

## Mobile Manipulation

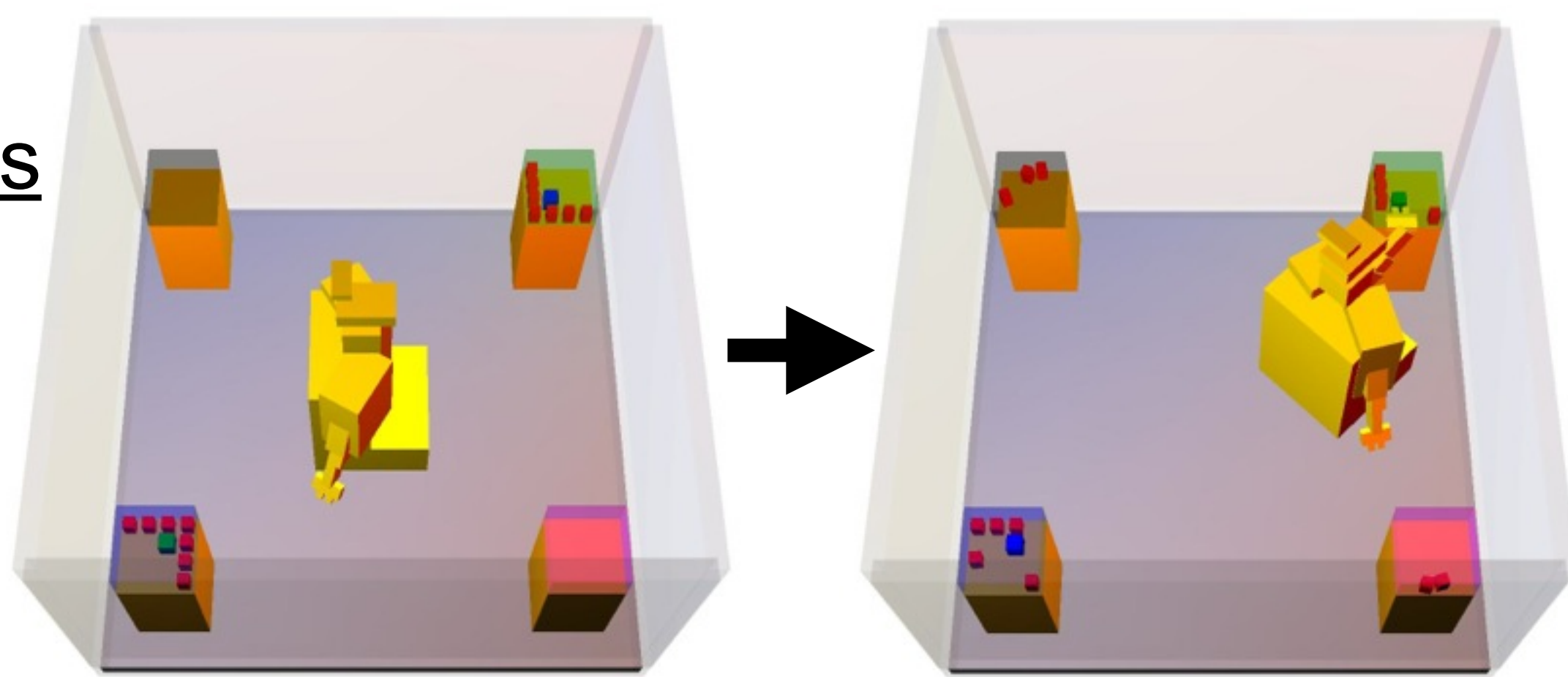


**Mobile Manipulation** - robot moving and manipulating world to achieve goals

**Applications** - shipping, debris cleanup, household chores, search and rescue, ...

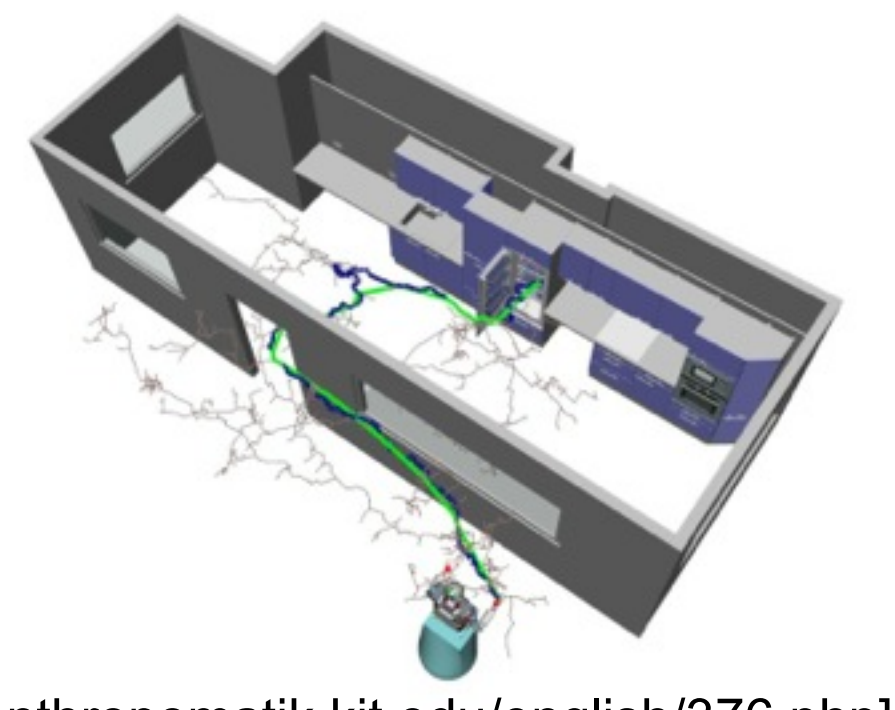
**Pick and Place Problem** - grasp and transport objects to goal regions while avoiding collisions with obstacles

Geometric and kinematic constraints introduce significant complication over purely symbolic blocks world



## Background

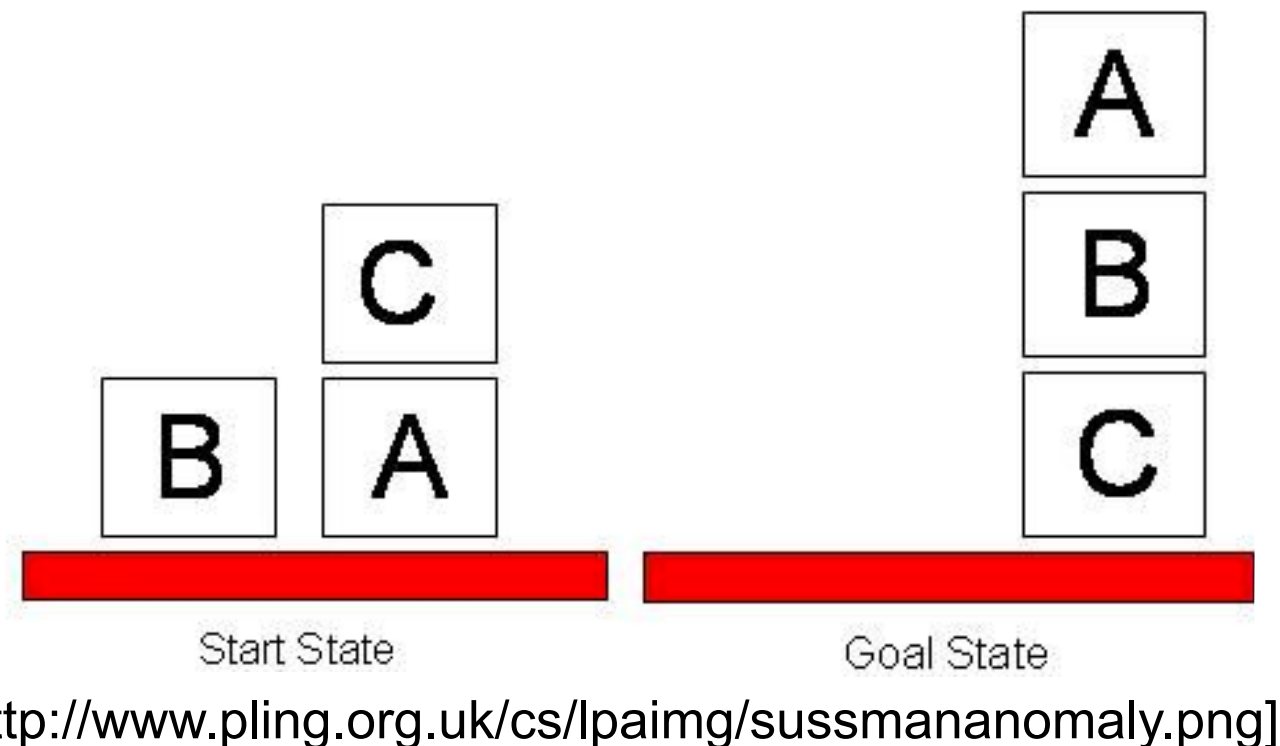
**Motion Planning** – planning motor specific movements to navigate between two robot configurations



[<http://h2t.anthropomatik.kit.edu/english/376.php>]

**Task Planning** – abstract, symbolic planning through states described by propositional formulas

**Combination reduces exponential dimensionality of planning**



**Prior work combines but treats each as a “black box”**

- Motion planner evaluates state as semantic attachment
- Symbolic planner heuristic guides motion planner

Our system integrates both symbolic and geometric information in heuristic search with a shared roadmap

## Actions and CRG

**Discretize planning problem by task driven sampling**

*Pick(C1, O, G, P, C2):*

*pre: HandEmpty, Pose(O, P), RobotConf(C1), CanGrasp(O, P, G, C2), Reachable(C1, C2)*

*add: Holding(O, G), RobotConf(C2)*

*delete: HandEmpty, RobotConf(C1)*

*Place(C1, O, G, P, C2):*

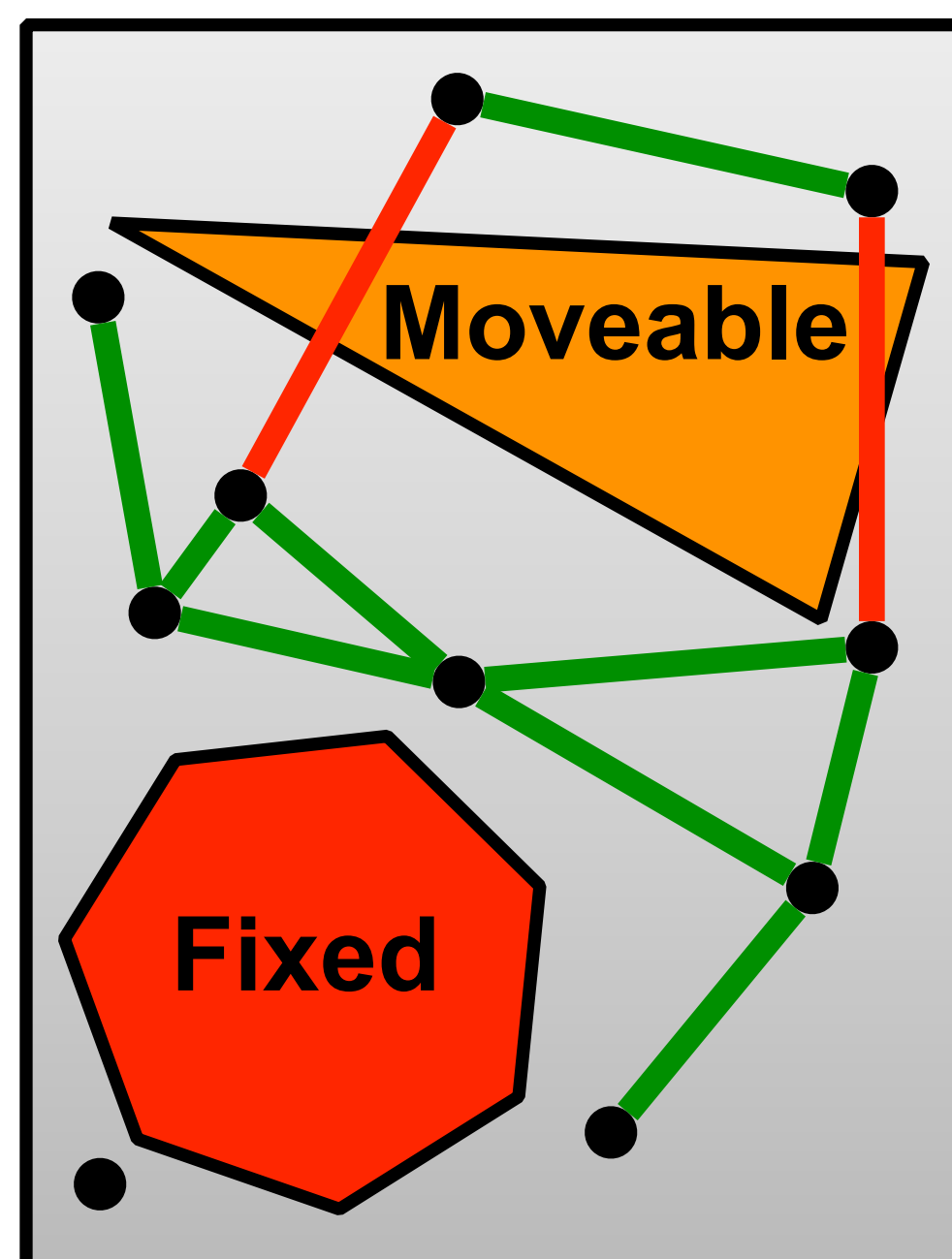
*pre: Holding(O, G), RobotConf(C1), CanGrasp(O, P, G, C2), Reachable(C1, C2)*

*add: HandEmpty, Pose(O, P), RobotConf(C2)*

*delete: Holding(O, G), RobotConf(C1)*

**Conditional Reachability Graph (CRG)**

- Connects sampled action configurations with a Probabilistic Roadmap (PRM)
- Updates reachable configurations given robot & object positions and grasp
- Provides additional geometric inference to evaluate *Reachable(C1, C2)*
- Lazy collision caching efficiently reuses expensive geometry computations
- Shared between search and heuristic



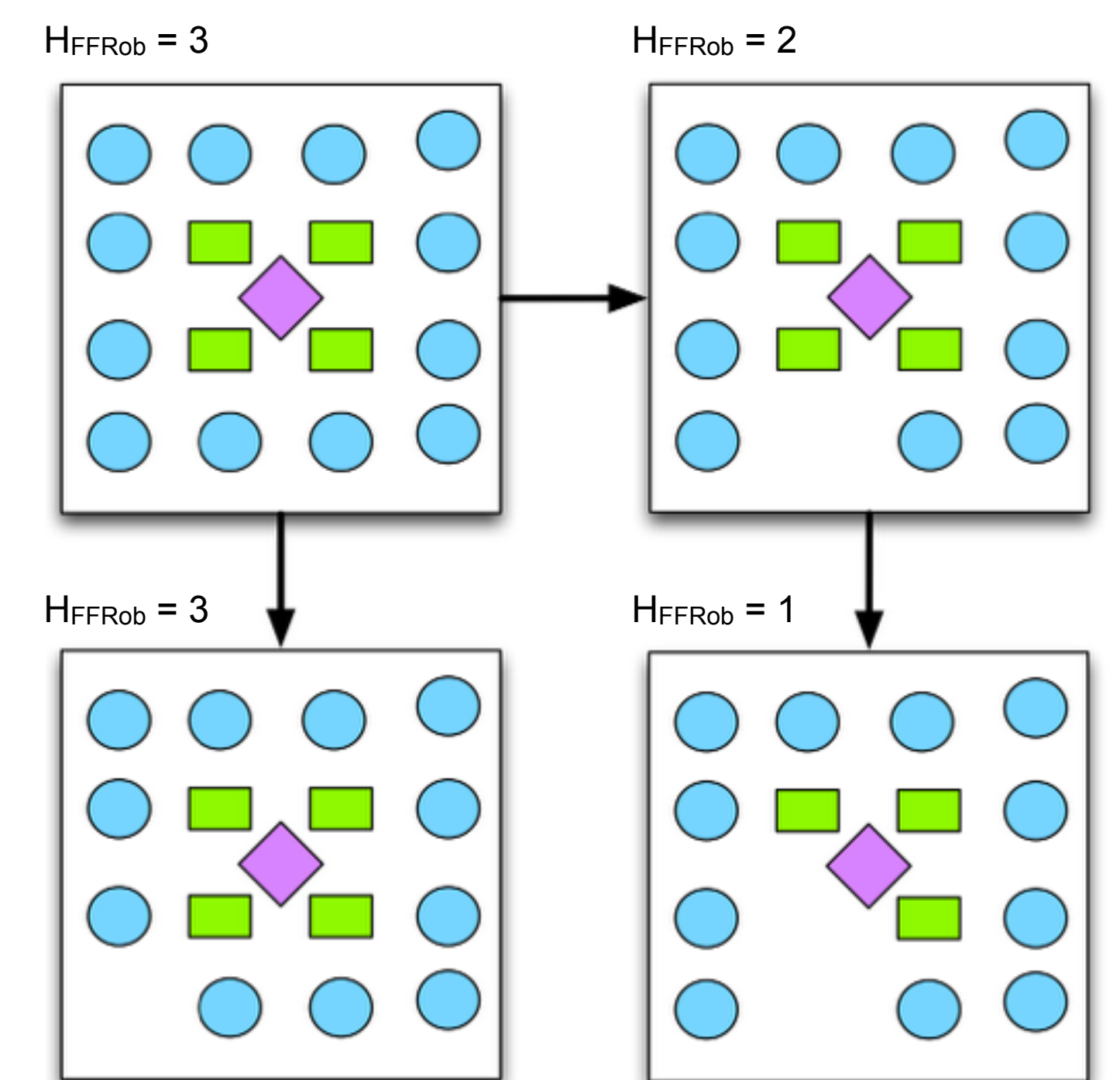
## FFRob

**FastForward (FF) Planner**

- Enforced hill-climbing forward heuristic search
- Relaxed PlanGraph gives  $H_{add}$  and  $H_{max}$  heuristics
- Action linearization extracts relaxed plan to give  $H_{FF}$
- Helpful actions further prune search space

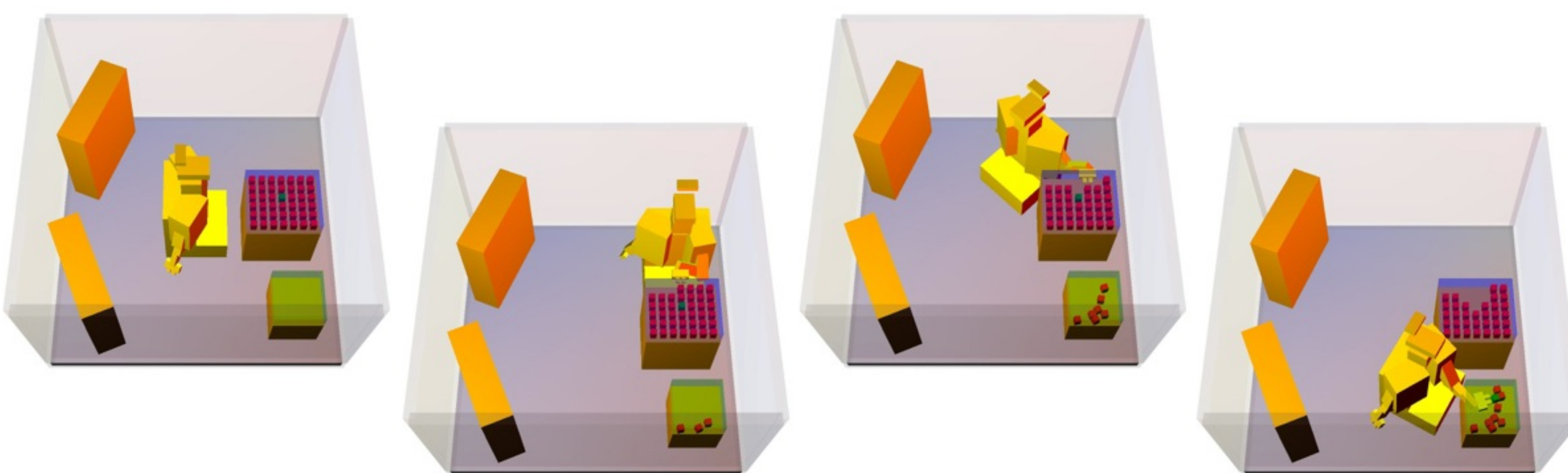
**FFRob - FF Planner applied to robotics**

- Captures both geometric and symbolic action guidance
- Relaxation of continuous variables implies reachability can only increase
- *Reachable(C1, C2)* has messy conditional effects complicating action linearization
- Minimum Constraint Removal finds minimum cost achievers
- Low amortized cost
- Geometric biases break by choosing states with more reachable placements

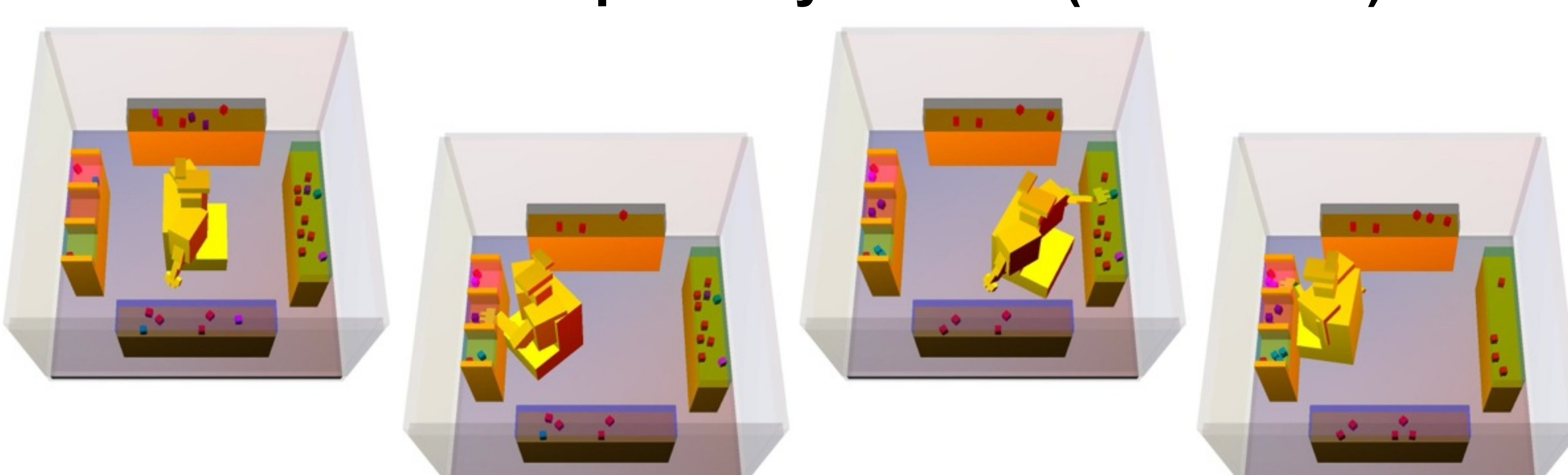


## Simulations

**Simulation 4 - dig block out of packed region (20 actions)**



**Simulation 5 - clean up messy kitchen (28 actions)**



## Results and Conclusion

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

- Performance table of 6 worlds (T) with a 300 sec timeout
- Median time in sec (t), MAD time (m), median states (s)

**Conclusion**

- Geometric information important for strong heuristic
- CRG reuses expensive geometric work

**Future Work**

- Generalization of approach
- Dynamic roadmap construction
- Uncertainty

