Heuristics and Symmetries in Classical Planning

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Classical Planning in STRIPS

A STRIPS Planning task is 4-tuple $\langle P, O, I, G \rangle$:

- P: finite set of propositions
- O: finite set of actions of form $\langle Pre, Add, Del, c \rangle$
  (Preconditions/Add/Delete; subsets of propositions)
  $c \in \mathbb{R}^{0+}$ captures action cost
- I: initial state (subset of propositions)
- G: goal description (subset of propositions)

Classical Planning as Heuristic Search

Recipe

1. Search algorithm - BFS ($GBFS$ or WA^*)
2. Heuristic(s) function(s)
3. Secret ingredients:
   - Inference–based state/action pruning
   - Action preferences
   - ...

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BFS tree step-by-step

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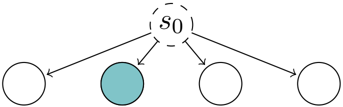

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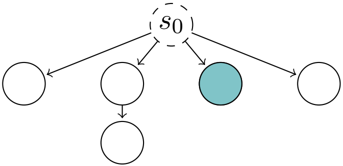

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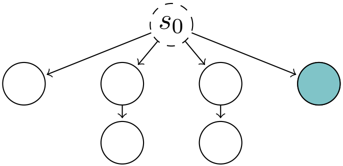

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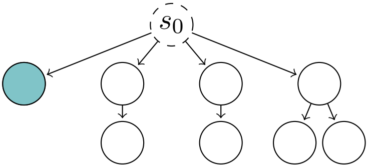

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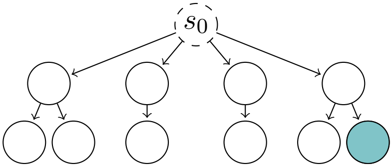

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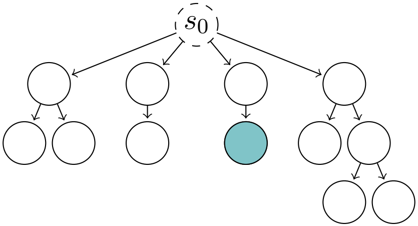

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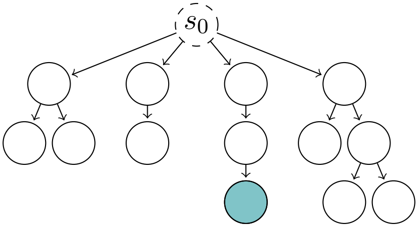

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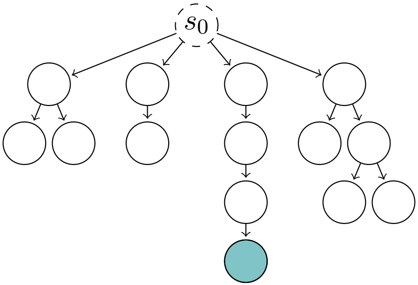

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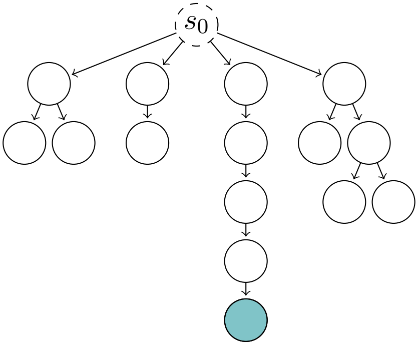

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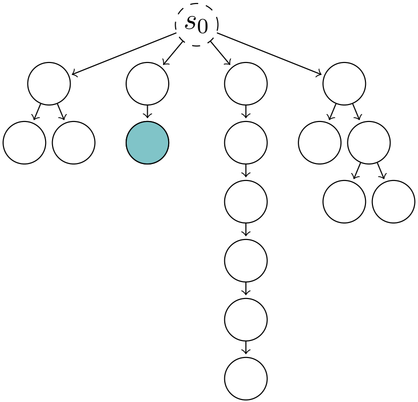

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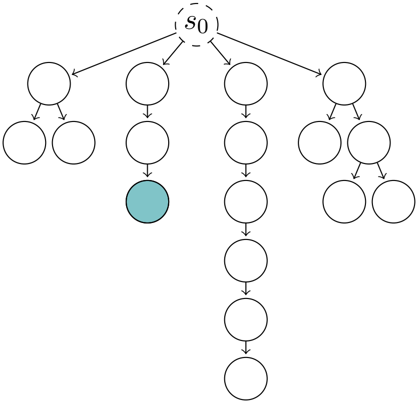

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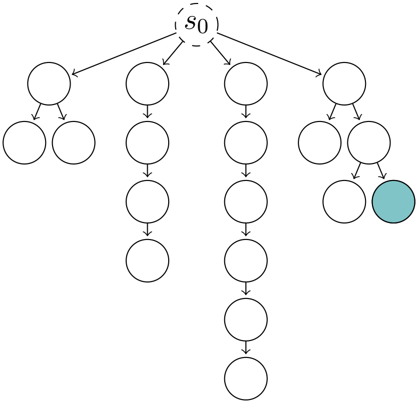

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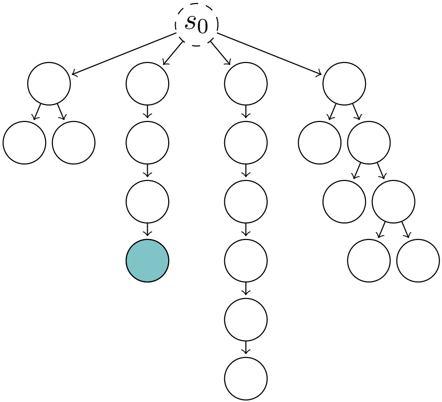

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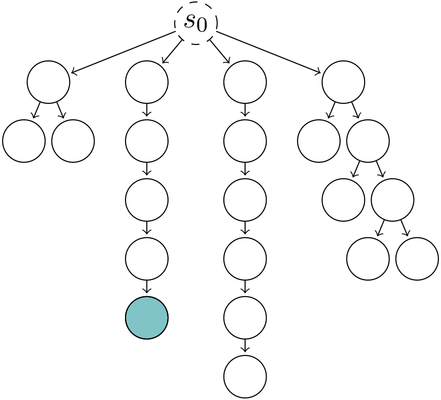

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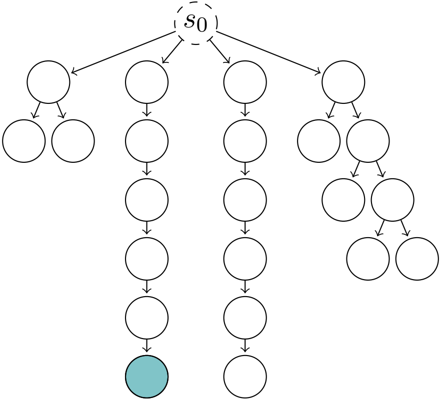

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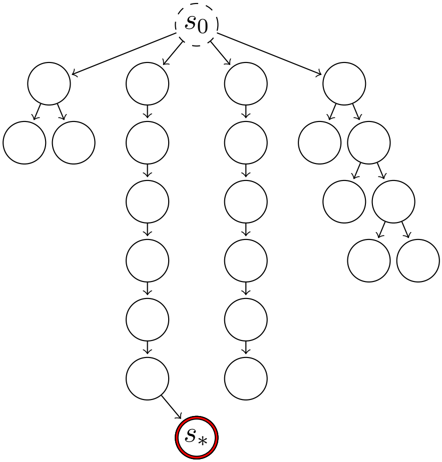

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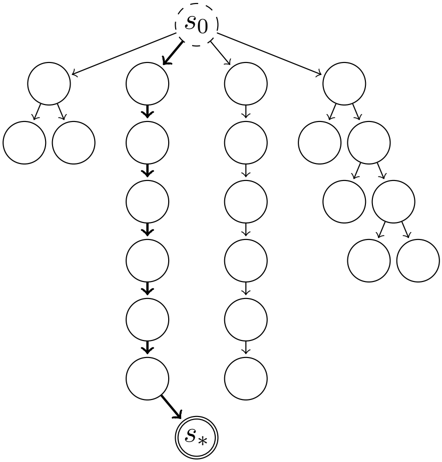
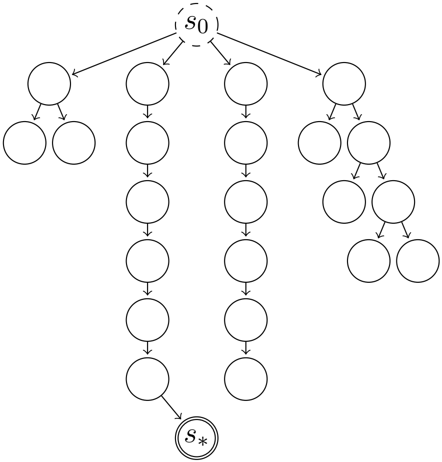


Motivation to use symmetries



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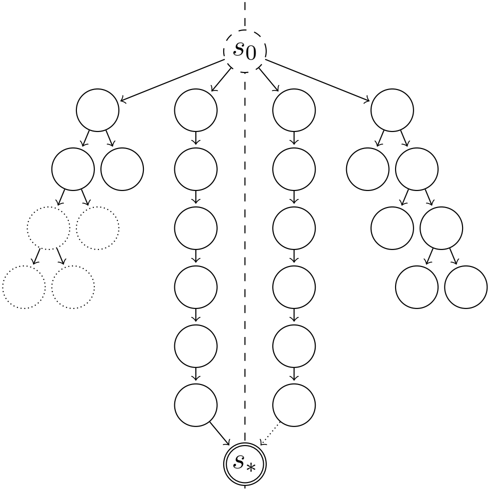

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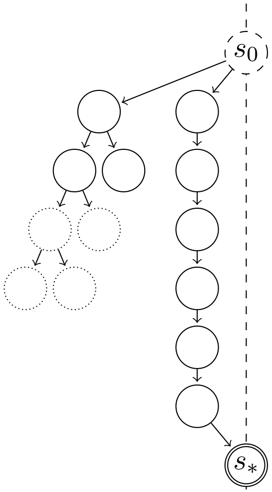

Exploiting Symmetries for Pruning

General Recipe

1. Efficiently generate a subgroup of the automorphism group of the problem's transition graph
   - efficiently = empirically efficiently
2. Use that subgroup to prune *some* symmetric states

- Emerson & Sistla (1996) *[model checking]*
- Rintanen (1993) *[planning as SAT]*
- Fox & Long (1999, 2002) *[Graphplan-style]*
- Pochter, Zohar, and Rosenschein (2011) *[heuristic search]*
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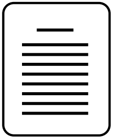
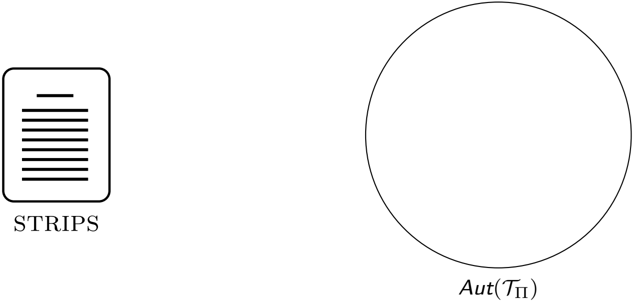
Symmetry Groups



STRIPS

Symmetry Groups



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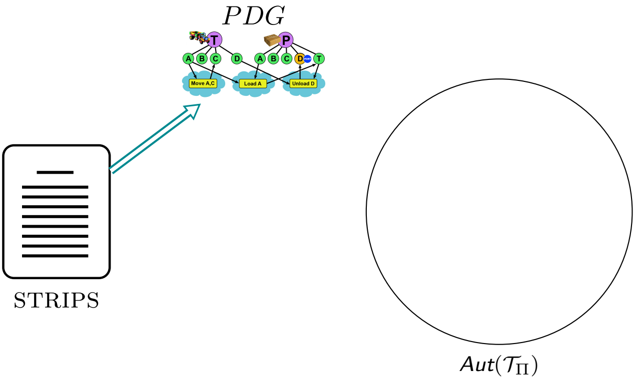

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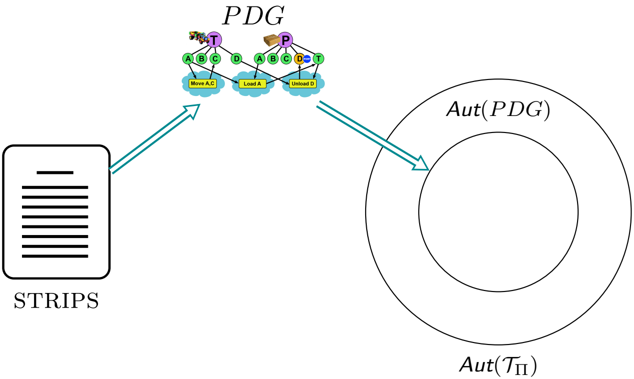

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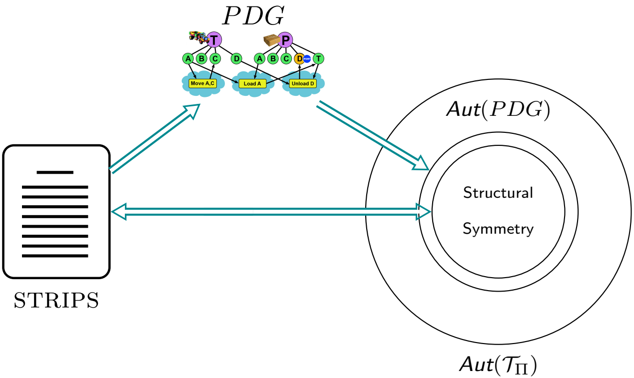

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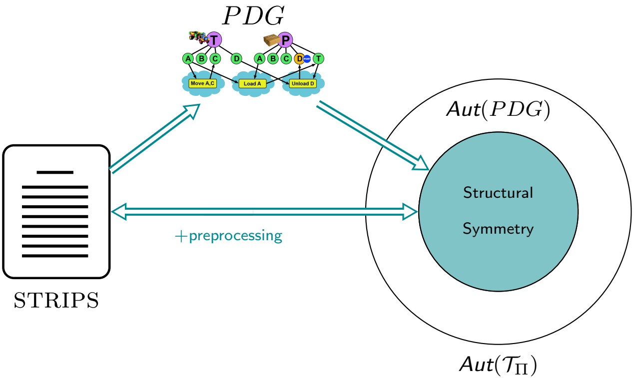


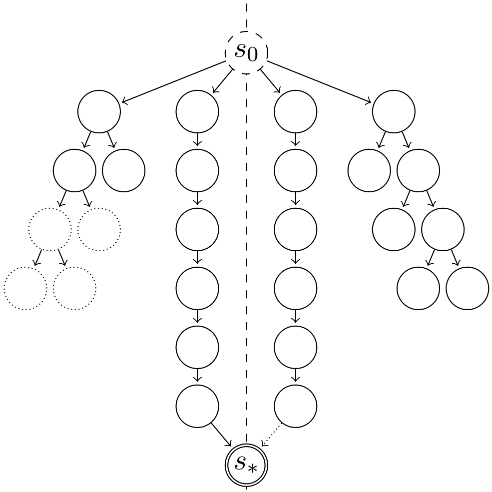
Structural Symmetry

Definition

Let $\langle P, O, I, G \rangle$ be a STRIPS planning task.
A permutation σ is a structural symmetry if

- $\sigma(P) = P$
- $\sigma(O) = O$, and for all $o \in O$:
  - $Pre(\sigma(o)) = \sigma(Pre(o))$
  - $Add(\sigma(o)) = \sigma(Add(o))$
  - $Del(\sigma(o)) = \sigma(Del(o))$
  - $C(\sigma(o)) = C(o)$
- $\sigma(G) = G$

Born equal?



Why do we want to know?

$$\boxed{A}$$

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$$\begin{tikzcd} \boxed{A} \arrow[d, Rightarrow, "\text{symmetry pruning}"] \\ \boxed{A'} \end{tikzcd}$$

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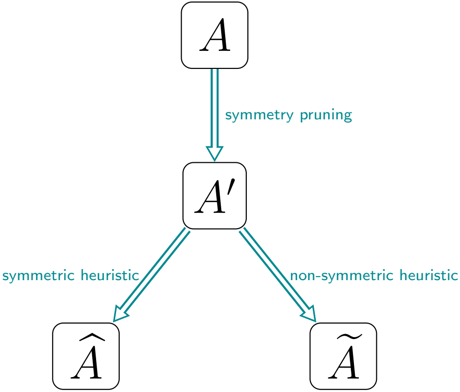

Heuristics Invariance Under Structural Symmetries

Non-symmetric

Symmetric

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h^+ Hoffmann & Nebel

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Heuristics Invariance Under Structural Symmetries

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h_{FF} Hoffmann & Nebel

$h_{\mathrm{FF}}/h_{\mathrm{add}}$ Keyder & Geffner

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Heuristics Invariance Under Structural Symmetries

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Symmetric

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$h_{\max}$ Bonet & Geffner

h_{add} Bonet & Geffner

$\mathbb{E}h_{\mathrm{FF}}$ Hoffmann & Nebel

h^m Haslum & Geffner

Heuristics Invariance Under Structural Symmetries

Non-symmetric	Symmetric
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$h_{\text{FF}}/h_{\max}$ Keyder & Geffner	
	h^m Haslum & Geffner
$h^{\text{LM-cut}}$ Helmert & Domshlak	$\mathbb{E}h^{\text{LM-cut}}$ Helmert & Domshlak

Landmarks and generation procedures

Non-symmetric

Symmetric

Landmarks and generation procedures

Non-symmetric

Symmetric

ZG Zhu & Givan 2003

Landmarks and generation procedures

Non-symmetric	Symmetric
	ZG Zhu & Givan 2003
	KRH Keyder, Richter, & Helmert 2010

Landmarks and generation procedures

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RHW Richter, Helmert, & Westphal 2008

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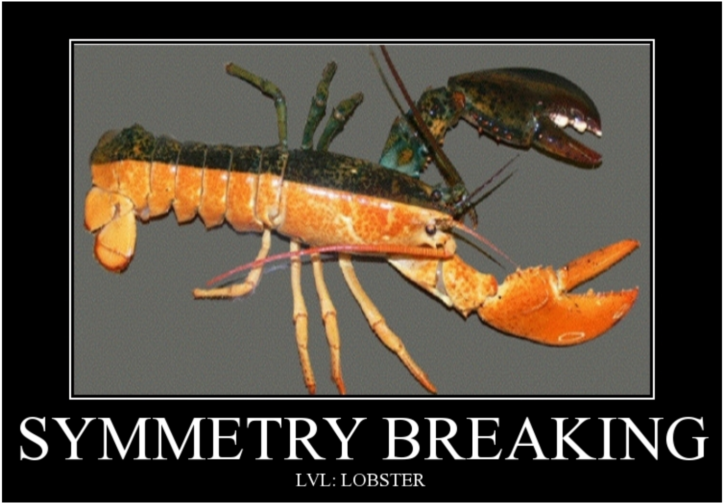
Given that generation method is invariant under structural symmetry the heuristics below are symmetric

- counting landmarks (Richter, Helmert, & Westphal)
- optimal/uniform cost partitioning (Karpas & Domshlak)
- hitting sets (Bonet & Helmert)

The END



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