Landmarks, the Universe, and Everything

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Universidad Politécnica de Valencia, Spain
Saarland University, Germany

June 13, 2013

Song # 1

Song # 1

```
Imagine there's no Landmarks
It's easy if you try
No benchmarks below us
Above us only Blai
Imagine all the planners
Planning for real
```

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Song # 2

Song # 2

`Planning, planning, planning,`

Song # 2

```
Planning, planning, planning,
      P-D-D-L scanning,
```

Song # 2

```
Planning, planning, planning,
P-D-D-L scanning,
Keep 'em planners planning, ICAPS!
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Uncertain durations,
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Uncertain durations,
Truth ramifications,
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Uncertain durations,
Truth ramifications,
Wishing FF was by my side!

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My soft goals they are kissin’

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My soft goals they are kissin'
My landmarks have gone missin'

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My landmarks have gone missin'
My stubborn set has turned off the light.

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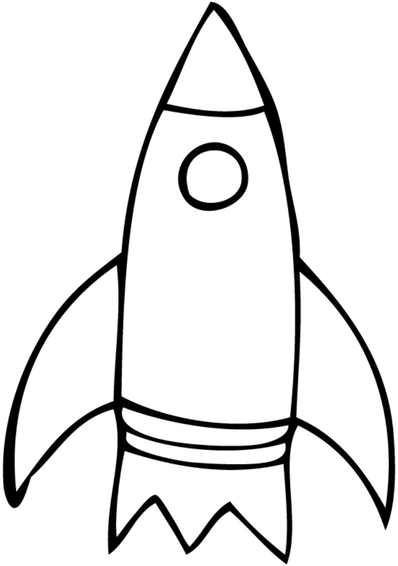
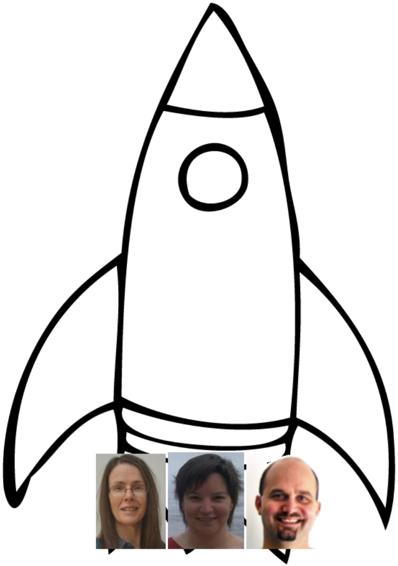
Agenda

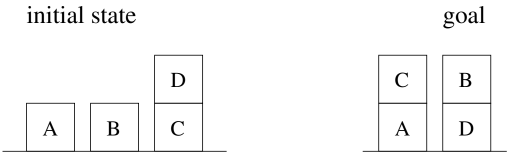


Agenda: Stage 0 (The Dark Ages)



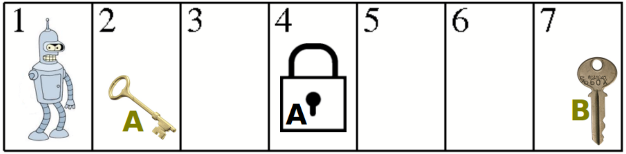
Once Upon a Time, There Was a Landmark . . .

Verbatim from [Porteous et al. (2001)]:



What Are Landmarks?

Problem: Bring key B to position 1.



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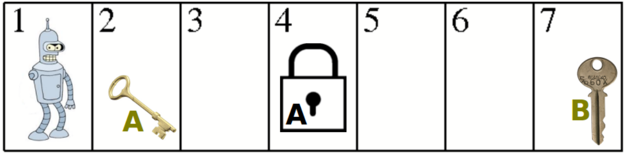

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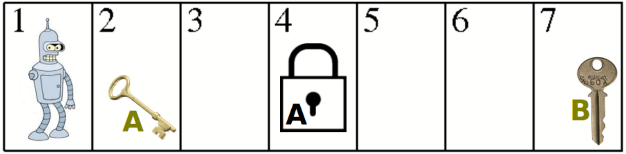

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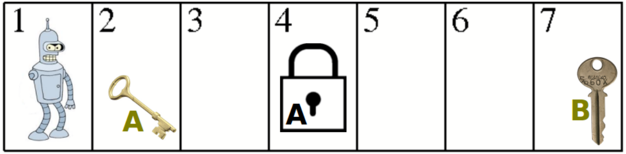

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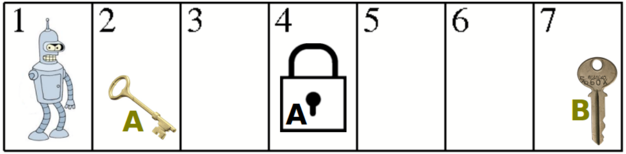

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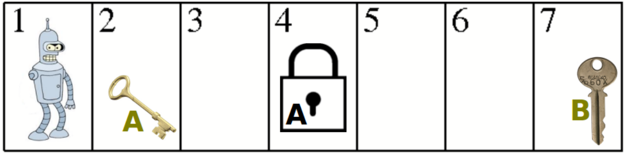

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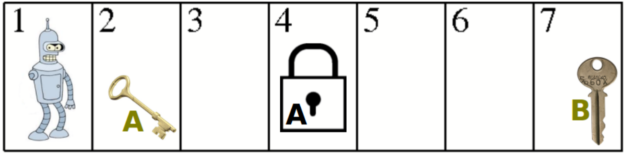

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→ A landmark is a fact that is true at some point on every solution plan.

- Find landmarks in a pre-process to planning.
- Can also find landmark orderings $L \leq L'$.

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ps. Actually, see [Vernhes *et al.* (2013)] for an interesting modernized version!

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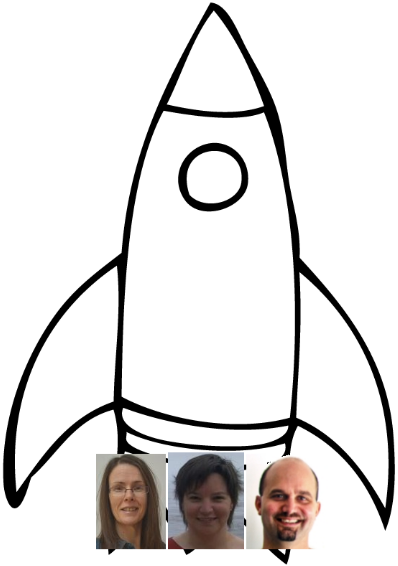

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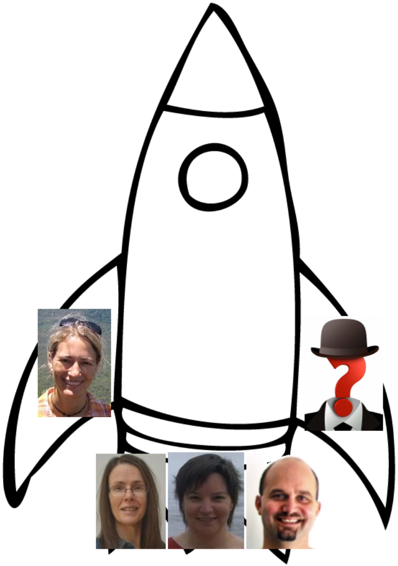

How To Use Landmarks!

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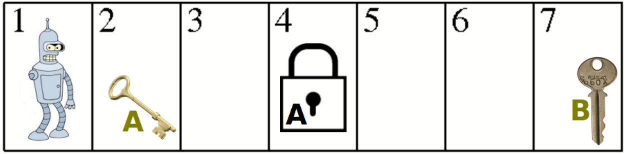

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$\rightarrow h(s) := |\{LM\} \setminus s|$. ("Number of open items on the to-do list")

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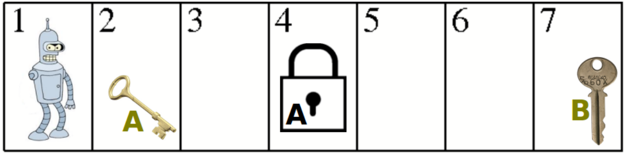

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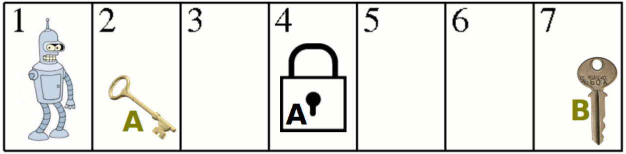

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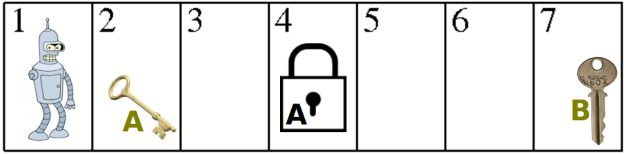

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- Credits to [Zhu and Givan (2003)] for their "forgotten work" . . . !

The Impact of Stage 1

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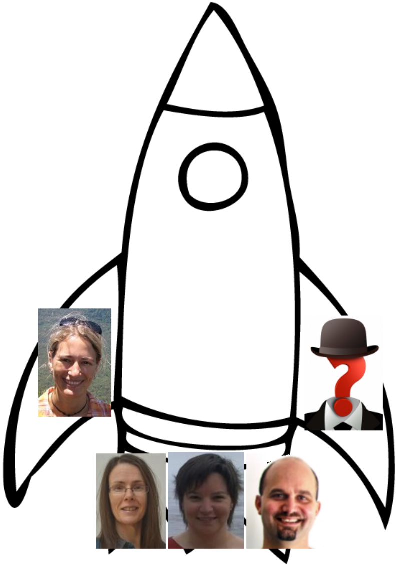
Agenda: Stage 2 (Leaving the Atmosphere)



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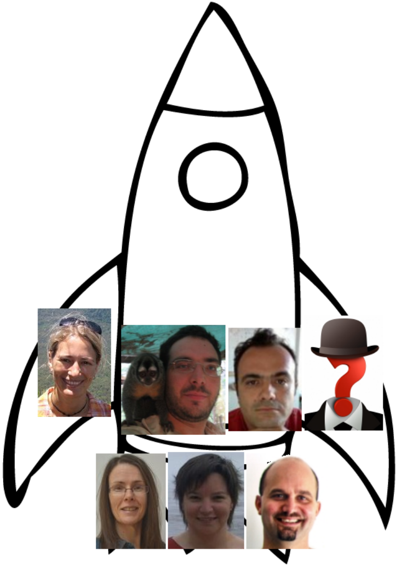

How To *Admissibly Combine* Landmarks!

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Planning task: Goals $G = \{A, B\}$, initial state $I = \emptyset$, actions $carA : \emptyset \rightarrow A$ cost 1, $carB : \emptyset \rightarrow B$ cost 1, $fancyCar : \emptyset \rightarrow A \wedge B$ cost 1.5.

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Solution: [Karpas and Domshlak (2009)]

1. Consider disjunctive action landmarks instead: $L_A = \{carA, fancyCar\}$, $L_B = \{carB, fancyCar\}$. (= Achievers of each landmark)
   $\rightarrow$ Elementary landmark heuristic $h^{\mathsf{LM}}_L(s) = \min\{c(a) \mid a \in L\}$ if L is a disjunctive action landmark for s, and $h^{\mathsf{LM}}_L(s) = 0$ otherwise.

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   $\rightarrow$ Elementary landmark heuristic $h_L^{\text{LM}}(s) = \min\{c(a) \mid a \in L\}$ if L is a disjunctive action landmark for s, and $h_L^{\text{LM}}(s) = 0$ otherwise.
2. Partition action costs to make $\sum_L h_L^{\text{LM}}(s)$ admissible!

Cost Partitionings

Cost Partitioning: Ensemble of functions $c_1, \dots, c_n : A \mapsto \mathbb{R}_0^+$ s.t. for all $a \in A$, $\sum_{i=1}^n c_i(a) \leq cost(a)$.

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Theorem. *Let s be a state, and let $L_1, \dots, L_n$ be disjunctive action landmarks for s. Then an optimal cost partitioning for s and $h^{\mathsf{LM}}_{L_1}, \dots, h^{\mathsf{LM}}_{L_n}$ can be computed in polynomial time.*

Proof. We can encode this optimization problem into Linear Programming.

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Example: $L_A = \{carA, fancyCar\}$, $L_B = \{carB, fancyCar\}$.

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\begin{array}{rcccl}
carA: & h_{L_A} & & & \leq 1 \\
carB: & & & h_{L_B} & \leq 1 \\
fancyCar: & h_{L_A} & + & h_{L_B} & \leq 1.5
\end{array}
$$

$\rightarrow$ Maximizing $h_{L_A} + h_{L_B}$ yields $h(I) = 1.5$.

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Note: First done for abstraction heuristics [Katz and Domshlak (2008)].

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→ For those of you who don't remember that scene: It didn't happen.

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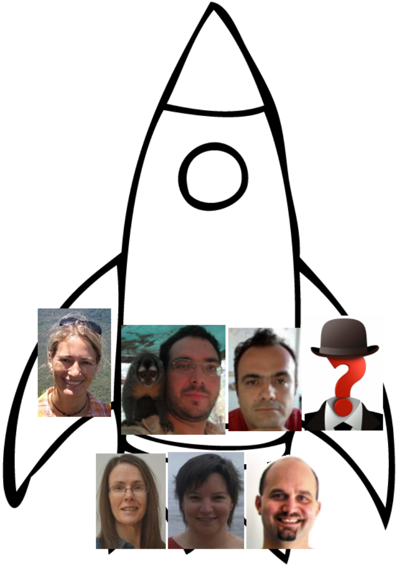
→ For those of you who don't remember that scene: It didn't happen. Karpas and Domshlak (2009)'s heuristic was part of Fast Downward Stone Soup and Selective Max in IPC'11.

Agenda: Stage 3 (Wasn't That Mars We Just Passed?)



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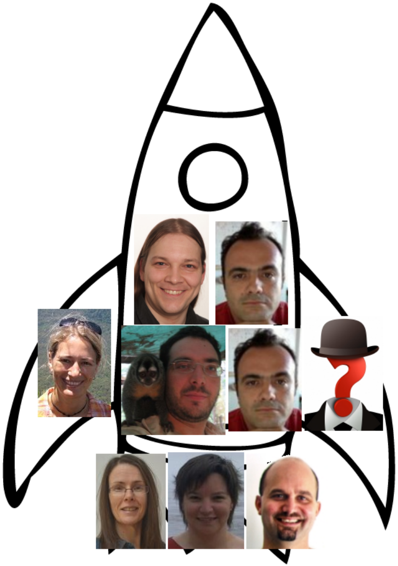
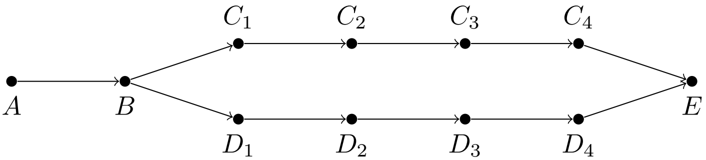


Many Disjunctive Action Landmarks!

Pre-Eff Structure: Actions $get(X, Y)$; init A, goal E.



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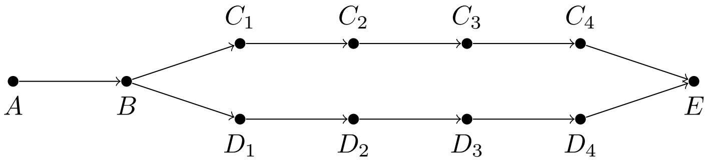

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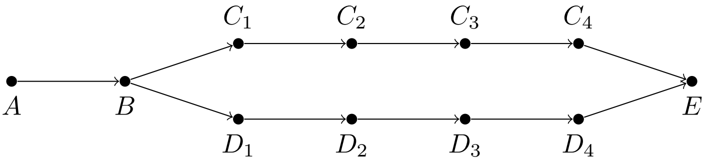

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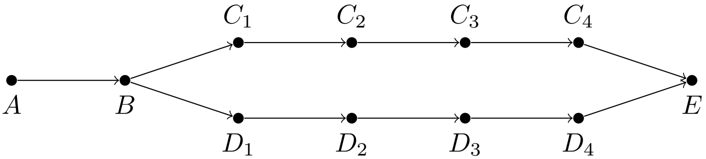
And now, let's pass Mars: LM-cut! [Helmert and Domshlak (2009)]



$\rightarrow h(I) = 0$

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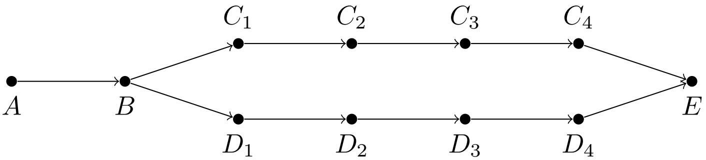

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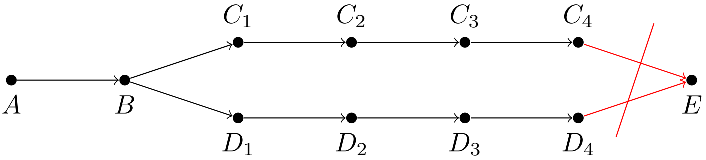

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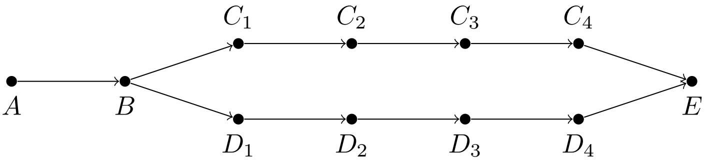

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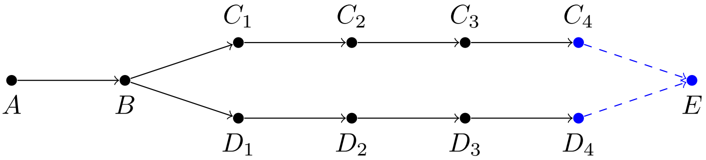

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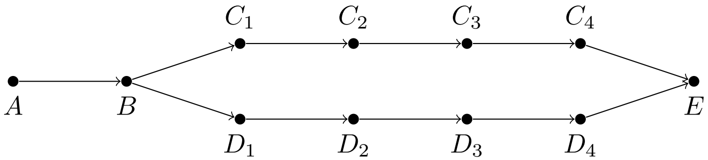

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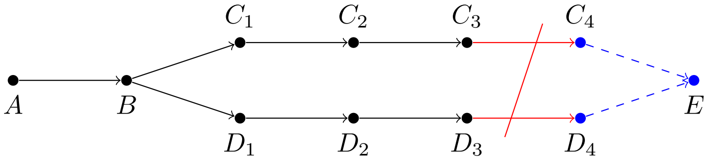

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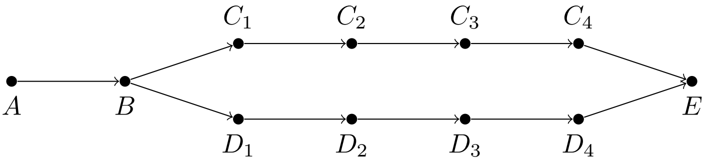
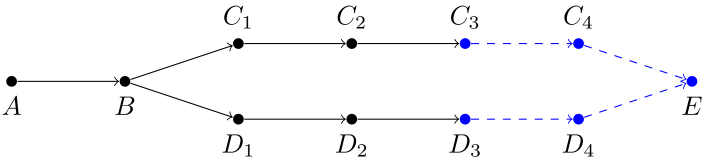


Fact landmarks: $\{B, E\}$, yielding $h(I) = 2$.

And now, let's pass Mars: LM-cut! [Helmert and Domshlak (2009)]



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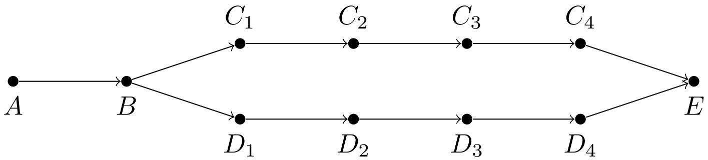

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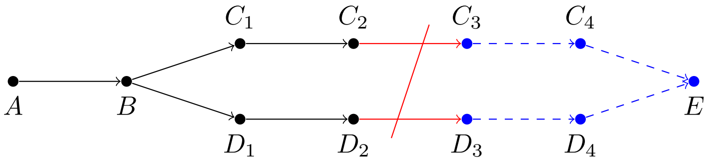

$\rightarrow h(I) = 3$

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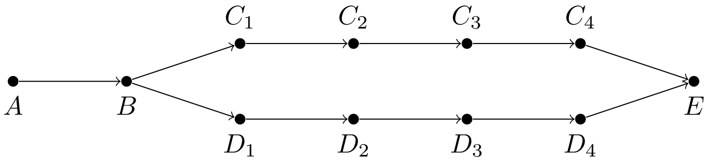

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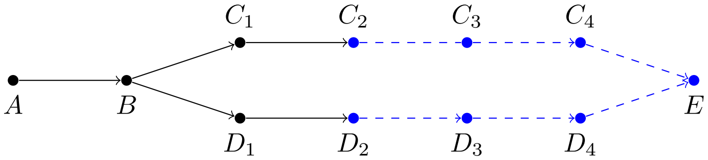

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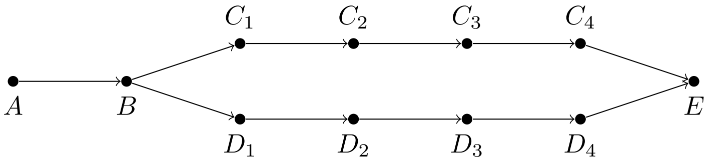

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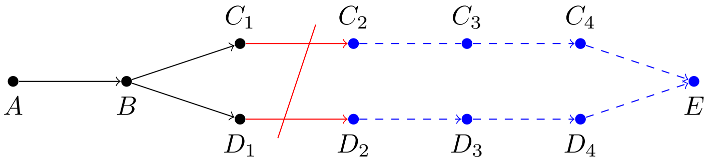
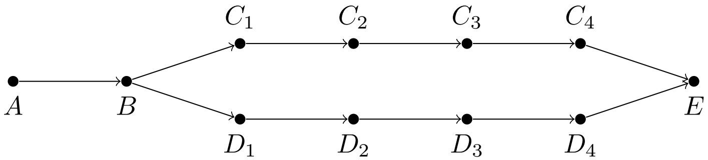


$\rightarrow h(I) = 4$

Many Disjunctive Action Landmarks!

Pre-Eff Structure: Actions $get(X, Y)$; init A, goal E.



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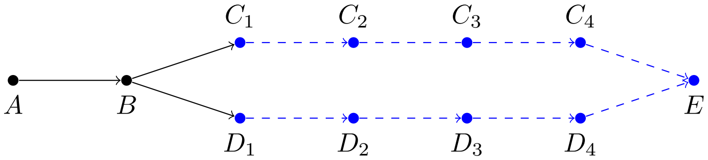

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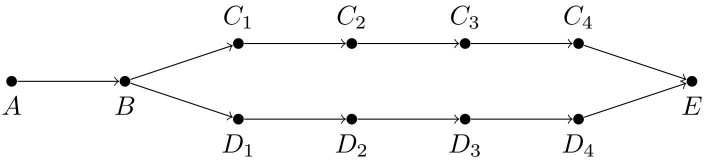

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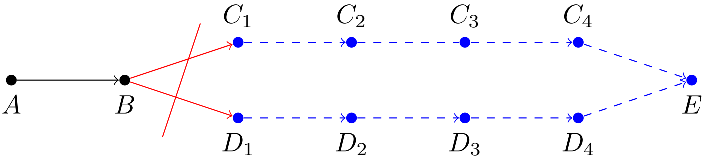

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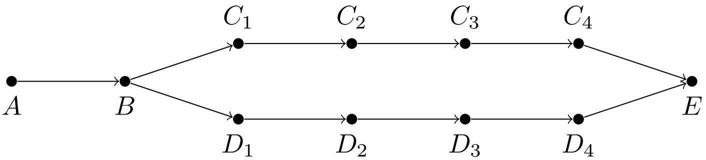

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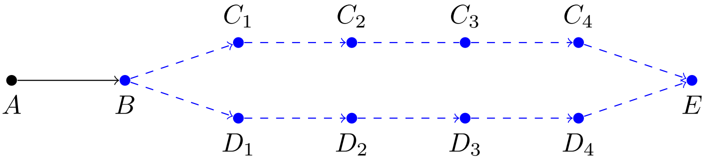

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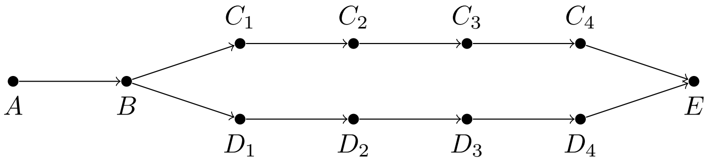

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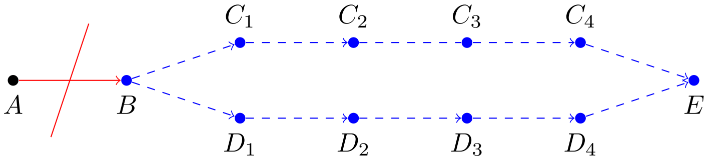

$\rightarrow h(I) = 6$

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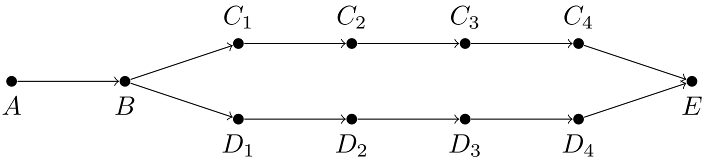

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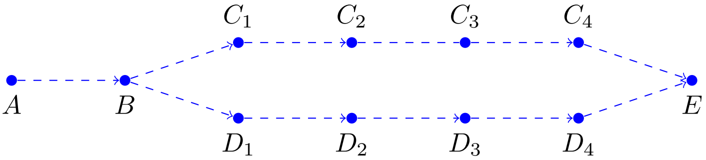

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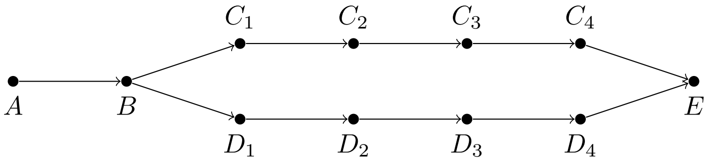

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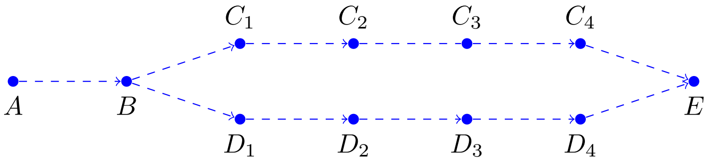
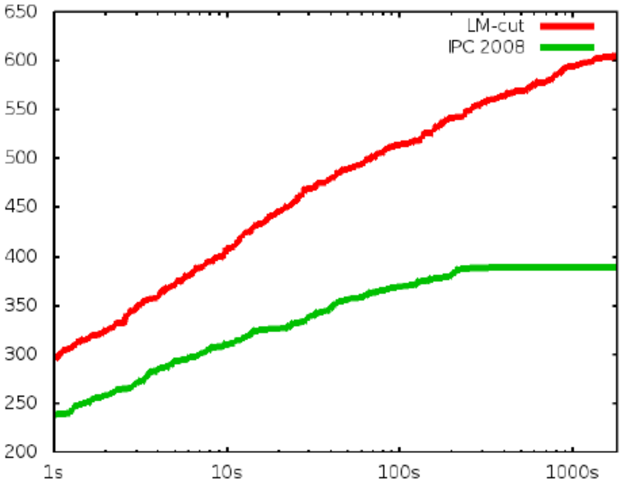


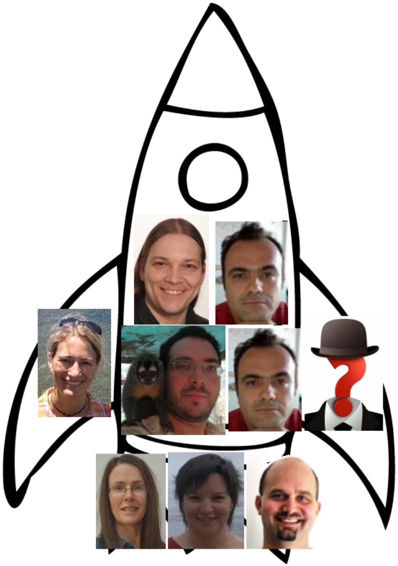
$\rightarrow h(I) = 6 = h^*(I)$.

The Impact of Stage 3



IPC 2008: Best optimal planner in the competition.

Agenda: Stage 4 (Off to the Milky Way!!)



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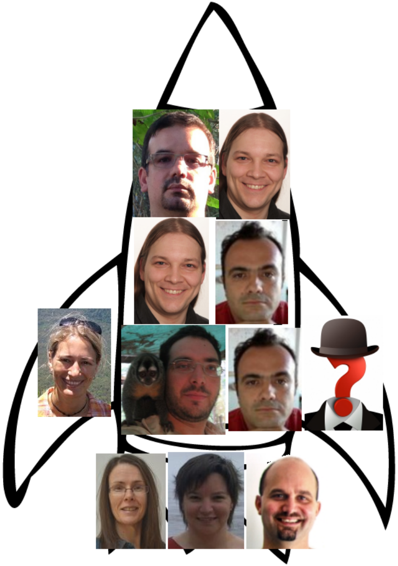

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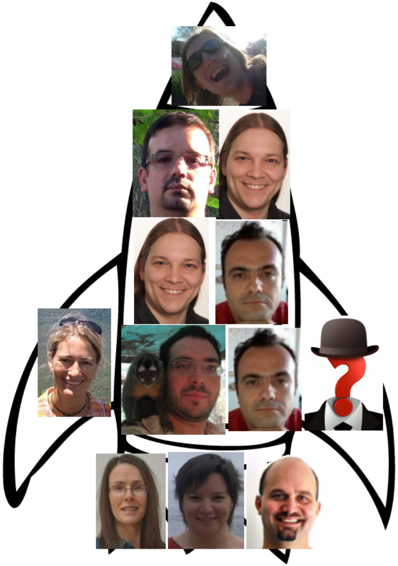
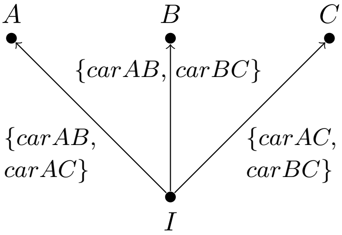


Hitting Sets Over Landmarks!



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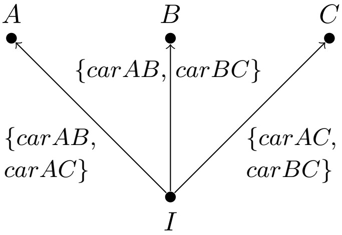

Precondition-Choice Functions

Landmarks:

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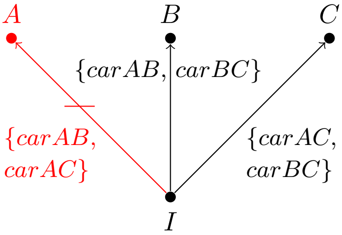

Precondition-Choice Functions

Landmarks: $\{carAB, carAC\}$

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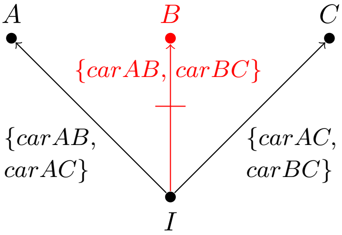

Precondition-Choice Functions

Landmarks: $\{carAB, carAC\}$, $\{carAB, carBC\}$

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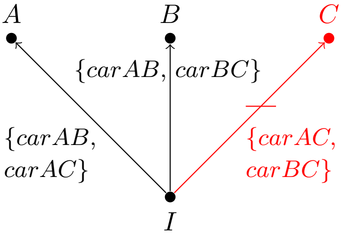

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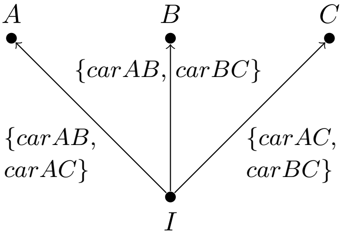

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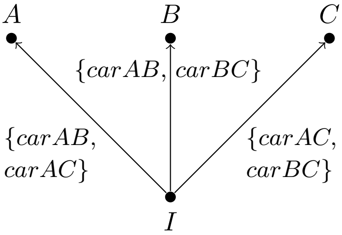

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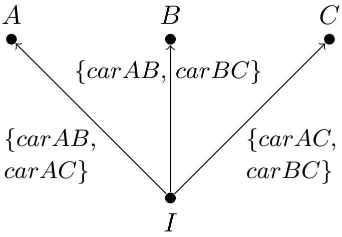

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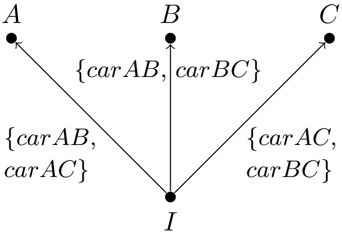

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Hitting sets are admissible: *Let $L_1, \dots, L_n$ be disjunctive action landmarks for s. Let H be a minimum-cost hitting set. Then $\sum_{a \in H} cost(a) \leq h^*(s)$.* (Simply because by definition every plan must hit every L_i.)

From Landmarks to h^+! [Bonet and Helmert (2010)]

Theorem. *Let s be a state, and let $L_1, \dots, L_n$ be the collection of disjunctive action landmarks for s resulting from all precondition-choice functions and cuts. Let H be a minimum-cost hitting set. Then $\sum_{a \in H} cost(a) = h^+(s)$.*

Proof. Any relaxed plan must hit $L_1, \dots, L_n$ so $\sum_{a \in H} cost(a) \leq h^+(s)$.

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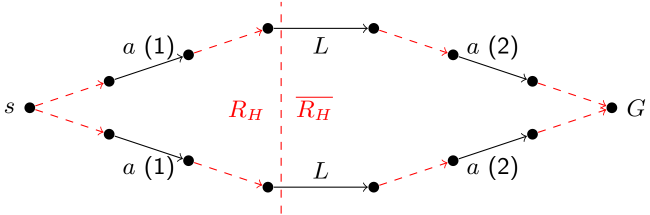

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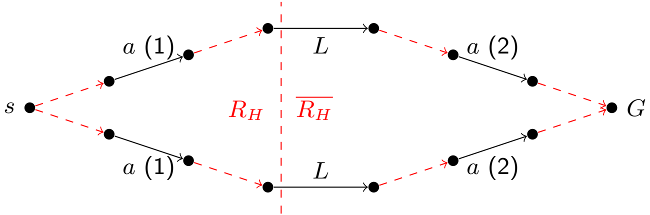

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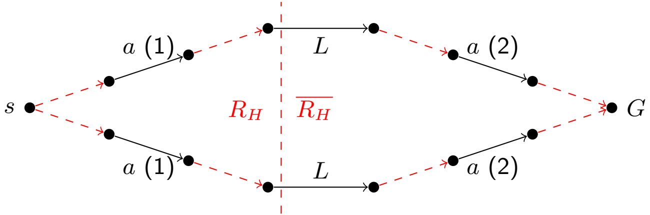

Case (1): If $pre_a \subseteq R_H$ then $add_a \subseteq R_H$ so $a \notin L$.
Case (2): If $pre_a \not\subseteq R_H$ then our precondition-choice function can select $p \in pre_a \setminus R_H$ so, again, $a \notin L$. So H does not hit L, in contradiction.

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Well, isn't it just beautiful?

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More concretely:

- Improved LM-cut, runtime-effective in cases with large search space reduction [Bonet and Helmert (2010); Bonet and Castillo (2011)].

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- State of the art method for computing h^{++}, i. e., h^+ computed in compilation Π^C, which converges to h^* [Haslum *et al.* (2012)].

Last Slide

And now: No questions. Off to dinner!

p.s.: Apologies and thanks to everybody who worked on landmarks but is not mentioned here!

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