



UNIVERSITÉ DE TECHNOLOGIE DE BELFORT-MONTBÉLIARD

# Planning

RO51 - Introduction to Mobile Robotics

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April 14, 2022

<https://yzrobot.github.io/>

[www.utbm.fr](http://www.utbm.fr)

# What?

- The task of coming up with a sequence of actions that will achieve a goal is called **planning**.
  - **Motion planning**: a process to find the movement steps from a starting state to a goal state.
  - **Task planning**: a process to find a series of actions taken to achieve a goal that cannot be achieved by a single action.
- Planning is a formalized procedure for decision-making.

# Why?

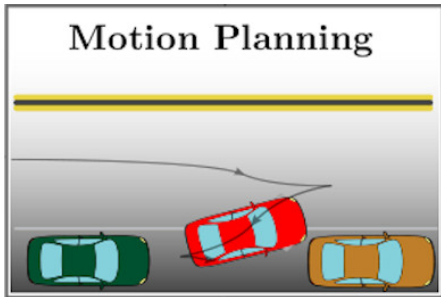
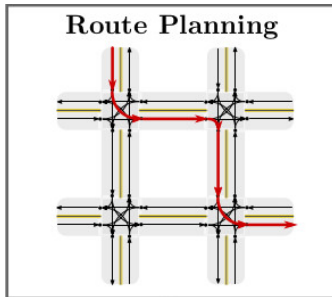
- Planning, whether for human society or the field of robotics, is an important means to achieve goals effectively.
- The essence of planning is an optimization problem.

# Motion planning

- In robotics, the motion planning problem involves producing a continuous robot motion from one configuration to another in a **configuration space** while avoiding collision with obstacles.
- Motion planning is eminently necessary for mobile robots since, by definition, a robot accomplishes tasks by moving in the real world.

# Motion planning

- Motion planning vs. Path planning:
  - **Motion Planning:** concrete, e.g. take into account the real size of the robot, kinematics and dynamics models, etc.
  - **Path planning:** abstract, e.g. treat the robot as a point, ignore its kinematics and dynamics models, etc.



# Motion planning

## Configuration space

- In classical mechanics, the parameters that define the configuration of a system are called generalized coordinates, and the space defined by these coordinates is called the **configuration space (or C-space)** of the physical system.
- In robotics, a robot configuration is a specification of the positions of all robot points relative to a fixed coordinate system, and the space of all configurations of the robot is called the **configuration space (or C-space)** of the robot.
- Simply speaking, the C-space is the space related to the structure and shape of the robot.

# Motion planning

## Configuration space

- The topology of C-space is usually not that of a Cartesian space.
- The C-space is described as a **topological manifold**.

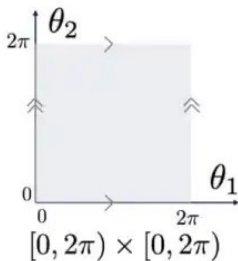


2DOF robot arm



Torus

$$C = S^1 \times S^1$$

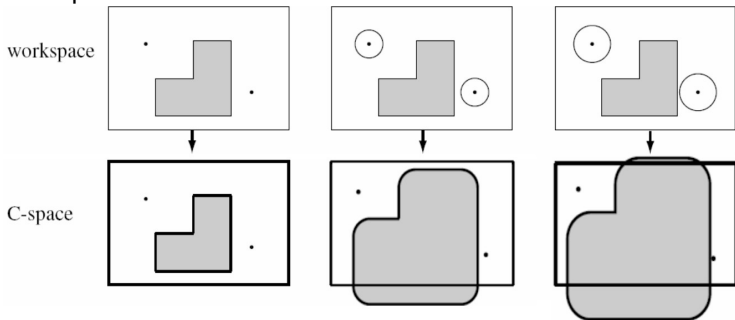


Note that the two edges with arrows are glued together.

# Motion planning

## Configuration space

- The robot and obstacle geometry is described in a 2D or 3D **workspace**, while the motion is represented as a path in **C-space**.
- Example: circular robot



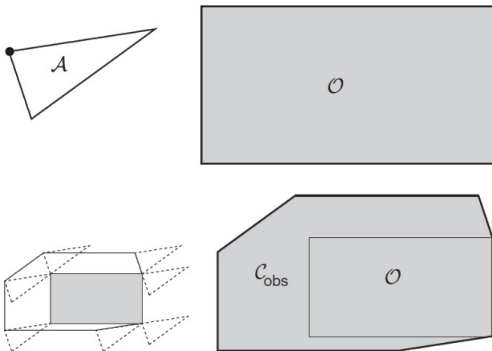
C-space is obtained by sliding the robot along the edge of the obstacle regions "blowing them up" by the robot radius.



# Motion planning

## Configuration space

- Example: polygonal robot, translation only

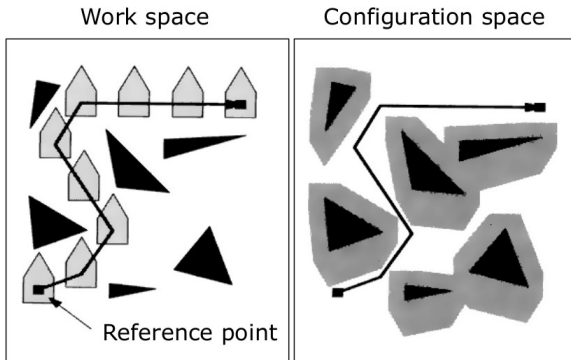


C-space is obtained by sliding the robot along the edge of the obstacle regions.

# Motion planning

## Configuration space

- Example: polygonal robot, translation only

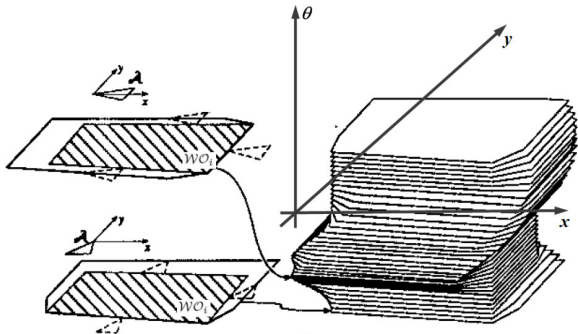


C-space is obtained by sliding the robot along the edge of the obstacle regions, and in C-Space, the robot can be represented as a point (vector).

# Motion planning

## Configuration space

- Example: polygonal robot, translation + rotation



C-space is obtained by sliding the robot along the edge of the obstacle regions in all orientations.

# Motion planning

## Configuration space

- For robots considered in 2D space, in simple terms, C-Space is the **expansion** of the workspace based on the size of the robot.
- Formally, the C-space is the special Euclidean group  $SE(2) = R^2 \times SO(2)$  (where  $SO(2)$  is the special orthogonal group of 2D rotations), and a configuration can be represented using three parameters  $(x, y, \theta)$ .
- If considering a robot in 3D space (e.g. drones), the C-space is the special Euclidean group  $SE(3) = R^3 \times SO(3)$ , and a configuration requires six parameters:  $(x, y, z)$  for translation, and Euler angles  $(\alpha, \beta, \gamma)$ .
- For a fixed-base robotic arm, the C-space (i.e. joint space) is N-dimensional, where N corresponds to the number of its joints.

# Motion planning

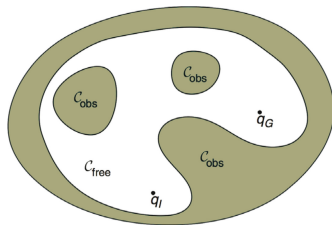
## Configuration Space

- Two sets: **free space** and **obstacle region**
- With  $W = \mathbb{R}^m$  being the work space,  $O \in W$  the set of obstacles,  $A(q)$  the robot in configuration  $q \in C$ :

$$C_{free} = \{q \in C \mid A(q) \cap O = \emptyset\}$$

$$C_{obs} = C / C_{free}$$

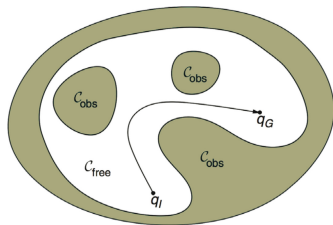
- We further define:  
 $q_I$ : start configuration  
 $q_G$ : goal configuration



# Motion planning

## Configuration Space

- Then, motion planning amounts to finding a continuous path  $\tau : [0, 1] \rightarrow C_{free}$  with  $\tau(0) = q_I, \tau(1) = q_G$
- Given this setting, we can do planning with the robot being a **point** in C-space.



# Motion planning

## Static vs Dynamic environments

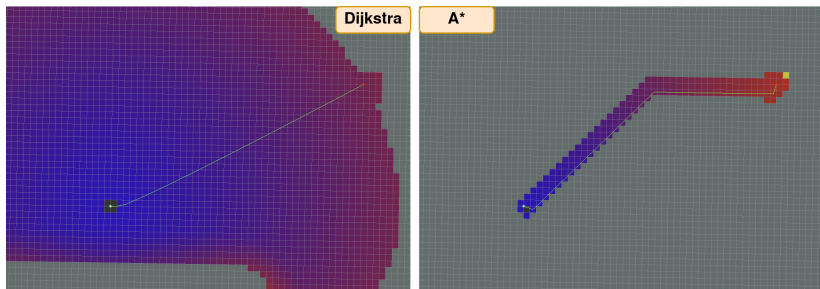
- In a static environment, all objects except the robot are static.
  - One-shot (global) path planning
  - Representative methods: Dijkstra, A\*
- In a dynamic environment, besides the robot itself, there are other objects moving, such as humans.
  - Constantly re-planning the path
  - Representative methods: Dynamic A\* (D\*)  $\leq$  originally designed for Mars rover, two-layered planning: global planning (for path finding) + local planning (for obstacle avoidance) such as A\* + Dynamic Window Approach (DWA)
- Sampling-based methods (e.g. Rapidly-exploring Random Tree (RRT), Probabilistic RoadMap(RPM)) can be used in both static and dynamic environments.

*A specific discussion of each algorithm is beyond the scope of this lecture (c.f. <https://yzrobot.github.io/#Research>, <http://wiki.ros.org/navigation>).*

# Motion planning

## Global planning

- **Dijkstra**: breadth-first search-like approach, solves the single-source shortest path problem in a weighted directed graph.
- **A\***: heuristic algorithm, an upgraded version of Dijkstra,  $f(n) = g(n) + h(n)$ .

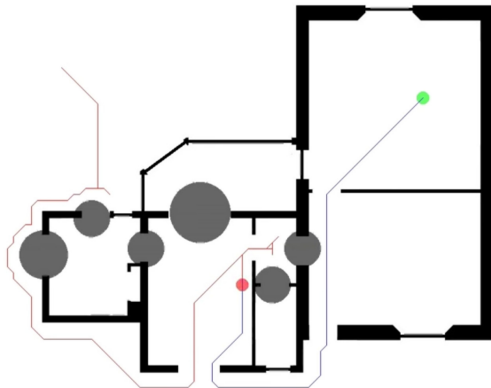




# Motion planning

## In dynamic environments

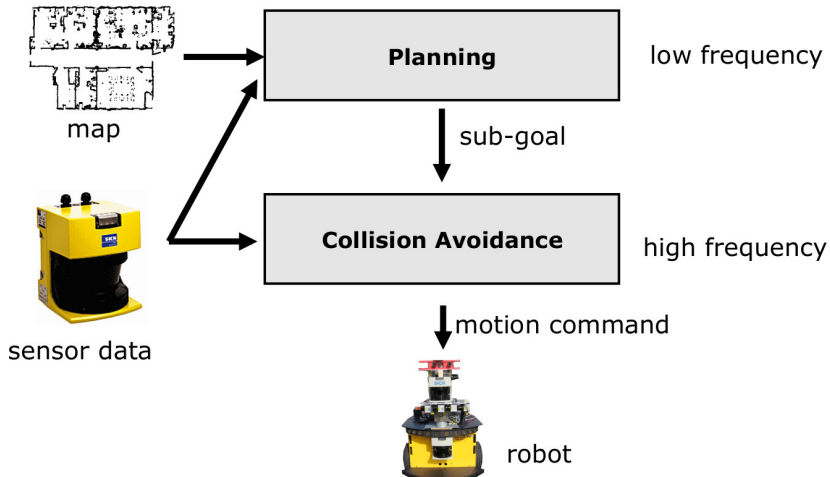
- $D^*$ : search the path from the target position to the starting position (opposite to the  $A^*$  algorithm).



# Motion planning

In dynamic environments

Two-layered robot motion planning architecture:



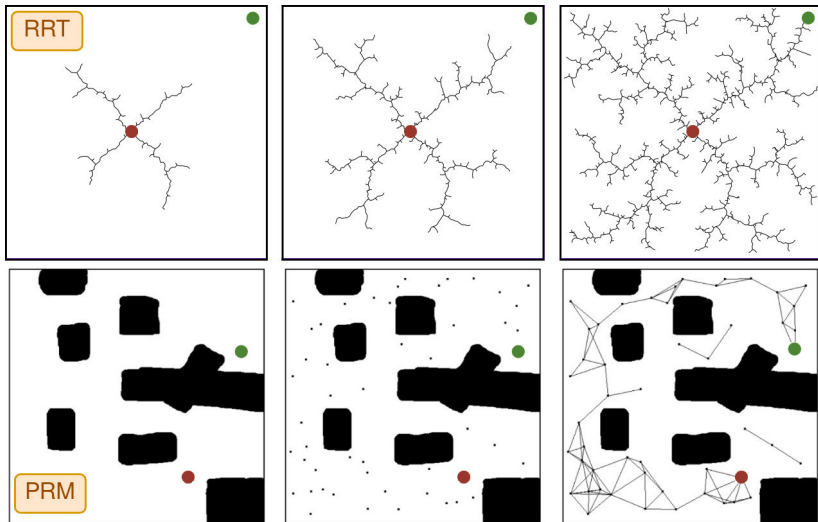
# Motion planning

## Sampling-based methods

- Stochastic method, effectively dealing with path search in high-dimensional space.
- Probabilistically complete and does not guarantee optimal paths.
- Suffer from narrow passages: the sampling point has only a small probability of falling inside.

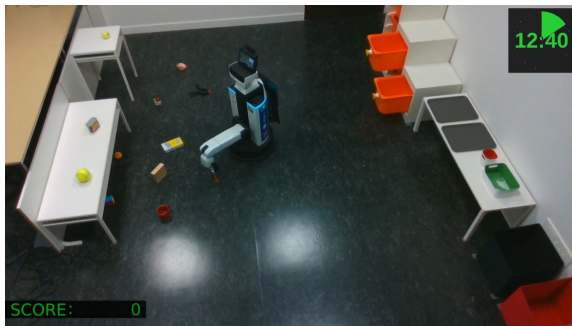
# Motion planning

## Sampling-based methods



# Task planning

- Recall: robots need task planning to sequence actions to achieve a goal that is not possible with a single action.
  - Finite State Machine (FSM)<sup>1</sup>
  - Planning Domain Definition Language (PDDL)<sup>2</sup>
  - Answer Set Programming (ASP)



<sup>1</sup>FSM in ROS: [http://wiki.ros.org/executive\\_smach](http://wiki.ros.org/executive_smach)

<sup>2</sup>PDDL in ROS: [https://kcl-planning.github.io/ROSPlan/](https://kcl-planning.github.io/ROSPPlan/)

# Task planning

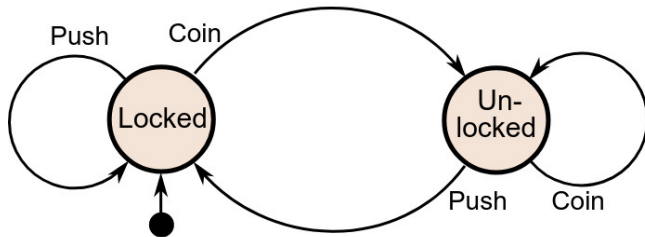
## An instance

A typical robot tidy-up task flow:

- 1 The robot enters the workspace and explores it to get where the objects are scattered.
  - Note: Rolling over objects is not allowed.  $\leq$  Avoid all obstacles at all times!
- 2 The robot selects an object and grabs it.  $\leq$  Which one?
- 3 The robot brings the object to the designated area.
- 4 The robot observes and chooses a suitable location to deliver the object.
- 5 The robot continues the grab and delivery process until all objects are sorted.

# Task planning

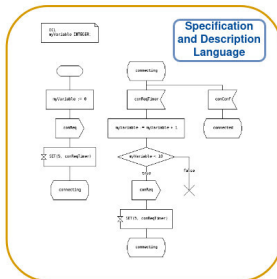
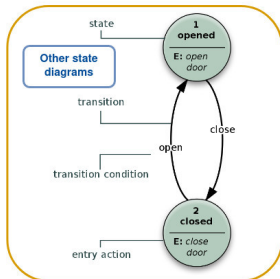
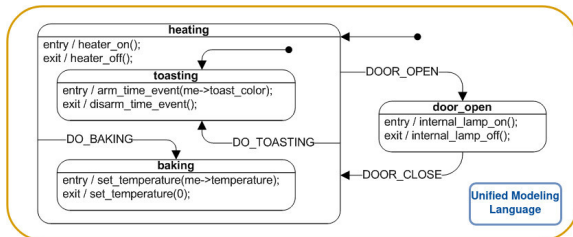
## Finite State Machine (FSM)



- Two **states**: Locked & Unlocked
- **Initial state**: Locked
- Two **inputs** that trigger each transition: Coin & Push  $\leq$  The change from one state to another is called a transition.

# Task planning

## Graphical representation of FSM





# Task planning

## FSM in table form

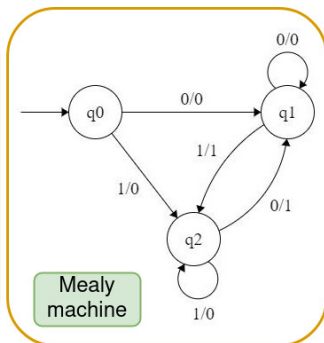
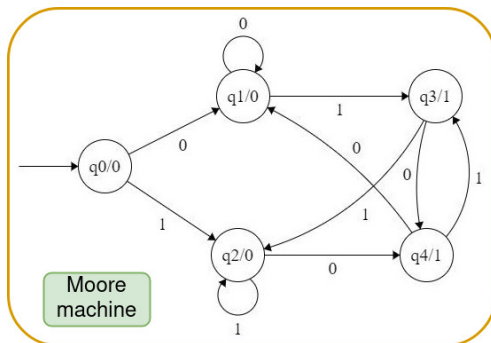
### State-transition table

<b>Current state</b> <b>Input</b>	<b>State A</b>	<b>State B</b>	<b>State C</b>
<b>Input X</b>	...	...	...
<b>Input Y</b>	...	State C	...
<b>Input Z</b>	...	...	...

# Task planning

## Two types of FSM

- **Moore type:** output depends only on state.
  - Simplified behavior but may require more state.
- **Mealy type:** output depends on both input and state.
  - Less state but possibly more complex behavior.



# Task planning

## Planning Domain Description Language (PDDL)

- PDDL is a standard **encoding language** for “classical” planning tasks.
- Components of a PDDL planning task:
  - **Objects**: Things in the world that interest us.
  - **Predicates**: Facts that we are interested in (e.g. properties of objects), which can be true or false.
  - **Initial state**: The state of the world that we start in (i.e. things that are true at the start).
  - **Goal specification**: The state of the world we want to end at (i.e. things that we want to be true at the end).
  - **Actions/Operators**: Ways of changing the state of the world (i.e. things that happen that change the facts).

# Task planning

## Form of PDDL

- PDDL files are text documents and usually have the extension *.pddl*.
- Planning tasks specified in PDDL are separated into two files:
  - A **domain file** for predicates and actions.
  - A **problem file** for objects, initial state and goal specification.

```
(define (domain <domain name>)
  (:predicates
    <predicate-list>
  )

  (:action
    <action-details>
  )
)
```

```
(define (problem <title>)
  (:domain <domain-name>)
  (:objects
    <object-list>
  )

  (:init
    <predicates>
  )
  (:goal
    <predicates>
  )
)
```

# Task planning

## PDDL for tidy-up

- **Objects:** A corridor, a room, a delivery area, 10 objects, a robot.
- **Predicates:** Is the robot inside the room? Is  $x$  the delivery area? Is  $y$  an object? Is the robot arm empty? etc.
- **Initial state:** The robot is in the corridor, the robot arm is empty, all objects are in the room, etc.
- **Goal specification:** All objects must be sorted out.
- **Actions/Operators:** The robot can move, pick up an object or drop an object.

# Task planning

## Answer Set Programming (ASP)

- ASP is a form of **declarative programming** (e.g. SQL) oriented towards difficult (primarily *NP – hard*) search problems.
- ASP tells the computer (robot) “what you (human) want to do”, not “how to do it”.
- A simple ASP program consists of three parts:
  - **Facts** and **rules**: describe the problem.
  - **Outputs**: check the results.

# Task planning

## Form of ASP

- ASP is syntactically similar to traditional logic programming and semantically close to non-monotonic logic.
- ASP applies important rules in non-monotonic reasoning: **closed world assumption (CWA)** and **negation as failure (NAF)**.
- All propositions that are not stated to be true are assumed to be false by default.
- if “A” is judged not to be inferred, then “not A” is inferred.  
     $\Leftarrow$  non-monotonic logic

# Task planning

## Form of ASP

- Consider a knowledge base consisting of information about service robots, cooking robots, and some individuals:
  - Most service robots move.
  - Cooking robots do not move.
  - Cooking robots are service robots.
  - HSR is a service robot.
  - Moley is a cooking robot.
- By ASP:
  - $move(X) \leftarrow service\_robot(X), not \neg move(X)$
  - $\neg move(X) \leftarrow cooking\_robot(X)$
  - $service\_robot(X) \leftarrow cooking\_robot(X)$
  - $service\_robot(HSR) \leftarrow$
  - $cooking\_robot(Moley) \leftarrow$



# Summary

- The planning of mobile robots mainly includes motion planning and task planning.
- The knowledge of configuration space is the basis for implementing robot motion planning.
- Global planning is to find a path from the robot's current position to the target position, while local planning is to avoid dynamic obstacles in the environment during movement.
- Task planning and other areas of AI have more in common.
- Extended reading: complete traversal path planning (e.g. for sweeping robot)

# The end

Thank you for your attention!

Any questions?