Humanoid TAMP using Backward-Forward Search

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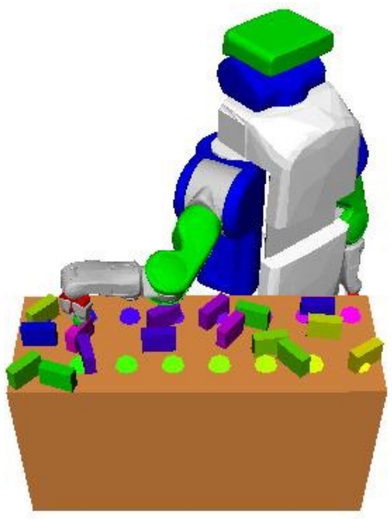
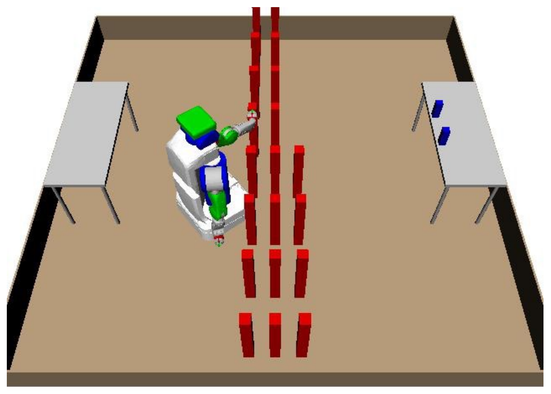
FFRob: Integrated Geometric and Symbolic Search

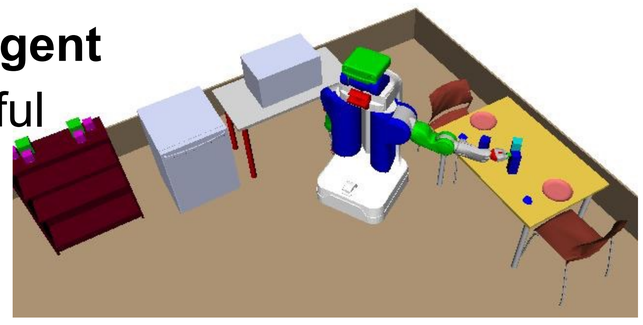
- Solves **pick-and-place, rearrangement, NAMO, and TAMP** problems
- Iteratively samples continuous operator parameters in batch
  - *Configurations, poses, grasps, …*
- Integrates TAMP in a single forward state-space search
- Includes complex **geometric preconditions in FF heuristic**
  - *Reachable(q1, q2), InRegion(p, R), …*
  - Only geometrically informed search heuristics are able to solve geometrically nontrivial problems
- **Probabilistically complete** and **exponentially convergent**
- **Problem** - batch sampling overestimates the set of useful parameters

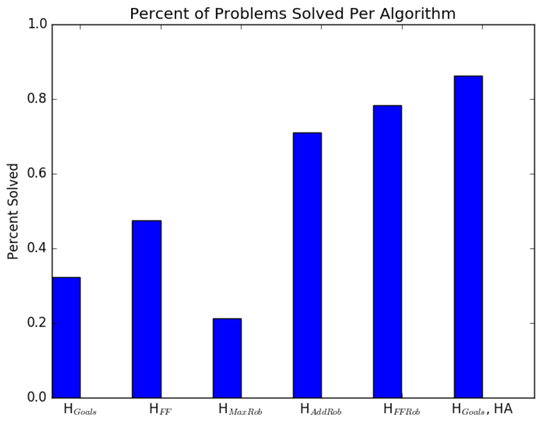
[WAFR 2014]

[Journal preprint at http://web.mit.edu/caelan]





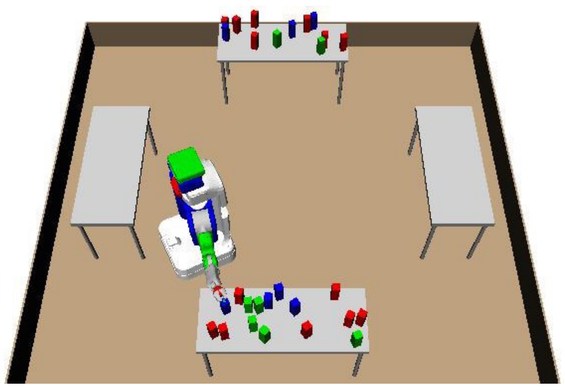


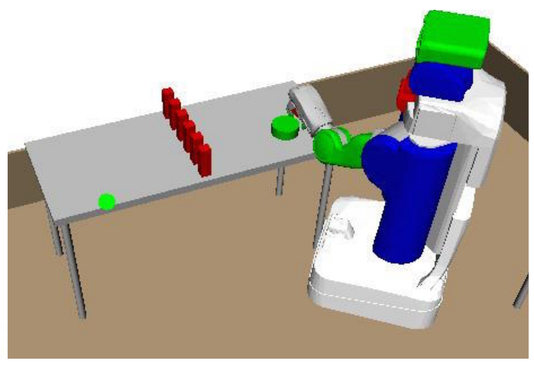


HBF: Backward-Forward Search for Hybrid Planning

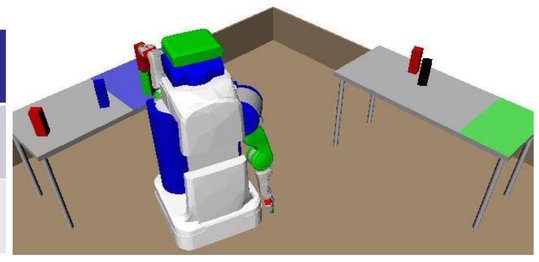
- **Improves on FFRob** by dynamically sampling parameters
- Direct search in mixed continuous/discrete state-space
  - **Long horizon** - need search guidance
  - **Infinite branching factor** - need informed successor sampling
- **Approximate backward search** computes successors and heuristic
  - Factors preconditions and achieves them independently
  - Continuous analog to relaxed planning
- **Persistent forward state-space search** resolves approximations
- **Probabilistically complete**
- Dynamic sampling enables **pushing, stacking, regrasping**
  - Still supports symbolic literals and actions

[IROS 2015]





	% Solved	Time
FFRob	*84%*	*157 s*
HBF	***100%***	***82 s***



Humanoid Task and Motion Planning (TAMP)

- Humanoid robots are more complicated than mobile manipulators
  - Higher dimensionality, stability constraints, whole body inverse kinematics, **footstep planning**
- Applied HBF to a HUBO robot for TAMP problems
- Task and motion planners produce many motion plans that are never used
  - **Footstep planning is computationally expensive**
- Plan with **bounding volumes** for full footstep cycle to ensure feasibility of a deferred footstep plan
- Experimented on problems with **"force fields" (doors)**
  - **Fully deferring motion planning leads to infeasibility**
  - Bounding volumes able to produce safe motion plans quickly
- Star roadmap that reuses trajectories increases efficiency