HEURISTIC SEARCH FOR TASK AND MOTION PLANNING

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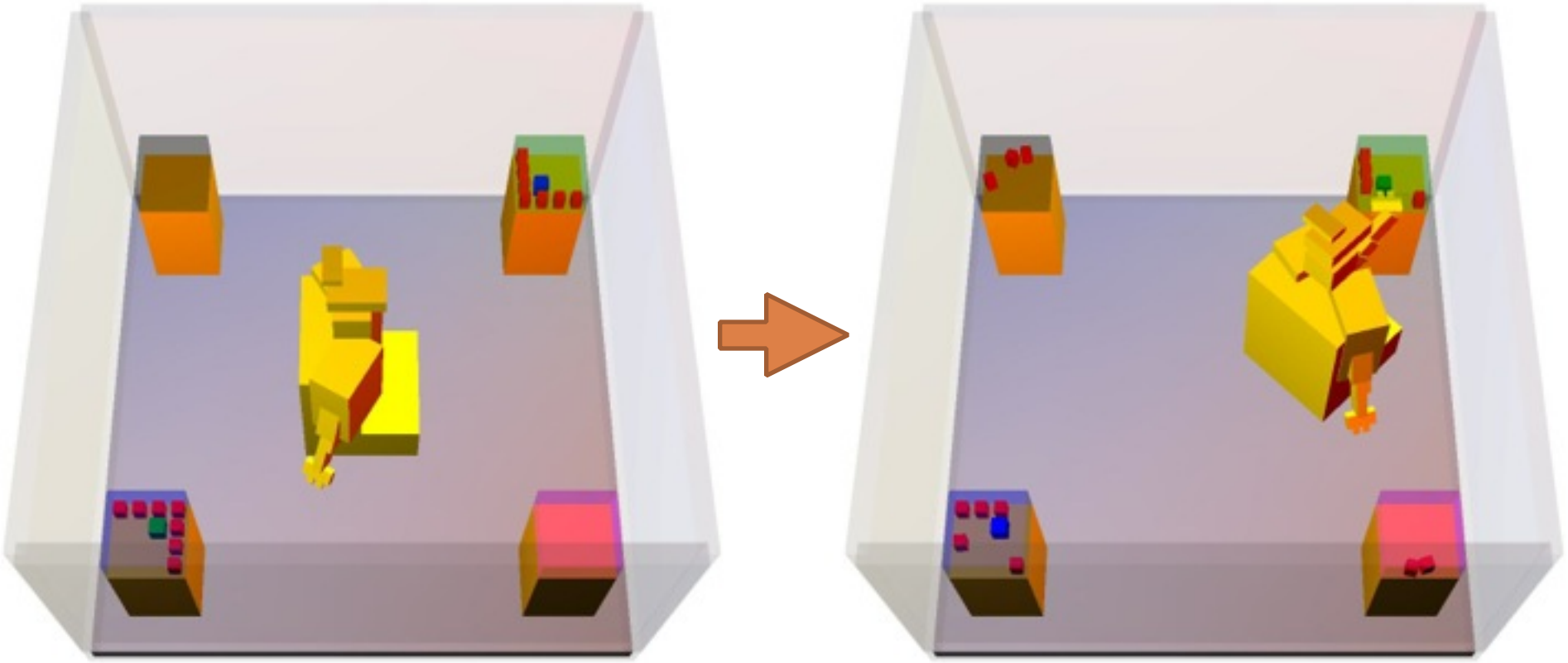
Task and Motion Planning

- Plan for robotic tasks like cooking dinner
- **Task planning** abstracts long action sequences
  - Doesn't involve geometry or kinematics
- **Motion planning** uses geometry and kinematics
  - Bad with long, multi-action plans

- **Pick and place** manipulation problem
- Geometric and kinematic constraints introduce substantial complication over blocks world

Swap Green and Blue Blocks



Prior Work

- Flavors of integration
  - **Motion planner guided by symbolic heuristic**
    - eg: Cambon et al.
  - **Symbolic planner with geometric predicates**
    - eg: Dornhege & Nebel
  - **Others**
    - eg: Srivastava, Lagriffoul, Saffiotti, …

Our Approach: Tight Integration

- None of these approaches fully incorporate symbolic and geometric information in heuristic
- Incorporating geometric information results in stronger heuristic
- Heuristic must be efficient to compute
  - Geometry queries are expensive
  - Need to reuse work

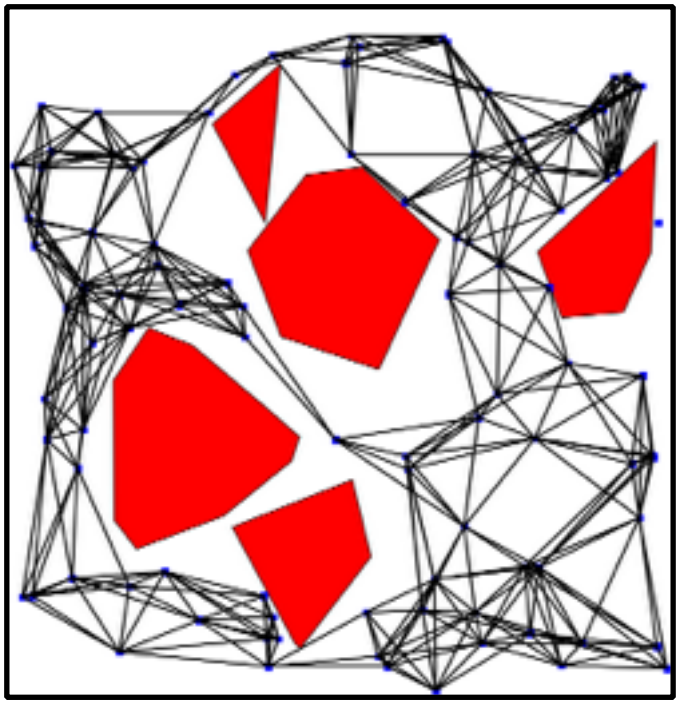
Mixed Discrete & Continuous Spaces

- Common approaches for handling motions
  - **Sampling (PRM & RRT)**
  - Optimization (CHOMP & Trajopt)
  - Combinatorial obstacle structure (Visibility Graph)

- Our approach
  - Discretize through task driven random sampling
  - Sample robot configuration and problem specific parameters (placements, grasps, etc)

Sample-Based Motion Planning

- Probabilistic roadmap (PRM)
  - Multi-query graph
  - Sample robot configurations
  - Connect nearby configurations
- Many variations that are more dynamic (RRT, etc…)
- Adaptively sample robot configurations until a feasible path exists



Pick and Place

- **Pick and place operator variables**
  - Start and end configurations - C1 & C2 (continuous)
  - Object - O (discrete)
  - Grasp - G (discrete in our formulation)
  - Placement - P (continuous)

Partial Operator Descriptions

- ***Pick(C1, O, G, P, C2)*:**
  - *pre: HandEmpty, Pose(O, P), RobotConf(C1),*
    CanGrasp(O, P, G, C2)
  - *add: Holding(O, G), RobotConf(C2)*
  - *delete: HandEmpty, RobotConf(C1)*

- ***Place(C1, O, G, P, C2)*:**
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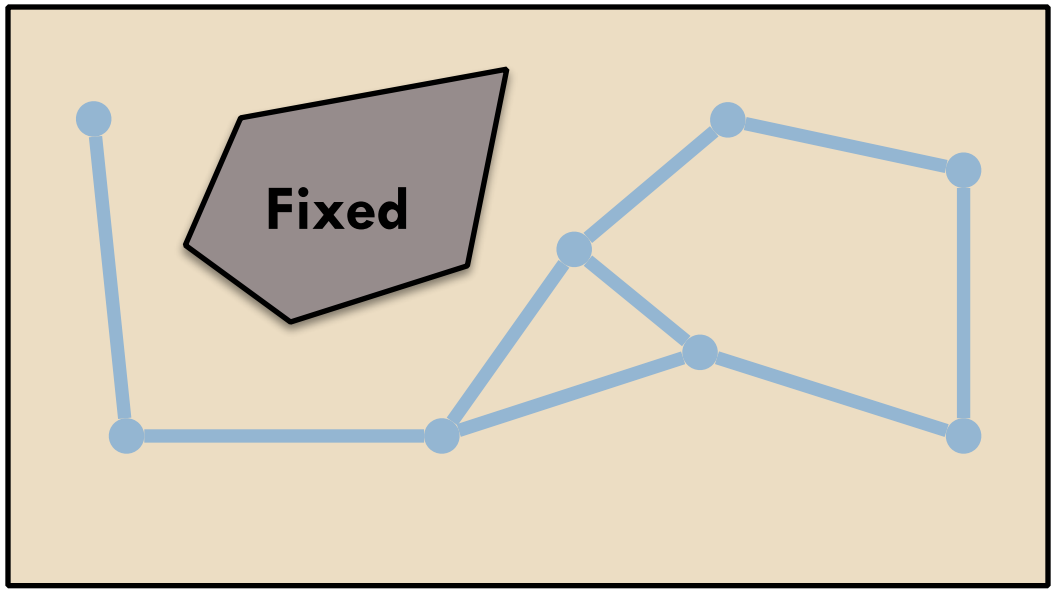
Conditional Reachability Graph

- CRG similar to a PRM but with moveable obstacles
- Additional geometric inference for the state
- Answers ***Reachable(C1,C2)*** queries for a state, conditional on object placements and grasp
- Shared between search and heuristic to reuse work



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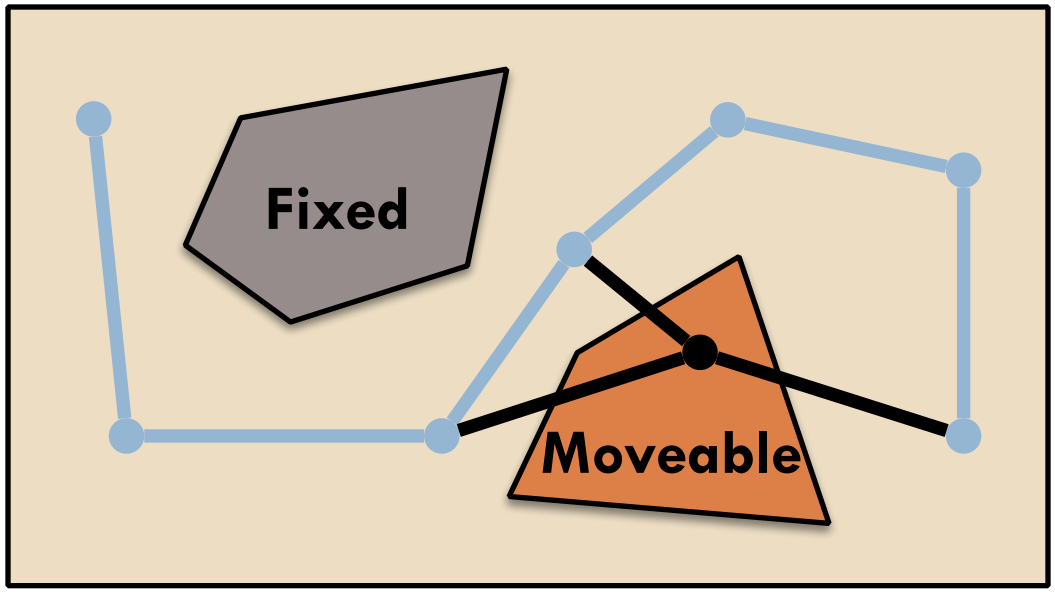


FFRob Planner

- Inspired by FF
  - Enforced-hill climbing forward heuristic search
  - Heuristic
    - Relaxed PlanGraph - H_{Add} and H_{Max}
    - Action linearization to find feasible relaxed plan and obtain H_{FF}
  - Helpful actions

- FFRob uses and updates the CRG during planning and heuristic computation

FFRob Relaxed PlanGraph

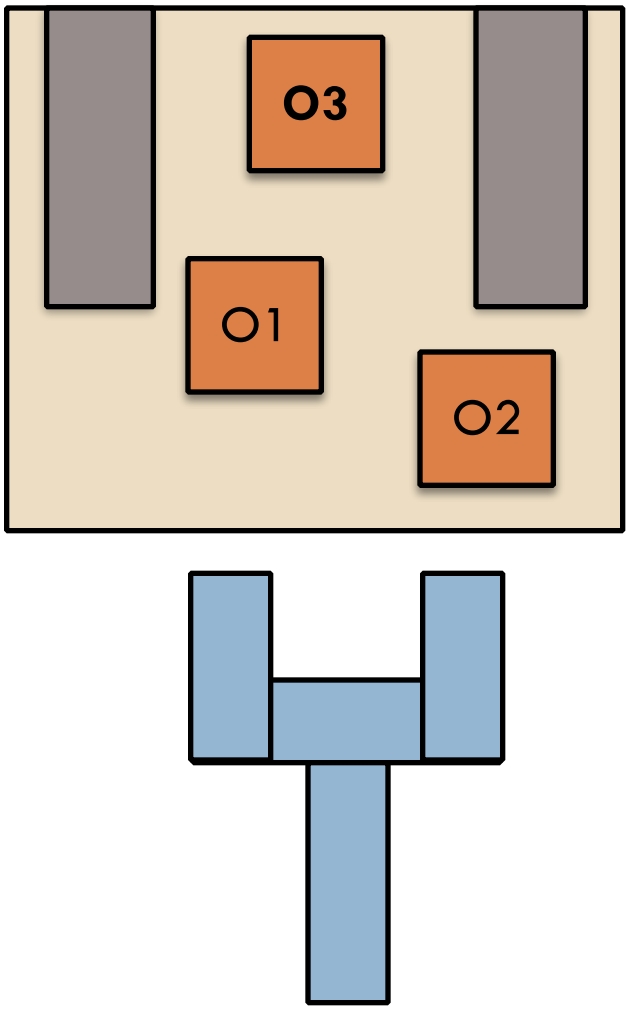
- Extend idea of geometric delete relaxation
- The CRG doesn't remove traversable edges
- Picking an object increases reachability
- Emptying the hand increases reachability
- Still includes symbolic relaxations

Pick Up Block O3

Action Layers:

HandEmpty
Pose(O1, …)
Pose(O2, …)
Pose(**O3**, …)
…

State Layers: 0



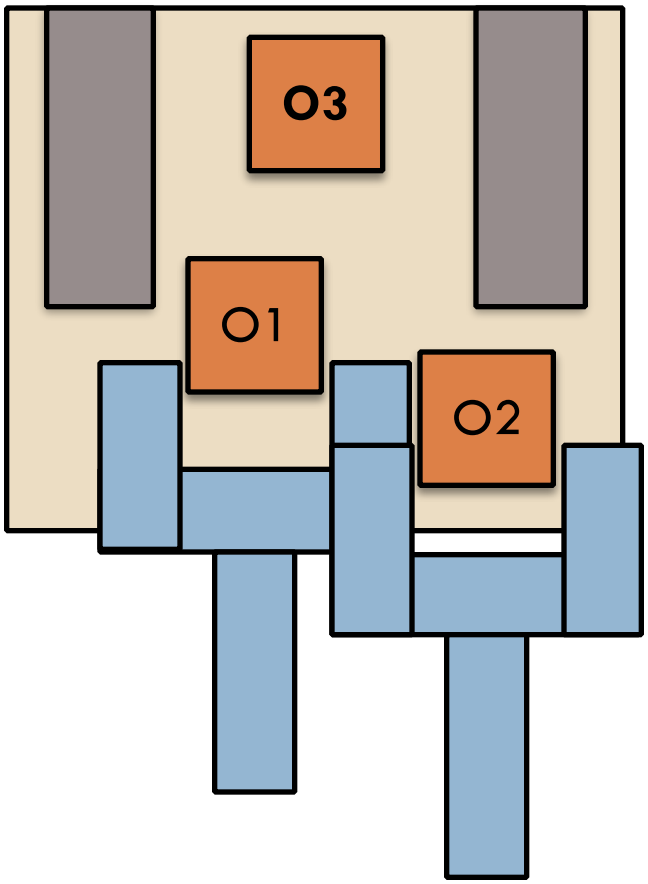
Pick Up Block O3

Action Layers: 1

Pick(O1, …)
Pick(O2, …)

HandEmpty
Pose(O1, …)
Pose(O2, …)
Pose(**O3**, …)
…

State Layers: 0



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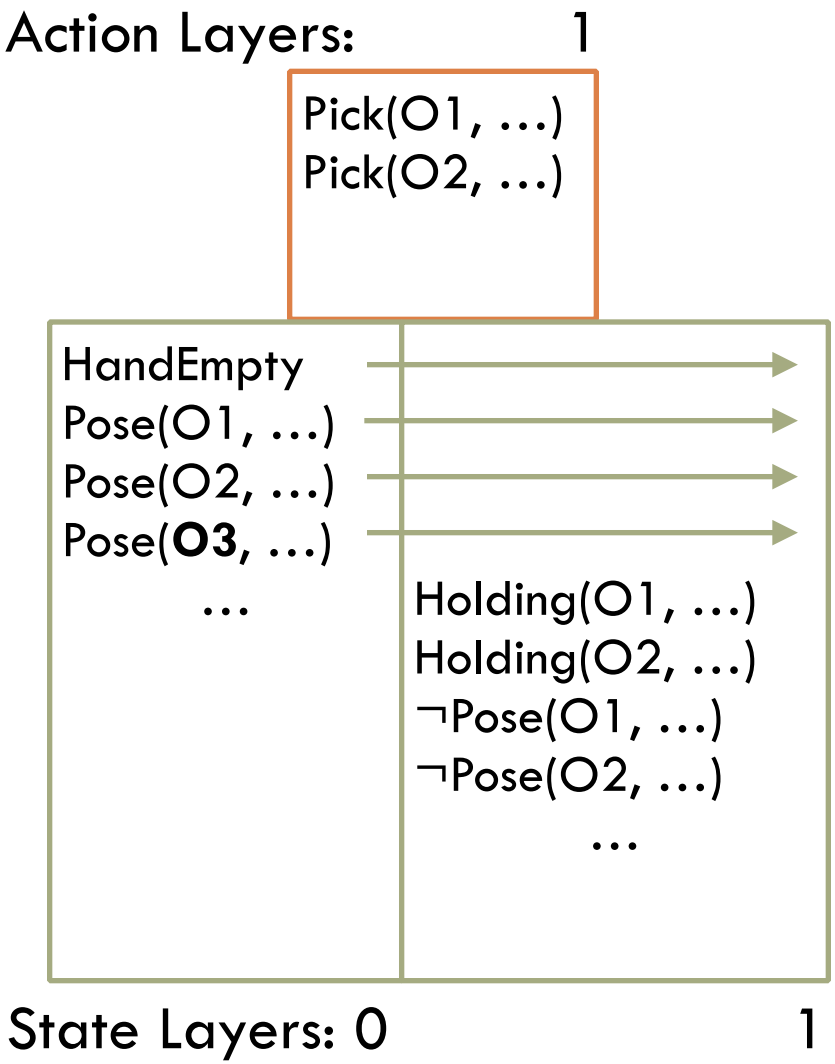

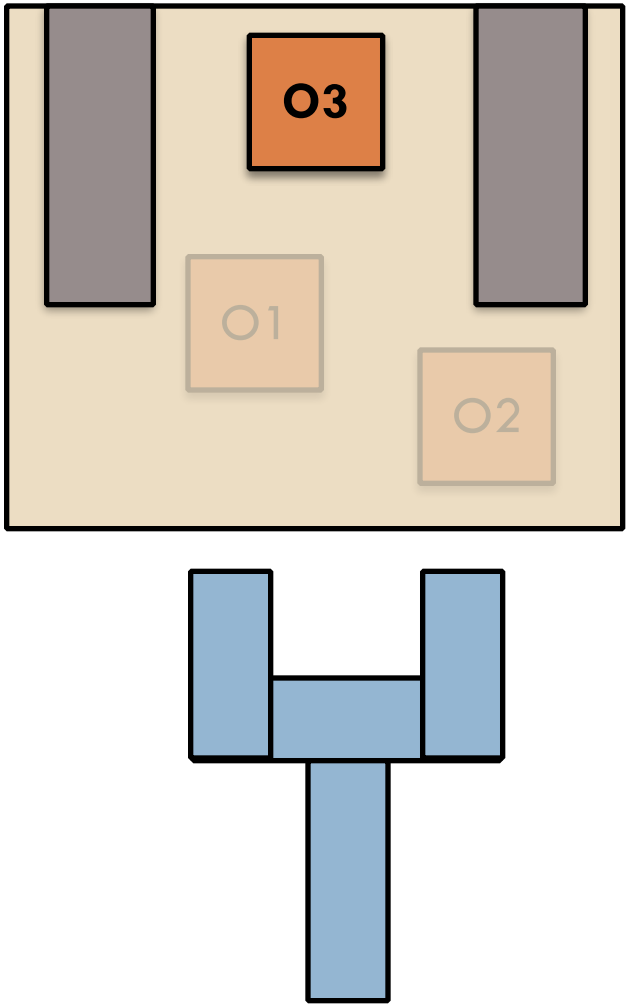

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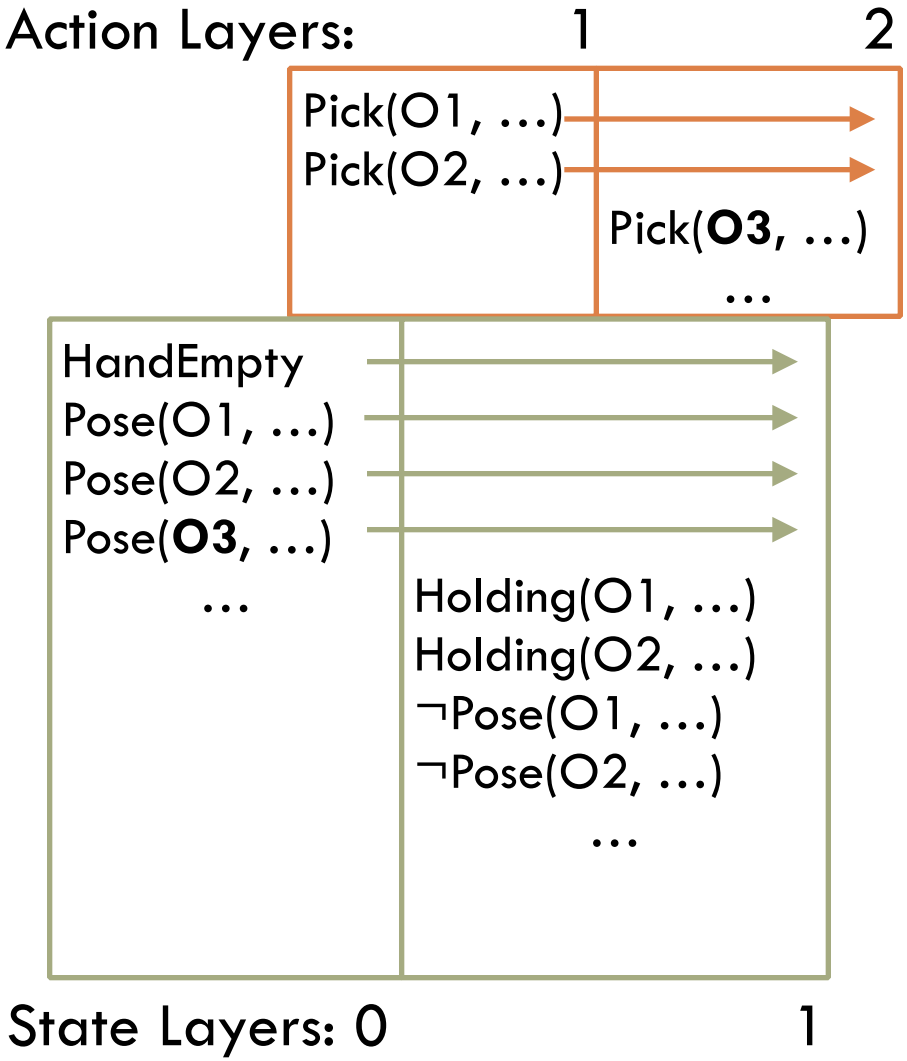
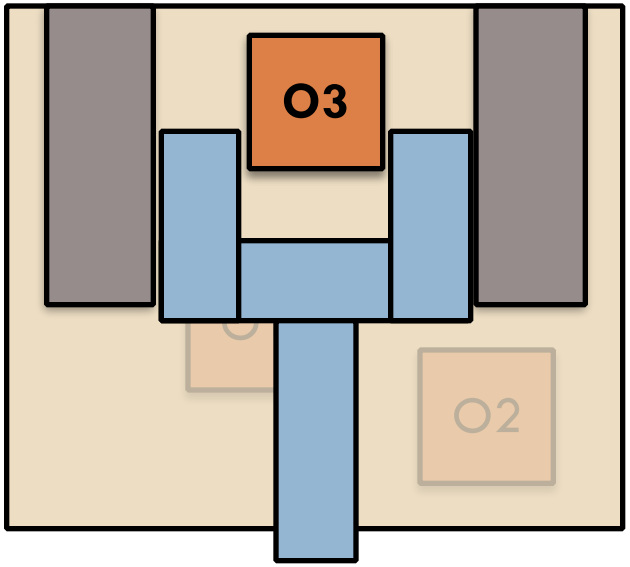
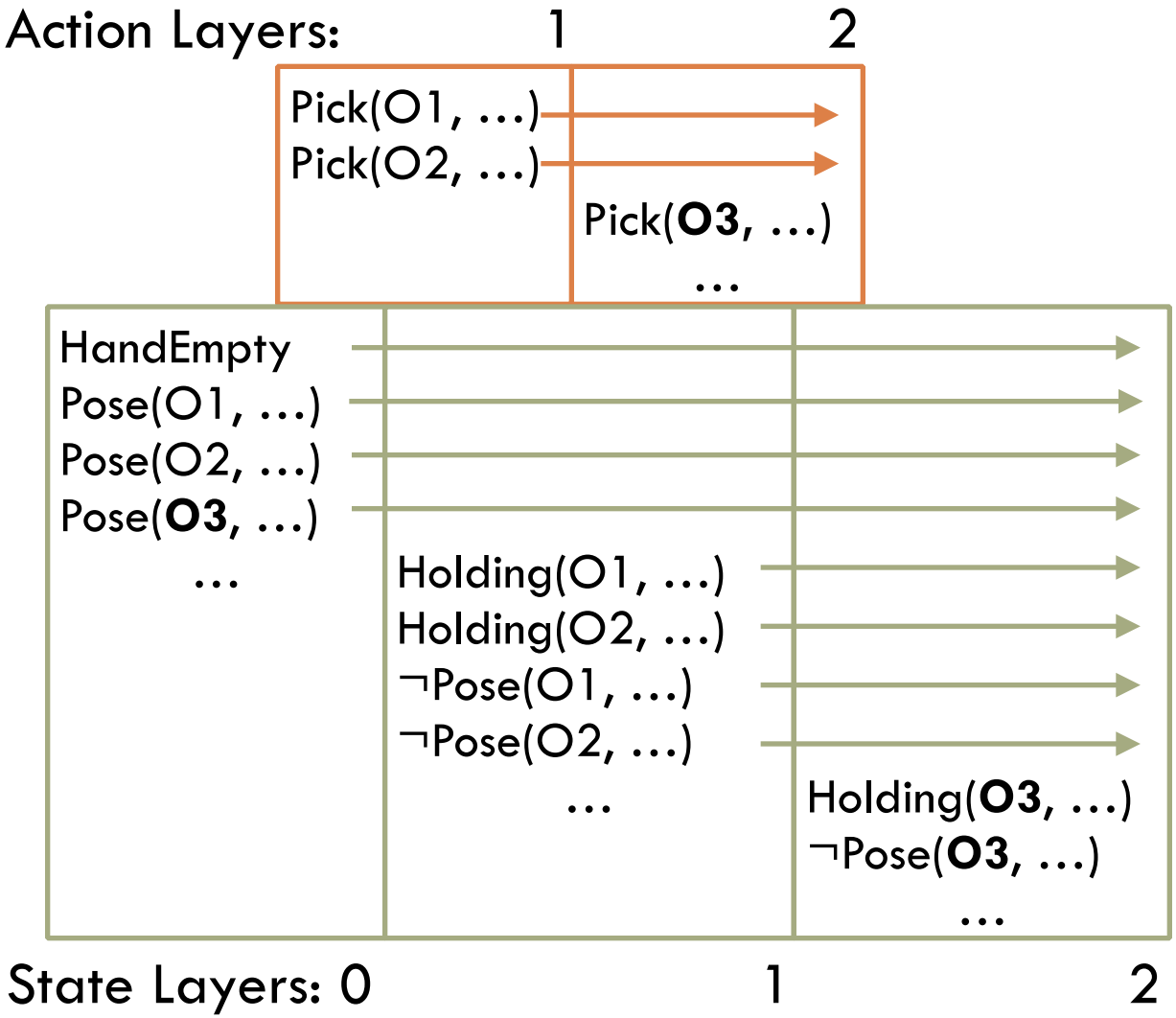
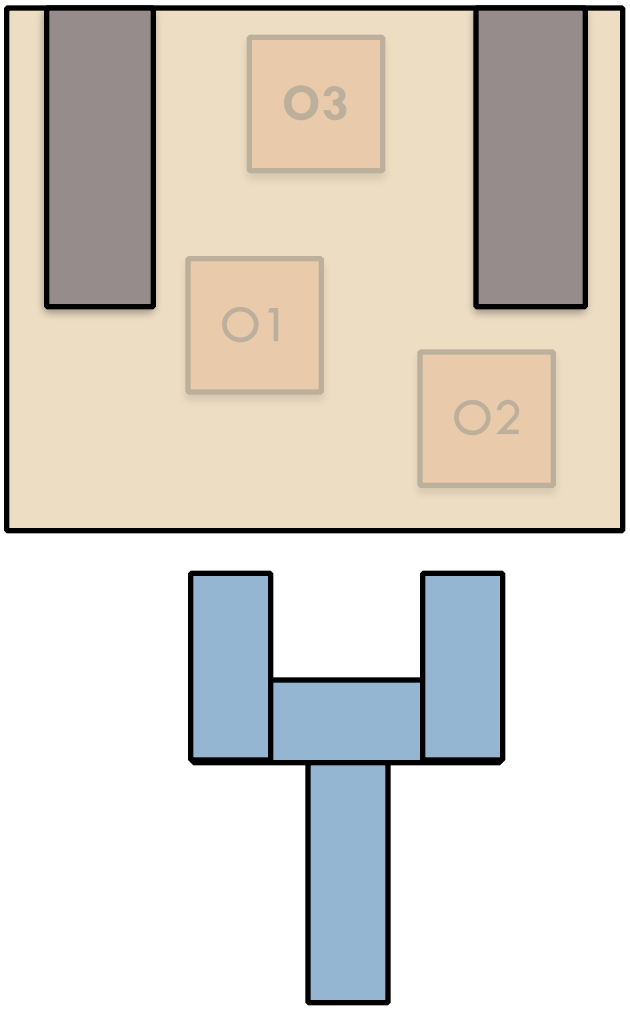




Pick Up Block O3



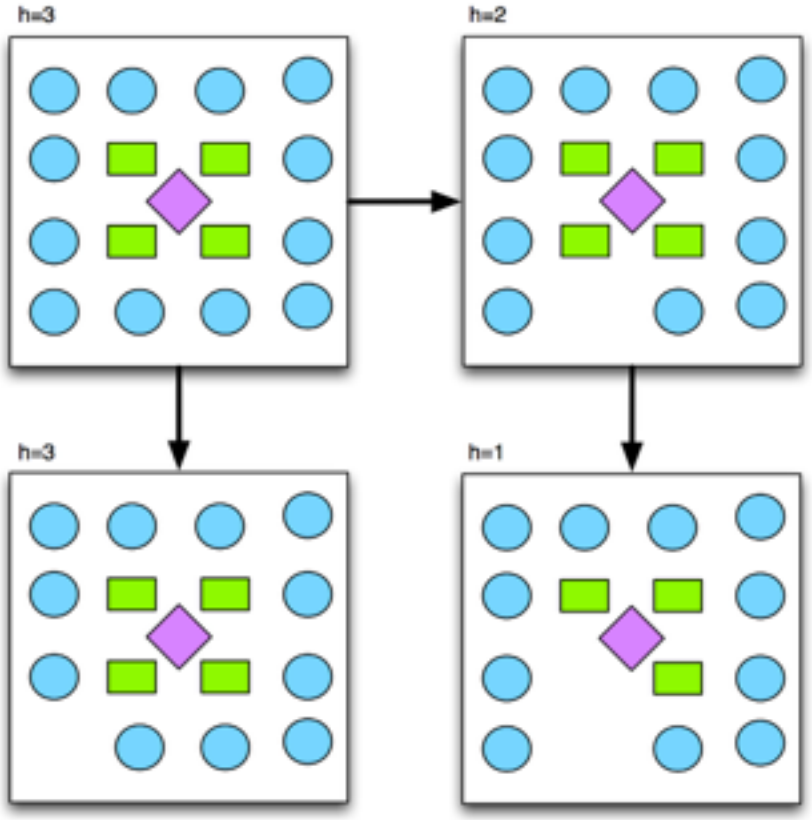


FFRob Action Linearization

- ***Reachable(C1,C2)*** can be achieved through many different actions
- Don't have list of least cost achievers
- Greedy minimum constraint removal on CRG to identify low cost achievers
- Extract relaxed plan

FFRob Heuristics

- ***H_{FFR}* heuristic** is length of relaxed plan
- Heuristic has inexpensive amortized cost
- **Helpful actions** prune descending states
- **Geometric biases** break ties by maximizing reachable placements and configurations

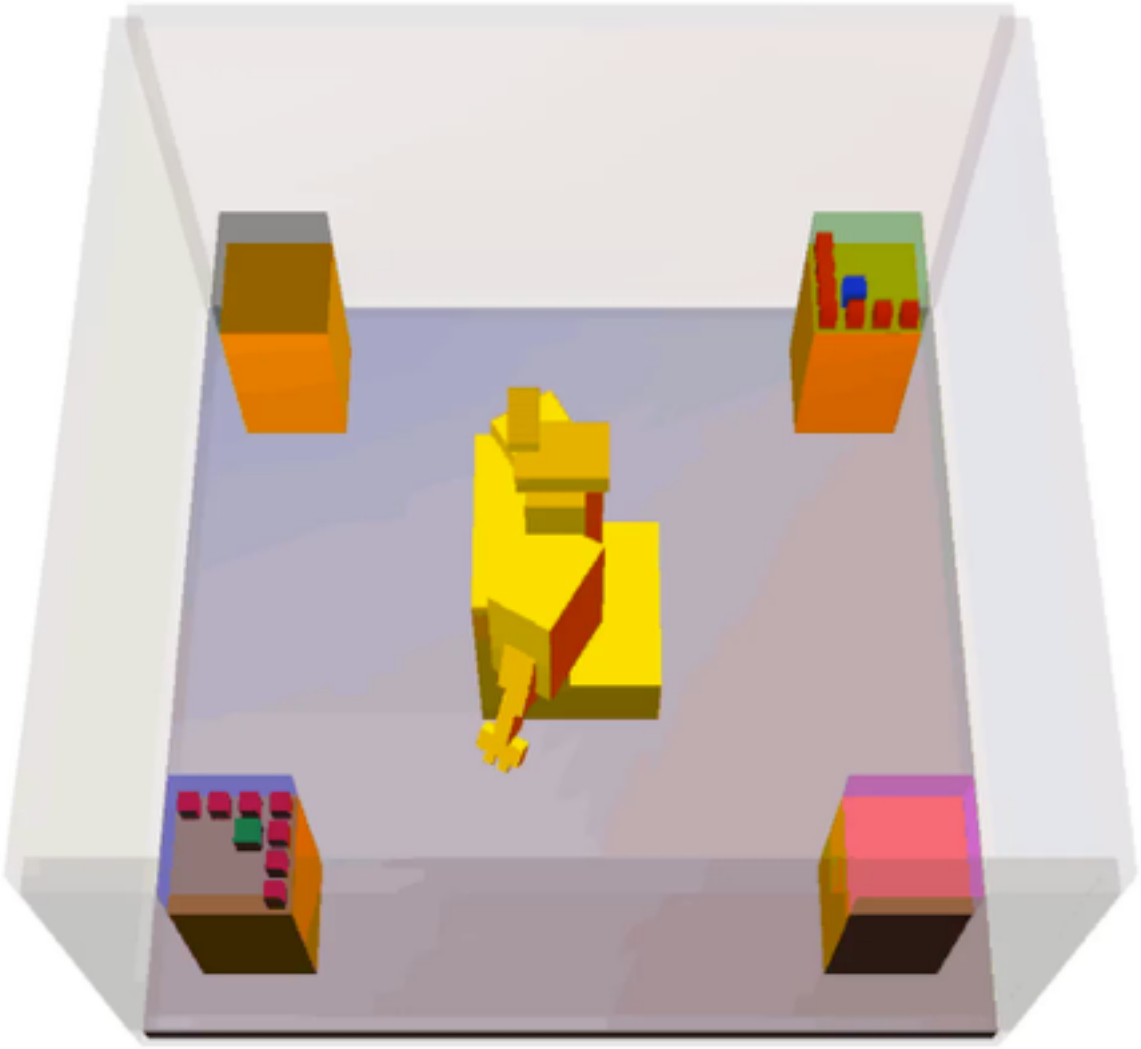


Task 4: Swap Green and Blue Blocks

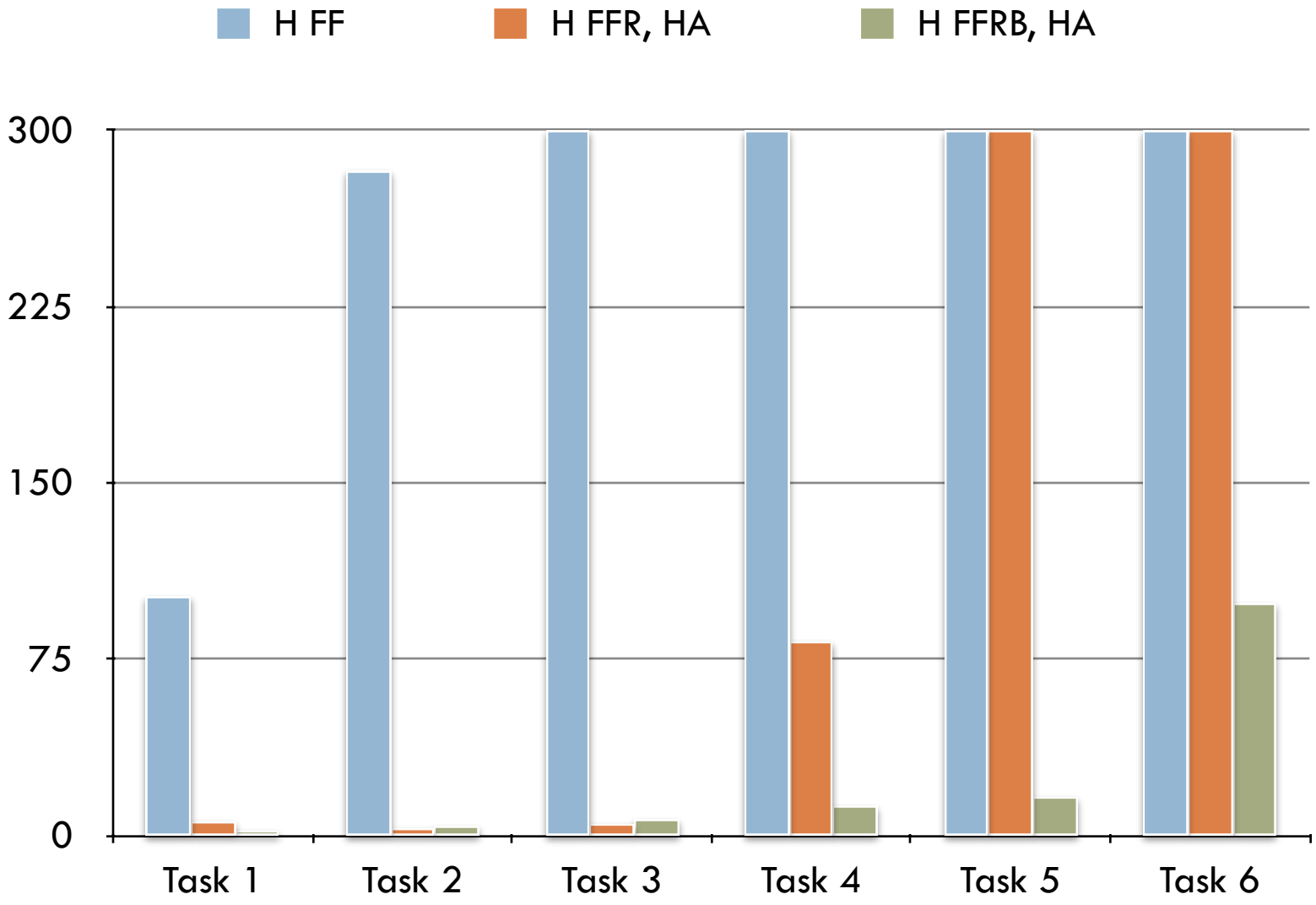
Task 4

Plan length
9 picks
9 places
493 movements

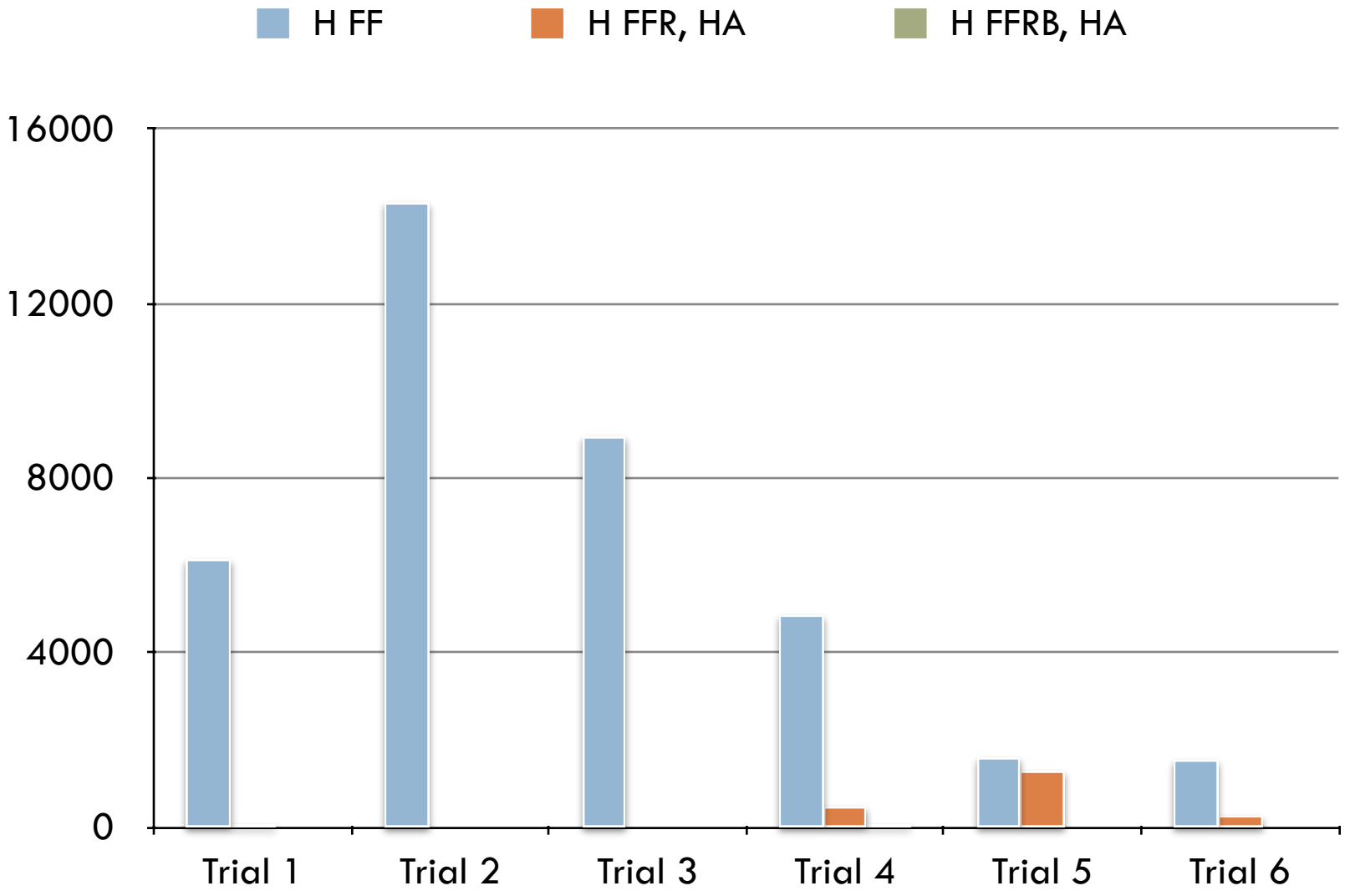
Planing resources
24s preprocessing
15s search
74 states explored



Median Plan Time (300s Timeout)



Median States Expanded



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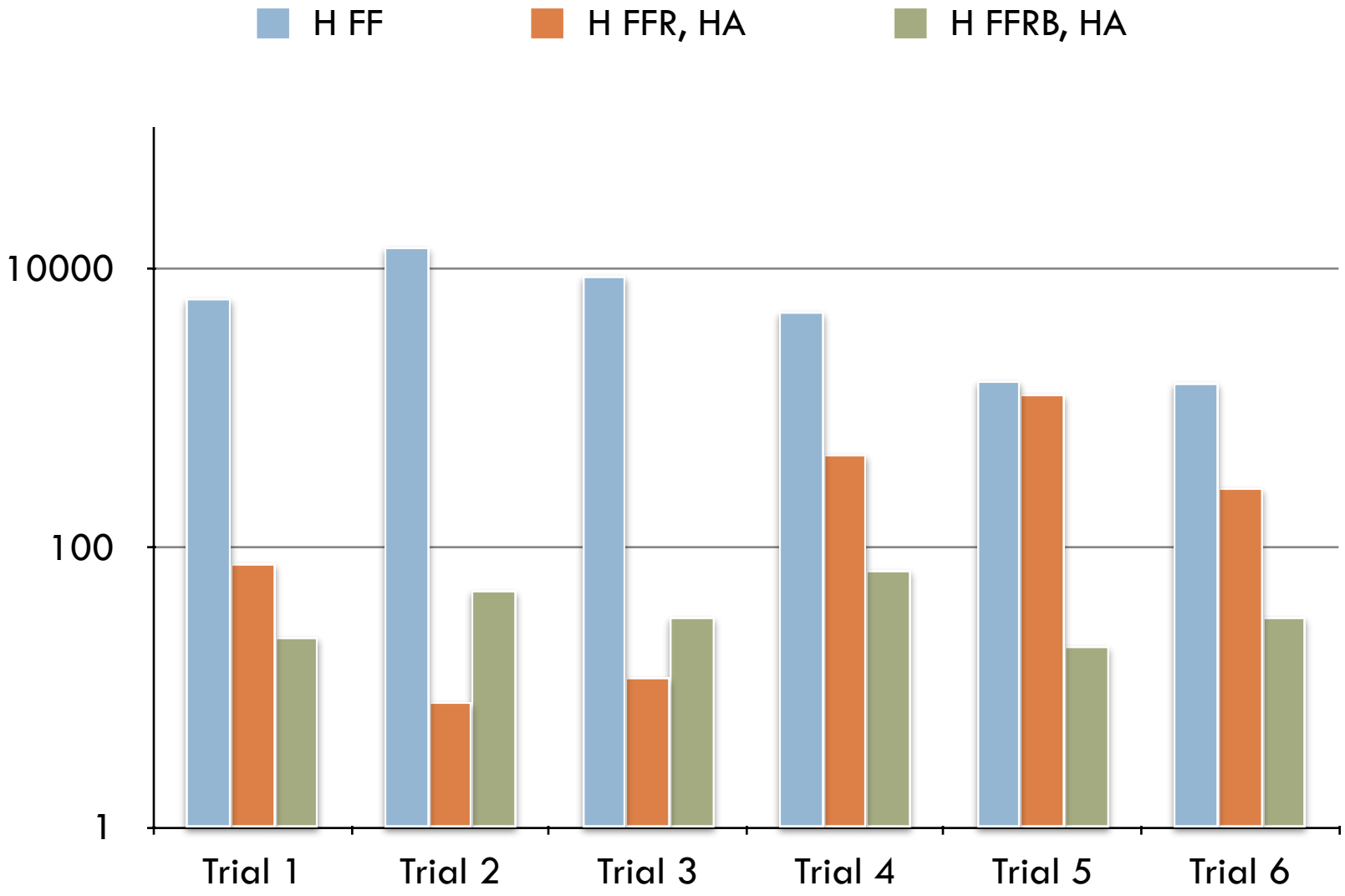


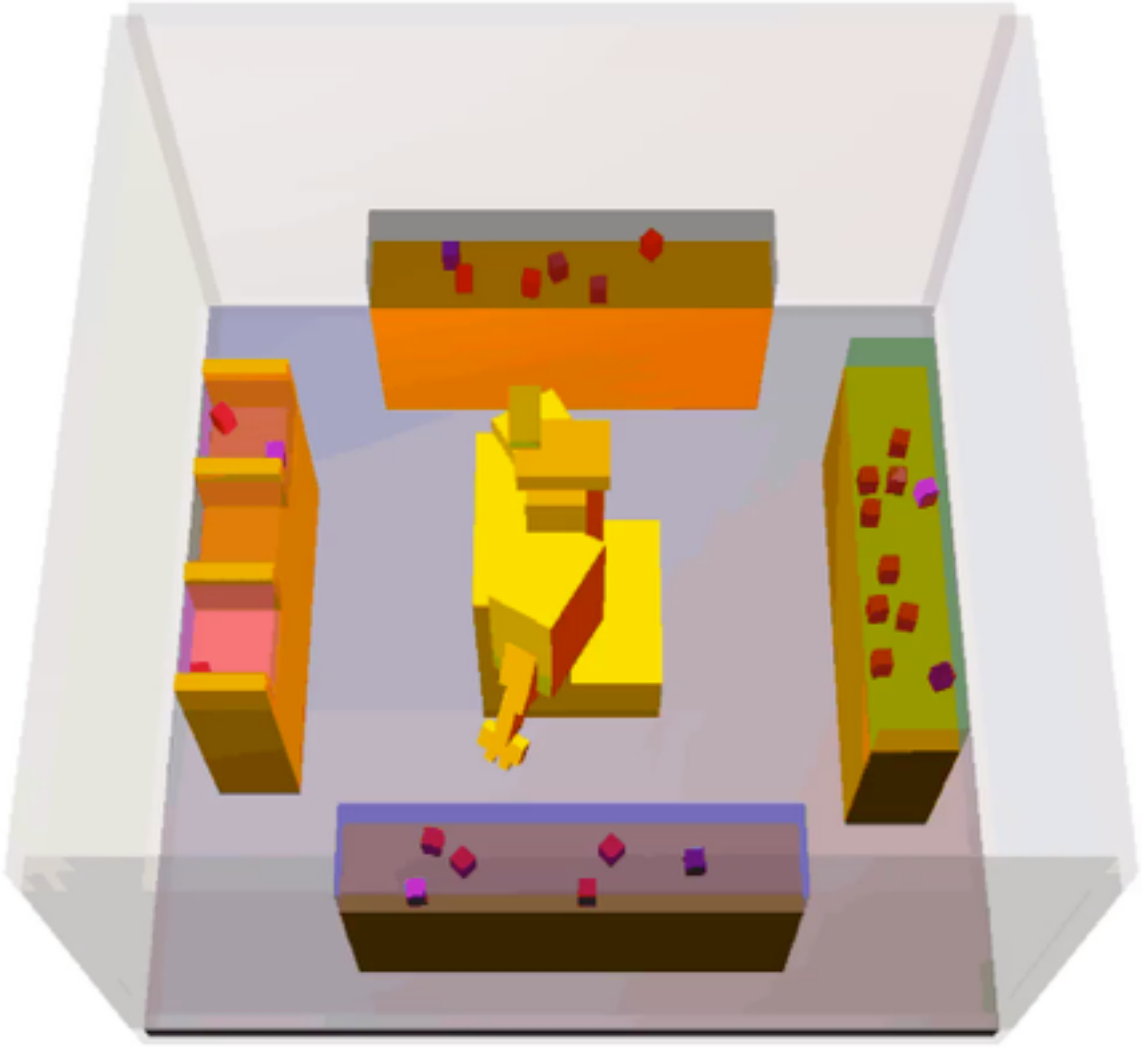
Conclusions

- Both symbolic and geometric information important for strong heuristic
- CRG roadmap enables efficient heuristic evaluation by reusing geometry work in search and heuristic
- **Future work**
  - Dynamic construction of CRG
  - Generalization of planner

Thank you!

Task 6

Questions?

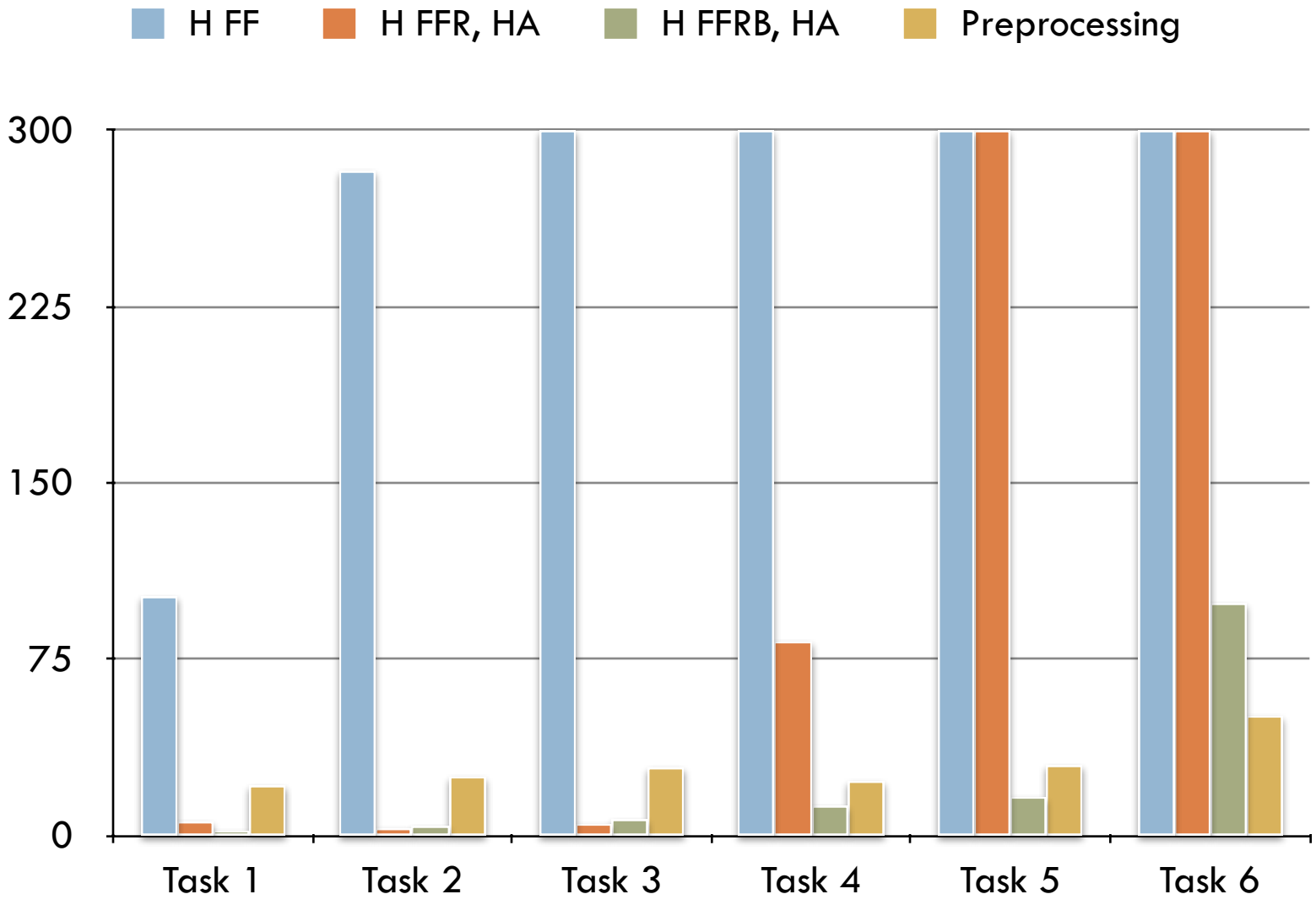


Full Results

T	Pre	No H			H_{FF}			H_{AddR}			H_{FFR}, HA			H_{FFRB}			H_{FFRB}, HA		
		t	m	s	t	m	s	t	m	s	t	m	s	t	m	s	t	m	s
0	21	265	35	48719	102	72	6123	41	19	536	6	5	78	7	5	87	2	0	23
1	25	300	0	63407	283	17	14300	162	55	2042	3	0	8	16	11	153	4	1	49
2	29	300	0	50903	300	0	8947	300	0	3052	5	1	12	17	13	114	7	2	32
3	23	300	0	39509	300	0	4849	300	0	1767	83	19	464	99	43	523	13	1	69
4	30	300	0	23920	300	0	1574	300	0	1028	300	0	1274	18	3	20	16	3	20
5	51	300	0	9422	300	0	1533	300	0	592	300	1	272	106	17	32	99	14	32

- Timeout of 300 seconds
- Median time: t (in gray)
- Median absolute deviation (MAD) time: m
- Median states expanded: s

Median Runtime (300s Timeout)



Move Green to Place Purple

Plan length
3 picks
3 places
226 movements

Planing resources
26s preprocessing
3s search
26 states explored