Symmetry-based Task Reduction for Relaxed Reachability Analysis

Gabriele Röger, University of Basel, Switzerland
Silvan Sievers, University of Basel, Switzerland
Michael Katz, IBM Research, USA

ICAPS 2018

Reachability

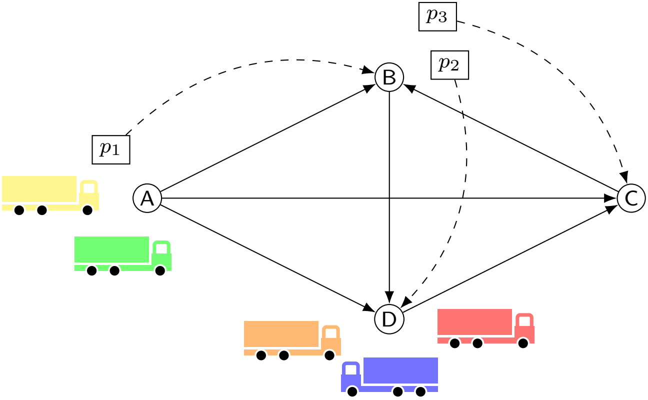
Question: Which atoms can become true
in the reachable part of the state space?

Reachability

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

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

Example Task



Idea

Idea

Perform analysis for fewer trucks and packages.

Illustration on Example Task

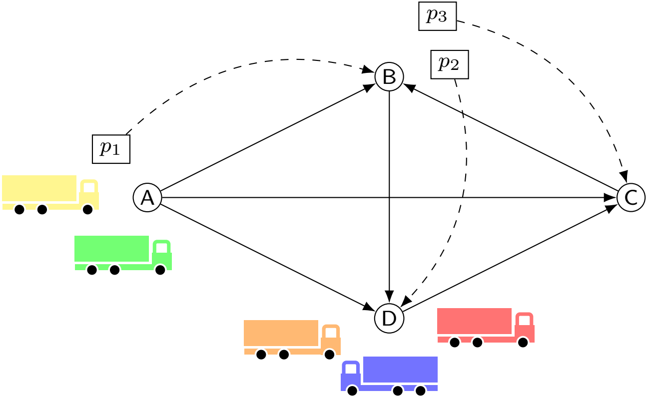


Illustration on Example Task

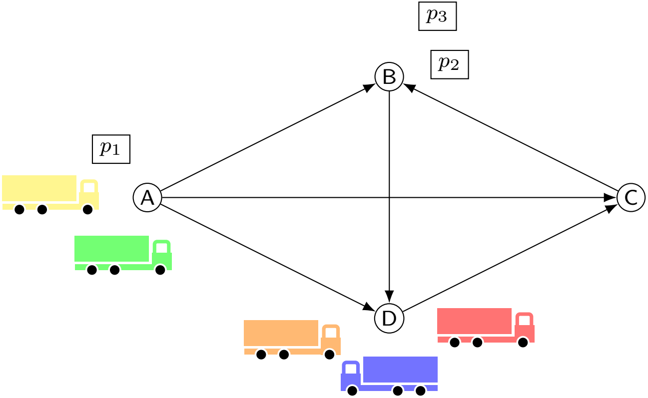


Illustration on Example Task

reduction:

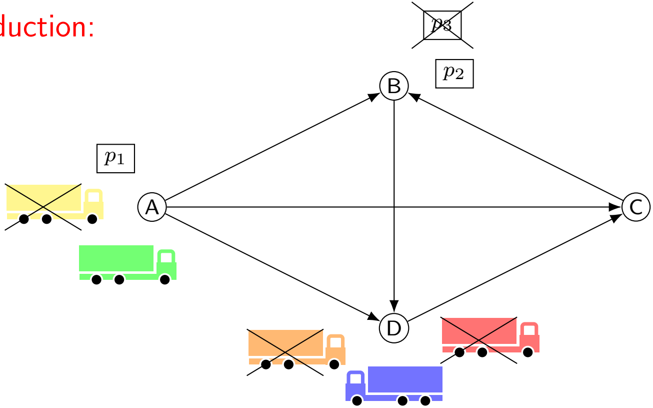
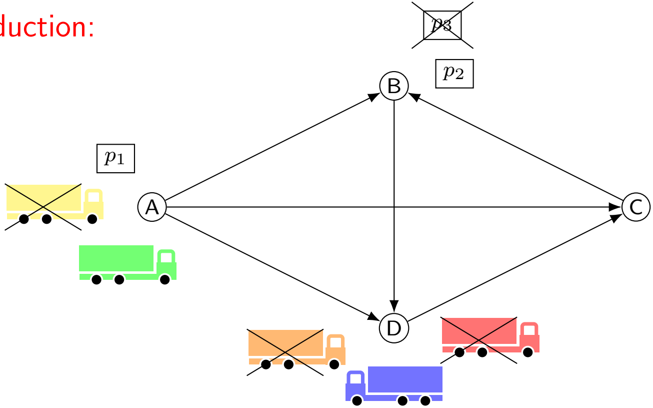


Illustration on Example Task

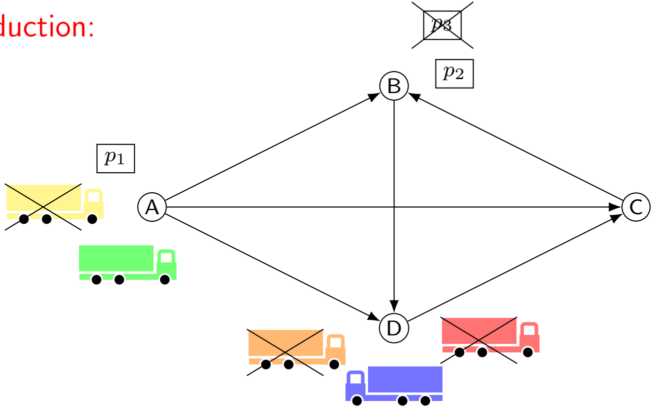
reduction:



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

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

More General Idea

$$
\begin{tikzcd}
\text{original task } \Pi \arrow[r, "\text{reachability analysis}"] \arrow[d, "\text{reduction}"'] & \text{reachable atoms on } \Pi \\
\text{smaller task } \Pi' \arrow[r, "\text{reachability analysis}"] & \text{reachable atoms on } \Pi' \arrow[u, "\text{expansion}"']
\end{tikzcd}
$$

Symmetries

- We consider a lifted task representation.
- As we only consider reachability we can ignore the goal.

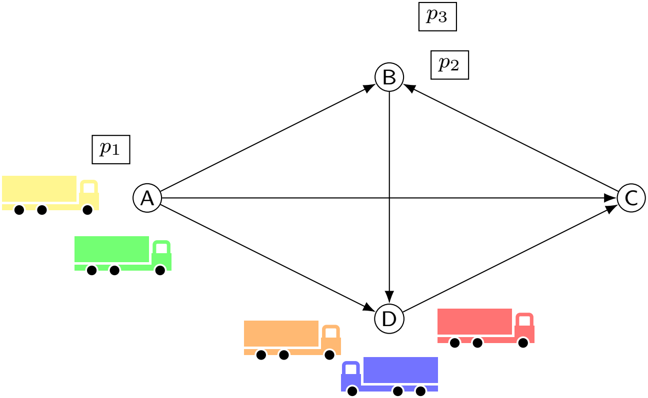
Symmetries

- 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).

Symmetries

- 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

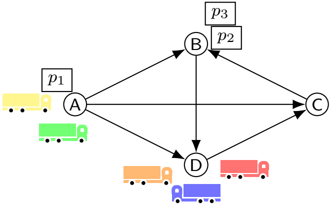


Reduction

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

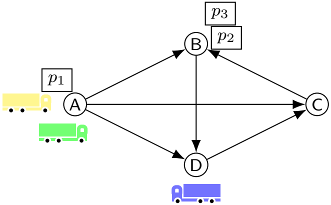
Reduction

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



Reduction

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



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)

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

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'
  - $\rightarrow$ maximal number of different constants from C in one literal

Symmetry-based Task Reduction

$$\begin{tikzcd}
\text{original task } \Pi \arrow[r, "\text{reachability analysis}"] \arrow[d, "\text{reduction}"'] & \text{reachable atoms on } \Pi \\
\text{smaller task } \Pi' \arrow[r, "\text{reachability analysis}"] & \text{reachable atoms on } \Pi' \arrow[u, "\text{expansion}"']
\end{tikzcd}$$

- Bounds on number of elements that must be preserved from a symmetric constant set

Symmetry-based Task Reduction

$$
\begin{tikzcd}
\text{original task } \Pi \arrow[r, "\text{reachability analysis}"] \arrow[d, "\text{reduction}"'] & \text{reachable atoms on } \Pi \\
\text{smaller task } \Pi' \arrow[r, "\text{reachability analysis}"] & \text{reachable atoms on } \Pi' \arrow[u, "\text{expansion}"']
\end{tikzcd}
$$

- Bounds on number of elements that must be preserved from a symmetric constant set
- Overall bounds depend on reachability system.

Symmetry-based Task Reduction

$$\begin{tikzcd}
\text{original task } \Pi \arrow[r, "\text{reachability analysis}"] \arrow[d, "\text{reduction}"'] & \text{reachable atoms on } \Pi \\
\text{smaller task } \Pi' \arrow[r, "\text{reachability analysis}"] & \text{reachable atoms on } \Pi' \arrow[u, "\text{expansion}"']
\end{tikzcd}$$

- Bounds on number of elements that must be preserved from a symmetric constant set
- Overall bounds depend on reachability system.
- b_C^{lit}: upper bound on the number of objects from C that can occur together in a reachable ground literal

Symmetry-based Task Reduction

$$\begin{tikzcd}
\text{original task } \Pi \arrow[r, "\text{reachability analysis}"] \arrow[d, "\text{reduction}"'] & \text{reachable atoms on } \Pi \\
\text{smaller task } \Pi' \arrow[r, "\text{reachability analysis}"] & \text{reachable atoms on } \Pi' \arrow[u, "\text{expansion}"']
\end{tikzcd}$$

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

Example: Relaxed Reachability of Literals

Definition (Relaxed Reachability of Literals)

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

- ℓ is true in the initial state, or
- ℓ 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 φ and in $pre(o)$ is $k-1$-reachable, or
- there is a ground axiom $\ell \leftarrow \psi$ such that each literal in ψ is k-reachable.

Preserve $\max\{b_C^{\text{lit}}, b_C^{\text{op}}, b_C^{\text{ax}}\}$ 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:

- $\ell \wedge \ell'$ 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
  - ...
- ...

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

Other Contributions

- finding symmetric constant sets
  - simple union-find algorithm
- tightening the bounds
  - use logic program to compute over-approximation of relaxation

Other Contributions

- 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

Results

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

- 51 domains with symmetric objects

Grounding:

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

Results

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

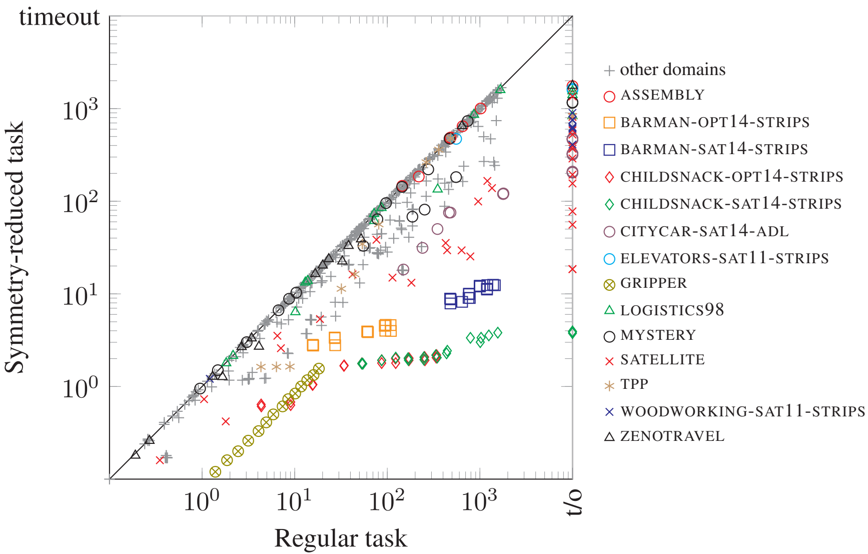
- 51 domains with symmetric objects

Grounding:

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

h^2 mutexes: reduction applicable to 610 tasks from 38 domains

Results – h^2 mutexes



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

Future Work

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

Definition 14 (Limited Instantiation) *For a given action set A, predicate set P, domain function D, type t, and integer $N \geq 1$, define*

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

$\rightarrow$ Clarify relationship and applicability to a wider range of invariant synthesis algorithms