# Planning with Unreliable Controllers

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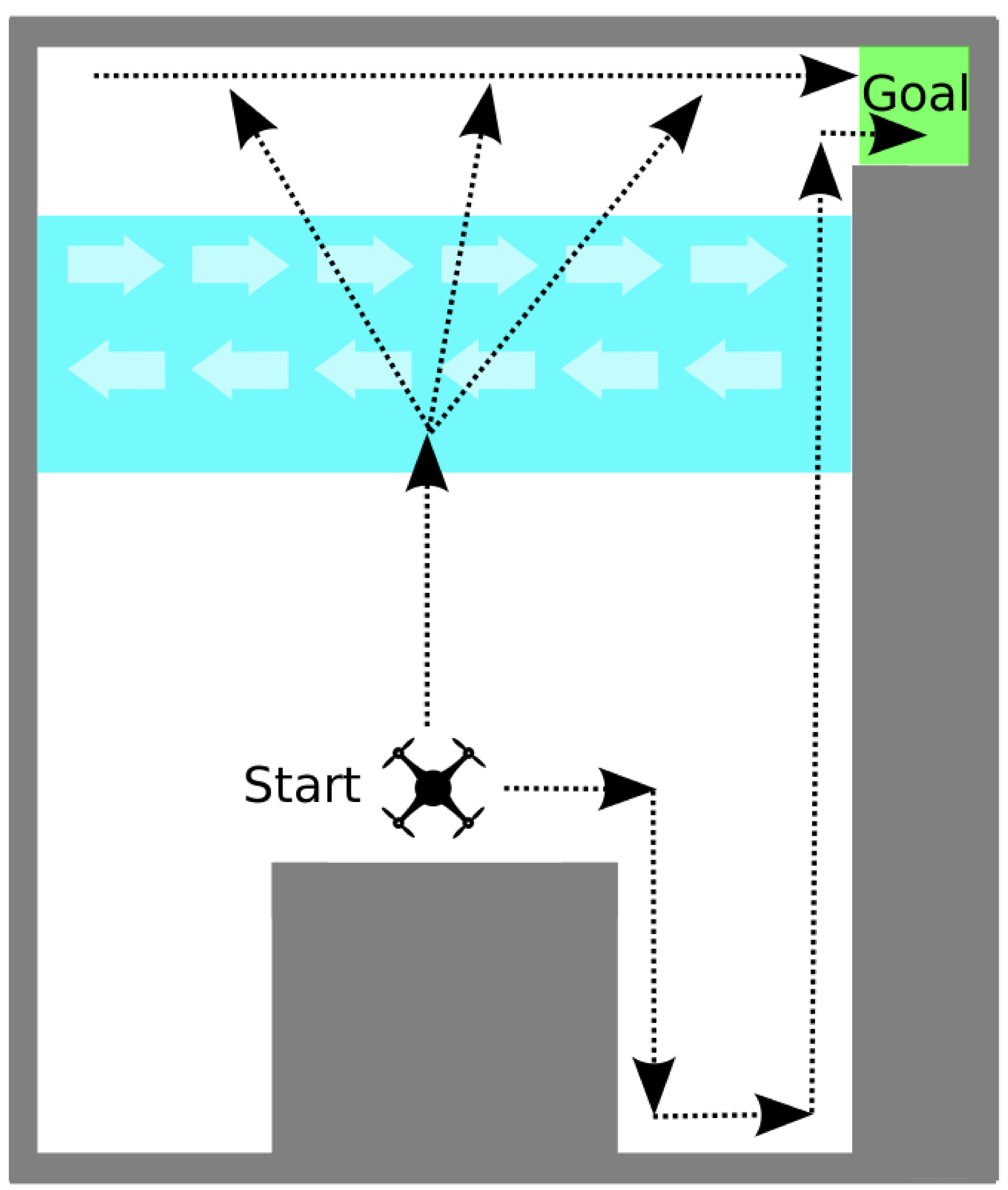
## Motivation

- Traditional search-based planning methods depend on reliable execution of metric motion primitives.
- Existing work [1] allows for search-based planning to reason over controllers such as wall-following or visual servoing.
- In some cases, it can be desirable to reason over unreliable controllers.

## Motivating Example




The robot must travel from the start to the goal, but there is a variable wind (blue) blowing across the room. The robot can either execute a series of reliable wall-following controllers or an unreliable proximity controller.

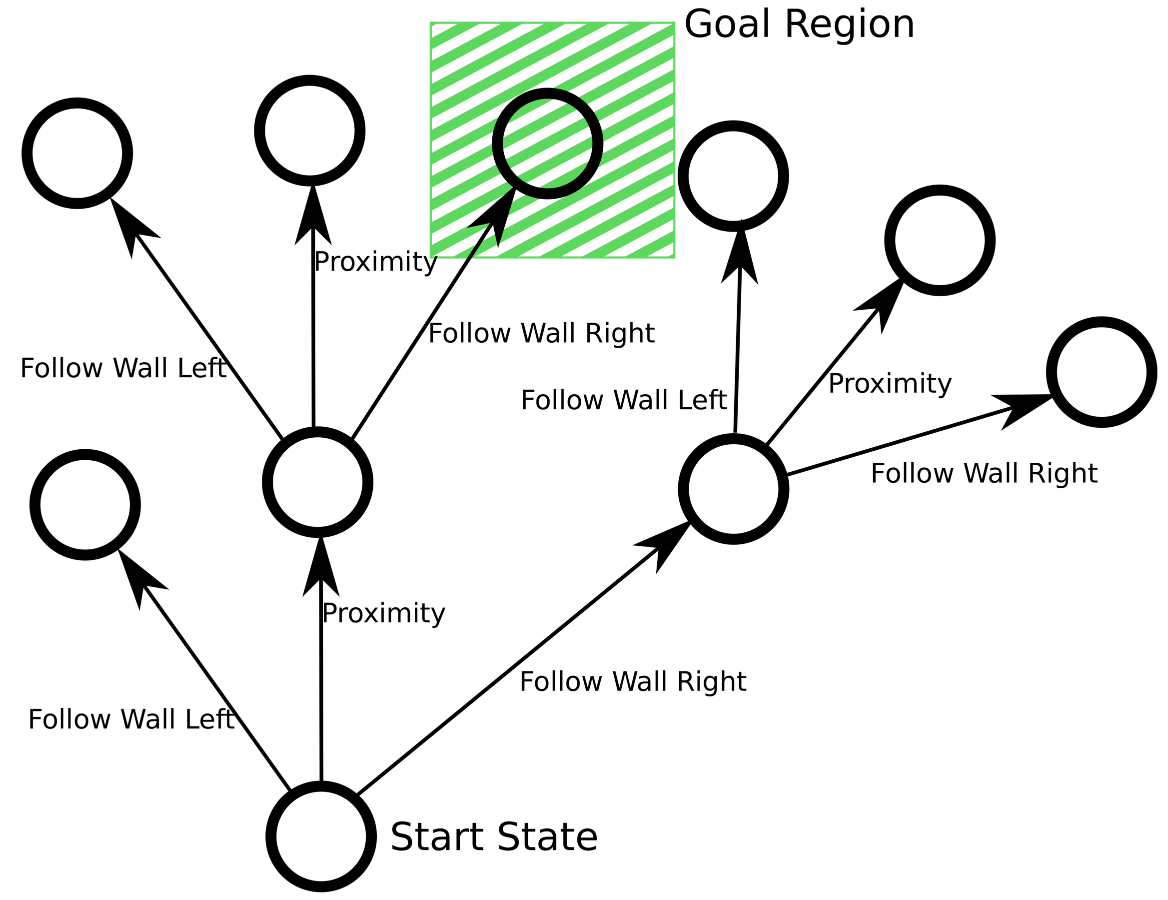
## Problem Statement

**Input:** State space $S$, start state $s \in S$, goal region $G \subset S$, set of controllers $\mathscr{C}$, stochastic cost function $\delta(c_1, \ldots, c_n)$ (which gives $\infty$ if the final state is not in $G$), $p \in [0, 1]$.
**Output:** Controller sequence $(c_1, \ldots, c_n)$ which minimizes the $p_{\text{th}}$ quantile of $\delta(c_1, \ldots, c_n)$.

## Approach

Our approach is a branch-and-bound algorithm which uses multiple forward simulations to estimate the cost of each controller sequence.

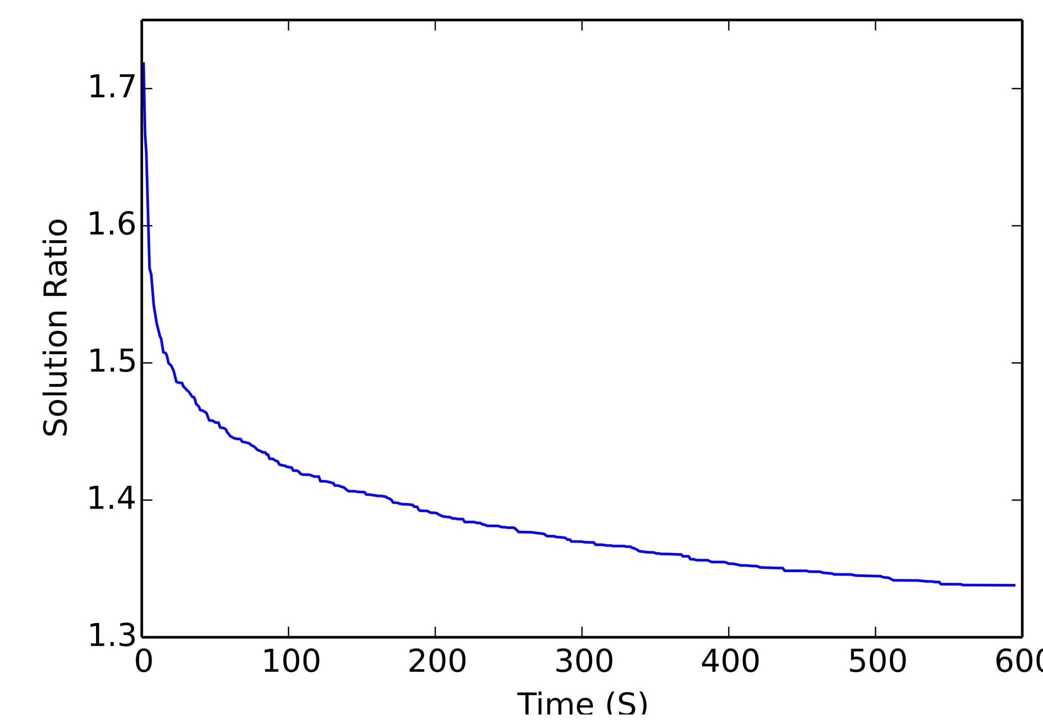
- Edges represent controllers, and nodes represent sequences of controllers.
- First an initial solution is found using an inflated heuristic.
- Then, all other branches are explored until the sub-optimality bound can be probabilistically met.




## Results

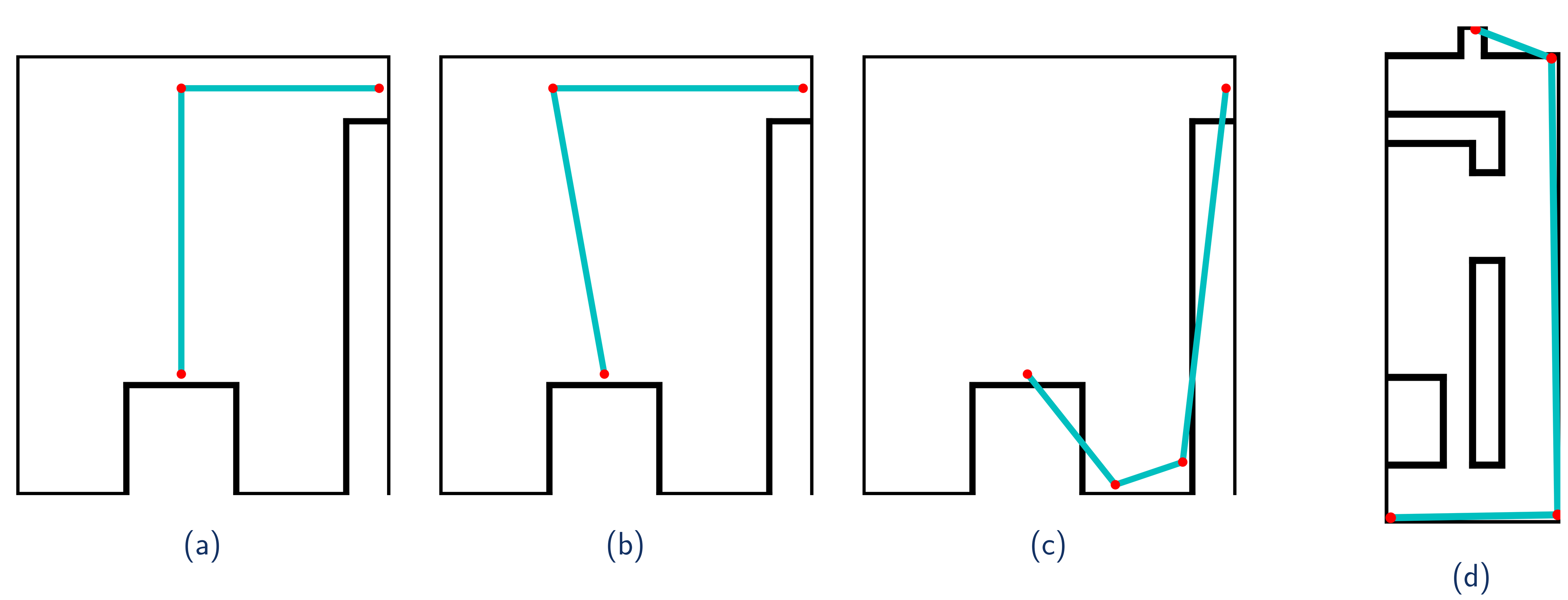
| Environment | Planning Time (s) | Cost (90th percentile) | |
|---|---|---|---|
| | | LCB | UCB |
| Small (No Noise) | 2.47 | 22.43 | 22.43 |
| Small (Low Noise) | 2.55 | 25.28 | 26.28 |
| Small (High Noise) | 7.15 | 33.15 | 33.52 |
| Large | 609.68 | 125.61 | 125.61 |

The planning times and solution costs for four environments are given. Since the cost can only be approximated, a lower and upper confidence bound are given.




The ratio, over time, between the lower bound on the cost of the optimal solution and the upper bound on the cost of the current solution. These results are for the large environment.

## Test Environments and Solutions



*(a)* In the small environment (17 x 20 m), the optimal solution without noise is to execute a proximity controller followed by a wall-following controller. *(b)* With a low amount of noise (wind), the optimal solution is unchanged. *(c)* With high noise, the optimal solution is to execute a series of wall-following controllers around the boundary. *(d)* For the large environment (30 x 85 m), the optimal solution is a series of wall-following controllers. Note that for all examples, only the endpoints (red) of each controller are drawn, so the path may appear to cut corners.

## Discussion and Future Work

- Initial results are promising, but planning times required for large environments may be prohibitive in some applications.
- Methods for improving performance are being explored by the authors.
- More rigorous simulation experiments on a wider variety of environments are planned.
- Physical experiments using the UBTECH Yanshee humanoid robot are also planned.

## References

[1] J. Butzke, K. Sapkota, K. Prasad, B. Macallister, and M. Likhachev, "State lattice with controllers: Augmenting lattice-based path planning with controller-based motion primitives," *IEEE International Conference on Intelligent Robots and Systems*, pp. 258–265, 2014.

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