LoopInvGen:

A Loop Invariant Generator based on Precondition Inference

SyGuS-COMP 2018

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Verification

C/C++ Code

```
int n, x = 0, m = 0;

while (x < n) {
  if (rand()) m = x;
  x = x + 1;
}

if(n > 0)
  assert (0 <= m && m <= n );
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SyGuS-INV Problem

```
(define-fun pre-f ((x Int) (n Int) (m Int)) Bool
    (and (= x 0) (= m 0)))

(define-fun trans-f ((x Int) (n Int) (m Int)
                     (x! Int) (n! Int) (m! Int)) Bool
    (or (and (and (and (< x n) (= x! (+ x 1)))
                  (= n! n)) (= m! m))
        (and (and (and (< x n) (= x! (+ x 1)))
                  (= n! n)) (= m! x))))

(define-fun post-f ((x Int) (n Int) (m Int)) Bool
    (not (and (and (>= x n) (> n 0))
              (or (<= n m) (< m 0)))))

(inv-constraint inv-f pre-f trans-f post-f)
```

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(define-fun inv-f ((x Int) (n Int) (m Int)) Bool
    (and (>= x m)
         (or (and (> n m) (> m 0))
             (= 0 m)))
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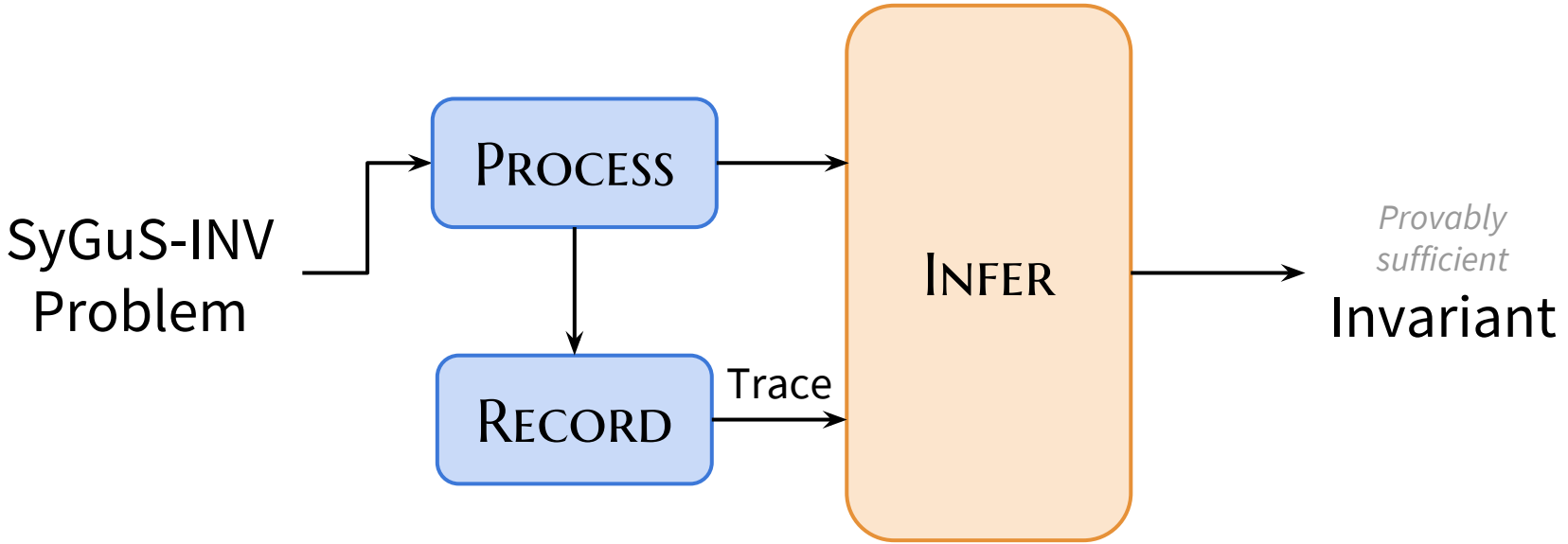
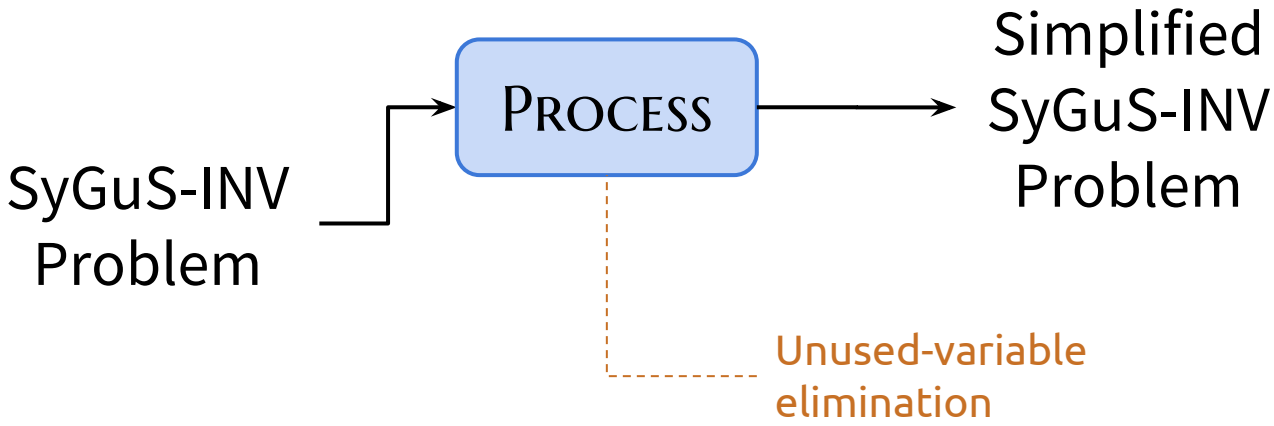
INV	Solved	Fastest	Shortest	Score
CVC4 1.6	109	82	59	850
DryadSynth	103	81	26	784
LoopInvGen	115	102	85	966
Horndini	68	21	25	428
EUSolver	61	15	61	411

Overview


SyGuS-INV
Problem
Process
Record
Trace
Infer
Provably
sufficient
Invariant

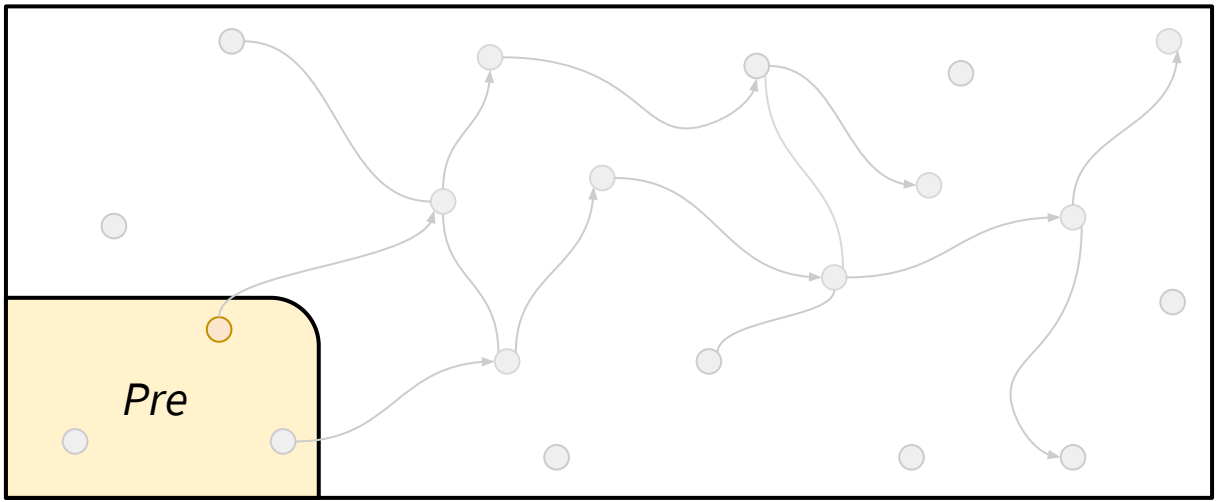
Initial PROCESS-ing

A static analysis pass for straight-forward simplifications



RECORD-ing Reachable States

SyGuS Problem (Pre, Trans, Post) → List of variable assignments



1. Pick state s, s.t. Pre(s)

RECORD-ing Reachable States

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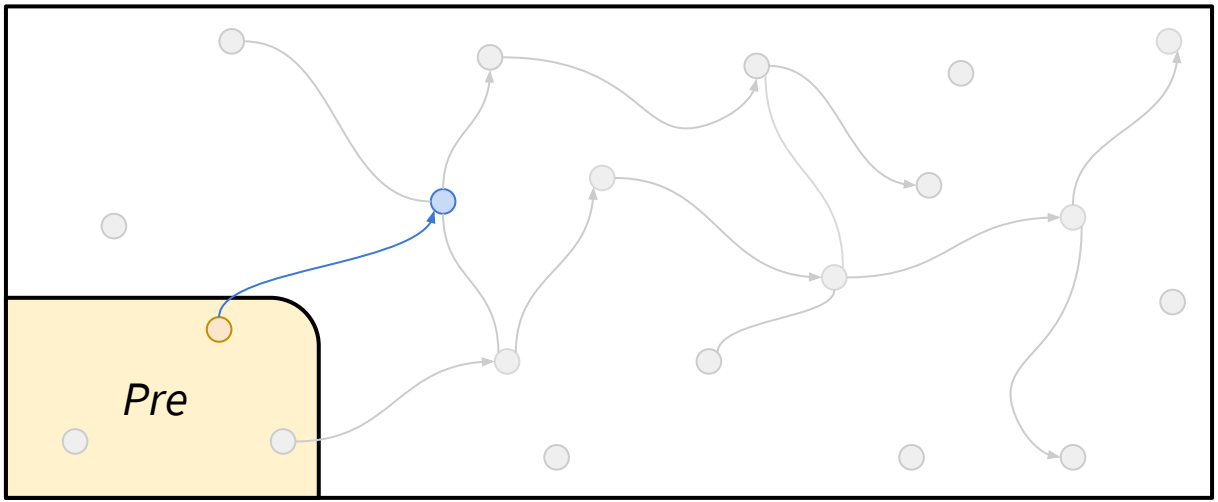

1. Pick state s, s.t. Pre(s)

2. Obtain state t, s.t. Trans(s,t)

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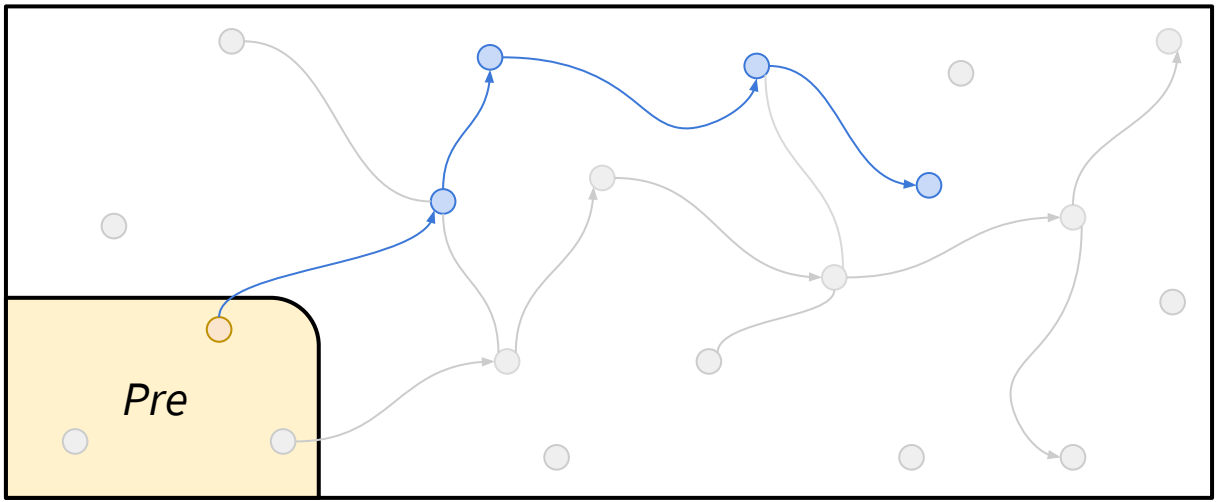
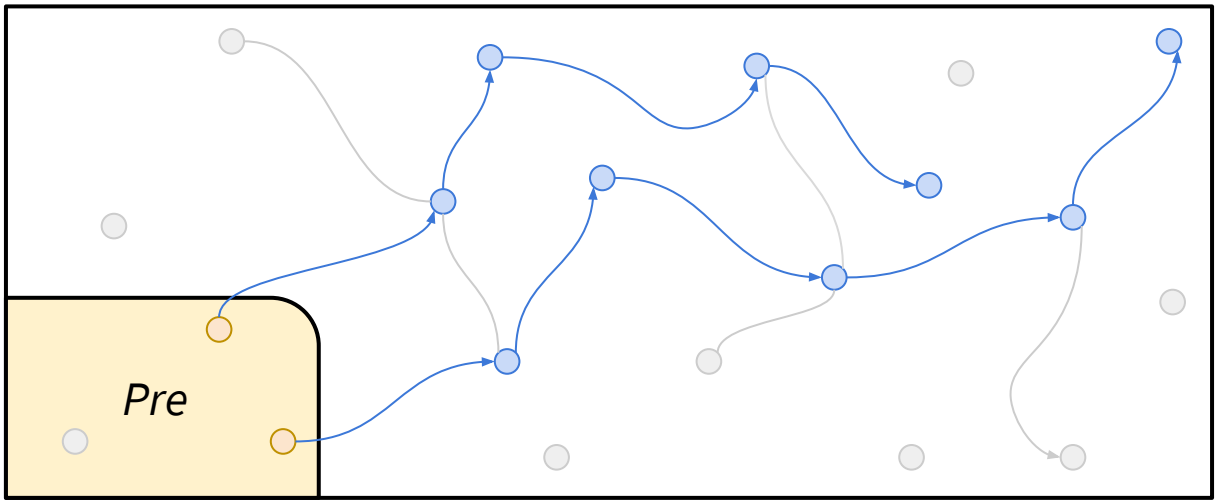


1. Pick state s, s.t. Pre(s)
2. Obtain state t, s.t. Trans(s,t)
3. Set s ← t and repeat (2)

RECORD-ing Reachable States

SyGuS Problem (Pre, Trans, Post) → List of variable assignments



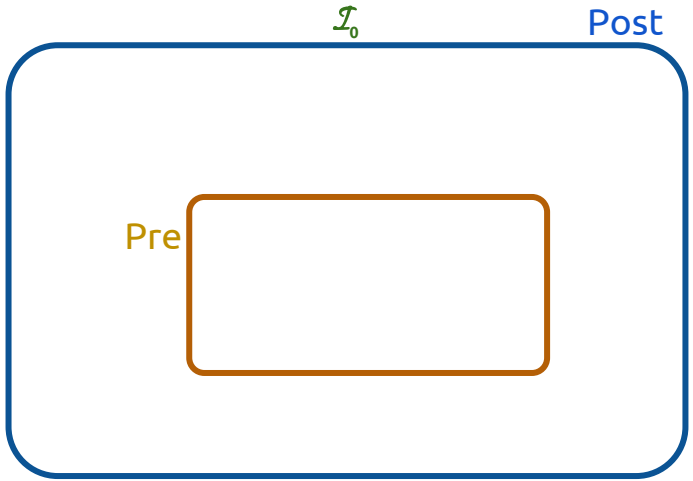
1. Pick state s, s.t. Pre(s) 2. Obtain state t, s.t. Trans(s,t) 3. Set s ← t and repeat (2)

4. Repeat (1,2,3) till the desired number of states has been collected

INFER-ing Sufficient Invariants

- ∀ s: Pre(s) ⇒ $\mathcal{I}$(s)
- ∀ s, t: $\mathcal{I}$(s) ∧ Trans(s,t) ⇒ $\mathcal{I}$(t)
- ∀ s: $\mathcal{I}$(s) ⇒ Post(s)

1. Start with the weakest candidate



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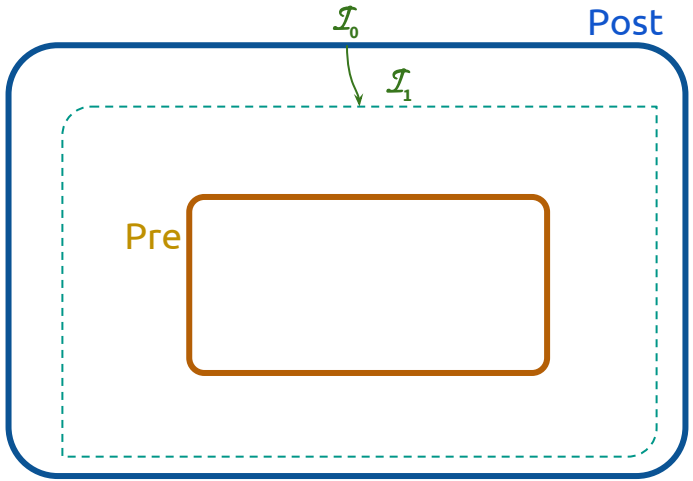
1. Start with the weakest candidate
2. Iteratively strengthen for inductiveness (data-driven precondition inference)



$\mathcal{I}_0$ = Post

$\mathcal{I}_1 = \delta_0 \wedge \mathcal{I}_0$

$\delta_0 \Rightarrow (\mathcal{I}_0 \wedge \text{Trans} \Rightarrow \mathcal{I}_0')$

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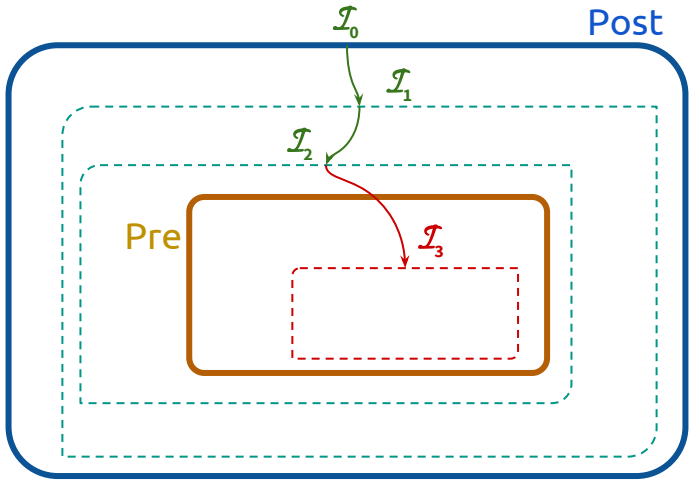

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⋮ ⋮ ⋮ ⋮

$\mathcal{I}_n = \delta_{n-1} \wedge \mathcal{I}_{n-1} = \mathcal{I}_{n-1}$

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1. Start with the weakest candidate
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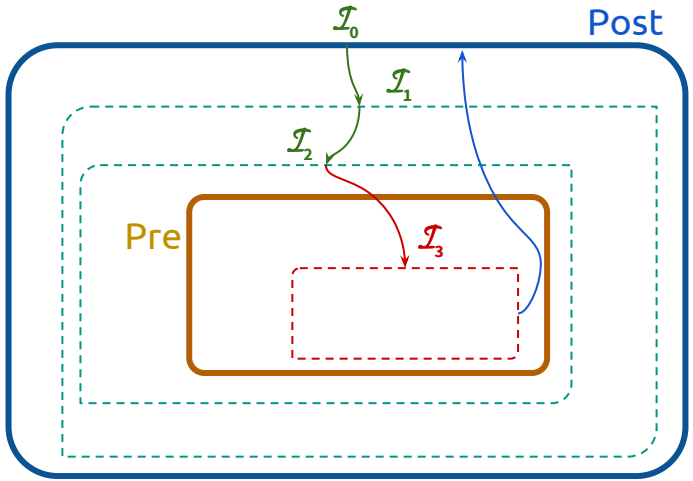
3. If the invariant is too strong, restart from (1) after augmenting the recorded states with appropriate counterexamples



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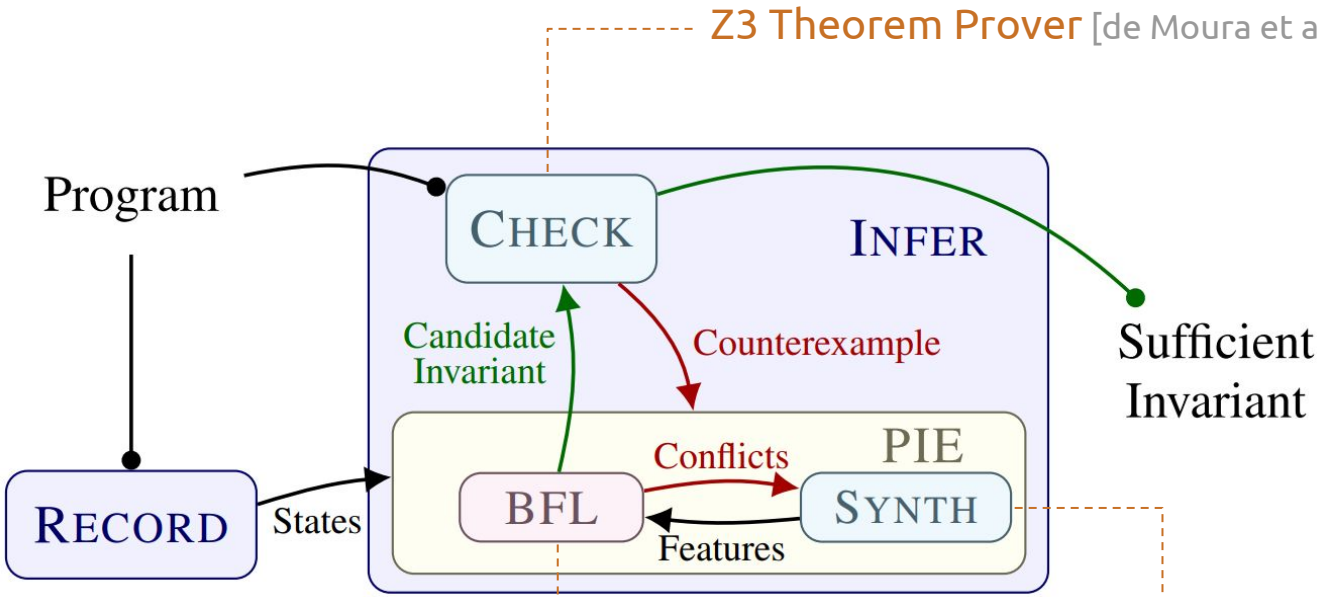
LoopInvGen Architecture



Thanks! ☺

Code + Benchmarks:

https://github.com/SaswatPadhi/LoopInvGen

Reach me at:

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