Lecture *Hierarchical Planning*

Chapter:
Problem Compilations for (Non-Hierarchical) Planning

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Overview:

Which Problem Representation is the Best?

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  - Derived Predicates (based on *axioms*).
  - Quantifiers in preconditions or effects.
  - Conditional effects.

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$\rightarrow$ They can all be “compiled away”!

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  - Ordinarily, the runtime of f is in $\mathbb{P}$ (but in the size of its input, which is neither $\mathcal{P}$ nor $\mathcal{P}'$).

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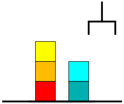
However, *natively* dealing with some language feature might be more efficient (in particular if the compilation increases the problem size significantly) but may be (much) more complicated.

Motivation

Consider Blocksworld:



- *n* blocks, 1 gripper.
- A single action either takes a block with the gripper or puts a block we are holding onto some other block/the table.

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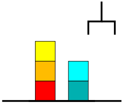

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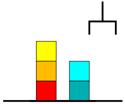

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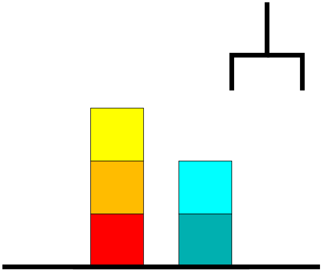
Motivation, cont'd



Predicates:

- $on(x, y)$ – x lies directly on y.
- $free(x)$ – x has no block above it.

Actions:

- $pickup(x)$ – pick up x, if it is free.
- $putdown(x, y)$ – put x on y, if y is free (the *table* is always free).

$\rightarrow$ Modeling in a lifted representation is much easier:

- Just 2 actions!
- Just 18+1 constants.

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- The standard description language for planning problems (PDDL: planning domain description language) relies upon such a lifted formalism.
- For example, consider the *Blocksworld domain* from the IPC 2000: https://github.com/potassco/pddl-instances/tree/master/ipc-2000/domains/blocks-strips-typed (see live demo)

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  - → Using the PG instead of the rPG results into less actions, but may be too expensive empirically.

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  - Complexity Analysis, proofs.
- Most heuristics rely on positive preconditions. What means delete relaxation if we have positive preconditions?

Problem Definition (given Negative Effects)

Blackboard/Whiteboard.
(See also exercise sheet.)

Delete-free Planning Problems, Complexities

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(2) As long as at least one action was applied, repeat. Also stop if the goal is generated.

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- Thus, the maximum *required* plan length (to achieve any goal description) is bounded by $b \leq |A|$.
- Now, guess a sequence of b actions and verify in linear time whether it's applicable.
- Return true or false (depending on whether all goals hold in the final state and the guessed plan is executable).

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- For each boolean variable $x_i \in V$ add two actions to A:

$$\neg x_i{-}\bot \;\; \boxed{x_i \mapsto \top} \;\; x_i{-}\top \quad \text{and} \quad \neg x_i{-}\top \;\; \boxed{x_i \mapsto \bot} \;\; x_i{-}\bot$$

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  $x_{j_i} - \top \; \boxed{\begin{array}{c}\text{“}x_{j_i} = \top\text{”} \\ C_j \mapsto \top\end{array}} \; C_j - \top$ or $x_{j_i} - \bot \; \boxed{\begin{array}{c}\text{“}x_{j_i} = \bot\text{”} \\ C_j \mapsto \top\end{array}} \; C_j - \top$

- $g = \{C_j - \top \mid 1 \leq j \leq m\}$.

Delete-free Planning Problems, Complexities

Theorem

Let $\mathcal{P}$ be a planning problem with negative preconditions (in addition to the positive ones). Then, deciding whether $\mathcal{P}^+$ has a solution is $\mathbb{NP}$-complete.

Hardness Proof: Reduction from CNF-SAT:

- Let $\varphi = \underbrace{\{C_1, \dots, C_m\}}_{\text{clauses}}$, $C_j = \underbrace{\{\varphi_{j_1}, \dots, \varphi_{j_k}\}}_{\text{literals}}$, and $V = \underbrace{\{x_1, \dots, x_n\}}_{\text{variables}}$.
- For each boolean variable $x_i \in V$ add two actions to A:

  $\neg x_i - \bot$ $\boxed{x_i \mapsto \top}$ $x_i - \top$ and $\neg x_i - \top$ $\boxed{x_i \mapsto \bot}$ $x_i - \bot$

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- $g = \{C_j - \top \mid 1 \leq j \leq m\}$. φ is satisfiable if and only if a plan exists.

Delete-free Planning Problems, Complexities, cont'd

Recap:

- Deciding whether $\mathcal{P}$ (with or without negative preconditions) has a solution is $\mathbb{PSPACE}$-complete (shown later).

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Question:
Since $\mathbb{NP} \subseteq \mathbb{PSPACE}$ (and presumably $\mathbb{NP} \subsetneq \mathbb{PSPACE}$), using $\mathcal{P}^+$ with negative preconditions as basis for heuristics is a (n expensive, but) useful relaxation heuristic, right?

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No! Although deciding it is easier, it's not a relaxation. *Why?*

Blackboard/Whiteboard.

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How to Combine Negative Preconditions and Delete-Relaxation?

If we can't use delete-relaxation for heuristics in case we have negative preconditions, what should we do?

$\rightarrow$ Compile them away!

Compilation Technique (easy)

Blackboard/Whiteboard (see also exercise sheet).

- Easy to understand and to implement.
- Number of additional variables is often unnecessarily high.

Compilation Technique (fancy)

Blackboard/Whiteboard (see also exercise sheet).

- Much more complicated to understand and to implement.
- Number of additional variables is minimal.

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- There are many such examples:
  - Use a light switch (rather than turn on/turn off).
  - . . . (You can also check the IPC.)

Problem Definition

- When actions have conditional effects, they have a set of two-tuples rather than an add and delete list. Each head of the tuple is a precondition set (analogous to STRIPS with negative preconditions, we can use negative preconditions here as well) and the body consists of an add and delete list.

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    - Then, $s' = (s \setminus del') \cup add'$.

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  $\rightarrow$ Note that $\neg\neg\varphi = \varphi$ and that mutex relations can be exploited, i.e., actions with a precondition $\neg a \wedge a$ can be ignored.

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- Instead, we can include additional state variables that prevent "standard actions" to be executed. Then, "synchonization actions" become applicable that produce the correct successor state and make standard actions applicable again.
- This technique only requires a linear space increase of the model, but required more effort for the planner.

Formal Definition

- Preconditions can involve disjunctions. You can assume that preconditions are given in conjunctive normal form.

Compilation

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  $\rightarrow$ Actions with preconditions that are mutex to each other (such as A_1: $a \wedge \neg a$) can be ignored.

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- Paint all blocks that don't have another block above them (all-quantified conditional effect).
  More realistic example:
  If a truck moves from one location to another, all objects it has loaded change their location as well.

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- In principle, also effects can make use of quantifiers, but they cannot be applied in *arbitrary* formulae, since disjunctions violate the standard action semantics. (Disjunctions correspond to non-deterministic effects.)
- For more standardized restrictions on how to use quantifiers, you can investigate PDDL.

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- Existence quantifiers can simply be ignored, but the variable might have to be renamed if it's already occurring as a free variable or as another existence quantified variable.

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- For *practical purposes*, STRIPS is *never* used. Instead, we have:
  - A *lifted* model, which is based on a first-order predicate logic rather than on propositional logic.

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$\rightarrow$ One way of dealing with additional features is compilation.

$\rightarrow$ One can also deal with them natively. This has the potential to be much more efficient for the respective algorithms, but all techniques (algorithm, heuristic, pruning techniques, reachability analysis, etc.) may have to be adapted by hand.