Task-Oriented Planning for Manipulating Articulated Mechanisms under Model Uncertainty

Venkatraman Narayanan and Maxim Likhachev

Carnegie Mellon
THE ROBOTICS INSTITUTE

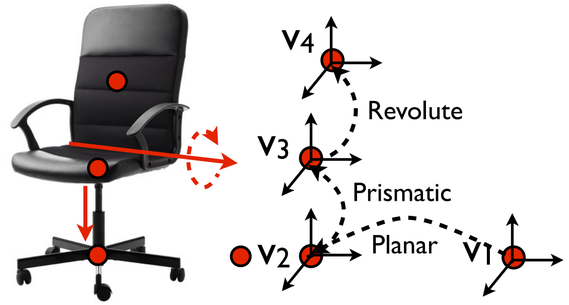
Articulated Objects

- Many household objects are articulated--doors, drawers, cabinets etc.
- Must understand the articulation (kinematic constraints) to manipulate these objects
- Existing approaches [1,2] are 'exploratory' learning methods: no task-grounding

Contributions

- A novel representation called the Generalized Kinematic Graph (GK-Graph) for modeling complex objects
- A planning formulation that reasons about uncertainty over candidate articulation models to accomplish a specific task
- Perception pipeline for auto-generating candidate articulation models

Generalized Kinematic (GK) Graph



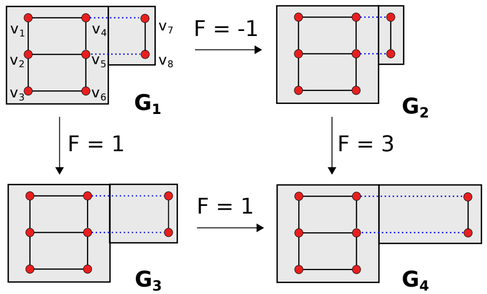
G = (V, E) vertex v: 6 DoF pose
edge e: <model type, parameters>

Allow edges to be a function of all vertices

e = f(V)

e.g., "revolute when handle turned, rigid otherwise"

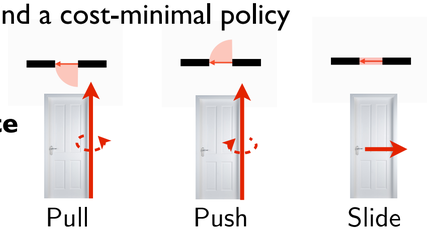
Planning with the GK-Graph



Planning under Uncertainty

Given N candidate articulation models (GK-Graphs) and a goal, find a cost-minimal policy

Candidate models



Goal

"can go through" "bowl visible"

POMDP formulation

State $s \in \mathcal{S} : \langle x, \theta \rangle$

Set of vertices in GK-Graph

Candidate models $\theta \in \{\theta_i\}$

- Following assumptions make tractable belief-MDP's dimensionality and branching factor

Uncertainty only over θ (mixed-observable MDP)

⇨ Don't need belief over all states $b(s)$
Sufficient to maintain $b_x(\theta)$

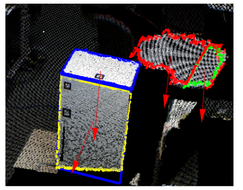
Transitions are deterministic given θ

⇨ Transitions in the belief space can produce at most N successor states

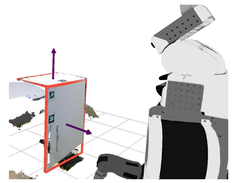
- Use LAO* [3] to efficiently solve belief-MDP

Evaluation

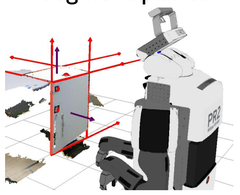
Perception Pipeline



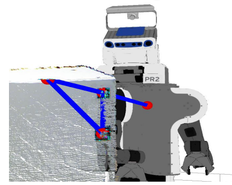
Segment planes



Fit rectangles



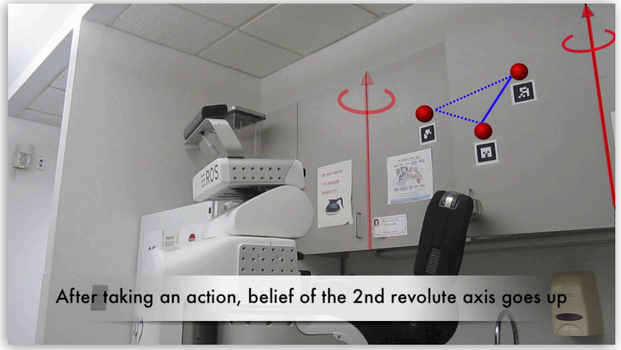
Generate candidate axes



Assign GK-Graph edges

PR2 Experiments

- Actions: forces sampled from unit sphere
- 5-10 candidate models per trial
- Interleave planning and execution
- Planning times ~ 5s, up to 4 replans
- Code: *github.com/venkatrn/ltm*



References

[1] Katz and Brock (ICRA '08, ICRA '13)
[2] Sturm et al. (IJCAI '09, Springer '13)
[3] Hansen and Zilberstein (AI '01)