Robotic Collaboration Through Scalable Reactive Synthesis

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Kavrakilab.org/nsf-nri-1830549.html

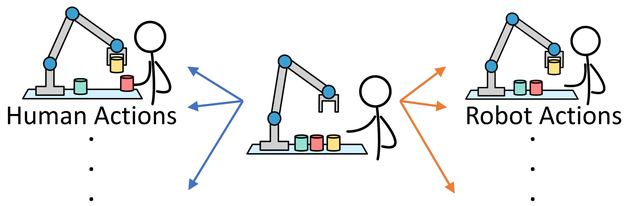
Problem Statement Given a finite-horizon temporal specification and a **stochastic** model of human-robot actions, synthesize a policy to **maximize the probability** of task completion for **manipulation** domains

Motivation For humans and robots to safely and effectively collaborate on complex tasks, we need to formally model the human-robot ensemble to provide formal guarantees of correctness and optimality

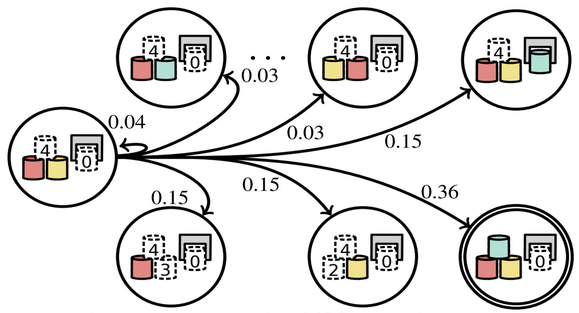
Relation to Our Previous Work Previously, we model the human as a stochastic agent, computing policies in **probabilistic synthesis** and tested in Gridworld. Now, we introduce a formalization of probabilistic manipulation domains to apply our techniques, and provide empirical comparison of different encodings

Approach

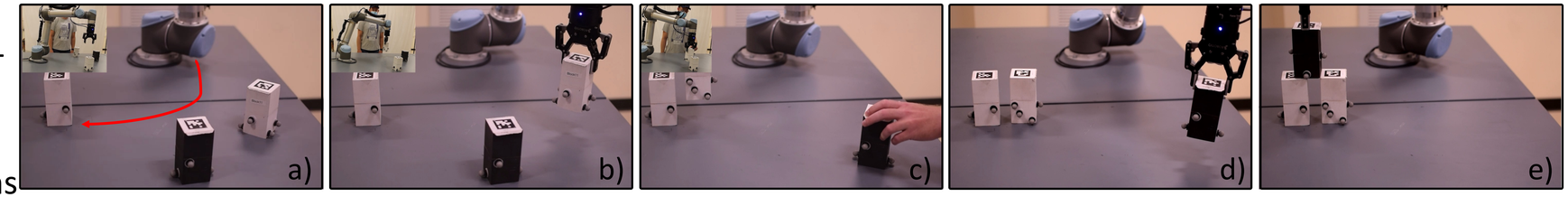
- We formalize the notion of probabilistic robot-human manipulation domain
- We show how to model such a domain as an MDP by combining the probability distributions of robot actions and human actions
- We synthesize policies that maximize the probability of satisfying an LTLf formula



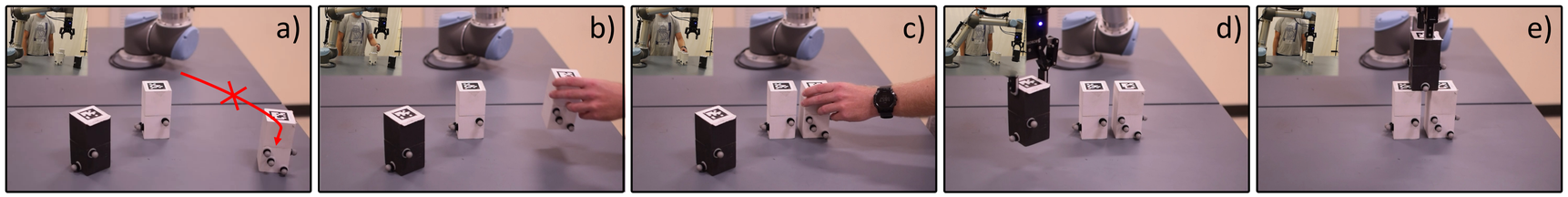
Probabilistic models of human actions and robot actions must be combined



Example portion of a manipulation MDP for a pick and place domain



At state (a) we anticipate adversarial human (c), leading to building the arch far away from the human (b-e).



At state (a) we anticipate human cooperation (b-d), leading to faster expected task completion (e).

Challenges

- Formalization of interaction (e.g., turns and conflicts)
- Correctness-preserving decompositions
- Symbolic synthesis necessary for scalability but sensitive to variable encoding

Results

- Encoding constraints in model is more efficient than in specification
- Different encodings were tried to understand sensitivity
- Trade-off between efficiency and expressivity among different encodings was measured

Broader Impact

- Guarantee robustness, correctness and safety
- Develop general tools for reactive and probabilistic synthesis
- Introduce techniques from formal methods to the robotics community

A. M. Wells, Z. Kingston, M. Lahijanian, L. E. Kavraki, and M. Y. Vardi, “Finite-Horizon Synthesis for Probabilistic Manipulation Domains,” in IEEE Intl. Conf. on Robotics and Automation, 2021.

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