Hybrid Planning with Preferences Using a Heuristic for Partially Ordered Plans

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Planning in a Nutshell

Most important kinds of planning problems:

- Classical Planning Problems
- Hierarchical Planning Problems
- Hybrid Planning Problems

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Solution: Any sequence $\bar{a} \in A^*$, s.t.

- $\bar{a}$ is executable in s_{init}
- $\bar{a}(s_{\text{init}}) \supseteq s_{\text{goal}}$

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Solution: Any sequence $\bar{t} \in T^*$, s.t.

- $\bar{t}$ is executable in s_{init}
- $\bar{t}$ is primitive
- $\bar{t}$ can be obtained by decomposing P_{init}

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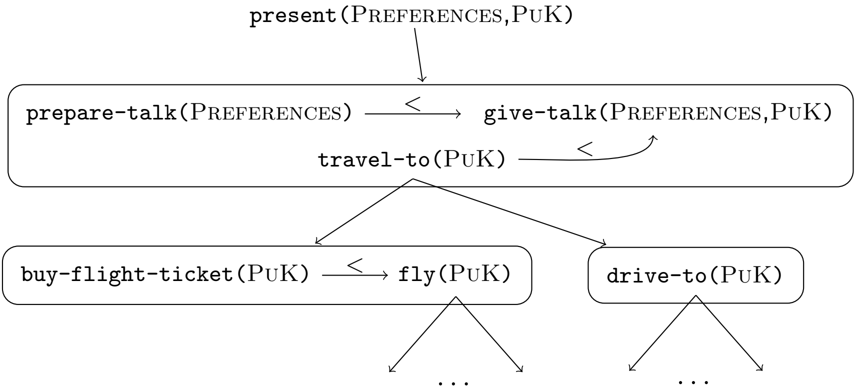
Solution: Any sequence $\bar{t} \in T^*$, s.t.

- $\bar{t}$ is executable in s_{init}
- $\bar{t}$ is primitive
- $\bar{t}$ can be obtained be decomposing P_{init} **and inserting tasks**
- $\bar{t}(s_{\text{init}}) \supseteq s_{\text{goal}}$

Example for Hierarchical & Hybrid Planning



Planning with Preferences — Motivation

Let P, P' be two different solutions to a planning problem.
Which one is *"the better one"*?

(1) $\textit{action-costs}(P) \leq \textit{action-costs}(P') \rightarrow P$ is better!

(2) $\textit{some-quality}(P) \leq \textit{some-quality}(P') \rightarrow P'$ is better!

(3) Some combination of (1) and (2)...

Arbitrary quality measures are possible.

Well-established: (PDDL) *Preferences!*

Planning with Preferences — Definition I

What are preferences?

Literature:

- Trajectory constraints (cf. PDDL),
  e.g., (*always* ϕ) or (*sometime* ϕ), ϕ logical formula.
- Soft goals (cf. PDDL),
  e.g., (*at-end* ϕ), ϕ logical fact formula.
- Constraints on action occurrences,
  i.e., trajectory constraints, where ϕ contains (*occ a*), *a* action.

In this work: Soft goals! (special case: only single facts)

Planning with Preferences — Definition II

How to define *some-quality*(P), P solution?

Each preference (soft goal fact) has a *weight*, its value. Let $\mathcal{F}$ be the set of atomic facts. Then, the set of all preferences and their weights is a set $\mathcal{P}ref \subseteq \mathcal{F} \times \mathbb{N}$. Now, we define:

$$\textit{some-quality}(P) \quad := \quad \sum_{\substack{(f,n) \in \mathcal{P}ref, \\ P \models f}} n$$

Then, a solution P is better than a solution P' if and only if

$$\textit{some-quality}(P) \geq \textit{some-quality}(P')$$

So what?

We want to **guide** the search towards a good solution.

This is a problem, since *some-quality*(P) is defined on *solutions*!
$\rightarrow$ Heuristic estimate is essential! *How to perform uniform search?*

Why is this a problem?

- No work in the literature for handling preferences in partial order causal link (POCL) planning.
- No work in the literature for estimating plan quality in *hybrid* planning.
- Only one work in the literature for estimating plan quality in POCL planning.

Excursion: POCL Planning

UNDER CONSTRUCTION

Estimate the Plan Quality — Idea

Let $\mathcal{P}(P_{\text{init}}) := \langle s_{\text{init}}, s_{\text{goal}}, P_{\text{init}}, D \rangle$, domain $D = \langle T, M \rangle$

(1) Transform a **hybrid** planning problem $\mathcal{P}(P)$, P being the current plan under consideration, into a *relaxed* **classical** planning problem $\mathcal{P}'$. s.t.:
$\mathcal{P}(P)$ has a solution $\rightarrow \mathcal{P}'$ has a solution.

(2) Perform a reachability analysis for $\mathcal{P}'$ to find groups of soft goals that can be true at the same time.

(3) Use the information gained in step (2) to calculate an *admissible* estimate of the plan quality.

Note: Procedure works both for hybrid planning problems and for classical POCL problems!

Estimate the Plan Quality — Step (1) I

Transformation of hybrid problem $\mathcal{P}(P) = \langle s_{\text{init}}, s_{\text{goal}}, P_{\text{init}}, D \rangle$, $D = \langle T, M \rangle$ into a *relaxed* **classical** problem $\mathcal{P}' = \langle s_{\text{init}}, s'_{\text{goal}}, \langle A \rangle \rangle$.

Let $P = \langle PS, \prec \rangle$ be the current (partially ordered) plan under consideration, where

- $(l : t)$ is a plan step, $l \in L$ is a label, $t \in T$ is a task,
- $\prec \subseteq L(PS) \times L(PS)$ are the ordering constraints of plan P.

Transformation sub step (a): Relaxation.

- Let $t = \langle \mathit{prec}, \mathit{eff} \rangle \in T$, then
  $a := \langle \mathit{prec}(t), \mathit{delete\text{-}relax}(\mathit{eff}(t)) \rangle \in A$.

Estimate the Plan Quality — Step (1) II

Transformation of hybrid problem $\mathcal{P}(P) = \langle s_{\text{init}}, s_{\text{goal}}, P_{\text{init}}, D \rangle$, $D = \langle T, M \rangle$ into a *relaxed* **classical** problem $\mathcal{P}' = \langle s_{\text{init}}, s'_{\text{goal}}, \langle A \rangle \rangle$.

Transformation sub step (b): Eliminate/encode plan P.

Let $(l : t) \in PS$, then

- $a \in A$, where $a := \langle prec(t) \wedge \neg occ\text{-}l, eff(t) \wedge occ\text{-}l \rangle$,
- $s'_{\text{goal}} := s_{\text{goal}} \wedge occ\text{-}l$

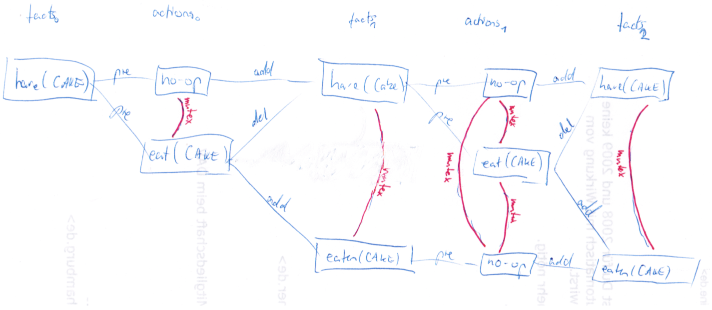
Let $(l_1 : t_1), (l_2 : t_2) \in PS, (l_1, l_2) \in \prec$, $a_1, a_2 \in A$ the corresponding actions. Then,

- $A := (A \setminus \{a_2\}) \cup \{a'_2\}$, where $a'_2 := \langle prec(a_2) \wedge occ\text{-}l_1, eff(a_2) \rangle$

Estimate the Plan Quality — Step (2)

Perform a reachability analysis for $\mathcal{P}'$ to find groups of soft goals that can be true at the same time.

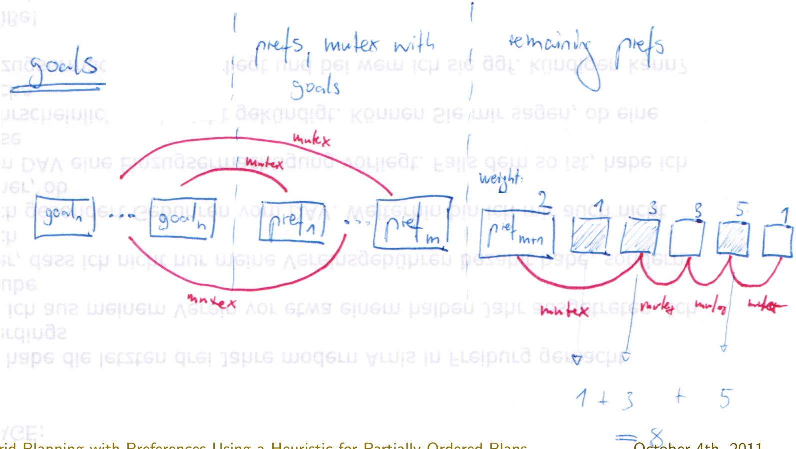
Build a (relaxed) planning graph until a fix point is reached to use the last fact layer and its mutex relations. Example:



Estimate the Plan Quality — Step (3) I

Use the information gained in step (2) to calculate an *admissible* estimate of the plan quality.

Calculate the optimal (admissible) estimate. Example:



Estimate the Plan Quality — Step (3) II

Use the information gained in step (2) to calculate an *admissible* estimate of the plan quality.

Let $b : \mathcal{F} \rightarrow \{\top, \bot\}$ be a truth assignment that is consistent with the mutex relations of $\mathcal{F}$. Then,

$$\mathit{heuristic}(s'_{\mathrm{init}}) := \sum_{\substack{(f,n)\in\mathcal{P}\mathit{ref}, \\ f \text{ has no mutexes}}} n + \max_{b} \Bigg(\sum_{\substack{(f,n)\in\mathcal{P}\mathit{ref}, \\ f \text{ has mutexes}, b(f)=\top}} n \Bigg)$$

where s'_{init} is the initial state of the transformed classical planning problem.

Summary

- Introduced first heuristic for soft goals for (hybrid and classical) POCL planning,
- basic idea behind this heuristic can be adapted, s.t. any POCL planner can use (almost) any heuristic from classical planning,
- approach can easily be extended to handle arbitrary formulas over soft goals,
- the paper also contains the first POCL search algorithm capable of handling soft goals