# Hierarchical Motion Planning

Course 4, Module 1, Lesson 4

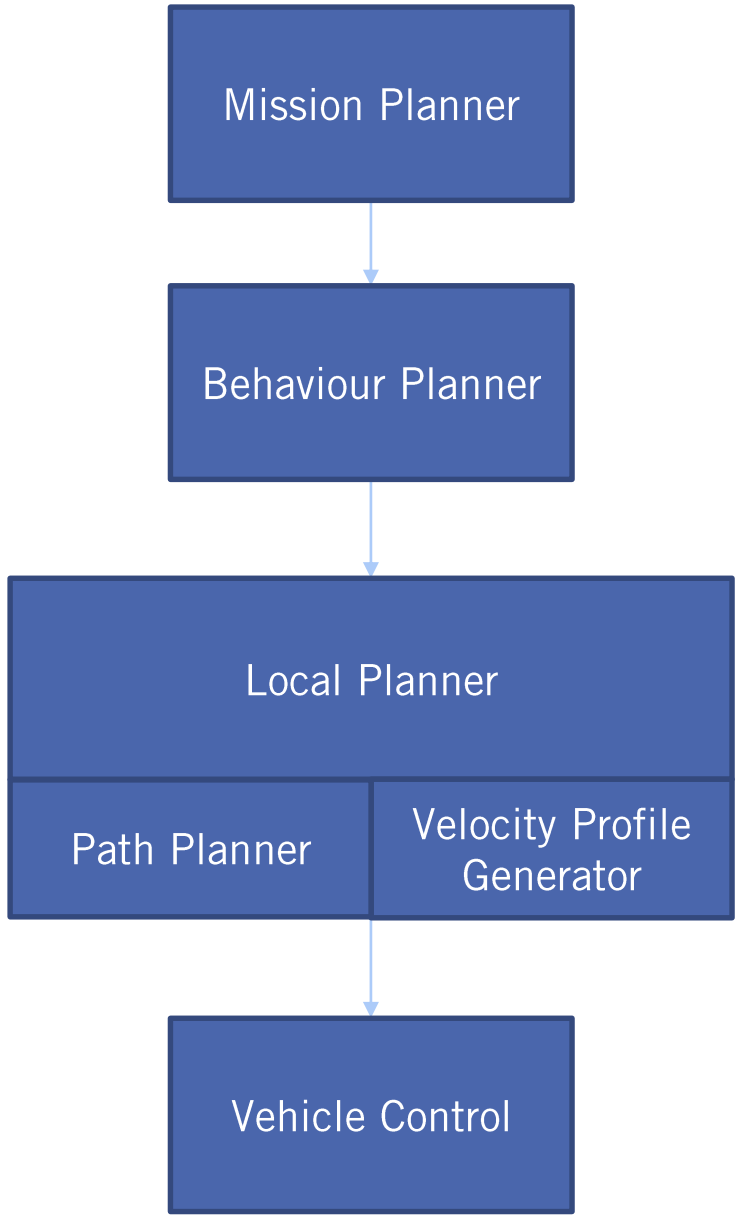
UNIVERSITY OF TORONTO
FACULTY OF APPLIED SCIENCE & ENGINEERING

# Learning Objectives

- Define the scope of the mission, behavior and local planner sub-problems
- Identify methods for solving each sub-problem
- Understand the reasons for the use of a hierarchical structure for motion planning

# Recall: Hierarchical Planner

- Motion planning broken into hierarchy of subproblems
- Mission planner is highest level, focuses on map-level navigation
- Behavioural planner focuses on other agents, rules of the road, driving behaviours
- Local planner focuses on generating feasible, collision-free paths



# Heirarchical Planning on the Autonomoose

# Mission Planner

map-level

- Highest level planner
- Focuses on autonomous driving mission
  - Navigate to destination at the map level
- Abstract away lower level details
- Can be solved with graph-based methods (Dijkstra's, A*)

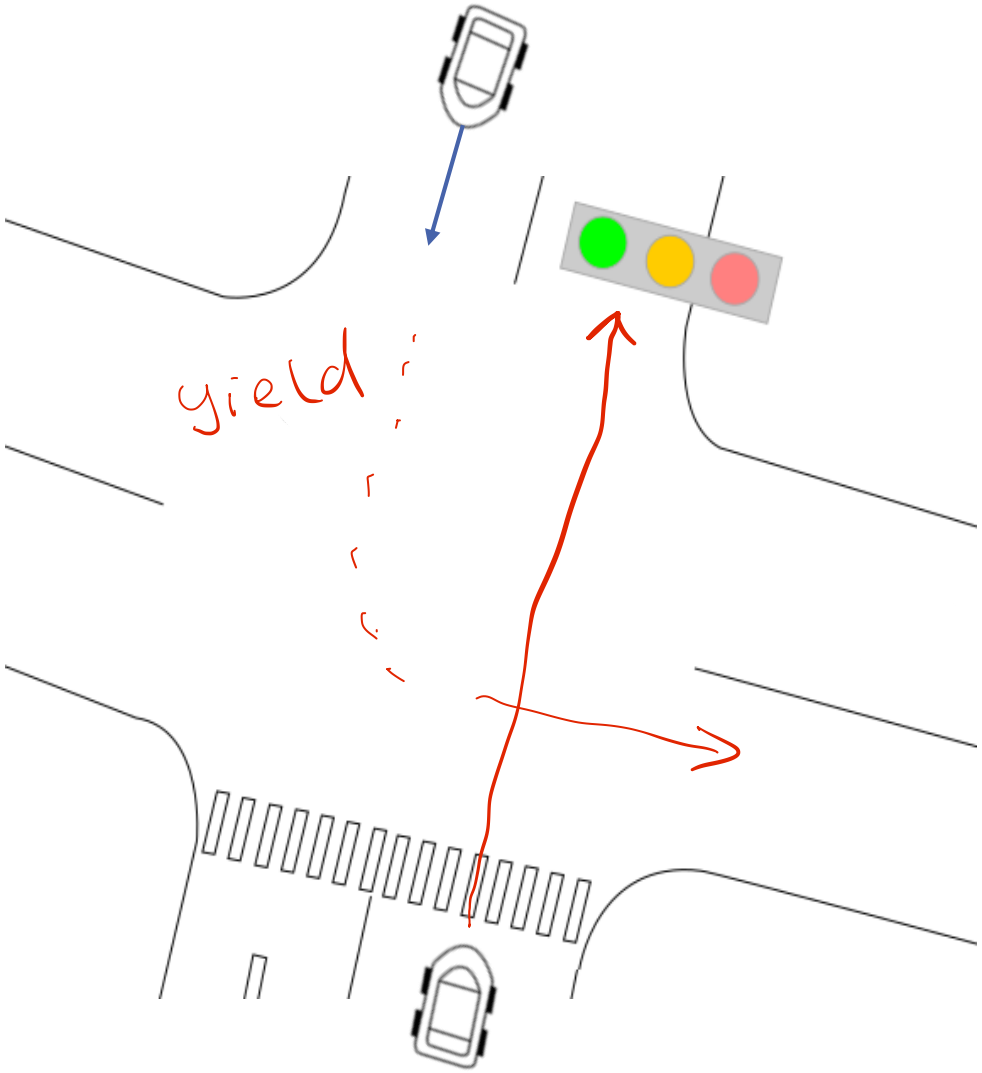
ex: obstacles & regulatory elements

shortest path

or time (more complex)

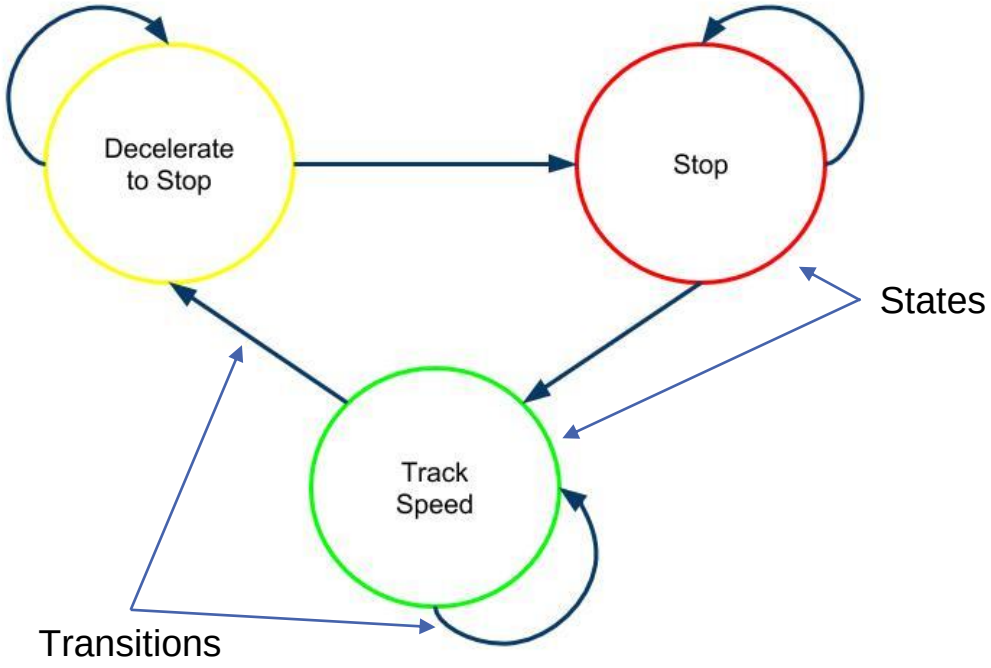
# Behavioural Planner

- Behavioural planner decides when it is safe to proceed
- Takes pedestrians, vehicles, cyclists into consideration
- Also looks at regulatory elements, such as traffic lights and stop signs



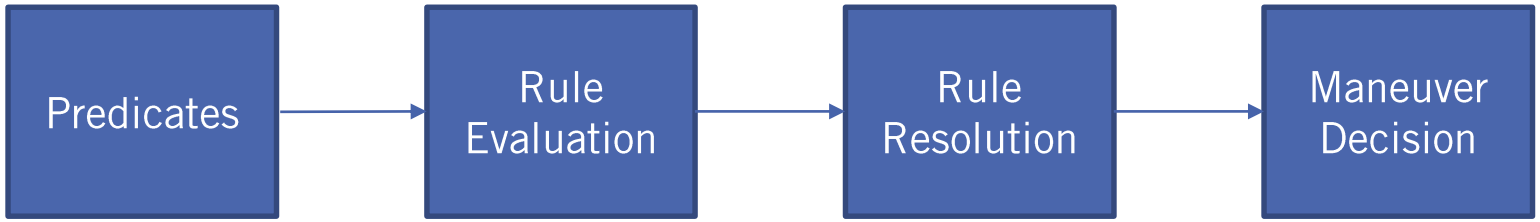
# Behavioural Planner - Finite State Machines

- Composed of states and transitions
  - States are based on perception of surroundings
  - Transitions are based on inputs to the driving scenario
    - e.g. stop lights changing colour
- FSM is memoryless
  - Transitions only depend on input and current state, and not on past state sequence



# Behavioural Planner - Rule-based System

- Rule-based systems use a hierarchy of rules to determine output behaviour
- Rules are evaluated based on logical predicates
  - Higher priority rules have precedence




- Example scenario with two rules
  - green light ∧ intersection → drive straight
  - pedestrian ∧ driving straight → emergency stop

higher priority than

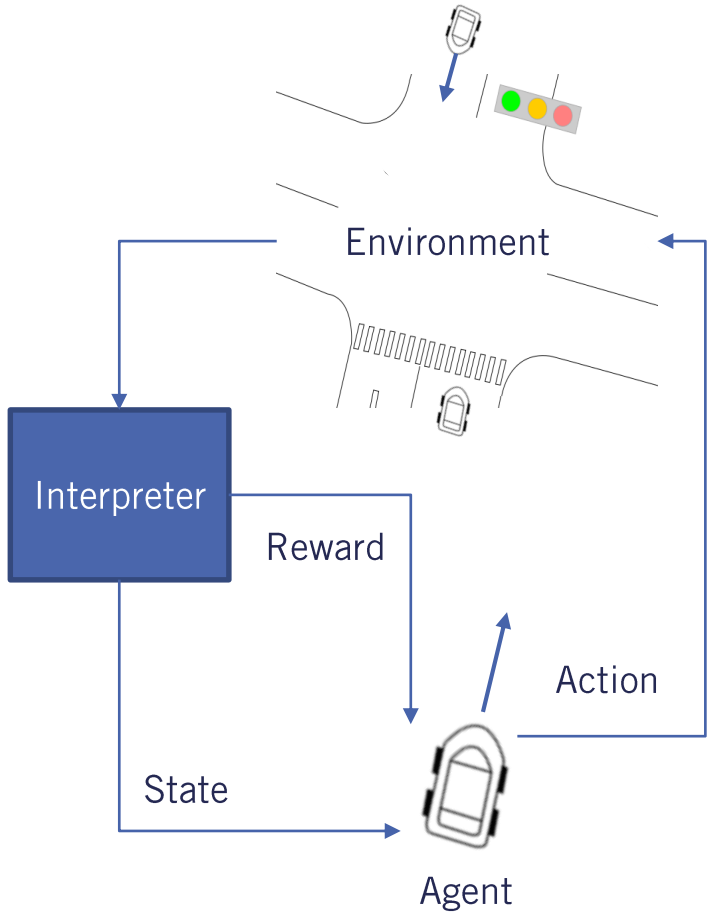
# Behavioural Planning - Reinforcement Learning

$$R = \sum_{t=0}^{\infty} \gamma^t R_{a_t}(s_t, s_{t+1})$$

Total Reward

Discount factor
$\gamma \in [0,1)$

Stage reward
given action, $a_t$



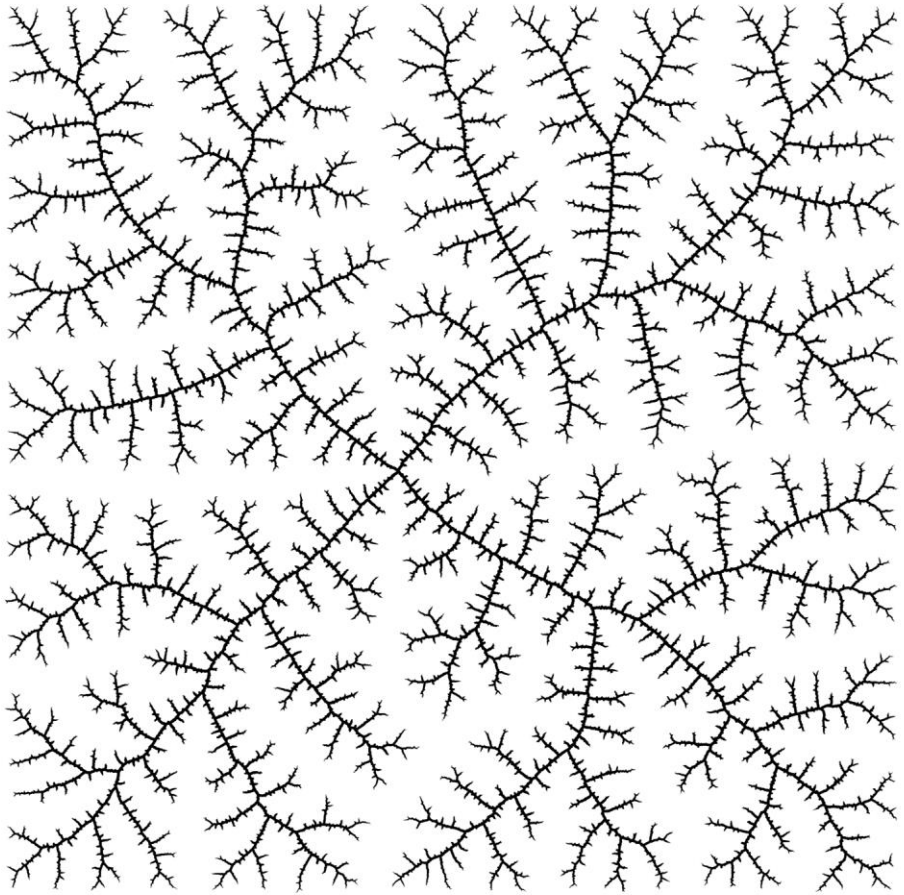
# Local Planner

- Local planning generates feasible, collision-free paths and comfortable velocity profiles

- Decomposed into path planning and velocity profile generation

# Sampling-based Planners

- Randomly sample the control inputs to quickly explore the workspace
- Collision-checking is performed as new points are added to the explored space
- Often very fast, but can generate poor-quality paths



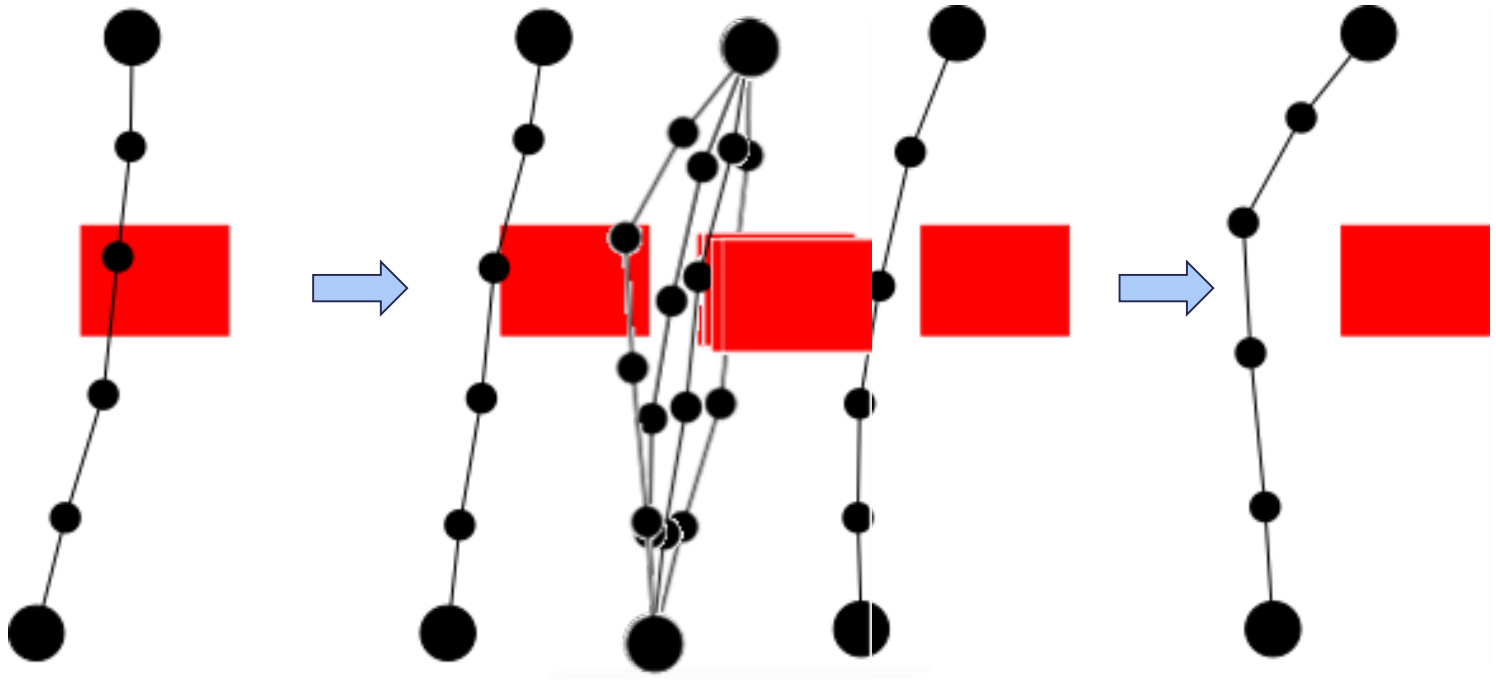
Rapidly Exploring Random Tree (RRT)

# Variational Planners

- Optimize trajectory according to cost functional
  - Contains penalties for collision avoidance and robot dynamics $\min_{\delta x} J(x + \delta x)$
- Can be slower, and less likely to converge to a feasible solution

trajectory planners:
combine path planning & velocity planning into a single step

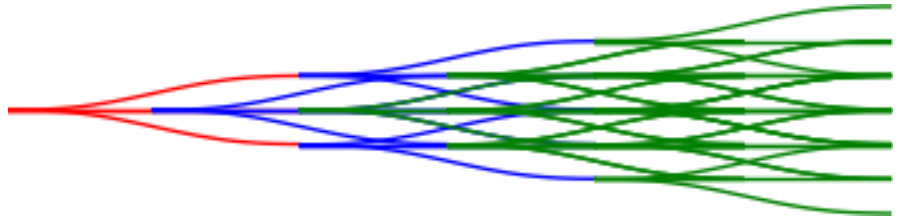
Ex: Chomp algorithm



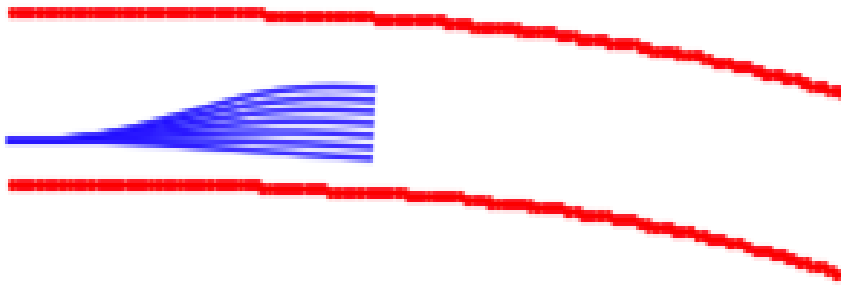
# Lattice Planners

- Constrain the search space by limiting actions available to the robot
  - Set of actions known as control set
- Layers of control actions form a graph, which can be searched using Dijkstra's or A*
- Conformal lattice planner fits the control actions to the road structure

Lattice Planner



Conformal Lattice Planner



# Velocity Profile Generation

a constrained optimization problem

- Smoothness

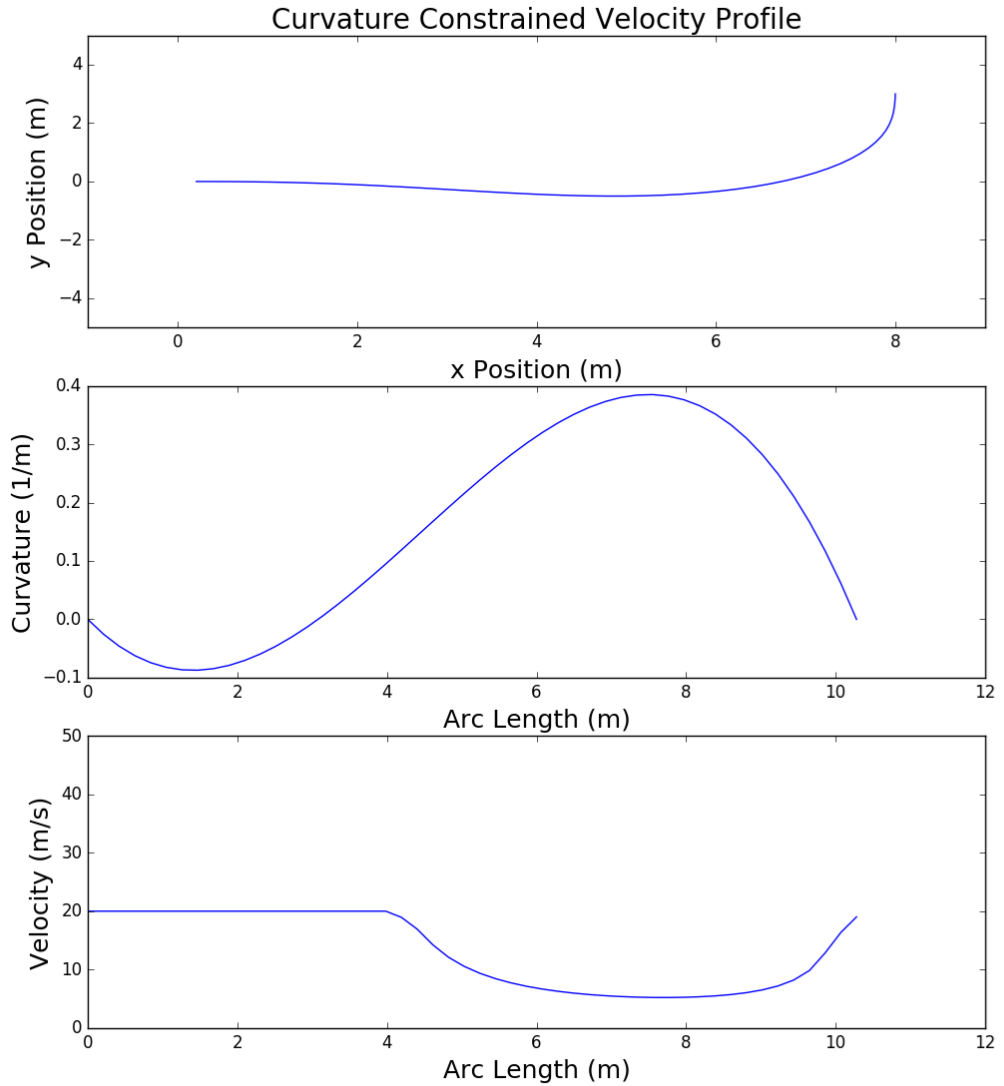
$$\int_0^{s_f} \|\ddot{x}(s)\| ds$$

- Deviation from reference

$$\int_0^{s_f} \|v(s) - v_{ref}(s)\| ds$$

- Lateral acceleration limit

$$v^2 \leq \frac{a_{lat_{max}}}{\kappa}$$



# Summary

- Discussed mission planning as a navigation problem
- Introduced the behavioural planning problem, and listed methods used for solving this problem
- Introduced various methods for conducting path planning for the local planner
- Discussed how to optimize a velocity profile for the local planner

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