Autonomous Vehicle Planning and Control

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What’s Autonomous Vehicle?

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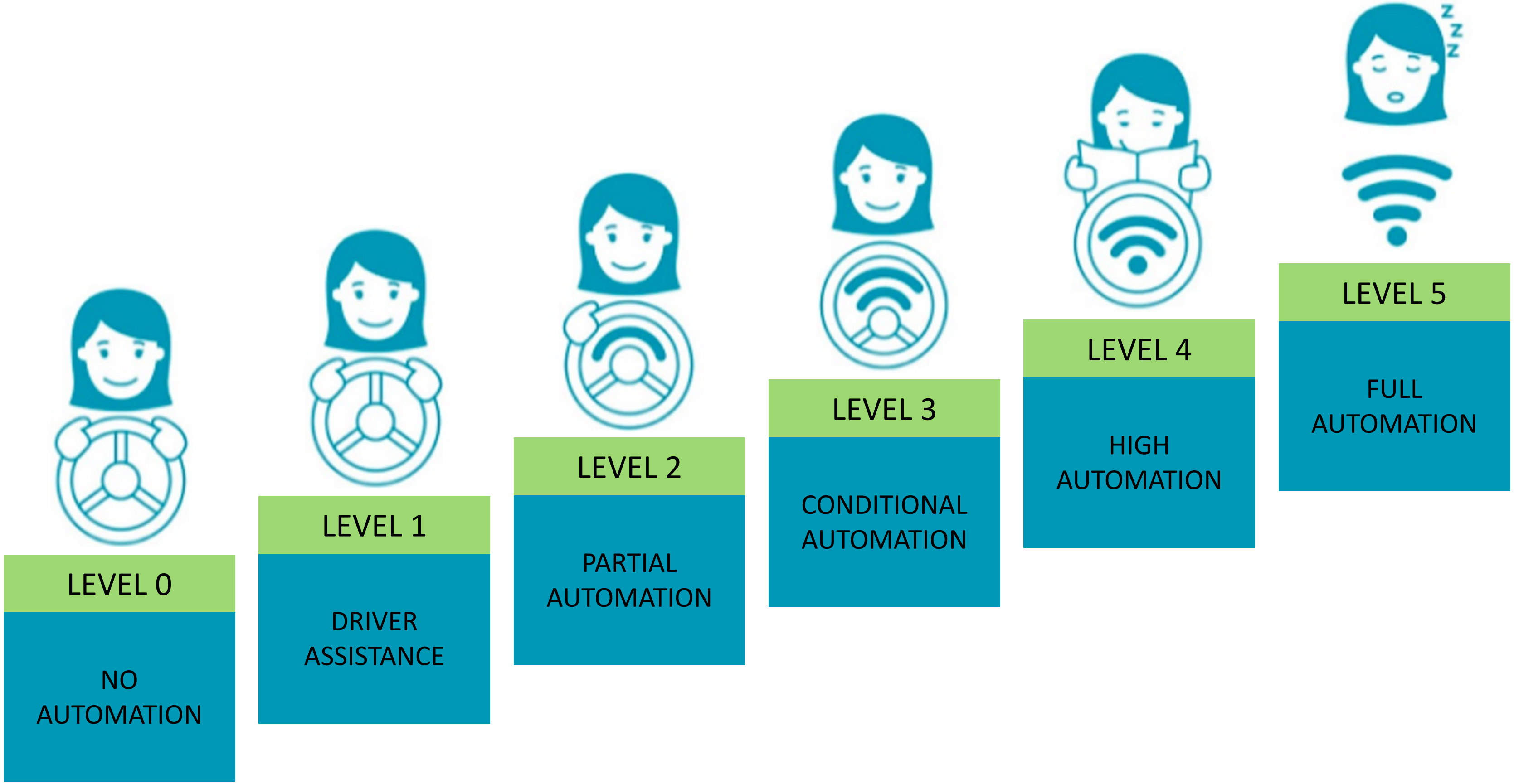
What are the different levels in Autonomous Vehicle?

SAE autonomous level

Level	Short name	Details and example product
Level 0	No control	The automated system issues warnings and may momentarily intervene but has no sustained vehicle control.
Level 1	Hands on	The driver and the automated system share control of the vehicle. Example: Cruise control, ACC, LKA
Level 2	Hands off	The automated system takes full control of the vehicle: accelerating, braking, and steering. The driver must monitor the driving and be prepared to intervene immediately at any time if the automated system fails to respond properly. Example: "Super-Cruise" in the Cadillac CT6 by General Motors or Ford's F-150 BlueCruise.
Level 3	Eye off	The driver can safely turn their attention away from the driving tasks, e.g. the driver can text or watch a film.
Level 4	Mind off	self-driving is supported only in limited spatial areas (geofenced) or under special circumstances.
Level 5	Fully auto	No human intervention is required at all. An example would be a robotic vehicle that works on all kinds of surfaces, all over the world, all year around, in all weather conditions.

SAE autonomous level



SAE autonomous level

Level 3: The driver can safely turn their attention away from the driving tasks, e.g. the driver can text or watch a film. Like co-driver that will alert you in an orderly fashion when it is your turn to drive.

Achieved: The vehicle will handle situations that call for an immediate response, like emergency braking.

Limitation: The driver must still be prepared to intervene within some limited time, specified by the manufacturer, when called upon by the vehicle to do so.

Example: a Traffic Jam Pilot

SAE autonomous level

Level 4: the driver may safely go to sleep or leave the driver's seat.

Achieved: As level 3, but no driver attention is ever required for safety under certain condition.

Limitation: self-driving is supported only in limited spatial areas (geofenced) or under special circumstances. Outside of these areas or circumstances, the vehicle must be able to safely abort the trip, e.g. slow down and park the car, if the driver does not retake control.

Example: a robotic taxi or a robotic delivery service that covers selected locations in an area, at a specific time and quantities

LEVEL 4

HIGH AUTOMATION

SAE autonomous level

Level 5: No limitation!

This is the dream of autonomous driving!

Ultimate GOAL!

LEVEL 5

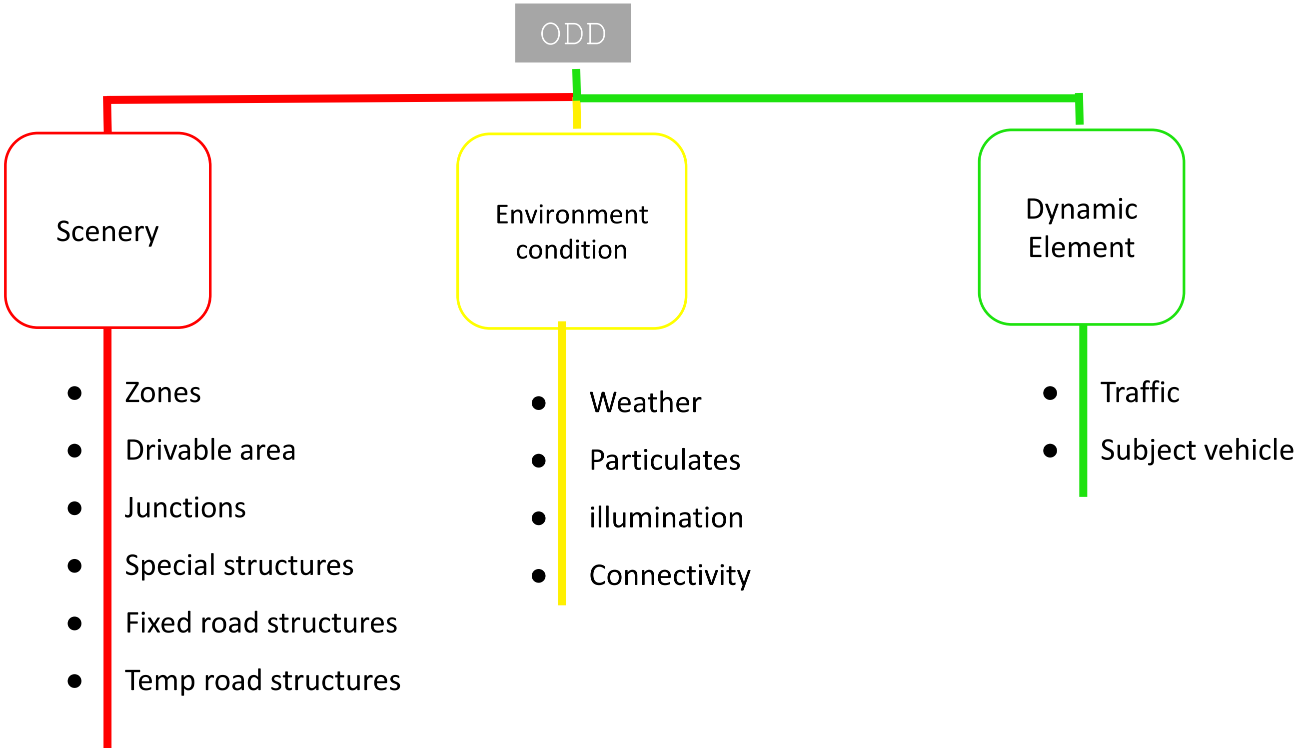
FULL AUTOMATION

Operational Design Domain (ODD)

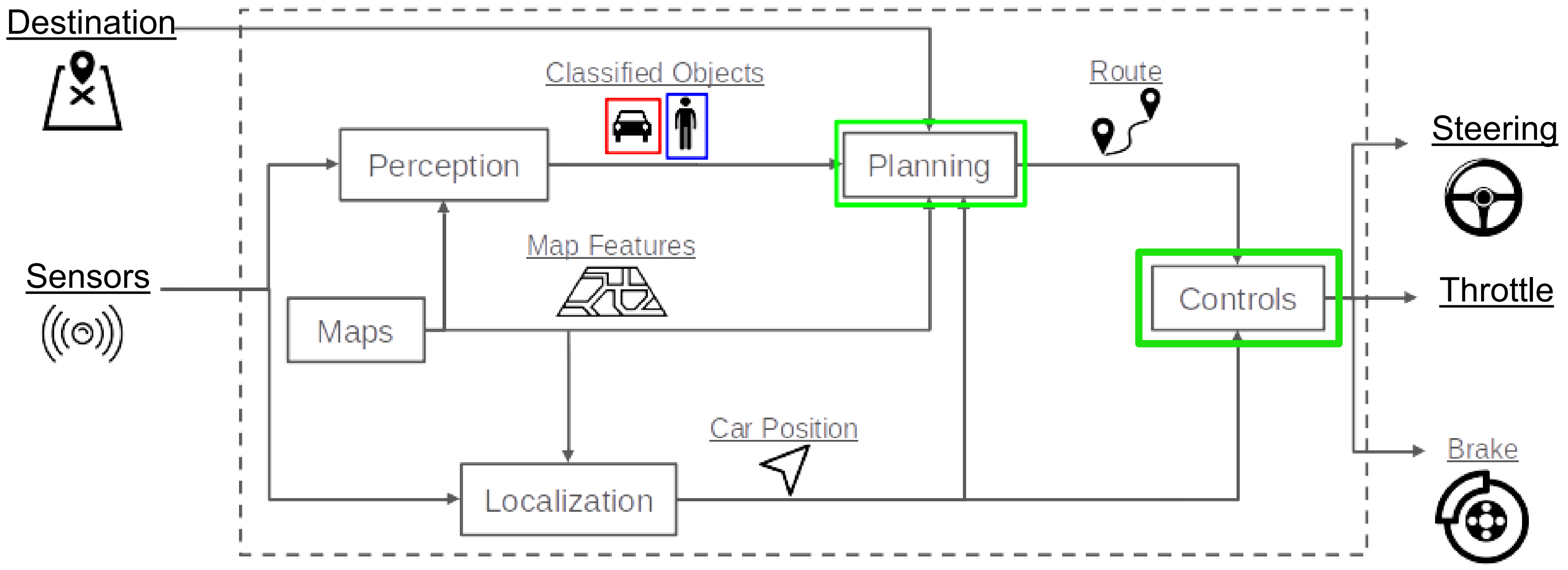
“Operation conditions under which a given driving automation system or feature thereof is specifically designed to function, including, but not limited to, environmental, geographical, and time-of-day restrictions, and/or the requisite presence or absence of certain traffic or roadway characteristics“

- SAE J3016 (2018)

Operational Design Domain (ODD)



General Architecture of Autonomous Vehicle



Localization Key components in Autonomous Vehicle

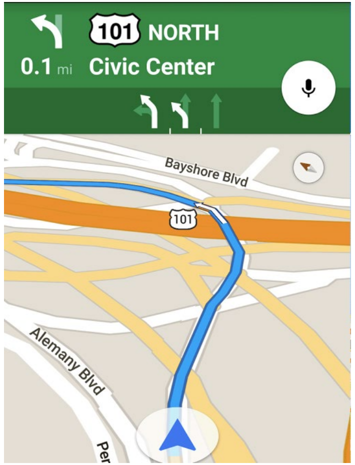
Goal: Estimates position and orientation of car relative to map; Used by Planner/Controller to follow path

Input:

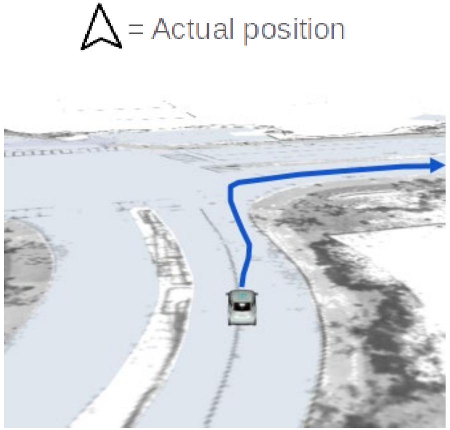
- Map,
- GPS (inaccurate),
- Motion sensors: odometry: (speedometer, IMU) (error accumulation),
- LiDAR (Particle and Kalman filters),

Output:

- Vehicle position/orientation.



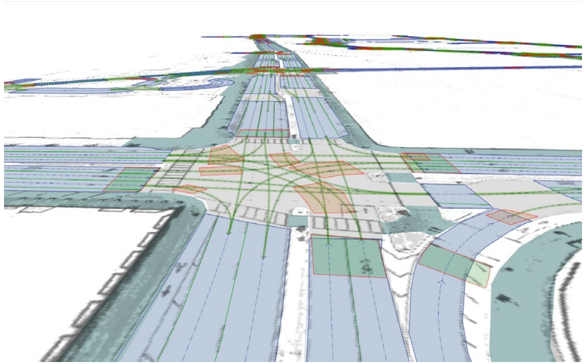
Bad localization = reroute/ replan



Bad localization = swerve into other objects

Mapping/HD map Key components in Autonomous Vehicle

Goal: Give planer, perception location based Pre-information:



Input: Map annotation

Output:

Main object types:

- Generic Area
- Intersections
- Road block (and RB connectors)
- Lane (and road/lane dividers, lane edges)
- Baseline path

"Add-on" objects types:

- Crosswalk
- Stop line (various types)
- Precedence Areas
- Traffic Lights
- Walkways
- Parking Area
- Slow zones*

HD map issues: expensive (annotation and maintenance)

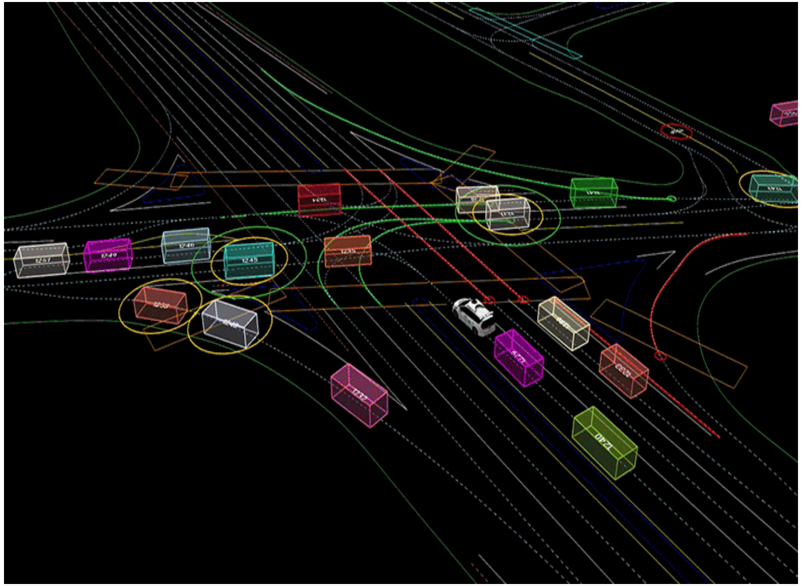
Perception Key components in Autonomous Vehicle

Goal: Understand the world around the vehicle, and classify objects in the environment;

Input:

(Map), Sensor data:

- LiDAR
- Radar
- Camera ..



Output:

Information about the objects in the environment: position, classification, speed and other information.

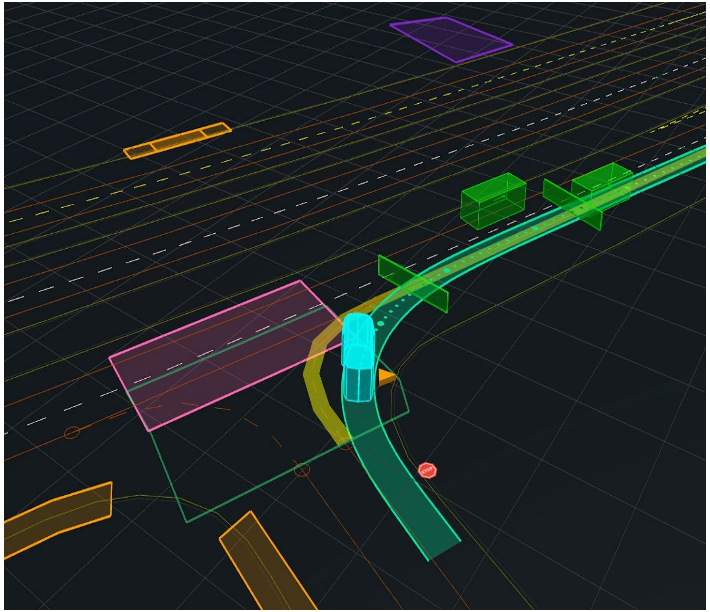
Prediction Key components in Autonomous Vehicle

Goal: A system attempts to understand the intents of agents in the environment.

Input:

output- Information about the objects in the environment:

pos, classification and speed;



Output:

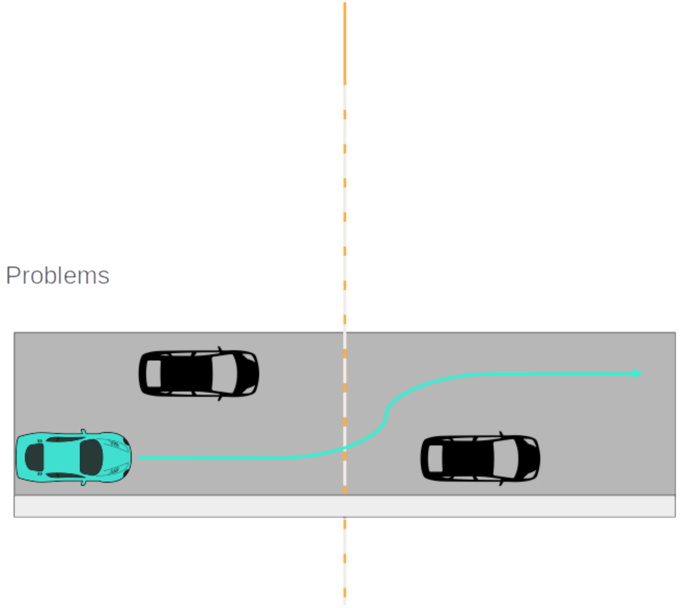
Future behaviors for agents; (trajectory + probabilities)

Planner Key components in Autonomous Vehicle

Goal: Provide the controller the safest, correct, predictable and comfortable navigation.

Input:

- Perception: provide us the perceived actual dynamic state of the environment
- Map: provide the prior information
- Localization: provide the current state estimate of the ego vehicle



Output:

- Controller: provide a feasible path and bounds (lateral and longitudinal) for the vehicle to track and stay within.
- Perception: sometimes provide the area affecting our assessment of behaviors.

Controller Key components in Autonomous Vehicle

Goal: To accurately execute the Planner's requested plan by understanding the vehicle's dynamic state, and actuating it (e.g., throttle, brake, steering, gear, ...). Optimize for passenger comfort within the bounds of the Planner's requested plan.

Input:

- Planner
- Localization

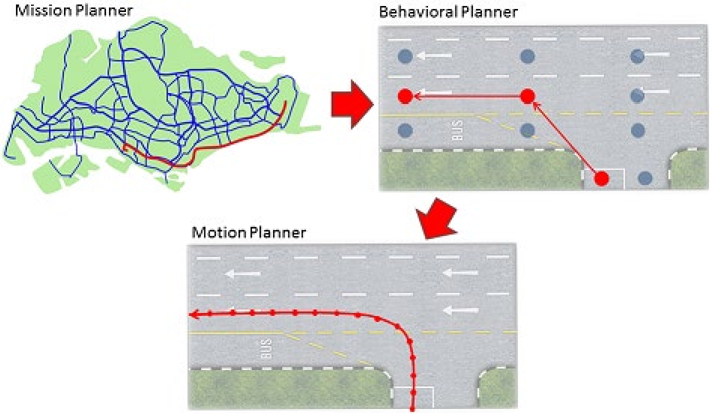
Output:

Trajectory, steering, speed or throttle/brake

What’s PnC (Planning and Control) in Autonomous Vehicle?

Basic Planning Control Architecture

- Classical decompose approaches:
    - Breakdown into long, medium, short term horizons
    - Breakdown of spatial path vs velocity planning
    - Homotopy search vs optimization



- Common DARPA urban challenge 2007 structure

Mission/ Route Planning → Behavior Planner/ Decision making → Motion planning/ Local planner → Motion Control → Vehicle

Mission/Route Planning

Goal: Find preferred route (or routes) over the road network

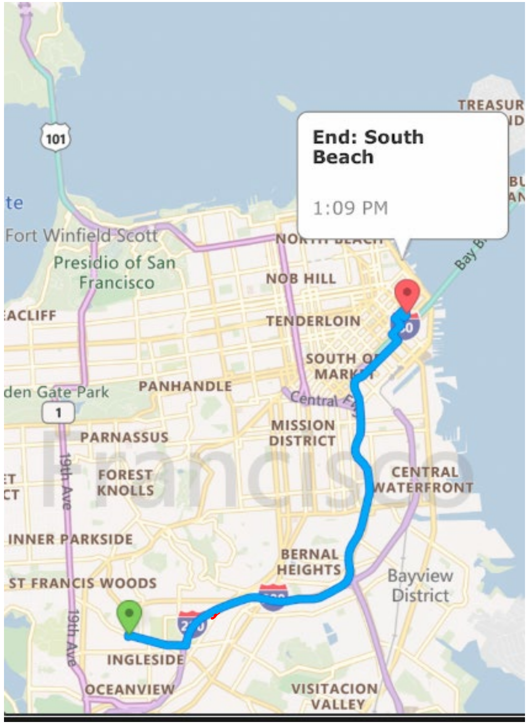
Input: Start, goal (pick-up/drop-off location), graph, cost function

Output: sequence of lanes/road segments (route)

Common Tech Approach: Graph search (Dijkstra, A*, et al)

Many algorithms shared with local planning methods.

- could plan for lane/connector route rather than laneGroup/intersection
- Cost function could penalize lane changes, turns (left or right), narrow lanes, etc.



Mission/ Route Planning → Behavior Planner/ Decision making → Motion planning/ Local planner → Motion Control → Vehicle

Behavioral Decision Making

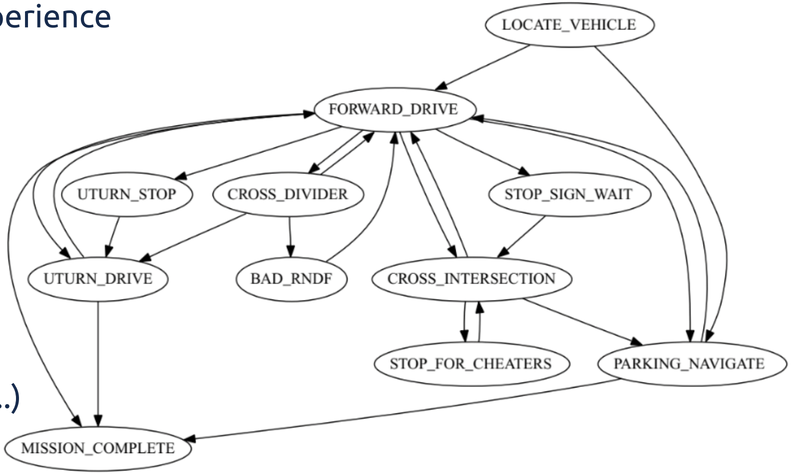
Goal: Determine high level actions: Eg. change lane now or later, stick to left or right lane, stop/go for crosswalk intersection

Input: Planner, localization, Map, Traffic rules, human experience

Output: Planner high level decision

Common Tech Approach:

- Finite State Machine
- Rule based approach: Minimum Violation Planning
- Formal Methods (STL, LTL, process algebra, µ-calculus,...)
- Markov Decision Process



Mission/ Route Planning → Behavior Planner/ Decision making → Motion planning/ Local planner → Motion Control → Vehicle

Motion planning/Local Planning

Goal: Find higher precision “good” (near optimal wrt cost function) path to execute

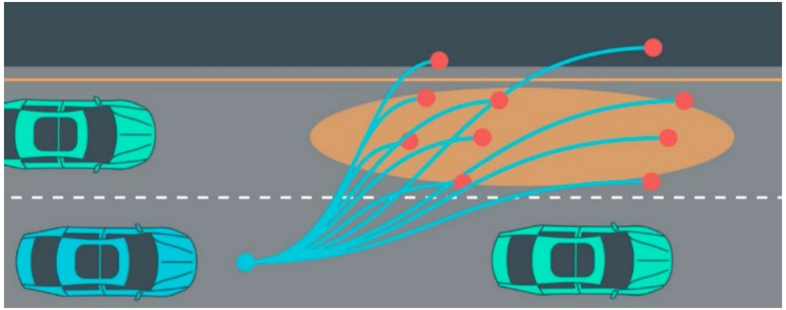
Input: Perception, Map, localization

Output: Planed reference path, Trajectory (with speed), Homotopy Space

Common Tech Approach:

- Searching based Methods
- Stochastic Sampling Methods
- MPC

Visibility Graph
(combinatorial)

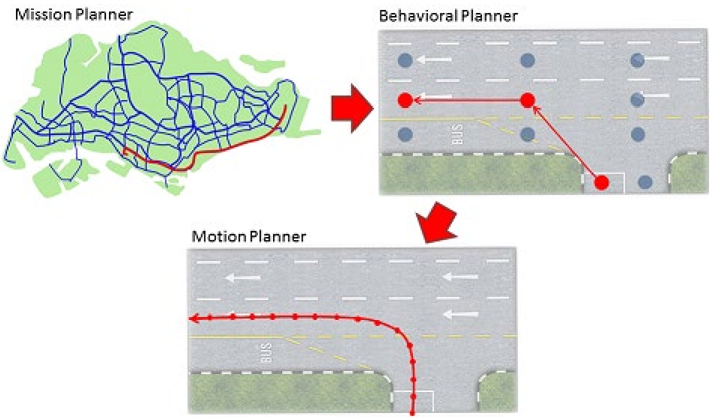


Mission/ Route Planning → Behavior Planner/ Decision making → Motion planning/ Local planner → Motion Control → Vehicle

Basic Planning Architecture

3 Tier Plan: Mission, Behavior, Local Planner
(Common used in DARPA Urban Challenge 2007).

- Local Planner – Choose finer precision paths, actions to reach goal and avoid obstacles
- Behavioral Planner – Decision making to interact with others and follow rules (discrete choices)
- Mission Planner – Set high level goals, i.e., pick-up/drop-off tasks, route choice



Mission/ Route Planning → Behavior Planner/ Decision making → Motion planning/ Local planner → Motion Control → Vehicle

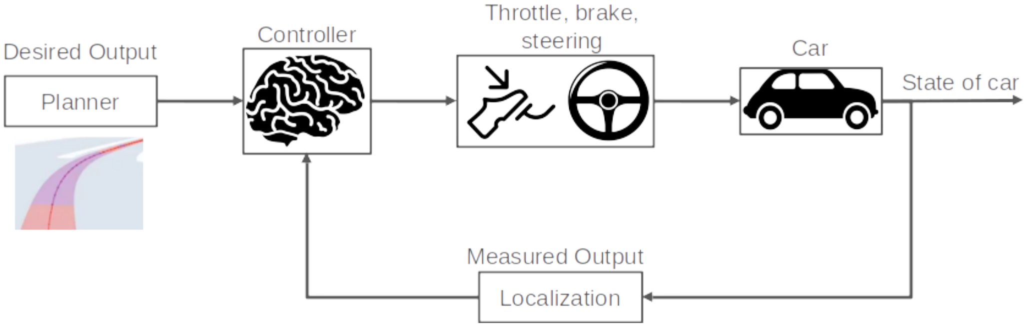
Motion Control

Goal: Track the “best“ Trajectory

Input: Planner, localization

Output: Steering, Throttle, Brake

Common Tech Approach: PID, Stanley, Pure pursuit, LQR, MPC



Mission/ Route Planning → Behavior Planner/ Decision making → Motion planning/ Local planner → Motion Control → Vehicle

Course structure

Course Structure

Philosophy of course design

From developer point of view (low level to high level);

a. How to control the vehicle;
b. How to generate an optimal trajectory;
c. How to generate a path
d. How to choose the best route

- Philosophy: from control to planning
    a. Good control is the foundation;
    b. Get better understanding of vehicle;

Course Structure

Structure of this course: Control

- Model:
  - Vehicle Geometric model
  - Linear kinematic/dynamic vehicle model
  - Nonlinear bicycle vehicle model
- Control theory
  - Classical control theory
  - Modern control theory
- Actual Application
  - Cruise control; ACC (Adaptive cruise control); ABS(Anti-lock brake system)…
  - Trajectory tracking
  - Trajectory optimization

Course Structure

Structure of this course: Planning

Introduce the problem first, then we will explain the basic theory. And how to use the algorithm to solve the actual problem.

3 Tier Mission, Behavior, Local Planner (Common used in DARPA Urban Challenge 2007).

- Local Planner – Choose finer precision paths, actions to reach goal and avoid obstacles
- Behavioral Planner – Decision making to interact with others and follow rules (discrete choices)
- Mission Planner – Set high level goals, i.e., pick-up/drop-off tasks, route choice

Course Structure

Structure of this course: sessions

1. General architecture of autonomous vehicle planning control
2. Vehicle Longitudinal control
3. Vehicle Lateral Control based on Vehicle Geometric Model
4. Vehicle Lateral Control based on Linear Vehicle Dynamics Model
5. Vehicle motion control based on MPC
6. Local Motion Planning
7. Behavior planning
8. Mission Planning

Course Structure

Structure of this course: Project

1. ACC design in Vehicle Longitudinal control
2. Trajectory Tracking by using Vehicle Geometric Model
3. Trajectory Tracking by using Linear Vehicle Dynamics Model
4. Trajectory Tracking by using nonlinear Vehicle Dynamics Mode + different method comparison
5. Path planning in the pre-defined scenarios
6. Route Planning in the pre-defined scenarios

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Thanks for Listening!