

Planning and Optimization

E6. Landmarks: LM-count Heuristic

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November 27, 2017

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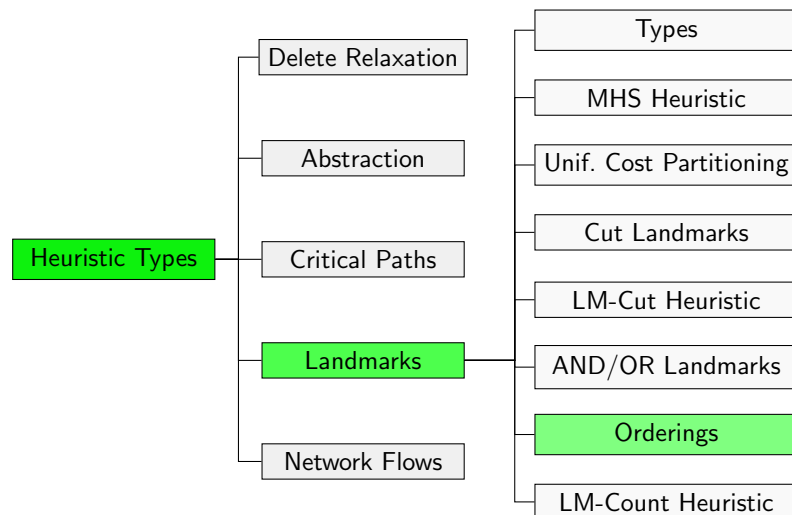
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E6.1 Landmark Orderings

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Content of this Course: Landmarks



E6.1 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 $\varphi \rightarrow \psi$) 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 $\varphi \rightarrow_n \psi$) 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 $\varphi \rightarrow_{gn} \psi$) 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 $\varphi \rightarrow \psi$) 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' with $v \neq v'$, if $n_{v'} \in LM(n_v)$ then $v' \rightarrow v$.

Greedy-necessary Orderings

Definition

There is a **greedy-necessary ordering** between φ and ψ (written $\varphi \rightarrow_{\text{gn}} \psi$) 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 $FA(n_v) = \{n_o \mid n_o \in \text{succ}(n_v) \text{ and } n_v \notin LM(n_o)\}$.
- ▶ Then $v' \rightarrow_{\text{gn}} v$ if $n_{v'} \in \text{succ}(n_o)$ for all $n_o \in FA(n_v)$.

E6.2 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 $Reached(\pi, \mathcal{L}) =$

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

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

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

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

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 particularly 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.



E6.3 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 (2)

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