This is a solution! (... but is it though?)
Verifying solutions of hierarchical planning problems

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Ulm University, Institute of Artificial Intelligence

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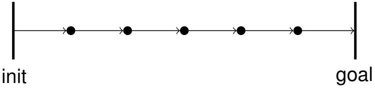
ICAPS 2017 – Pittsburgh

Plan Verification



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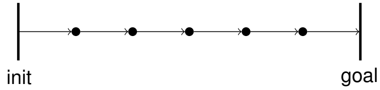

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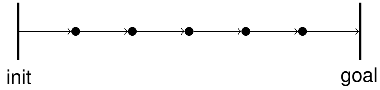

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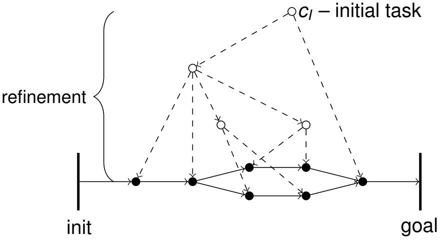

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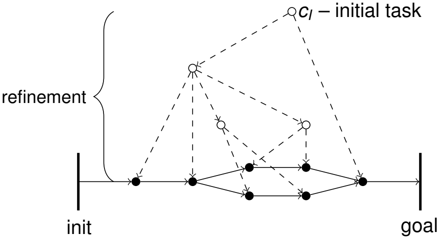

- $\mathcal{O}(n)$ for totally ordered classical plans
- VAL provides for plan verification in classical domains
- $\mathbb{NP}$-complete for HTN (Hierarchical Task Network) planning [Behnke et al. 2015]
- So far, no HTN plan verifier exists

Why plan verification?

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What have we done?

1. Provided a translation of Plan Verification problem into SAT
2. Provided succinct decomposition depth bounds for plans
3. Showed that verifying plans using SAT is empirically feasible

Hierarchical Task Network (HTN) Planning

$\mathcal{P} = (P, C, c_I, M, L, s_I)$

- P a set of primitive tasks
- C a set of compound tasks
- $c_I \in C$ the initial task
- $M \subseteq C \times 2^{TN}$ the methods
- L a set of variables
- $s_I \subseteq L$ the initial state

A solution $tn \in Sol(\mathcal{P})$ must

- be a refinement of the initial task
- only contain primitive tasks
- have a linearisation,
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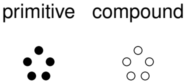

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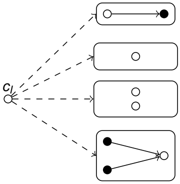

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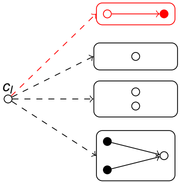

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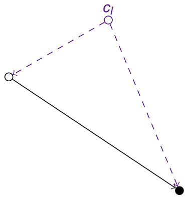

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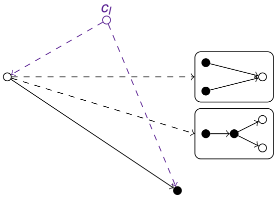

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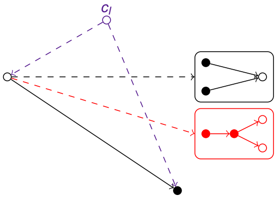

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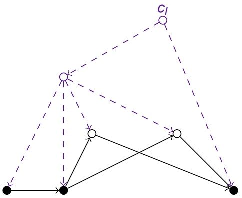

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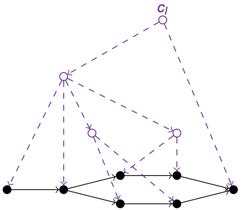

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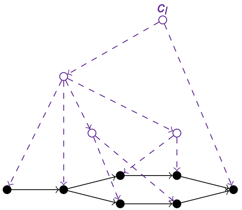

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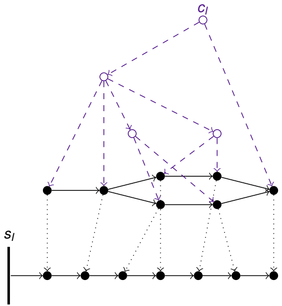

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Let $\mathcal{P}$ be a planning problem and tn be a task network.
Decide whether $\mathrm{tn} \in \mathit{Sol}(\mathcal{P})$.

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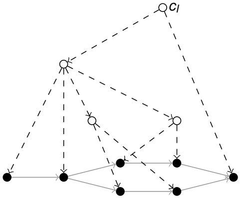

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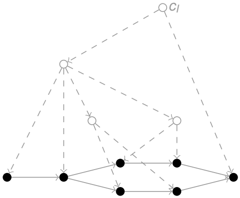

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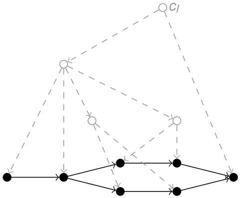

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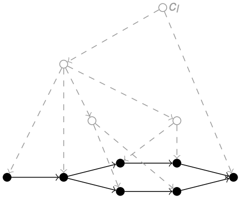

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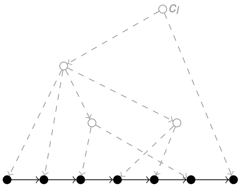
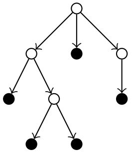


Translation into SAT

- Let's have a look at a Decomposition Tree leading to a solution



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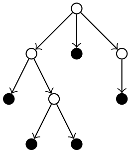
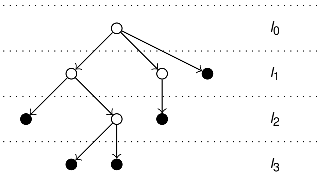
- We can arrange its vertices (i.e. primitive and abstract tasks) in layers





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- Let's have a look at a Decomposition Tree leading to a solution
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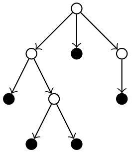

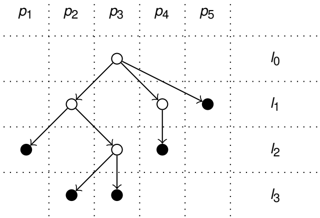

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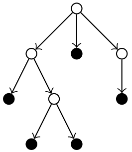
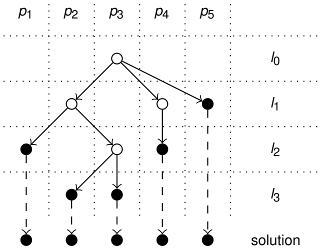
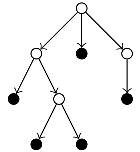
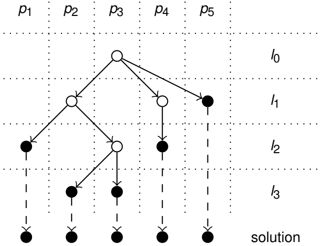




Translation into SAT

- Let's have a look at a Decomposition Tree leading to a solution
- We can arrange its vertices (i.e. primitive and abstract tasks) in layers
- ... and assign each vertex a row.
- Our SAT formula models this assignment process





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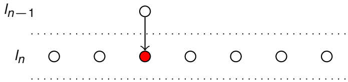

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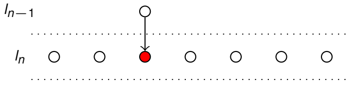

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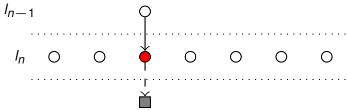

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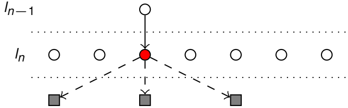

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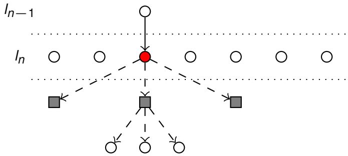

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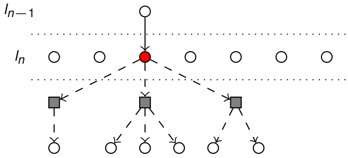

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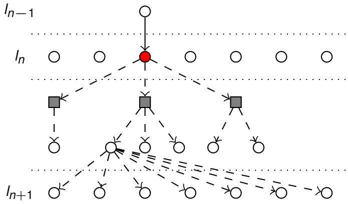

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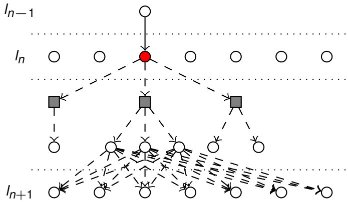

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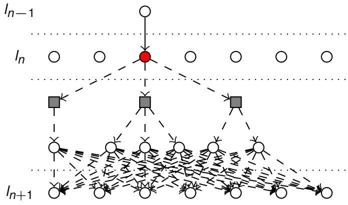

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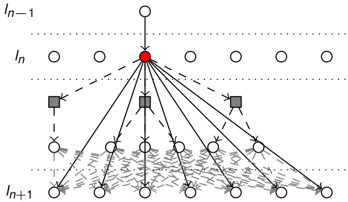

Translation into SAT

Clauses describe local restrictions at position

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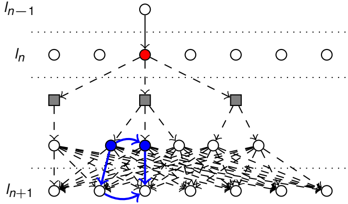

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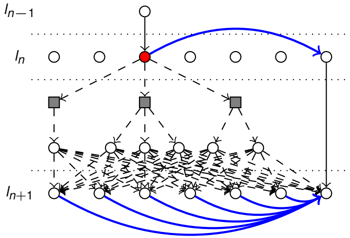

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  The first three are described in the paper, the fourth is new.

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Method 1:

- In Behnke et al. (ICAPS 2015) we showed that plan verification is $\mathbb{NP}$ complete
- The proof provides a theoretical upper bound $K_{theo} = 2|plan|(|C| + 1)$

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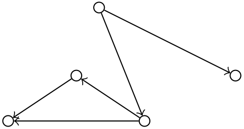

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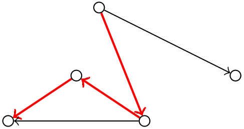

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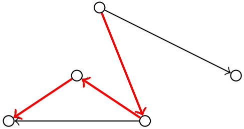

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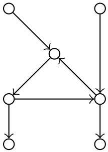

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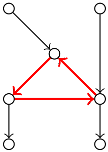

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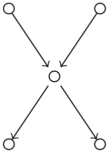

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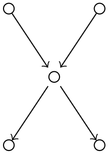

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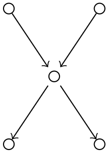

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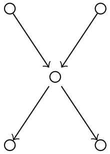

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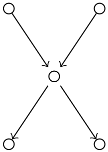

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$\Leftarrow$ take the minimum

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- To ascertain the performance of our SAT-translation, we have conducted an empirical study on five common HTN benchmarking domains

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Satellite ●	22	8	70	1	17	7	78	11	541
SmartPhone ●	3	44	47	5	8	16	18	14	99
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- For 88 of 101 instances the computed height bound was exact.

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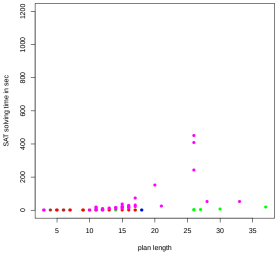

Figure: Runtime on actual solutions.

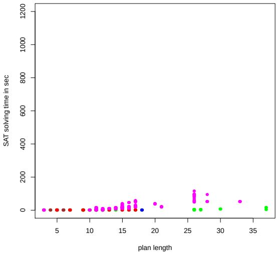

Figure: Runtime on non-solutions, generated by random-walking.

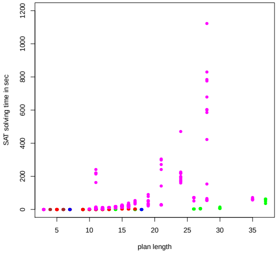

Figure: Runtime on non-solutions, generated by replacing a single action in a solution.

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