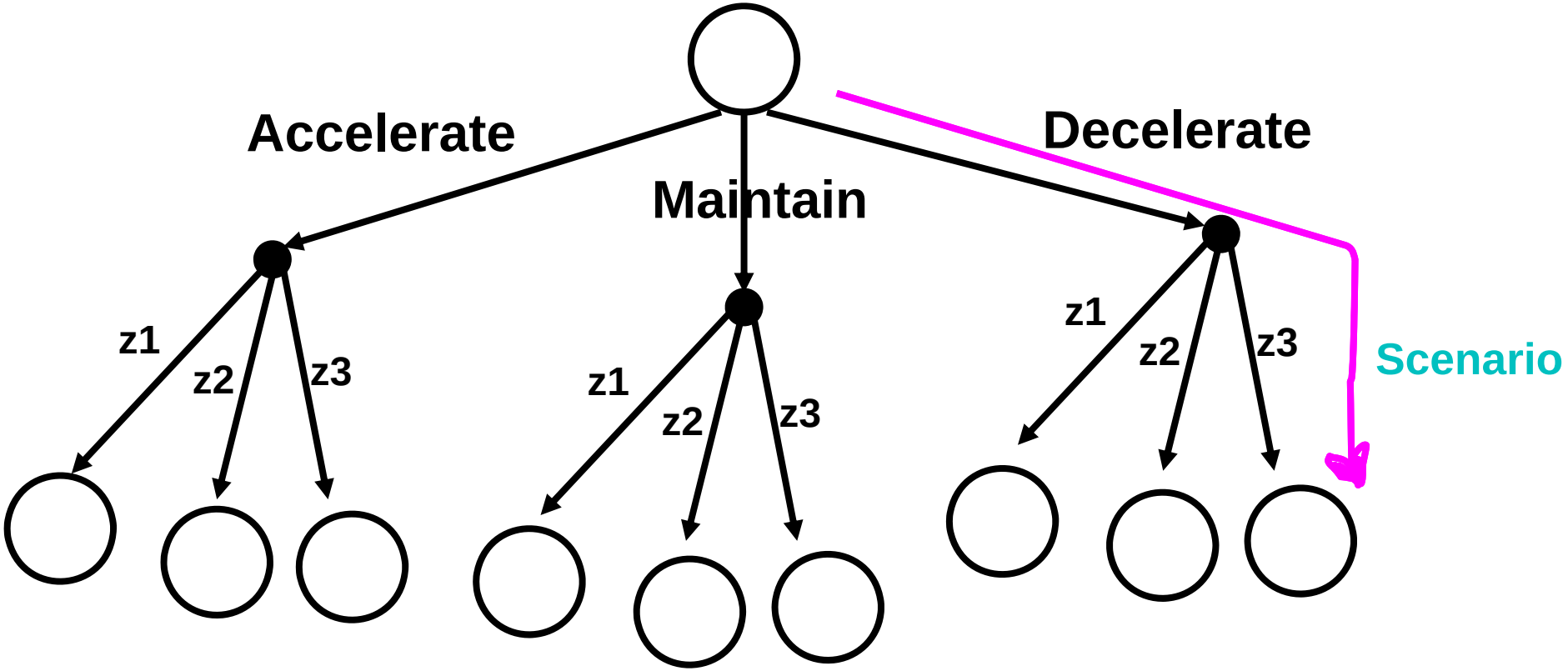
Framework – Online POMDP

- **Online POMDP procedure**



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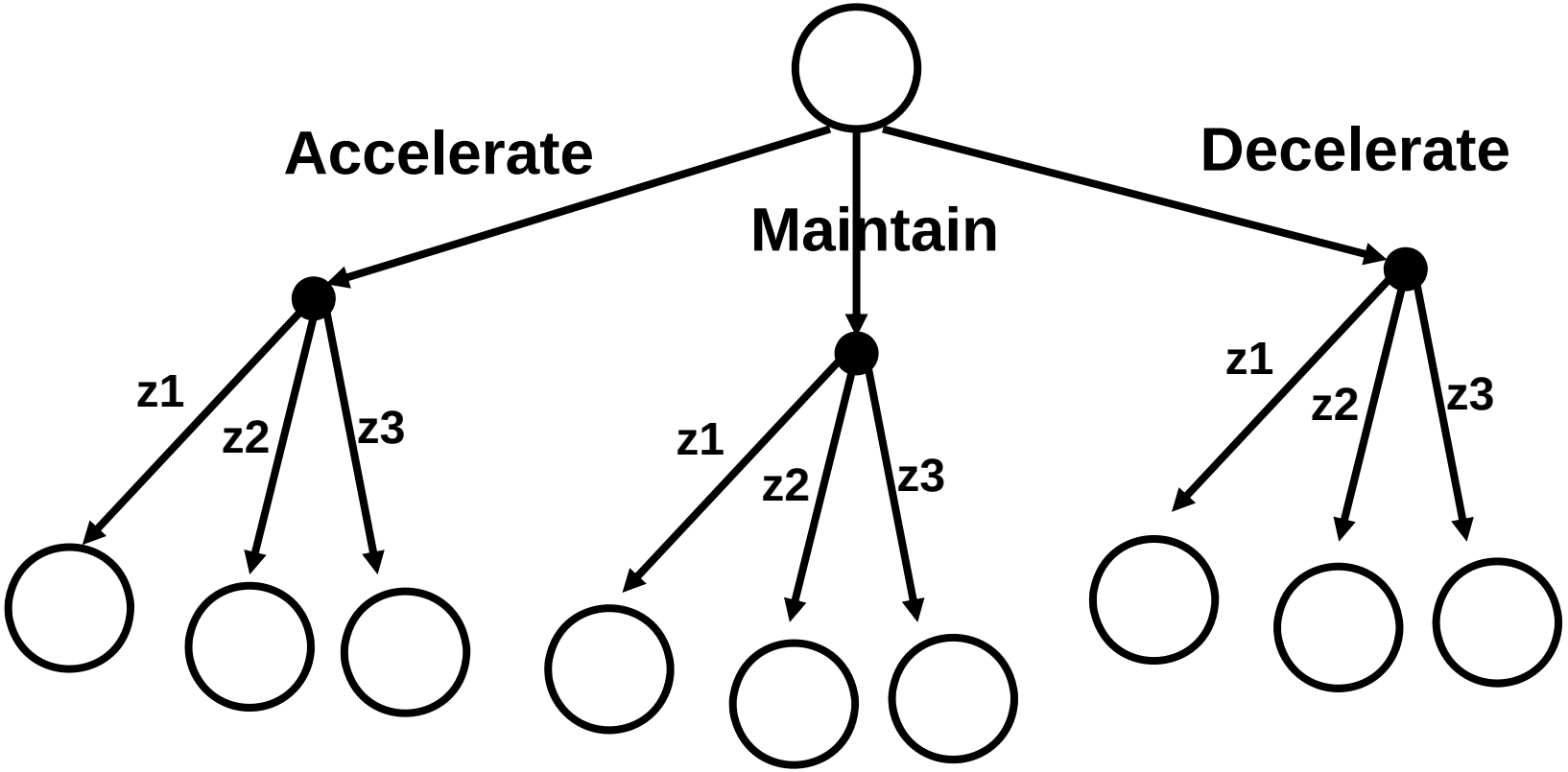
Framework – Online POMDP

- **The problem is scenarios grow exponentially**



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Framework – Online POMDP

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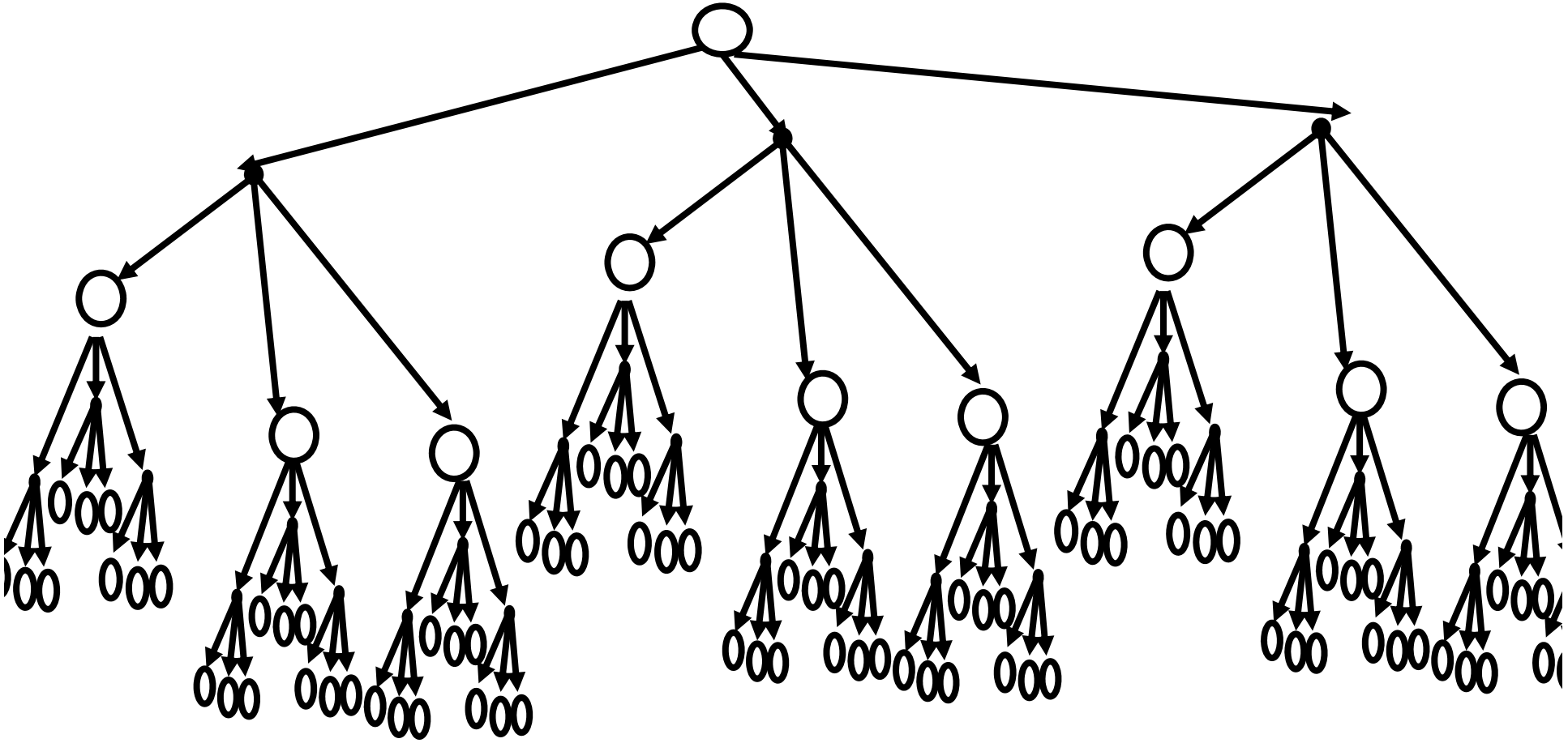

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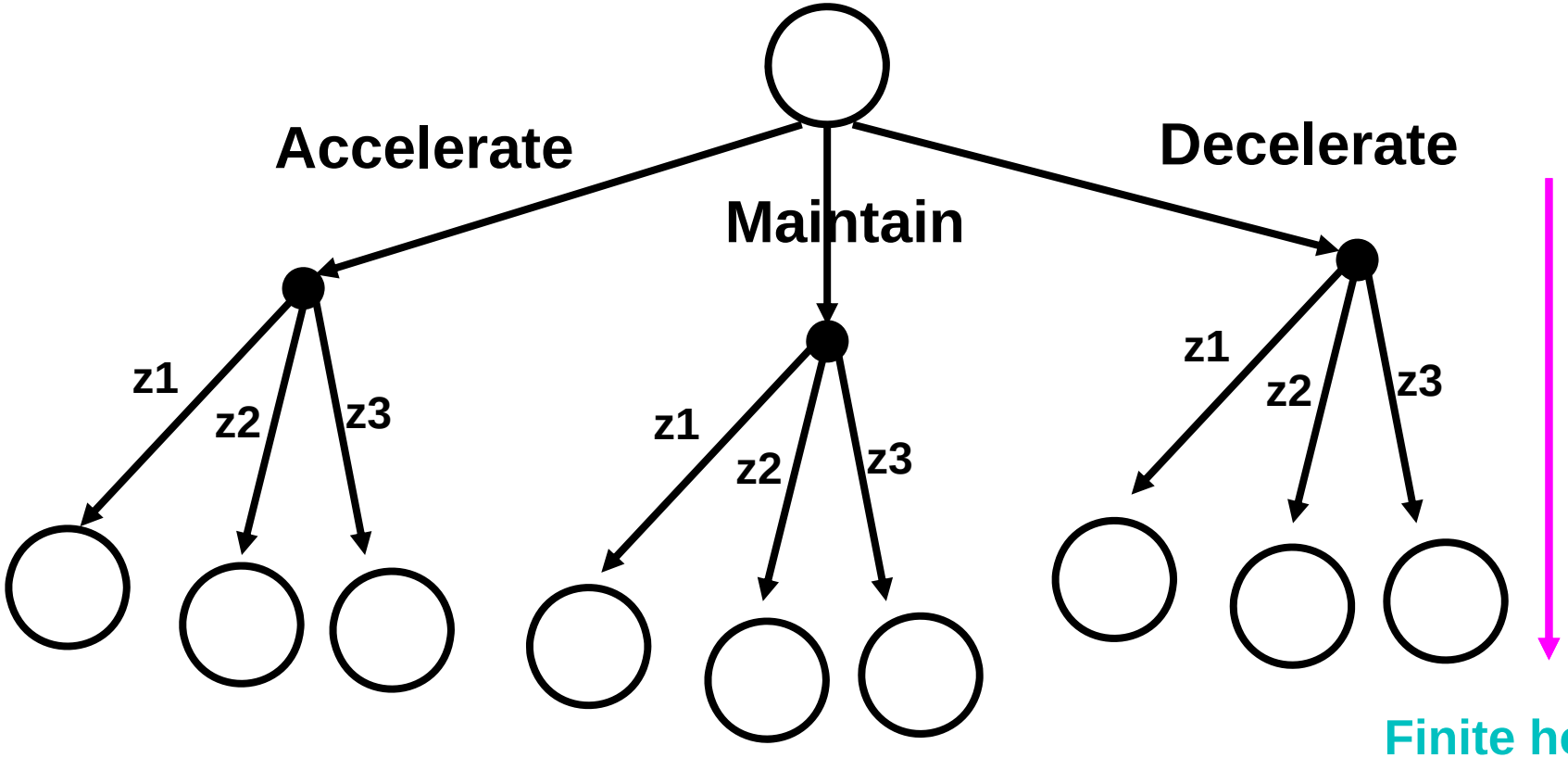
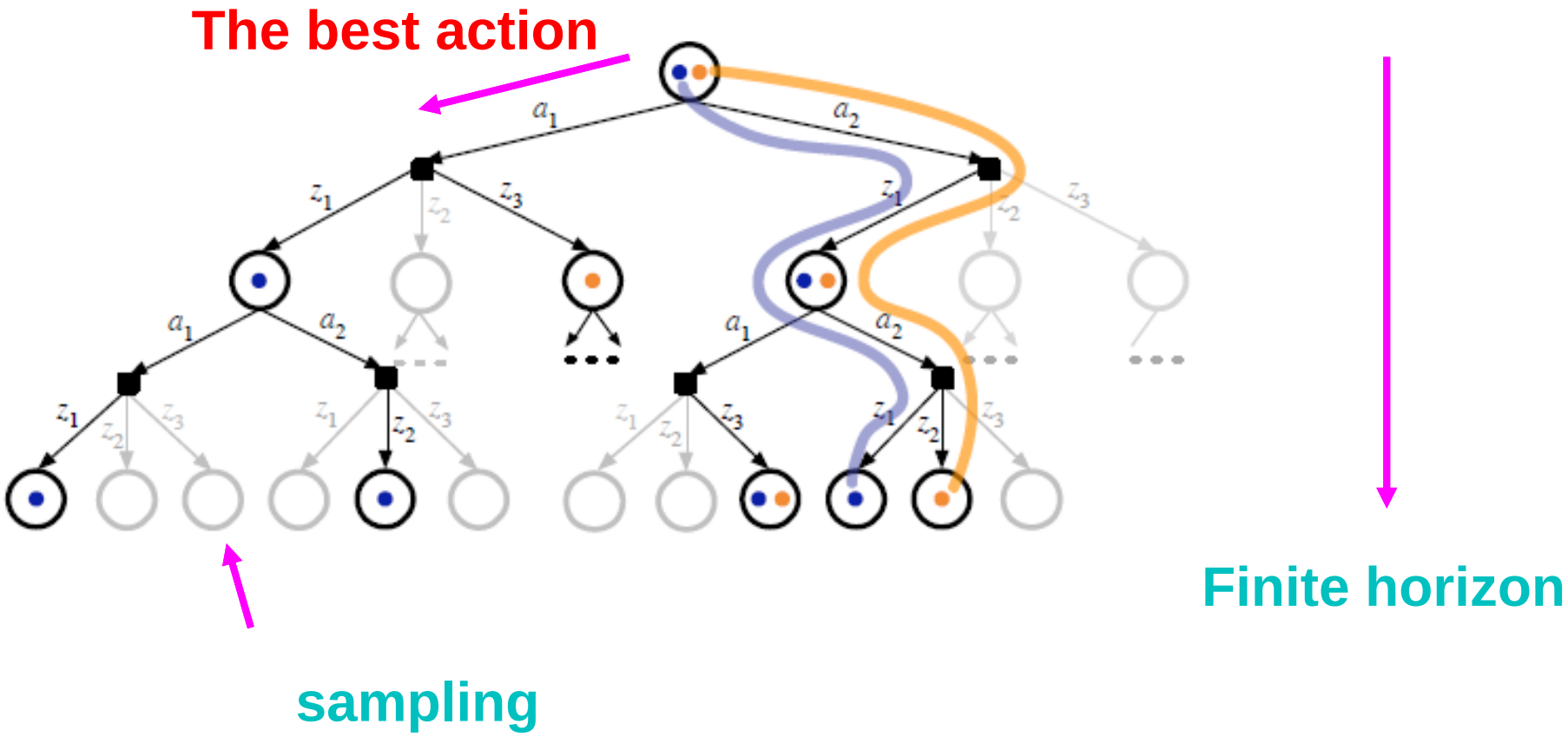
Framework – Online POMDP

- **Online POMDP procedure**
  - **Random sampling of observations**



Framework – Online POMDP

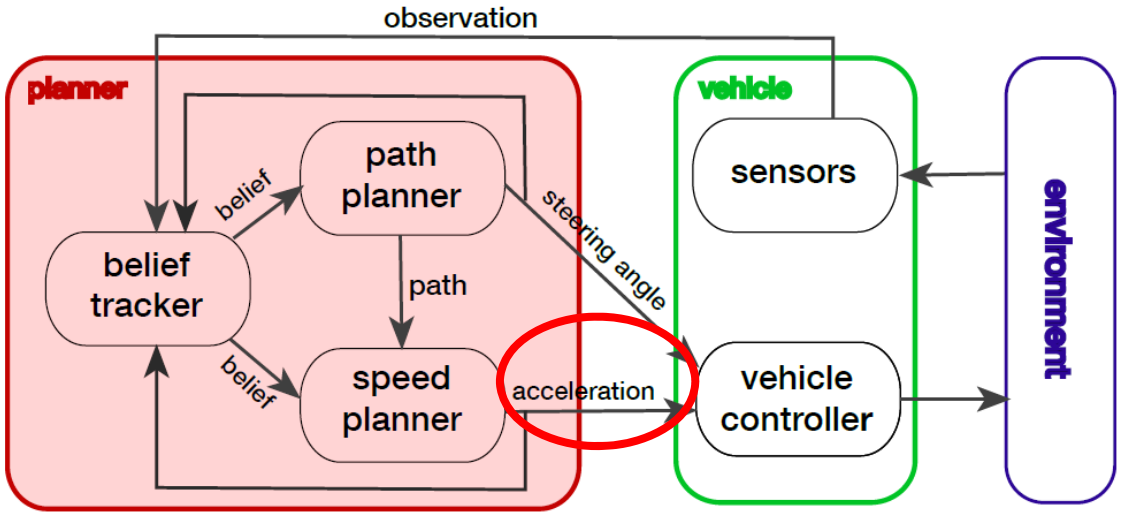
- **Online POMDP procedure**



Framework – Online POMDP

- **Utilize finite horizon scenarios**
  - **Consider long-term effect of the current action**

- **Execute current action**



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Demo video

Result

- **Demo video**

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Pros and cons

Pros and cons

- **Pros**
  - **Seems somewhat success.**
  - **Tries to anticipate future.**
  - **There is room for development. (Deep learning)**

- **Cons**
  - **Sub-goal concept is somewhat restricted.**
  - **The pedestrians should behave normally.**
  - **Decision quality trade off with computation time.**

- **Q&A**