USC Viterbi
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# Using Machine Learning Techniques for Speeding up Manipulator Path Planning to Find High Quality Paths in Cluttered Environments

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# Motivation

- Robot paths for repetitive tasks are typically manually programmed
- We need an approach for generating paths with the following attributes
  - Handle complex obstacles without failure
  - High-quality paths
  - Fast planning time

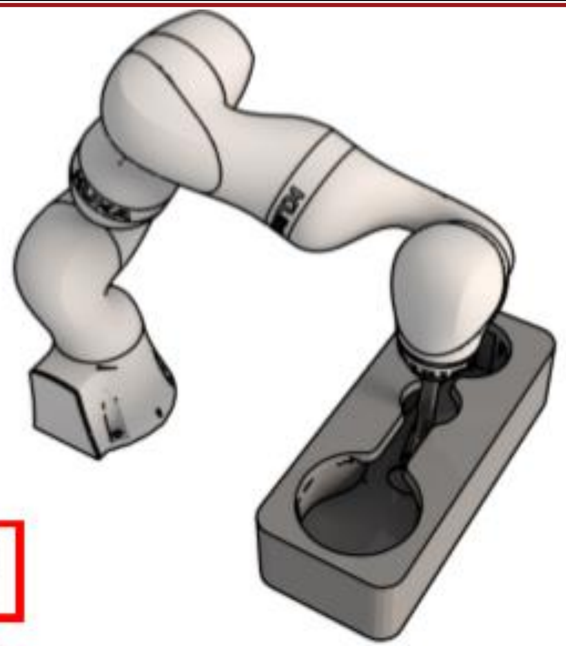
https://giphy.com/gifs/internet-of-things-X7iepbZ2WCCHe

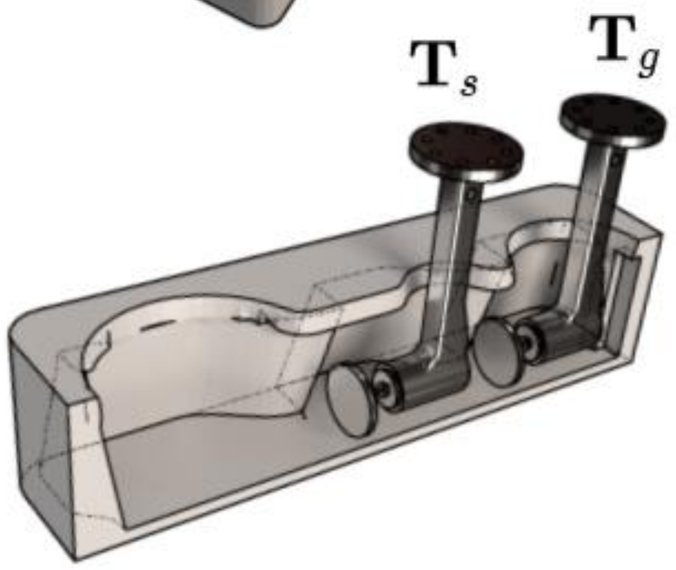
# Problem Statement

## Given:

| | |
|---|---|
| Workspace | $\mathcal{W}$ |
| Workspace obstacles | $\mathcal{O} \subset \mathcal{W}$ |
| Robot geometric model | $\mathcal{M}(\mathbf{q}) \subset \mathcal{W}$ |
| Robot kinematic model | $FK(\mathbf{q}), IK(\mathbf{T})$ |
| Configuration space obstacle | $\mathcal{C}_{obs} = \{\mathbf{q} : \mathcal{M}(\mathbf{q}) \cap \mathcal{O} \neq \emptyset\}$ |
| Start/Goal tool pose | $\mathbf{T}_s$ , $\mathbf{T}_g$ |

Not explicitly known






## Compute:

A collision-free continuous path $\mathbf{Q}(\mathbf{s}) : [0, 1] \mapsto \mathcal{C}_{free}$

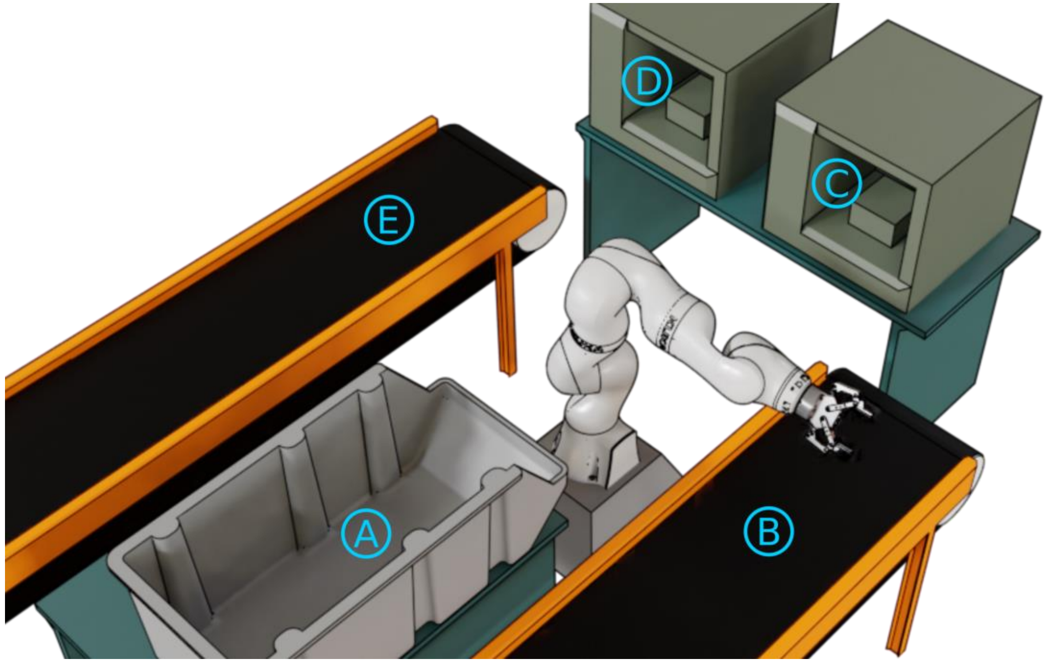
such that $FK(\mathbf{Q}(0)) = \mathbf{T}_s$

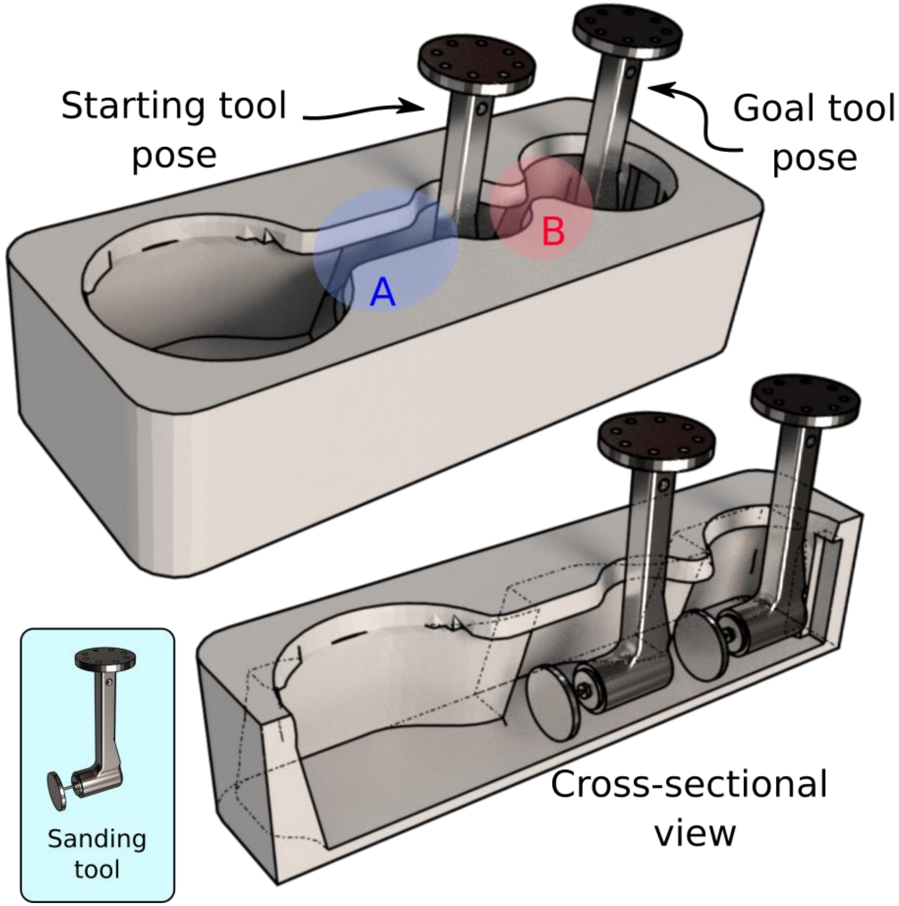
$$FK(\mathbf{Q}(1)) = \mathbf{T}_g$$

# Background

- Deterministic graph-search methods do not scale well in high-dimensions
  - A* graph search with worst case time-complexity $O(b^d)$
  - Require specialized heuristics to accelerate search
  - Fail to produce paths in reasonable time
- Sampling-based methods scale well in high-dimensions, but face challenges like
  - Narrow-passages (can occur due to complex obstacles)
  - Path quality is not very good

# Role of Workspace Hints

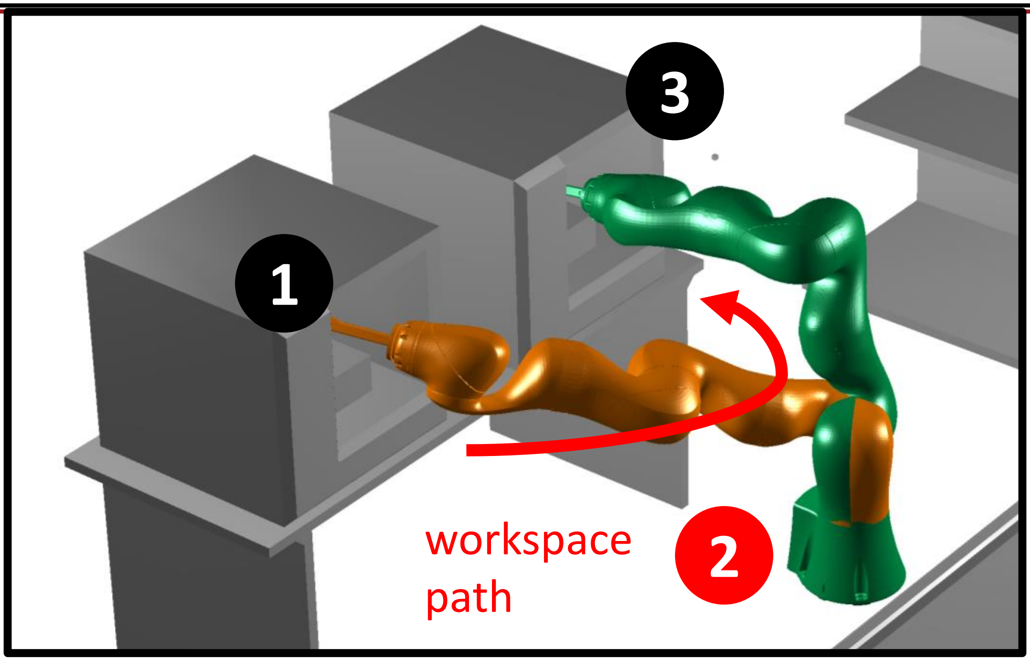



Workspace hints are useful

Workspace hints are not useful

# Approach Overview




1 3 Heavy configuration space sampling + Light workspace sampling

– to escape cavity and enter cavity

2 Light configuration space sampling + Heavy workspace path sampling

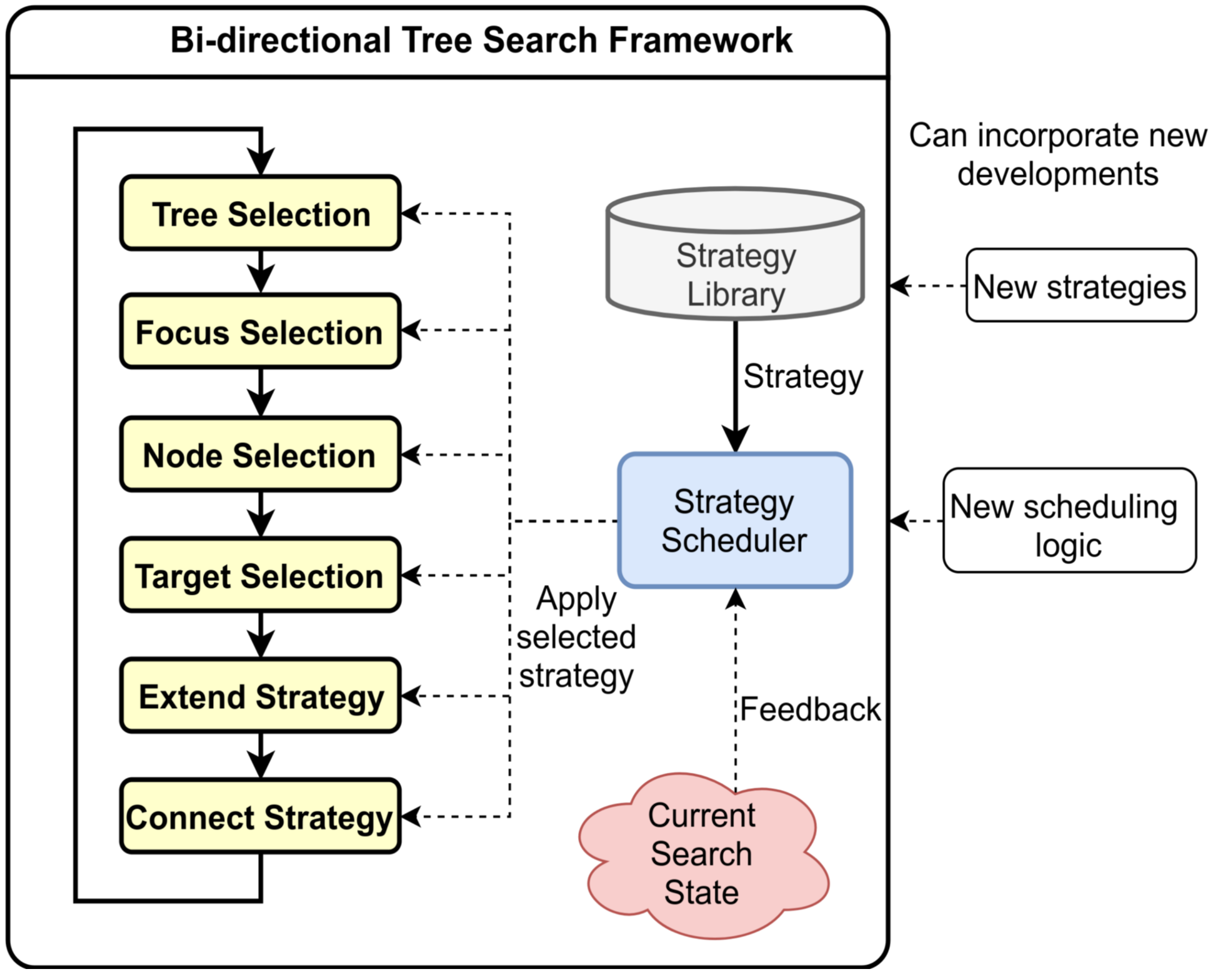
-- to quickly traverse large spaces

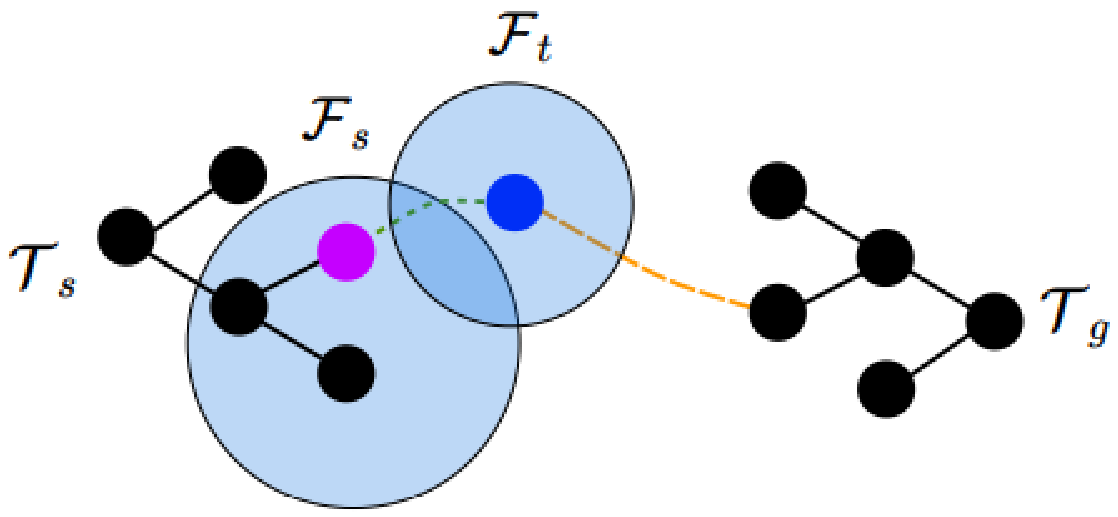
4

After a solution is found, we revert back to heavy focusing along workspace path.

We can do this as we have at least a solution. And now, we can invest rest of the time attempting to improve solution quality.

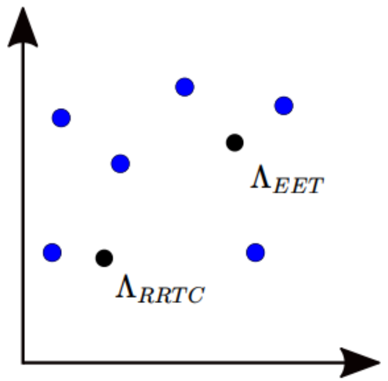
# Idea Behind Approach



# Using Learning to Guide Search

Search state
$\mathcal{S}$
↓
Dynamic Strategy Sequence
$\Lambda(\mathcal{S})$




CODES3

Config. space ↓ Workspace ↓

Initially, try using workspace hints —Set→

$$\lambda_{FS} = \{p_{FS_A} = 0, p_{FS_B} = 1\}$$
$$\lambda_{NS} = \{p_{NS_A} = 0.5, p_{NS_B} = 0.5\}$$
$$\lambda_{TaS} = \{p_{TaS_A} = 0.5, p_{TaS_B} = 0.5\}$$

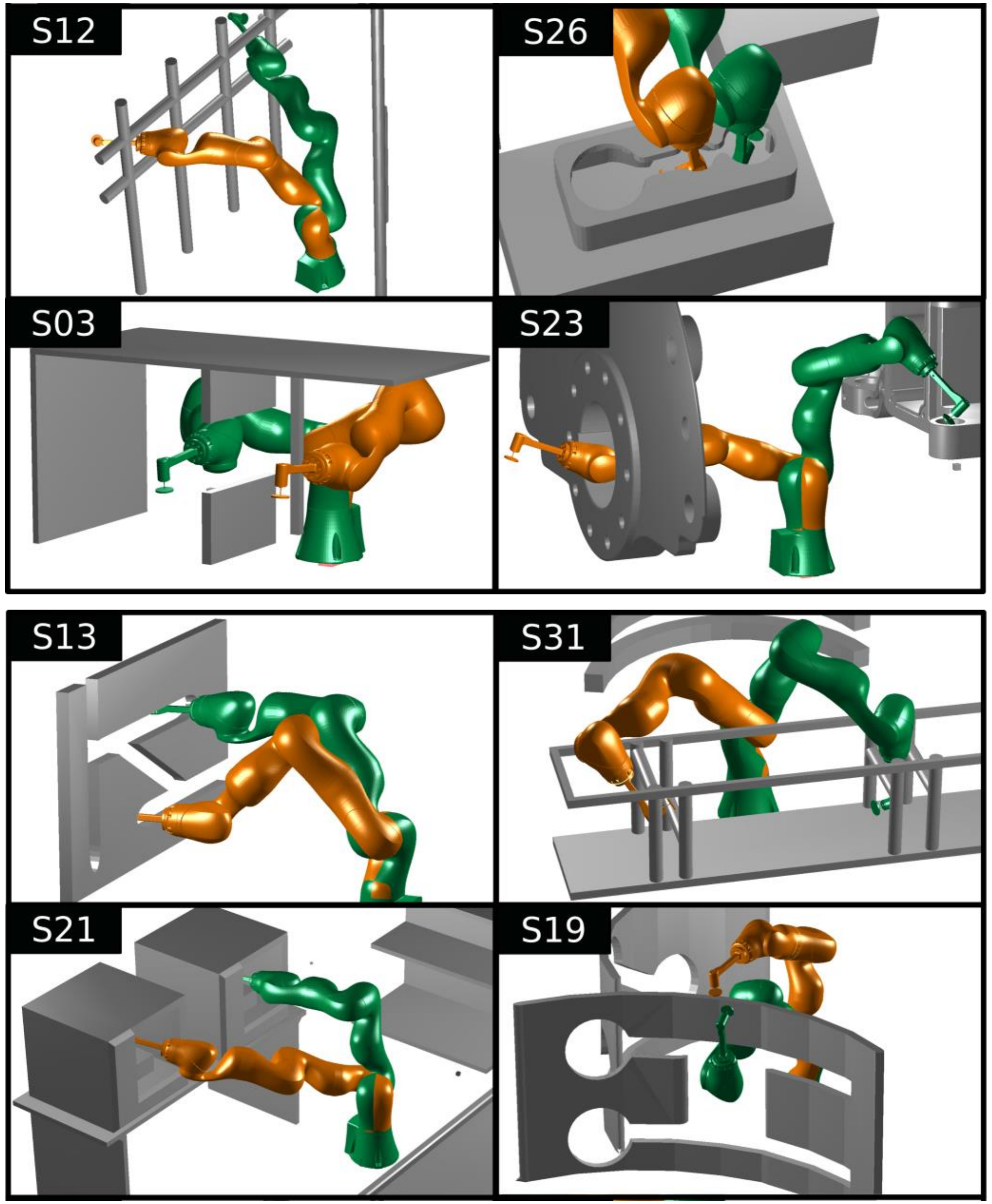
After collision queries exceeds a certain threshold —Update→

$$\lambda_{FS} = \{p_{FS_A} = 0.4, p_{FS_B} = 0.6\}$$

After a solution is found, revert to using workspace hints till timeout —Update→

$$\lambda_{FS} = \{p_{FS_A} = 0, p_{FS_B} = 1\}$$

# 30-problem Test Suite



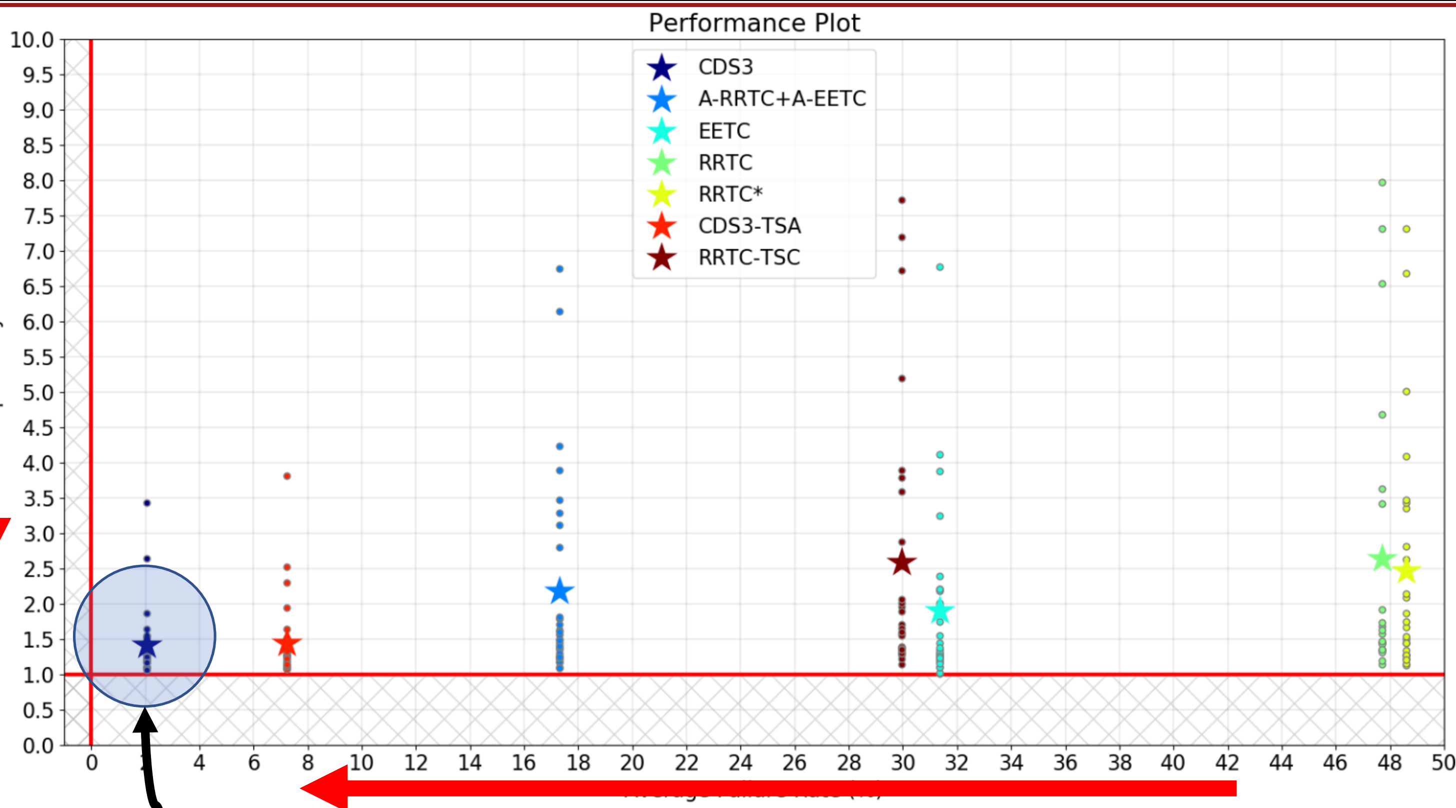

- Test suite contains
  - problems that vary in difficulty
  - problems motivated by real life applications in cluttered environments
  - problems with both informative and un-informative workspace cues
- All the tested methods are given deadline of 7.5 seconds to solve the problem
- Missing deadline => Failure

# Test Problems and Computed Solutions

https://www.youtube.com/watch?v=jjm2Y4lleP8

# Results on 30-problem test suite

Better solution quality




Lower failure rate

No solution in 7.5 s is considered a failure

**Failure rate: 2.05 %**
**Suboptimality factor: 1.42**

Our method CODES3 is able to solve tough problems **quickly** with **better path quality**

# References


- A. M. Kabir, B. C. Shah, and S. K. Gupta, “Trajectory planning for manipulators operating in confined workspaces,” in *IEEE International Conference on Automation Science and Engineering (CASE)*, Munich, Germany, Aug 2018
- P. Rajendran, S. Thakar, and S. K. Gupta, “User-guided path planning for redundant manipulators in highly constrained work environments,” in *IEEE International Conference on Automation Science and Engineering (CASE)*, Vancouver, Canada, August 2019
- P. Rajendran, S. Thakar, A. Kabir, B. Shah, and S. K. Gupta, “Context-dependent search for generating paths for redundant manipulators in cluttered environments,” in *IEEE International Conference on Intelligent Robots and Systems (IROS)*, Macau, China, November 2019