Introduction to Robot Motion Planning & Navigation

Introduction

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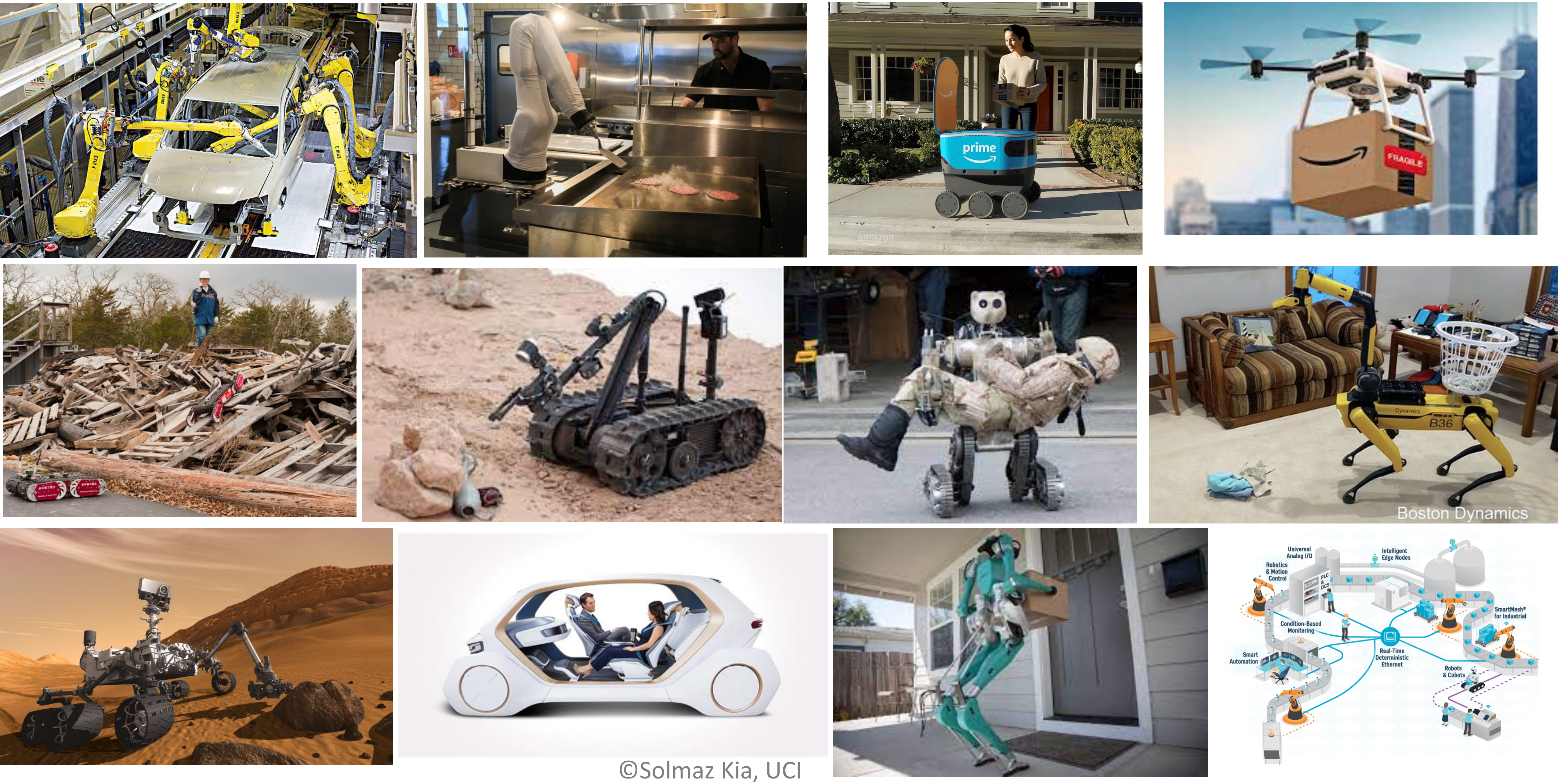
Robots: realization of people’s dream of building intelligent machines to perform tasks.



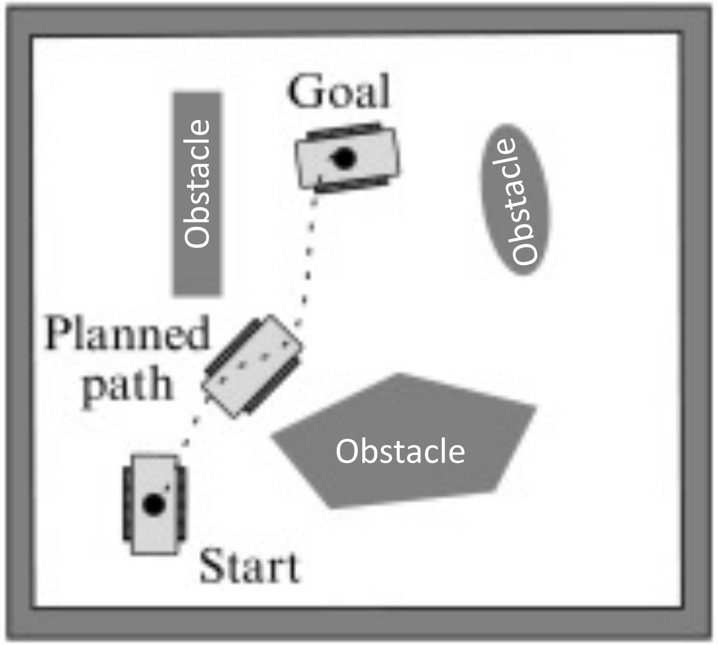
Why do we care about robot motion planning?

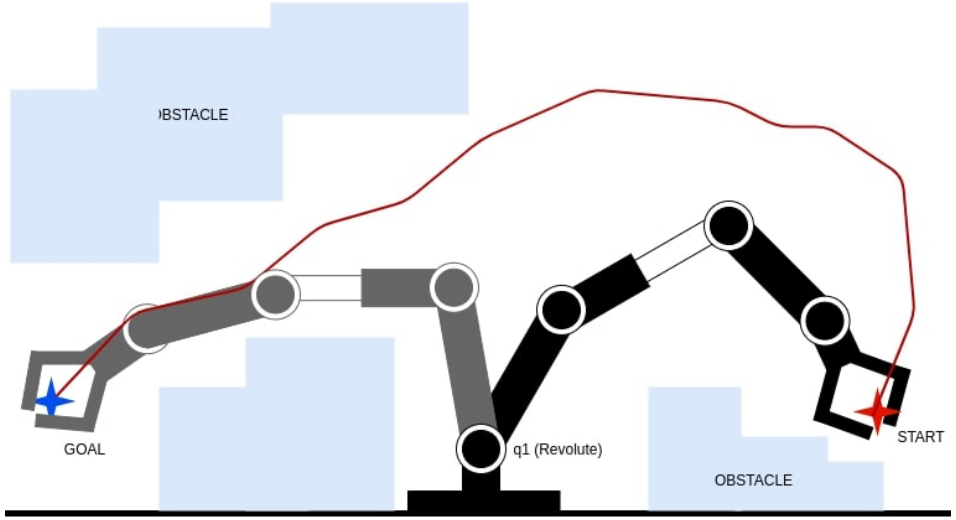
Regardless of the form of the robots or the task it must perform, robots must maneuver through the world.

Motion planning is the problem of finding a robot motion from a start state to a goal state in a cluttered environment to achieve various goals while avoiding collisions.

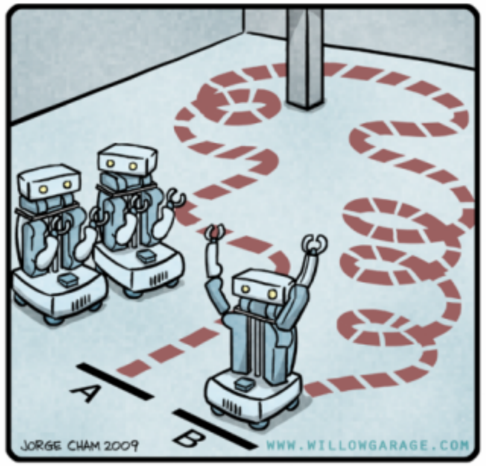
In its simplest form, the motion planning problem is:

how to move a robot from a "start" location to a "goal" location avoiding obstacles.



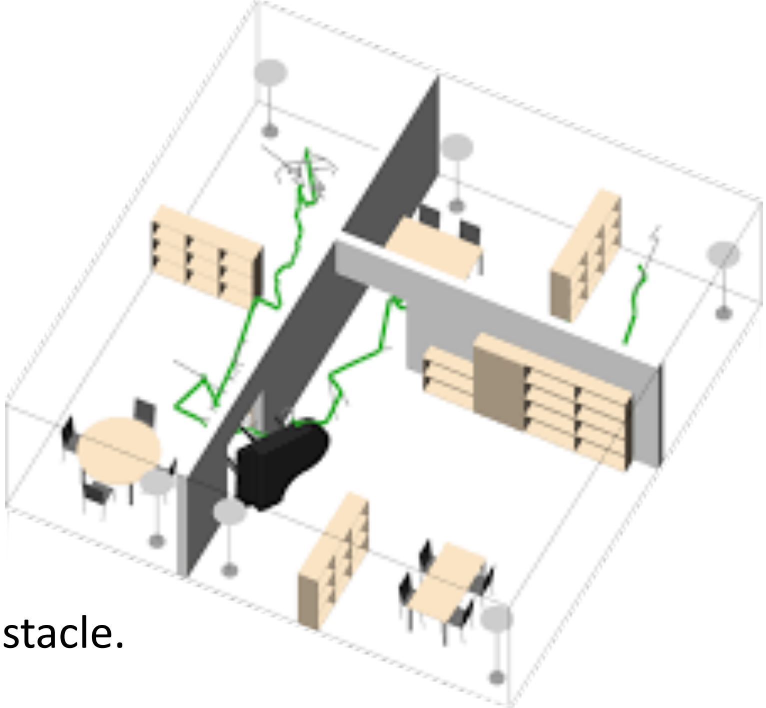


R.O.B.O.T. Comics



"HIS PATH-PLANNING MAY BE SUB-OPTIMAL, BUT IT'S GOT FLAIR."

Motion Planning: Problem Formulation



The problem of motion planning can be stated as follows:

Given:

- ☐ A start pose of the robot
- ☐ A desired goal pose
- ☐ A geometric description of the robot
- ☐ A geometric description of the world

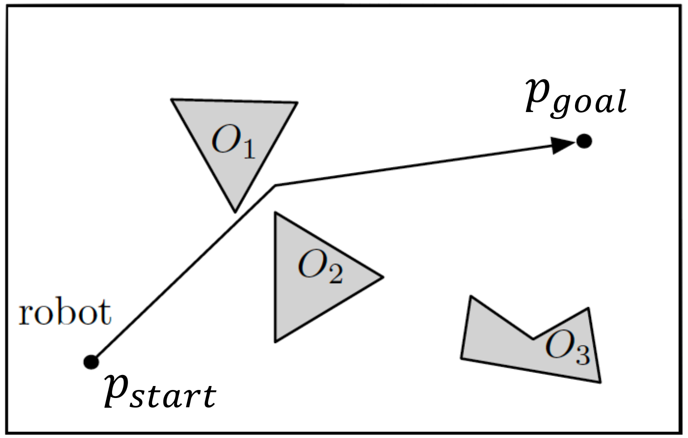
Find a path that moves the robot gradually from start to goal while never touching any obstacle.

https://youtu.be/HdfAzUXvmOQ

This problem is sometimes referred to as the “move from A to B” or the “**piano movers problem**” (how do you move a complex object like a piano in an environment with lots of obstacles, like a house).

Motion Planning: Workspace

a robot described by a moving point (that is, the robot has zero size).

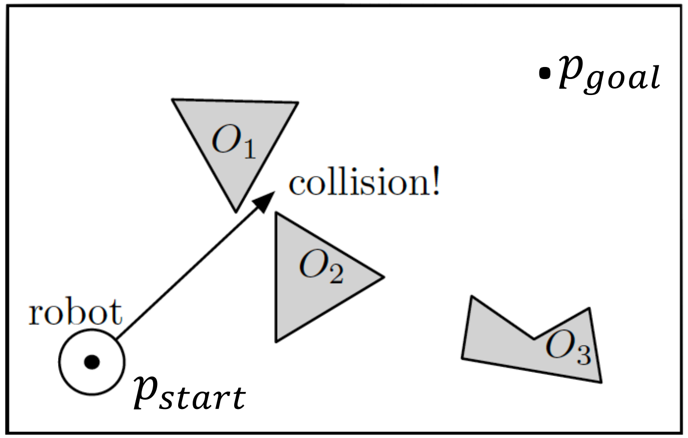


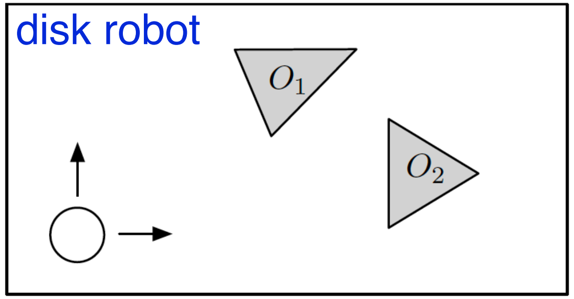
- A workspace $W \subset R^2$ or R^3, often just a rectangle;
- Some obstacles $O_1, O_2, \cdots, O_n$;
- A start point p_{start} and a goal point p_{goal};

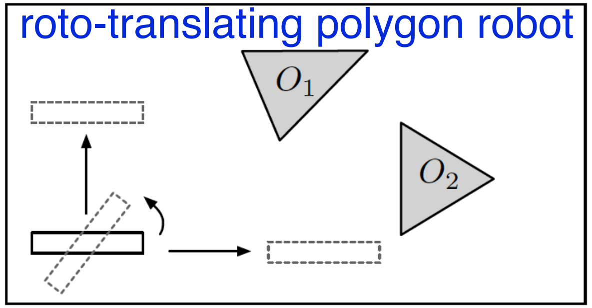
free workspace: $W_{free} = W \backslash (O_1 \cup O_2 \cup \cdots \cup O_n)$: the set of points in W that are outside all obstacles.

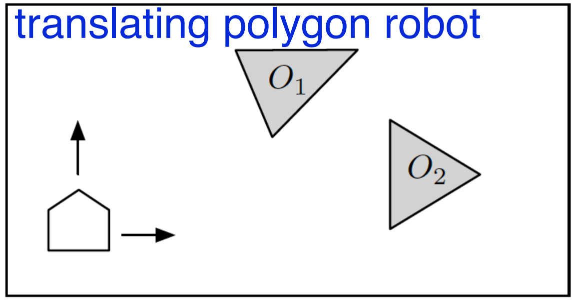
Motion Planning: Configuration space

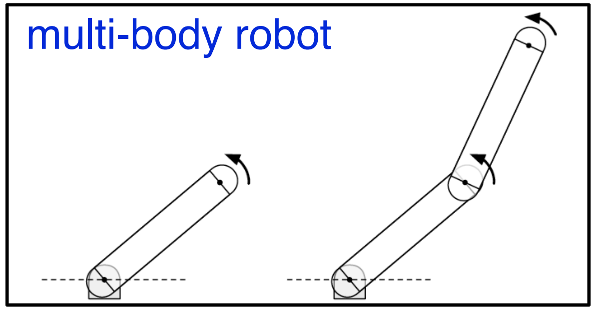
robots with a finite shape and size (a robot is composed of a single rigid body or multiple interconnected rigid bodies).




disk robot


roto-translating polygon robot


translating polygon robot


multi-body robot

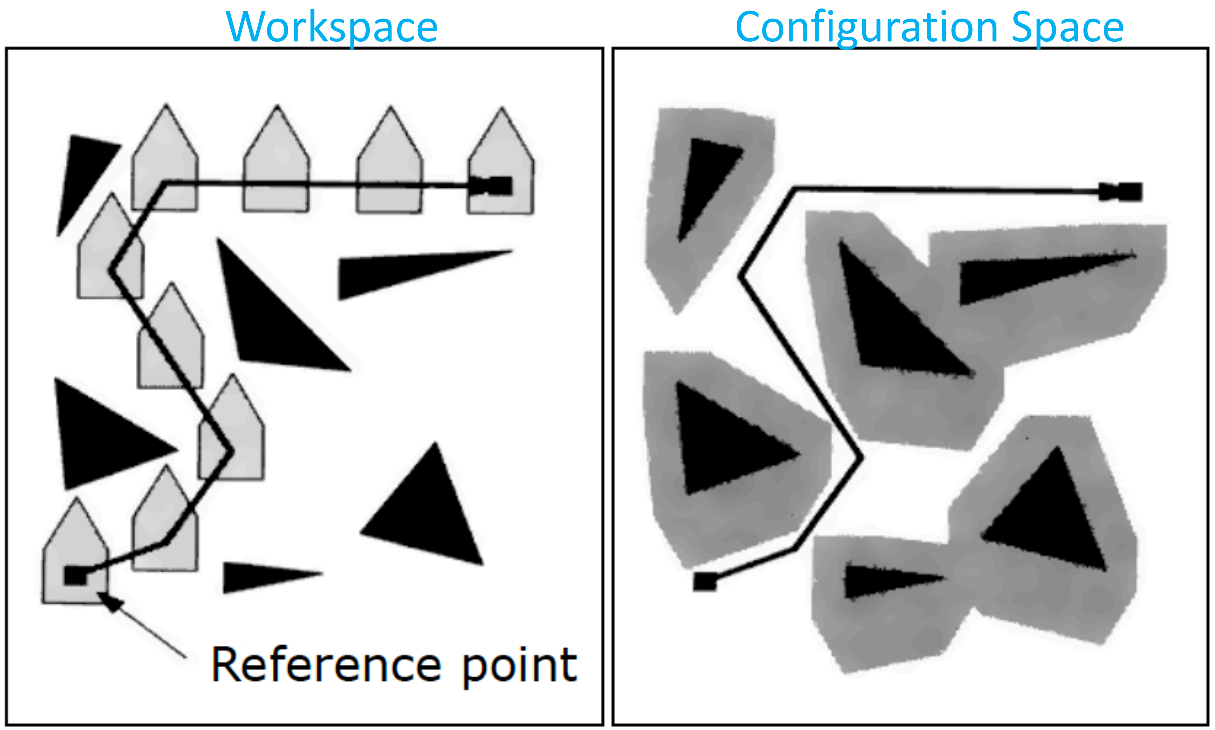
- A configuration of a robot is a minimal set of variables that specifies the position and orientation of each rigid body composing the robot. The robot configuration is usually denoted by the letter q.

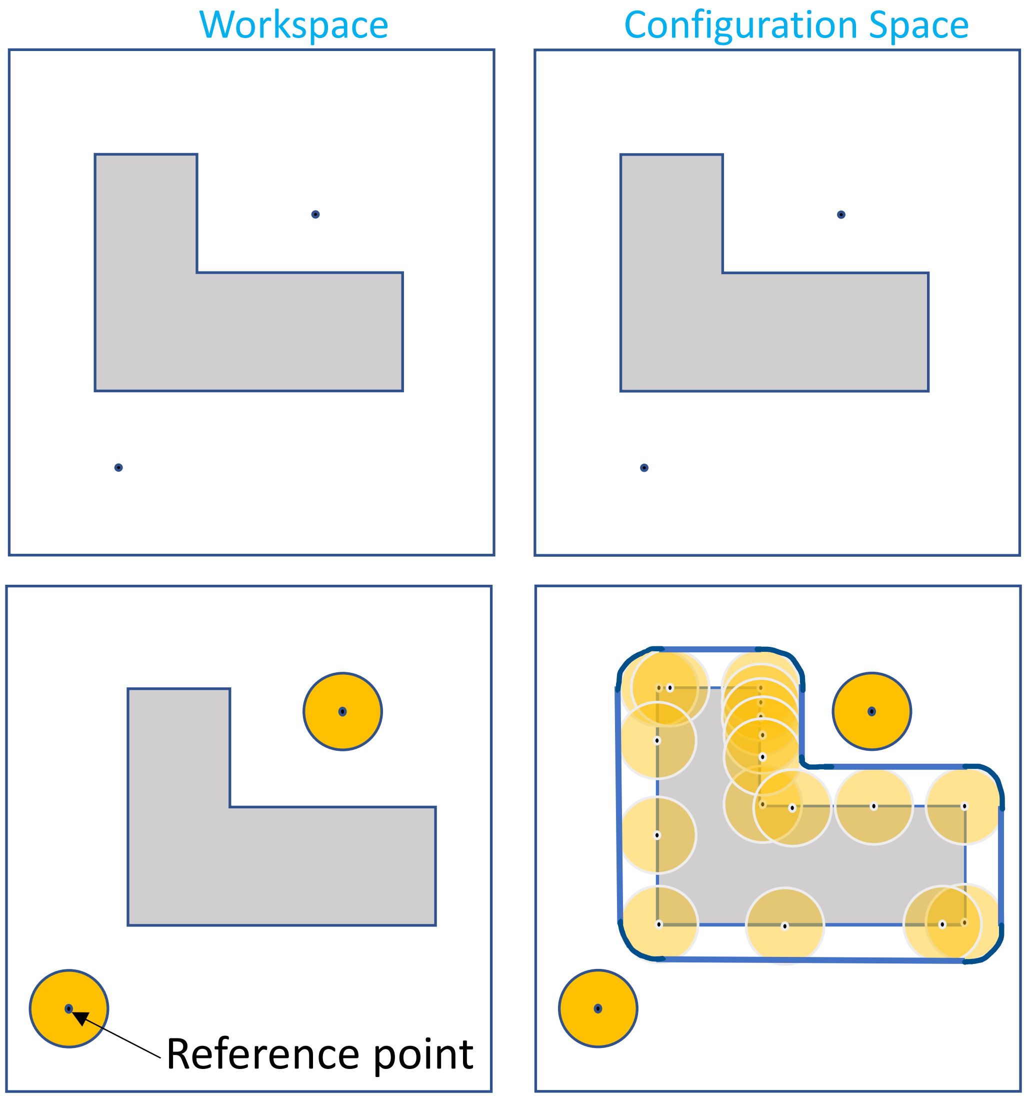
- The configuration space is the set of all possible configurations of a robot. The robot configuration space is usually denoted by the letter Q, so that $q \in Q$.

The free Q-space, Q_{free} consists of the configurations where the robot neither penetrates an obstacle nor violates a joint limit.

Motion Planning: Configuration space

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





Q-space is obtained by "blowing the edge of the obstacles up" by the robot radius

Types of Motion Planning Problems

Online versus off-line. A motion planning problem requiring an immediate result, perhaps because obstacles appear, disappear, or move unpredictably, calls for a fast, online, planner. If the environment is static, then a slower off-line planner may suffice.

Optimal versus satisficing. In addition to reaching the goal state, we might want the motion plan to minimize (or approximately minimize) a cost J, e.g., shortest time, shortest distance traveled.

Exact versus approximate. We may be satisfied with a final state $\mathrm{p}(T)$ that is sufficiently close to p_{goal}.

With or without obstacles. The motion planning problem can be challenging even in the absence of obstacles, particularly if number of controllers available is less than degrees of the freedom of the robot or optimality is desired.

Properties of Motion Planners

Completeness.

- A motion planner is said to be complete if it is guaranteed to find a solution in finite time if one exists, and to report failure if there is no feasible motion plan.

- A weaker concept is resolution completeness. A planner is resolution complete if it is guaranteed to find a solution if one exists at the resolution of a discretized representation of the problem, such as the resolution of a grid representation of Q_{free}.

- Finally, a planner is probabilistically complete if the probability of finding a solution, if one exists, tends to 1 as the planning time goes to infinity.

Computational complexity.

- The computational complexity refers to characterizations of the amount of time the planner takes to run or the amount of memory it requires.

- These are measured in terms of the description of the planning problem, such as the dimension of the Q-space or the number of vertices in the representation of the robot and obstacles.

- For example, the time for a planner to run may be exponential in n, the dimension of the Q-space.
- The computational complexity may be expressed in terms of the average case or the worst case.

- Some planning algorithms lend themselves easily to computational complexity analysis, while others do not.

Properties of Motion Planners

Multiple-query versus single-query planning. If the robot is being asked to solve a number of motion planning problems in an unchanging environment, it may be worth spending the time building a data structure that accurately represents Q_{free}. This data structure can then be searched to solve multiple planning queries efficiently. Single query planners solve each new problem from scratch.

“Anytime” planning. An anytime planner is one that continues to look for better solutions after a first solution is found. The planner can be stopped at any time, for example when a specified time limit has passed, and the best solution returned.

To properly describe the motion planning problem, we need to specify:

- What capacities does the robot have?
- What information does the robot have?

References:
- F. Bullo and S. L. Smith. Lecture notes on robotic planning and kinematics
- Kevin M. Lynch and Frank C. Park. Modern Robotics Mechanics, Planning, and Control
- H. Choset, K. Lynch, S. Hutchinson, G. Kantor, et al. Principles of Robot Motion, Theory, Algorithms, and Implementations.