Precise Lazy Initialization for Programs with Complex Heap Inputs

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SYMBOLIC EXECUTION

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func(int x, int y) {
  if (x < 10) {
    if (y > x)
      x = x + y;
    else
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  }
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$x = \mathbf{X}\,;\, y = \mathbf{Y}$

PC: True

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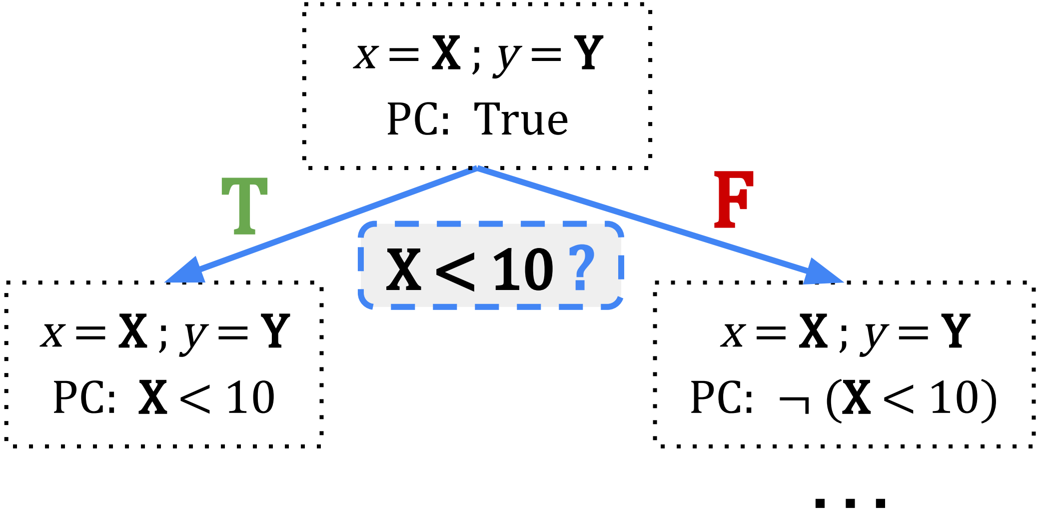

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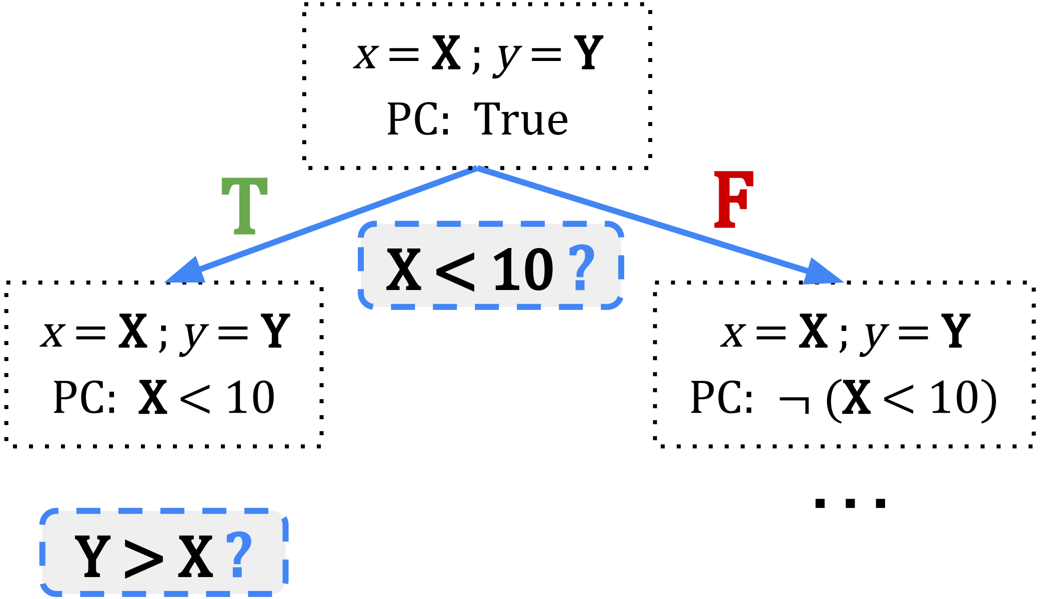

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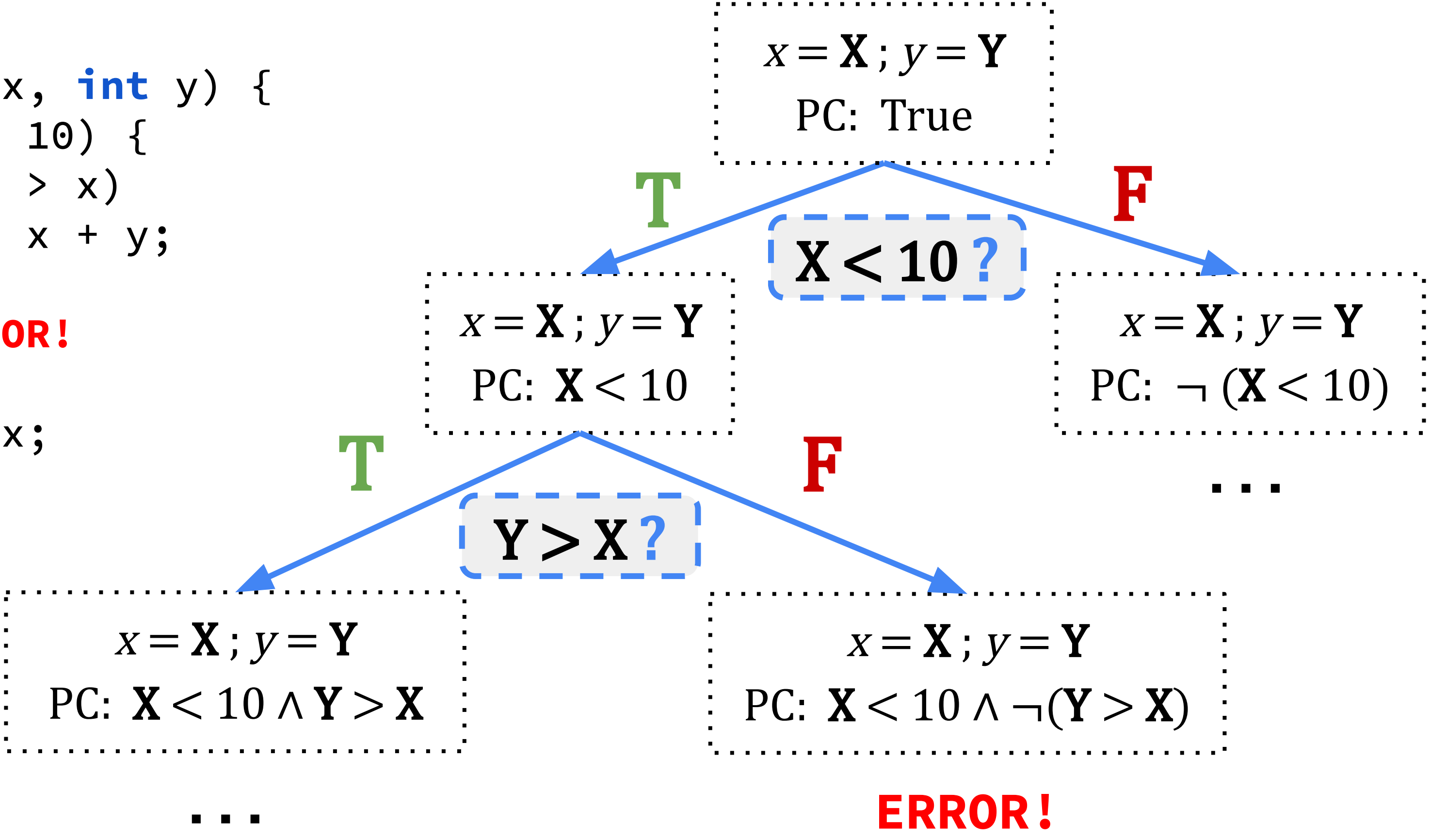

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$\mathbf{Y} > \mathbf{X}$?

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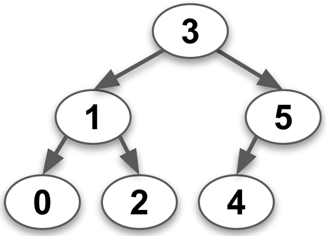

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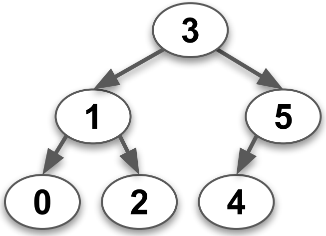

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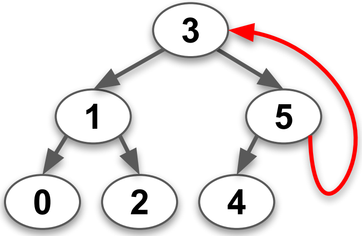

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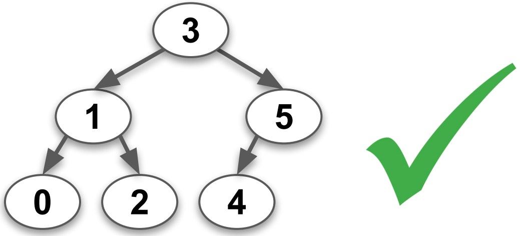

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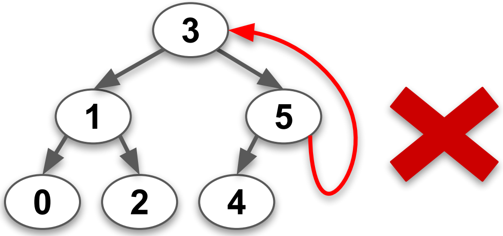
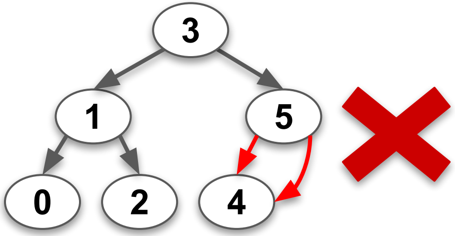


  - No **Node Sharing**



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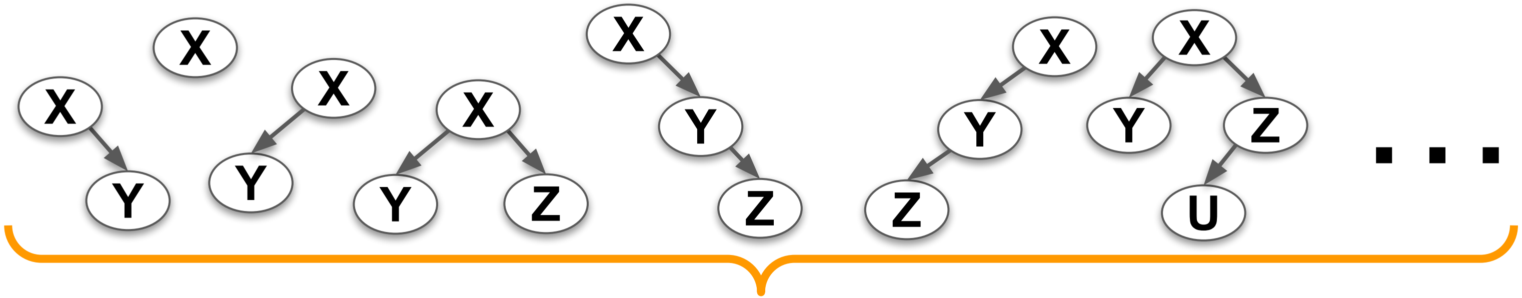

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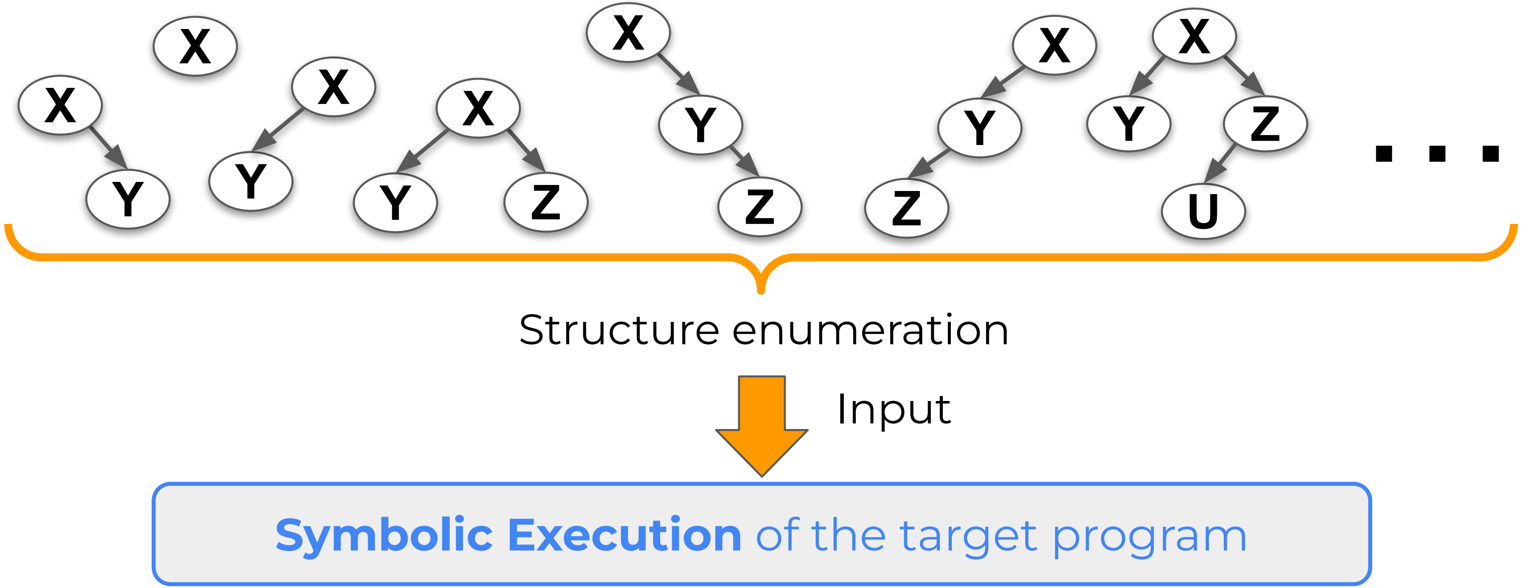

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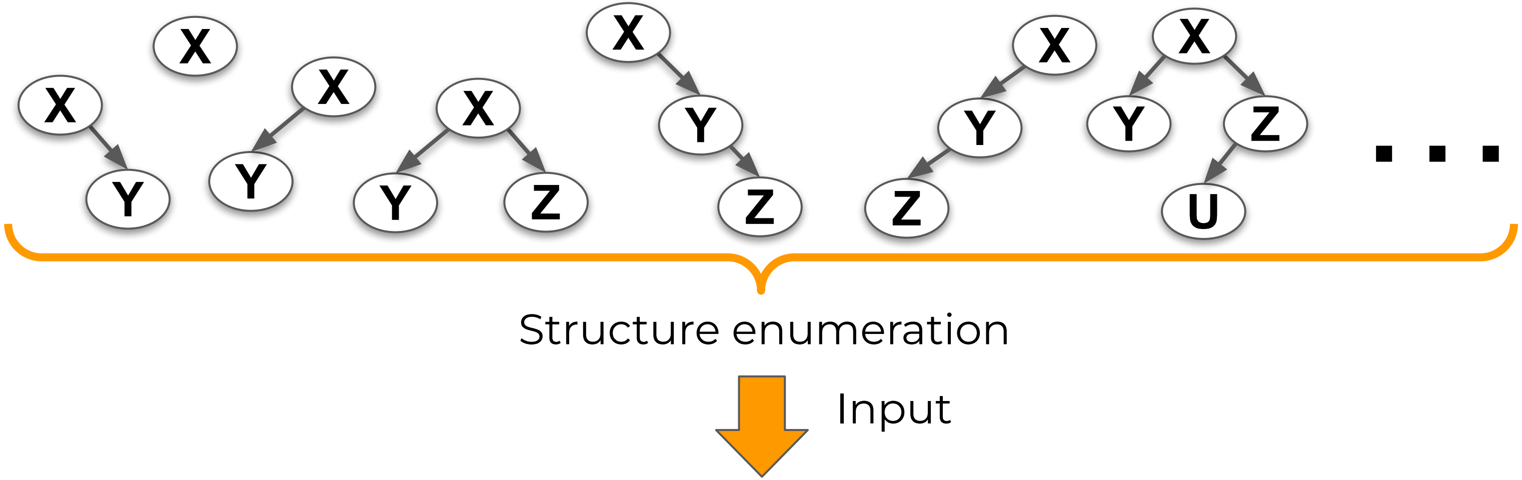

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Structure explosion problem

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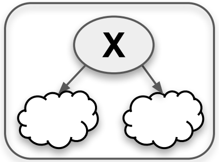

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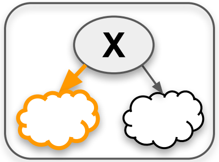

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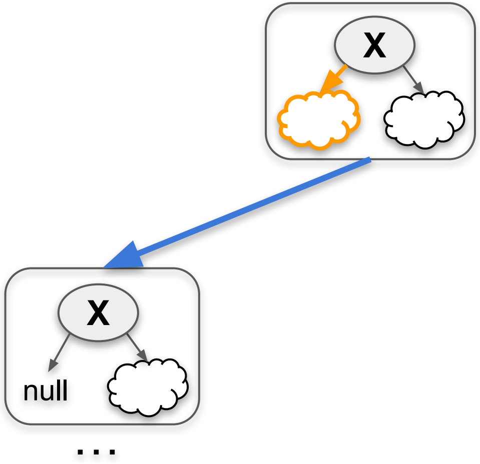

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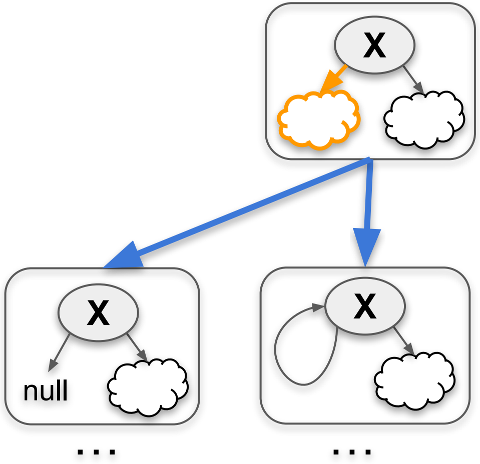

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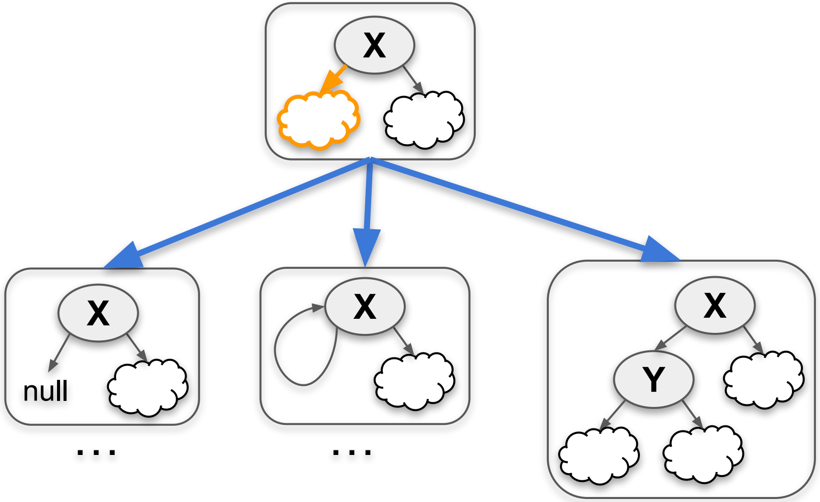

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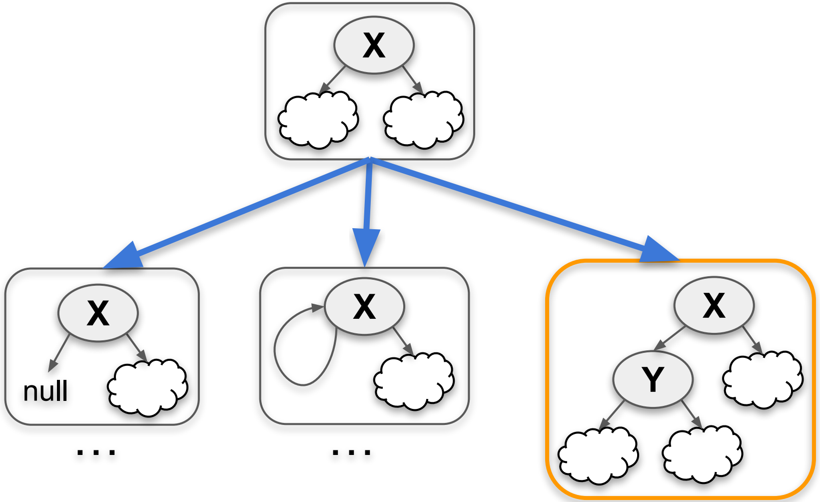

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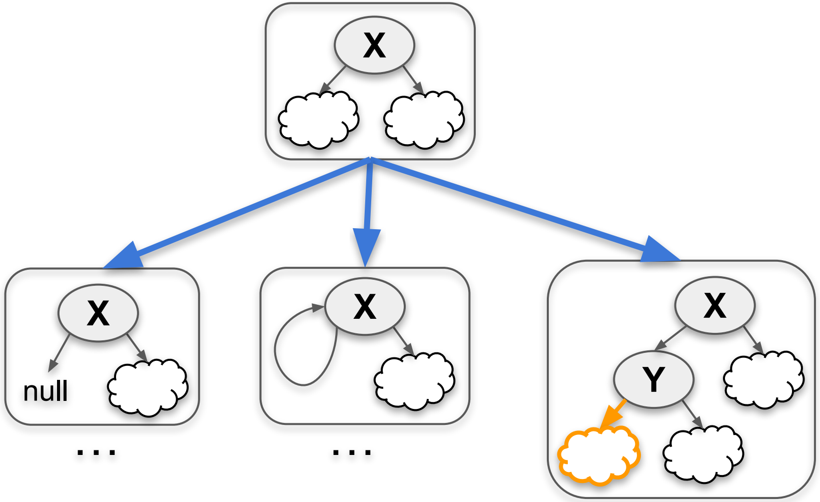

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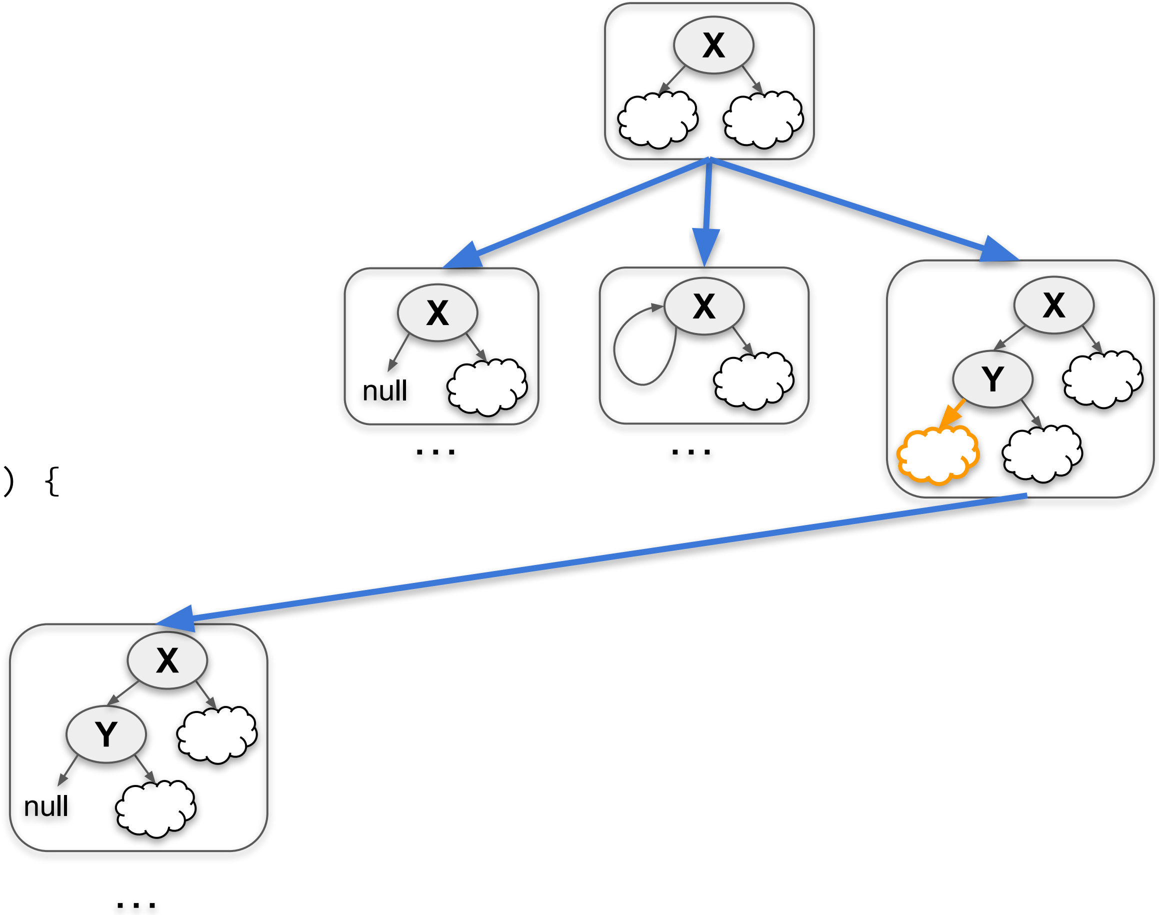

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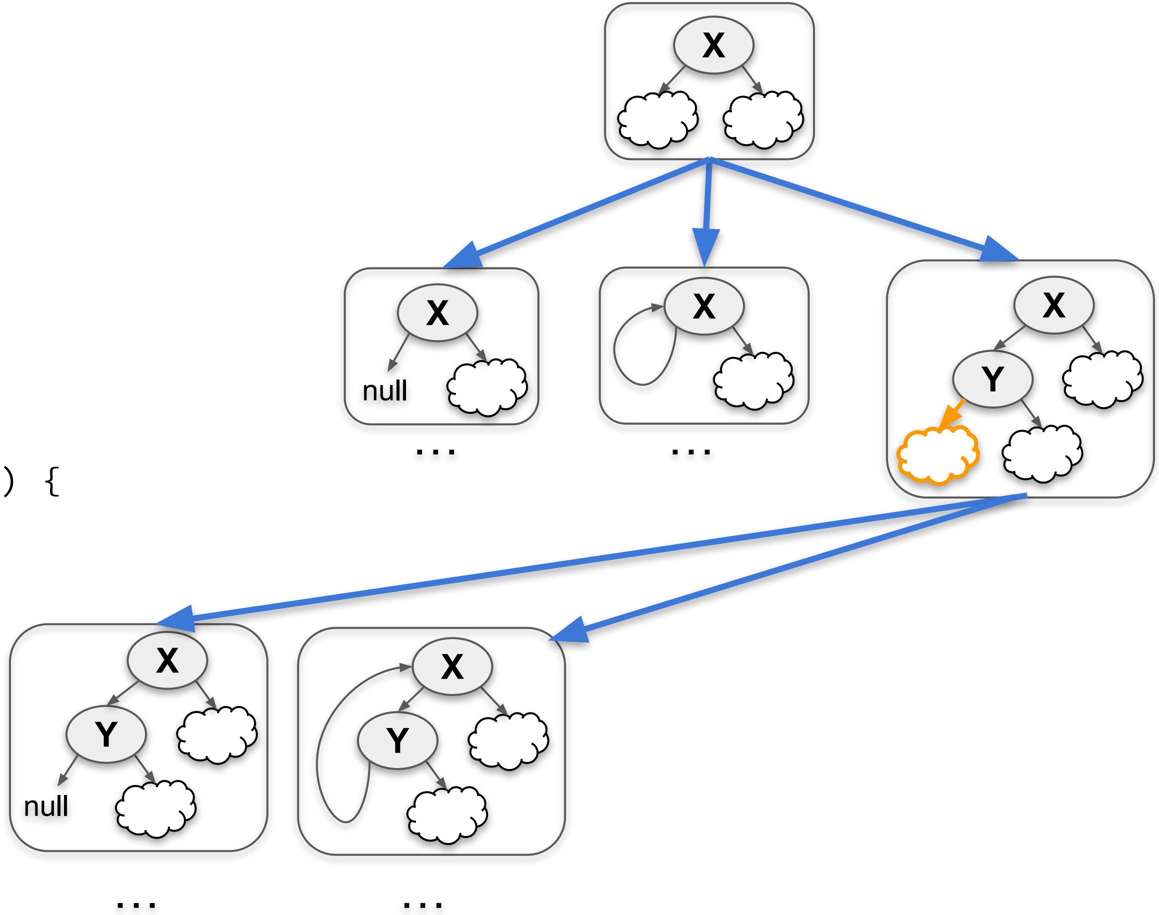

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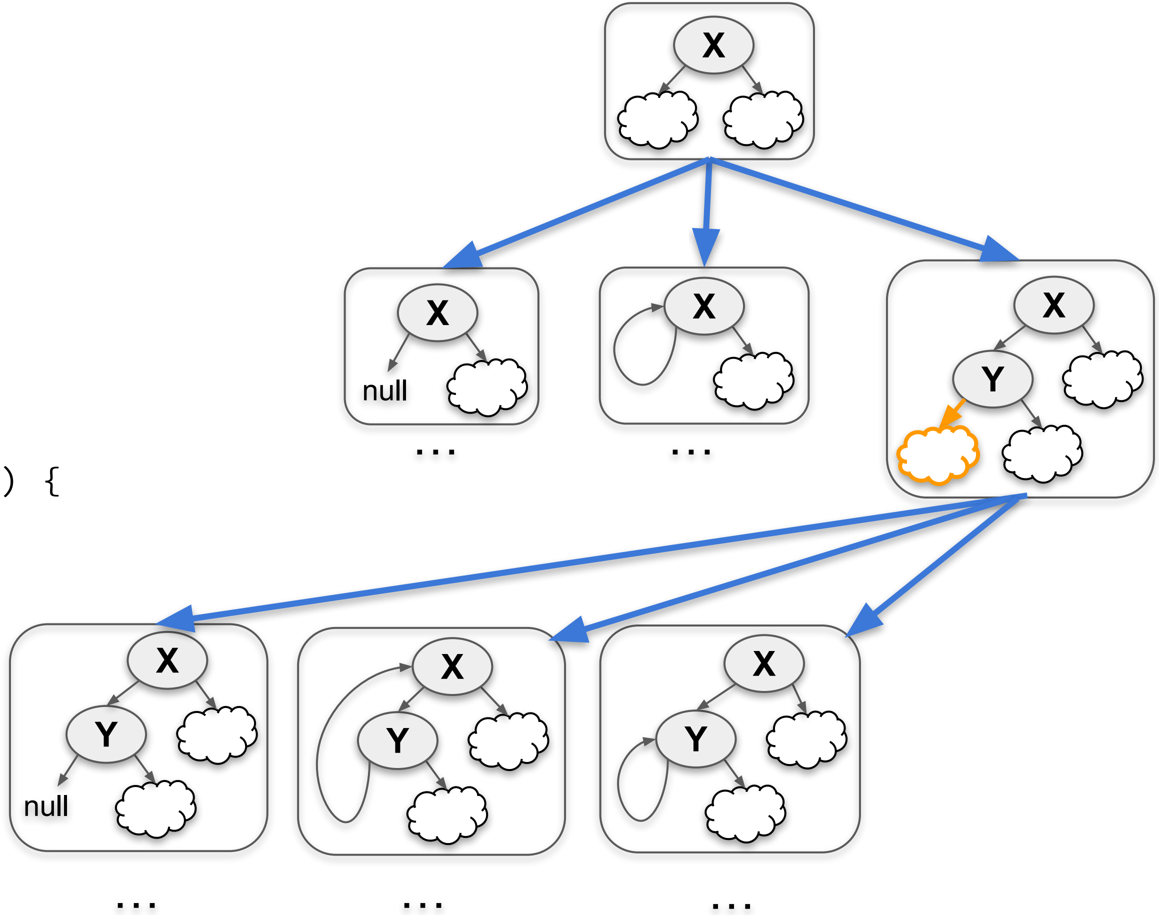

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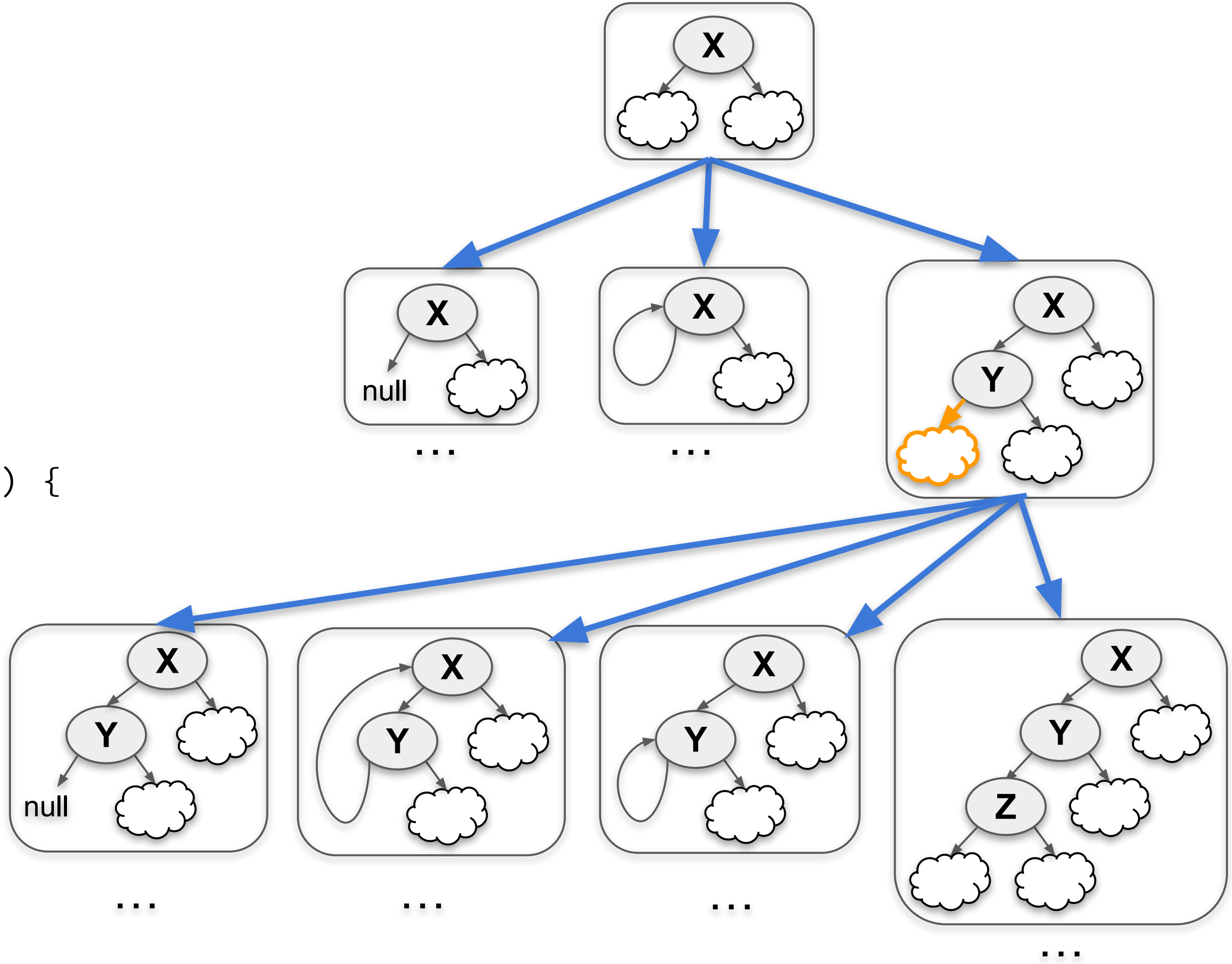

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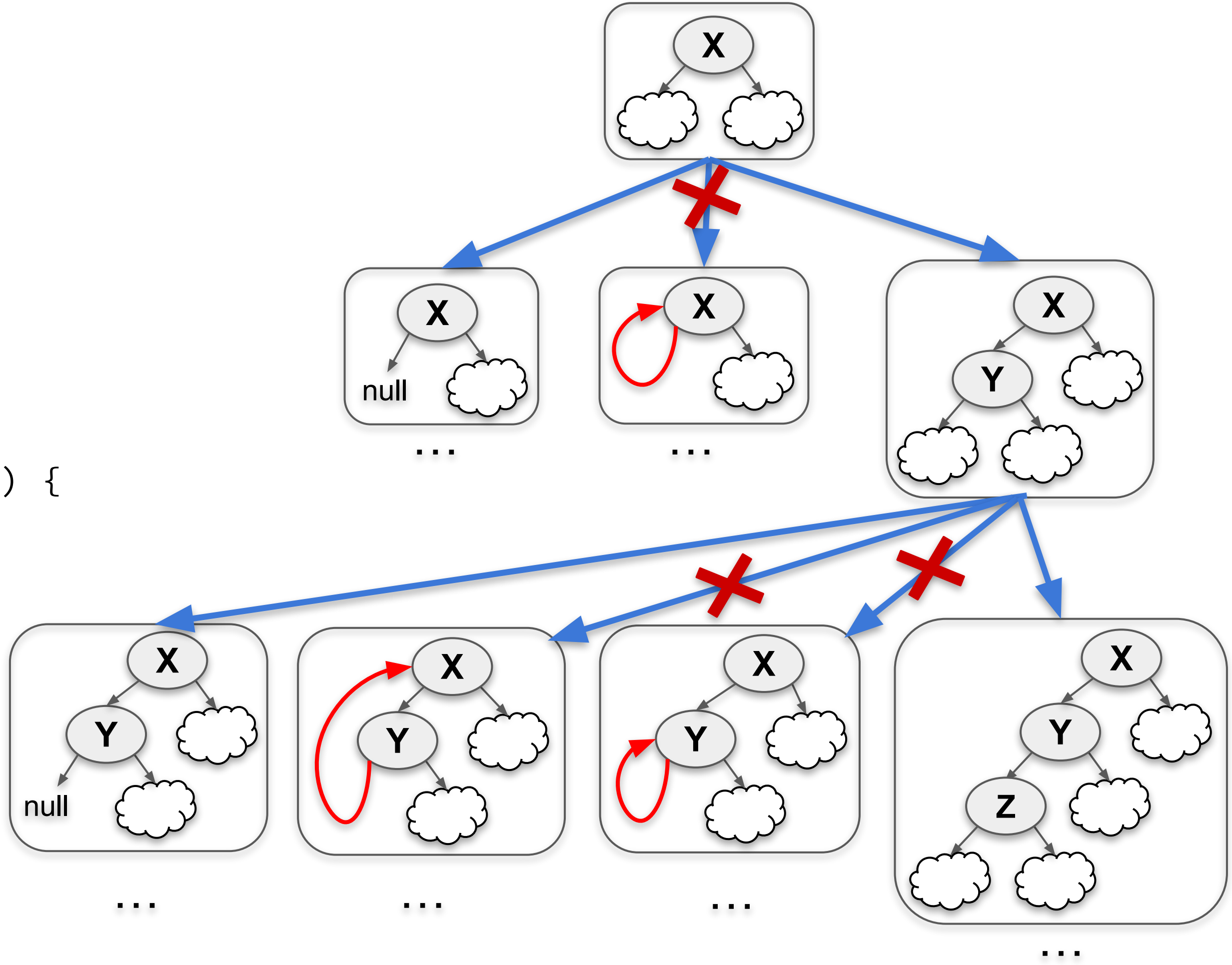

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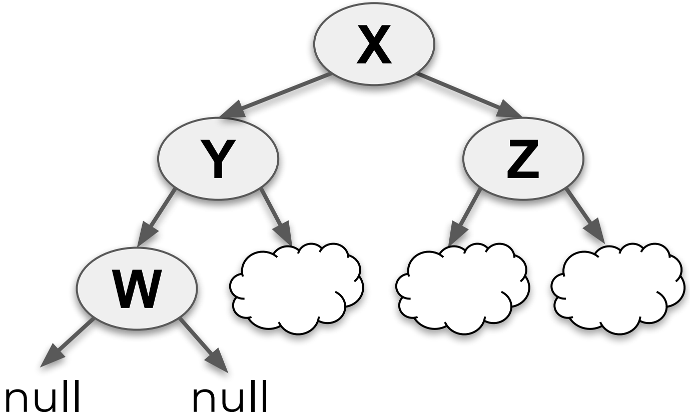

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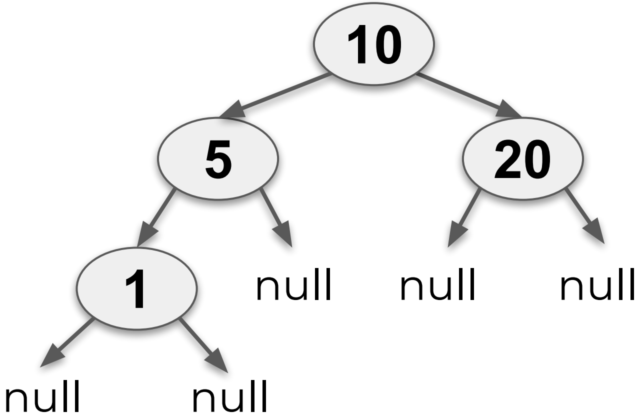

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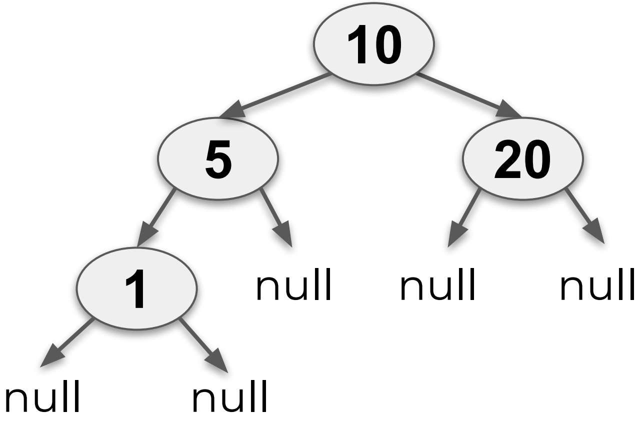

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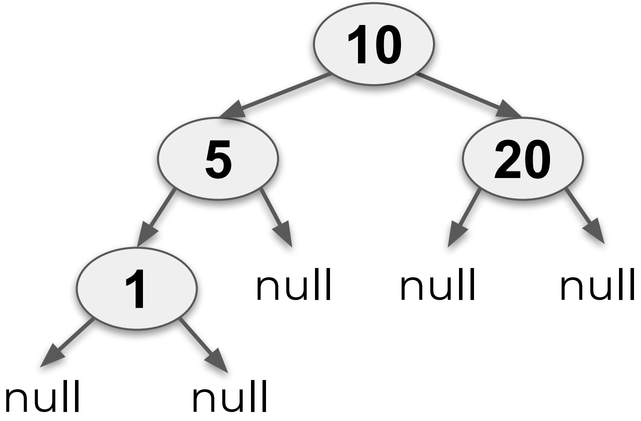

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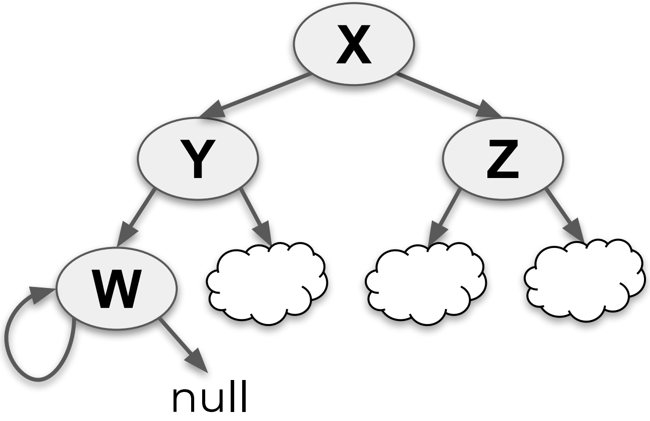

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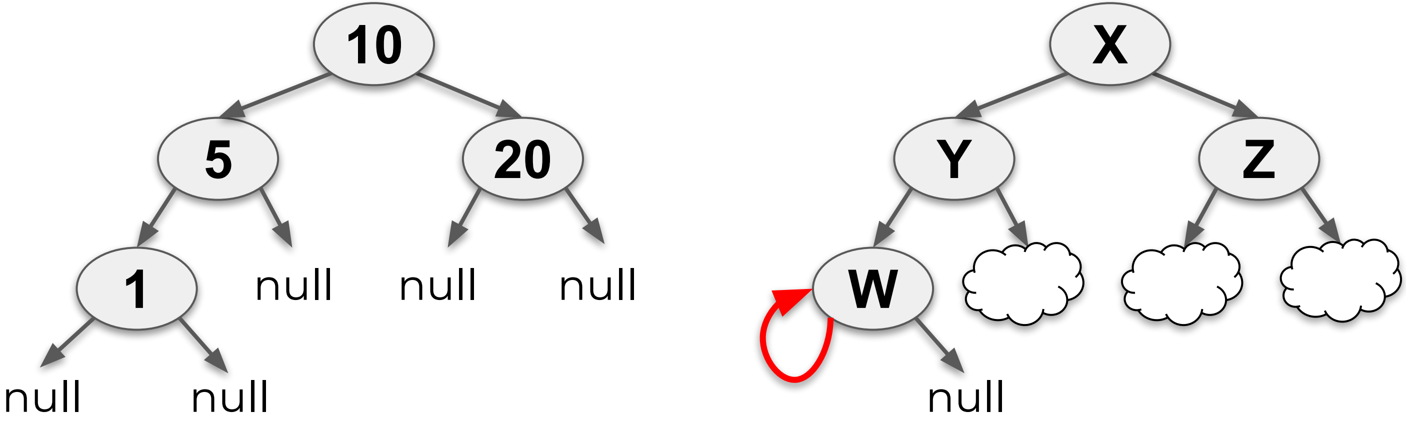

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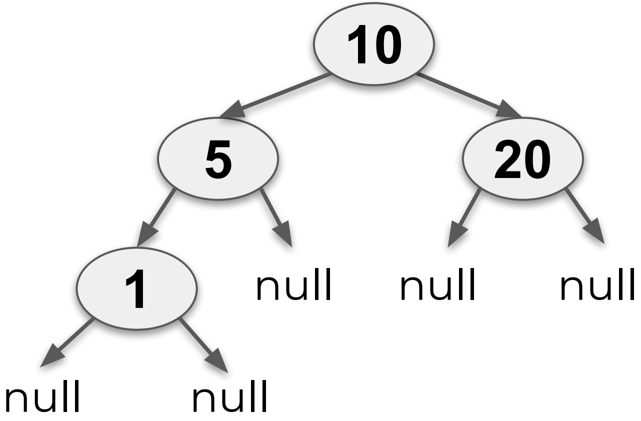

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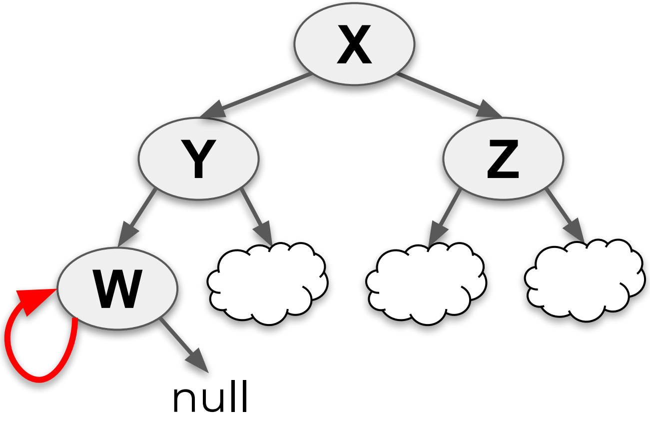

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Symbolic-aware operational specifications

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public boolean isBinTree() {
  if (!IS_SYMBOLIC(root))
       return true;
  Set<BST> visited = new HashSet<>();
  LinkedList<BST> worklist = new LinkedList<>();
  visited.add(root);
  worklist.add(root);
  while (!worklist.isEmpty()) {
    BST node = worklist.removeFirst();
    if (!IS_SYMBOLIC(node.left)) {
      if (node.left != null && !visited.add(node.left))
        return false;
      worklist.add(node.left);
    }
    if (!IS_SYMBOLIC(node.right)) {
      if (node.right != null && !visited.add(node.right))
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Declarative Specifications

```
instanceof avl_tree/AvlTree_Any expands to instanceof avl_tree/AvlTree_HEX &&

------------------------------------------------
{R_ANY}/root(/left|/right)* instanceof avl_tree/AvlNode_HEX aliases nothing &&
{R_ANY}/root instanceof avl_tree/AvlNode_HEX expands to instanceof
avl_tree/AvlNode_HEX triggers
avl_tree/AvlNode_HEX:(Lavl_tree/AvlNode_HEX;)V:_got_AvlNode_onRoot:{$REF} &&
{R_ANY}/root(/left|/right)*/left instanceof avl_tree/AvlNode_HEX expands to
instanceof avl_tree/AvlNode_HEX triggers
avl_tree/AvlNode_HEX:(Lavl_tree/AvlNode_HEX;)V:_got_AvlNode_onTheLeft:{$REF} &&
{R_ANY}/root(/left|/right)*/right instanceof avl_tree/AvlNode_HEX expands to
instanceof avl_tree/AvlNode_HEX triggers
avl_tree/AvlNode_HEX:(Lavl_tree/AvlNode_HEX;)V:_got_AvlNode_onTheRight:{$REF} &&
{R_ANY}/root(/left|/right)*/left instanceof avl_tree/AvlNode_HEX null triggers
avl_tree/AvlNode_HEX:(Lavl_tree/AvlNode_HEX;)V:_got_null_onTheLeft:{$REF}/{UP} &&
{R_ANY}/root(/left|/right)*/right instanceof avl_tree/AvlNode_HEX null triggers
avl_tree/AvlNode_HEX:(Lavl_tree/AvlNode_HEX;)V:_got_null_onTheRight:{$REF}/{UP}
&&

{R_ANY}/root/parent instanceof avl_tree/AvlNode_HEX expands to nothing &&
{R_ANY}/root/parent instanceof avl_tree/AvlNode_HEX aliases nothing &&
{R_ANY}/root(/left|/right)+/parent instanceof avl_tree/AvlNode_HEX not null &&
{R_ANY}/root(/left|/right)+/parent instanceof avl_tree/AvlNode_HEX expands to
nothing &&
{R_ANY}/root(/left|/right)+/parent instanceof avl_tree/AvlNode_HEX aliases
{$REF}/{UP}/{UP}
```

APPROACHES OVERVIEW

	Eager	**Lazy**
Pros		
Cons		

APPROACHES OVERVIEW

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Pros	- **Don’t** necessarily require a **specification**.	
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  Set<BST> visited = new HashSet<>();
  LinkedList<BST> worklist = new LinkedList<>();
  visited.add(root);
  worklist.add(root);
  while (!worklist.isEmpty()) {
    BST node = worklist.removeFirst();
    if (node.left != null) {
      if (!visited.add(node.left))
        return false;
      worklist.add(node.left);
    }
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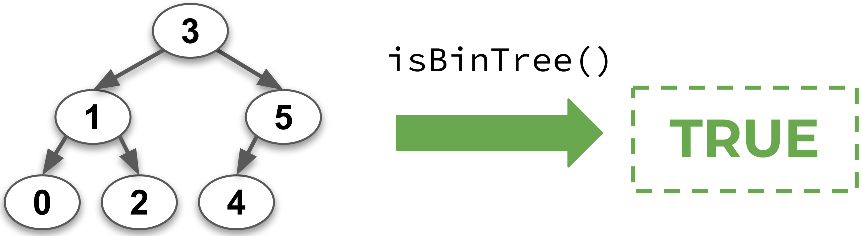

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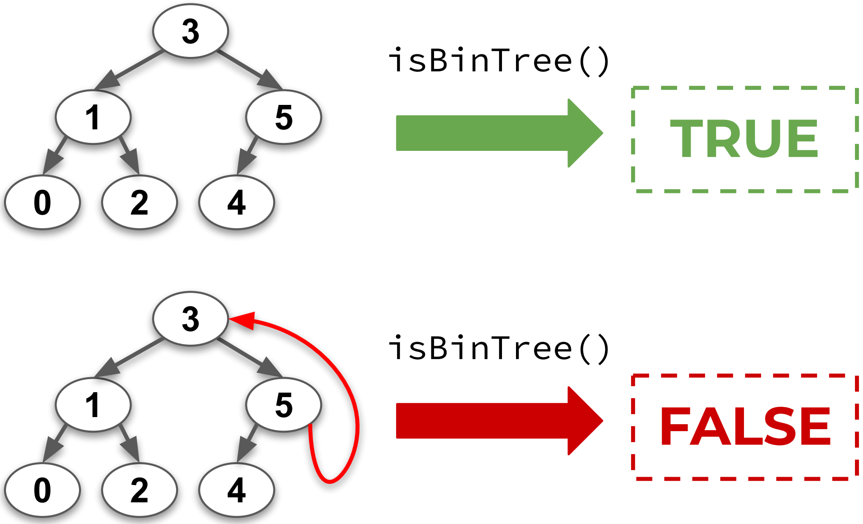

`isBinTree()`

TRUE

`isBinTree()`

FALSE

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SYMSOLVE

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SymSolve

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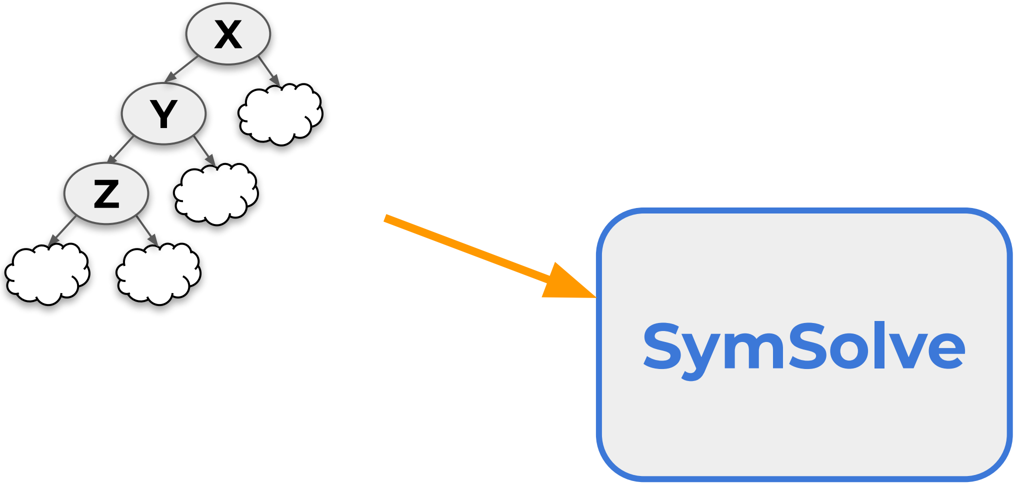

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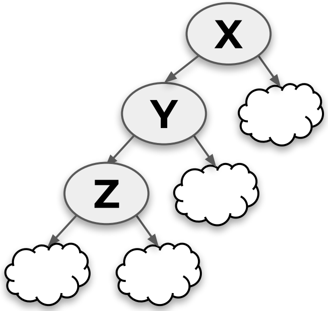
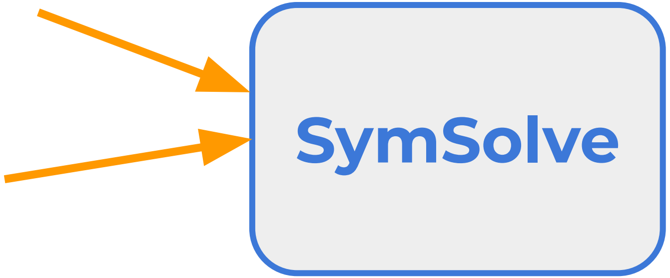


Scopes:

e.g. 5 Nodes.



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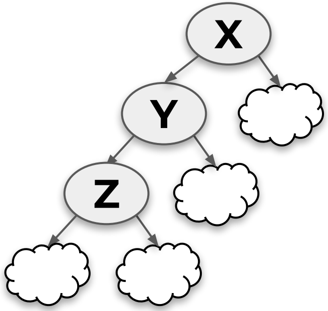

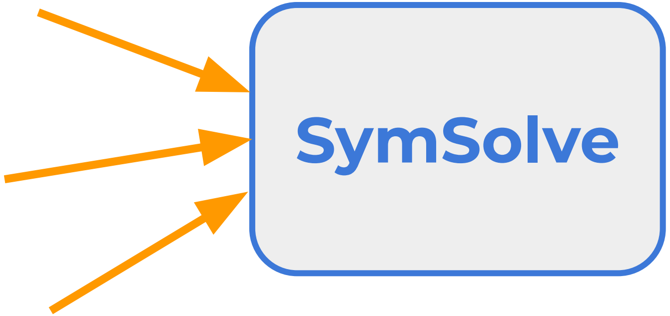

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Operational specification:

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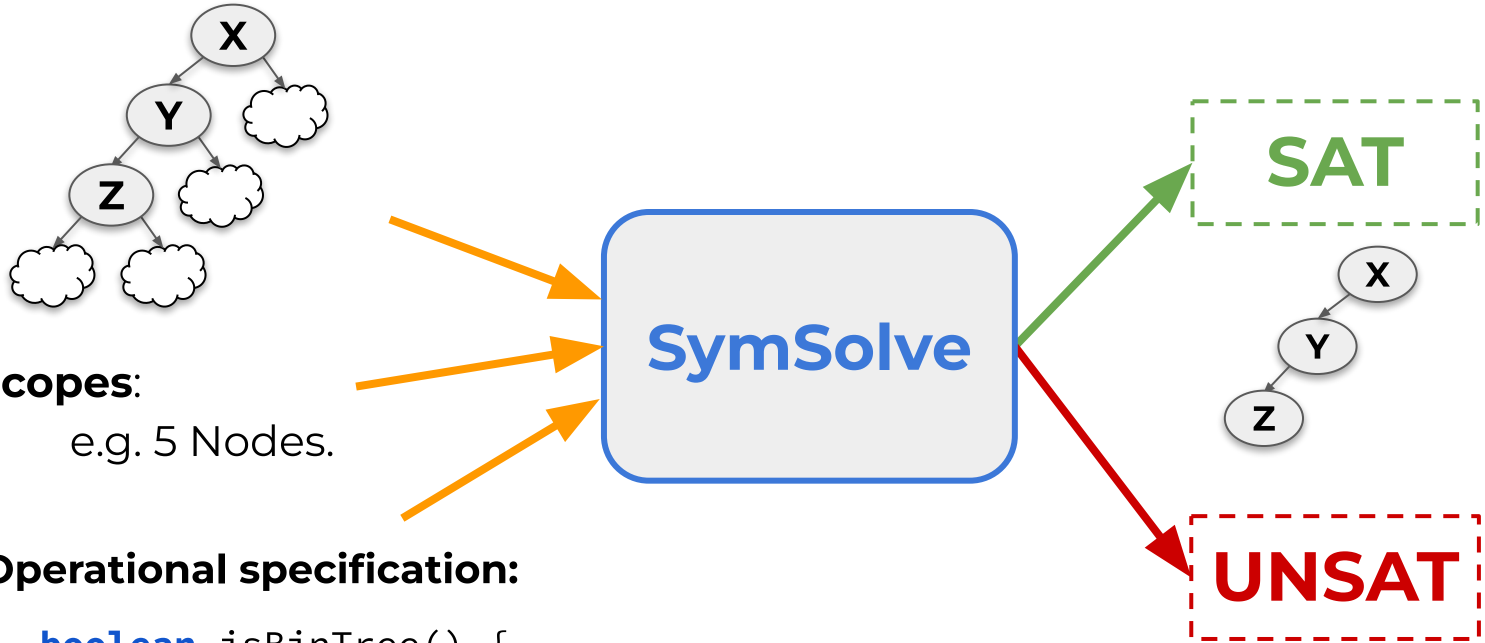
SymSolve

SYMSOLVE



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SymSolve

SAT

UNSAT

APPROACHES OVERVIEW

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PATH CONDITION AND HEAP SEPARATION PROBLEM

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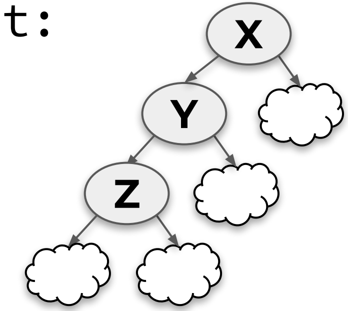
`t:`



PC: `[t.size == 2]`

PATH CONDITION AND HEAP SEPARATION PROBLEM

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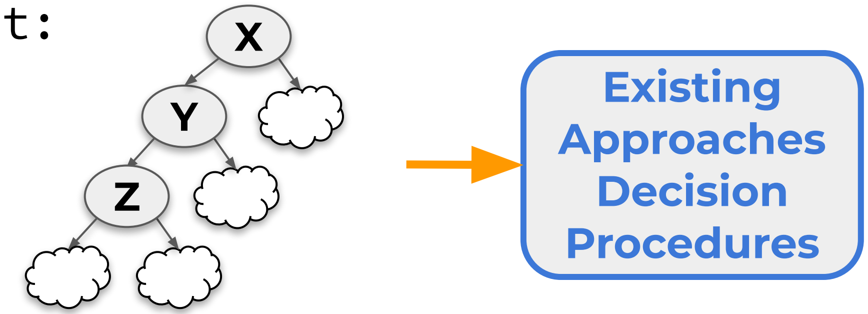

Existing Approaches Decision Procedures

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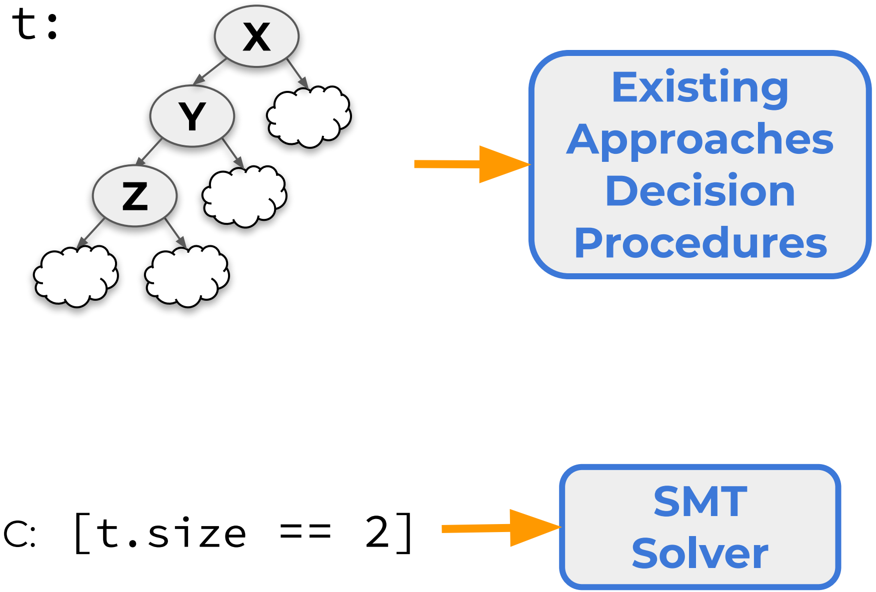

`t:`

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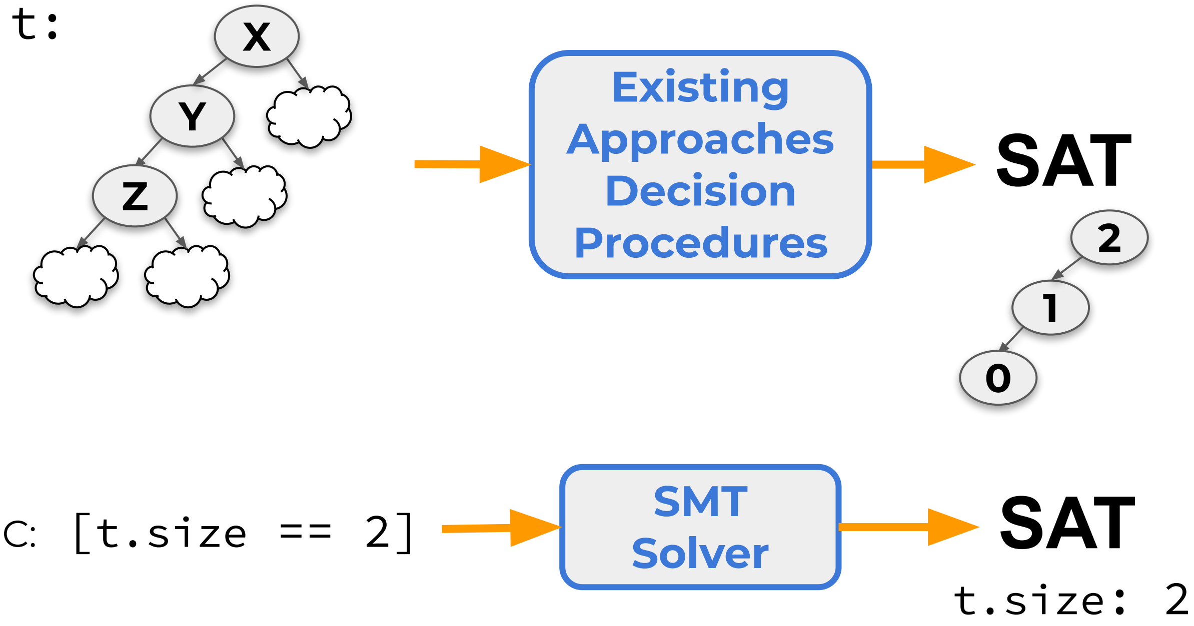
SMT Solver

PATH CONDITION AND HEAP SEPARATION PROBLEM



`t:`

Existing Approaches Decision Procedures

SAT

PC: `[t.size == 2]`

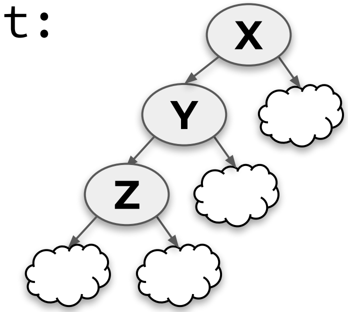
SMT Solver

SAT

`t.size: 2`

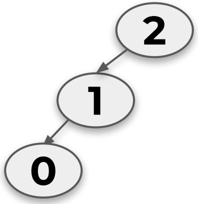
PATH CONDITION AND HEAP SEPARATION PROBLEM

`t:`



Existing Approaches Decision Procedures

SAT



SAT

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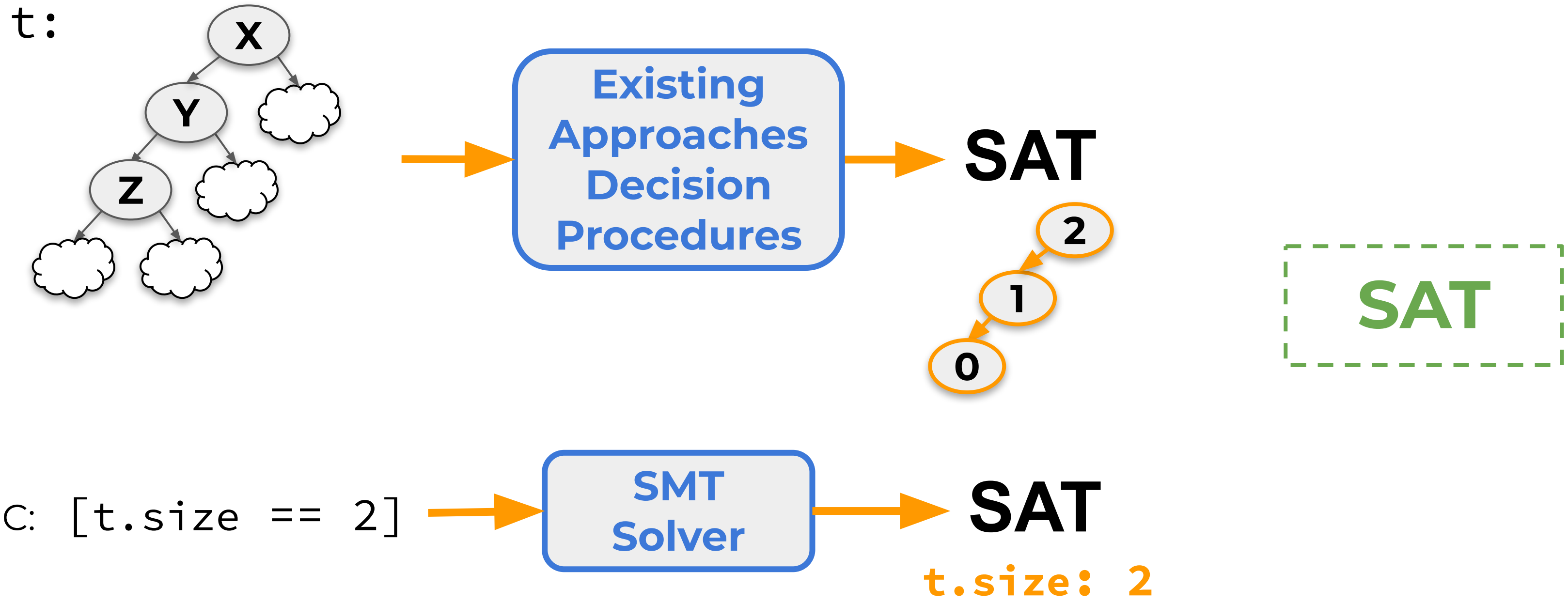
SMT Solver

SAT

`t.size: 2`

PATH CONDITION AND HEAP SEPARATION PROBLEM



`t:`

Existing Approaches Decision Procedures

SAT

SAT

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SMT Solver

SAT

`t.size: 2`

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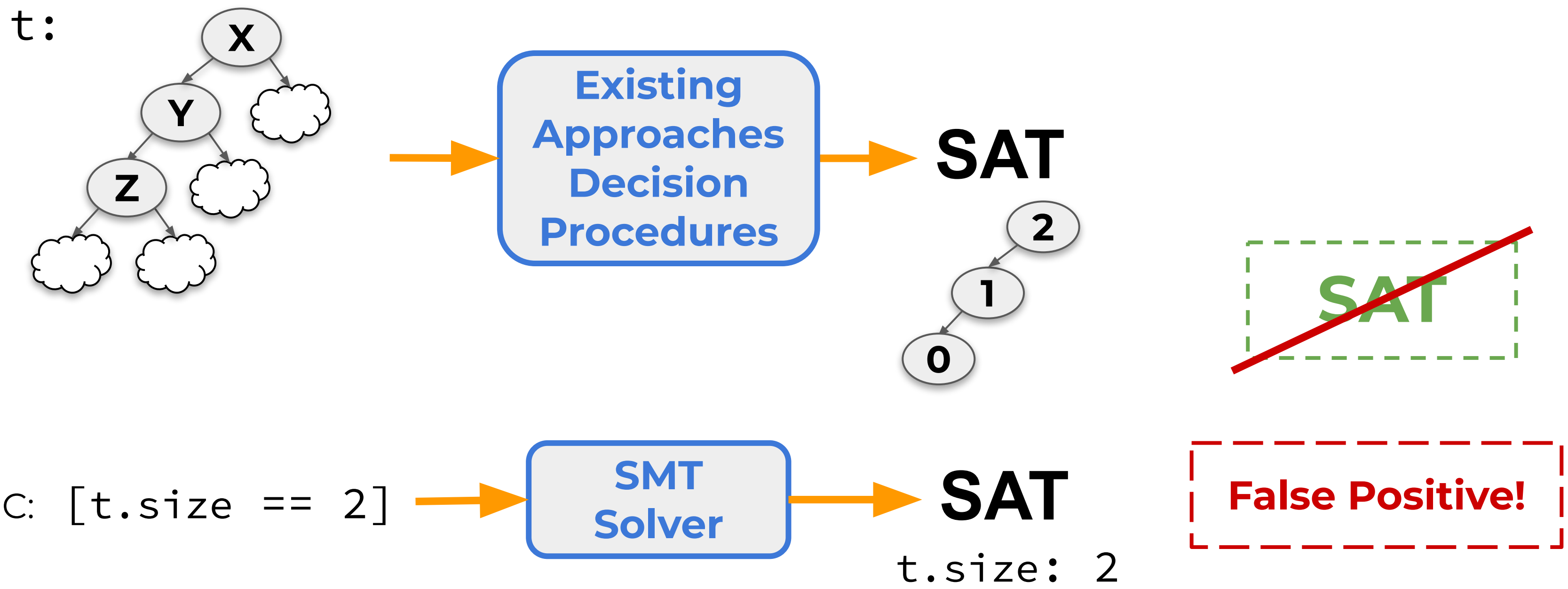

`t:`

Existing Approaches Decision Procedures

SAT

~~SAT~~

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SMT Solver

SAT

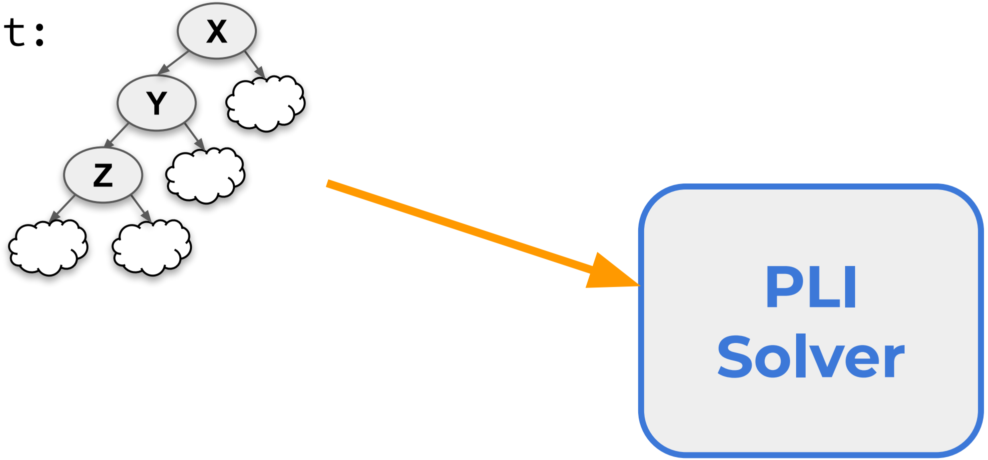
`t.size: 2`

False Positive!

PLI: PRECISE LAZY INITIALIZATION

PLI Solver

PLI: PRECISE LAZY INITIALIZATION



PLI Solver

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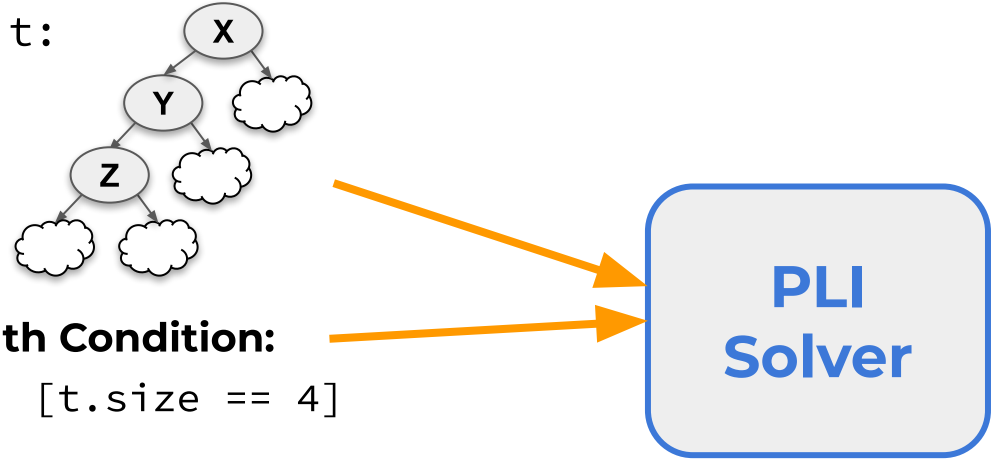

Path Condition:

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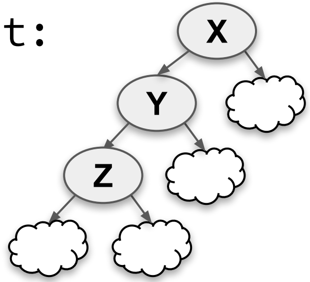
PLI Solver

PLI: PRECISE LAZY INITIALIZATION

`t:`



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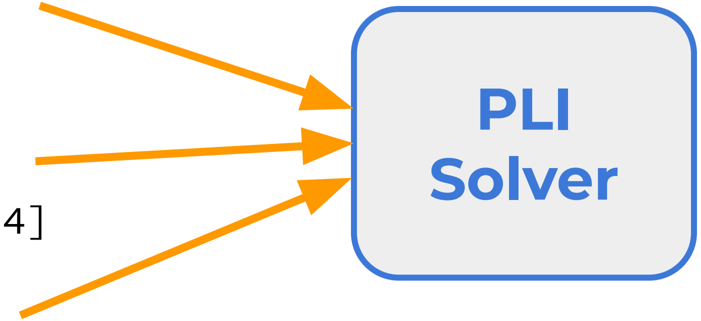

PLI Solver

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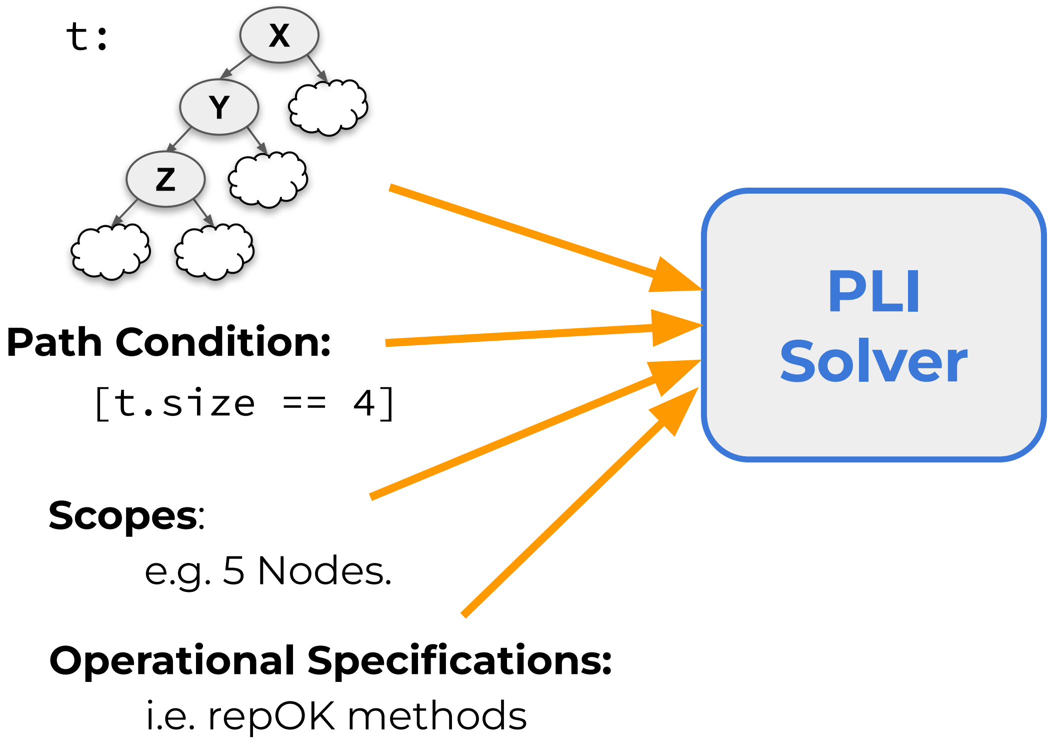

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Operational Specifications:

i.e. repOK methods

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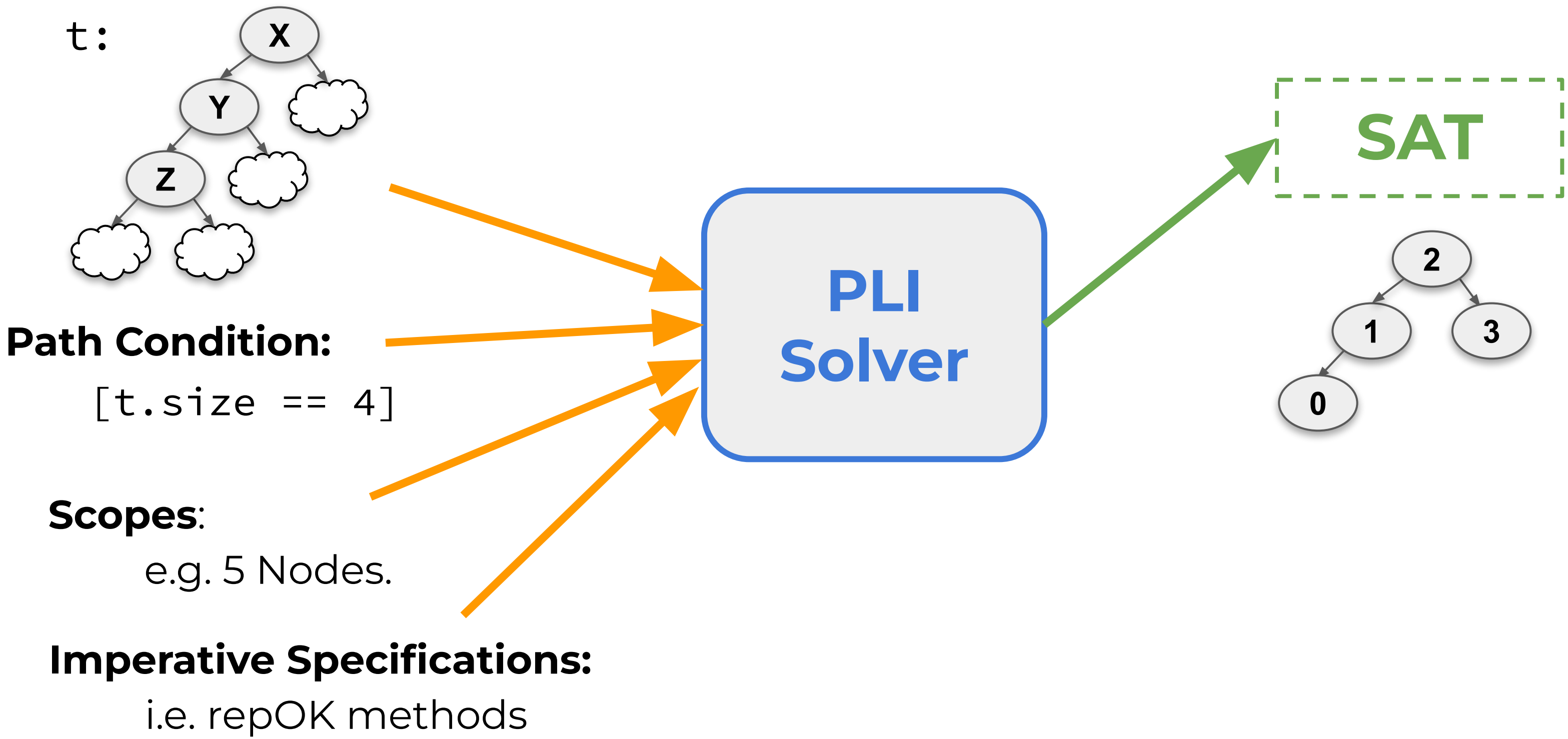

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PLI Solver

SAT

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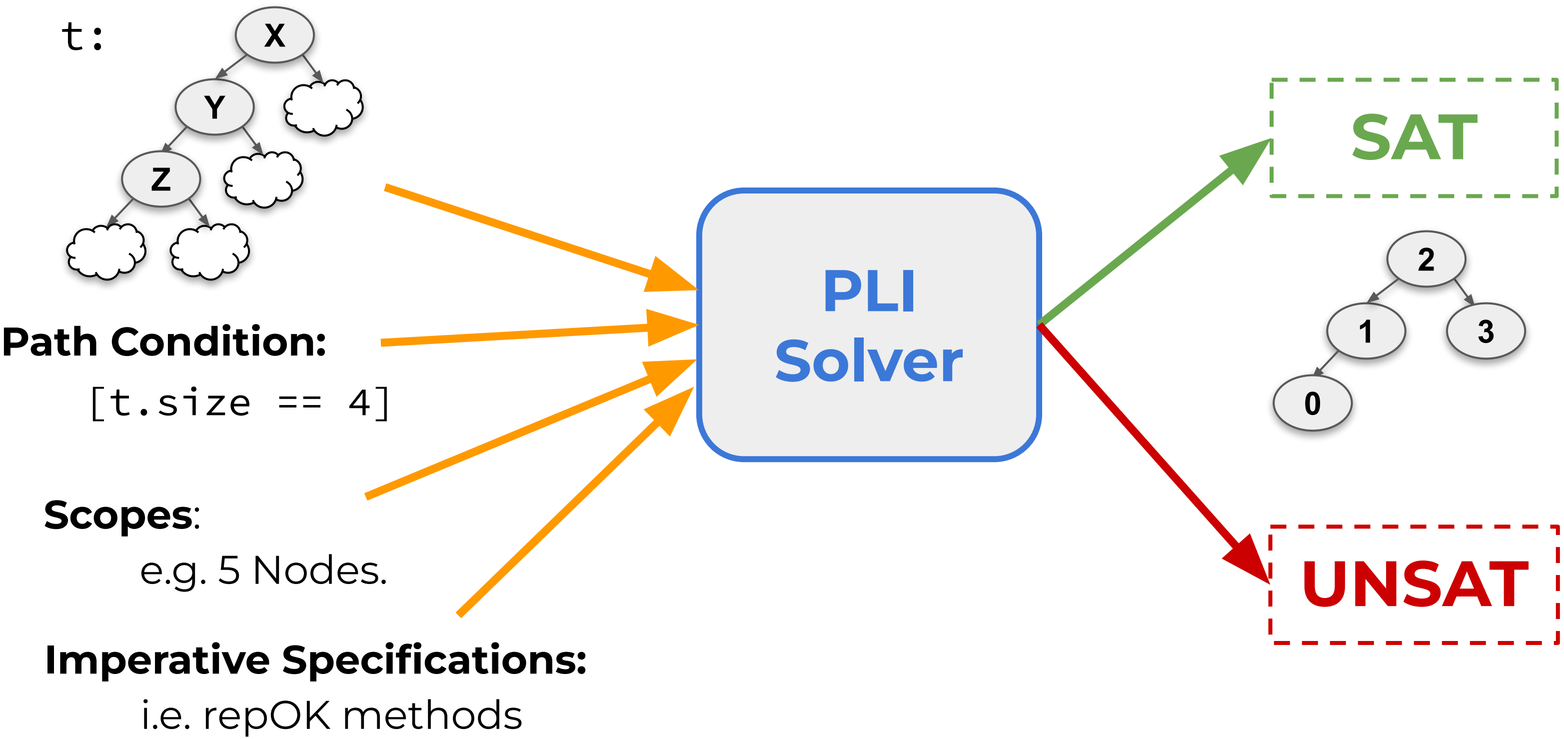

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SAT

UNSAT

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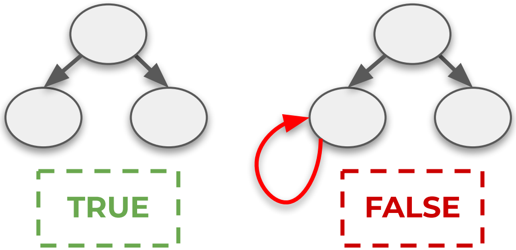

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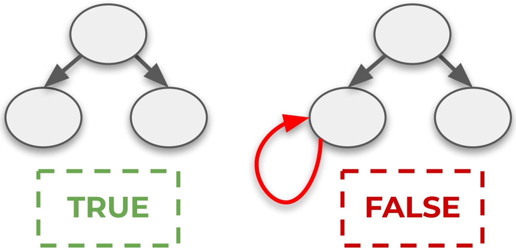

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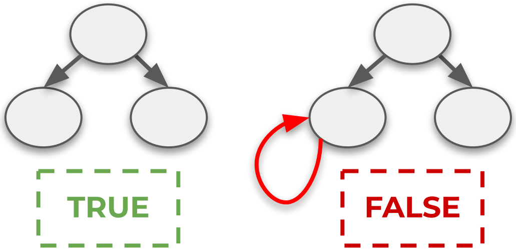

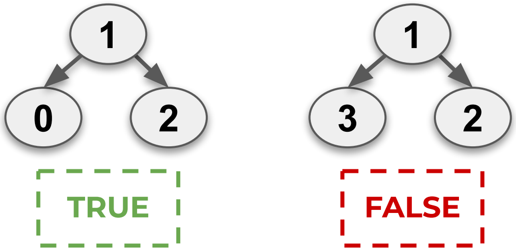

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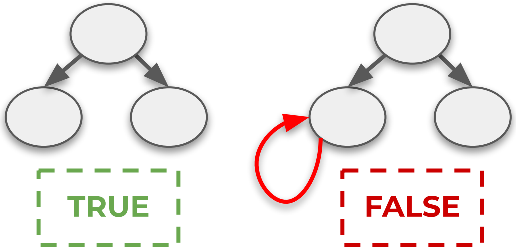

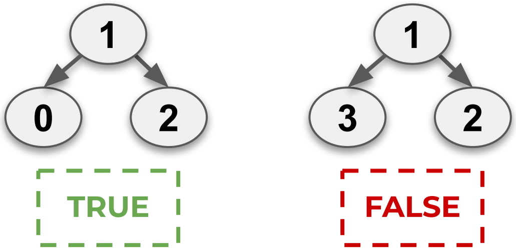

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THE PLI SOLVER

THE PLI SOLVER

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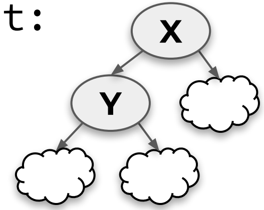

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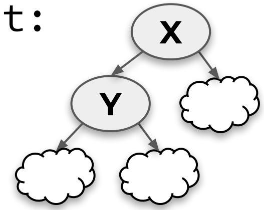

Scope: 5 Nodes

THE PLI SOLVER

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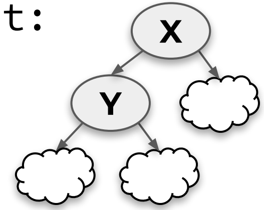

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PC: `[t.size == 3]`

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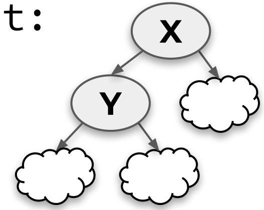

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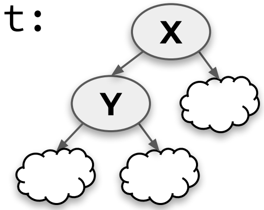
THE PLI SOLVER



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THE PLI SOLVER

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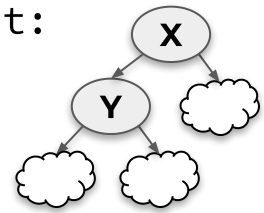

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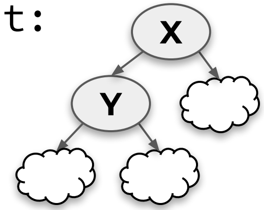
PLI Solver

SymSolve

THE PLI SOLVER



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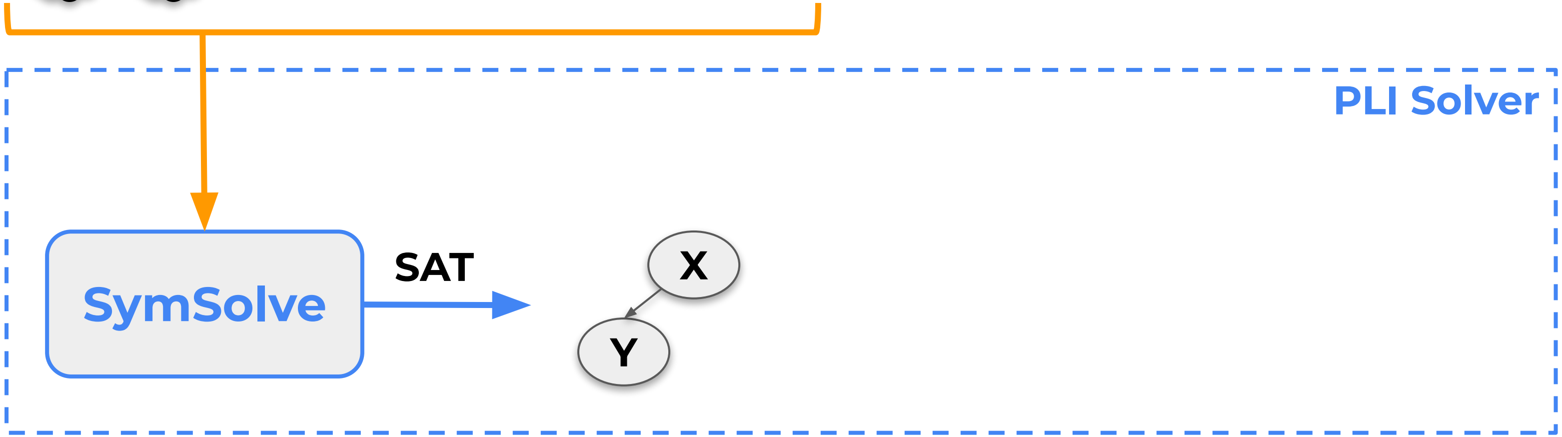
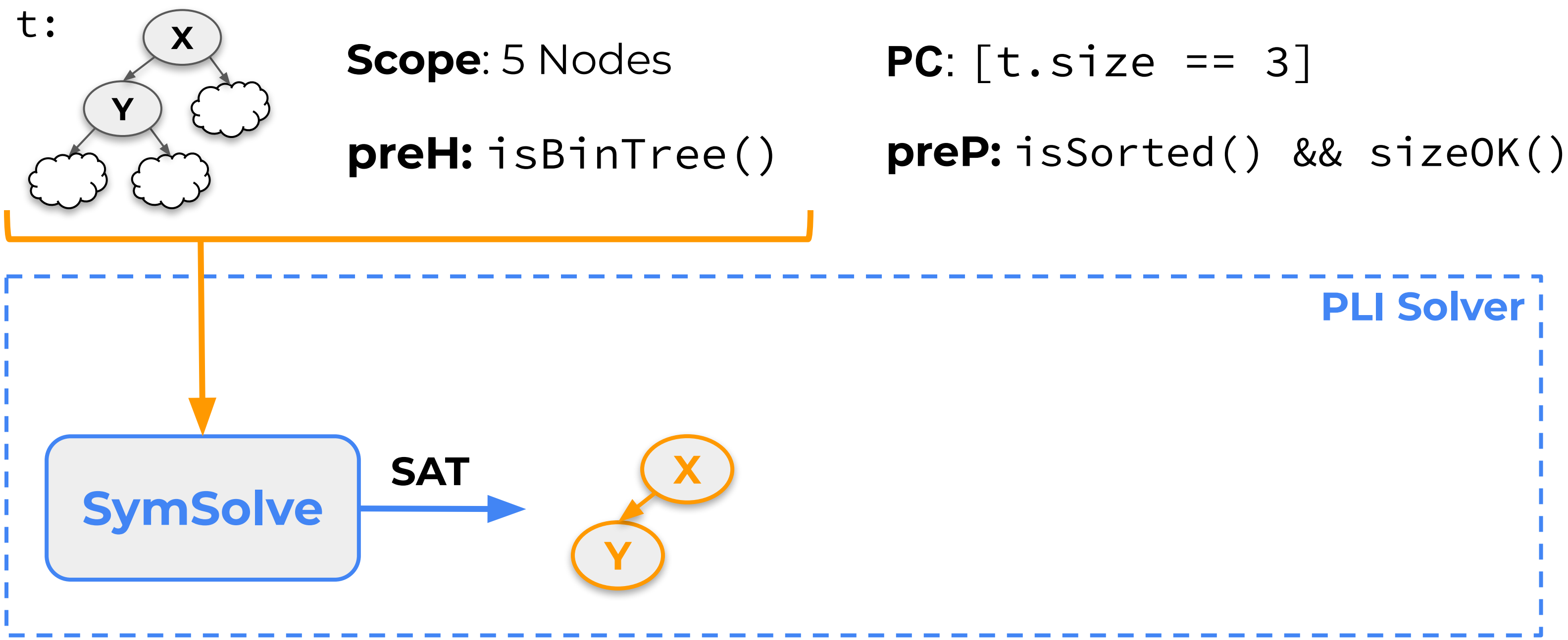


THE PLI SOLVER



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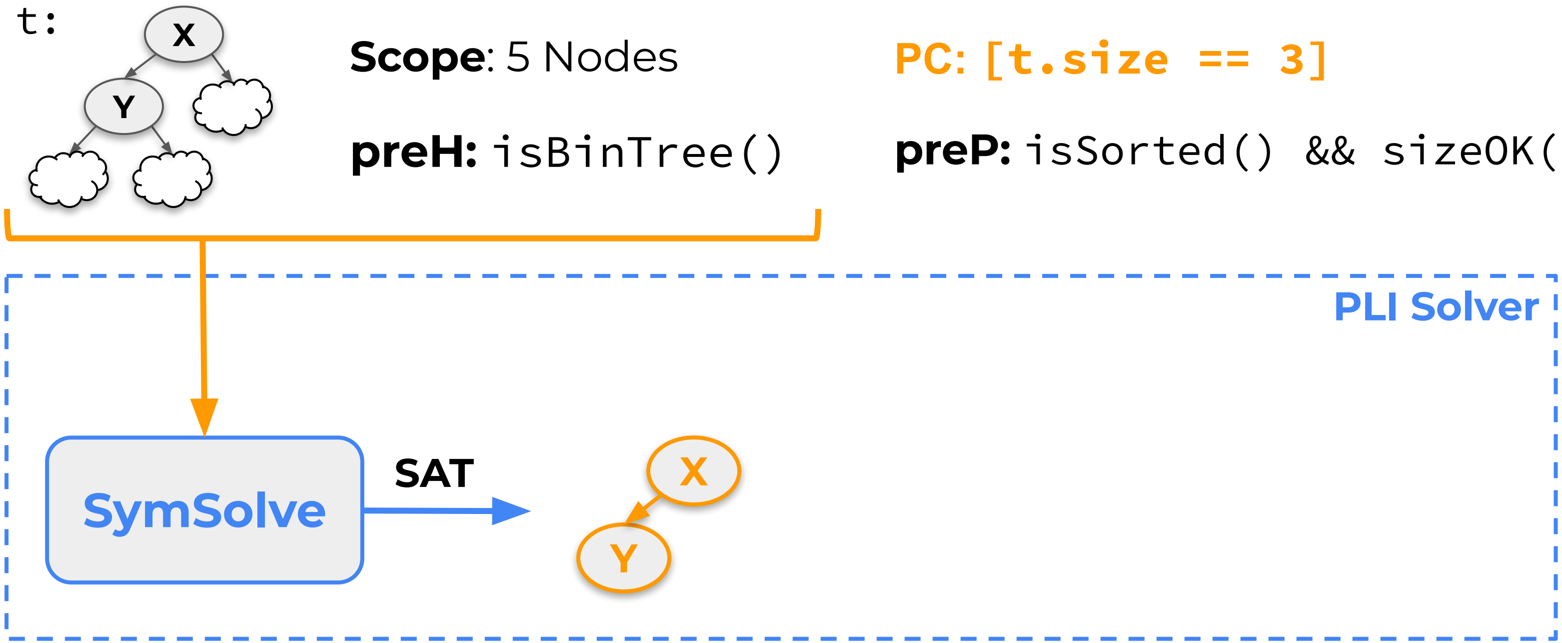

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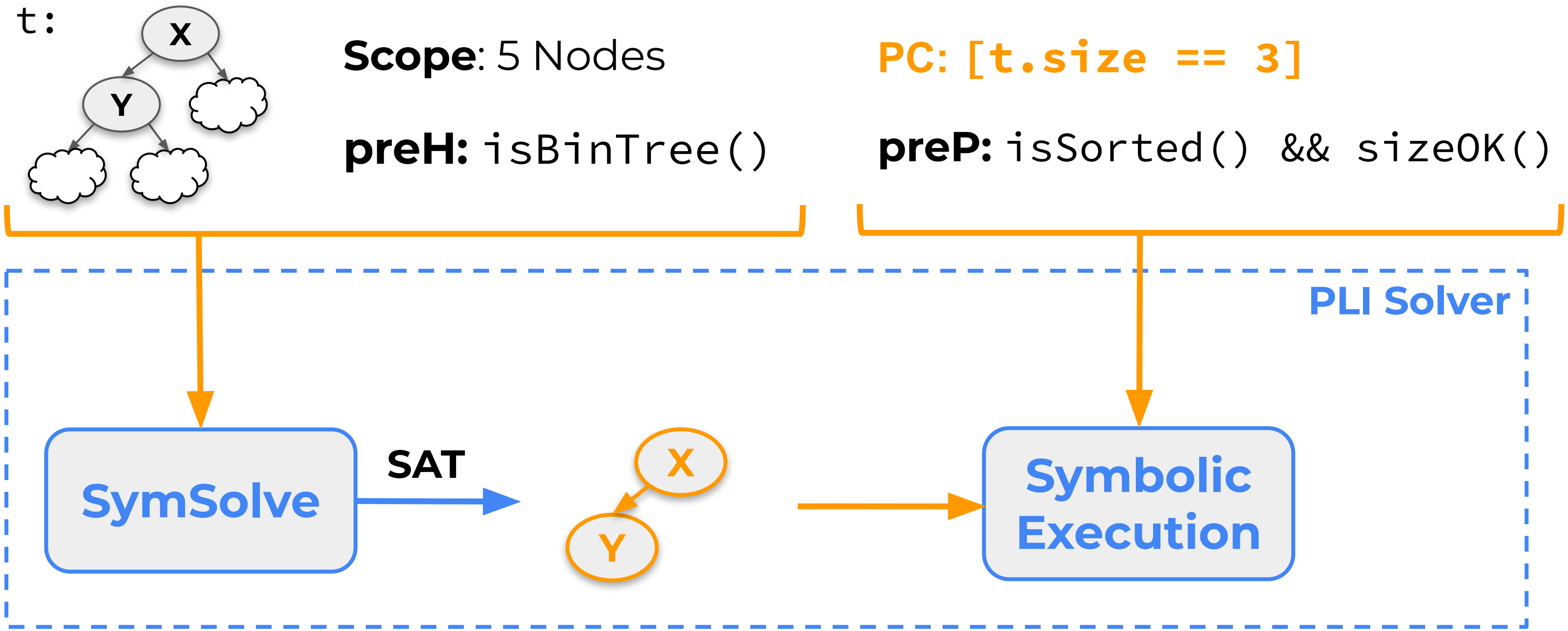

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PLI Solver

SymSolve

SAT

Symbolic Execution

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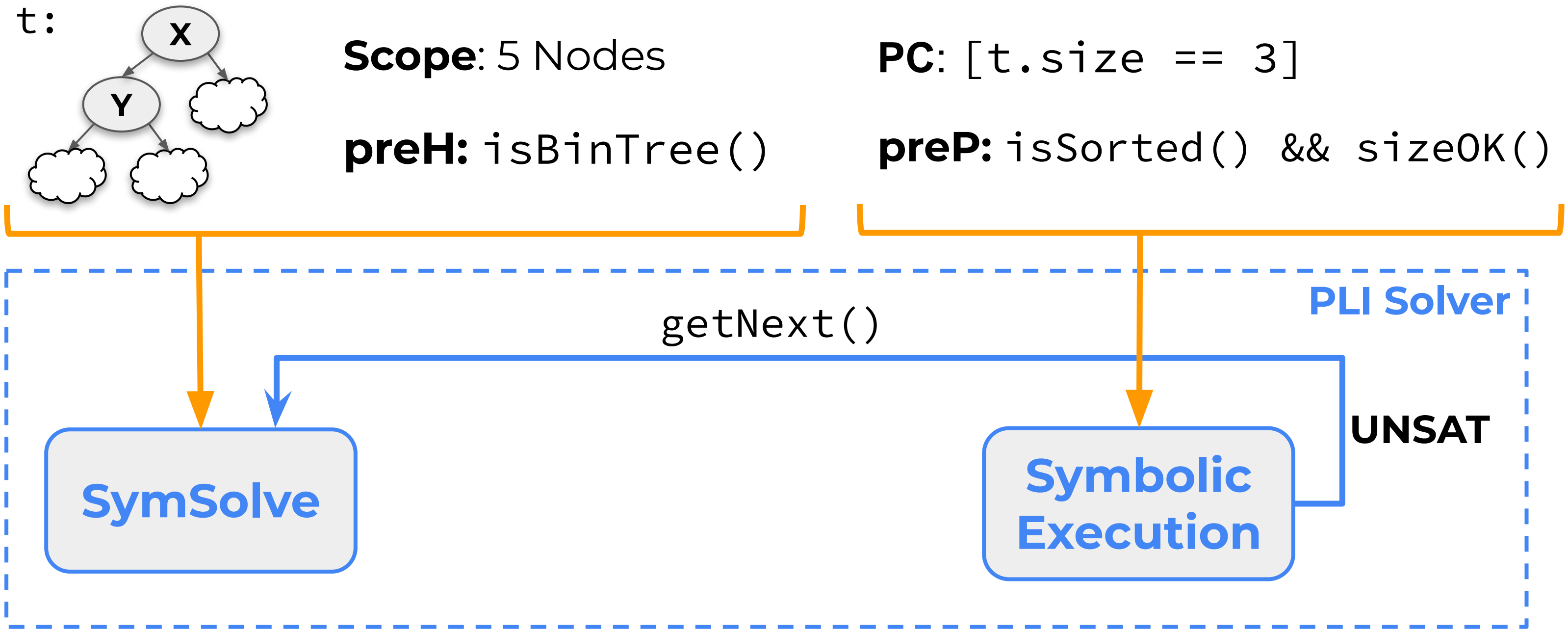

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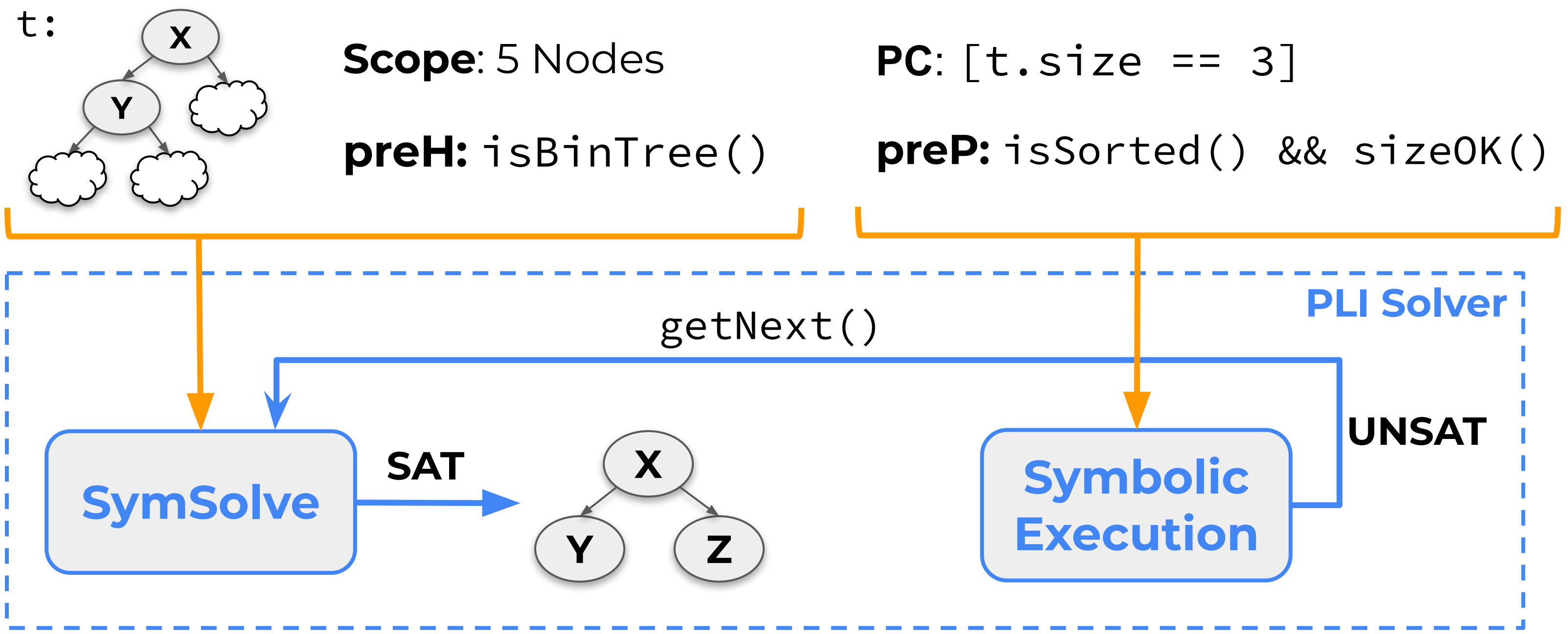

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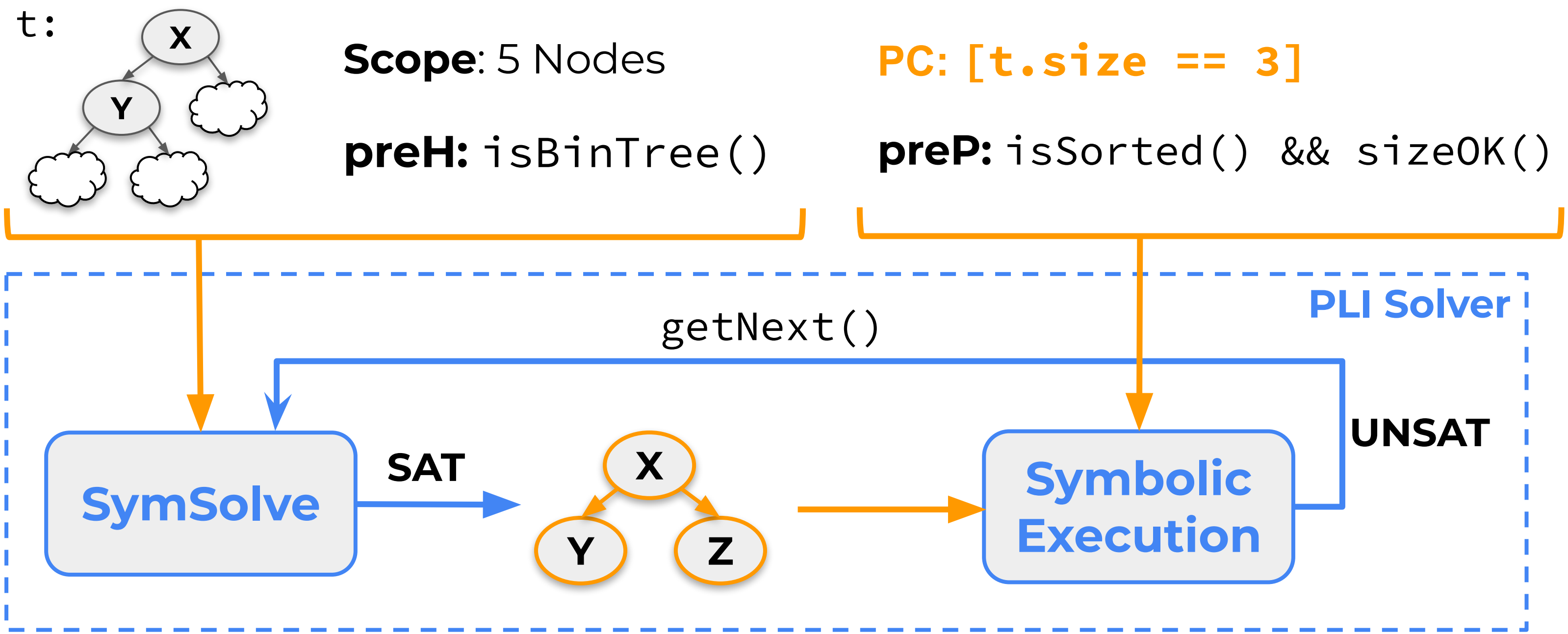

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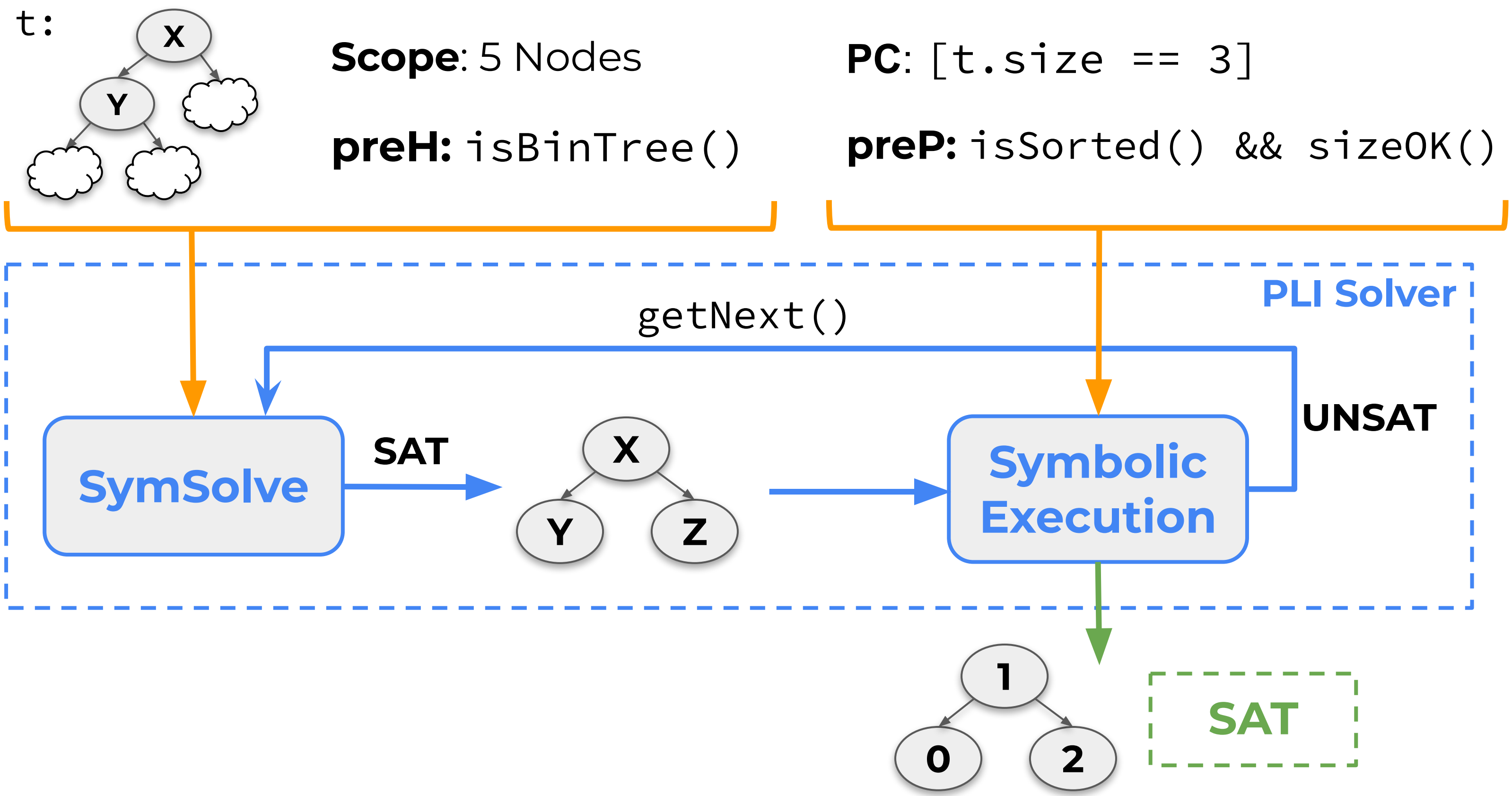

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Y

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PLI Solver

`getNext()`

SymSolve

SAT

X

Y

Z

Symbolic Execution

UNSAT

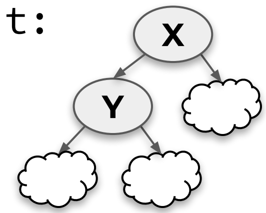
1

0

2

SAT

THE PLI SOLVER



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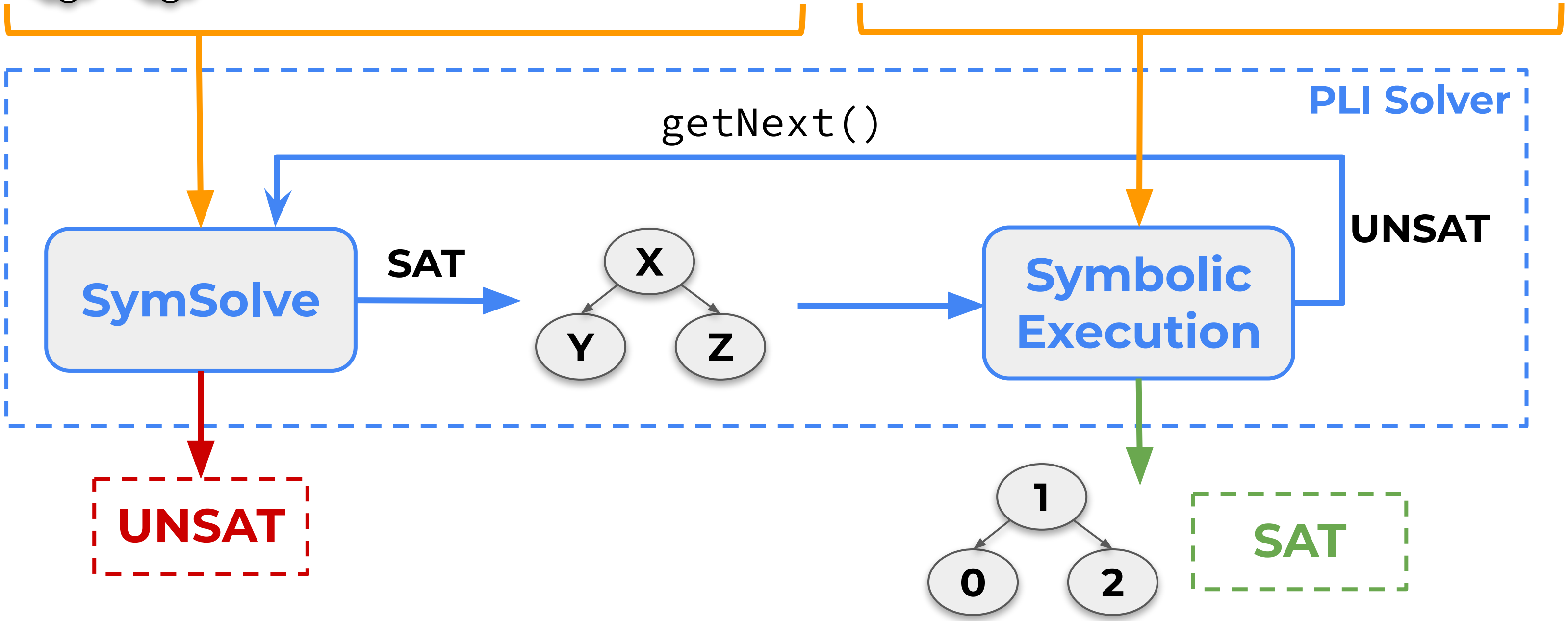

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- We evaluated PLI on 12 case studies:
    - 4 Data structures from the **java.util** package: TreeMap, TreeSet, HashMap, LinkedList.
    - An AVL and BinomialHeap implementations from the literature.
    - 5 programs from **SF110**.
    - A scheduler implementation from the **SIR** repository.

EXECUTION TIME AND SCALABILITY

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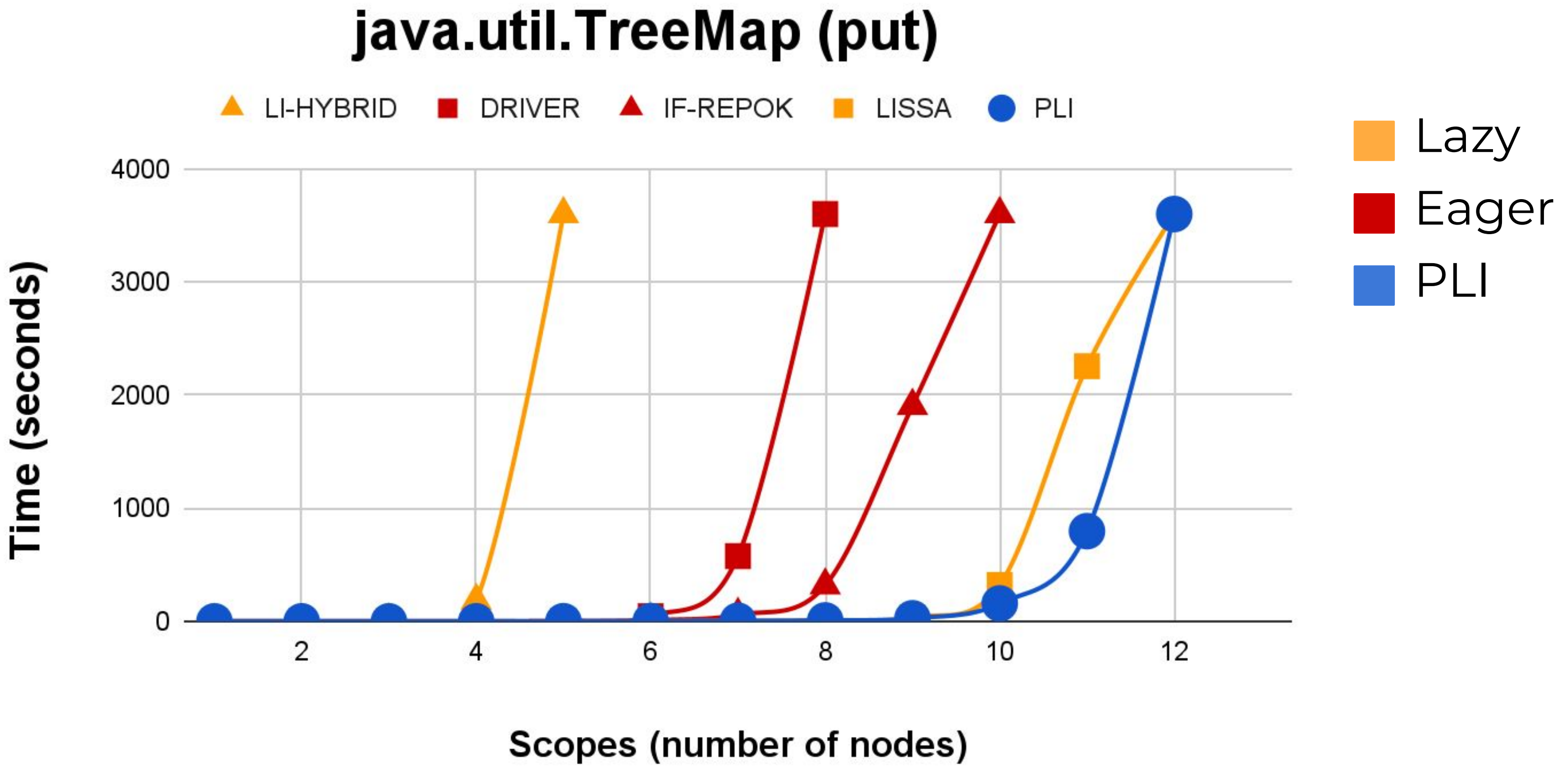

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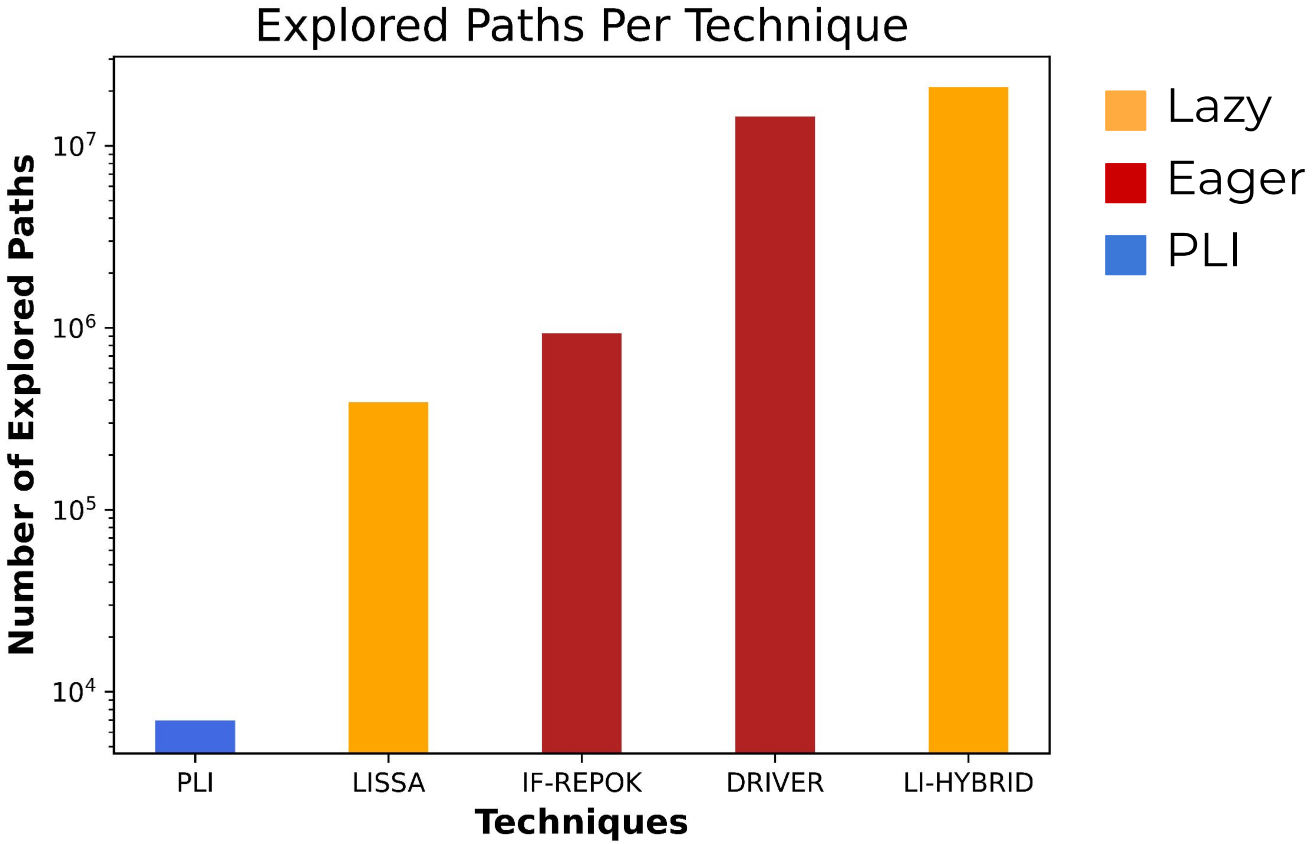

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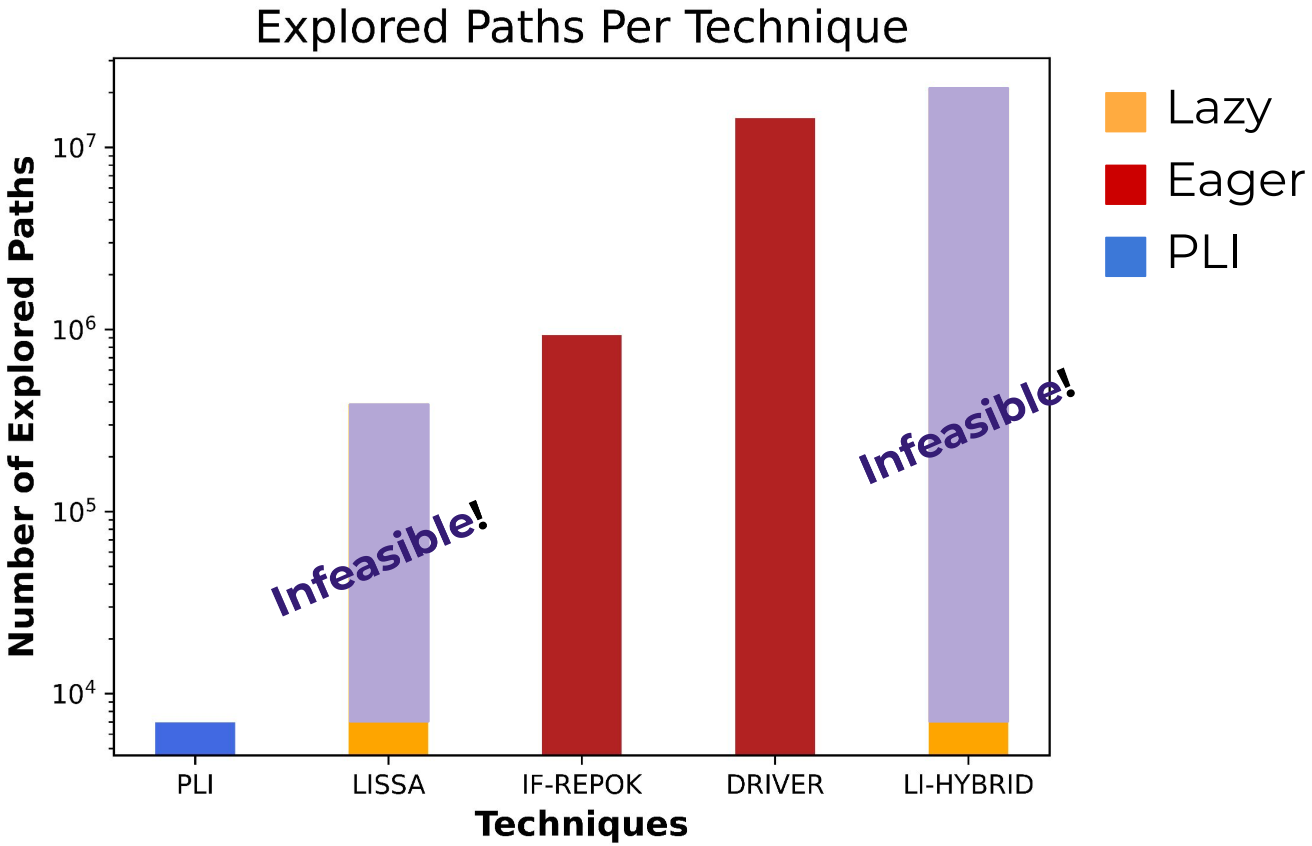

FALSE ALARMS

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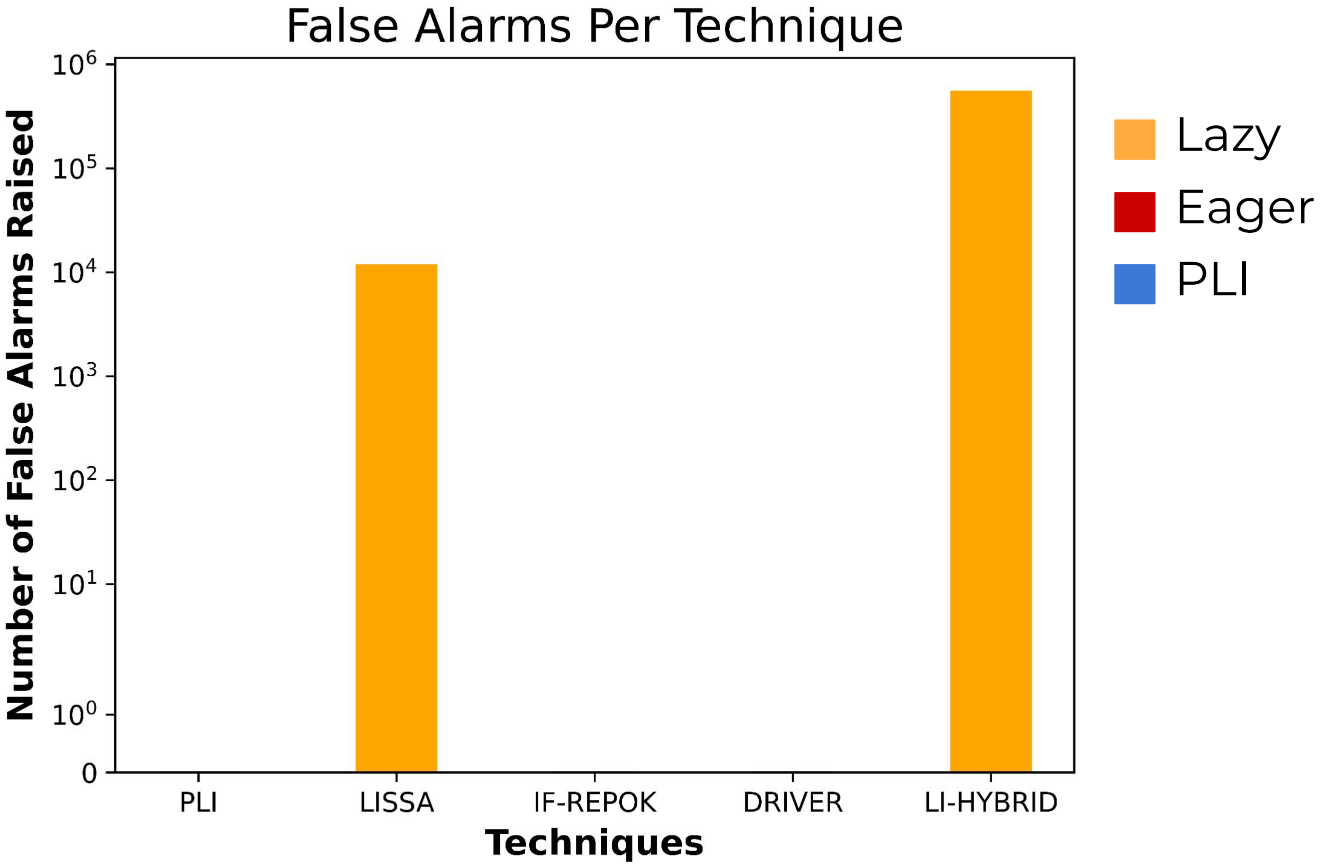

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    - Require **operational predicates** as specifications.
    - Solves the **path-condition / symbolic heap separation problem** of lazy approaches.
    - Eliminates **false positives** and **false alarms**.
    - Performance is comparable to the fastest lazy approach.

THANK YOU!

The artifact received the **available**, **reviewed** and **reproducible** badges:

https://github.com/JuanmaCopia/spf-pli