Robotic Collaboration Through Scalable Reactive Synthesis

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Problem Statement Given high-level specifications for robot manipulation tasks, synthesize policies that satisfy qualitative constraints *and* quantitative ones.

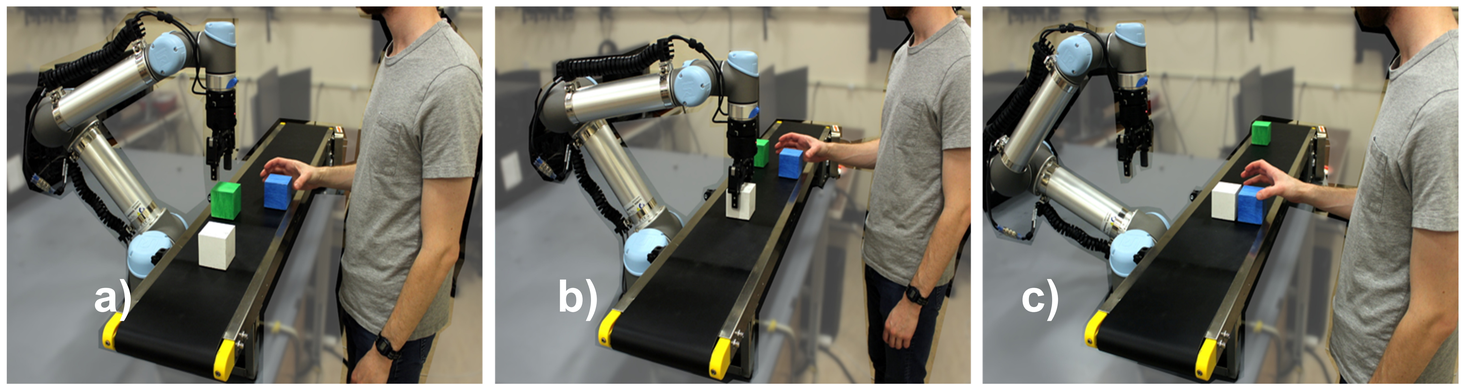
Motivation Complex collaborative tasks between humans and robots usually require not only hard constraints (e.g., safety), but also soft constraints (e.g., maximize reward). We need formal models of the human-robot ensemble for guarantees of correctness and optimality.

Background Linear Temporal Logic (LTL) is widely used for symbolic specification. We use **discounted-sum** (DS) rewards to express quantitative constraints, which converge for infinite-horizon tasks.

Relation to Our Previous Work Previously, we used probabilistic synthesis to generate policies that maximize the success of the human-robot system. Now, we integrate DS rewards in addition to LTL constraints and show the first sound algorithm for policy synthesis that guarantees a threshold for DS rewards.

Approach

- We formalize the robot-human domain with LTL goals and DS rewards with discount factor in (1,2) range
- We model this domain as a parity game by combining a reachability game to maximize the reward and a parity game to satisfy LTL goals
- We synthesize policies that achieve the LTL goals while maximizing DS rewards to a given threshold



(a) LTL constraints enforce avoiding the human and grabbing green blocks. (b) Rewards are given for white blocks. (c) LTL constraints are respected over rewards.

Challenges

- Combining LTL constraints with soft DS
- DS rewards with discount factor in (1,2) range needed for practical applications
- Optimization combined with earlier LTL synthesis methods produces unsound solutions

Results

- First sound algorithm for LTL constraints guaranteeing DS rewards to a threshold on all executions when discount factor in (1,2) range
- Scales linearly on co-safe LTL temporal goals, common in robotics manipulation

Broader Impact

- Our synthesis framework elegantly includes quantitative constraints
- Scalable approach with high quality solutions
- Applications in important robotics domains such as collaborative warehouses

S. Bansal, L. E. Kavraki, M. V. Vardi, and A. Wells, “Synthesis from Satisficing and Temporal Goals,” in *Proceedings of the AAAI Conference on Artificial Intelligence*, 2022.

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