Symmetry-based Task Reduction for Relaxed Reachability Analysis

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Reachability

**Question**: Which atoms *can become true* in the *reachable* part of the state space?
Reachability

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- Relevant for grounding, mutexes (pairs of atoms), ... 
- As **hard** as the planning problem 
- Usually: relaxation-based over-approximation
Example Task
Idea

Perform analysis for fewer trucks and packages.
Illustration on Example Task

The diagram illustrates a network of tasks represented by nodes A, B, C, and D, connected by symmetries and paths labeled $p_1$, $p_2$, and $p_3$. The symmetries are represented by dashed lines indicating that certain tasks can be reached by multiple paths. The analysis section notes that a blue truck can reach B, C, and D, and the expansion section highlights that both orange and red trucks can also reach B, C, and D.
Illustration on Example Task
Illustration on Example Task

reduction:
Illustration on Example Task

reduction:

analysis: Blue truck can reach B, C, and D
Illustration on Example Task

**reduction:**

**analysis:** Blue truck can reach B, C, and D

**expansion:** Also orange and red truck can reach B, C, and D
More General Idea

original task $\Pi$ \rightarrow \text{reachability analysis} \rightarrow \text{reachable atoms on } \Pi
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original task $\Pi$ \rightarrow \text{reachability analysis} \rightarrow \text{reachable atoms on } \Pi

reduction

smaller task $\Pi'$ \rightarrow \text{reachability analysis} \rightarrow \text{reachable atoms on } \Pi'

expansion
Symmetries

- We consider a \textit{lifted} task representation.
- As we only consider \textit{reachability} we can ignore the goal.
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- Two objects are **symmetric** if swapping them in the task description does not change it (up to ordering of elements).
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- We consider a **lifted** task representation.
- As we only consider **reachability** we can **ignore the goal**.
- Two objects are **symmetric** if swapping them in the task description does not change it (up do ordering of elements).
- **Symmetric constant set**: set of pairwise symmetric objects
Truck Example
Reduction

- $C, C'$ set of objects, $C' \subseteq C$.
- Reduction $R_{C \downarrow C'}(\Pi)$ removes from task $\Pi$ all occurrences of objects from $C \setminus C'$.
Reduction

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$R_{\{\}, \{\}} \downarrow \{\}$

Diagram:

- Nodes: A, B, C, D
- Edges: A to B, A to C, B to C, B to D, C to D
- Labels: $p_1, p_2, p_3$
Reduction

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Expansion

Expansion $E_C(L)$ extends a set of atoms $L$ with all atoms that can be generated by permuting elements of $C$ in a literal from $L$.

Example (Expansion)

$$E_{\{o_1,o_2,o_3\}}(\{P(o_1, o_2, o_2), Q(o_1, o_4)\}) =$$

$$\{P(o_1, o_2, o_2), P(o_1, o_3, o_3), P(o_2, o_1, o_1), P(o_2, o_3, o_3), P(o_3, o_1, o_1), P(o_3, o_2, o_2), Q(o_1, o_4), Q(o_2, o_4), Q(o_3, o_4)\}$$
Reduction and Expansion

For symmetric constant set $C$ and $C$-symmetric set of atoms

$E_C(R_C\downarrow C'(L)) \subseteq L$
Reduction and Expansion

For symmetric constant set $C$ and $C'$-symmetric set of atoms

- $E_C(R_{C\downarrow C'}(L)) \subseteq L$
- $L = E_C(R_{C\downarrow C'}(L))$ for sufficiently large $C'$
Reduction and Expansion

For symmetric constant set $C$ and $C'$-symmetric set of atoms

- $E_C(R_{C\downarrow C'}(L)) \subseteq L$
- $L = E_C(R_{C\downarrow C'}(L))$ for sufficiently large $C'$
  - maximal number of different constants from $C$ in one literal
Symmetry-based Task Reduction

- Bounds on number of elements that must be preserved from a symmetric constant set
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Symmetry-based Task Reduction

- Bounds on number of elements that must be preserved from a symmetric constant set
- Overall bounds depend on reachability system.
- $b_{\text{lit}}^C$: upper bound on the number of objects from $C$ that can occur together in a reachable ground literal
- $b_{\text{op}}^C, b_{\text{ax}}^C$: analogously for ground operators and axioms
Example: Relaxed Reachability of Literals

Definition (Relaxed Reachability of Literals)

The set of $k$-reachable ground literals $\ell$ ($k \in \mathbb{N}_0$) is the smallest set that contains literal $\ell$ if

- $\ell$ is true in the initial state, or
- $\ell$ is the default value of an axiom, or
- $k > 0$ and there is a ground operator $o$ such that
  - $o$ has an effect $\varphi \triangleright \ell$, and
  - each literal in $\varphi$ and in $\text{pre}(o)$ is $k - 1$-reachable, or
- there is a ground axiom $\ell \leftarrow \psi$ such that each literal in $\psi$ is $k$-reachable.

Preserve $\max\{b^\text{lit}_C, b^\text{op}_C, b^\text{ax}_C\}$ objects from $C$
Example: $h^2$ Mutexes

**Definition (Relaxed Reachability of Pairs of Literals)**

For $k \in \mathbb{N}_0$, the set $M_k$ of $k$-reachable pairs of ground literals is the smallest set that contains pair $\{\ell, \ell'\}$ if one of the following holds:

- $\ell \land \ell'$ is true in the initial state.
- $k > 0$ and there is a ground operator $o$ such that
  - $o$ has effects $\varphi \triangleright \ell$ and $\varphi' \triangleright \ell'$, and
  - $\ldots$
- $\ldots$

Preserve $\max\{b_{C}^{\text{lit}}, b_{C}^{\text{op}}, b_{C}^{\text{ax}}\} + b_{C}^{\text{lit}}$ objects from $C$
Other Contributions

- finding symmetric constant sets
  - simple union-find algorithm
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  - use logic program to compute over-approximation of relaxation
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- finding symmetric constant sets
  - simple union-find algorithm
- tightening the bounds
  - use logic program to compute over-approximation of relaxation
- combination of several symmetric constant sets
  - unproblematic if they are disjoint
Implementation

- translator component of Fast Downward
- grounding: use existing implementation
- $h^2$ mutexes: add logic program
Results

77 domains with 2518 tasks from IPC benchmarks (sequential tracks, including axioms, no duplicates)

- 51 domains with symmetric objects
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Grounding:

- symmetry reduction applicable to 1004 tasks from 49 domains
- however: regular grounding is so fast that reduction and expansion is not faster
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Grounding:

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\( h^2 \) mutexes: reduction applicable to 610 tasks from 38 domains
Results – $h^2$ mutexes

- Regular task
- Symmetry-reduced task

Graph showing the timeout values for regular and symmetry-reduced tasks across various domains. The graph uses a log-log scale to compare the timeout values and demonstrates the effectiveness of symmetry-based task reduction.

Domains included:
- ASSEMBLY
- BARMAN
- BARMAN-OPT
- BARMAN-SAT
- CHILDSNACK
- CHILDSNACK-OPT
- CHILDSNACK-SAT
- CITYCAR
- ELEVATORS
- ELEVATORS-SAT
- GRIPPER
- LOGISTICS
- MYSTERY
- SATELLITE
- TPP
- WOODWORKING
- ZENOTRAVEL
Summary

- With symmetric constant sets...
- ...we can reduce the size of a task...
- ...perform a reachability analysis on the smaller task...
- ...and reconstruct the original result with an expansion.
Future Work

- Formulation for general rule-based systems
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- Rintanen (AAAI 2017): Schematic Invariants by Reduction to Ground Invariants

\[ L_t^N (A, P) = \max(\max_{a \in A} \text{prms}_t(a), \max_{p \in P} \text{prms}_t(p)) + (N - 1) \cdot (\max_{p \in P} \text{prms}_t(p)) \]

→ Clarify relationship and applicability to a wider range of invariant synthesis algorithms