A Heuristic for Hybrid Planning With Preferences

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Abstract

We present a heuristic for hybrid planning with preferences on final states.

- It can be used for *hybrid planning* and for *POCL* planning,
- it reduces the problem of estimating the quality of a *task network* to the problem of estimating the quality of a *state*, and
- it performs a reachability analysis based on a planning graph [2].

Hybrid Planning with Preferences (Problem Definition)

Hybrid planning [1] fuses HTN planning [3] with POCL planning [4].
A hybrid planning problem is a tuple $(\mathscr{P}, \mathscr{T}_p, \mathscr{T}_c, \mathscr{M}, s_{init}, TN_{init}, g)$ with:

- $\mathscr{P}$ is a set of atomic, ground propositions,
- $\mathscr{T}_p, \mathscr{T}_c \subseteq 2^{\mathscr{P}} \times 2^{\mathscr{P}} \times 2^{\mathscr{P}}$ are sets of primitive and compound task schemata, resp.,
- $\mathscr{M} \subseteq \mathscr{T}_c \times \mathscr{TN}$ is a set of decomposition methods,
- $s_{init} \in 2^{\mathscr{P}}$ is the initial state,
- $TN_{init} \in \mathscr{TN}$ is the the initial partial plan, and
- $g \subseteq \mathscr{P}$ is the goal description.

The preferences on final states are given by weighted propositions:
The function $w : Pref \to \mathbb{R}$ maps preferences to their weight (or value).

Definition (Task Network) A task network *TN* is a tuple $(T, \prec, CL)$ with:

- T, a set ob labeled tasks $l{:}t$, l being a label symbol and $t \in \mathscr{T}_p \cup \mathscr{T}_c$,
- $\prec$, a partial order on T, and
- CL, a set of causal links $l' \to_\phi l$.

The set of all task networks is referred to by $\mathscr{TN}$

Hybrid Planning with Preferences (Solution Criteria, -Quality)

A task network *TN* is a solution to a hybrid planning problem if and only if:

- *TN* is a refinement of TN_{init} w.r.t. decomposition and insertions,
- *TN* contains no compound tasks, and
- *TN* has no open preconditions and no causal threats.

The quality of a solution is $q(TN) := \sum_{p \in Pref \text{ with } TN \models p} w(p)$. A solution TN_1 is preferred over a solution TN_2 if and only if $q(TN_1) \geq q(TN_2)$

Heuristic (Overview)

The heuristic consists of two steps:

1. domain transformation: transform a hybrid planning problem with a current *task network* into a relaxed classical planning problem with a current *state*
2. reachability analysis based on transformed problem

DomainTransformation

Given $\pi = (\mathscr{P}, \mathscr{T}_p, \mathscr{T}_c, \mathscr{M}, s_{init}, TN_{init}, g)$ and a task network $TN = (T, \prec, CL)$, we construct a (relaxed) *classical* planning problem π', s.t.:

- if *TN* can be refined to a solution of π, then π' is solvable as well, and
- every solution of π' is a refinement of *TN* w.r.t. its primitive tasks.

$\pi' = (\mathscr{P}', \mathscr{T}_p', s_{init}', g')$ is given by:

- $\mathscr{P}' := \mathscr{P} \cup \bigcup_{l:t \in T, t \in \mathscr{T}_p} \{l, not\text{-}l\}$
- $\mathscr{T}_p' :=$ *delete-relax*$(\mathscr{T}_p) \cup$ *encode*(TN) with
  delete-relax$(\mathscr{T}_p) := \{(\text{prec}, \text{add}, \emptyset) \mid (\text{prec}, \text{add}, \text{del}) \in \mathscr{T}_p\}$ and
  encode$(TN) := \{$*encode*$(l{:}t) \mid l{:}t \in T$ and $t \in \mathscr{T}_p\}$, where
  encode$(l{:}(\text{pre}, \text{add}, \text{del})) :=$
  $(\text{pre} \cup \{not\text{-}l\} \cup \{l' \mid l' \prec l$ *or* $l' \to_\phi l \in CL, l'{:}t' \in T,$ and $t' \in \mathscr{T}_p\},$
  $\text{add} \cup \{l\},$
  $\text{del} \cup \{not\text{-}l\})$
- $s_{init}' := s_{init} \cup \{not\text{-}l \mid \exists t \in \mathscr{T}_p,$ s.t. $l{:}t \in T\}$
- $g' := g \cup \{l \mid \exists t \in \mathscr{T}_p,$ s.t. $l{:}t \in T\}$

Example

Let $\pi = (\mathscr{P}, \mathscr{T}_p, \mathscr{T}_c, \mathscr{M}, s_{init}, TN_{init}, g)$ with $deliver(loc_2) \in \mathscr{T}_c$ and $d_1 :=$ *drive*$(truck_3, loc_1, loc_2) \in \mathscr{T}_p$, $d_2 :=$ *drive*$(truck_3, loc_2, loc_3) \in \mathscr{T}_p$, and *TN* given by:

Then, $\pi' = (\mathscr{P}', \mathscr{T}_p', s_{init}', g')$ with:

- $\mathscr{P}' := \mathscr{P} \cup \{l_1, not\text{-}l_1, l_3, not\text{-}l_3\}$
- $\mathscr{T}_p' :=$ *delete-relax*$(\mathscr{T}_p) \cup$
  $\{(pre(d_1) \cup \{not\text{-}l_1\}, add(d_1) \cup \{l_1\}, del(d_1) \cup \{not\text{-}l_1\})\} \cup$
  $\{(pre(d_2) \cup \{not\text{-}l_3, l_1\}, add(d_2) \cup \{l_3\}, del(d_2) \cup \{not\text{-}l_3\})\}$
- $s_{init}' := s_{init} \cup \{not\text{-}l_1, not\text{-}l_3\}$
- $g' := g \cup \{l_1, l_3\}$

Heuristic Calculation (Overview)

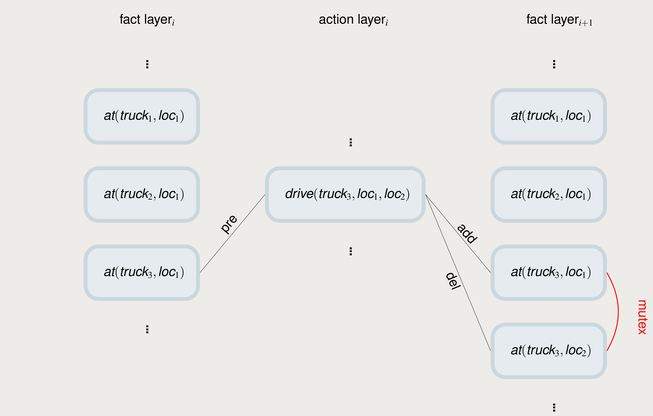
The heuristic value is calculated in two steps:

1. Calculate a partially relaxed planning graph until it has converged.
2. Use the mutex relations of the last fact layer to estimate the final plan quality based on the reachable (preferred) facts.

Planning Graph Construction

The planning graph can be used for a (relaxed) reachability analysis.

Example

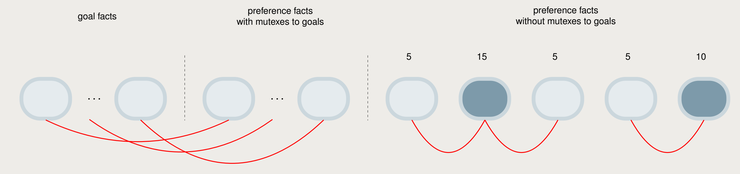


Heuristic Calculation

The final fact layer (and its mutexes) are used to estimate the plan quality:
Let *TN* be the current task network, s_{init}' the new initial state of the transformed problem, and b a "mutex-respecting" truth assignment. Then,

$$h(TN) = h(s_{init}') := \max_b \Big(\sum_{\substack{p \in Pref, \\ b(p) = \top}} w(p) \Big)$$

Example



Best possible quality of a task network featuring the given final fact layer is $15 + 10 = 25$

References

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