Introduction to Motion Planning

Dr Pradipta Biswas, **PhD (Cantab)**

Associate Professor
Indian Institute of Science

https://cambum.net/index.htm

Demo Videos

Fixed base Bot

Gaze Controlled Safe HRI for Users with SSMI

Ground Moving Bot

Virtual obstacle avoidance & heterogenous multi-robot coordination in mixed reality with a human in the loop

Ajay Kumar Sandula, Dr Pradipta Biswas, Arushi Khokhar, Dr Debasish Ghose

I3D Lab

RBCCPS Department

Indian Institute of Science, Bangalore

Flying Bot


Button
Drop is
Selected
ICRA
IEEE INTERNATIONAL CONFERENCE
ON ROBOTICS AND AUTOMATION
ATLANTA 2025
Aerial Manipulation Made Easy :
An Intuitive Framework for a
Human-Drone-Manipulator team
Suprakas Saren, Rubini M, Prithwish Dey,
Pradipta Biswas, and Debasish Ghose
भारतीय विज्ञान संस्थान

Knowledge Representation

Aim

- Finding best path / route
  - Optimal path
  - Optimal with respect to ….
- Finding solution in finite time
  - Completeness
  - Space Complexity
  - Time Complexity
- Amount of information required
  - Start and Destination
  - Distance among waypoints / Nodes
  - Heuristics / Reward / Utility

8

Motion Planning in Discrete Space

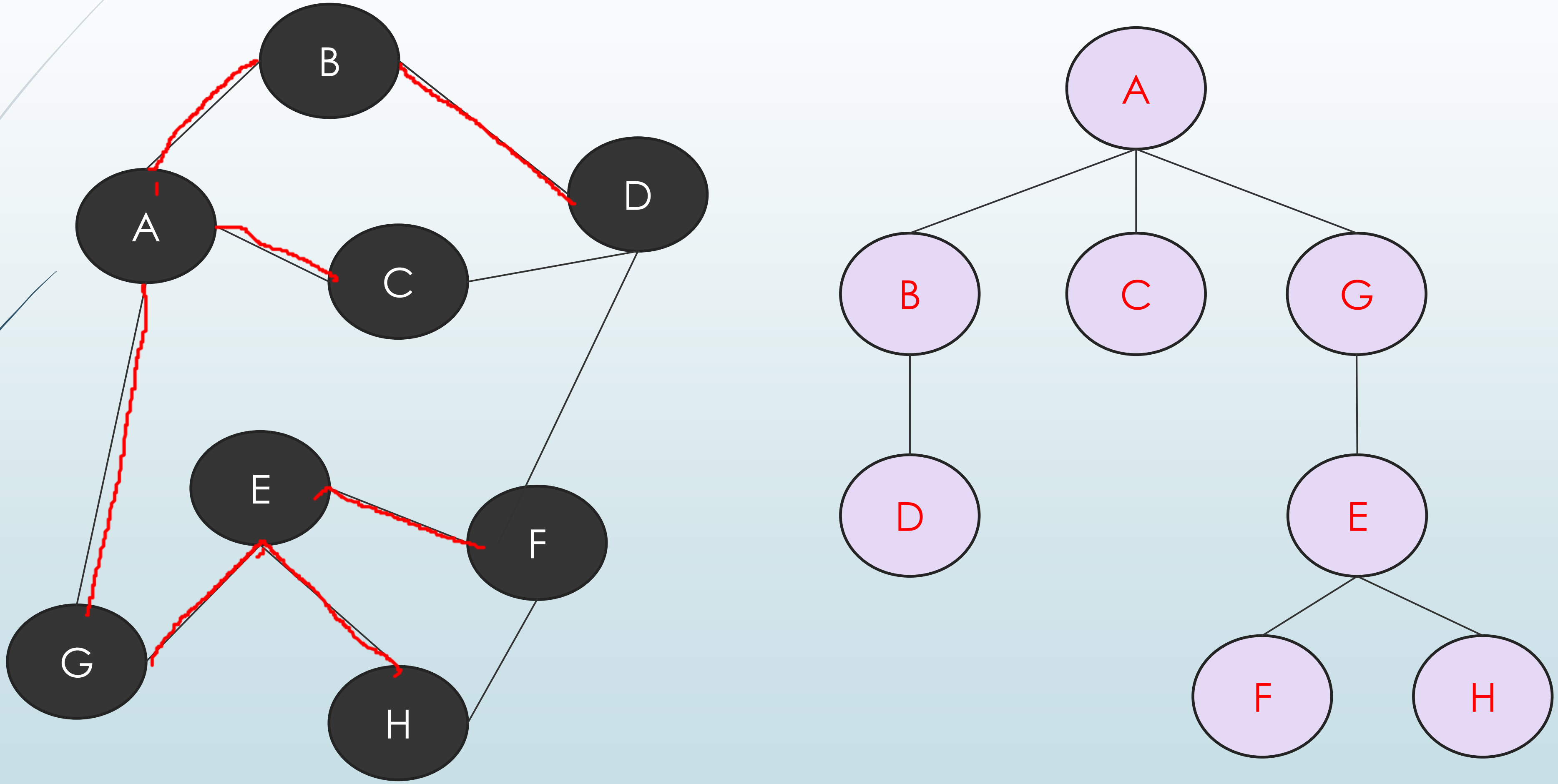
State-Space Search

- Many problems in AI take the form of ***state-space search***.
- The ***states*** might be legal board configurations in a game, towns and cities in some sort of route map, collections of mathematical propositions, etc.
- The ***state-space*** is the configuration of the possible states and how they connect to each other e.g. the legal moves between states.
- When we do not have an ***algorithm*** which tells us definitively how to negotiate the state-space we need to search the state-space to find an optimal path from a start state to a goal state.
- We can only decide what to do (or where to go), by considering the possible moves from the current state, and trying to look ahead as far as possible. Chess, for example, is a very difficult state-space search problem.

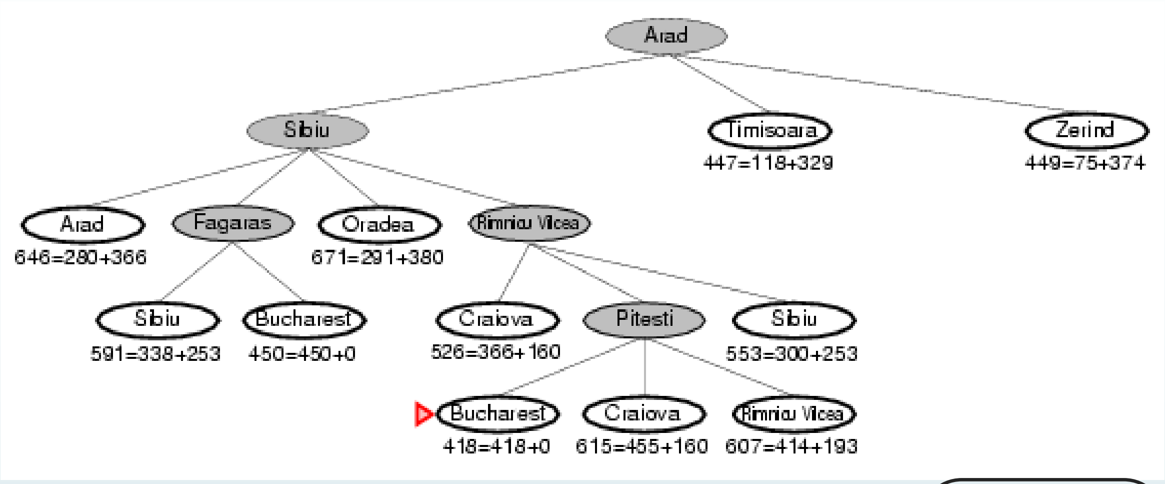
State-Space Model

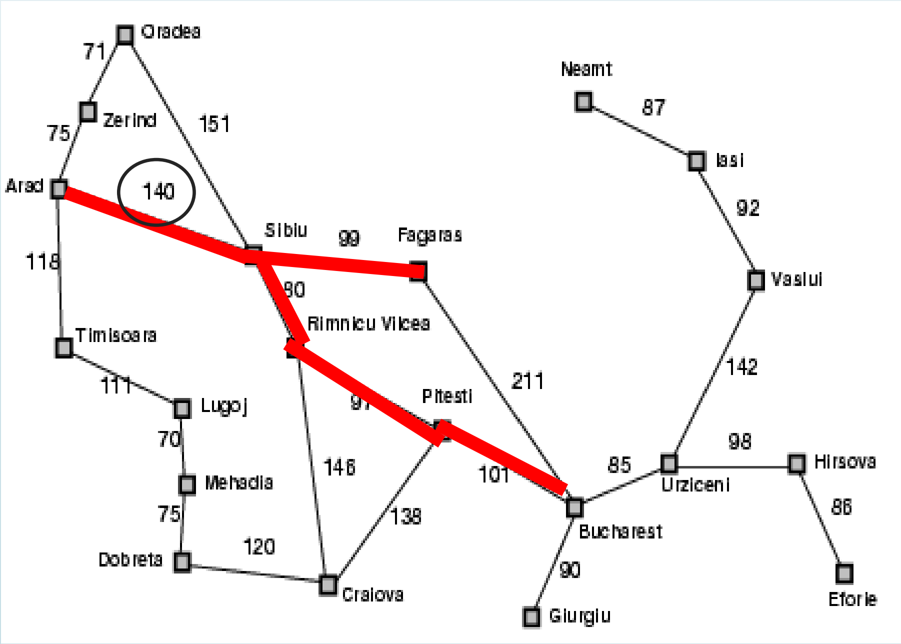
- Initial State
- Operators: maps a state into a next state
    - alternative: successors of state
- Goal Predicate: test to see if goal achieved
- Optional:
    - cost of operators
    - cost of solution

Uninformed Search - BFS



Informed Search -A* search



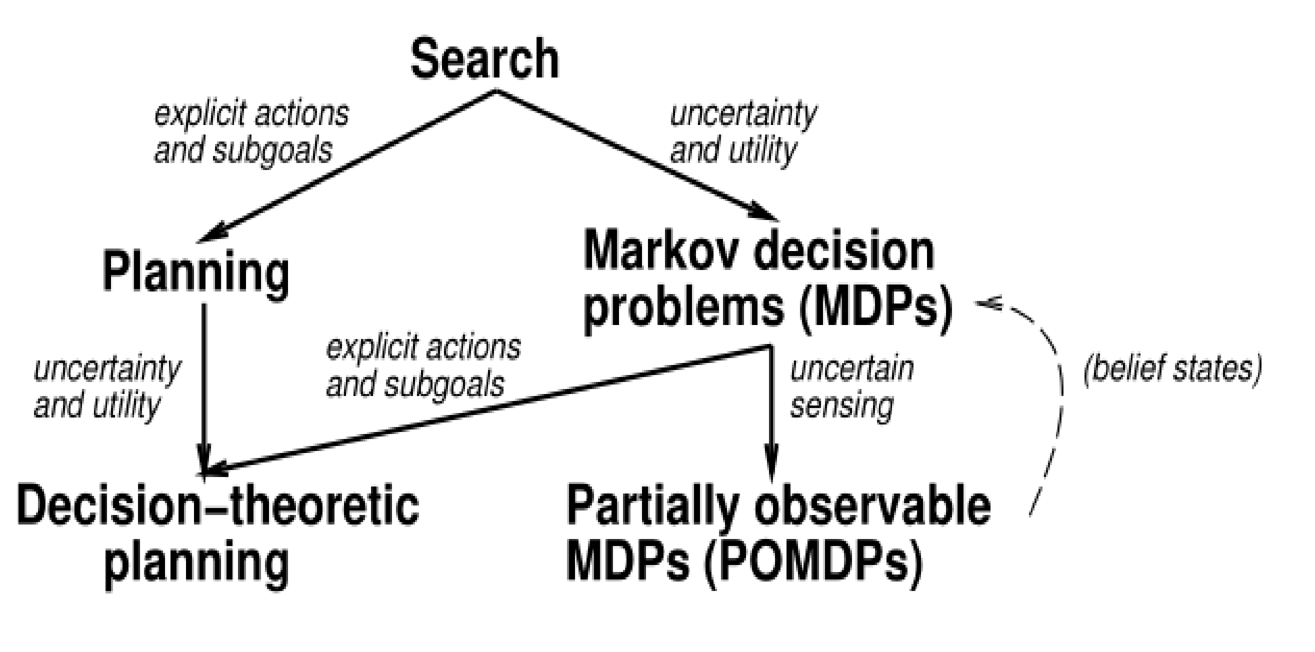


Straight−line distance to Bucharest

Arad	366
Bucharest	0
Craiova	160
Dobreta	242
Eforie	161
Fagaras	176
Giurgiu	77
Hirsova	151
Iasi	226
Lugoj	244
Mehadia	241
Neamt	234
Oradea	380
Pitesti	10
Rimnicu Vilcea	193
Sibiu	253
Timisoara	329
Urziceni	80
Vaslui	199
Zerind	374

Sequential Decision Problems

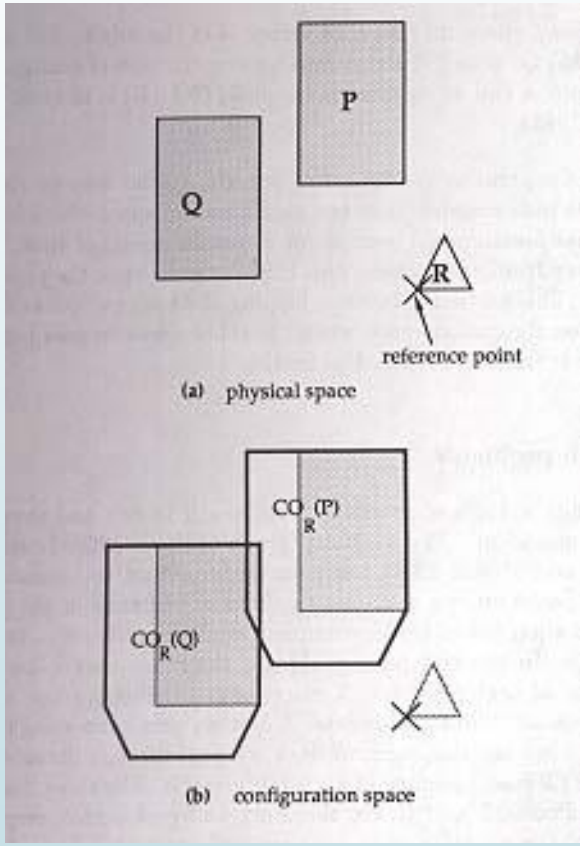
- Sequential decision problems vs. episodic ones
- Fully observable environment
- Stochastic actions



Motion Planning in Continuous Space

The Configuration Space

- The configuration space is a transformation from the physical space in which the robot is of finite-size into another space in which the robot is treated as a point. In other words, the configuration space is obtained by shrinking the robot to a point, while growing the obstacles by the size of the robot.
- The figures illustrates the concept of configuration space. P and Q are fixed obstacles in physical space, and R is the robot, whose orientation is fixed.
- Figure b shows the corresponding configuration space.
- The free space of a configuration space simply consists of the areas not occupied by obstacles. Any configuration within this space is called a free configuration.
- The free path between an initial configuration and a goal configuration is the path which lies completely in free space and does not come into contact with any obstacles.

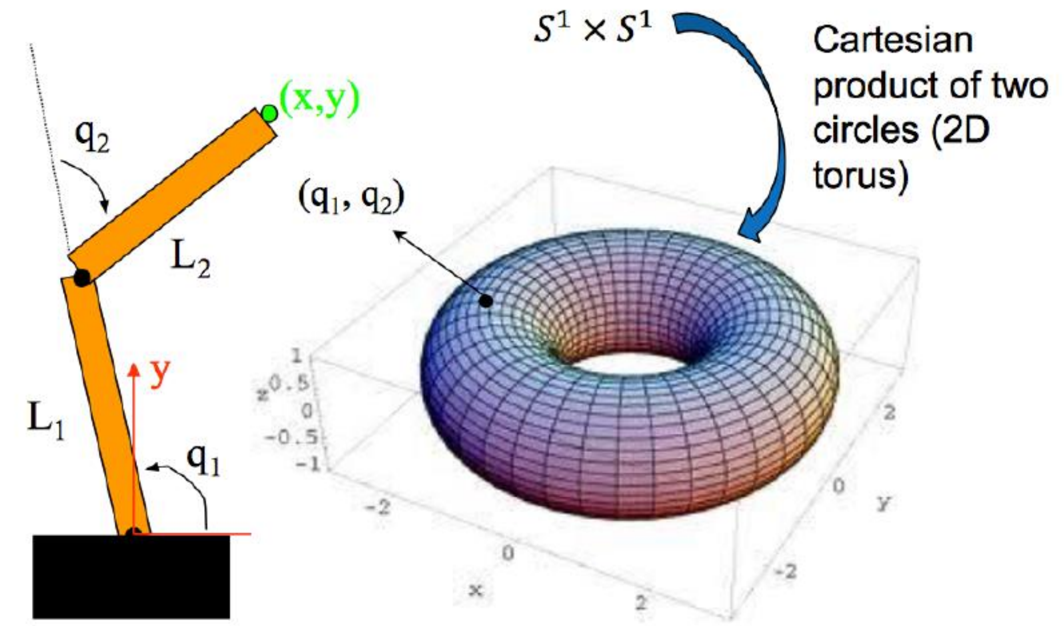


(a) physical space
(b) configuration space

Task Space and Workspace

- The task space is a space in which the robot's task can be naturally expressed.
- For example, if the task is to control the position of the tip of a marker on a board, then task space is the Euclidean plane. If the task is to control the position and orientation of a rigid body, then the task space is the 6-dimensional space of rigid body configurations. One only has to know about the task, not the robot, to define the task space.
- The workspace is a specification of the configurations that the end-effector of the robot can reach, and has nothing to do with a particular task.
- The workspace is often defined in terms of the Cartesian points that can be reached by the end-effector, but it is also possible to include the orientation. The set of positions that can be reached with all possible orientations is sometimes called the dexterous workspace.

Configuration Space & Motion Planning



Topology of Configuration Space

- To facilitate motion planning, the configuration space was defined as a tool that can be used with planning algorithms.
- A configuration *q* will completely define the state of a robot (e.g. mobile robot (*x*, *y*, *θ*)
- The configuration space C, is the space of all possible configurations of the robot.
- The free space $F \subseteq C$ is the portion of the free space which is collision-free.
- The goal of motion planning then, is to find a path in *F* that connects the initial configuration q_{start} to the goal configuration q_{goal}
- For a robot with *k* total motion DOFs, C-space is a coordinate system with *one dimension per DOF*

Examples of Configuration Space

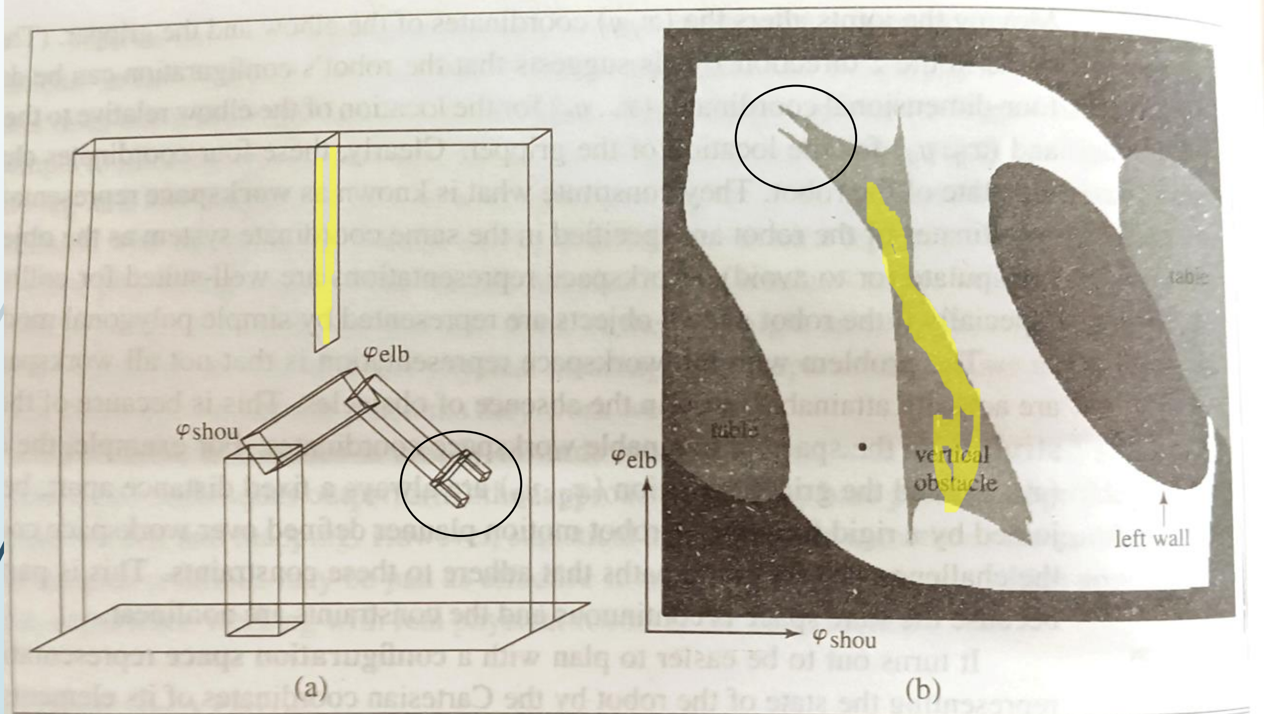


Figure 25.12 (a) Workspace representation of a robot arm with 2 DOFs. The workspace is a box with a flat obstacle hanging from the ceiling. (b) Configuration space of the same robot. Only white regions in the space are configurations that are free of collisions. The dot in this diagram corresponds to the configuration of the robot shown on the left.

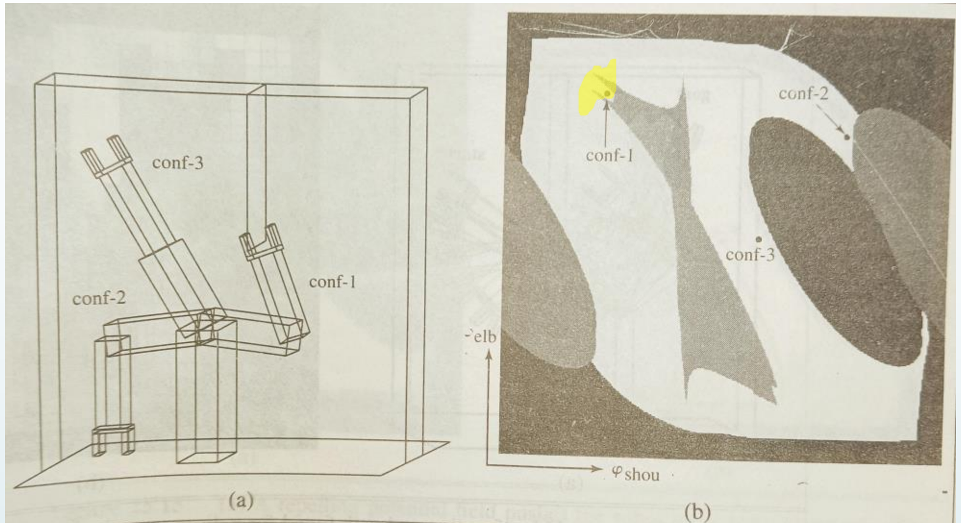


Figure 25.13 Three robot configurations, shown in workspace and configuration space.

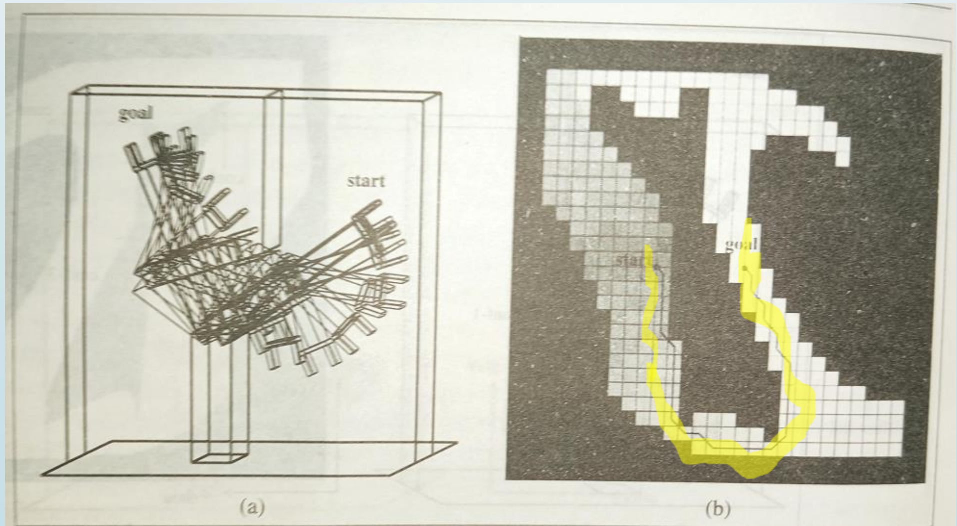
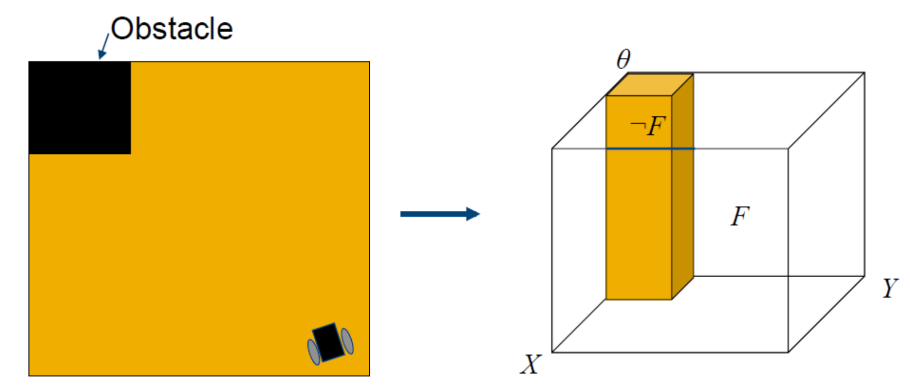


Figure 25.14 (a) Value function and path found for a discrete grid cell approximation of the configuration space. (b) The same path visualized in workspace coordinates. Notice how the robot bends its elbow to avoid a collision with the vertical obstacle.

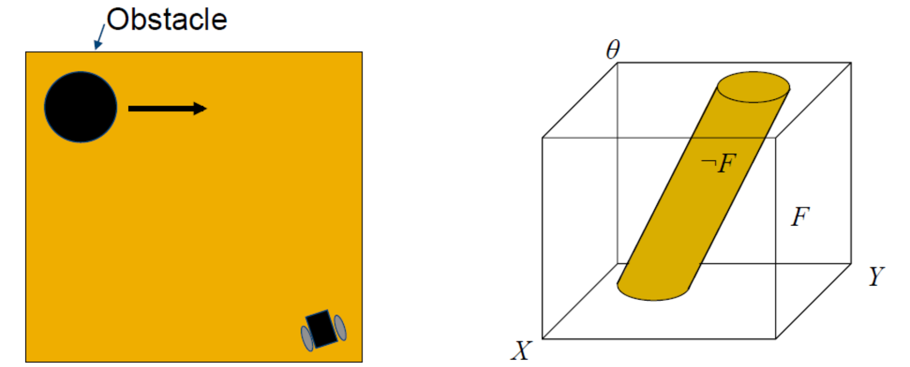
Examples of Configuration Space

Mobile Robot



Workspace | Configuration Space

Mobile Robot with moving obstacle



Workspace | Configuration Space

How to Plan Motion

- Define space with one dimension per robot motion (or pose) DOF
- Map robot to a point in this space

  C-space = all robot configurations

  C-obstacle = locus of infeasible configurations due to obstacle
- Motion planning is usually done with three steps:

  1. Define C
  2. Discretize C
  3. Search C
- Each planning problem may have a different definition of C.
  - Example 1: Include 3DOF for a mobile robot in static environment - (x,y,θ).
  - Example 2: Include only 2DOF for a mobile robot in static environment - (x,y).
  - Example 3: Include 5DOF for a mobile robot in dynamic environment - (x,y,θ,v,t).

Take Away Points

- Basic Concept of Motion Planning
- Motion Planning in Discrete and Continuous space
- State Space Search
- Uninformed and Informed Search
- Concept of Configuration Space
- Motion Planning in Configuration Space