Learning and Intelligent Systems

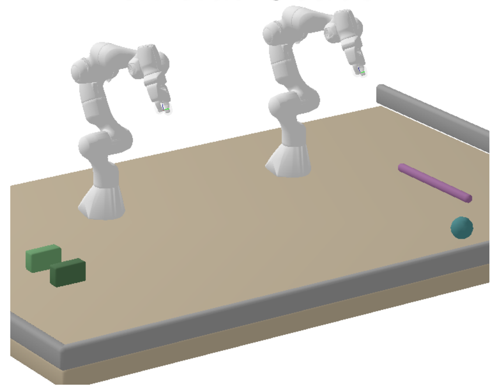
Conflict-Directed Diverse Planning for Logic-Geometric Programming

imprs-is

Joaquim Ortiz-Haro[1], Erez Karpas[2], Marc Toussaint[1], Michael Katz[3]   [1]TU Berlin, [2]Technion, [3]IBM Research

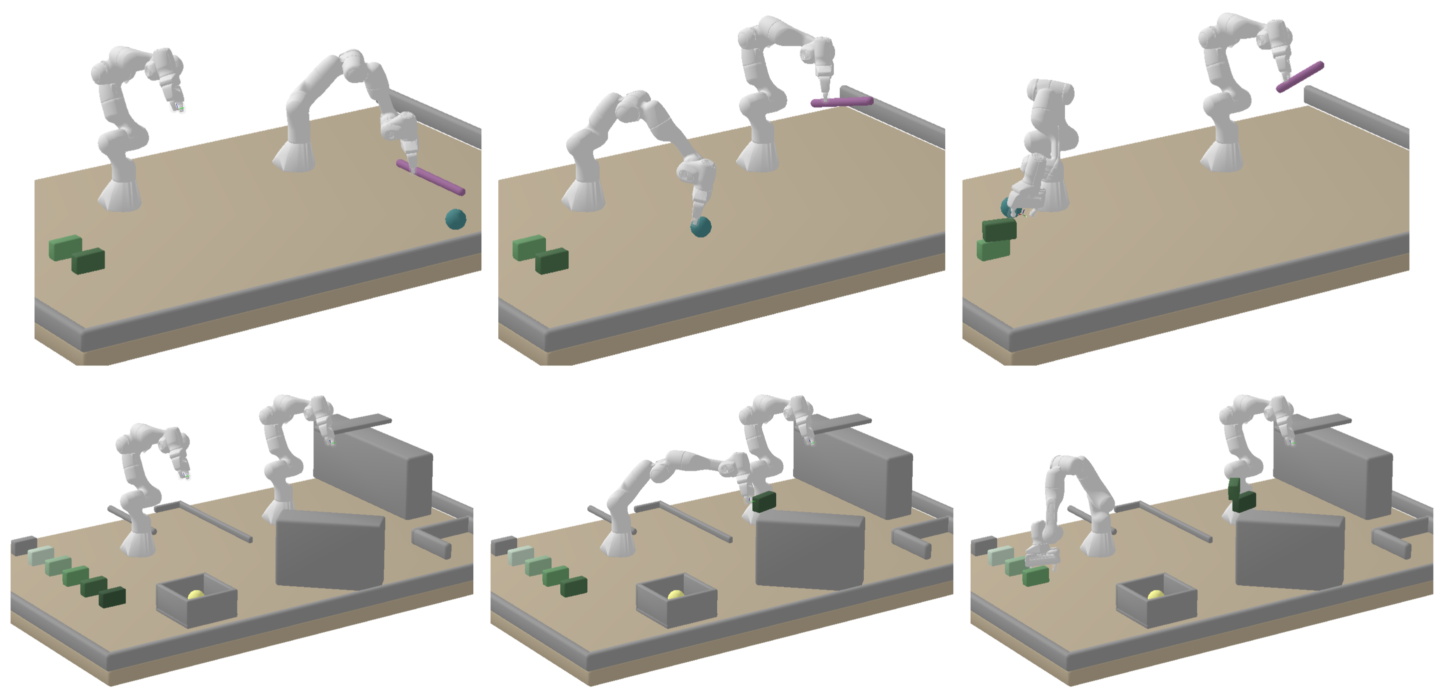
Task and Motion Planning (TAMP)

Initial State



Symbolic Goal
```
Dark green on light green
Blue ball on dark green
```

- Symbolic plans often fail in the geometric level [1]
- Calls to the motion optimizer are expensive



Manipulation tasks solved by our algorithm (Push and Blocks).

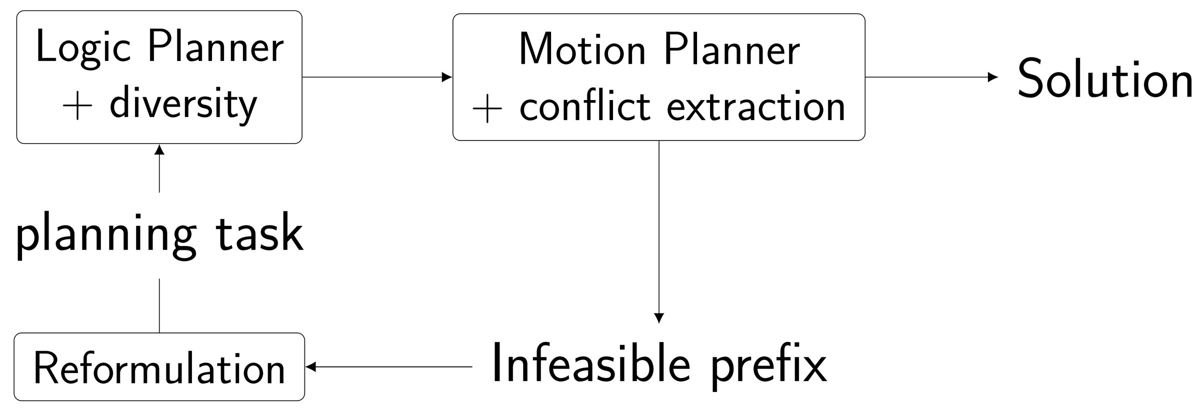
Logic Geometric Program (LGP)

Joint optimization of logical decision variables $\langle a_1 \dots a_K \rangle$, $\langle s_1 \dots s_K \rangle$ and a continuous trajectory $x(t) : t \in \mathbb{R} \to \mathbb{R}^n$ [3].

$$\textbf{LGP} \quad \min_{x, s_{1:K}, a_{1:K}, K} \sum_{k=0}^{K-1} \int_{kT}^{(k+1)T} c(x(t), s_{0:k})\, dt \qquad \text{(1a)}$$
$$x(0) = x_0,$$
$$\forall k \in 0, \dots, K :$$
$$h_k(x(t), s_{0:k}) \le 0, \; t \in [kT, (k+1)T],$$
$$s_k = s_{k-1}[a_k],$$
$$g \subseteq s_K.$$

Logic: SAS+ Planning task $\Pi = \langle \mathcal{V}, \mathcal{A}, s_0, g, cost \rangle$.
Geometry: Nonlinear constraints $h(\cdot)$ and cost $c(\cdot)$ on the trajectory.
Logic sequence $\langle a_1 \dots a_K \rangle$ implies nonlinear program NLP$(a_{1:K})$ on $x(t)$.
Using only mode-switch configurations $x(t_k)$ we define the *Pose* and *Sequence* bounds of a NLP$(a_{1:K})$.

Iterative Logic Planning for LGP



Prefixes as Geometric Conficts

Theorem: If a sequence of logical actions π is geometrically infeasible, any sequence of actions π' which contains π as a prefix is also infeasible.

Tree Forbidding Compilation

- Forbid $\langle a_1 \dots a_K \rangle$ as a prefix, instead of as a plan [2].
- Simultaneously forbid multiple prefixes with a prefix tree $T = (N, E)$

Reformulated planning task $\Pi_T^- = \langle \mathcal{V}', \mathcal{A}', s_0', g', cost' \rangle$ **contains additional variables and action operators to ensure that new plans do not start with the infeasible prefixes.**

Conflict Extraction

Imagine that a plan $\langle a_1 \dots a_K \rangle$ is geometrically infeasible (NLP$(a_{1:K})$ is infeasible). Which conflict do we return?
Note: we can choose to evaluate NLP$(a_{1:k})$ for any $k = 1 \dots K$.

Lazy: return $\langle a_1 \dots a_K \rangle$
Eager: find min k s.t $\langle a_1 \dots a_k \rangle$ is infeasible (with binary search)
Metareasoning
- Middle-ground approach between lazy and eager.
- When searching for conflict in $a_{1:K}$, we have a range $[l, u]$ such that $a_{1:u}$ is not geometrically feasible, while $a_{1:l}$ yes.
- Should we return $a_{1:u}$ as conflict or search a smaller conflict (between l, u)?

Formulate a Markov Decision Process (MDP)
- States $S_\pi = \{\langle l, u \rangle\}$ – current range of the search. Terminal states: converged search $\langle u, u \rangle$. Start: $\langle 0, K \rangle$.
- Actions at $\langle l, u \rangle$: A) stop searching (reach state $\langle u, u \rangle$), or B) check any node $l < m < u$.

Estimate transition probabilities and rewards from past plans evaluation.

Diverse Logical Planning for LGP

How to choose which plan π to test next? $\to$ **Prefix Novelty**
$np(\pi, LP) := -\min\{k \mid \forall \pi' \in LP, \pi' k \neq \pi k\}$ (LP is set of plans)
- High chance to extract a short conflict from that plan.
- Explore the space of logical plans.

Experimental Results

Benchmark 20 problems in 3 domains: Blocks, Hanoi, Push.
Metrics Computational time, pose and sequence bounds NLPs.
Baselines Multibound Tree Search Algorithm (MBTS) for LGP [3].
Results
- Our approach (N=1, eager conflict extraction) is faster (16 vs 2) and solves more problems (18 vs 12) than any of the MBTS baselines.
- Diverse planning with the novelty measure improves over incremental plan generation (total time 833 vs 976 seconds, 115 vs 145 seq bounds)
- Metareasoning is faster than eager and lazy conflict extraction (783 vs 833 seconds, and 57 vs 115 solved sequence bounds)

Conclusion

- Systematic interface between a PDDL-Planner and a nonlinear solver. Key: Identify and encode geometric conflicts (infeasible prefixes).
- Extension with novelty selection criteria and metareasoning.
- Outperform previous solvers for LGP.

Future Work: 1 - Combine geometric and logical heuristics (with information about feasible prefixes). 2- Detect and encode stronger conflicts (subset of infeasible constraints). Preprint: *A Conflict-driven Interface between Symbolic Planning and Nonlinear Constraint Solving*.

References

[1] Caelan Reed Garrett, Rohan Chitnis, Rachel Holladay, Beomjoon Kim, Tom Silver, Leslie Pack Kaelbling, and Tomás Lozano-Pérez. Integrated task and motion planning. *Annual Review of Control, Robotics, and Autonomous Systems*, 4(1):265–293, 2021.

[2] Michael Katz, Shirin Sohrabi, Octavian Udrea, and Dominik Winterer. A novel iterative approach to top-k planning. In *Proceedings of the Twenty-Eighth International Conference on Automated Planning and Scheduling, ICAPS 2018, Delft, The Netherlands, June 24-29, 2018*, pages 132–140. AAAI Press, 2018.

[3] Marc Toussaint, Kelsey R. Allen, Kevin A. Smith, and Joshua B. Tenenbaum. Differentiable physics and stable modes for tool-use and manipulation planning. In *Robotics: Science and Systems XIV, Carnegie Mellon University, Pittsburgh, Pennsylvania, USA, June 26-30, 2018*, 2018.