Planning and Optimization

C22. Landmarks: LM-count Heuristic

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C22.1 Landmark Orderings

Why Landmark Orderings?

- LM-cut heuristic uses integrated landmark and heuristic computation in each state.
- Other landmark-based heuristics compute landmarks once and propagate them over operator applications.
- Landmark orderings are used to detect landmarks that should be further considered because they (again) need to be satisfied later.

Terminology

Let $\pi = \langle o_1, \dots, o_n \rangle$ be a sequence of operators applicable in state I and let φ be a formula over the state variables.

- φ is true at time i if $I[\![\langle o_1, \dots, o_i \rangle]\!] \models \varphi$.
- Also special case $i = 0$: φ is true at time 0 if $I \models \varphi$.
- No formula is true at time $i < 0$.
- φ is added at time i if it is true at time i but not at time $i - 1$.
- φ is first added at time i if it is true at time i but not at any time $j < i$.

Landmark Orderings

Definition (Landmark Orderings)

Let φ and ψ be formula landmarks. There is

- a natural ordering between φ and ψ (written $\varphi \to \psi$) if in each plan where ψ is true at time i, φ is true at some time $j < i$,
- a necessary ordering between φ and ψ (written $\varphi \to_{\mathrm{n}} \psi$) if in each plan where ψ is added at time i, φ is true at time $i - 1$,
- a greedy-necessary ordering between φ and ψ (written $\varphi \to_{\mathrm{gn}} \psi$) if in each plan where ψ is first added at time i, φ is true at time $i - 1$.

Natural Orderings

Definition

There is a natural ordering between φ and ψ (written $\varphi \to \psi$) if in each plan where ψ is true at time i, φ is true at some time $j < i$.

- We can directly determine natural orderings from the LM sets computed from the simplified relaxed task graph.
- For fact landmarks v, v', if $n_{v'} \in LM(n_v)$ then $v' \to v$.

Greedy-necessary Orderings

Definition

There is a greedy-necessary ordering between φ and ψ (written $\varphi \to_{\mathrm{gn}} \psi$) if in each plan where ψ is first added at time i, φ is true at time $i - 1$.

- We can again determine such orderings from the sRTG.
- For an OR node n_v, we define the set of first achievers as $FA(n_v) = \{n_o \mid n_o \in succ(n_v) \text{ and } n_v \notin LM(n_o)\}$.
- Then $v' \to_{\mathrm{gn}} v$ whenever $n_{v'} \in succ(n_o)$ for all $n_o \in FA(n_v)$.

C22.2 Landmark-count Heuristic

Reached Landmarks

A landmark is reached by a path if it has been true in any traversed state.

Definitions (Reached Landmarks)

Let $\mathcal{L}$ be a set of formula landmarks for task $\langle V, I, O, \gamma \rangle$ and let π be an operator sequence applicable in I.

The set of reached landmarks is defined as $\mathit{Reached}(\pi, \mathcal{L}) =$

$$\begin{cases} \{\psi \in \mathcal{L} \mid I \models \psi\} & \pi = \langle\rangle \\ \mathit{Reached}(\pi', \mathcal{L}) \cup \{\psi \in \mathcal{L} \mid I[\![\pi]\!] \models \psi\} & \pi = \pi'\langle o \rangle \end{cases}$$

Can be computed incrementally.

Required Again

A reached landmark is required again, if it is currently false but must be true due to an ordering or because it is required by the goal.

Definitions (Required Again)

Let $\mathcal{L}$ be a set of formula landmarks for $\Pi = \langle V, I, O, \gamma \rangle$ with orderings *Ord*, and let π be an operator sequence applicable in I.

The set of landmarks that are required again is defined as

$$\mathit{ReqAgain}(\pi, \mathcal{L}, \mathit{Ord}) = \{\varphi \in \mathit{Reached}(\pi, \mathcal{L}) \mid I[\![\pi]\!] \not\models \varphi \text{ and } (\gamma \models \varphi \text{ or exists } \varphi \to_{\mathrm{gn}} \psi \in \mathit{Ord} : \psi \notin \mathit{Reached}(\pi, \mathcal{L}))\}.$$

Landmark-count Heuristic

The landmark-count heuristic counts the landmarks that have not been reached or are required again.

Definition (LM-count Heuristic)

Let Π be a planning task with initial state I and let $\mathcal{L}$ be a set of landmarks for I with orderings *Ord*.

The LM-count heuristic for an operator sequence π that is applicable in I is

$$h^{\text{LM-count}}_{\mathcal{L}}(\pi) = |(\mathcal{L} \setminus \mathit{reached}(\pi, \mathcal{L})) \cup \mathit{ReqAgain}(\pi, \mathcal{L}, \mathit{Ord})|.$$

LM-count Heuristic is Path-dependent

- LM-count heuristic gives estimates for paths (it is a path-dependent heuristic).
- Search algorithms need estimates for states.
- $\rightsquigarrow$ use estimate for the currently considered path to the state.
- $\rightsquigarrow$ heuristic estimate for a state is not well-defined.

LM-count Heuristic is Inadmissible

Example

Consider STRIPS planning task $\Pi = \langle \{a, b\}, \emptyset, \{o\}, \{a, b\} \rangle$ with $o = \langle \emptyset, \{a, b\}, \emptyset, 1 \rangle$. Let $\mathcal{L} = \{\{a\}, \{b\}\}$ and $Ord = \emptyset$.

The estimate for the initial state $I = \{\}$ is $h_{\mathcal{L}}^{\text{LM-count}}(\langle\rangle) = 2$ while $h^*(I) = 1$.

$\rightsquigarrow$ $h^{\text{LM-count}}$ is inadmissible.

LM-count Heuristic: Comments

- Practical implementations store the set of reached landmarks for each state.
- LM-Count alone is not a particularily informative heuristic.
- On the positive side, it complements h^{FF} very well.
- For example, the LAMA planning system alternates between expanding a state with minimal h^{FF} and minimal $h^{\text{LM-count}}$ estimate.
- There is an admissible variant of the heuristic based on operator cost partitioning.

C22.3 Summary

Summary

- The LM-count heuristic propagates landmarks over operator applications.
- It counts how many landmarks still need to be satisfied.
- The LM-count heuristic is inadmissible (but there is an admissible variant).
- Landmark orderings can be useful for detecting when a landmark should be further considered.

Literature (1)

References on landmark heuristics:

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Literature (3)

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Cost-Optimal Planning with Landmarks.
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