Lecture *Hierarchical Planning*

Chapter:
Introduction to HTN Planning

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Winter Term 2018/2019

(Compiled on: February 19, 2019)

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Overview:

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→ That's only the case for *non-hierarchical* planning and different from *hierarchical* planning!

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"[Hierarchical] planners differ from classical planners in what they plan for and how they plan for it. In [a hierarchical] planner, the objective is not to achieve a set of goals but instead to perform some set of tasks."

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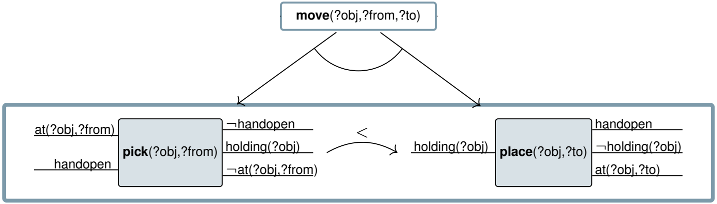
- It's not about generating some goal state! The goal is find a refinement of the initial task(s), not to satisfy some goal description.
- There is no arbitrary task insertion: to alter task networks, we need to decompose compound tasks using their pre-defined methods (see next slide).

What is Hierarchical Planning? . . . More Precisely? Example?

The model specifies a ***task hierarchy***: *compound* (or *complex*, *abstract*, *high-level*) tasks need to be decomposed into *primitive tasks*.



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Top: A compound task.
Bottom: A task network.
Together: A (decomposition) method.

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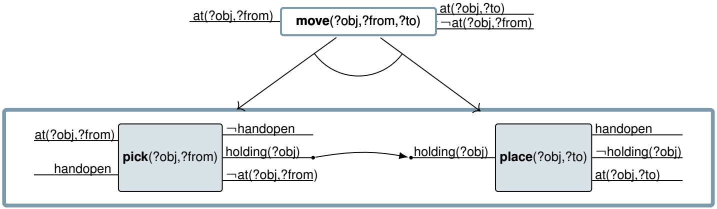

Goal: Find a (primitive) executable *refinement* of an initial hierarchical task network (HTN) or partial plan.

Top: A compound task (with precs/effs).
Bottom: A partial (POCL) plan.
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- But of course we *also* need new/adapted planning techniques...
- *It's not about generating some goal state!* The goal is find a refinement of the initial compound task(s), *not* to satisfy some goal description.
- There is (normally) no arbitrary task insertion: To alter task networks/partial plans, we need to decompose compound tasks using their pre-defined methods. ("Task insertion" is an additional feature (actually: solution criteria!) that has to be provided/allowed in addition.)

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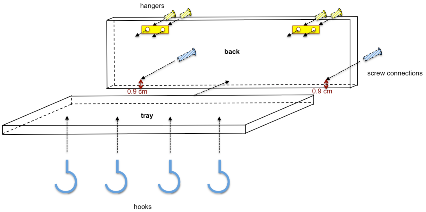
- Communicate plans on different levels of abstraction.
- Incorporate task abstraction in plan explanations.

Motivation, Example: Do-It-Yourself (DIY) Assistant



The material:

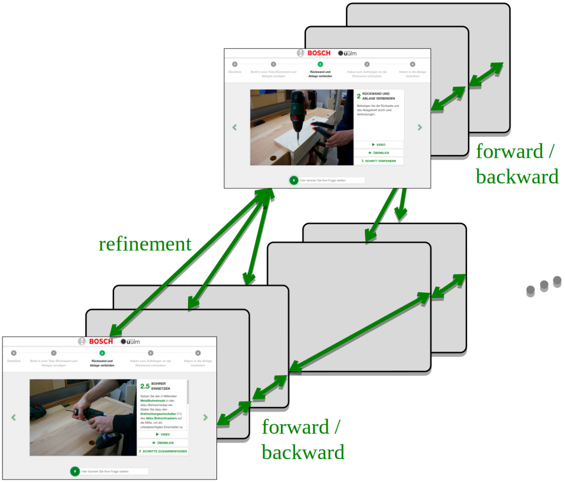
- Boards (need to be cut first)
- Electrical devices like drills and saws
- Attachments like drill bits and materials like nails

Motivation, Example: Do-It-Yourself (DIY) Assistant, cond't

Presentation of instructions on different levels of abstraction:

Abstract Level

Detailed Level



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- One of the best-known formalizations is called *hierarchical task network* (HTN) planning, so it is often used as a synonym to hierarchical planning although the latter can be regarded as the more general expression/field.
- Since the HTN formalism can be regarded a standard and the most simplistic one, we will start with that. Later, we extend it in several directions.

HTNs vs. HTN Problems vs. HTN Planning

- HTN is short for *(hierarchical) task network*.
  Thus, it is a *data structure*, not a formalism or an approach.

  $\rightarrow$ Never write/say something like: “In HTNs, we have to/aim at ...”.
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- The term “HTN planning” can still refer to either the problem class or an (HTN) planning approach (similar to classical planning).
- In the context of the HTN planning framework, we use *HTNs* as basic data structure, i.e., partially ordered tasks.
  If we also use causal links there, we refer to these data structures as *partial plans* instead.

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- *Actions* known from classical planning are the same as *primitive tasks* in hierarchical planning.
- In hierarchical planning, the term *task* is used to refer to either *actions* (i.e., primitive tasks) or *abstract tasks*.

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  - Rather than plan steps being 2-tuples $l{:}a$, we have another mapping α to map l to a (see later).

Literature

Most definitions (in particular: the ground HTN and TIHTN formalisms, and the decomposition tree) are taken from:

- Thomas Geier and Pascal Bercher. "On the Decidability of HTN Planning with Task Insertion". In: *Proc. of the 22nd Int. Joint Conf. on Artificial Intelligence (IJCAI 2011)*. AAAI Press, 2011, pp. 1955–1961

Definitions of the lifted HTN and TIHTN formalisms can be found in:

HTN Ron Alford, Pascal Bercher, and David Aha. "Tight Bounds for HTN Planning". In: *Proc. of the 25th Int. Conf. on Automated Planning and Scheduling (ICAPS 2015)*. AAAI Press, 2015, pp. 7–15

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Problem Definition, Example Search Process

$\mathcal{P} = (V, P, \delta, C, M, s_I, c_I)$ with:

- V, a set of state variables.

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primitive tasks

compound tasks

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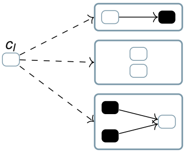

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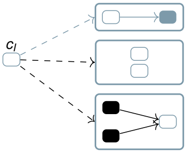

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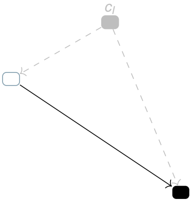

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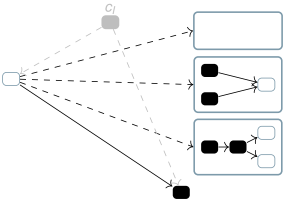

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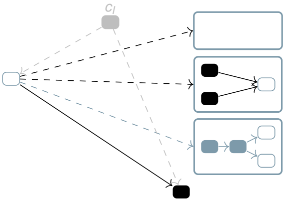

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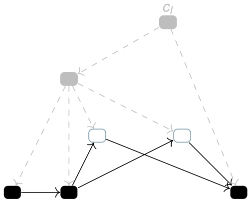

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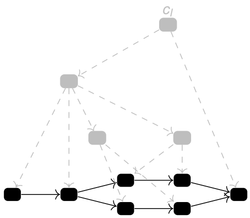

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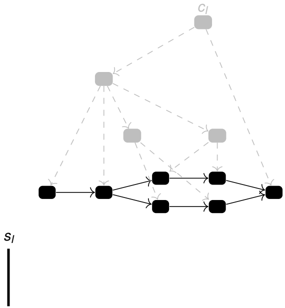

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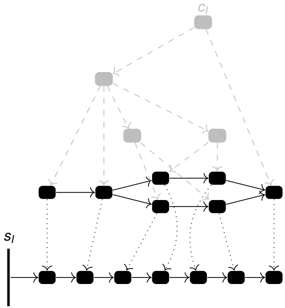

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- have an executable linearization.

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  - For all task identifiers $t \in T$ holds $\alpha(t) = \alpha'(\sigma(t))$.

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- TN_X refers to the set of all task networks using only task names in X.

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  Then, the application of m to tn results in the task network $tn' = ((T \setminus \{t\}) \cup T_m, \prec \cup \prec_m \cup \prec_X, \alpha \cup \alpha_m)|_{(T \setminus \{t\}) \cup T_m}$ with:

$$\prec_X := \{(t', t'') \mid (t', t) \in \prec, t'' \in T_m\} \cup \{(t'', t') \mid (t, t') \in \prec, t'' \in T_m\}$$

  where $(X_1, \ldots, x_n)|_Y$ restricts the sets X_i to elements in Y.

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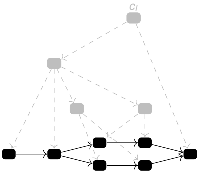

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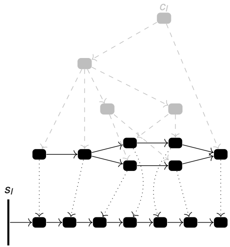
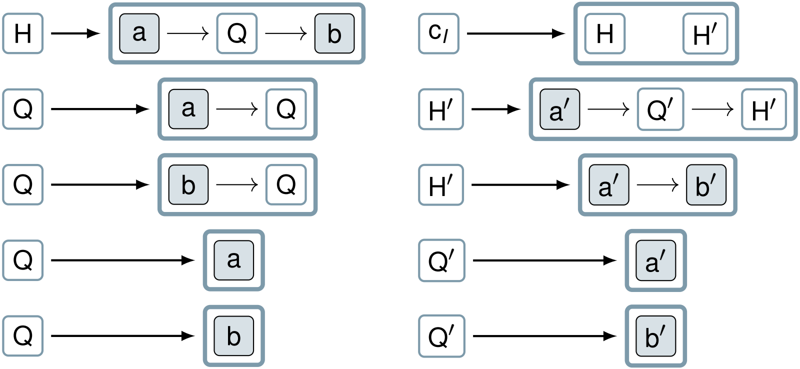


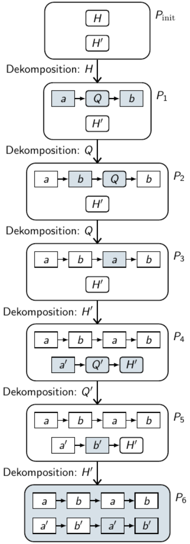
How to Represent Decomposition?

Consider the following decomposition methods:

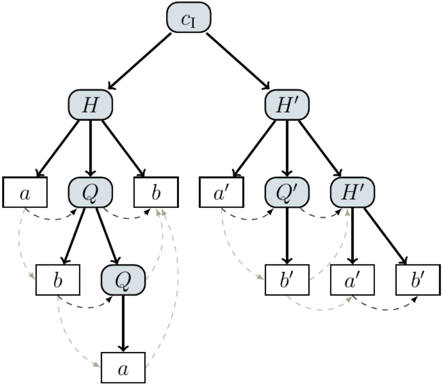


(Preconditions and effects don't matter for now.)

Decomposition Tree: Example



Representation as a tree:



Decomposition Tree: Definition

Definition (Decomposition Tree)

A *decomposition tree* $dt = (T, E, \prec, \alpha, \beta)$ is a five-tuple with the following properties:

- (T, E) is a tree with task identifier symbols T (the nodes of the tree) and directed edges $E \subseteq T \times T$ pointing towards the leafs,

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- $\beta : T' \to M \times Iso$, with $T' \subseteq T$, is a function mapping each node out of a (possibly strict) superset of the inner nodes to a tuple consisting of a method $m \in M$ and an isomorphism $\sigma \in Iso$, Iso denoting the set of all isomorphisms over the task instances in T.

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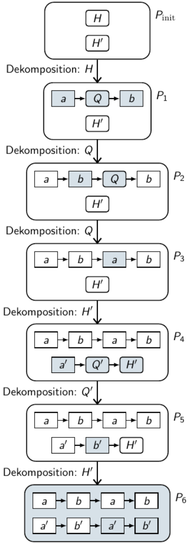
- A task instance $t' \in T$ is called an ancestor of t if $t \in T(dt[t'])$.

Decomposition Tree: Example – Are We There Yet?



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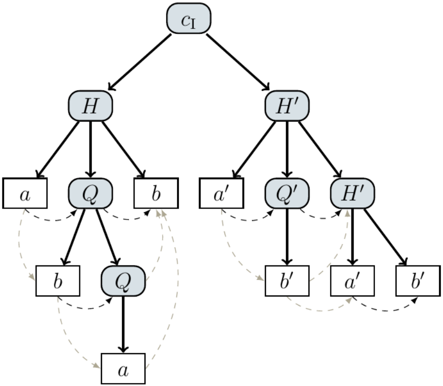

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3. There are no other ordering constraints than those demanded by Criterion 2 or those required by the definition of decomposition trees.

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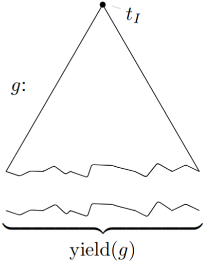

Properties of Decomposition Trees

Theorem

Given a planning problem $\mathcal{P}$, then for any task network $tn \in TN_{C \cup P}$ there exists a valid decomposition tree dt with $yield(dt) = tn$ if and only if $tn_I \rightarrow^*_{TD} tn$.

Proof:

Straight-forward.

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- That way, we can also define several problems for the same domain.

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Recap: $\mathcal{P} = (V, P, \delta, C, M, s_I, c_I)$ describes an HTN planning problem as described before.

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Proof:

Let $\mathcal{P}^\star = (V, P, \delta, C, M, s_I, \boldsymbol{tn_I})$ be an HTN planning problem with initial task network tn_I.

Then, there is an HTN planning problem $\mathcal{P}' = (V, P, \delta, \boldsymbol{C'}, \boldsymbol{M'}, s_I, \boldsymbol{c_I})$ with the same set of solutions:

Let $C' := C \,\dot{\cup}\, \{c_I\}$ and $M' := M \cup \{(c_I, tn_I)\}$.

Identical solution set is obvious.

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Then, a task network *tn* is a solution if and only if:

- There is a sequence of decomposition methods $\overline{m}$ that transforms c_I into *tn*,
- *tn* contains only primitive tasks,
- the (still partially ordered) task network *tn* admits an executable linearization $\overline{t}$ of its tasks, and
- **the task sequence $\overline{t}$ generates a goal state $\boldsymbol{s} \supseteq \boldsymbol{g}$.**

Impact of Goal Description, cont'd

Theorem: **Goal descriptions can be compiled away.**

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Proof:

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Then, there is an HTN planning problem $\mathcal{P}' = (V, \boldsymbol{P'}, \boldsymbol{\delta'}, C, M, s_I, \boldsymbol{tn_I})$ with the same set of solutions:

Here, tn_I contains two tasks: c_I followed by a new primitive task p with no effects and g as precondition, $\delta(p) = (g, \emptyset, \emptyset)$.

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Then, the initial task network in $\mathcal{P}'$ can be compiled away as before.

Identical solution set is obvious.

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→ For this criterion, we must allow ordering insertion, as otherwise solutions with the demanded properties might not exist.

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- Task insertion makes the problem computationally easier (can be exploited for heuristics).

Problem Definition

In *HTN planning with task insertion*, *TIHTN planning*, tasks may be added arbitrarily to task networks (not just via decomposition):

Let $\mathcal{P}^\star = (V, P, \delta, C, M, s_I, c_I)$ be a **TIHTN planning problem**.

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Then, a task network *tn* is a solution if and only if:

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Then, a task network *tn* is a solution if and only if:

- There is a sequence of decomposition methods $\overline{m}$ that transforms c_I into $\boldsymbol{tn'}$,
- $\boldsymbol{tn \supseteq tn'}$ **contains all tasks and orderings of** $\boldsymbol{tn'}$,
  (Note: allowing $\prec \supseteq \prec'$ *would imply that we allow ordering insertion, which would, similar to HTN planning, be required if we demand all linearizations to be executable.)*
- *tn* contains only primitive tasks, and
- the (still partially ordered) task network *tn* admits an executable linearization $\overline{t}$ of its tasks.

Problem Formalization

State constraints have been introduced in the HTN formalization by Erol et al. (1994):

- (l, t), the literal l holds immediately before task t.
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In case t, resp. t', are compound, a constraint (l, t) is, upon decomposition, translated to $(l, \mathit{first}[t_1, \dots, t_n])$, where the t_i are all sub tasks of t. ((t, l) and (t, l, t') are handled analogously.)

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No compilation known yet.

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Summary

- Hierarchical planning is *not* about generating a goal state (i.e., about finding a plan that generates a goal state) but about achieving a set of tasks.
- There are various different hierarchical planning formalisms (some of them covered later) with different theoretical properties.
- HTN planning is *the* standard hierarchical planning formalism.
- Also for HTN planning there are various formalization choices with differing impact on theoretical properties.