

Probabilistic Roadmaps for Path Planning in High-Dimensional Configuration Spaces

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Outline

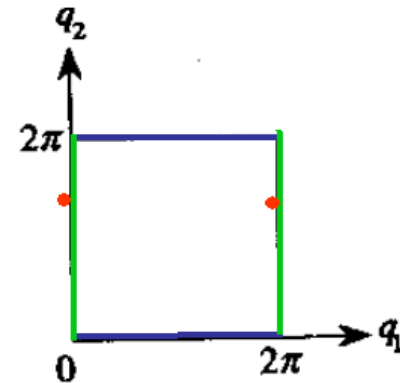
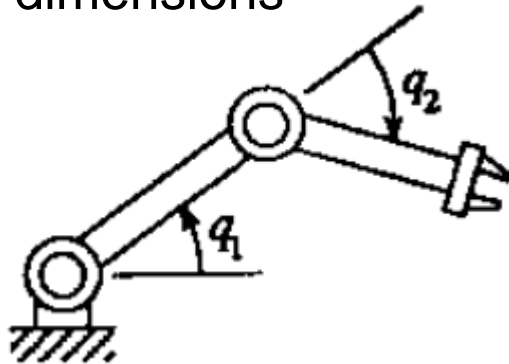
- Background
- Problem Statement
- Approach
- Examples and Test Results
- Conclusion

Examples

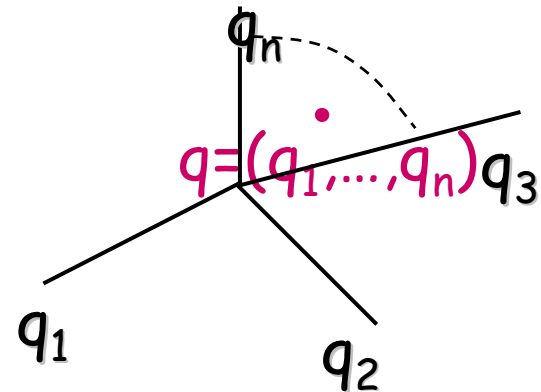
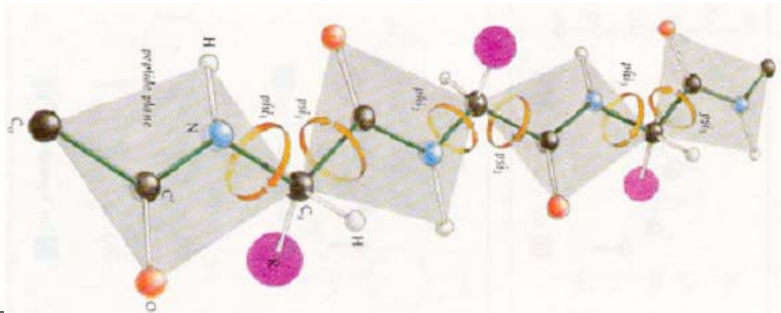


Configuration Space

- Two dimensions

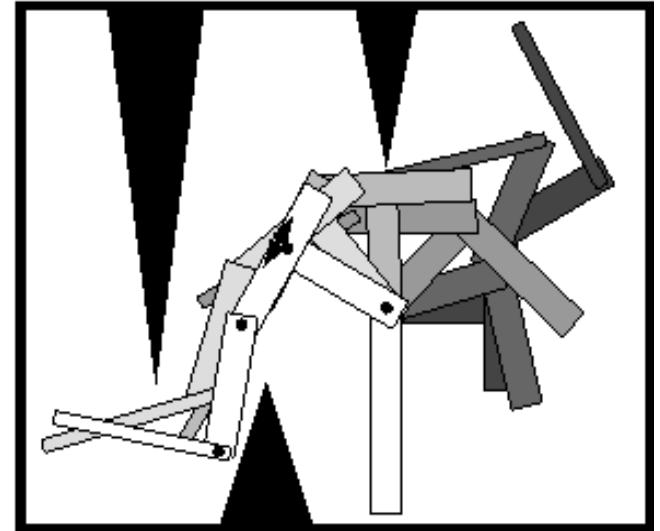


- N-dimensions

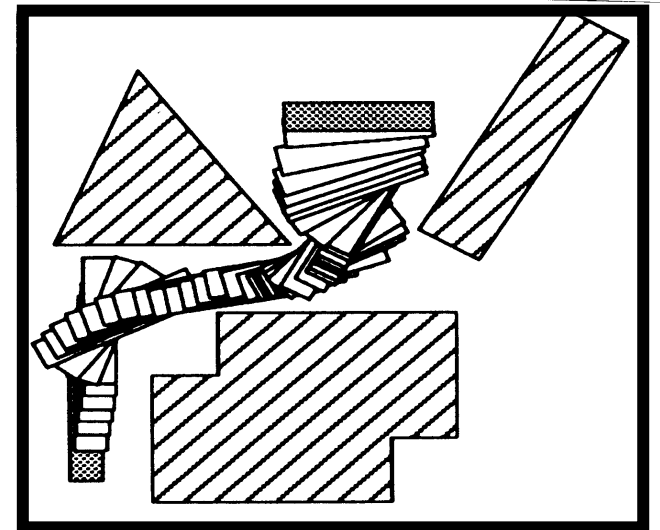


Assumptions/Definitions

- Holonomic Robot
 - Articulated
 - 2-D Physical Robot*
- Static Workspace
 - Limited (Bounded) Physical Space
 - Fixed physical Boundaries
 - Fixed Obstacles
 - 2-D Workspace*



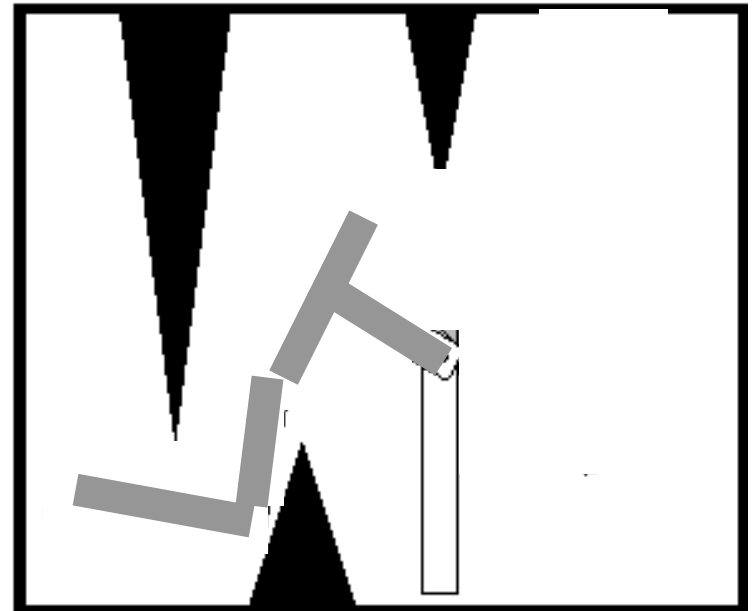
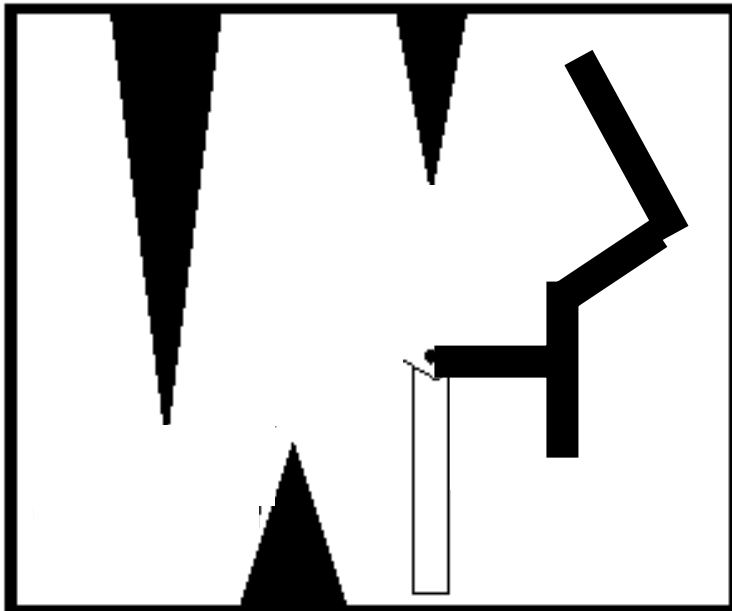
4-Dimension C-Space



3-Dimension C-Space

Goal: Problem Statement

- Propose a motion planning* method for robots in static workspace from a given start configuration to a desired goal configuration.

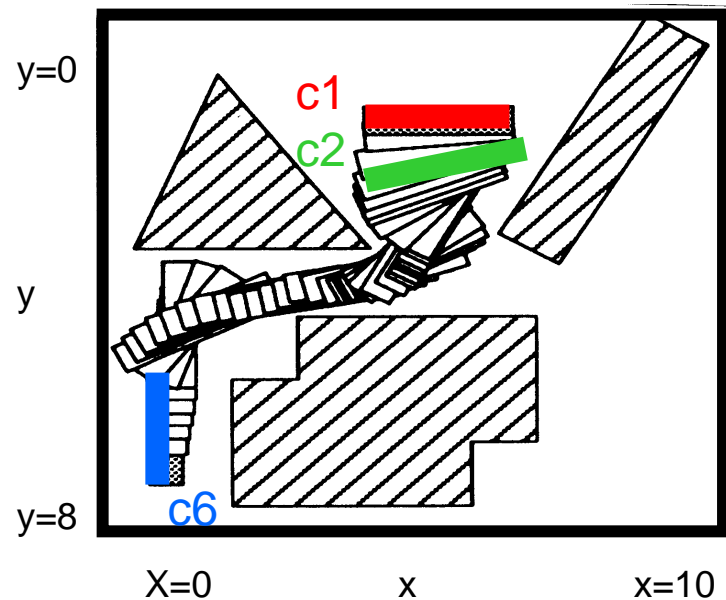


Related Work

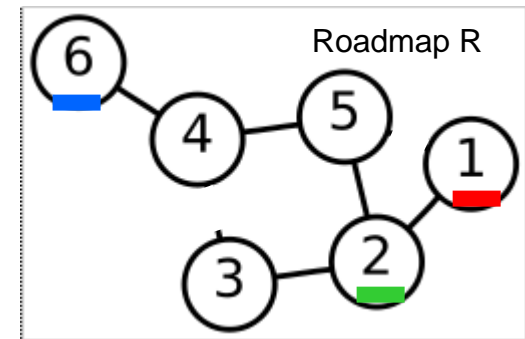
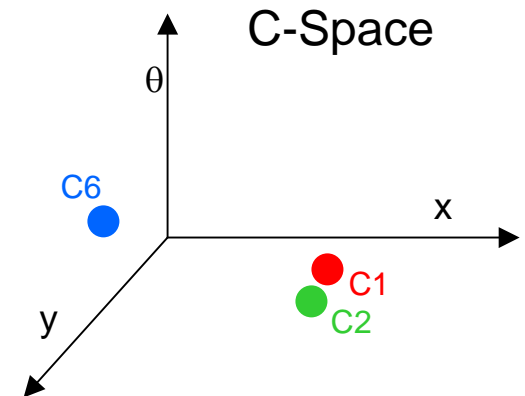
- **Potential Field Methods** [FT87] Faverjon, Tournassoud 1987
 - Heuristic Function w/ Local Minima
 - Avoids minima by human interaction
- **Randomized Path Planner (RPP)** [BL91] Barraquand, Latombe 1991
 - Expensive computation
 - Narrow passages are difficult
- **Dynamic Programming** [BF94] Barraquand, Ferbach 1994
- **Visibility Graph, Voronoi Diagram, Silhouette methods**

Approach

- Represent the roadmap as an undirected graph $R=(N,E)$
 - Where the nodes represent specific robot configurations
 - And the Edges indicate that a path exists between adjacent nodes



$$C = (x, y, \theta)$$
$$C1 = (5, 1, 0^\circ)$$
$$C2 = (5, 2, 10^\circ)$$
$$C6 = (1, 7, 90^\circ)$$



Path Planning Model Components

- Local Planner
 - Deterministic process of evaluating if a path exists between two similar configurations.
- Distance Function
 - Measure similarity between two configurations (a and b)

$$(a, b) \in \mathcal{C} \times \mathcal{C} \quad \mapsto \quad D(a, b) = \sum_{i=1}^{q+1} \|J_i(a) - J_i(b)\|^2,$$

- Collision Checking
 - Assuming 2d workspace, articulated robot with identical links
 - Generate 3d bitmap (3D array) with 0 if free and 1 if collides with obstacle for a single link
 - Check bitmap for collisions for each link (x, y, θ)

Path Planning Model

- Divide Model into Learning and Query Phases:
 - Learning Phase
 - Construction
 - Build roadmap by adding randomly generated configurations
 - Expansion
 - Expand roadmap by adding nodes on difficult/sparse regions
 - Query Phase
 - Given start and goal configurations, find the path if one exists

Path Planning Model: Learning Phase

Construction Step

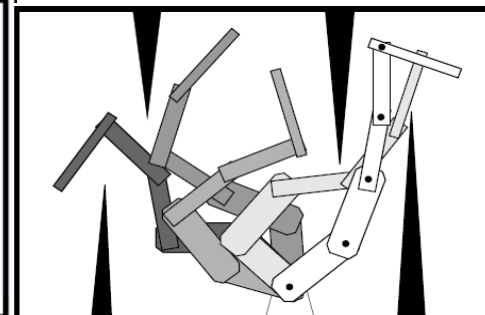
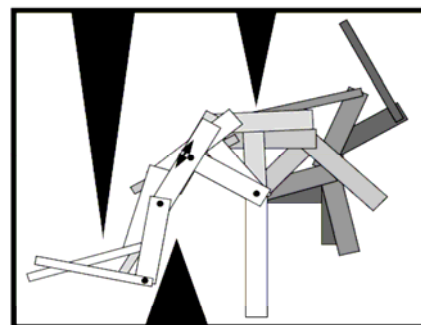
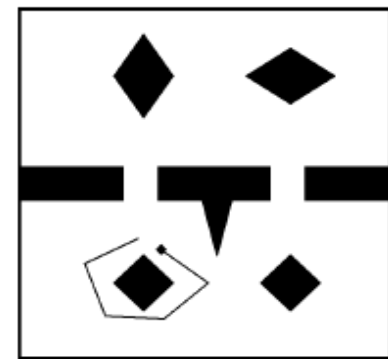
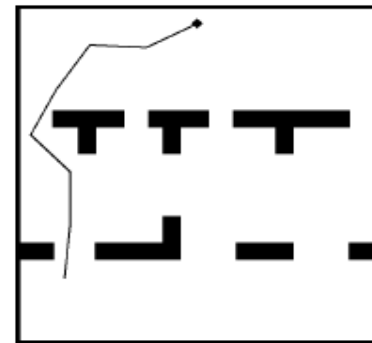
- (1) $N \leftarrow \emptyset$
- (2) $E \leftarrow \emptyset$
- (3) **loop**
- (4) $c \leftarrow$ a randomly chosen free configuration Collisions Check
- (5) $N_c \leftarrow$ a set of candidate neighbors of c chosen from N
- (6) $N \leftarrow N \cup \{c\}$
- (7) **forall** $n \in N_c$, in order of increasing $D(c, n)$ **do** Euclidean Distance in C-Space
- (8) **if** $\neg \text{same_connected_component}(c, n) \wedge \Delta(c, n)$ **then**
- (9) $E \leftarrow E \cup \{(c, n)\}$ Local Planner
- (10) update R 's connected components Avoid Cycles

Path Planning Model: Learning Phase

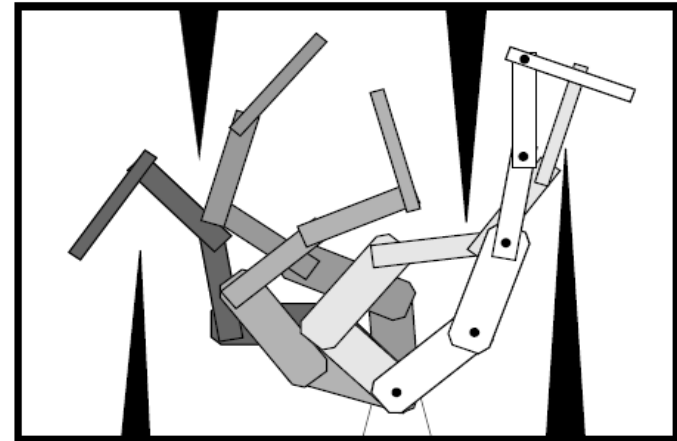
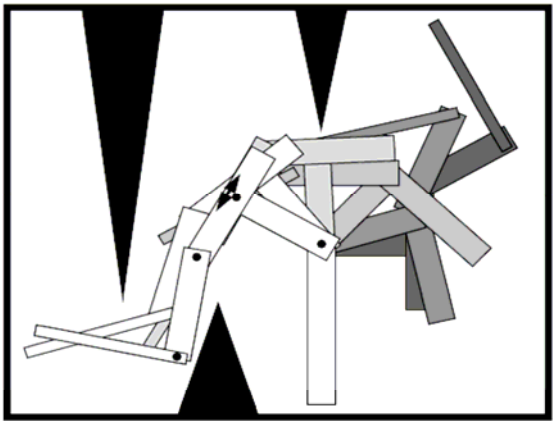
- Expansion Step
 - Select a few nodes from N that lie on difficult, narrow regions of C -space
 - Assign weight $w(c)$ to each node as a heuristic to measure the difficulty around node c . Heuristics:
 - Nearest neighbors around c
 - Distance to nearest disconnected component
 - Local Planner Success Rate
 - Perform short random bounce walks from node c
 - Save explicit path from c to n (non-deterministic path)

Experiments

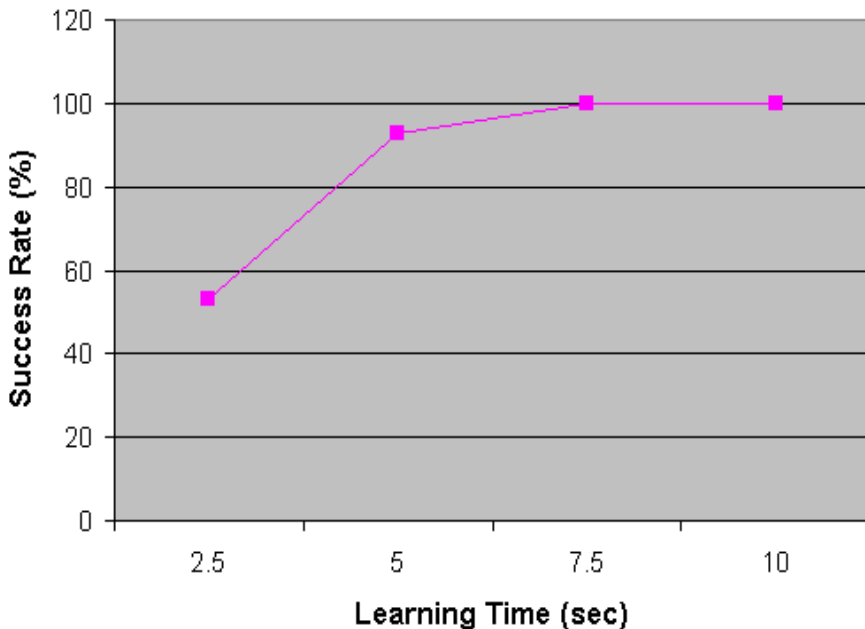
- Test 1: 2D, fixed base, 7 dof
 - Can a configuration be connected to the roadmap?
- Test 2: 2D, free base, 7 dof
 - Can a configuration be connected to the roadmap?
- Test 3: 2D, general case, 4 and 5 dof
 - Is there a path from start to Goal?



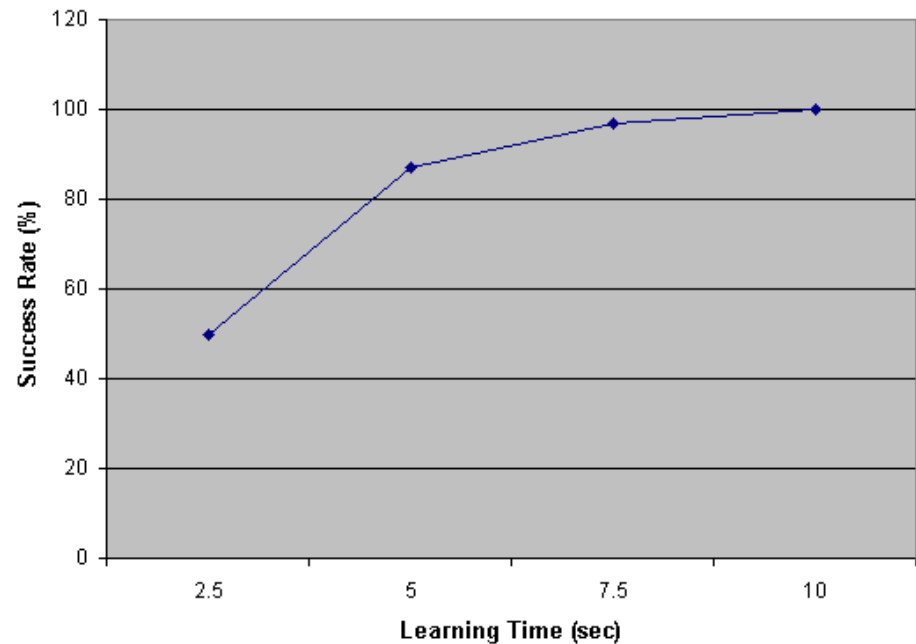
Test 3: General Implementation



Test 3: General Implementation, 2D, Scene 1, 4dof



Test 3: General Implementation, 2D, Scene 2, 5dof



Summary:

Probabilistic Roadmaps for Path Planning in High-Dimensional Configuration Spaces

- Probabilistic
 - Random Sampling of C-Space to generate nodes
- Roadmaps
 - Undirected Graph without cycles connecting similar configurations
- Path Planning
 - Find if we can change the configuration of a robot from a given starting configuration to a desired goal configuration
- High-Dimensional*
 - Tested a 7 Dimensional Robot, each Dimension represents a movable joint in an articulated robot
- Configuration Spaces
 - hyperspace containing all possible robot configuration, each configuration represented by a point in c-space.

Conclusion

- Limitations and Deficiencies:
 - High Dimensional *is* affected by curse of dimensionality
 - High Dimensions would result in very sparse roadmaps
 - Static Workspace is a significant limitation
 - Does Not generalize for dynamic environment
 - Bitmap Method for Collision Checking is limited to 2-D
 - High-resolution require large storage of bitmap
 - Finds “a Path” that might not be the shortest path
 - Does not allow cycles in the Graph (roadmap)
 - Does not reference any Manifold Techniques
 - focus on execution time instead of Graph size/Complexity
 - 150 MIPS (~150 MHz)
 - 126 SPECfp92 and 74.3 SPECint92

Discussion?

