An Empirical Case Study on Symmetry Handling in Cost-Optimal Planning as Heuristic Search

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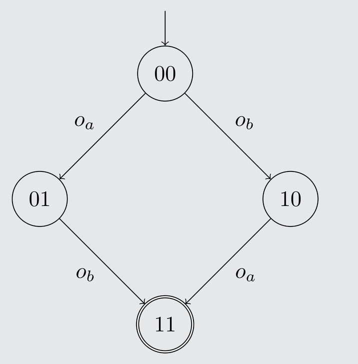
Classical Planning Task (SAS$^+$)

- Finite-domain state variables
- Initial state: complete variable assignment
- Goal description: partial variable assignment
- Operators: preconditions, effects, cost

Transition Graph

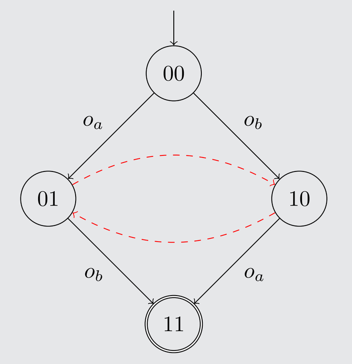


Structural Symmetries (Shleyfman et al. 2015

- Permutation of facts and operators
- Induced symmetry on the transition graph is a goal-stable automorphism

Example Symmetry

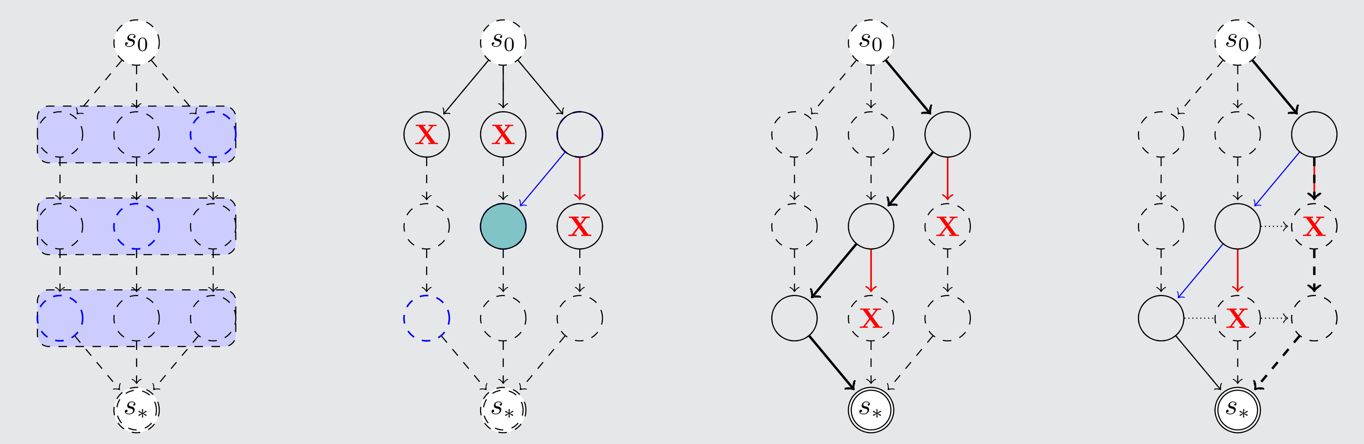
$\sigma(o_a) = o_b$
$\sigma(o_b) = o_a$



Orbit Space Search (Domshlak et al. 2015)

- Modified A* search:
  - When expanding state s, replace successors by orbit representatives
  - Save regular operators
- Non-standard plan extraction:
  - Compute the "real" state sequence
  - Find operators connecting the sequence

Example



Credits: A. Shleyfman

Symmetrical Lookups (Felner et al. 2005)

- When evaluating state s with heuristic h:
  - Compute (a subset of) the orbit containing s: $S := \{s, s^1, \dots s^m\}$
  - Compute heuristic as $\bar{h}(s) := \max\{h(s') \mid s' \in S\}$

Bidirectional Pathmax (Felner et al. 2011)

- Symmetrical lookups usually render heuristics inconsistent
- Bidirectional pathmax (BPMX) rule: $h(s') = \max(h(s'), h(s) - cost(o))$

Merge-and-Shrink Heuristics (Helmert et al. 2014)

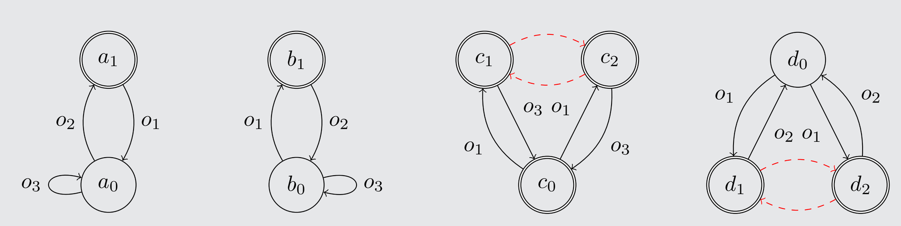
$\mathcal{T} := \{$atomic transition systems$\}$
While $|\mathcal{T}| > 1$:
  Choose $\Theta_1, \Theta_2 \in \mathcal{T}$
  Possibly shrink and/or Θ_1, Θ_2
  Merge: replace Θ_1 and Θ_2 by the synchronized product $\Theta_1 \otimes \Theta_2$ in $\mathcal{T}$
Return single element in $\mathcal{T}$

Factored Symmetries (Sievers et al. 2015)

- Work on a set $\mathcal{T}$ of transition systems
- Locally permute abstract states within transition systems (goal preserving) and globally permute transition labels

Example

$\sigma(o_1) = o_1$, $\sigma(o_2) = o_2$,
$\sigma(o_3) = o_3$



Case Study: Symmetries in Planning Benchmarks

Symmetries	# tasks total	# tasks symm	# generators sum	# generators median	# generators of order 2	3	4	5
Total	1396	1103	24016	4	24010	3	2	1

→ lots of symmetries, diverse domains

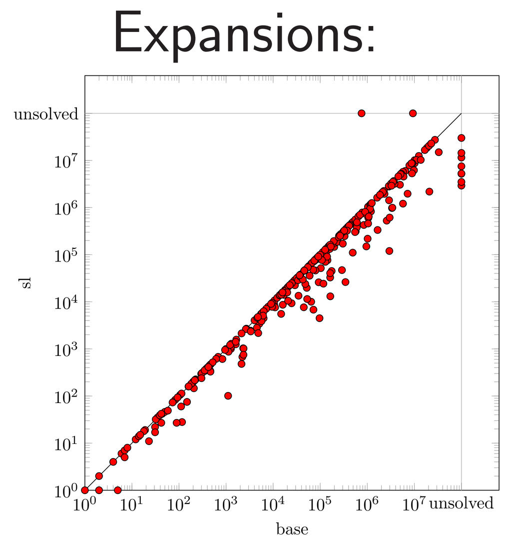
Additional Facts

- Only 3 domains wiht no symmetries
- 38 domains with > 50% of tasks with symmetries
- Most of these with > 95% of tasks with symmetries

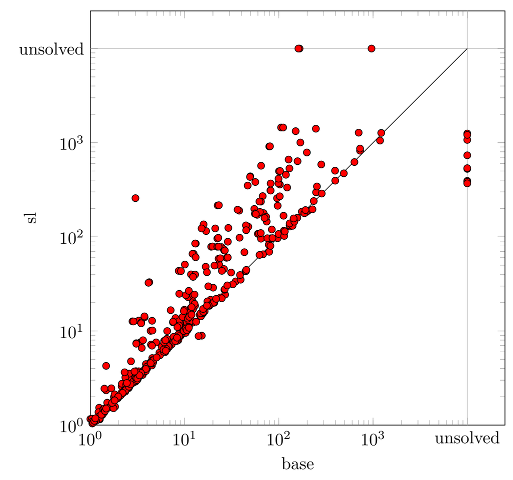
Case Study: Symmetrical Lookups for Planning

M&S	base	1 state	5 states	10 states	orbit
Coverage	652	656	**658**	**658**	**658**
Exp. sum	607602428	501671723	493848579	**471769190**	493848579
Exp. median	1263	1059	**811**	**811**	**811**

Expansions:



Runtime:



→ tradeoff between runtime and heuristic quality

Case Study: Bidirectional Pathmax for Planning

Merge-and-Shrink	base	sl	sl-bpmx
Coverage	652	**658**	**658**
Expansions sum	607602428	**471769190**	471769236
Expansions median	1260	**751**	**751**

→ no performance gain: pathmax corrections only in 2 % of the tasks

Case Study: Combinations of Techniques

M&S	base	oss	sl	fs	oss-sl	oss-fs	sl-fs	all
C	652	696	658	654	691	**698**	655	692
E. sum	5.16e+8	2.68e+8	4.01e+8	3.65e+8	2.54e+8	2.39e+8	3.44e+8	**2.32e+8**
E. med	5077	4292	4481	7432	2814	5499	6216	4593

Observations

- All techniques improve performance
- Orbit space search by far the strongest technique
- Best combination: orbit space search & factored symmetries
- Including orbit space search always helpful
- Including symmetrical lookups not helpful (for coverage)

Case Study: Combinations of Techniques

	CEGAR base	CEGAR oss	CEGAR sl	CEGAR oss-sl	iPDB base	iPDB oss	iPDB sl	iPDB oss-sl
C	698	**731**	689	728	661	**723**	657	713
E. sum	50.8e+8	29.2e+8	44.5e+8	**19.1e+8**	33.2e+8	15.0e+8	31.4e+8	**13.3e+8**
E. med	5118	7285	5799	**2906**	6931	2440	6339	**1952**

Observations

- Again: orbit space search best performer
- Again: including symmetrical lookups not helpful

Conclusions

- Planning benchmarks contain lots of symmetries
- Symmetries improve state of the art planning techniques
- Best symmetry-based technique: orbit space search