Lilotane: A Lifted SAT-based Approach To Hierarchical Planning

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TOHTN Planning

Totally Ordered Hierarchical Task Network (TOHTN) Planning:

- **Task**: Parametrized signature of something that must be achieved, e.g., *reach*(car, destination). Can be *primitive* or *compound*.
- **Operator**: *Achieves* a primitive task. Alters the current *world state*: Has *preconditions* and *effects*.
- **Method**: Achieves a compound task by replacing it with *totally ordered subtasks*. Has preconditions.
- Input: **Initial state** s_I (collection of *facts*), **initial tasks** T
- Objective: Successively achieve all tasks at hand until only primitive tasks are left and form a **plan** (an executable sequence of actions)
- Central decisions: *Which method with which arguments* to pick for each compound task?

SAT-based HTN [2, 3]

1. **Ground** parametrized operators and methods into "flat" **actions** and **reductions**
2. **Encode** problem hierarchy up to **layer** (depth) l in propositional logic
3. Perform **SAT solving** on formula
4. While unsatisfiable: l++, goto 2.
5. **Decode** plan from satisfying assignment

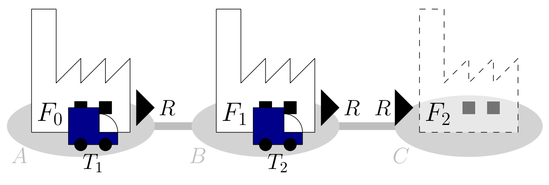
Grounding can be a problem!

- Consider method ***deliver***(r, t, x, Y) where place Y is determined by a parent task and resource r, truck t, place x have 20 possible values each $\Rightarrow$ 8 000 reductions!
- **Blowup** in input size, **bottleneck** w.r.t. time and memory

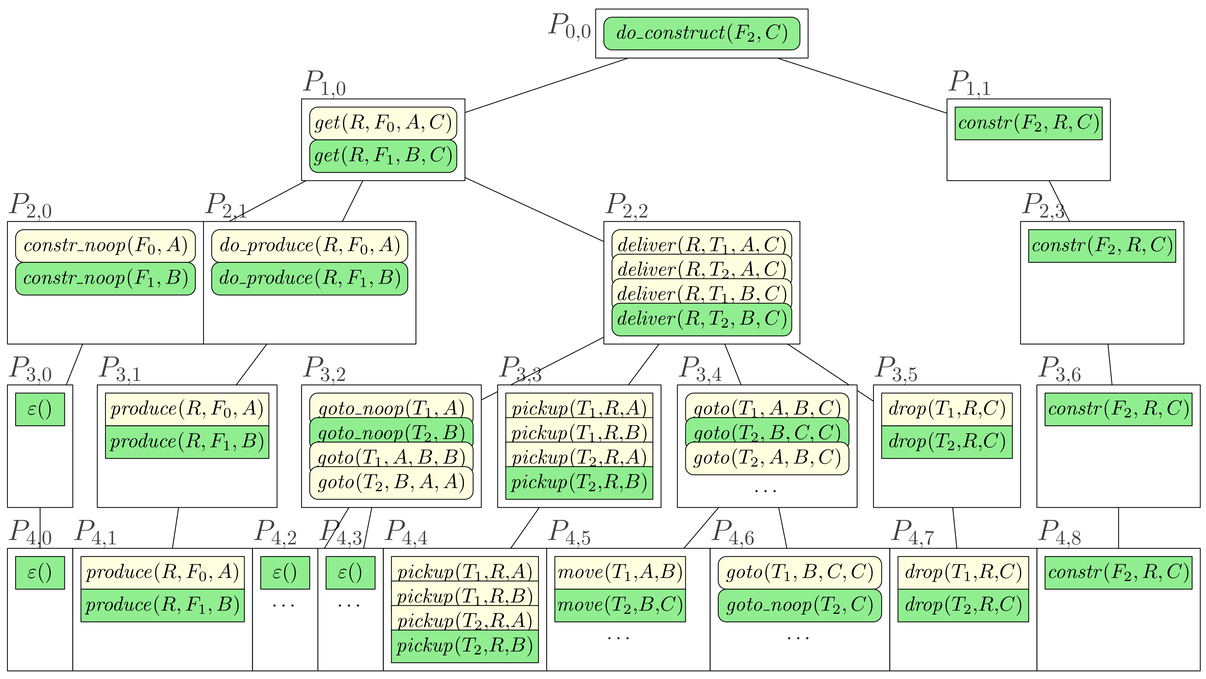
Objectives

- **Skip grounding**: Instantiate problem hierarchy as little as possible, only when needed
- **Avoid blowup**: Find a more compact logical representation than fully instantiating all free arguments

Minimalistic Example



Factories F_0, F_1 produce resource R; Trucks T_1, T_2 can transport resources; Factory F_2 must be built using R.

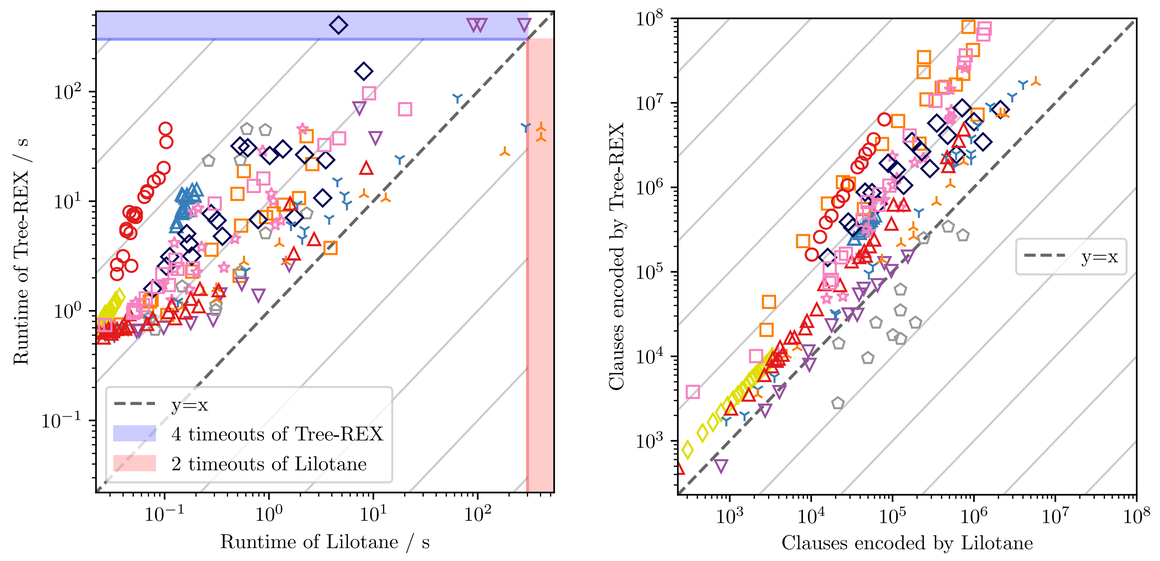


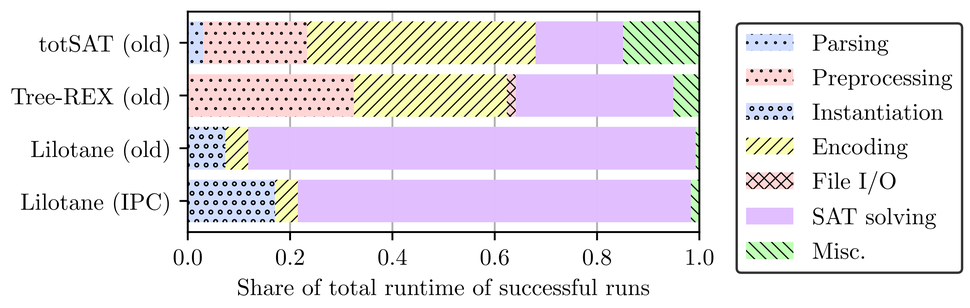
Layers $L_0, \ldots, L_4$ and positions $P_{l,x}$ which contain possible **operations**, i.e., actions (rectangular) and reductions (rounded); a solution is highlighted.

Central Idea: Lifted Encoding

Consider method ***deliver***(r, t, x, Y): Instead of many new ground operations, introduce **pseudo-constants** ρ, τ, ξ and only instantiate and encode a single operation $o = deliver(\rho, \tau, \xi, Y)$. Encode operation o *relative to pseudo-constants*: Boolean variable for o, for each possible pseudo-constant substitution, and for each precondition/effect with pseudo-constants. Add clauses to logically enforce preconditions/effects relative to the active substitutions.

Experiments





Lilotane: Features

- **Lazy instantiation** layer by layer until success
- **Reachability analysis** at each layer prunes invalid operations
- **Lifted encoding**: Decisions on method arguments are deferred to SAT solving
- Encoding exponential along fewer dimensions than Tree-REX [3]
- Designed around **Incremental SAT solving** – also allows for **anytime plan improvement**

Discussion

- Performs better, produces much **smaller formulae** than previous SAT-based TOHTN planners (Tree-REX [3], PANDA-totSAT [2])
- Shifts majority of effort to SAT solver, reduces memory footprint
- Few domains where merits of grounding appear to outweigh its problems (e.g. Entertainment)
- **Competitive** in state-of-the-art TOHTN planning: Runner-up in Total Order track of IPC 2020
- Produces plans of **high quality** even without plan improvement; often finds **optimal plans** when using plan improvement
- Lifted instantiation and encoding techniques may be applicable for related planning approaches, e.g., general HTN planning

References

[1] Dominik Schreiber.
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[2] Gregor Behnke, D. Höller, and S. Biundo.
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[3] Dominik Schreiber, Damien Pellier, Humbert Fiorino, et al.
Tree-REX: SAT-based tree exploration for efficient and high-quality HTN planning.
In *29th ICAPS*, pages 382–390, 2019.