University of Basel

Unrolling of Negative Axioms in Delete Relaxation Heuristics

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Background

Axioms

Definition

An axiom is a rule of the form:

$$h = T \leftarrow \varphi$$

Head h: variable with domain $\{F, T\} \Rightarrow$ derived variable
Body $\varphi := c_1 \wedge \cdots \wedge c_n$
Atom $c := v = x$, variable v with value from its domain x

Default value for derived variables always F

Dependencies

Axioms induce dependencies between derived variables:

Definition

Default Dependency: $x = T \leftarrow \dots \wedge y = F \wedge \dots$
Non-Default Dependency: $x = T \leftarrow \dots \wedge y = T \wedge \dots$

Example Axioms

Derived Variables: A, B, C, D
Non-derived variables: X, Y

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Dependency Graph

Build graph from non-default dependencies:

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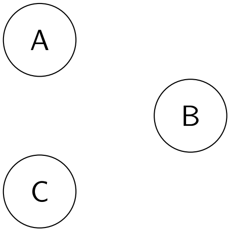

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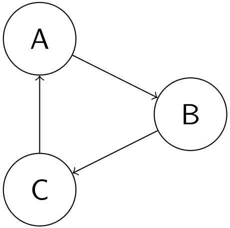

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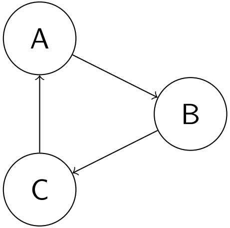

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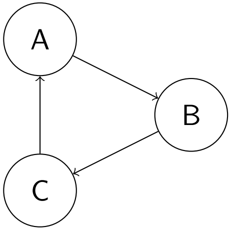
$\Rightarrow$ Cyclic Dependency

Axiom Evaluation



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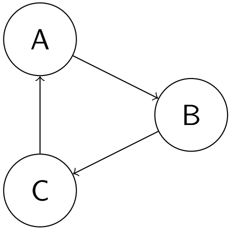

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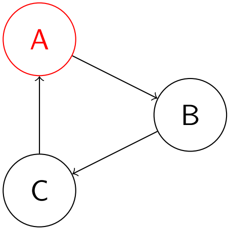

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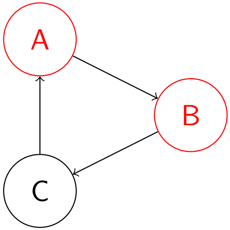

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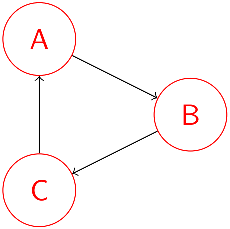

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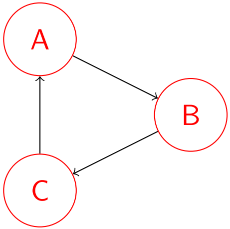

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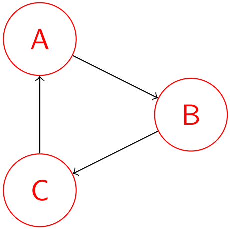

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$\Rightarrow$ Fixed point

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Idea: Introduce new axioms to derive default value

Default Value Axioms

New axioms of form: $\hat{h} = F \leftarrow \varphi$
For derived variable h: $\hat{h} = F$ can be derived if $h = T$ cannot be derived

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Note: Only for heuristics, not used for search

Our Goal

Compute these default value axioms exactly

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- Preserve all information

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- Preserve all information
- Improve heuristics
- Find solutions faster and with less memory

Previous Approaches

Default Value Needed

Not every derived variable needs default value axiom

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Remember example axiom: $D = T \leftarrow A = F$
$\Rightarrow$ Need default value for A

Approximate Negative

For all variables where default needed, create axiom with empty body
$\Rightarrow$ Default value for free

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In our example: $A = F \leftarrow \emptyset$

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Overapproximation with huge information loss
Very fast computation

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Only overapproximate variables in cycles
Compute other default value axioms exactly

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$\Rightarrow X = T \leftarrow Y = T \vee Z = T$
$\Rightarrow X = F \leftarrow \neg(Y = T \vee Z = T)$

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Cannot use for cyclic dependencies $\rightarrow$ result would be wrong

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Cannot use for cyclic dependencies $\rightarrow$ result would be wrong

More information but still approximation
Can be slow due to CNF to DNF transformation

Unrolling

Concept

Transform cyclic dependencies into acyclic representation

Unrolling - Variables

Derived Variables: A, B, C, D
Variables: X, Y

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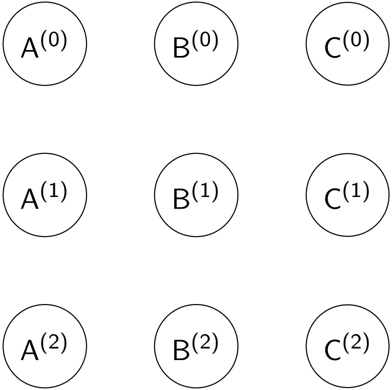

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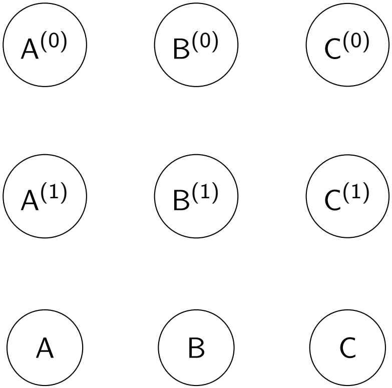

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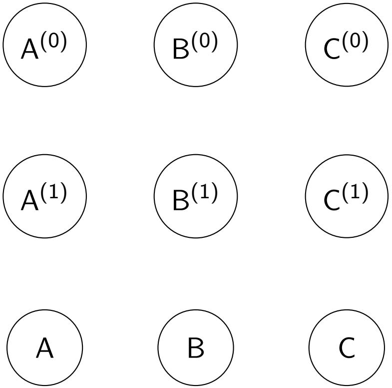
Unrolling - Cycle-Independent Axioms



New axioms of form: $h^{(0)} = T \leftarrow \varphi$
Only if no cycle-variables in body

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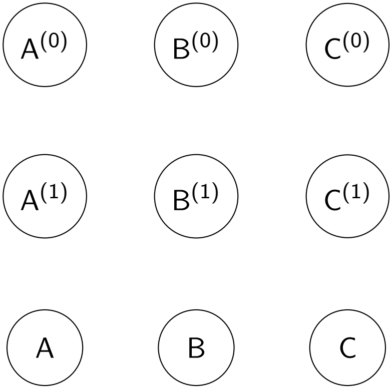

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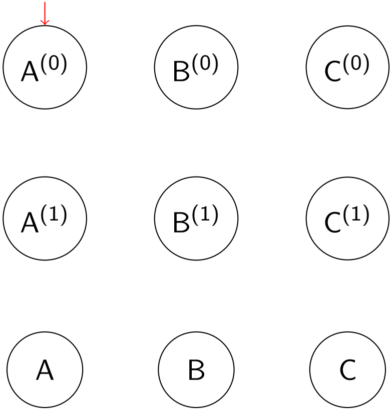

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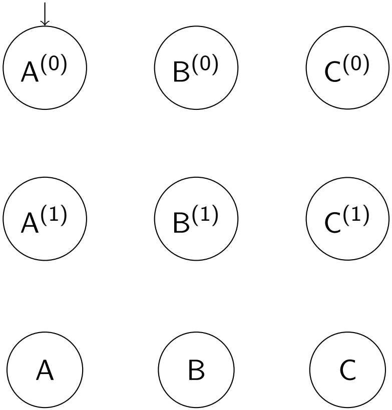

New axioms of form:
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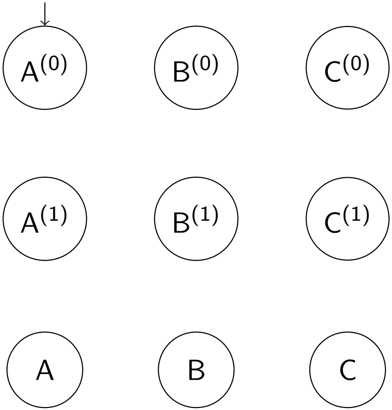

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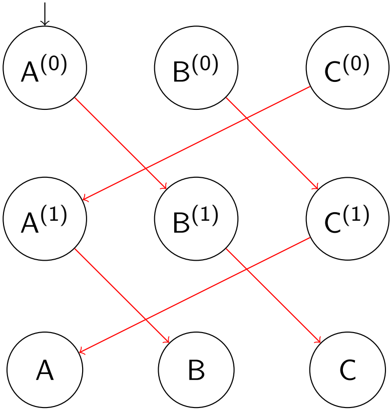

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New axioms:

$A^{(1)} = T \leftarrow C^{(0)} = T$ $\quad A = T \leftarrow C^{(1)} = T$
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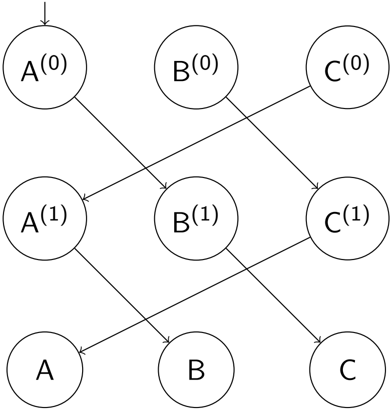
Unrolling - Propagation Axioms



New axioms of form:
$v^{(k+1)} = T \leftarrow v^{(k)} = T$
For every derived variable v

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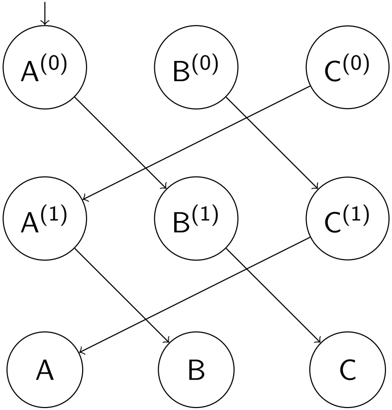

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Variables:
A, B and C

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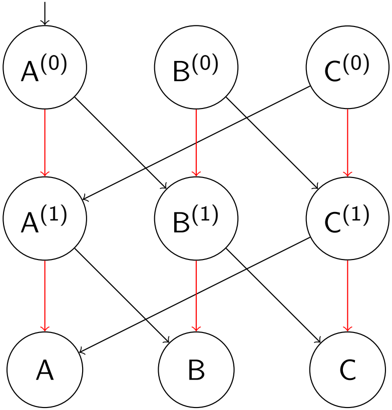

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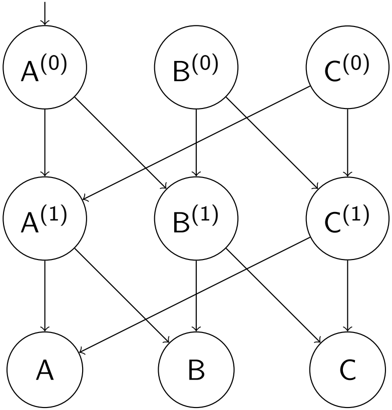
Unrolling - Axiom Evaluation



$$S_0^{\text{unroll}} = \{$$
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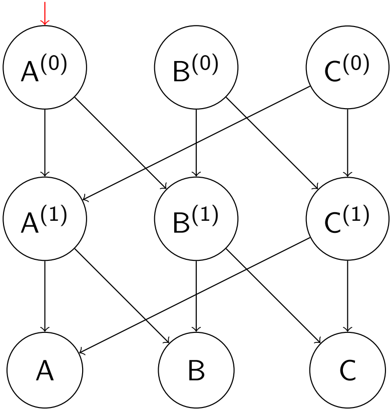

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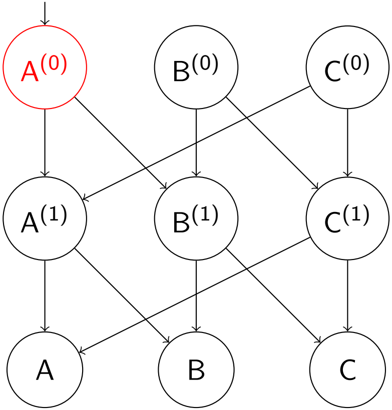

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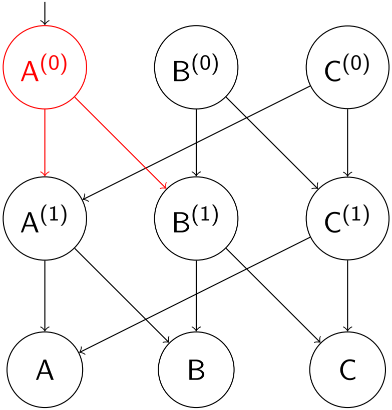

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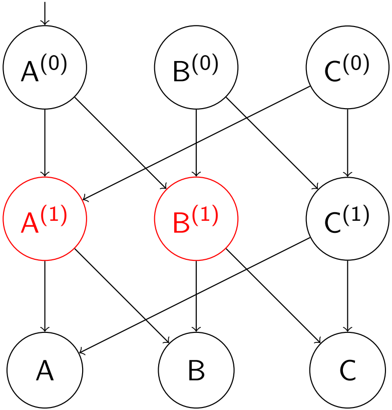

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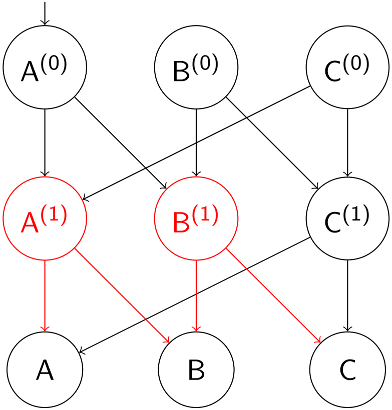
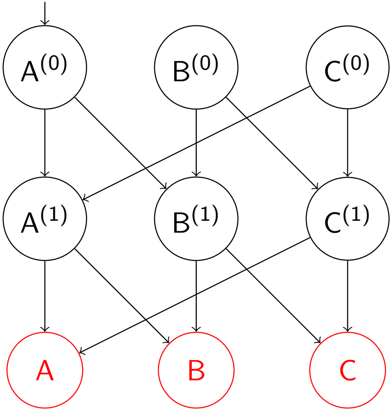
Unrolling - Axiom Evaluation



$$S_2^{\text{unroll}} = \{ \\ X = 0, Y = 1, \\ A^{(0)} = T, B^{(0)} = F, C^{(0)} = F, \\ A^{(1)} = T, B^{(1)} = T, C^{(1)} = F, \\ A = F, B = F, C = F \\ \}$$

Unrolling - Axiom Evaluation



$$S_3^{\text{unroll}} = \{ \\ X = 0, Y = 1, \\ A^{(0)} = T, B^{(0)} = F, C^{(0)} = F, \\ A^{(1)} = T, B^{(1)} = T, C^{(1)} = F, \\ A = T, B = T, C = T \\ \}$$

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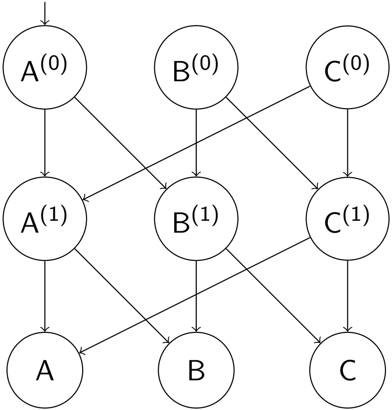

$S_4^{\text{unroll}} = \{$
$X = 0, Y = 1,$
$A^{(0)} = T, B^{(0)} = F, C^{(0)} = F,$
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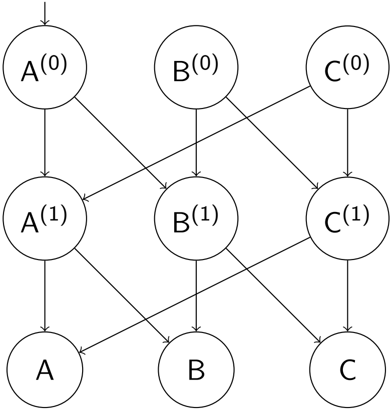

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$\Rightarrow$ Fixed Point

Fixed Point

Original axioms:

$S_3 = \{$
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$A = T, B = T, C = T$
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Unrolling axioms:

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$\Rightarrow$ Same fixed point for original variables (formal proof in thesis)

Computing Default Value Axioms

Unrolling as preprocessing

Computing Default Value Axioms

Unrolling as preprocessing

For any given set of axioms:
Detect cycles → Unroll cycles → Compute default value axioms exactly

Evaluation

Domains

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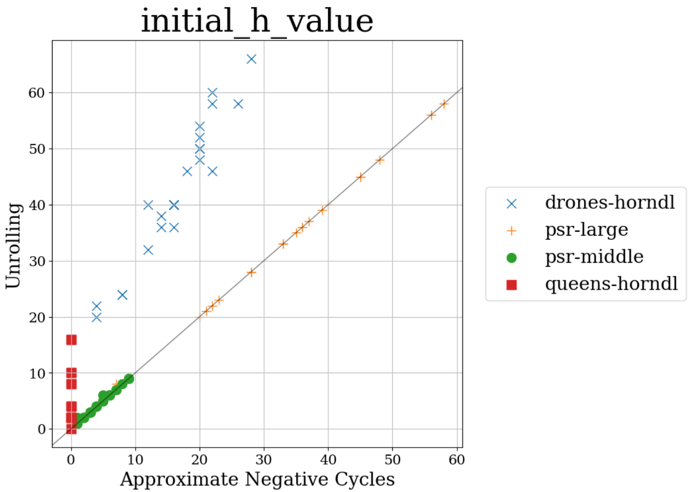
- *psr-middle*: Only a few cycles, usually of size $|V| < 60$
- *psr-large*: Similar to *psr-middle* but some cycles of size $|V| > 300$

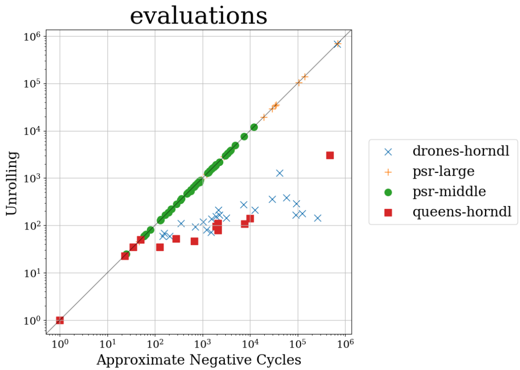
New Axiom Percentages

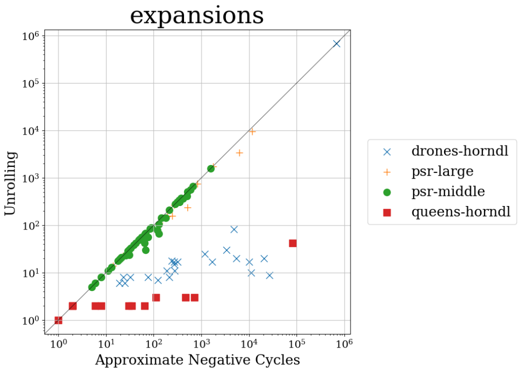
Benchmark	A^{def} (neg)	A^{def} (neg cyc)	A^{def} (unroll)	A^{unroll}
drones-horndl	1%	66%	63%	5%
queens-horndl	0%	4%	39%	60%
psr-middle	0%	9%	4%	80%
psr-large	0%	5%	2%	80%

Heuristic Value for Initial State

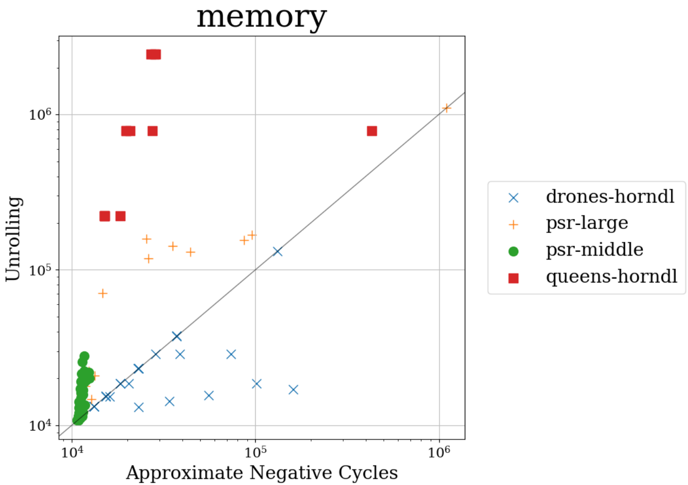


Evaluated and Expanded States

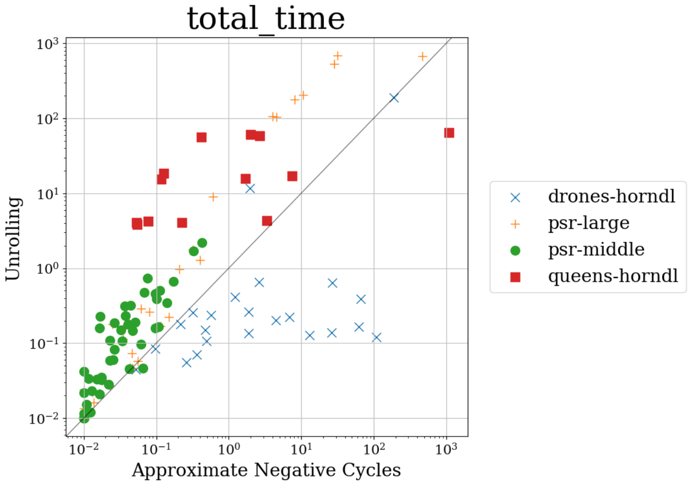




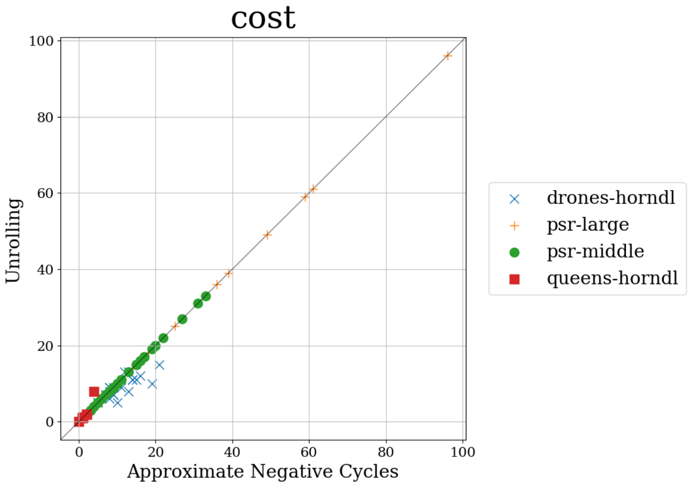
Memory


memory
Unrolling
10^6
10^5
10^4
10^4
10^5
10^6
Approximate Negative Cycles
drones-horndl
psr-large
psr-middle
queens-horndl

Total Time


total_time
Unrolling
Approximate Negative Cycles
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
drones-horndl
psr-large
psr-middle
queens-horndl

Solution Cost



Coverage

Benchmark	h^{add} (neg)	h^{add} (neg cyc)	h^{add} (unroll)
drones-horndl	22	22	23
queens-horndl	36	36	32
psr-middle	50	50	50
psr-large	17	17	15
total	125	125	120

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- Big cycles: Create memory and preprocessing time overhead ($\rightarrow$ *psr-large*)
- Not all unrolling axioms used to create default value axioms ($\rightarrow$ *psr-large*)
- Heuristics more informed if more default value axioms created ($\rightarrow$ *queens-horndl*)

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- Heuristics more informed
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- Overhead too large for big cycles
- No positive effects on some domains
- Future work: Reduce number of new axioms

Questions?