Lecture 8 | Path Planning

Secure Autonomous Systems

CSCI 6907/3907 86

Spring 2024

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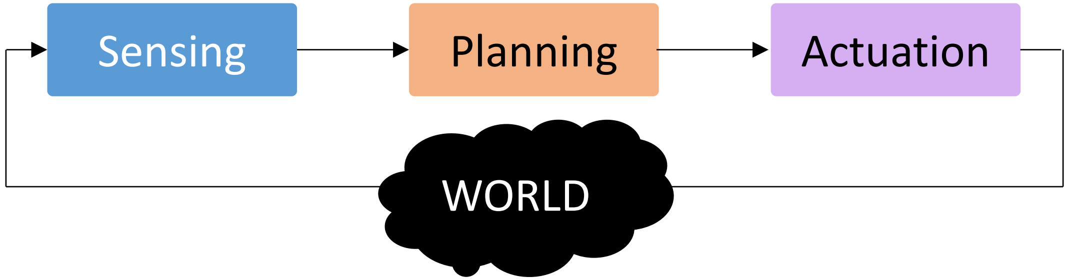
https://bit.ly/secureauto-spring24

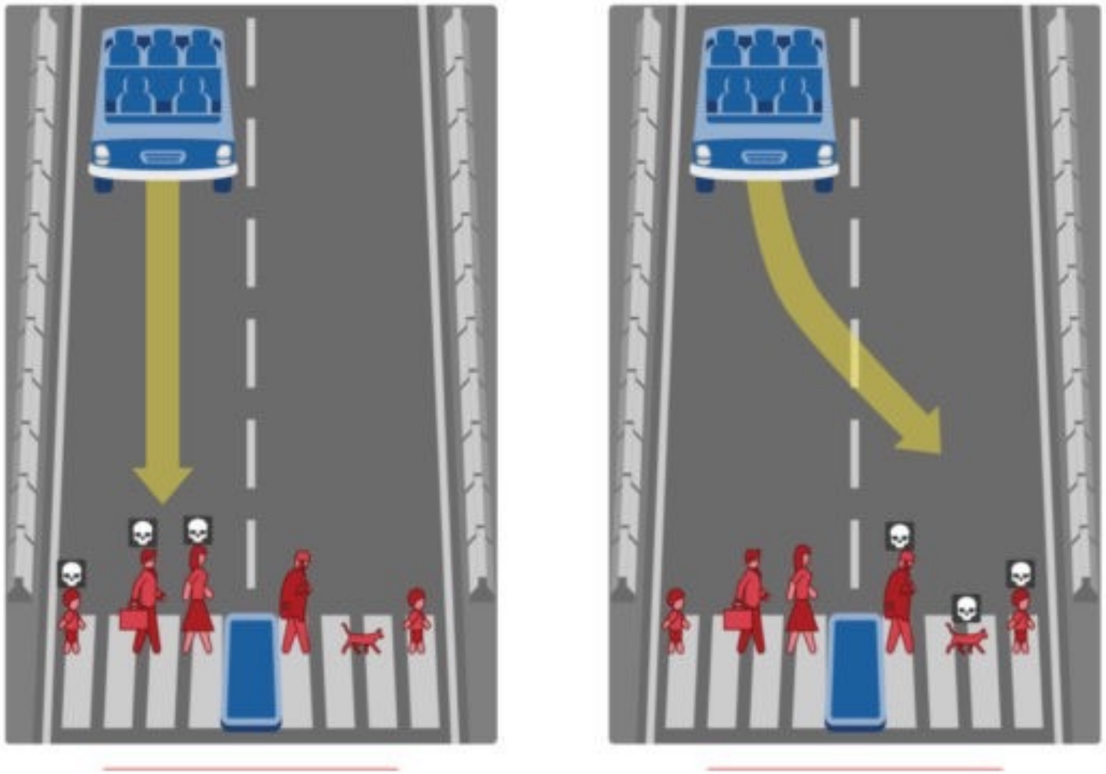
Sensing, Planning, Actuation



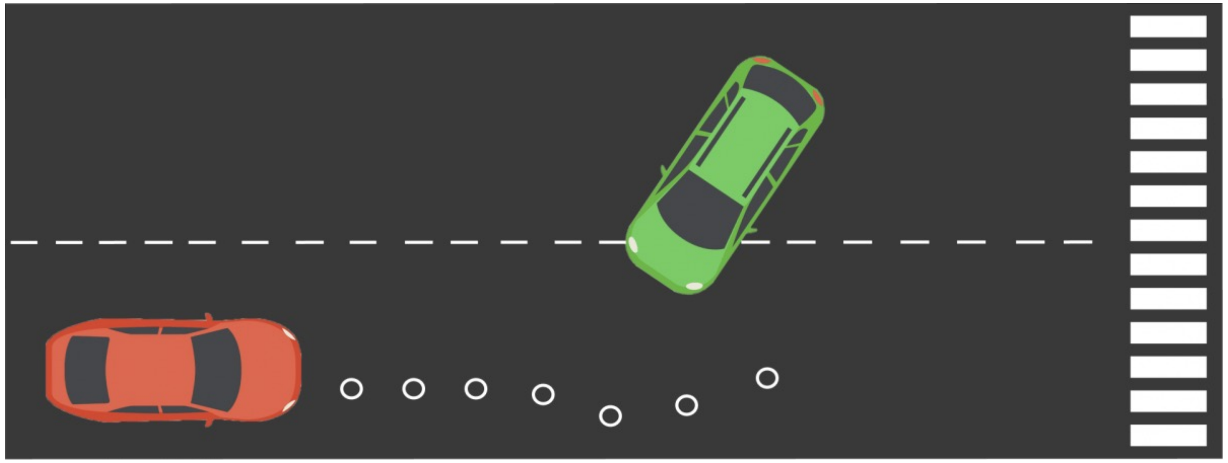
Sensors Abstraction	Sensor Fusion	World Model	Behavior Generation	Planning	Vehicle Control	Actuation
RADAR LIDAR Cameras GPS V2X Internal St	Object Det Global Pos Local Pos Vehicle State	Internal Model External Model Data Sinks Bird's Eye View	HMI Route i/p Global Routing Behavior Gen. Behavior Select	Path Planning Monitoring Lane Keeping Lane Change Collision Avoid HMI Driver Alert	Lateral Longitudinal Trajectory Intention Comm.	Steering Brake Throttle Transmission

Path Planning for Autonomous Systems

- Decision making
- Predictions
  - Other cars
  - Pedestrians
  - Traffic signals
- Routes must be
  - Safe
  - Convenient
  - Economically beneficial



Consider this Example



Four options for the green car:

1. stay in lane, speed up
2. stay in lane, slow down
3. stay in lane, constant speed
4. change lane

each scenario ➔ a **probability** associated with it

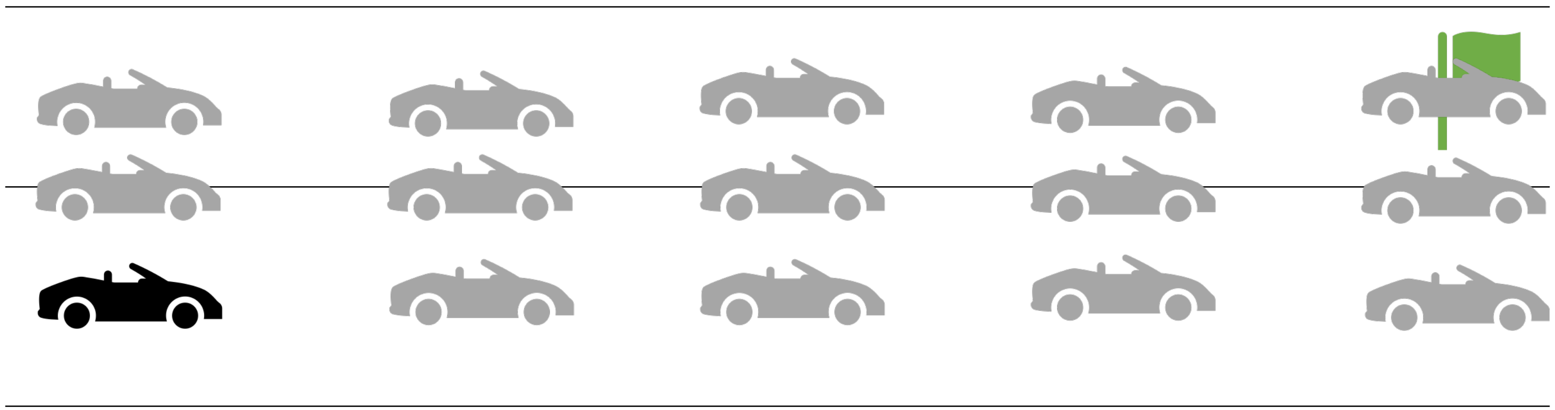
starting configuration

destination

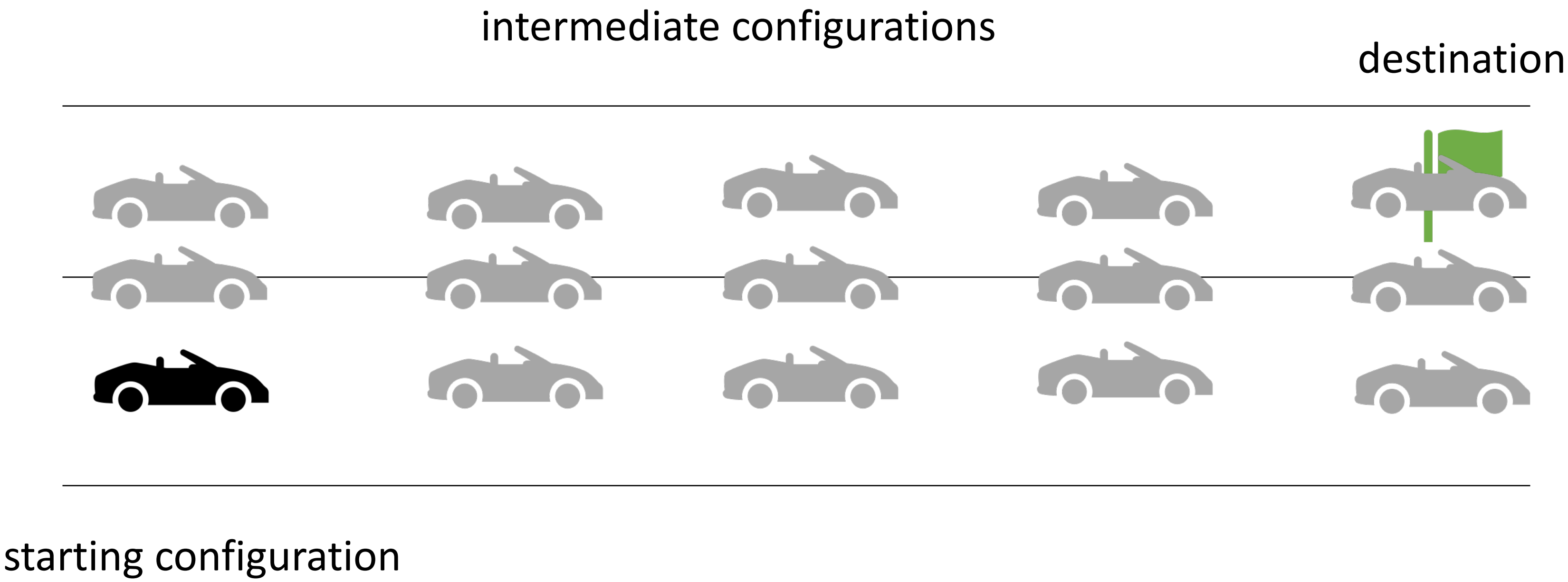
starting configuration

intermediate configurations

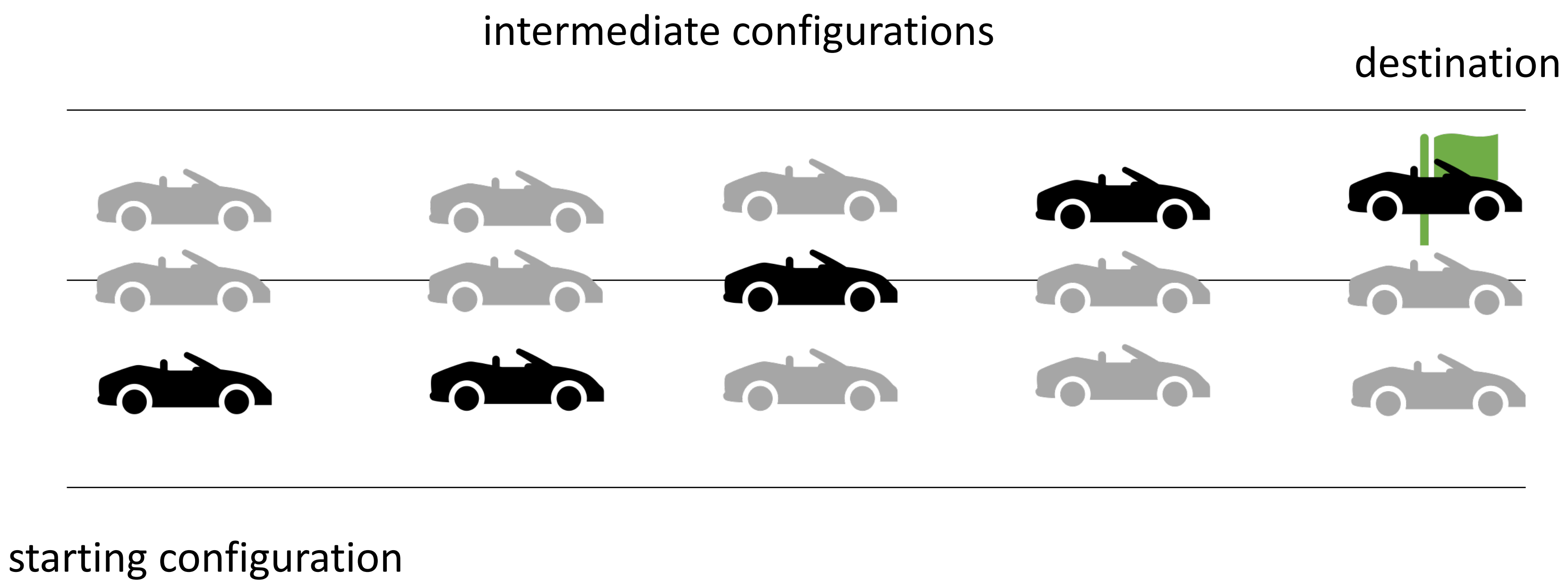
destination



starting configuration

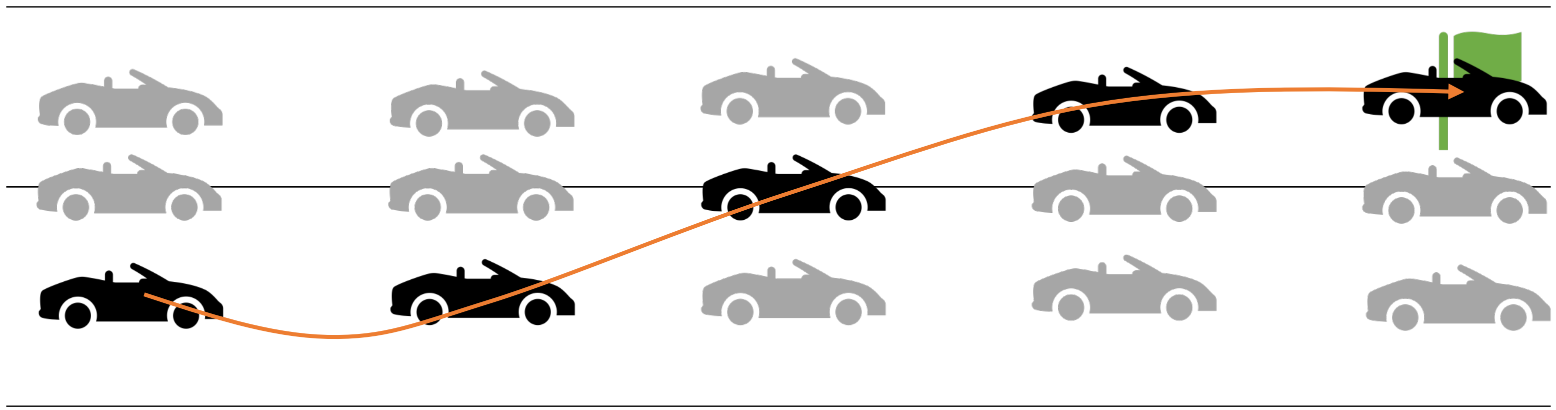

intermediate configurations
destination
starting configuration

Path Planning | Terminology



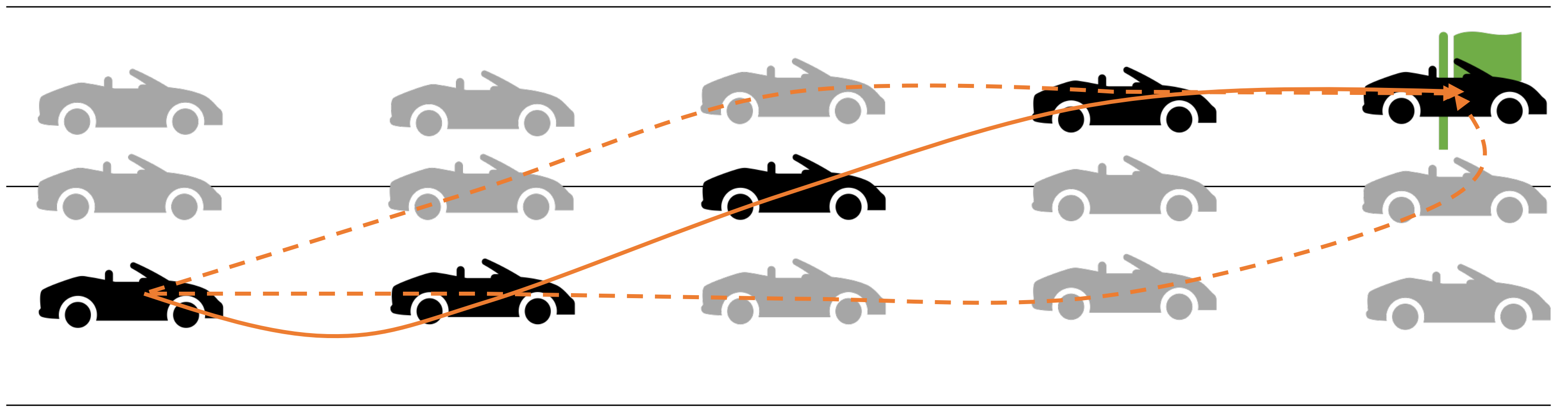
Path: continuous sequence of configurations → starting/ending with boundary configurations

Path Planning | Terminology



Path planning: find a geometric path from initial to given config ➔ each configuration state is feasible

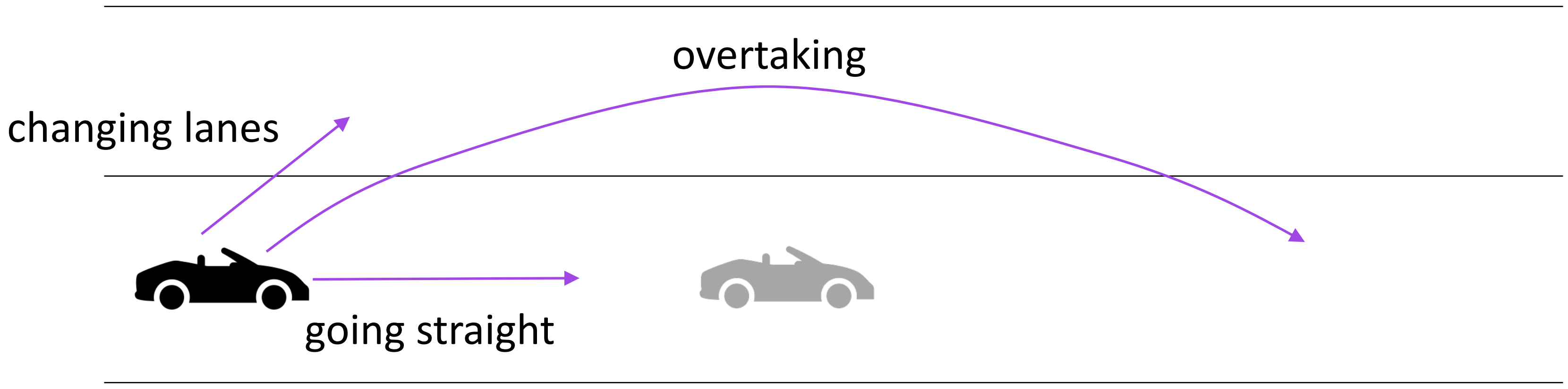
Path Planning | Terminology



alternate paths!

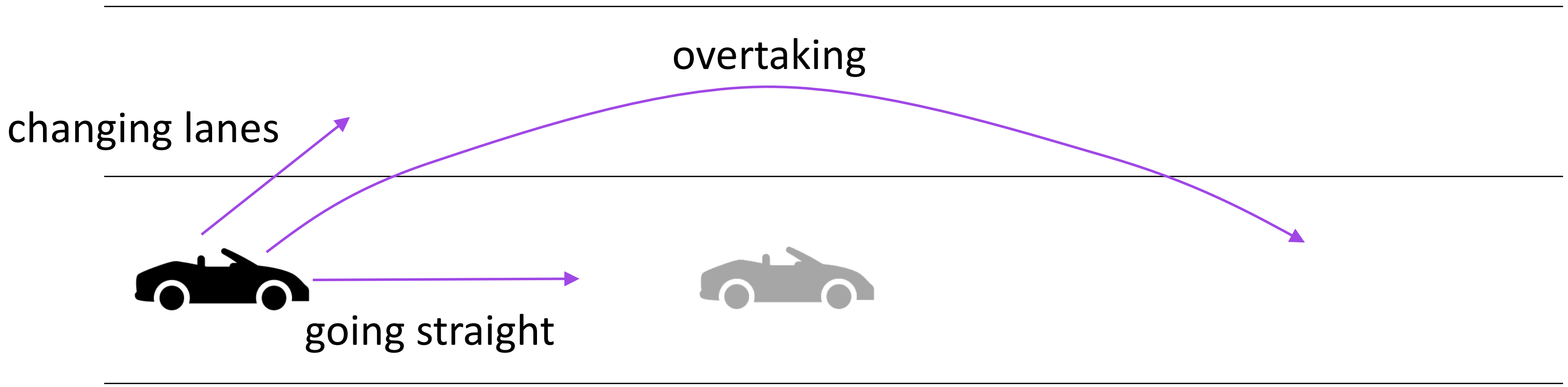
Path planning: find a geometric path from initial to given config ➔ each configuration state is feasible

Path Planning | Terminology



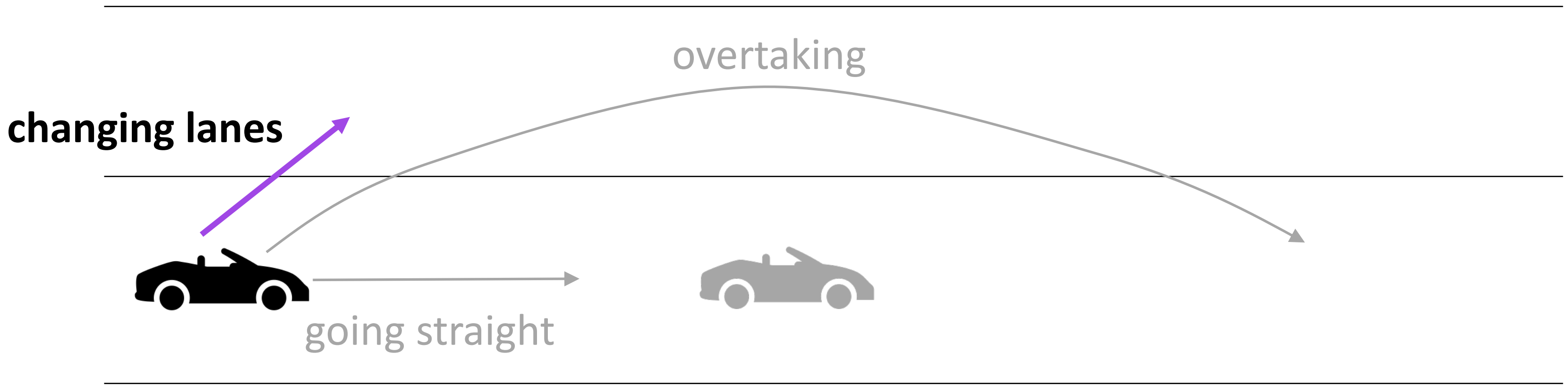
Maneuver: high-level characteristic of vehicle’s motion ➔ Encompasses position+speed of vehicle

Path Planning | Terminology



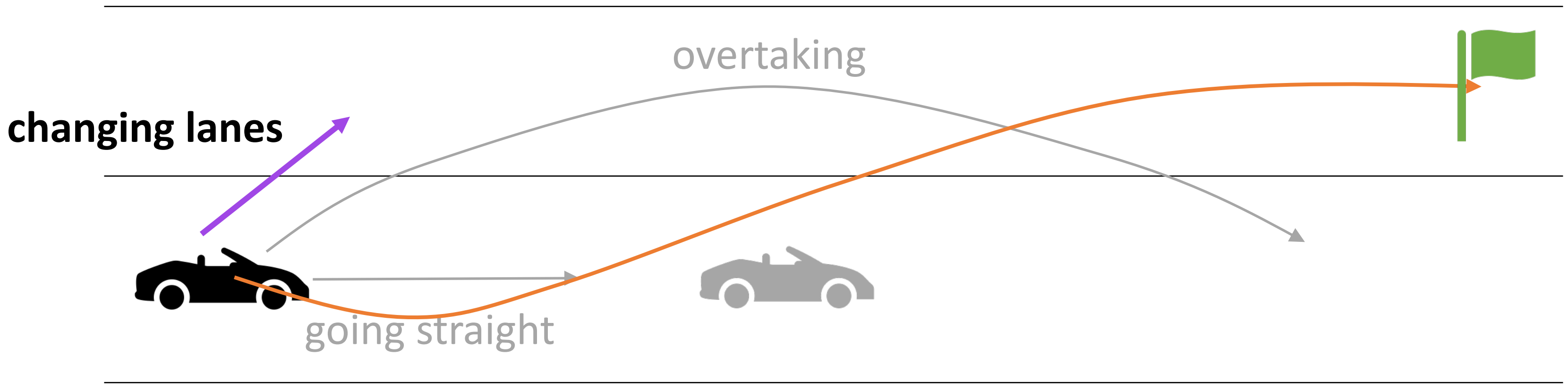
Maneuver planning: take best high-level decision for vehicle

Path Planning | Terminology



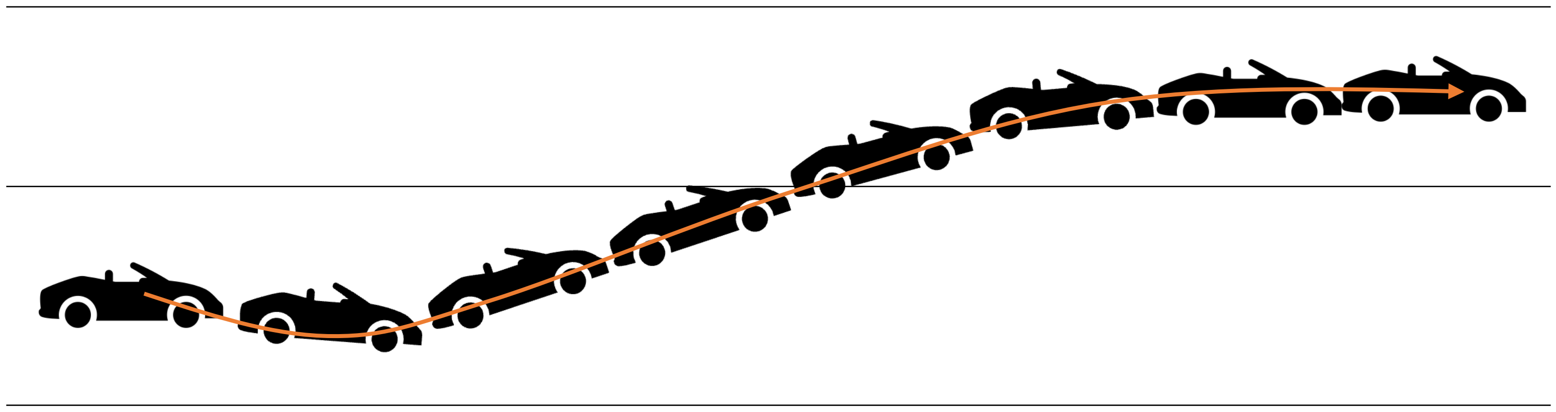
Maneuver planning: take best high-level decision for vehicle

Path Planning | Terminology



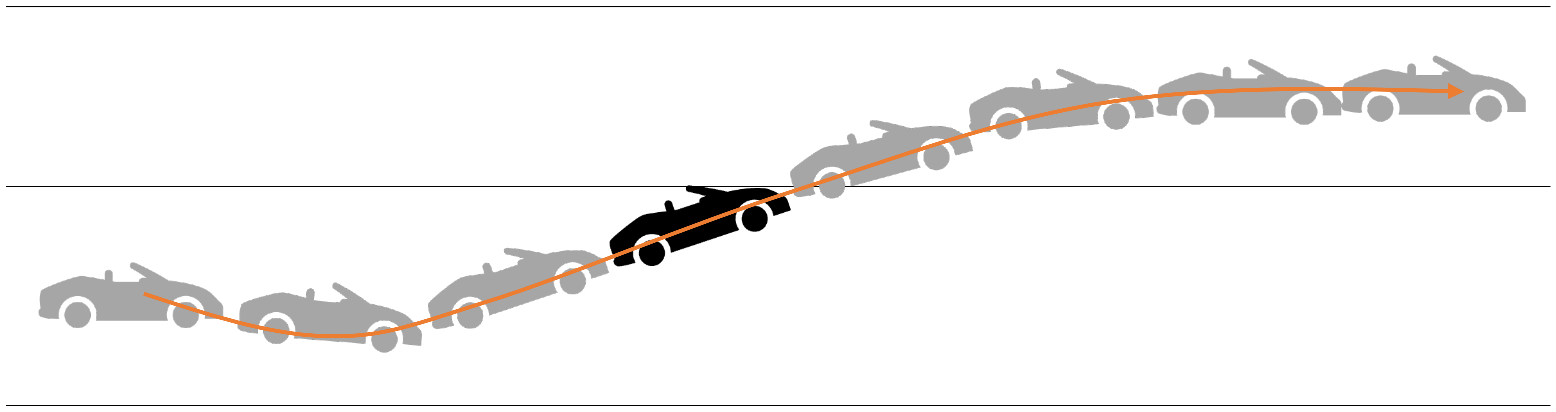
Maneuver planning: take best high-level decision for vehicle ➔ account for path from planning algorithm

Path Planning | Terminology



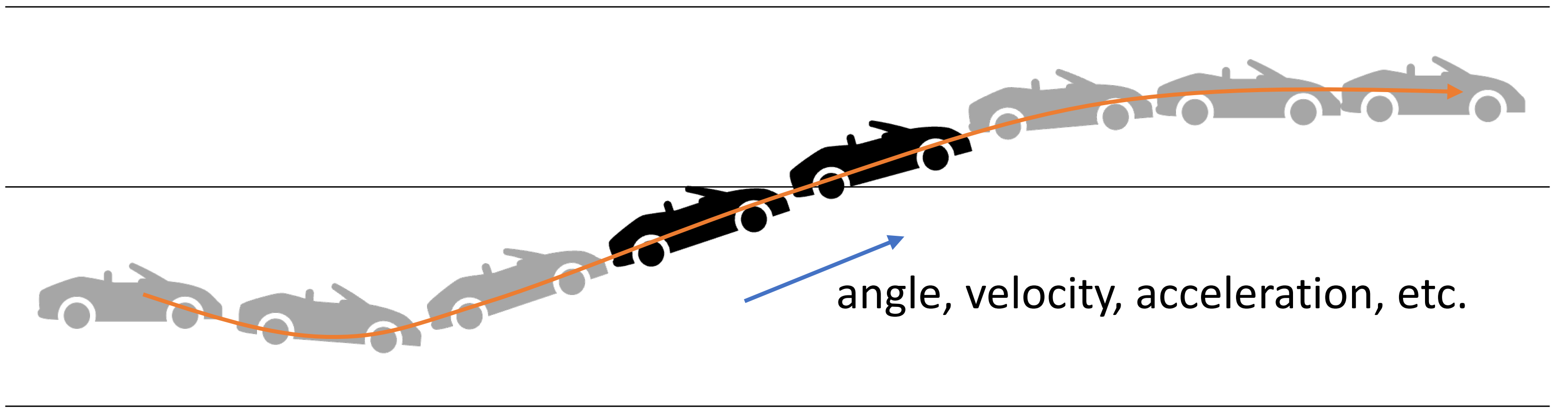
Trajectory: sequence of states visited by vehicle → parameterized by time and velocity

Path Planning | Terminology



Trajectory planning: real-time planning of vehicle's move ➔ from one feasible state to next

Path Planning | Terminology



satisfied by car's **kinematics**

Trajectory planning: real-time planning of vehicle's move ➔ from one feasible state to next

Path Planning | Terminology

- **Path**: continuous sequence of configurations
  - starting/ending with boundary configurations
- **Path planning**: find a geometric path from initial to given config
  - Each configuration and state on path is feasible
- **Maneuver**: high-level characteristic of vehicle's motion
  - Encompasses position and speed of vehicle on road
  - E.g.: going straight, changing lanes, turning, right, overtaking, etc.
- **Maneuver planning**: take best high-level decision for vehicle
  - Take into account path specified by planning algorithm
- **Trajectory**: sequence of states visited by vehicle
  - Parameterized by time and velocity
- **Trajectory planning**: real-time planning of vehicle's moves
  - From one feasible state to the next, satisfied by car's kinematics

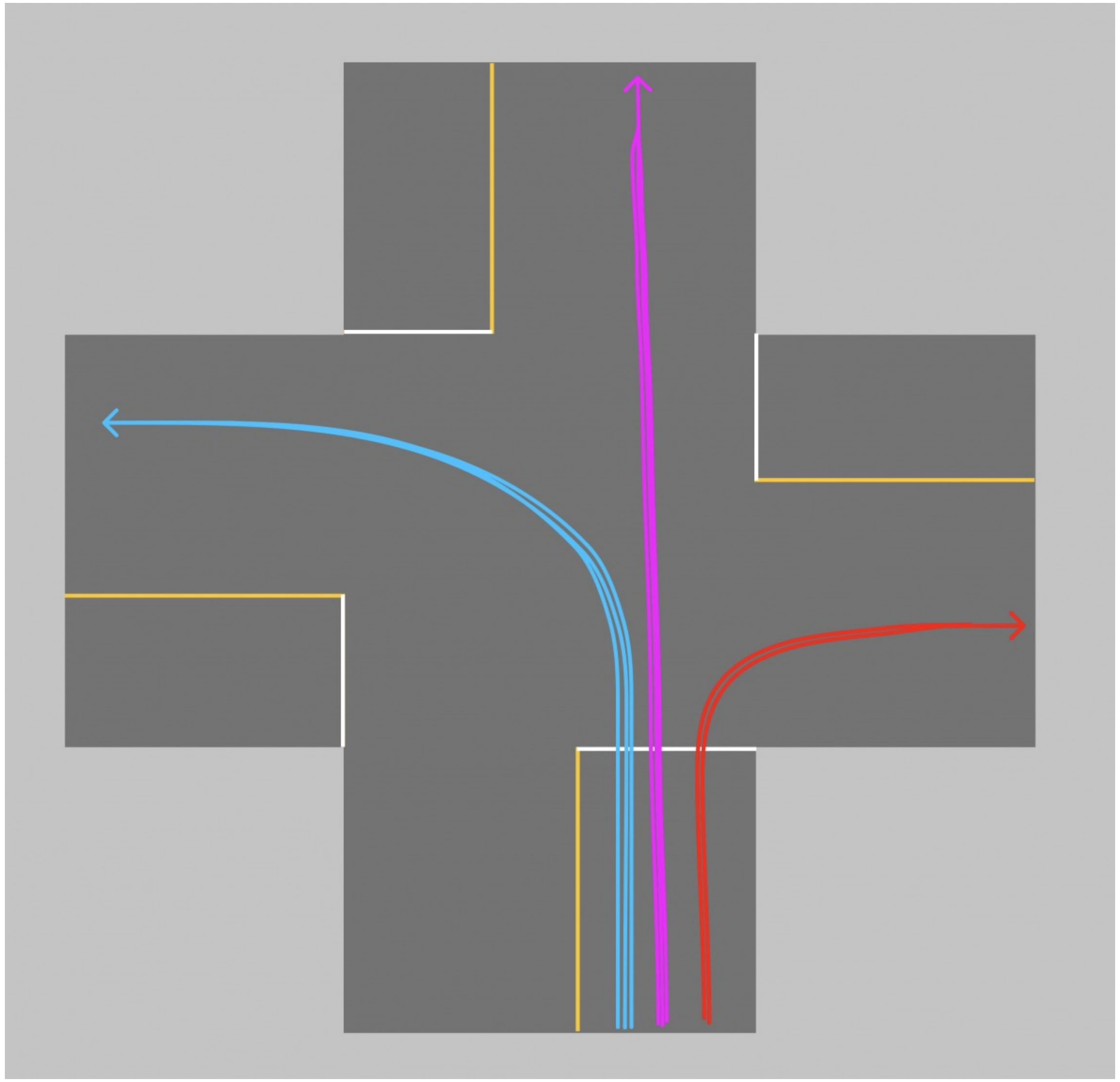
Path Planning | Predictions

- Predict what each element of environment will do
  - A few seconds in the future
- E.g.: pedestrian will move (and direction), traffic sign remains still

- Multiple Approaches
  1. **All possible trajectories** for each possible situation
  2. **Machine learning** to establish similarity with training data
  3. **Model-based** approach

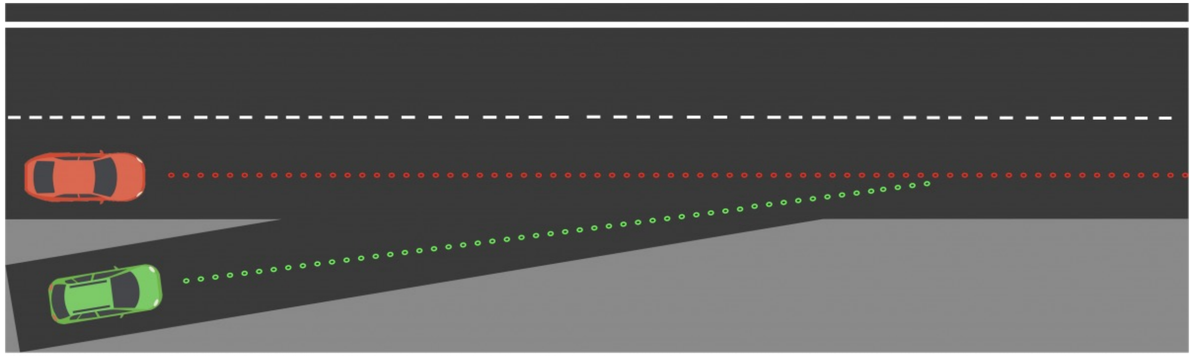
Path Planning | Machine-Learning

- **Training** phase:
  - gather massive history of vehicles and paths
  - Hundreds of vehicles, different actions at intersection
- **Unsupervised** learning
  - Clustering algorithms
  - Each cluster a typical trajectory for vehicle
- More driving leads to more data
  - Past behavior can affect current decisions



Path Planning | Model-based

Imagine **possible choices** for vehicle



- Implements **feasibility** of trajectory
- Eliminates **Impossible Behaviors**
- Focus on what's **possible**, not on past

Four choices for the other car:

1. speed up
2. slow down
3. constant speed
4. change lanes

Each has a **probability** that **changes with observations**

Sensors work in real-time

Path Planning | Decision Making

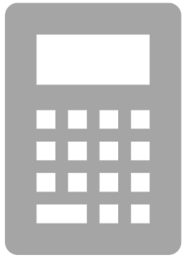
- With estimate of future environment, make a **decision**
  - Brake if obstacle detected?
  - Accelerate or change lanes?
- Environment Classification
  - Highway vs parking lot?
  - Safety, feasibility, efficiency, legality, passenger comfort
- **Finite State Machines**

Path Planning | Finite State Machines

Define states of a car

E.g., on highway, options:

stay in lane, change to left lane, overtake a car



Cost functions define choice of state

Computed (independently) for each possible scenario

Added up ➔ lowest cost wins

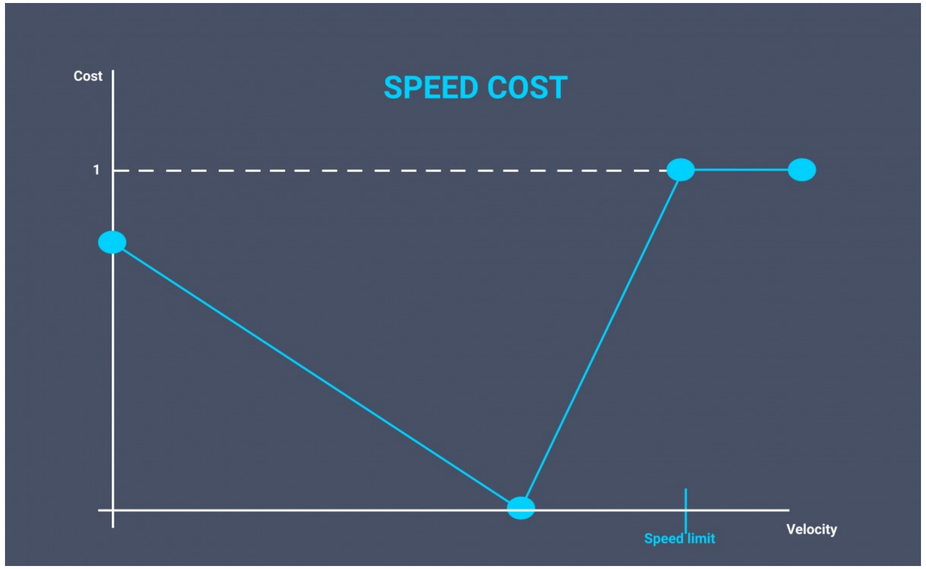
How to **define** cost?

Path Planning | Finite State Machines | Costs

feasibility cost
security cost
legal cost
speed cost

$$\text{Total Cost} = F_c * 5 + S_c * 4 + L_c * 3 + C_C * 2 + S_c * 1$$

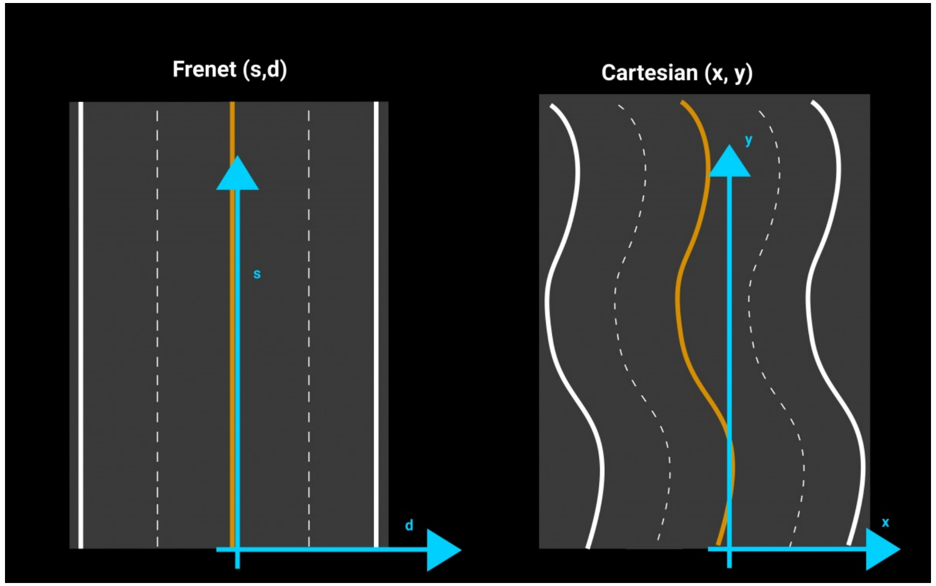
comfort cost



Path Planning | Trajectory Generation

- Typically use **a Frenet coordinate system**, not Cartesian

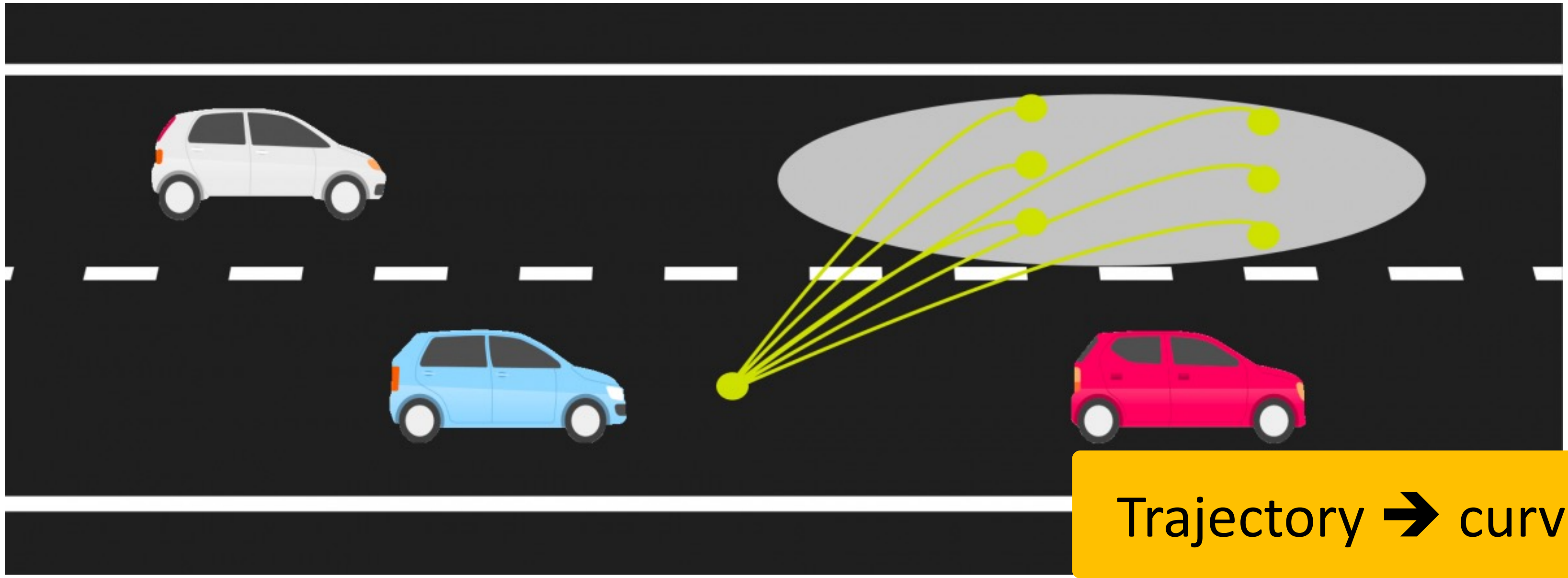
advance relative to track ← (s, d) → distance to center of lane



- After decision (e.g., overtake), algorithm **generates several trajectories**

Path Planning | Trajectories

- Choose best one based on criteria
  - Feasibility, safety, legality, efficiency, comfort



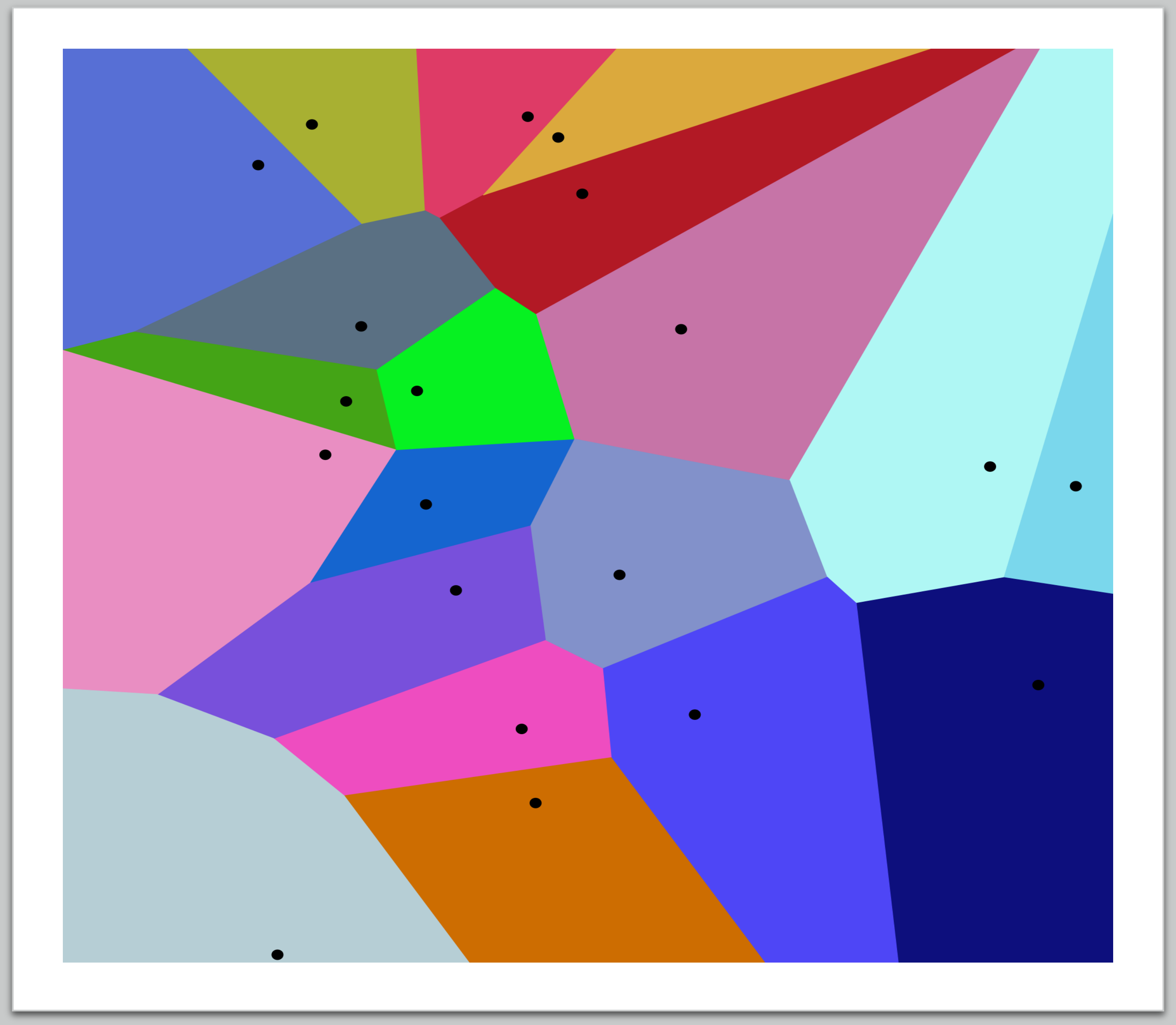
Trajectory ➔ curve through waypoints

- **Polynomial** that passes through waypoints
  - Waypoints ➔ longitudinal distance, lateral distance, moment of passing

Path Planning Algorithms

Higher-order planning

1. Voronoi Diagrams

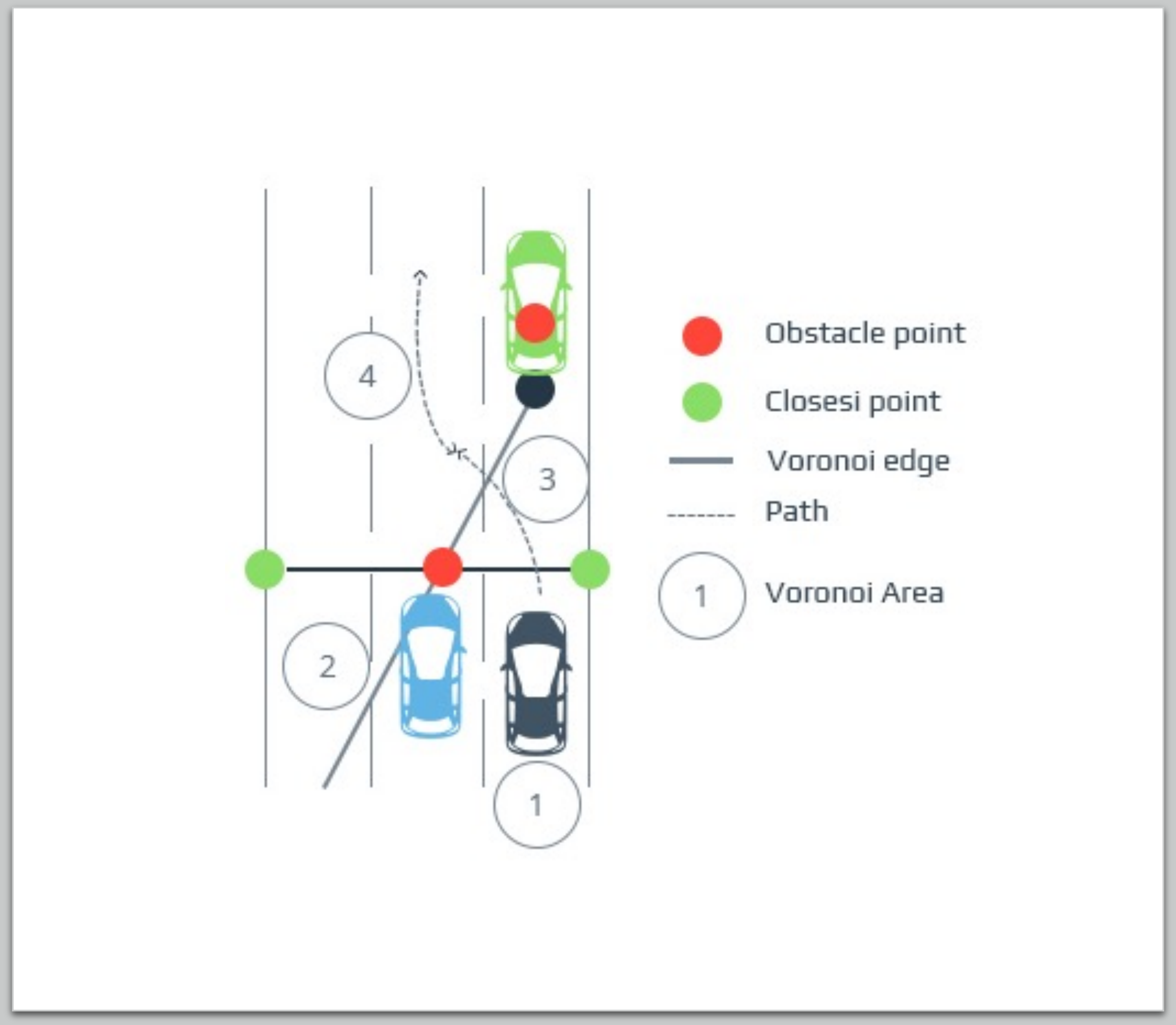


Path Planning Algorithms

Higher-order planning

Voronoi Diagrams

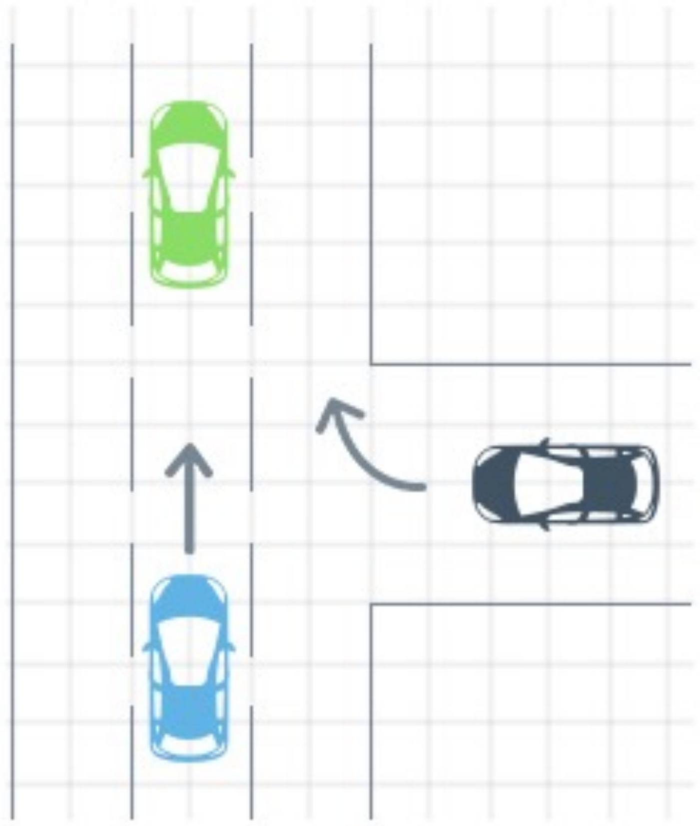
- Generates paths that **maximize distance** between vehicle and surrounding obstacles



Path Planning Algorithms

2. Occupancy Grid

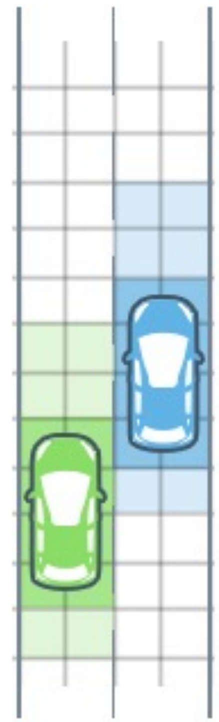
- Similar to Voronoi diagram
- Risk and feasibility computed using obstacles and lane/road boundaries



Path Planning Algorithms

3. Cost Maps

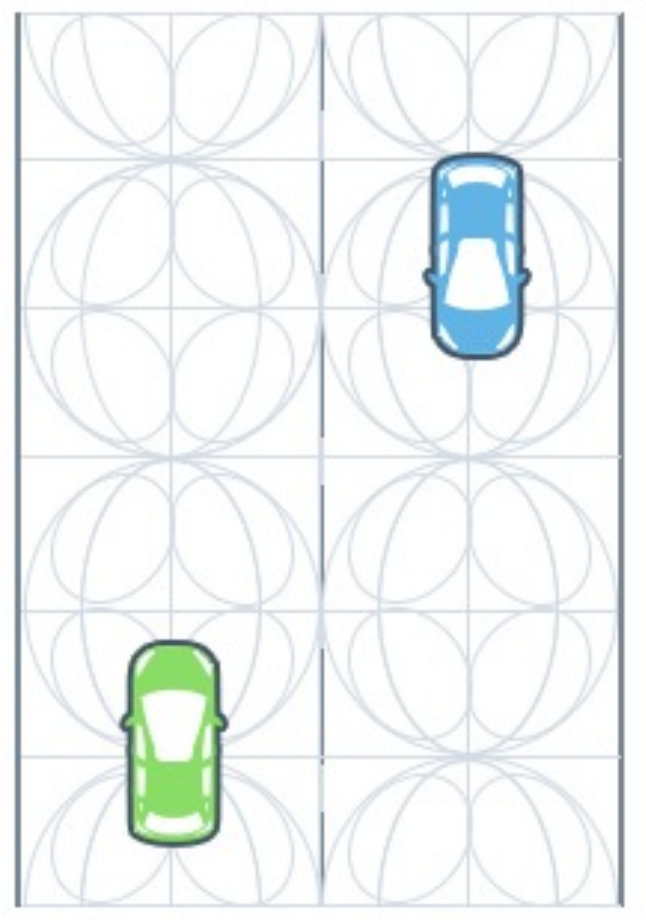
- Similar to occupancy grid
- Higher cost cells get more intense representation on map



Path Planning Algorithms

4. State Lattices

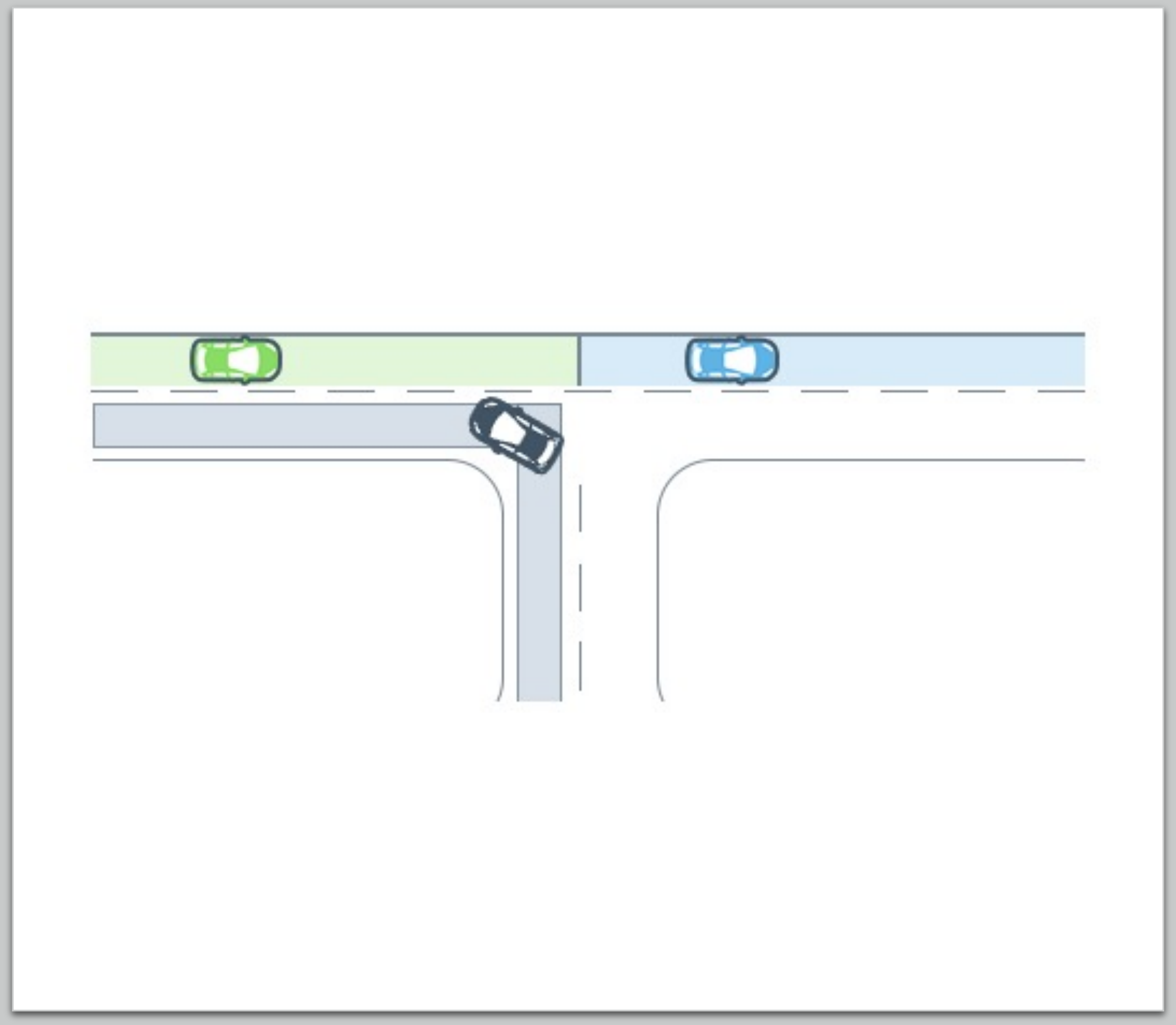
- Generalization of grids
- Grids built using repetition of rectangles or squares that discretize continuous space
- **Lattices** are constructed using regularly repeating primitive paths that connect possible states



Path Planning Algorithms

5. Driving corridors

- Recreates continuous collision-free spaces bounded by lanes and other obstacles
- Use data from maps and SLAM



Path Planning | Higher-order Decision Making

- Moral Machines
- Self driving car mindmap

References

- Path planning for self driving cars:

https://www.thinkautonomous.ai/blog/?p=path-planning-for-self-driving-cars

- Path planning with some discussion about algorithm classes

https://intellias.com/path-planning-for-autonomous-vehicles-with-hyperloop-option/

- Video that explains the self-driving car mind map:

https://www.thinkautonomous.ai/the-self-driving-car-engineer-mindmap/

- A* search algorithm

https://www.youtube.com/watch?v=ySN5Wnu88nE