

Landmarks Revisited

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Outline

- 1 Introduction to SAS⁺ Planning
- 2 Landmarks in Previous Work
- 3 Using Landmarks as Pseudo-Heuristic
- 4 Extended Landmark Generation

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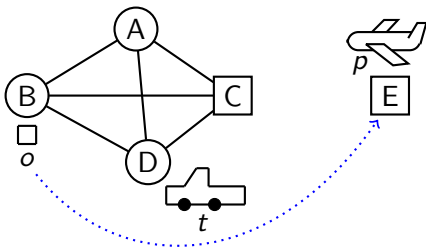
SAS⁺ planning task

SAS⁺ planning task: $\Pi = \langle \mathcal{V}, \mathcal{A}, s_0, s_\star \rangle$

- \mathcal{V} : **state variables** with finite domain \mathcal{D}_v
Fact: variable-value pair $v \mapsto d$ ($v \in \mathcal{V}, d \in \mathcal{D}_v$)
State: variable assignment for all $v \in \mathcal{V}$
- \mathcal{A} : **actions** $\langle pre, eff \rangle$, with *pre*, *eff* fact sets
 - Action $a = \langle pre, eff \rangle$ applicable in state s if $pre \subseteq s$
 - Applying a in s updates s
- s_0 : **initial state**
- s_\star : partial variable assignment called the **goal**

Sequence of actions π a **plan** iff $s_\star \subseteq s_0[\pi]$.

Encoding of example task



$$\mathcal{V} = \{v_o, v_t, v_p\}$$

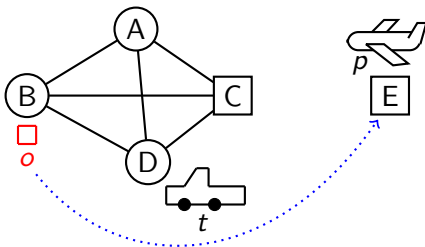
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$$\mathcal{A} = \{\text{drive-t-D-B}, \text{load-o-t-B}, \dots\}$$

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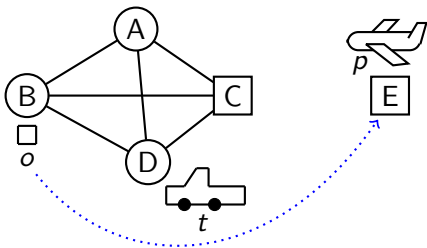
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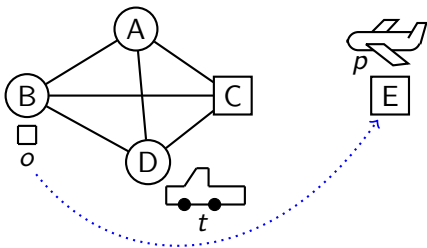
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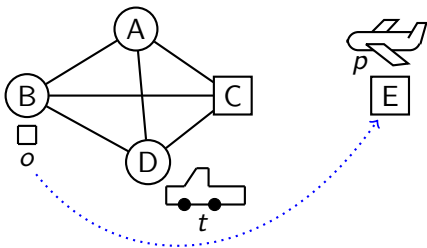
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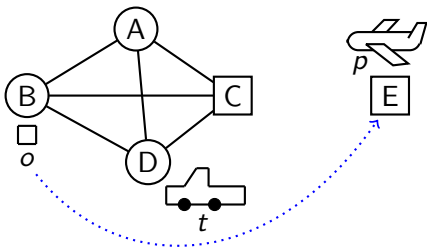
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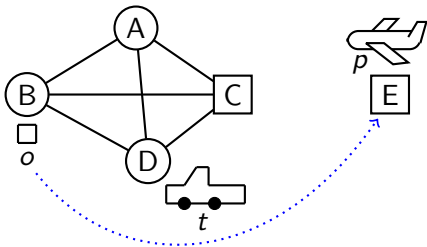
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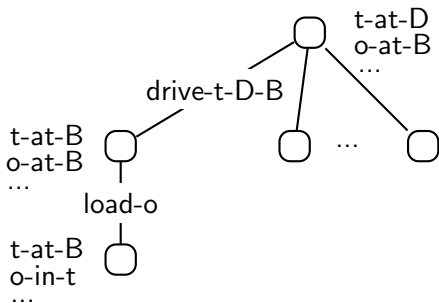
$$s_x = \{v_o \mapsto E\} \quad \text{o-at-E}$$

Encoding of example task cont'd



load-o-t-B : $\langle \text{Pre} = \{v_o \mapsto B, v_t \mapsto B\},$
 $\text{Eff} = \{v_o \mapsto t\} \rangle$

Preferred Operators



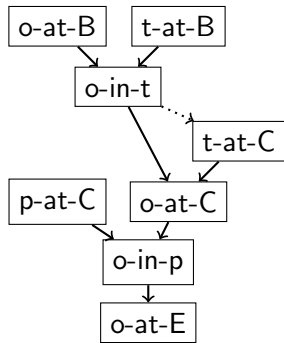
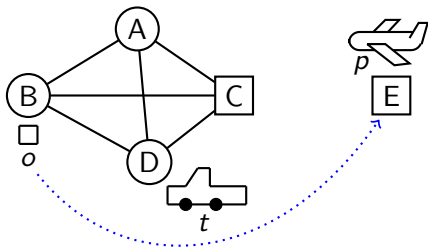
- Improvement of heuristic search approaches (Helmert 2006)
- Idea: prefer actions that are likely to improve heuristic value
- E. g. those which are part of plan for simplified problem

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Landmarks in Previous Work

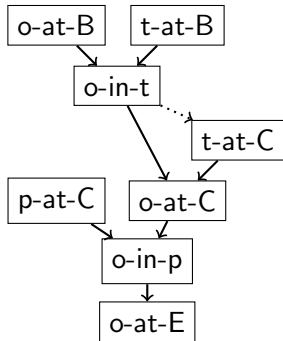
- Facts that **must** be true in every plan
(Porteous et al. 2001 & 2002; Hoffmann et al. 2004)
- Intuitively helpful to direct search
- Automatically found, incl. orderings



Landmarks in Previous Work cont'd

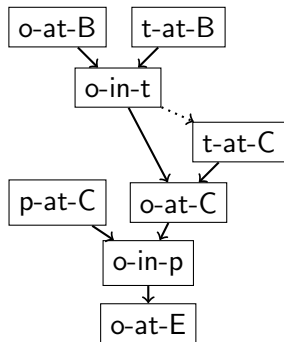
Find landmarks by backchaining

- Every goal is a landmark
- If B is landmark and all actions that first achieve B have A as precondition, then A is a landmark
- Approximation with RPGs: consider all achievers “possibly before” B (Porteous et al. 2002)
- Disjunctive landmarks also possible: $(o\text{-in-}p_1 \vee o\text{-in-}p_2)$



Landmarks in Previous Work cont'd

- Use as **subgoals**, then simply concatenate plans of subtasks (“LM-local”)
- Greatly speeds up search in many domains
- But: bad-quality plans, incomplete (dead ends)
- Any base planner possible for subtasks



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Landmark Heuristic + Preferred Operators

Novel usage of landmarks

- **Pseudo-Heuristic** = #landmarks that still need to be achieved
- Take orderings into account (see paper for details)
- **Preferred operators** = landmark-achieving operators or operators in relaxed plan to nearest landmark
- Combination with other heuristics through multi-heuristic BFS (Helmert 2006)

Experiments with several heuristics (FF, CG, blind) on all tasks from past planning competitions

Results: %Tasks solved (Average)

Base Heuristic	Algorithm		
	base	LM-local	LM-heur
FF heuristic	87	82	88
CG heuristic	74	66	87
blind heuristic	25	52	84

Note: updated results for LM-local

- With all 3 heuristics, LM-heur dominates other approaches
- LM-local worse than base with CG and blind heuristic (dead ends in 8 domains)
- FF-heuristic: base and LM-local are close. . .

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Results: #Tasks solved exclusively (FF heuristic)

Domain	FF heuristic	
	base	LM-heur
Airport (50)	6	2
Depot (22)	0	2
Freecell (80)	1	3
Logistics-1998 (35)	0	2
Miconic-FullADL (150)	2	0
MPrime (35)	0	3
Mystery (30)	0	1
Pathways (30)	1	2
Philosophers (48)	0	2
Pipesworld-NoTankage (50)	0	2
Pipesworld-Tankage (50)	1	5
Schedule (150)	0	1
Storage (30)	1	0
Total	12	25

LM-heur solves twice as many tasks exclusively as base

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Extended Landmark Generation

- Adapted previous procedures to SAS⁺ planning
- Admit disjunctive landmarks
- Find additional landmarks through DTGs

Domain Transition Graphs (DTGs)

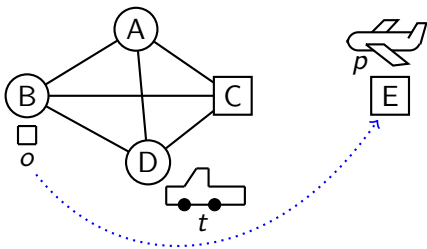
The **domain transition graph** of $v \in \mathcal{V}$ (DTG _{v}) represents how the value of v can change

Given: a SAS⁺ task $\langle \mathcal{V}, \mathcal{A}, s_0, s_* \rangle$

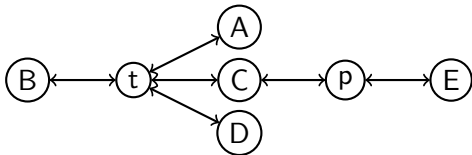
DTG _{v} is a directed graph with **nodes** \mathcal{D}_v that has **arc** $\langle d, d' \rangle$ iff

- $d \neq d'$, and
- \exists action with $v \mapsto d'$ as effect, and either
 - $v \mapsto d$ as precondition, or
 - no precondition on v

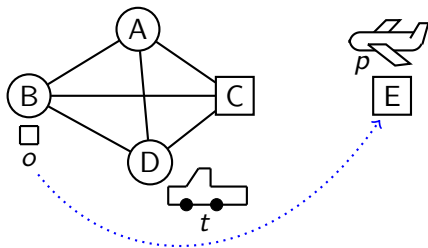
DTG Example



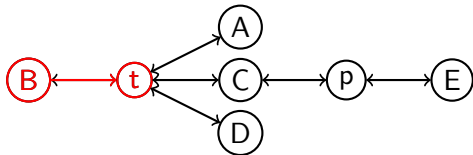
DTG for v_o :



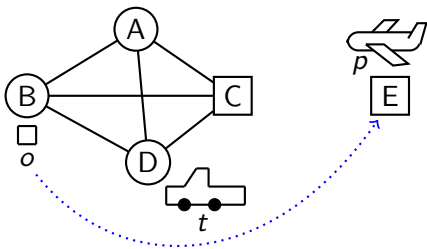
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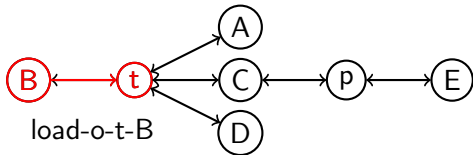
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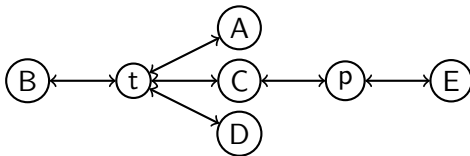
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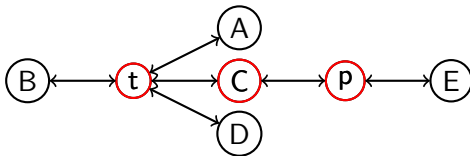


Extended Landmark Generation



- Find additional landmarks through DTGs: if
 - $s_0(v) = d_0$,
 - $v \mapsto d$ landmark, and
 - every path from d_0 to d passes through d' ,then $v \mapsto d'$ landmark
- No further improvement in % solved, but shorter plans

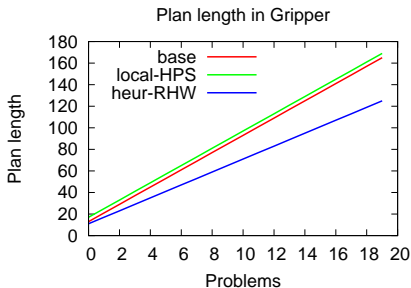
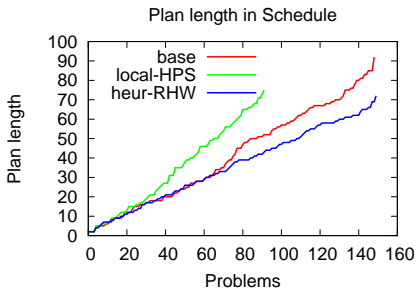
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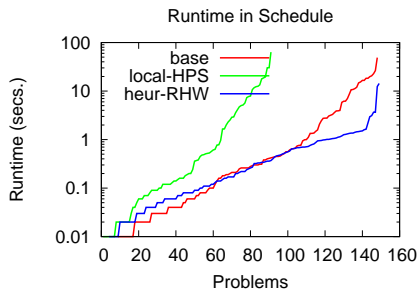
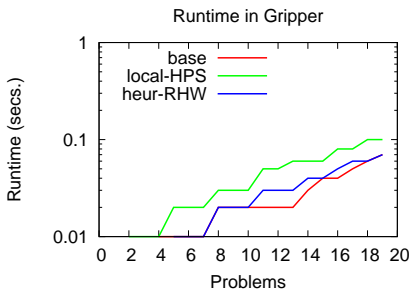
Extended landmark generation – Plan length

- Local: plans 6% longer than with base
- Heur: plans 1% shorter
- Heur with extended LMs: plans 3% shorter



Remarks on Runtime

- LM generation usually < 1 sec. (max. 2 min.)
- During search: slight overhead through landmarks ($\leq 18\%$)
- Overhead typically outweighed by benefit in larger problems



Summary

- Landmark heuristic significantly improves existing heuristics
- More tasks solved
- Better quality of solutions (plan lengths)
- Complete, unlike previous local search approach
- First approach that handles disjunctive landmarks

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