Strengthening Canonical Pattern Databases with Structural Symmetries

Silvan Sievers[1] Martin Wehrle[1] Malte Helmert[1]
Michael Katz[2]

[1] University of Basel, Switzerland
[2] IBM Watson Health, Haifa, Israel

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Motivation

- Structural symmetries in recent work:
  - Symmetry-based pruning in forward search
  - Symmetric lookups
  - Enhancing merge-and-shrink heuristics

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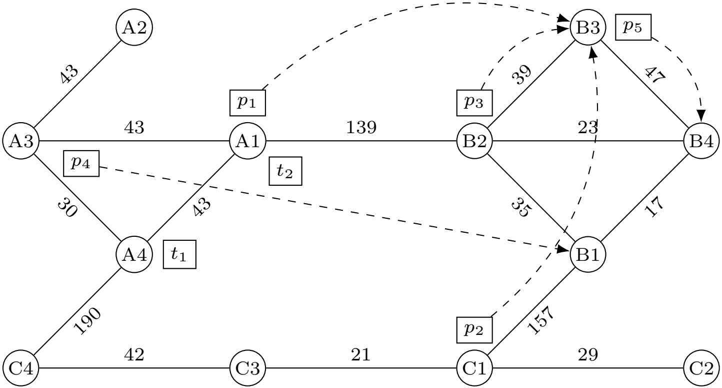
- Structural symmetries in recent work:
  - Symmetry-based pruning in forward search
  - Symmetric lookups
  - Enhancing merge-and-shrink heuristics
- In this work:
  - Symmetric pattern databases
  - Canonical PDB heuristic invariant under symmetry

Outline

1. Background
2. Structural Symmetries and (Canonical) PDBs
3. Experiments

Setting

- Optimal classical planning



TRANSPORT-OPT11, #5

Canonical PDB Heuristic

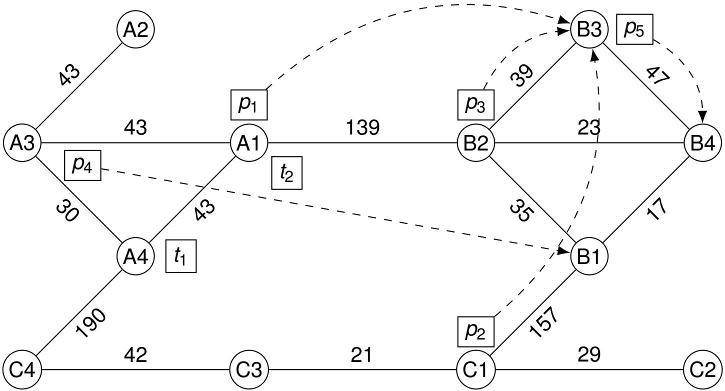
- Set of patterns: pattern collection $\mathcal{C}$
- Maximal-disjoint-additive subsets $\mathcal{A}$ of $\mathcal{C}$
- Canonical PDB heuristic: sum PDB values whenever possible, maximize otherwise

$$h^{\mathcal{C}_\mathcal{C}}(s) = \max_{\mathcal{B} \in \mathcal{A}} \sum_{P \in \mathcal{B}} h^P(s)$$

Structural Symmetries

- Permutation of variables, operators, and facts
- Goal-stable automorphisms: preserve structure

Example


A2
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A3
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p1
A1
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B2
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B3
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B4
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t2
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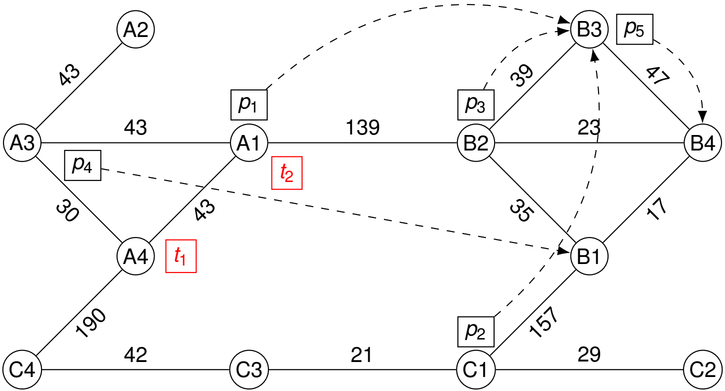
157
C4
42
C3
21
C1
29
C2

Example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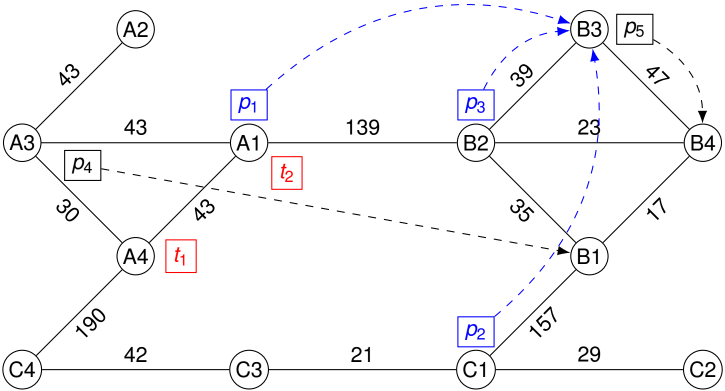
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Symmetric Patterns

Definition

For pattern $P = \{v_1, \ldots, v_n\}$ and symmetry σ of planning task Π, the symmetric pattern is $\sigma(P) = \{\sigma(v_1), \ldots, \sigma(v_n)\}$.

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Theorem

For all states s of Π: $h^P(s) = h^{\sigma(P)}(\sigma(s))$.

Implicit PDBs

- Patterns P, Q with $\sigma(Q) = P$
- Alternative to computing both PDBs:
  - Compute h^P
  - Keep $\langle h^P, \sigma \rangle$ as implicit representation
  - Computation of implicit PDB: $h^Q(s) = h^P(\sigma(s))$

Symmetric and Disjoint-additive Pattern Collections

Definition

Pattern collection C is closed under symmetry group Γ if for all $\sigma \in \Gamma$ and for all $P \in C$, $\sigma(P) \in C$.

- $\overline{C}$ symmetric closure of C if $P, \sigma(P) \in \overline{C}$ for all $P \in C$

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Theorem

If pattern collection C is disjoint-additive, then also $\overline{C}$ is disjoint-additive.

Invariance and Dominance of the CPDB Heuristic

Theorem

If pattern collection C is closed under symmetry group Γ, then for all states s of Π: $h^{\mathcal{C}_C}(s) = h^{\mathcal{C}_C}(\sigma(s))$.

Invariance and Dominance of the CPDB Heuristic

Theorem

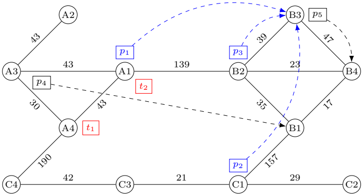
If pattern collection C is closed under symmetry group Γ*, then for all states s of* Π*:* $h^{\mathcal{C}_C}(s) = h^{\mathcal{C}_C}(\sigma(s))$.

Theorem

For pattern collection C and symmetry group Γ*, for all states s of* Π*:* $h^{\mathcal{C}_C}_{SL}(s) \leq h^{\mathcal{C}_{\overline{C}}}(s)$.

Algorithm – Example

C $\{v^{p_2}\}$ $\{v^{p_3}\}$ $\{v^{p_4}\}$ $\{v^{p_5}\}$ $\{v^{t_1}, v^{t_2}, v^{p_1}\}$



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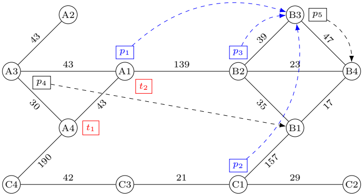

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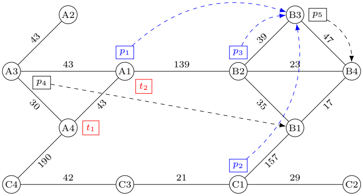

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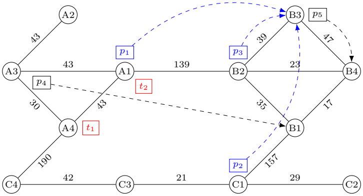

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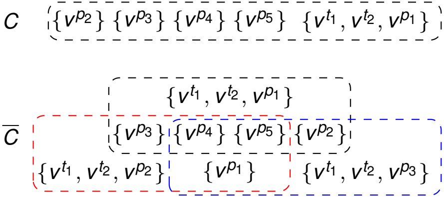

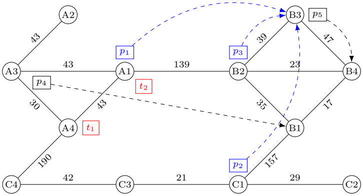

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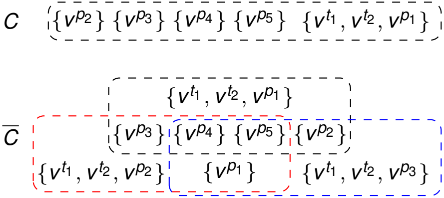
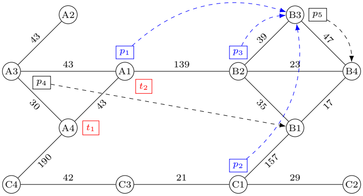
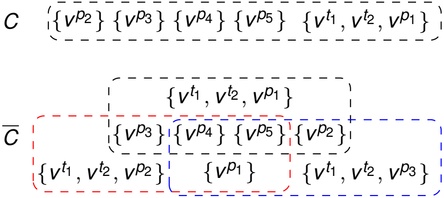
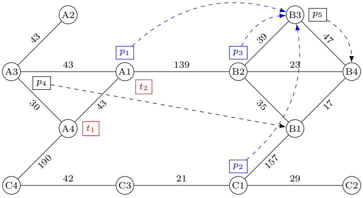




- Example computations for the initial state:

Algorithm – Example





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$$h^{\mathcal{C}_C}(s_0) = \max\{2+2+2+2+180\} = 188$$

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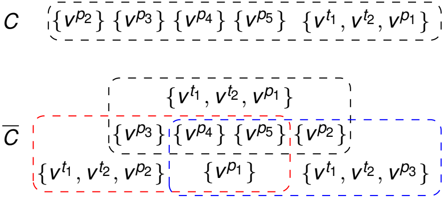
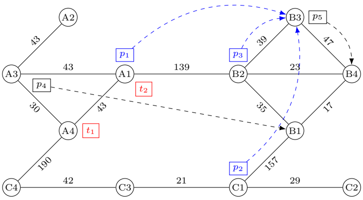




- Example computations for the initial state:

$$h^{\mathcal{C}_C}(s_0) = \max\{2+2+2+2+180\} = 188$$

$$\begin{aligned} h^{\mathcal{C}_{\overline{C}}}(s_0) = \max\{&180+2+2+2+2,\\ &476+2+2+2+2,\\ &180+2+2+2+2\} = 484 \end{aligned}$$

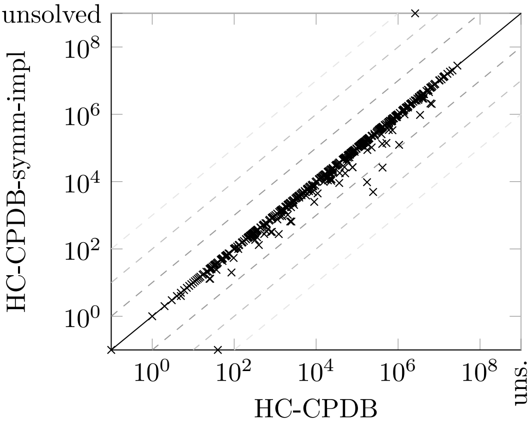
Outline

Results for A^*

	HC-CPDB		
	orig	**symm**	**symm-impl**
Coverage (# solved tasks)	814	813	813
Search out of memory	774	736	730
Search out of time	70	109	115

- Not shown: dominance over symmetric lookups

Expansions



(dominance in 194 task across 33 domains)

Results for Symmetry-based Pruning

	HC-CPDB with DKS		
	orig	**symm**	**symm-impl**
Coverage (# solved tasks)	887	893	891
Expansions 95th percentile	3510224	2584593	2584593

Conclusions

- Implicit PDBs: trade-off between memory and runtime
- CPDB heuristic invariant under symmetry if using symmetric closure of pattern collection
- Fruitful combination with symmetry-based pruning methods