Planning and Optimization

E6. Landmarks: LM-count Heuristic

Malte Helmert and Gabriele Röger

Universität Basel

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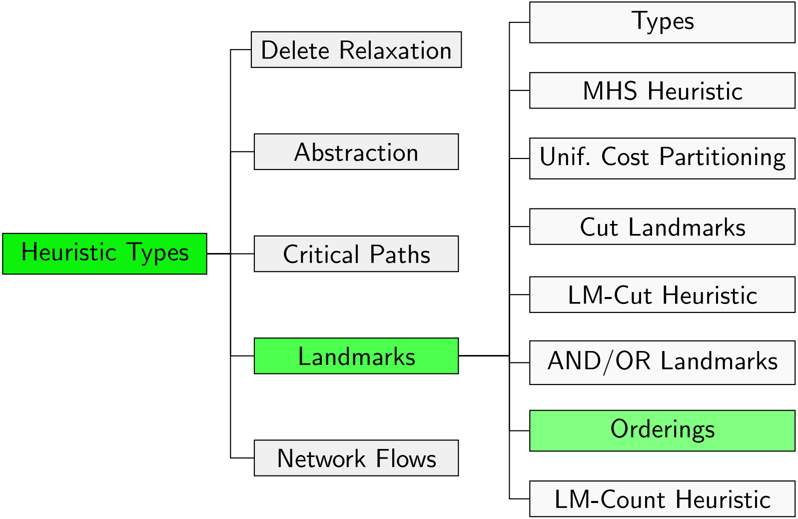
Content of this Course: Landmarks



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 $\varphi \rightarrow_{\mathsf{n}} \psi$) 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 $\varphi \rightarrow_{\mathsf{gn}} \psi$) 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' with $v \neq v'$, 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 $\varphi \rightarrow_{\text{gn}} \psi$) 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 $FA(n_v) = \{n_o \mid n_o \in succ(n_v) \text{ and } n_v \notin LM(n_o)\}$.
- Then $v' \rightarrow_{\text{gn}} v$ if $n_{v'} \in succ(n_o)$ for all $n_o \in FA(n_v)$.

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

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

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

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

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 $h^{\text{LM-count}}_{\mathcal{L}}(\langle\rangle) = 2$ while $h^*(I) = 1$.

$\leadsto$ $h^{\text{LM-count}}$ 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.

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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On the Extraction, Ordering, and Usage of Landmarks in Planning.
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Proc. ICAPS 2009, pp. 162–169, 2009.
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Literature (2)

Lin Zhu and Robert Givan.
Landmark Extraction via Planning Graph Propagation.
Doctoral Consortium ICAPS 2003, 2003.
Core idea for complete landmark generation.

Emil Keyder, Silvia Richter and Malte Helmert.
Sound and Complete Landmarks for And/Or Graphs
Proc. ECAI 2010 , pp. 335–340, 2010.
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and usage of Π^m compilation.

Literature (3)

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The LAMA Planner: Guiding Cost-Based Anytime Planning with Landmarks.
JAIR 39 (2010) , pp. 127–177, 2010.
Introduces landmark-count heuristic and contains another landmark generation method.

Erez Karpas and Carmel Domshlak.
Cost-Optimal Planning with Landmarks.
Proc. IJCAI 2009, pp. 1728–1733, 2009.
Introduces admissible variant of landmark heuristic.