Lecture *Hierarchical Planning*

Chapter:
Further Hierarchical Planning Formalisms

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Overview:

Introduction

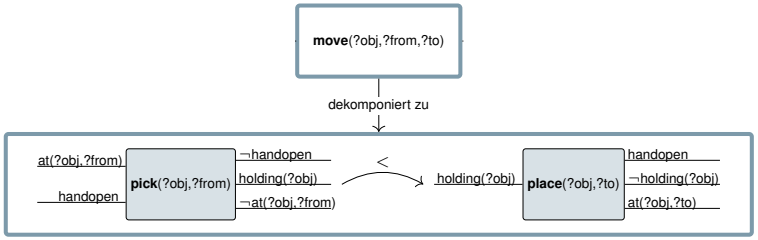
- So far, all investigations based upon a simplistic formalization of HTN planning.
- However, there several further hierarchical planning formalisms can be found in the literature.
- Some, we already covered so far:
  - TIHTN planning (covered in detail).
  - A lifted version of HTN and TIHTN planning (introduced rather informally).
  - A lifted HTN planning formalism that allows to express state constraints (briefly mentioned).
- But there are many more:
  - Some regard the task hierarchy *advice* rather than a *restriction*. Their goal is to solve *classical problems* rather than hierarchical ones (but do so hierarchically).
  - Others extend HTN planning to allow modeling support.
  - Others focus on the idea to refine/decompose *state features* rather than compound tasks.

Introduction

- Here, we deal with the *problem class* “hybrid planning”, not with the *algorithm* hybrid planning!
- To clarify: In the literature, the *Decomposition-based* planning approach (i.e., algorithm) for solving (TI)HTN problems via plan-based search using POCL techniques is also referred to as *hybrid planning* – so don’t confuse them
- Essentially, hybrid planning (from now on: the *problem class*!) is the same as (TI)HTN planning problem, but slightly extended:
  - Compound tasks can have preconditions and effects as well.
  - They can be used to define *implementation criteria* – they define the circumstances under which a decomposition method is regarded an *implementation* of its compound task.
  - Further, the model (and initial task network) can contain causal links.

  → Consequently, the solution criteria also involve causal links.

Motivation



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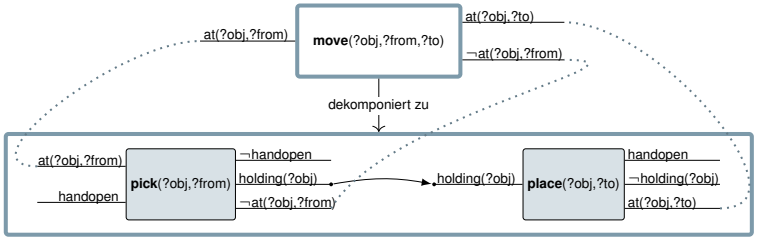

The hybrid planning formalism allows to define preconditions and effects for compound tasks. But why?

- To generate abstract (i.e., non-primitive) solutions.
- To exploit it during search.
- To provide *modeling support* by restriction to legal models (test all decomposition methods).

Problem Description

- Here, we give only a rather informal description of hybrid problems via only mentioning the *differences* to (TI)HTN and POCL problems.
- The problem description extends (TI)HTN problems as follows:
  - Rather than task networks, the model uses *partial plans* known from POCL planning or from decomposition-based search (i.e., plan steps can be abstract as well and there might be causal links).
  - Compound tasks have the same syntactic form as actions, i.e., they allow for preconditions and effects.
  - Consequently, causal links are allowed to point to or from compound tasks as well.
  - Thus, we need to alter how causal links induce ordering constraints: In contrast to the previous definition (cf. first lecture) only those causal links induce an ordering that are defined between two primitive tasks.

Solution Criteria

- The solution criteria are essentially the same as for (TI)HTN planning, but extended in two ways:
  - To deal with the causal links pointing to or from a compound task, we demand that upon decomposition they get decomposed to any possible consumer (branching over all possibilities).
  - Solutions are defined as primitive plans without flaws. (Similar to the decomposition-based algorithm.)
- Similar to HTN vs. TIHTN problems, task insertion is an optional property of the the hybrid planning problem class.

Introduction

- *Legality criteria* (or *implementation criteria*) are criteria under which decomposition methods are assumed to be correct (or legal) implementations of their compound task.
- They all try to express “what it means that a compound task has preconditions or effects”.
- There are differently strong restrictions, though their theoretical impact is very limited.

Downward Compatible

Definition (Downward Compatible, Bercher et al. 2016)

Let $m = (n_c, P)$ be a method, $n_c = (pre, eff)$ an abstract task and P a partial plan.

- If $\varphi \in pre$, then there exists φ as precondition of a task in P without causal link, which points towards it.
- If $\varphi \in eff$, then exists φ as effect of a task in P.

- Prevents/detects the most obvious modeling flaws.
- abstract tasks can always be decomposed – as it is the case in standard HTN planning

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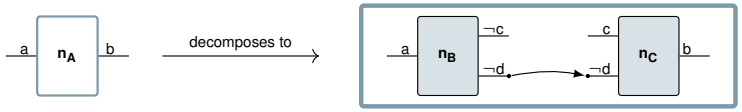

Does this method satisfy the criterion?

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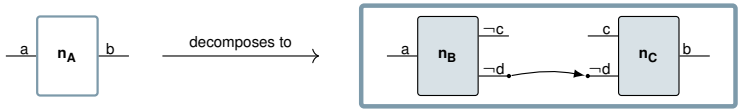

Does this method satisfy the criterion? Yes!

State-transition Semantics

Definition (Biundo and Schattenberg, 2001)

Let $m = (n_c, P)$ be a method, $n_c = (pre, eff)$ an abstract task, and P a totally ordered plan.

- There needs to be a state s satisfying pre, $s \models pre$, such that P's task sequence $\bar{t}$ is executable in s.
- For all states satisfying the first criterion, $\bar{t}$ generates a state satisfying eff, $s \models eff$.

- State-transition semantics adopted to abstract tasks.
- Strong assumption: open preconditions need to be supported by one single state.

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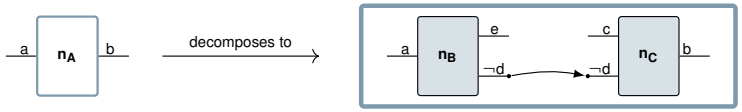

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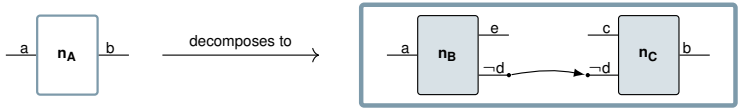

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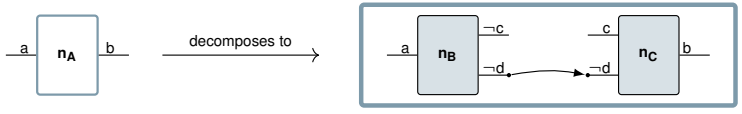

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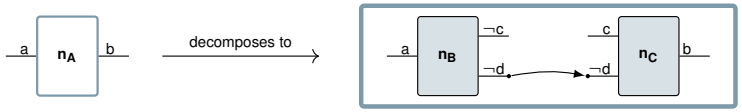

Does this method satisfy the criterion? No!

Causal Threat Criterion

Definition (Yang, 1990)

Let $m = (n_c, P)$ be a method, $n_c = (pre, eff)$ an abstract task, and P a plan.

- *pre* and *eff* are actual preconditions and effects in P.
- There are no causal threats.

- Slightly weaker than the last criterion: open preconditions do not need to be achieved by one single state.

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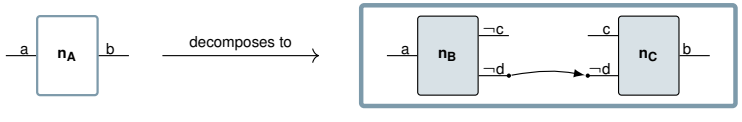

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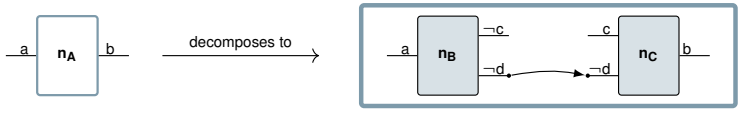

Does this method satisfy the criterion? Yes!

Causal Link Chain Criterion

Definition (Young et al., 1994)

Let $m = (n_c, P)$ be a method, $n_c = (pre, eff)$ an abstract task, and P a plan.

- Any of n_c's preconditions *pre* contributes to at least one of its effects *eff* via a chain of causal links
- ... and vice versa.

- Neither stronger, nor weaker than the previous criterion.

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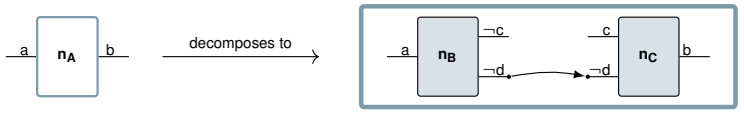

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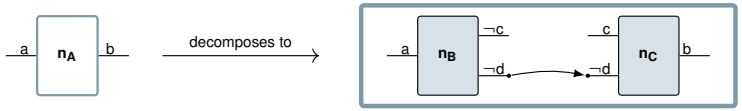

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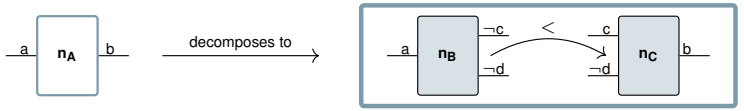

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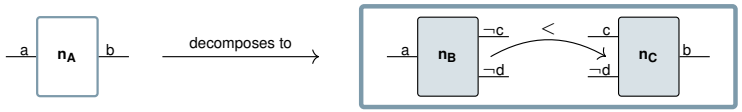

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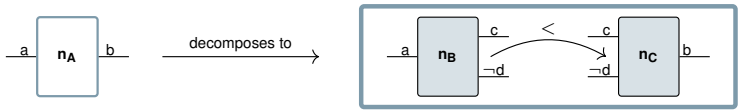

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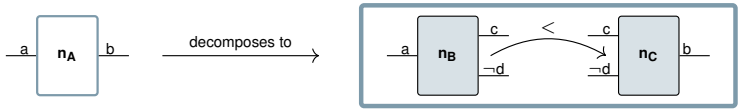


Does this method satisfy the criterion? No!

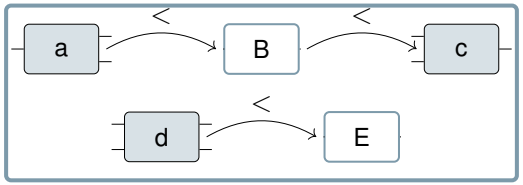
More than a Name?

- Which impact have the legality criteria on the expressivity?
- We show that every HTN problem $\mathcal{P}$ can be transformed into a hybrid planning problem $\mathcal{P}'$, such that:
  - $\mathcal{P}$ and $\mathcal{P}'$ have the same set of solutions (see discussion),
  - $\mathcal{P}'$ satisfies all legality criteria.

Encoding HTN Problems into Hybrid Problems

For each primitive task t, create an abstract copy T without preconditions and effects. Then:

- Add a method $m = (T, P)$ with P containing exactly t.
- In each plan, replace t by T.



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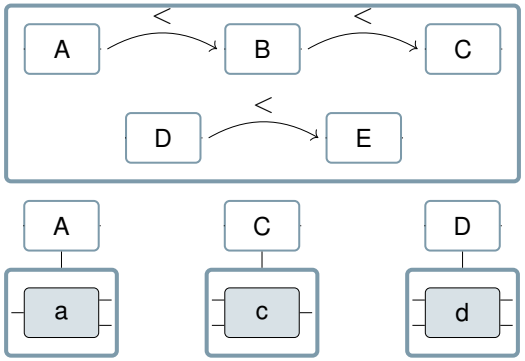

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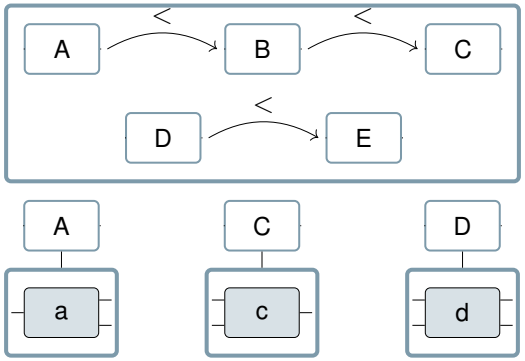

Properties:

- All abstract tasks do not have preconditions or effects
- For all plans holds:
  - either there are only abstract tasks
  - or at most one.
- Thus, all methods in $\mathcal{P}'$ satisfy all legality criteria.

Introduction

- The problem definition and the solution criteria changed, so we have a new problem class with potentially different theoretical properties.
- So, how hard (or easy) is this problem?
- As we will see: we can express every HTN problem as a hybrid problem without violating any criterion.
- Thus, it's as hard as HTN planning.
- Membership results (lower bounds) are open, but probably identical to those from HTN planning as well.

Complexity Results (Plan Existence)

Theorem

Hybrid planning is strictly semi-decidable.

Proof:

semi-decidable:

- Perform BFS starting in the initial partial plan.

undecidable:

- Reduce the undecidable HTN plan existence problem to hybrid planning
- For this, we use the property shown before, i.e., that every HTN problem can be encoded by a hybrid problem that satisfies *all* legality criteria.

Hybrid Planning Algorithm

- To solve hybrid problems, we have to use the hybrid planning *algorithm* (i.e., decomposition-based search), because it's the only one being able to deal with causal links by now.
- That is, as soon as a compilation from hybrid models to standard (TI)HTN models is known, we can again use all standard techniques.
- Reminder: Now, partial plans can already contain causal links. Do we have to change the algorithm? Yes!
  - In some cases, we get fewer successors when decomposing, because we can use the effects of compound tasks as producer (see example from blackboard).
  - When decomposing an abstract task that's involved in causal links, we get, in general, much more successors than it's number of methods (see example from blackboard).

Motivation and Problem Definition

- *Decompositional planning* was created as a means to reduce search effort for solving classical problems via hierarchical planning techniques.
- That is, it is defined in exactly the same way as *hybrid planning with task insertion*, but without an initial partial plan. Why?
  - Now, also compound tasks can be inserted, which (hopefully) lead to solutions quicker than compared to relying on primitive task insertion completely.
  - Theory-wise, the problem is as expressive as classical planning, because we are not forced to insert compound tasks (and if there is a solution with compound task insertion then there is also one without).

Summary

- There are many hierarchical planning formalisms – more than just the HTN or TIHTN formalisms discussed so far.
- One of them is hybrid planning, which extends (TI)HTN planning with concepts known from POCL planning.
- Closely related is decompositional planning, which is essentially hybrid planning with task insertion, but without initial partial plan.
- Another formalism is HGN planning, Hierarchical Goal-Task Network planning (we only discussed this briefly).