Factor-Guided Motion Planning for a Robot Arm

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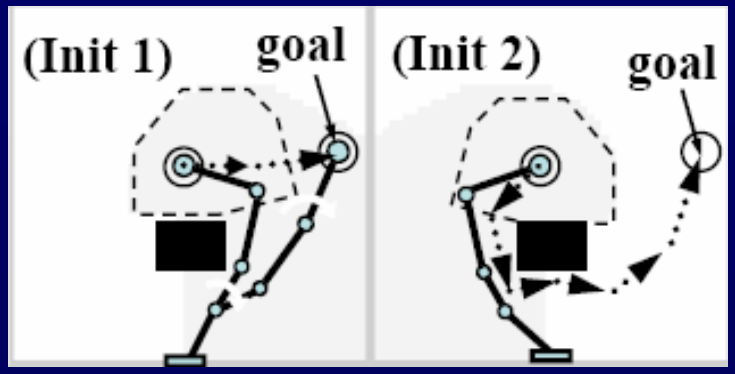
Problem Definition



- **Given:**
  - **A planar(2D) arm with n revolute joints**
  - **A Start configuration* (q_{init})**
  - **A Goal configuration (q_{goal})**
  - **Static obstacles (including island (or floating) obstacles)**

- **Goal:** finding a collision-free path from the q_{init} to q_{goal}

***Configuration: the vector of the angular values of all joints.**
(θ_1, θ_2, θ_3 …, θ_n)

Related Works in Motion Planning

- **Algorithms for a 2D planar robot are analyzed in many works:** Schwartz, Sharir, 1983; Maciejewski, Fox, 1993; Zlajpah, Nemec, 2002; **Likhachev, Gordon, Thrun, 2003 (ARA*), Liu, Trinkle, 2005, Tang, Thomas, Amato, 2006**

- **Workspace-based roadmap method is applied in many works:** Wilmarth, Amato, Maprm, 1999; Foskey, Garber, Lin, Manocha, 2001; Brock, Kavraki, 2001

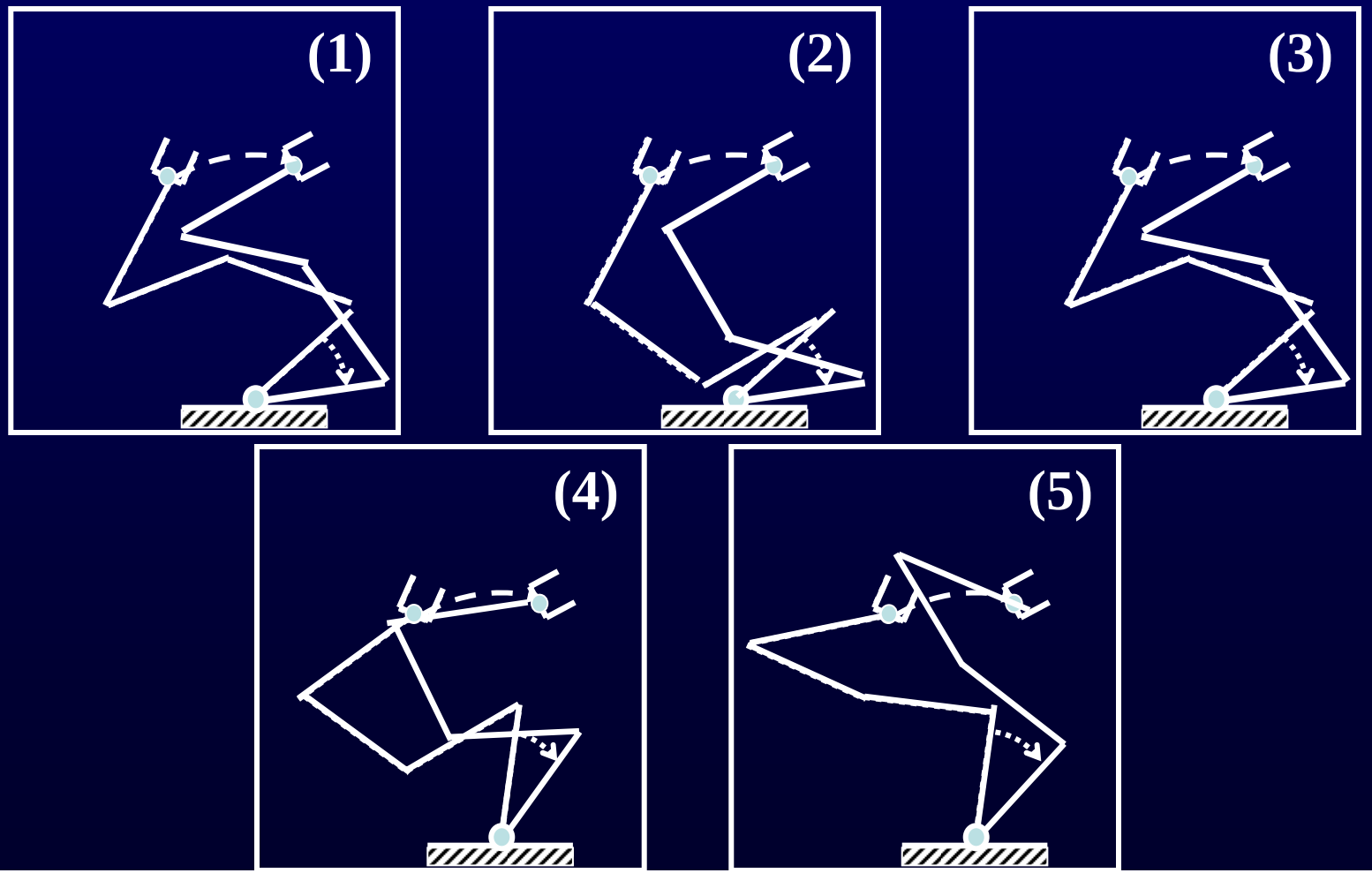
- **Efficient Grid-Based A* algorithms for robots: Stentz, 1995 (D*);** Koenig, Likhachev, 2002 (D* Lite); Likhachev, Gordon, Thrun, 2003 (ARA*)

Talk Outline

- **Problem Definition**
- **Motivation & Our Method**
- **Detail of Our Algorithm**
- **Complexity Analysis**
- **Experimental Results**
- **Conclusion**

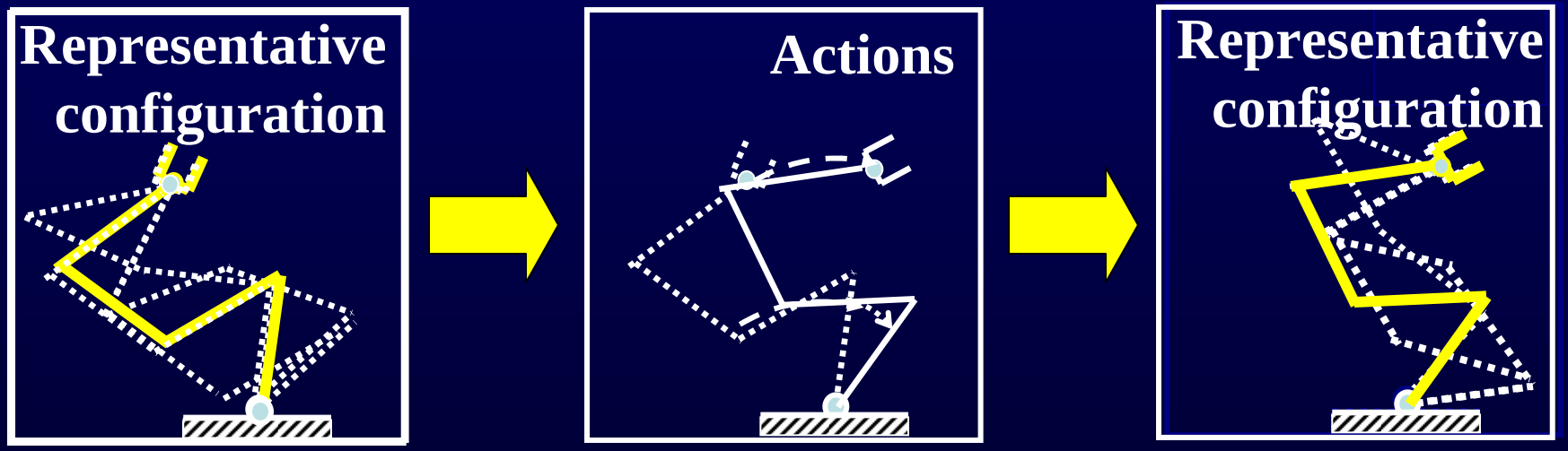
Motivation

- How **<u>different</u>** are **these movements**?
- **Our claim: These are not so different movements.**



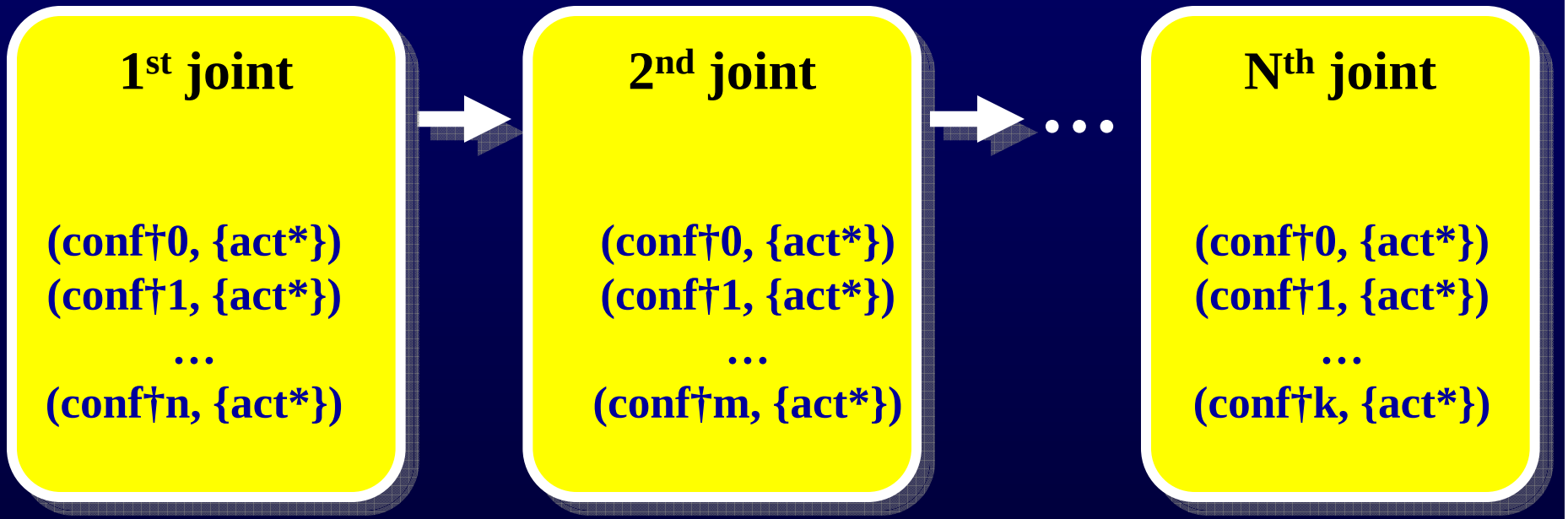
Our Method

- Reduce the complexity by using a **representative configuration**.



Our contribution:
(Dynamic Programming = Factored Planning)

- A polynomial time algorithm w/ dynamic programming

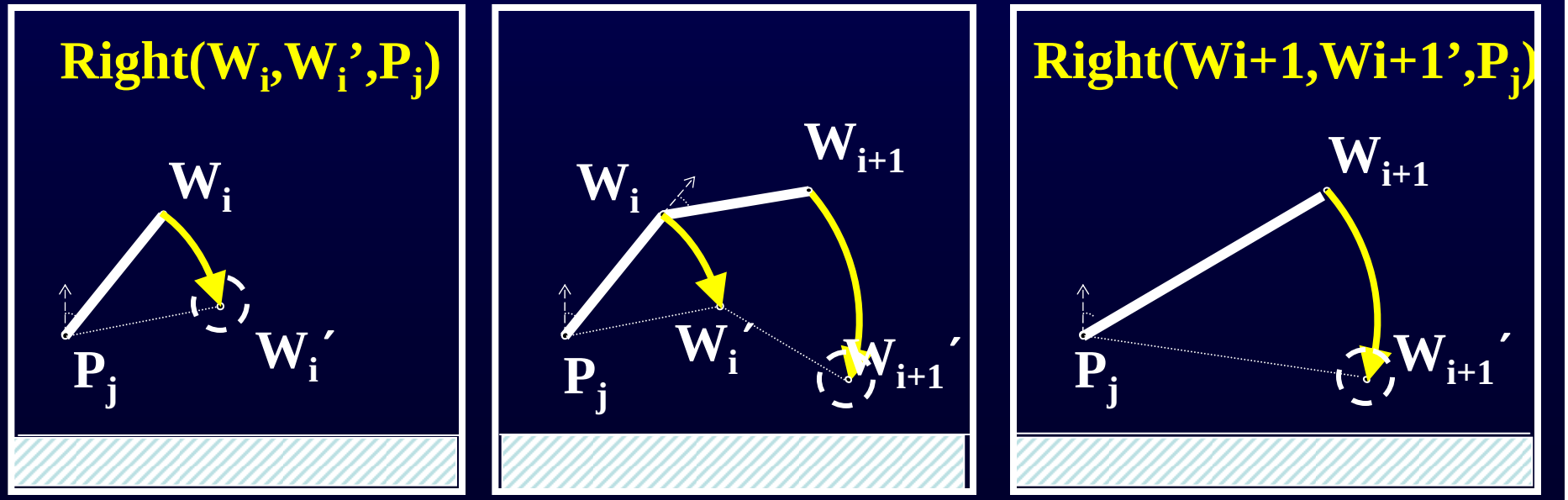


- The actions of each joint are independent on other joints except the previous joint (assumption)
- The i^{th} joint include all possible topological class of configurations and local actions of that joint

act*: actions / conf†: representative configuration

Propagating the actions

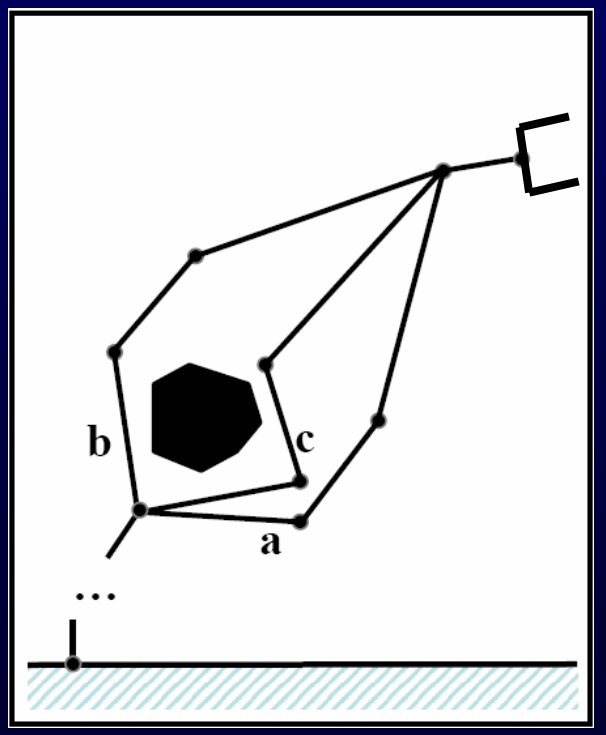
- A step of the Factored Planning
  - An action for i^{th} End Effector(EE) in PDDL
    - Right(W_i,W_i',P_j)
      - Pre: $end_j(P_j)$ ^ $end_i(W_i)$
      - Del: $end_i(W_i)$
      - Add: $end_i(W_i')$
    - $end_i(W)$ is true when the EE of i^{th} joint is at W



Merging the actions

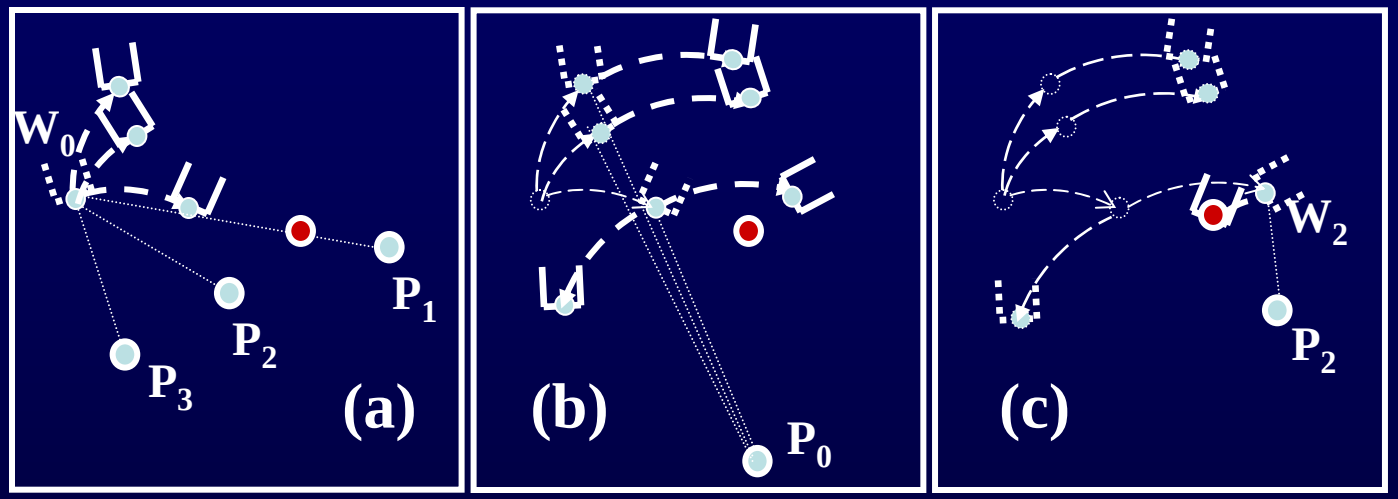
- Can we merge the set of actions in all cases? **No!**

- **A Topological Class of Configurations:** when the configurations are in the same direction to all obstacles in workspace.

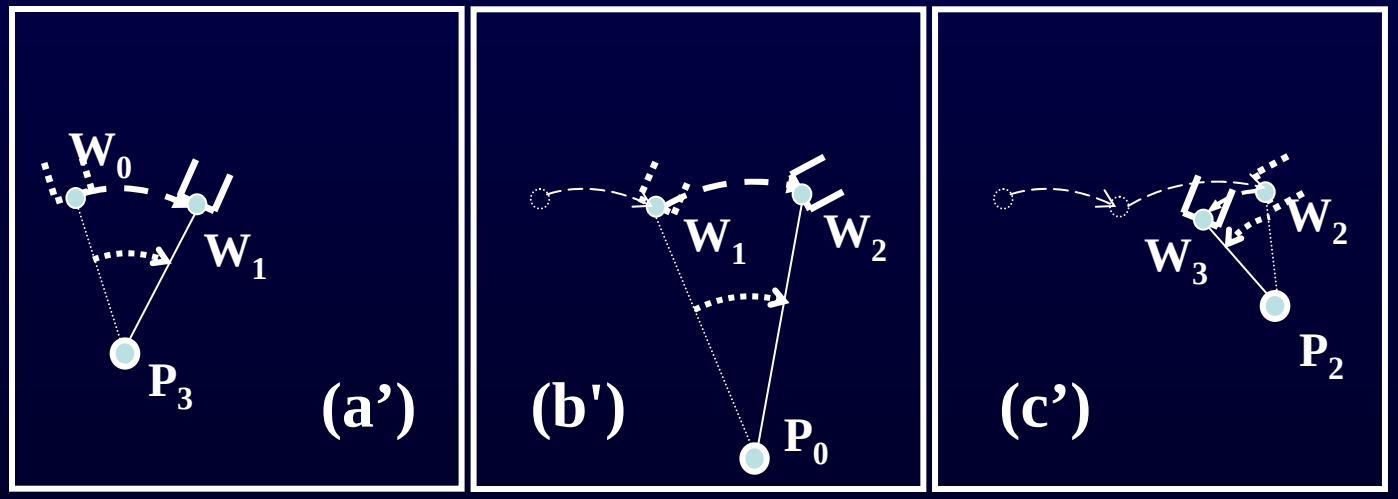


Finding a Path

- With **representatives configuration** and **sets of actions.**
- **Dynamic Programming like WaveFront* Method**



[Barraquand and Latombe, 1991]



[Local Planner: ARA*]

Complexity Analysis

- **Without obstacle**
  - **$O(n^4l)$**
- **With m island (floating) obstacles**
  - **$O(n^4l2^m)$: an island obstacle makes at most two topological class in workspace**

l: the number of joints of the arm

m: the number of island obstacles

n: length of a longer side of workspace

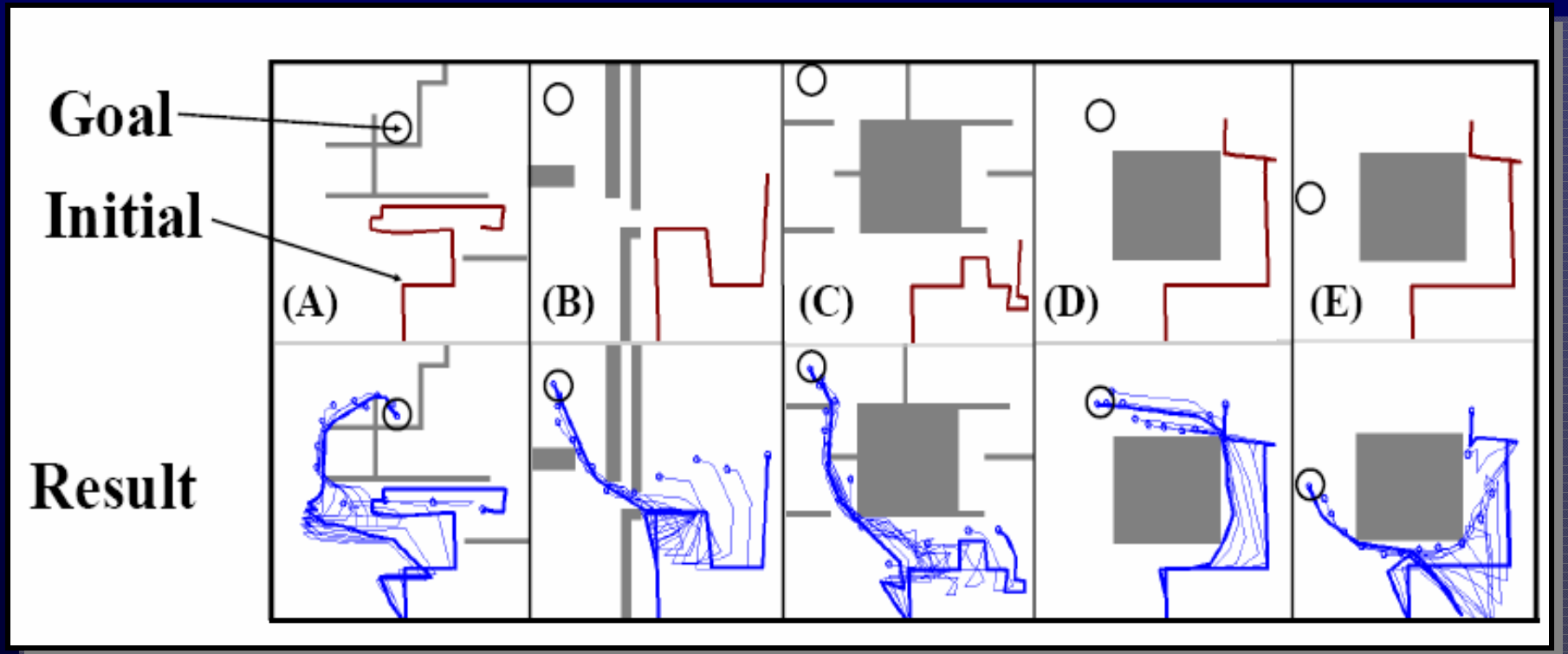
Assumption: given a problem, there is a polytime local planner that finds a path within a topological class

Benefit & Cost

- **Benefit**
  - **Efficient: only using Workspace (polynomial to the number of joints)**
  - **Decomposition: actions of a joint are independent on other joints except the previous joint.**
- **Cost**
  - **Local Planner***

***Assumption: if two configurations are in the same topological class and there is a path between them, our local planner finds the path**

Experimental Setting in Simulation



Experimental Result in Simulation

w/o self collision between links

Environments	ARA* (sec)	Factored Motion Planning	
		Preprocess (Sec)	Planning (Sec)
(A)	>580	19	83
(B)	78	12	5
(C)	17	12	2
(D)	4	27	3
(E)	>580	27	9

Experimental Result in Simulation

w/ self collision between links

Environments	ARA* (sec)	Factored Motion Planning	
		Preprocess (Sec)	Planning (Sec)
(A)	>580	19	193
(B)	>580	12	>580
(C)	13	12	2
(D)	5	27	4
(E)	>580	27	33

Conclusion

- **An algorithm whose complexity is polynomial to the number of joints $O(n^4l)$**
- **Key idea: group the configurations if they are in the same topological class against obstacles**
- **Future Works:**
  - **Extension to 3D work space**
  - **Combine with a sampling method (eg. RRT)**

Thank you!

question?

Thanks to Maxim Likhachev for providing his source codes for ARA*

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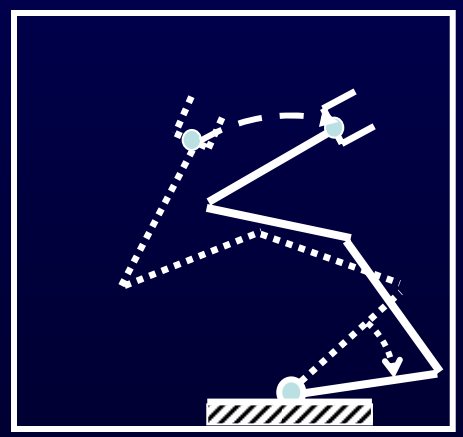
Domain Description

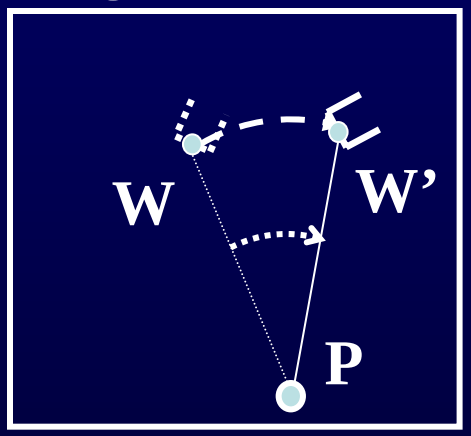
- Divide a movement into **an action** & **a representative conf.**
  - **An action has 3 conditions**
    - **A pre location (W)**
    - **A post location (W')**
    - **A pivot (P)**

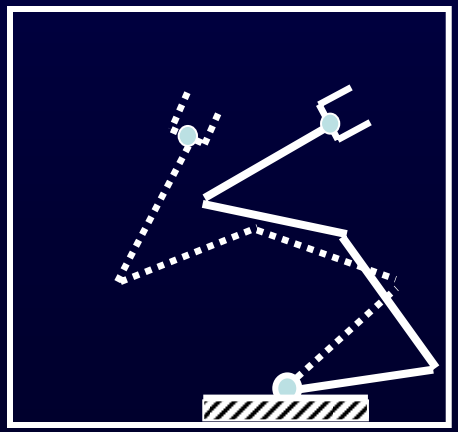


Action

Representative Configuration

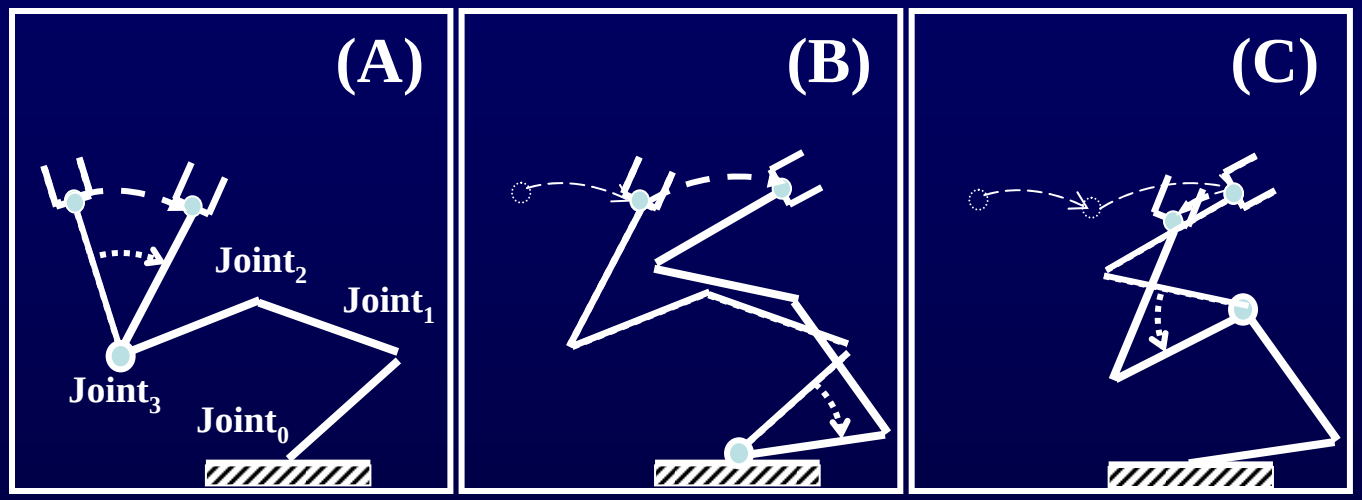
Right(W,W',P)





Problem Definition

- **An example of movement in Configuration Space**



Start conf.

Joint3	**Ang3**	**Move(A)**	**Ang3'**		
Joint2	Ang2		Ang2		
Joint1	Ang1		Ang1	**Move(B)**	Ang3'
Joint0	Ang0		**Ang0**		**Ang2**
					Ang1
					Ang0'

Move(C)	Ang3'	
	Ang2'	$O(c^N)$
	Ang1	**C: constant**
	Ang0'	

Goal conf.