Optimality & Constraints in the Open Motion Planning Library

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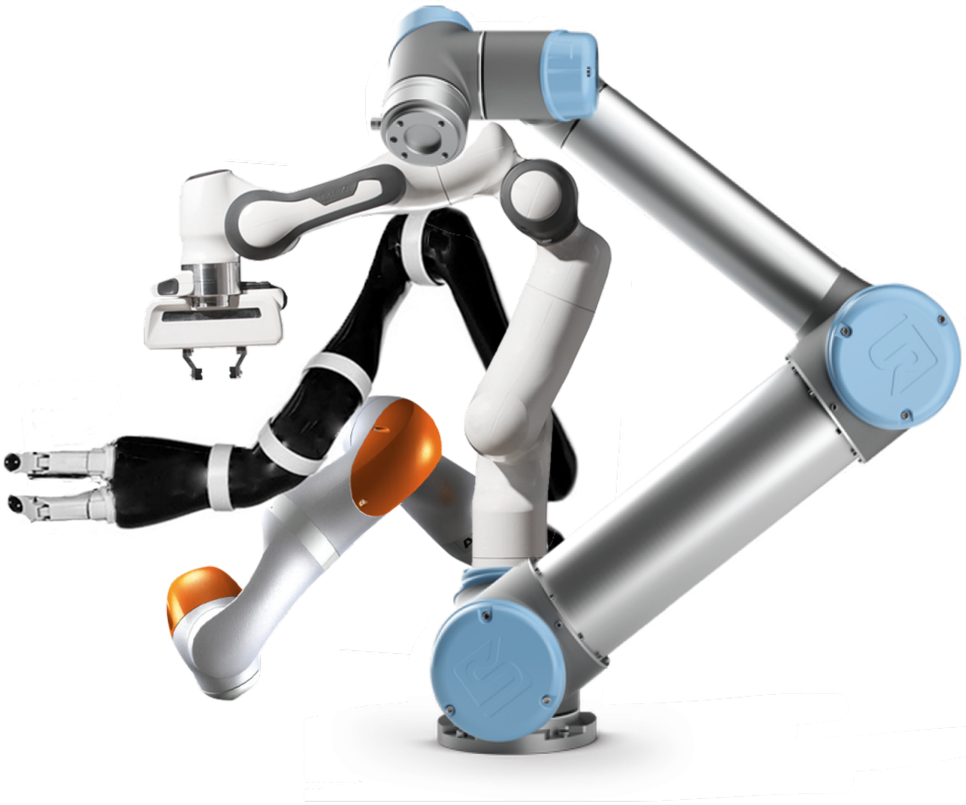
Outline

- OMPL overview
- Planning with costs
- Planning with constraints
- Planning with multiple goals
- Summary



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Preface

OMPL Overview

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OMPL: a generic motion planning library

- Focused on sampling-based algorithms
- Does not contain representations of robots / environments
- Higher-level robotics software framework is needed for OMPL to be practically useful:

MoveIt

Robotics Library

MORSE
the Modular OpenRobots Simulation Engine

v-rep
virtual robot experimentation platform

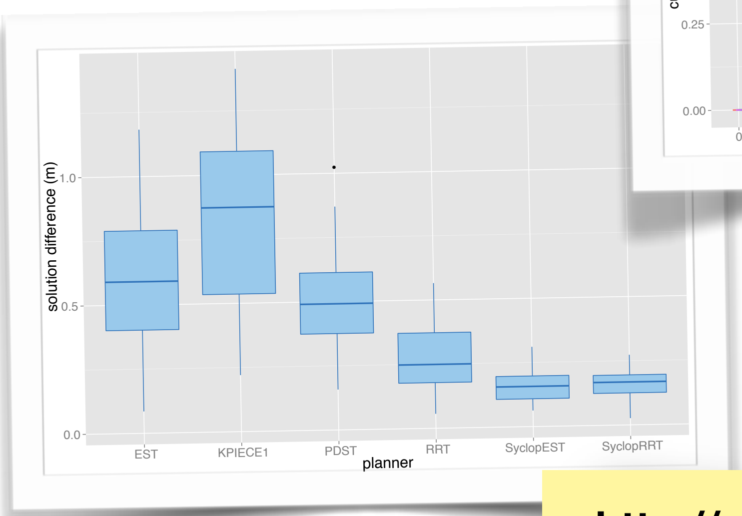
VEROSIM
SOLUTIONS

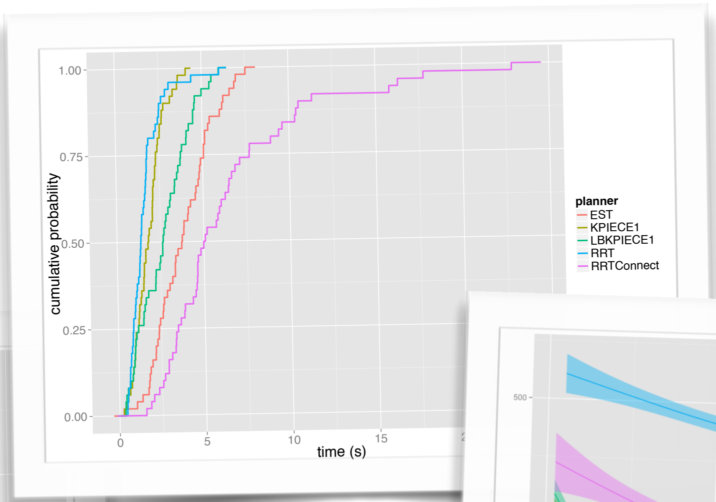
OpenRAVE

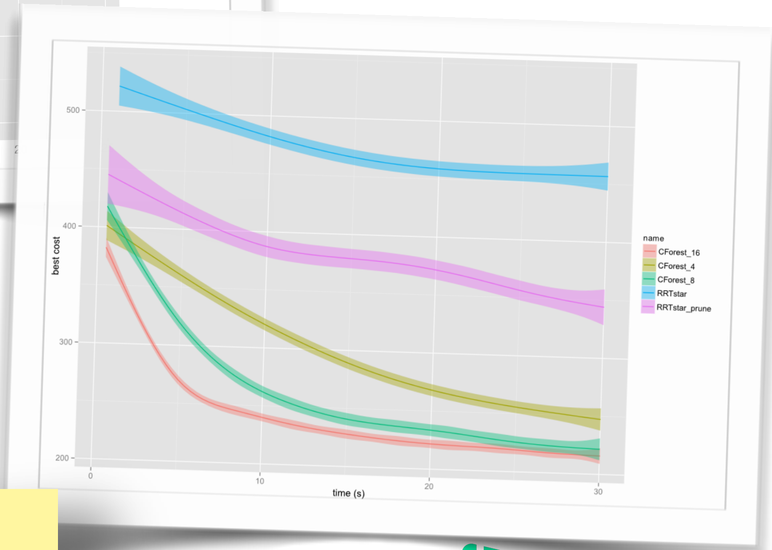
OMPL metrics

- > 2,600 **registered** users (many more get OMPL from package managers or do not register)
- > 70,000 downloads
- > 800 citations
- OMPL web site since January 2011:
  - ~500,000 sessions
  - ~200,000 unique visitors
  - ~2,000,000 page views

Benchmarking







http://plannerarena.org

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Part 1

Planning with costs

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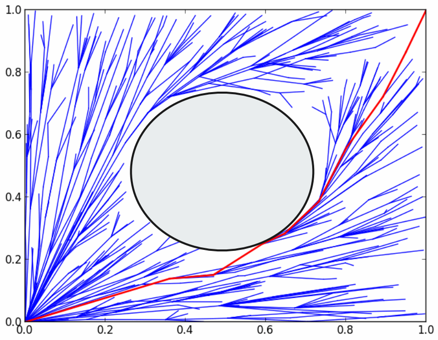
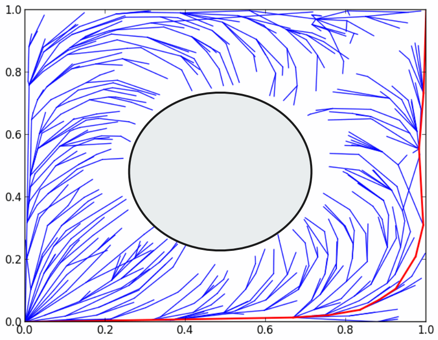
What is *optimal* motion?

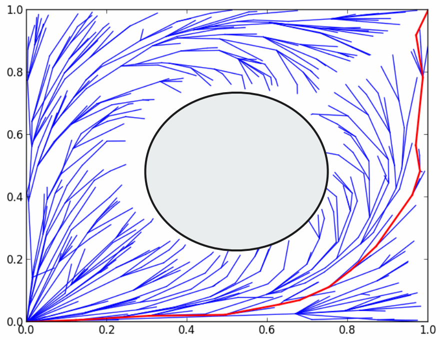
- Shortest? (Using what distance metric?)
- Smoothest?
- Safest?



path length



clearance



combination

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General cost infrastructure

- Costs can be defined per state (waypoint) along a path (e.g., using a cost map)
- Additionally, the cost of the motion between waypoints can be defined (e.g., path length)
- The way costs are aggregated can be defined (sum, min, max, etc.)
- Terminal costs, admissible heuristics
- Many optimizing planners (with different optimality guarantees)
  - PRM*, RRT*, BIT*, FMT, SST, ...
- Path post-processing tools are (mostly) cost-aware

A counterintuitive way to optimize paths

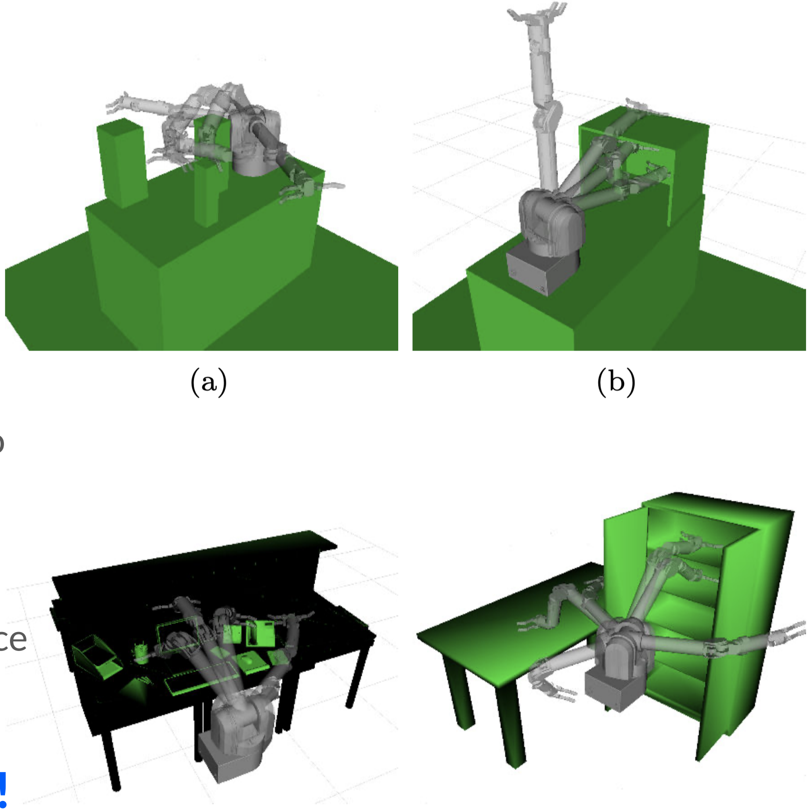
1. Use a bag of planners to compute feasible (but suboptimal) solution paths
2. Simplify and hybridize paths (graft good partial path segments together)
3. Repeat until convergence / timeout (keep all solution paths from all previous iterations)

→ **Converges faster than most planners that explicitly optimize!**

More testing needed to select good portfolio of planners to get good trade-offs in (1) path quality, (2) compute time, (3) repeatability.

R. Luna, I. A. Șucan, M. Moll, and L. E. Kavraki, "Anytime solution optimization for sampling-based motion planning," ICRA 2013

OMPL & other path optimization techniques



OMPL:
typically fast at finding feasible solutions, convergence to optimal is slow

Trajectory optimization (CHOMP, TrajOpt, GPMP2):
fast, but current implementations still fail often to produce feasible trajectories

OMPL + trajectory optimization: win-win!

B. Willey, "Combining sampling and optimizing in robotic path planning," Master's thesis, Department of Computer Science, Rice University, Houston, Texas, Aug. 2018.

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Part 2

Planning with Constraints

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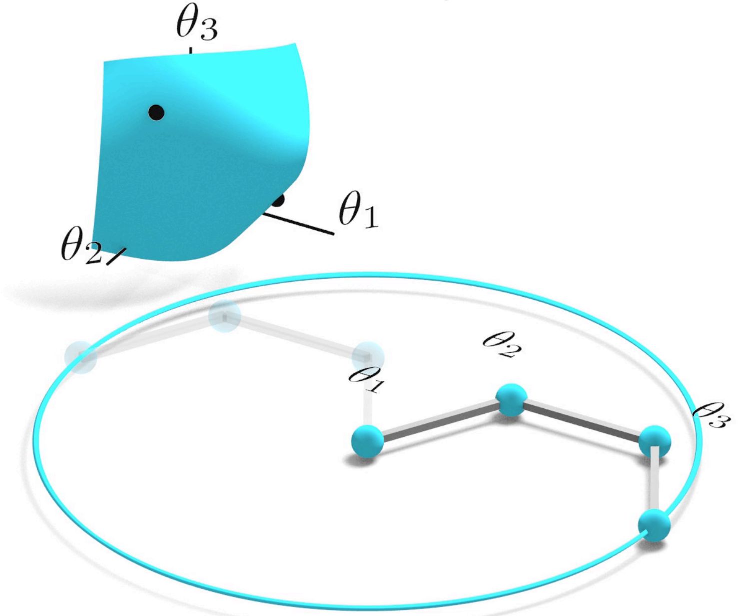
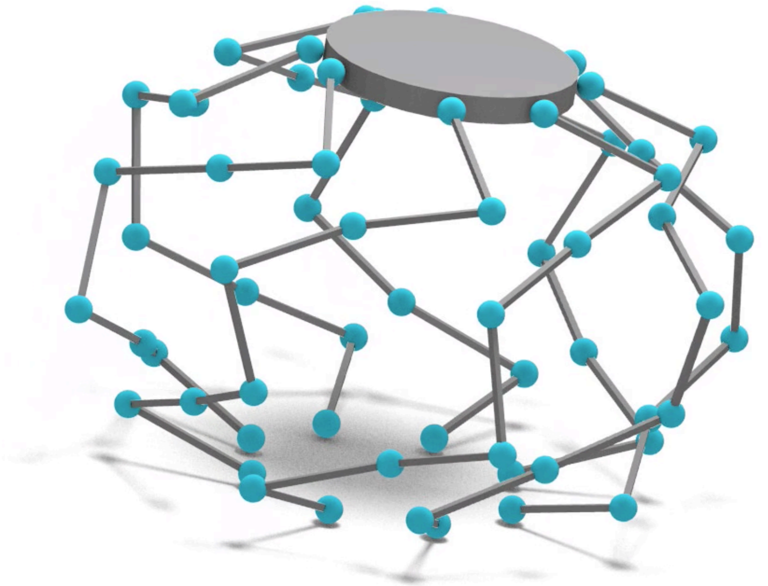
Constrained motion planning



Z. Kingston, M. Moll, and L. E. Kavraki, “Exploring implicit spaces for constrained sampling-based planning,” IJRR 38(10–11):1151–1178, Sept. 2019.



168 degrees of freedom
69 constraints

motion planned in ~14.5s.

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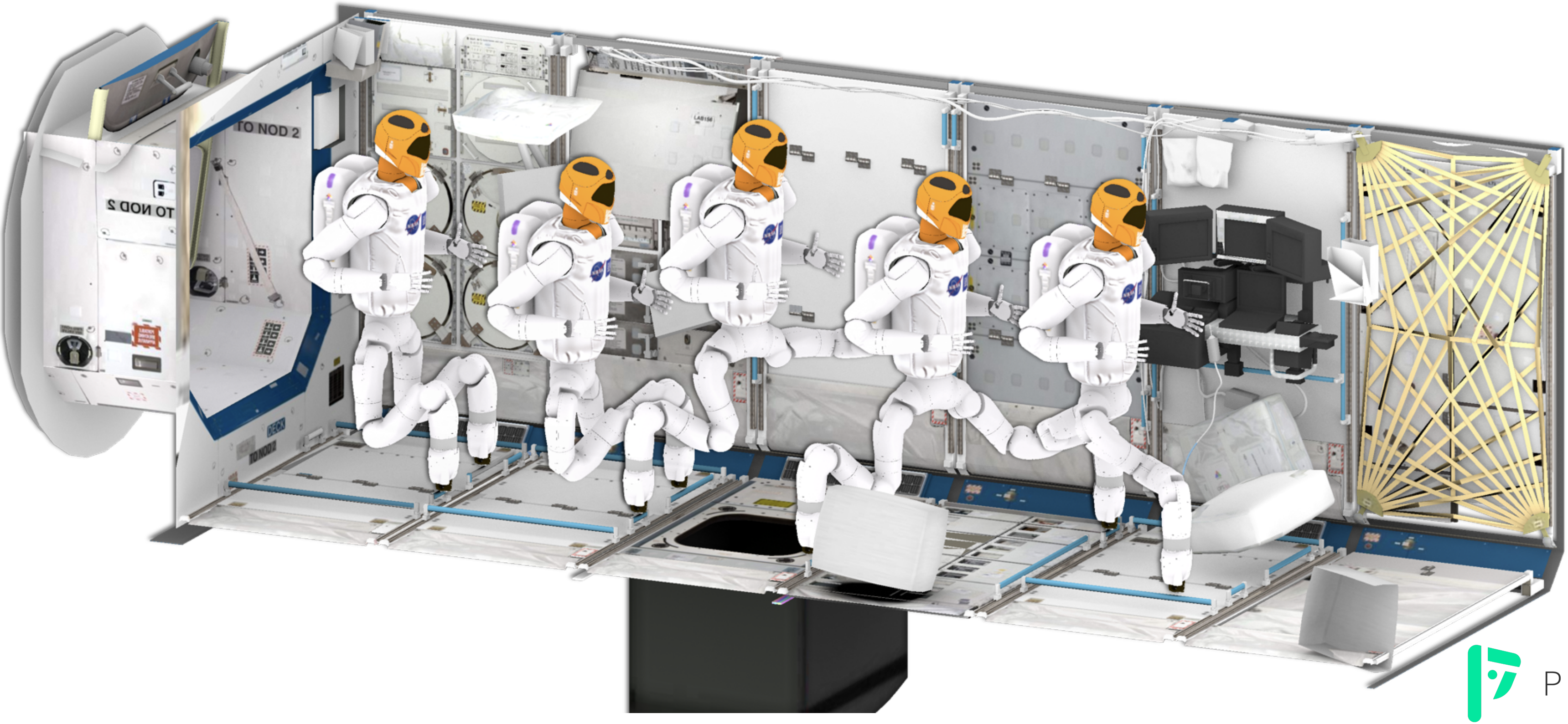
NASA's Robonaut2 climbing inside the ISS



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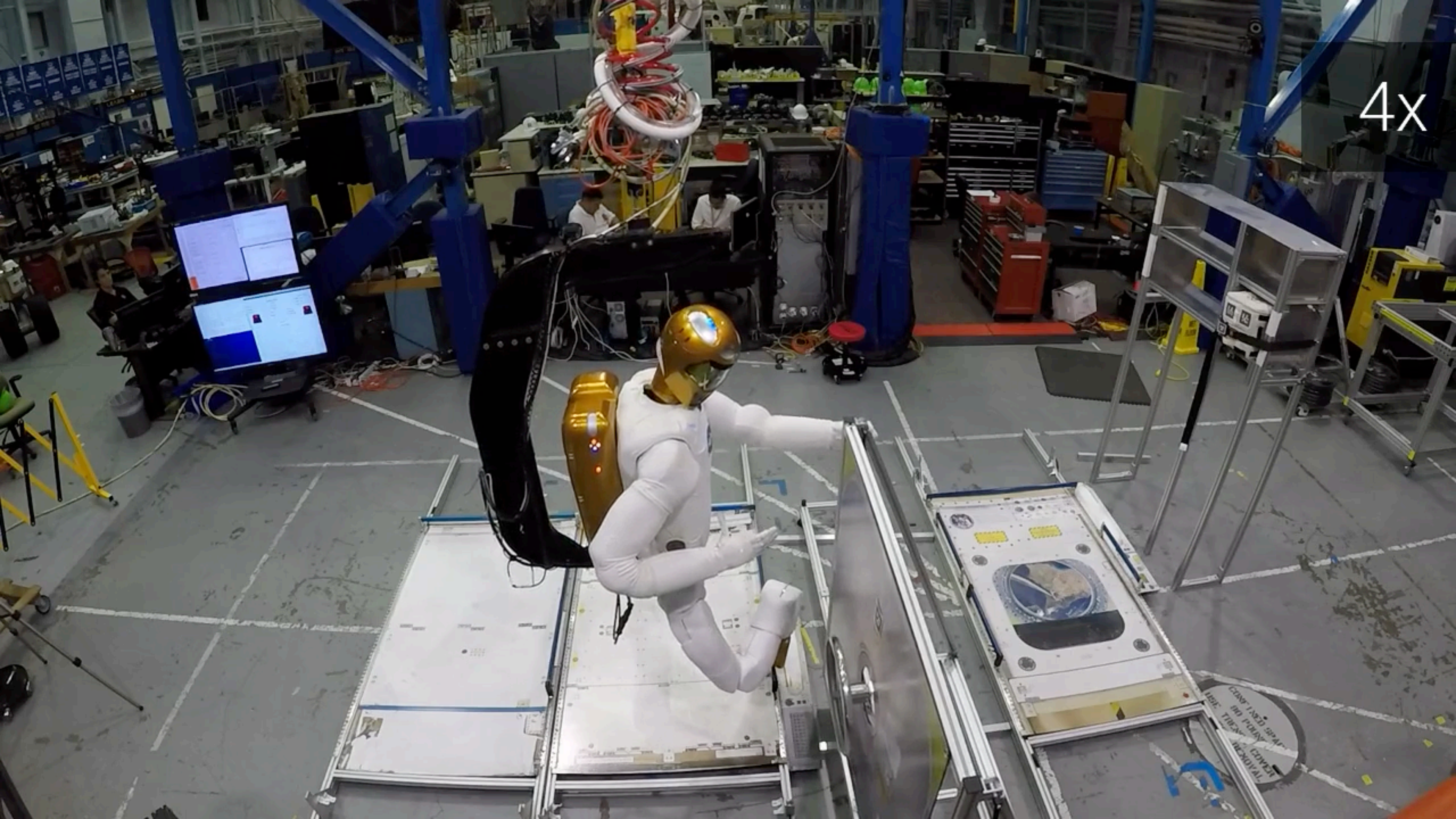
4x

Part 3

Planning with Multiple Goals

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Motivation

High-level specifications often have multiple valid interpretations.

Can translate interpretations to (sub)goals for motion planning.

"pick up one of the white blocks"

Problem:
how to choose "good" goals:
feasible IK solutions exist and is reachable from current pose

J. D. Hernández, M. Moll, and L. E. Kavraki, "Lazy evaluation of goal specifications guided by motion planning," ICRA 2019.

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Approach

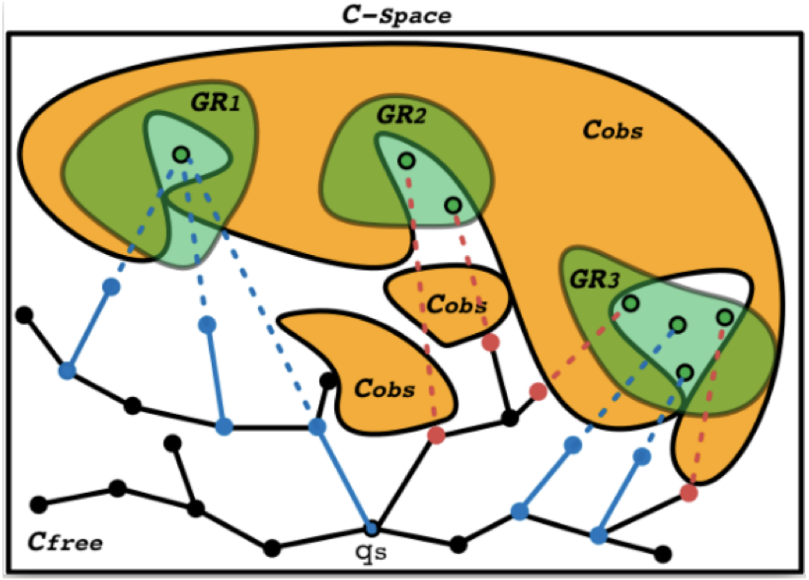
(for pick-and-place tasks):

Create implicit goal regions corresponding to all possible interpretations (e.g., end effector constraints, placement constraints).

Grow search tree, bias towards “best” goal state.

Initial goal cost can be based on heuristic (cost to come)

During planning, cost is adjusted through penalty-reward scheme based on success in expanding towards goal state.



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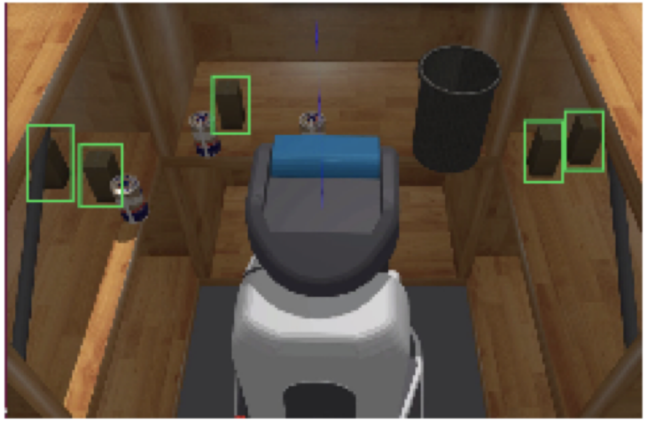
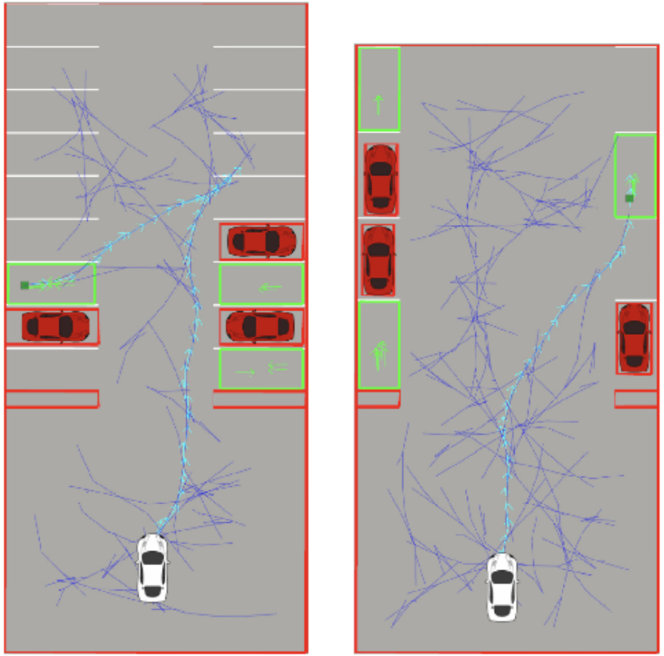
Experiments

~50% faster in finding feasible solution compared to considering all goals equally likely.



"Pick up any of the blocks"



(a) Scenario 1 (b) Scenario 2

"Park in any of the green spaces"

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Summary & future work

OMPL feature	Status in MoveIt
Planning with costs	Available now
Planning with constraints	Research code, significant work to make it a general purpose feature
Planning with multiple goals	Research code, no timeline yet for getting into MoveIt

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