Validating SMT Solvers via Semantic Fusion

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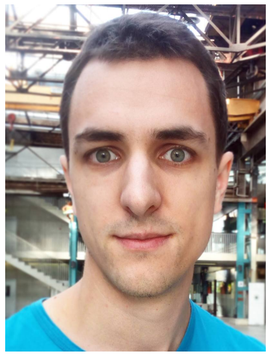
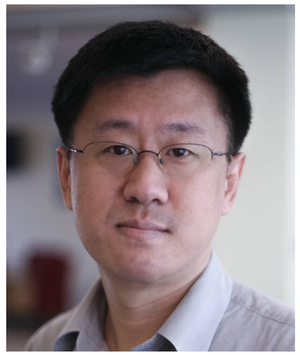
ETH Zurich, Switzerland

(*Equal contributions)





PLDI ’20, June 15–20, 2020, Online

SMT Problem

$$\varphi : x > 0 \wedge x < 0$$

SMT Problem

$$\varphi : x > 0 \wedge x < 0$$

UNSAT

SMT Problem

$$\varphi : x > 0 \wedge x < 1$$

SMT Problem

$$\varphi : x > 0 \wedge x < 1$$

SAT

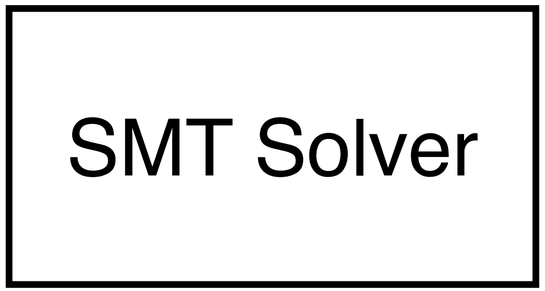
SMT Problem

$$\varphi : x > 0 \wedge x < 1$$

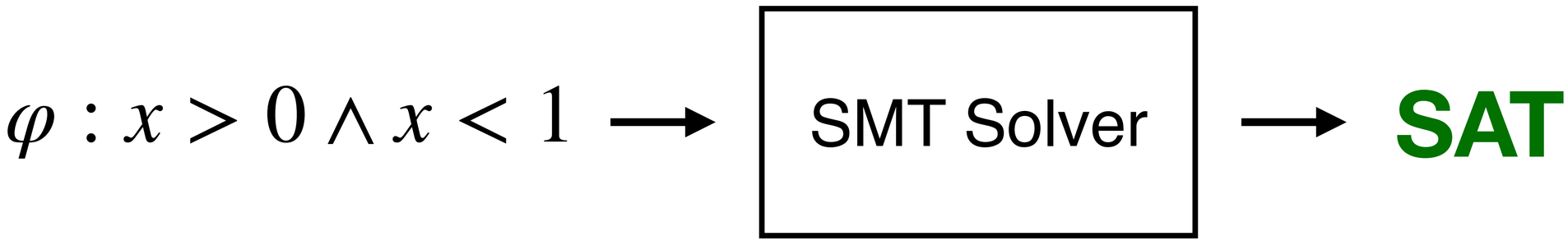
SAT

$$x = 0.5$$

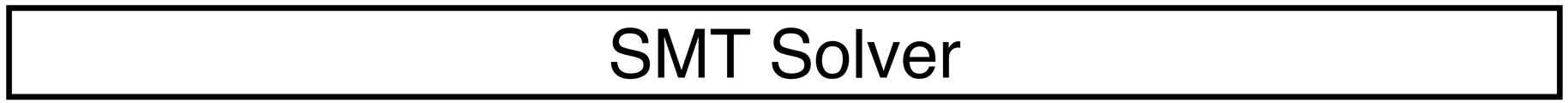
SMT Solver

$\varphi : x > 0 \wedge x < 1 \longrightarrow$ 

SMT Solver

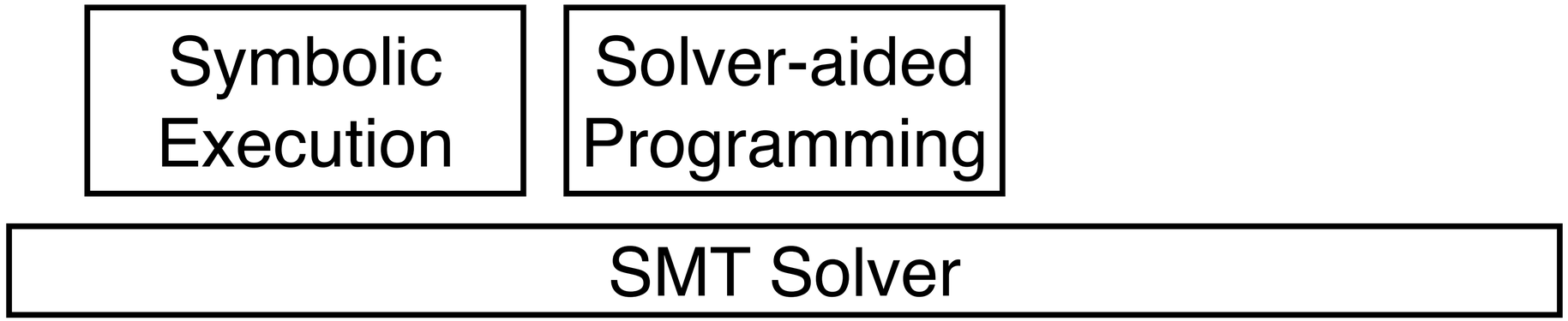


SMT Solver

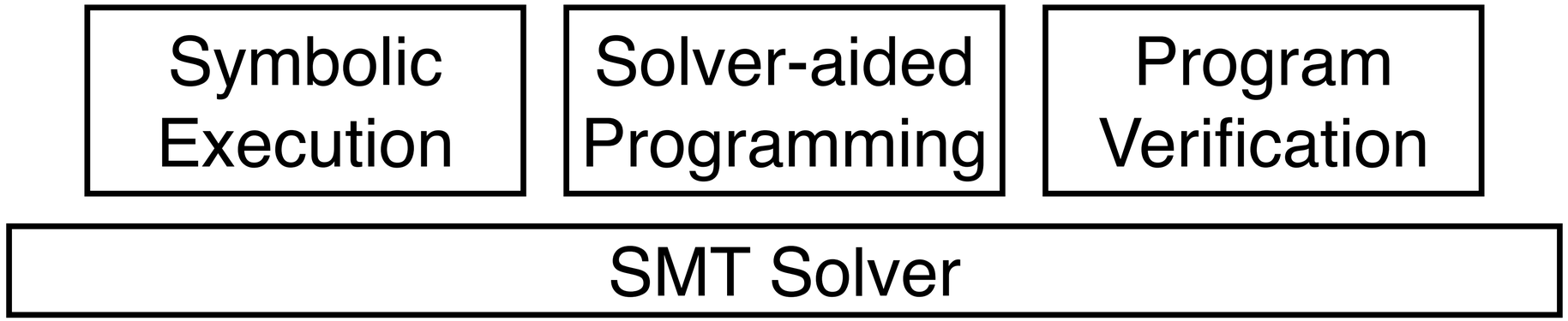


SMT Solver

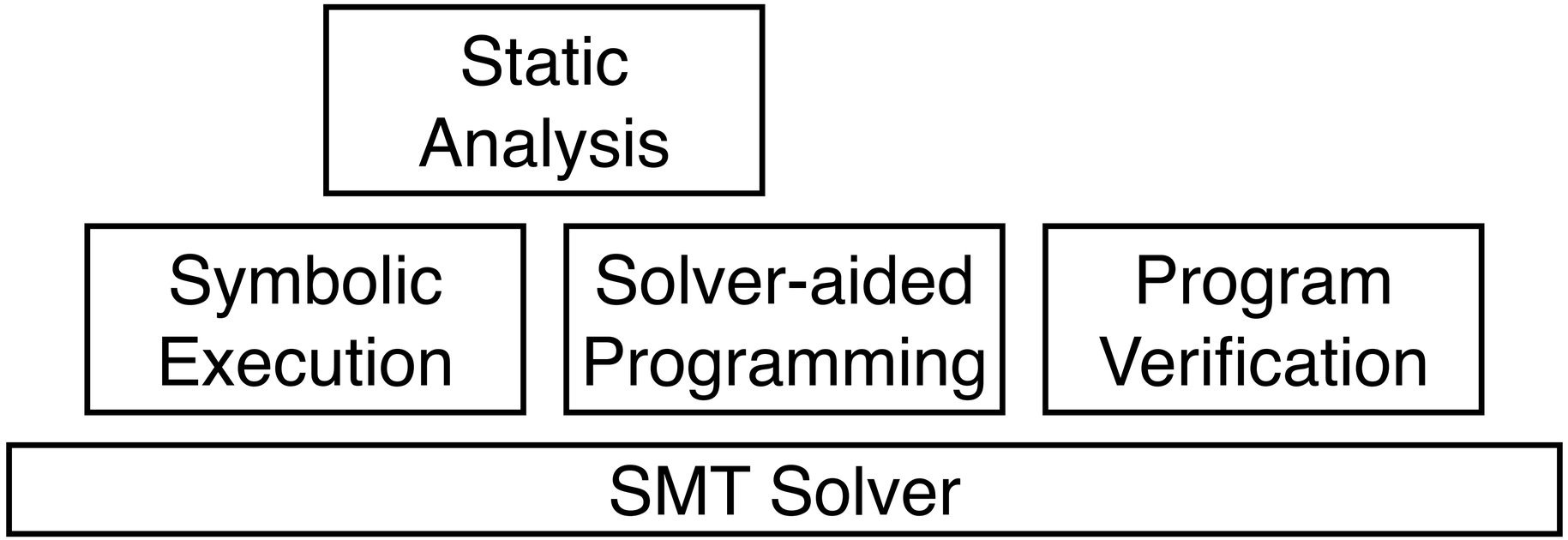
SMT Solver



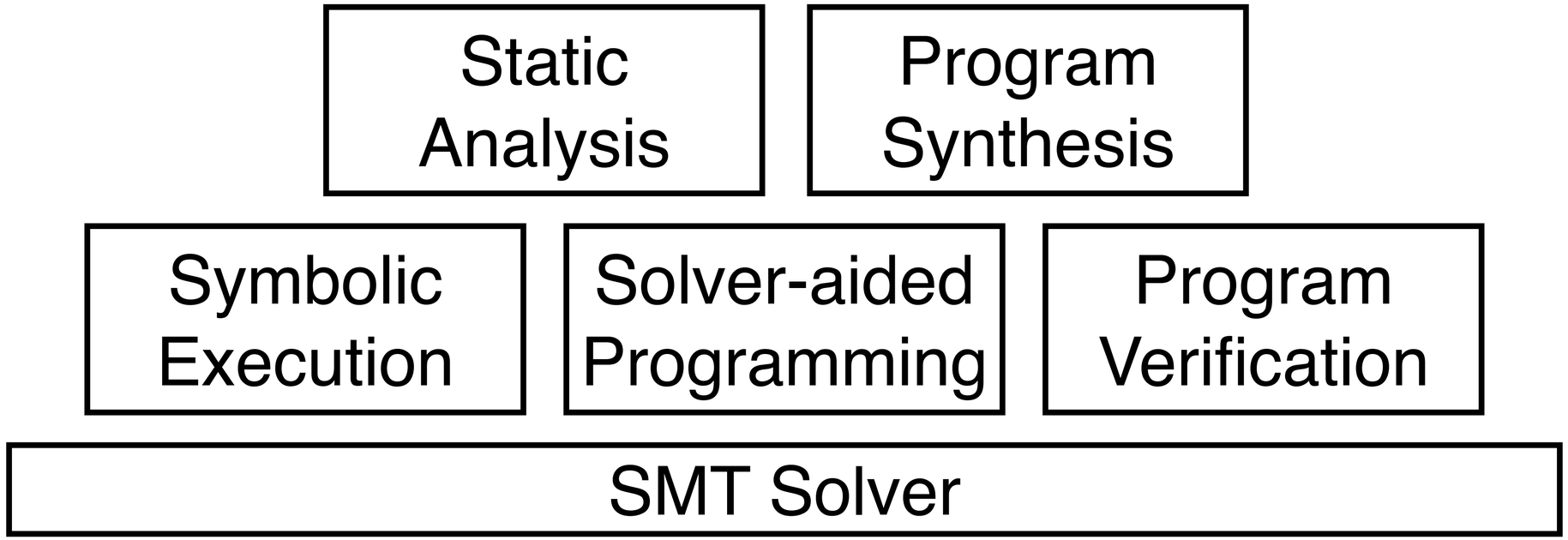
SMT Solver


Symbolic Execution
Solver-aided Programming
Program Verification
SMT Solver

SMT Solver


Static
Analysis
Symbolic
Execution
Solver-aided
Programming
Program
Verification
SMT Solver

SMT Solver


Static Analysis
Program Synthesis
Symbolic Execution
Solver-aided Programming
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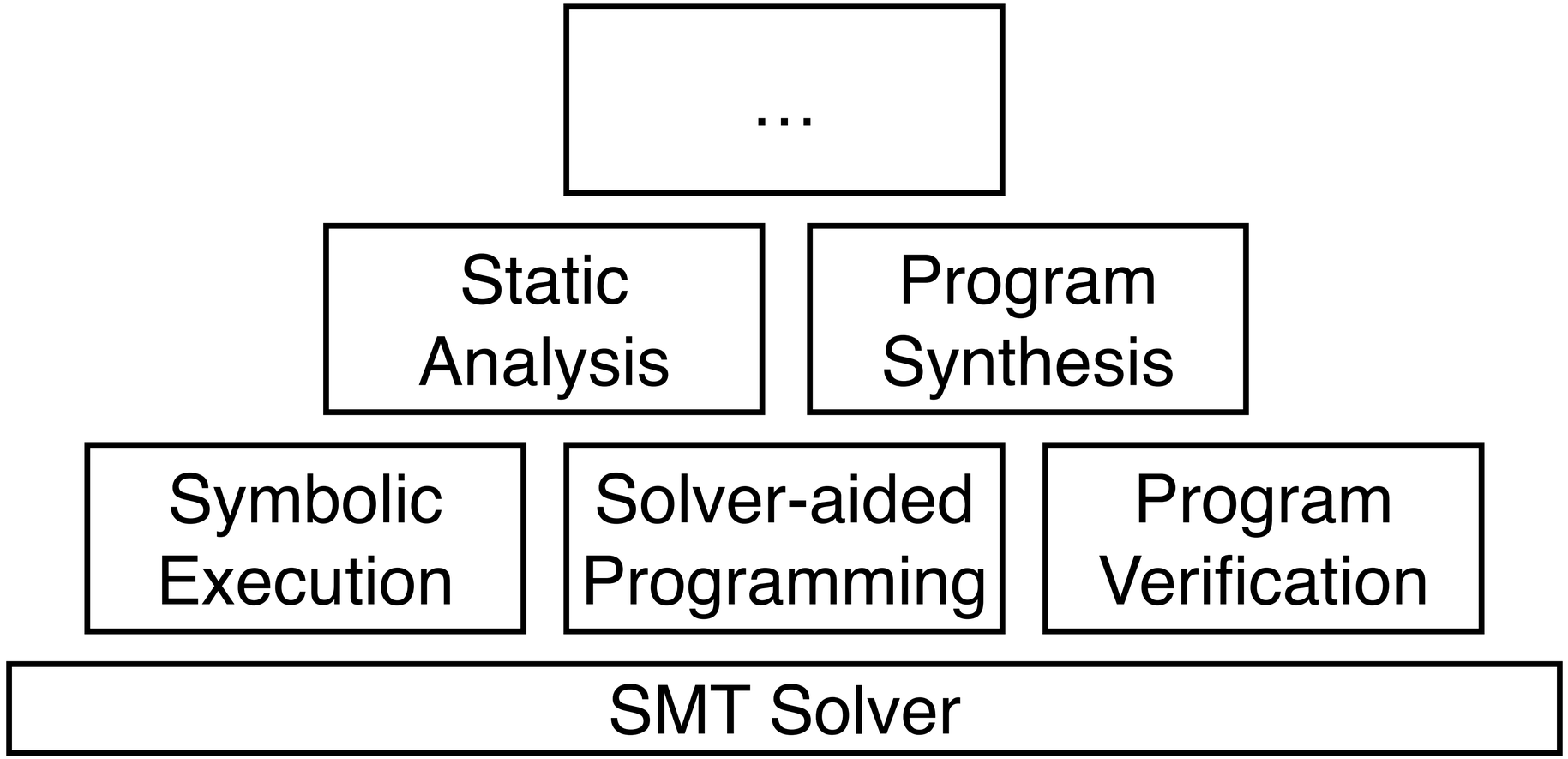
SMT Solver


...
Static Analysis
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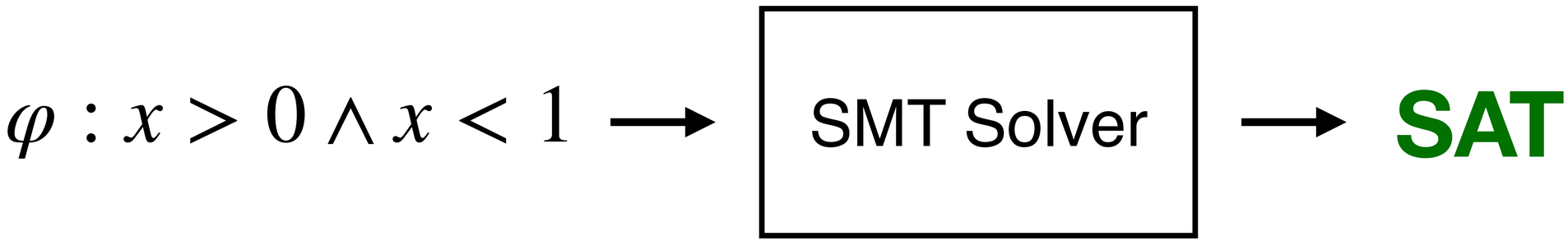
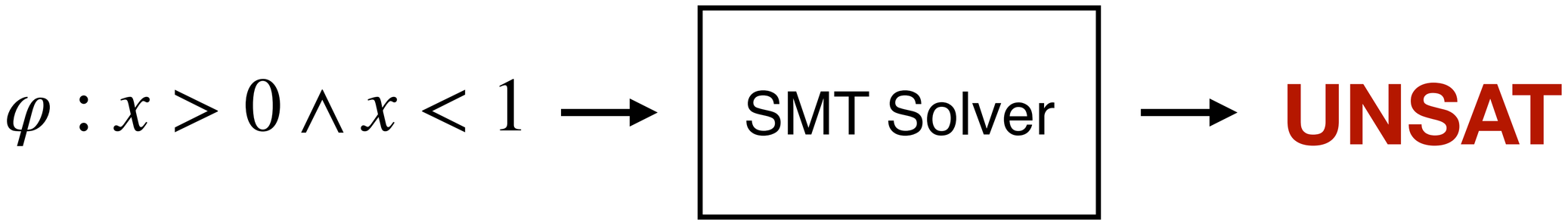
SMT Solver



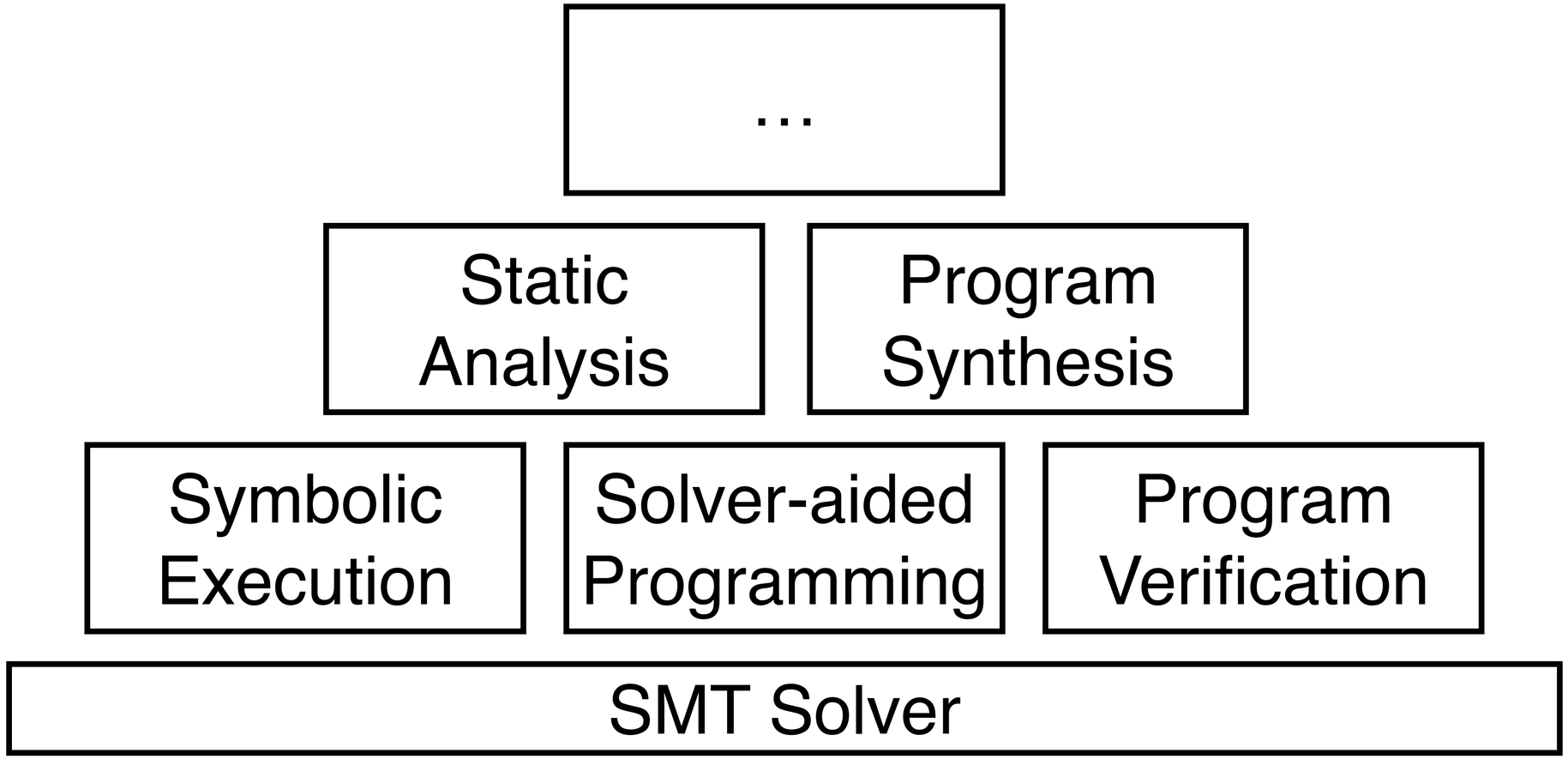
SMT Solver



SMT Solver

$\varphi : x > 0 \wedge x < 1$ → SMT Solver → **UNSAT** 

SMT Solver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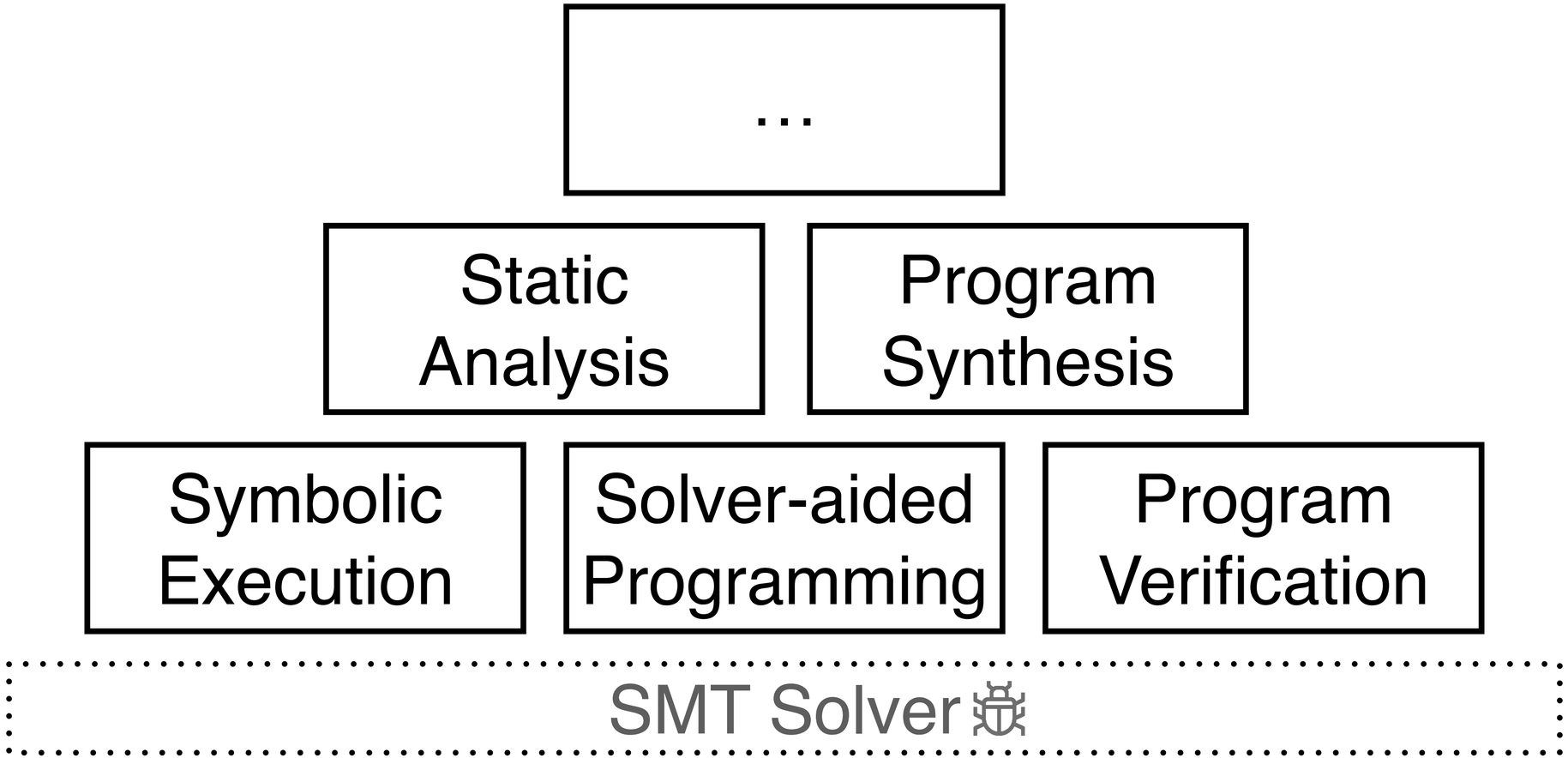
SMT Solver


...
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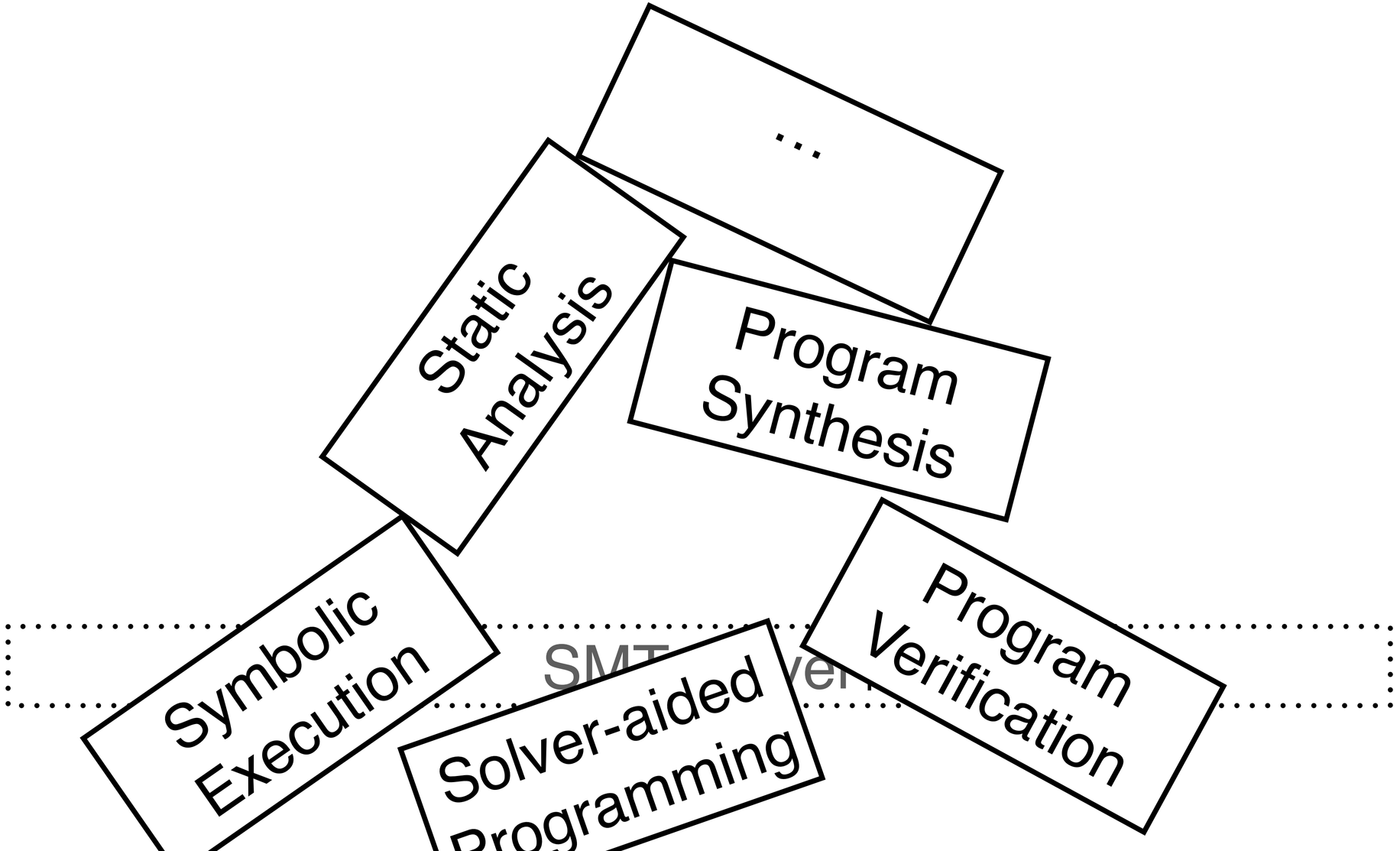
SMT Solver


...
Static Analysis
Program Synthesis
Symbolic Execution
Solver-aided Programming
Program Verification

Testing SMT solvers is challenging

Testing SMT solvers is challenging

- How to generate test formulas?

Testing SMT solvers is challenging

- How to generate test formulas?
- How to obtain the test oracles?

Testing SMT solvers is challenging

```
(declare-fun a () Real)
(declare-fun p () Real)
(declare-fun b () Real)
(declare-fun c () Real)
(declare-fun d () Real)
(declare-fun k () Real)
(declare-fun e () Real)
(declare-fun q () Real)
(assert (or
            (not (exists ((f Real))
                (=>
                (and
                    (>= c 0)
                    (> (/ b q) 2)
                    (>= (/ p q) 1)
                    (<= d 12)
                    (>= (/ p q) (- (* 1 k)))
                    (<= (/ p q) (+ 10 k)))
                (<= (+ (* (- 2) (- a e)) d) 12))))
            (exists ((o Real))
                (forall ((g Real))
                    (exists ((h Real))
                        (and
                            (or
                                (>= g (* (- 3) h) 57)
                                (and (> (* 79 o) 8 (+ g h) 0) (= h 0))
                                (< 0 (+ g h) 0))
                            (> (+ (* (- 97) o) g) 0)))))))
(assert (= a (+ c e)(* d q)(/ b q)))
(assert (= q (/ b k)))
(check-sat)
(get-model)
```

Testing SMT solvers is challenging

- How to generate test formulas?
- How to obtain the test oracles?

Testing SMT solvers is challenging

- How to generate test formulas?
- How to obtain the test oracles?
- It is challenging to find bugs.

Semantic Fusion

- Fusing test formulas while preserving satisfiability
- Finding bugs in two state-of-the-art SMT solvers

Semantic Fusion

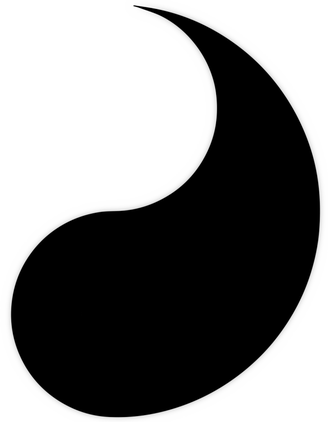
- Fusing test formulas while preserving satisfiability
- Finding bugs in two state-of-the-art SMT solvers

46 Bugs Confirmed, 42 Bugs Fixed
in Z3 and CVC4 default mode

Semantic Fusion

φ_1

φ_2



Semantic Fusion

$$\varphi_{concat}$$

Semantic Fusion

$$\varphi_{fused}$$

Semantic Fusion

$$\varphi_1 = x > 0 \wedge x > 1 \quad \textbf{SAT}$$
$$\varphi_2 = y < 0 \wedge y < 1 \quad \textbf{SAT}$$

Semantic Fusion

$$\varphi_1 \qquad\qquad \varphi_2$$

$$(x > 0 \wedge x > 1) \wedge (y < 0 \wedge y < 1)$$

Semantic Fusion

$$\varphi_{concat} = \underbrace{(x > 0 \wedge x > 1)}_{\varphi_1} \wedge \underbrace{(y < 0 \wedge y < 1)}_{\varphi_2}$$ **SAT**

Semantic Fusion

$$\varphi_{concat} = \underbrace{(x > 0 \wedge x > 1)}_{\varphi_1} \wedge \underbrace{(y < 0 \wedge y < 1)}_{\varphi_2} \quad \textbf{SAT}$$

$$x = 1 \qquad y = -1$$

Semantic Fusion

$$\varphi_{concat} = \underbrace{(x > 0 \wedge x > 1)}_{\varphi_1} \wedge \underbrace{(y < 0 \wedge y < 1)}_{\varphi_2} \quad \textbf{SAT}$$

$$\searrow \quad z \quad \swarrow$$

Semantic Fusion

$$\varphi_{concat} = \underbrace{(x > 0 \wedge x > 1)}_{\varphi_1} \wedge \underbrace{(y < 0 \wedge y < 1)}_{\varphi_2} \quad \textbf{SAT}$$

$$z = x + y$$

Semantic Fusion

$$\varphi_{concat} = \underbrace{(x > 0 \wedge x > 1)}_{\varphi_1} \wedge \underbrace{(y < 0 \wedge y < 1)}_{\varphi_2}$$

SAT

$$z = x + y$$

Fusion Function

Semantic Fusion

$$\varphi_{concat} = \underbrace{(x > 0 \wedge x > 1)}_{\varphi_1} \wedge \underbrace{(y < 0 \wedge y < 1)}_{\varphi_2} \quad \textbf{SAT}$$

$$z = x + y$$

Semantic Fusion

$$\varphi_{concat} = \underbrace{(x > 0 \wedge x > 1)}_{\varphi_1} \wedge \underbrace{(y < 0 \wedge y < 1)}_{\varphi_2}$$

SAT

$$z = x + y$$

$$x = z - y \qquad y = z - x$$

Semantic Fusion

$$\varphi_{concat} = \underbrace{(x > 0 \wedge x > 1)}_{\varphi_1} \wedge \underbrace{(y < 0 \wedge y < 1)}_{\varphi_2}$$ **SAT**

$$z = x + y$$

$$x = z - y \qquad y = z - x$$

Inversion Functions

Semantic Fusion

$$\varphi_{concat} = \underbrace{(x > 0 \wedge x > 1)}_{\varphi_1} \wedge \underbrace{(y < 0 \wedge y < 1)}_{\varphi_2}$$

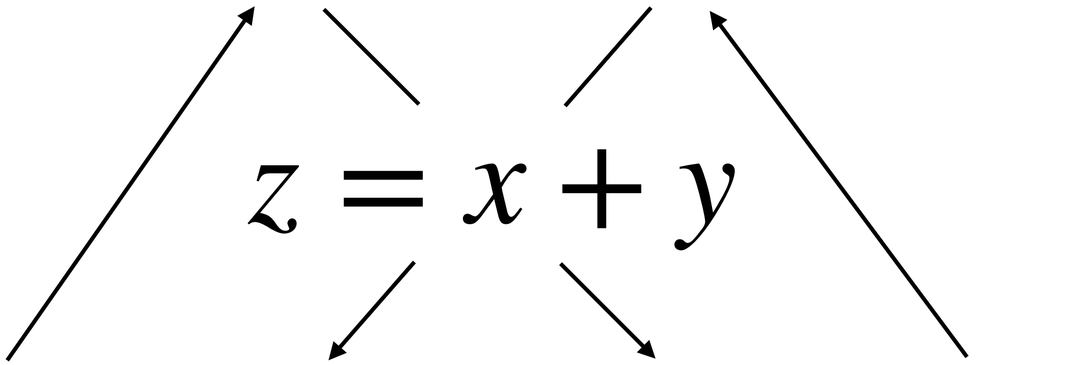
SAT

$$z = x + y$$

$$x = z - y \qquad y = z - x$$

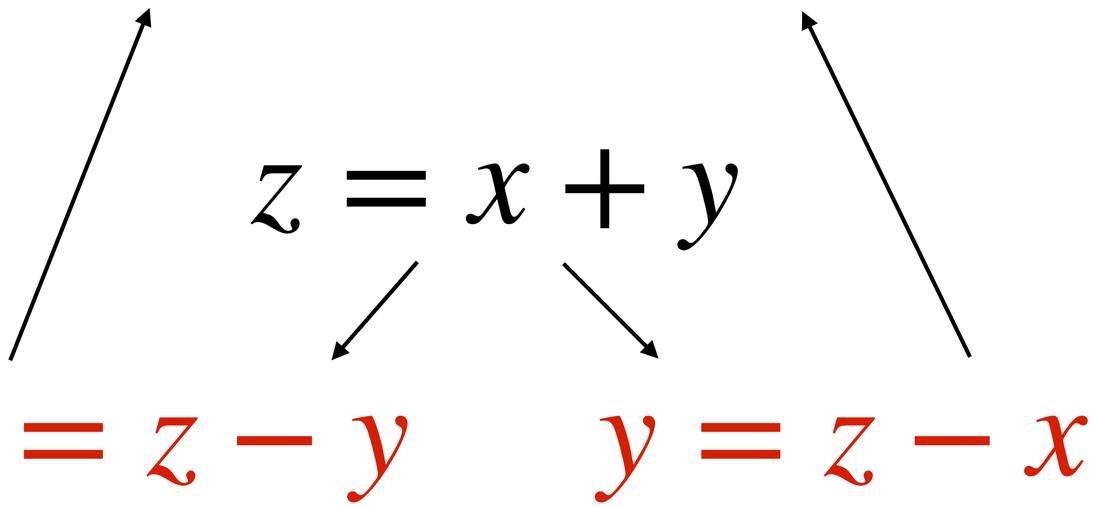
Semantic Fusion

$$\varphi_{concat} = \underbrace{(x > 0 \wedge x > 1)}_{\varphi_1} \wedge \underbrace{(y < 0 \wedge y < 1)}_{\varphi_2} \quad \textbf{SAT}$$



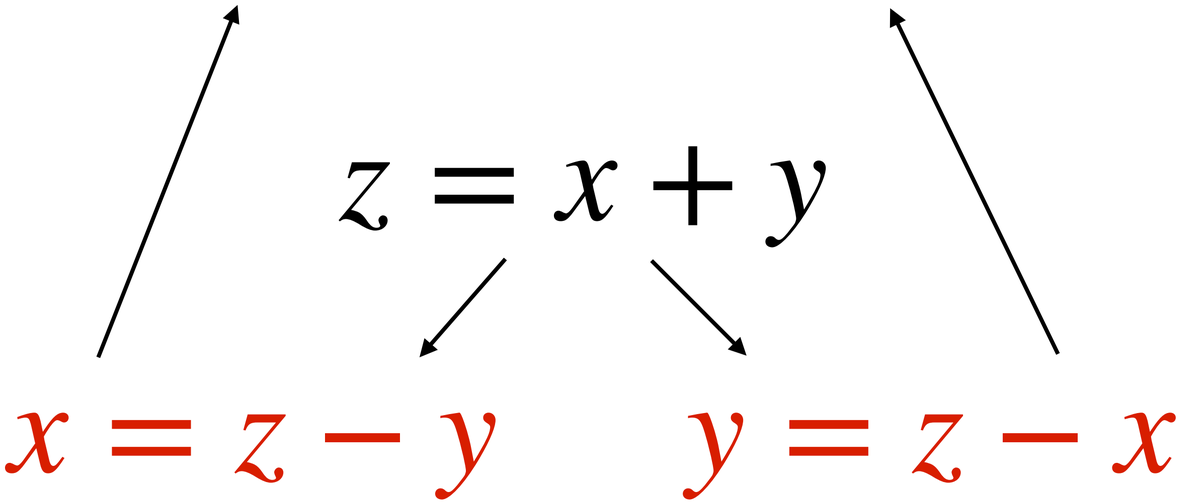
Semantic Fusion

$$\varphi_{fused} = (x > 0 \wedge \underbrace{(z - y) > 1}_{\varphi_1}) \wedge (\underbrace{(z - x) < 0}_{\varphi_2} \wedge y < 1)$$



Semantic Fusion

$$\varphi_{fused} = (x > 0 \wedge (z - y) > 1) \wedge ((z - x) < 0 \wedge y < 1)$$ **SAT**



Semantic Fusion

$$\varphi_{concat} = (x > 0 \wedge x > 1) \wedge (y < 0 \wedge y < 1)$$

$x = 1 \qquad y = -1$

$$\varphi_{fused} = (x > 0 \wedge (z - y) > 1) \wedge ((z - x) < 0 \wedge y < 1)$$ **SAT**

$$z = x + y$$

$$x = z - y \qquad y = z - x$$

Semantic Fusion

$$\varphi_{concat} = (x > 0 \wedge x > 1) \wedge (y < 0 \wedge y < 1)$$

$$x = 1 \quad z = x + y = 0 \quad y = -1$$

$$\varphi_{fused} = (x > 0 \wedge (z - y) > 1) \wedge ((z - x) < 0 \wedge y < 1)$$ **SAT**

$$z = x + y$$

$$x = z - y \qquad y = z - x$$

Semantic Fusion: an Example

```
(declare-fun x () Int)
(declare-fun w () Bool)
(assert (= x (- 1)))
(assert (= w (= x (- 1))))
(assert w)
```

SAT

```
(declare-fun y () Int)
(declare-fun v () Bool)
(assert (= v (not (= y (- 1)))))
(assert (ite v false (= y (- 1))))
```

SAT

Semantic Fusion: an Example

```
(declare-fun x () Int)
(declare-fun w () Bool)
(assert (= x (- 1)))
(assert (= w (= x (- 1))))
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(declare-fun y () Int)
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Semantic Fusion: an Example

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Semantic Fusion: an Example

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(assert w)
(assert (= v (not (= y (- 1)))))
(assert (ite v false (= y (- 1))))
```

Semantic Fusion: an Example

```
(declare-fun x () Int)
(declare-fun w () Bool)
(declare-fun y () Int)
(declare-fun v () Bool)
(declare-fun z () Int)
(assert (= x (- 1)))
(assert (= w (= x (- 1))))
(assert w)
(assert (= v (not (= y (- 1)))))
(assert (ite v false (= y (- 1))))
```

Semantic Fusion: an Example

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(declare-fun x () Int)
(declare-fun w () Bool)
(declare-fun y () Int)
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(declare-fun z () Int)
(assert (= x (- 1)))
(assert (= w (= x (- 1))))
(assert w)
(assert (= v (not (= y (- 1)))))
(assert (ite v false (= y (- 1))))
```

```
z = x * y
```

Semantic Fusion: an Example

```
(declare-fun x () Int)
(declare-fun w () Bool)
(declare-fun y () Int)
(declare-fun v () Bool)
(declare-fun z () Int)
(assert (= (div z y) (- 1)))
(assert (= w (= x (- 1))))
(assert w)
(assert (= v (not (= y (- 1)))))
(assert (ite v false (= (div z x) (- 1))))
```

```
z = x * y
```

Semantic Fusion: an Example

```
(declare-fun x () Int)
(declare-fun w () Bool)
(declare-fun y () Int)
(declare-fun v () Bool)
(declare-fun z () Int)
(assert (= (div z y) (- 1)))
(assert (= w (= x (- 1))))
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(assert (= v (not (= y (- 1)))))
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```

SAT

Semantic Fusion: an Example

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(declare-fun x () Int)
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(declare-fun y () Int)
(declare-fun v () Bool)
(declare-fun z () Int)
(assert (= (div z y) (- 1)))
(assert (= w (= x (- 1))))
(assert w)
(assert (= v (not (= y (- 1)))))
(assert (ite v false (= (div z x) (- 1))))
```

SAT

```
$ cvc4 example.smt2
unsat
```

Semantic Fusion: an Example

```
(declare-fun x () Int)
(declare-fun w () Bool)
(declare-fun y () Int)
(declare-fun v () Bool)
(declare-fun z () Int)
(assert (= (div z y) (- 1)))
(assert (= w (= x (- 1))))
(assert w)
(assert (= v (not (= y (- 1)))))
(assert (ite v false (= (div z x) (- 1))))
```

SAT

```
$ cvc4 example.smt2
unsat
```

https://github.com/CVC4/CVC4/issues/3413

Semantic Fusion

$$\varphi_1 = x > 1 \wedge x < 0 \quad \textbf{UNSAT}$$
$$\varphi_2 = y < 0 \wedge y > 1 \quad \textbf{UNSAT}$$

Semantic Fusion

$$\varphi_1 \qquad\qquad \varphi_2$$

$$(x > 1 \wedge x < 0) \vee (y < 0 \wedge y > 1)$$

Semantic Fusion

$$\varphi_{concat} = \underbrace{(x > 1 \wedge x < 0)}_{\varphi_1} \vee \underbrace{(y < 0 \wedge y > 1)}_{\varphi_2}$$

UNSAT

Semantic Fusion

$$\varphi_{concat} = \underbrace{(x > 1 \wedge x < 0)}_{\varphi_1} \vee \underbrace{(y < 0 \wedge y > 1)}_{\varphi_2}$$

UNSAT

z

Semantic Fusion

$$\varphi_{concat} = \underbrace{(x > 1 \wedge x < 0)}_{\varphi_1} \vee \underbrace{(y < 0 \wedge y > 1)}_{\varphi_2}$$

UNSAT

$$z = x + y$$

Semantic Fusion

$$\varphi_{concat} = \underbrace{(x > 1 \wedge x < 0)}_{\varphi_1} \vee \underbrace{(y < 0 \wedge y > 1)}_{\varphi_2}$$

UNSAT

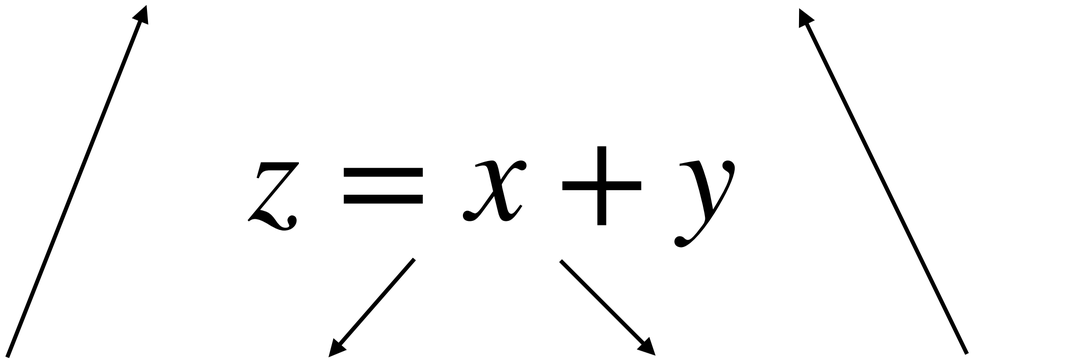
$$z = x + y$$

$$x = z - y \qquad y = z - x$$

Semantic Fusion

$$\varphi_{fused} = (x > 1 \wedge (z - y) < 0) \vee ((z - x) < 0 \wedge y > 1)$$

φ_1 φ_2



Semantic Fusion

$$\varphi_{fused} = (x > 1 \wedge (z - y) < 0) \vee ((z - x) < 0 \wedge y > 1)$$ **SAT**

Semantic Fusion

$$x = 2 \qquad z = 0 \qquad y = 2$$

$$\varphi_{fused} = (x > 1 \wedge (z - y) < 0) \vee ((z - x) < 0 \wedge y > 1)$$ **SAT**

Semantic Fusion

$$\varphi_{fused} = ((x > 1 \wedge (z - y) < 0) \vee ((z - x) < 0 \wedge y > 1)) \wedge z = x + y$$

Fusion Constraint

Semantic Fusion

$$\varphi_{fused} = ((x > 1 \wedge (z - y) < 0) \vee ((z - x) < 0 \wedge y > 1)) \wedge z = x + y$$

UNSAT

Semantic Fusion: an Example

```
(declare-fun x () Real)
(assert (not (= (+ (+ 1.0 x) 6.0)
                (+ 7.0 x))))
```

UNSAT

```
(declare-fun y () Real)
(declare-fun w () Real)
(declare-fun v () Real)
(assert (and (< y v) (>= w v)
             (< (/ w v ) 0) (> y 0)))
```

UNSAT

Semantic Fusion: an Example

```
(declare-fun x () Real)
(assert (not (= (+ (+ 1.0 x) 6.0)
                (+ 7.0 x))))
```

```
(declare-fun y () Real)
(declare-fun w () Real)
(declare-fun v () Real)
(assert (and (< y v) (>= w v)
             (< (/ w v ) 0) (> y 0)))
```

Semantic Fusion: an Example

```
(declare-fun x () Real)
(declare-fun y () Real)
(declare-fun w () Real)
(declare-fun v () Real)
(assert (or
        (not (= (+ (+ 1.0 x) 6.0)
                (+ 7.0 x))))
        (and (< y v) (>= w v)
             (< (/ w v ) 0) (> y 0))))
```

Semantic Fusion: an Example

```
(declare-fun x () Real)
(declare-fun y () Real)
(declare-fun w () Real)
(declare-fun v () Real)
(assert (or
        (not (= (+ (+ 1.0 x) 6.0)
                (+ 7.0 x))))
        (and (< y v) (>= w v)
             (< (/ w v ) 0) (> y 0))))
```

Semantic Fusion: an Example

```
(declare-fun x () Real)
(declare-fun y () Real)
(declare-fun w () Real)
(declare-fun v () Real)
(declare-fun z () Real)
(assert (or
        (not (= (+ (+ 1.0 x) 6.0)
                (+ 7.0 x))))
        (and (< y v) (>= w v)
             (< (/ w v ) 0) (> y 0))))
```

Semantic Fusion: an Example

```
(declare-fun x () Real)
(declare-fun y () Real)
(declare-fun w () Real)
(declare-fun v () Real)
(declare-fun z () Real)
(assert (or
        (not (= (+ (+ 1.0 x) 6.0)
                (+ 7.0 x))))
        (and (< y v) (>= w v)
             (< (/ w v ) 0) (> y 0)))))
```

```
z = x * y
```

Semantic Fusion: an Example

```
(declare-fun x () Real)
(declare-fun y () Real)
(declare-fun w () Real)                          z = x * y
(declare-fun v () Real)
(declare-fun z () Real)
(assert (or
        (not (= (+ (+ 1.0 (/ z y)) 6.0)
                (+ 7.0 x))))
        (and (< (/ z x) v) (>= w v)
             (< (/ w v ) 0) (> (/ z x) 0))))
```

Semantic Fusion: an Example

```
(declare-fun x () Real)
(declare-fun y () Real)
(declare-fun w () Real)
(declare-fun v () Real)
(declare-fun z () Real)
(assert (or
        (not (= (+ (+ 1.0 (/ z y)) 6.0)
                (+ 7.0 x))))
        (and (< (/ z x) v) (>= w v)
             (< (/ w v ) 0) (> (/ z x) 0))))
(assert (= z (* x y)))
(assert (= x (/ z y)))
(assert (= y (/ z x)))
```

```
z = x * y
```

Semantic Fusion: an Example

```
(declare-fun x () Real)
(declare-fun y () Real)
(declare-fun w () Real)
(declare-fun v () Real)
(declare-fun z () Real)
(assert (or
        (not (= (+ (+ 1.0 (/ z y)) 6.0)
                (+ 7.0 x))))
        (and (< (/ z x) v) (>= w v)
             (< (/ w v ) 0) (> (/ z x) 0))))
(assert (= z (* x y)))
(assert (= x (/ z y)))
(assert (= y (/ z x)))
```

UNSAT

Semantic Fusion: an Example

```
(declare-fun x () Real)
(declare-fun y () Real)
(declare-fun w () Real)
(declare-fun v () Real)
(declare-fun z () Real)
(assert (or
        (not (= (+ (+ 1.0 (/ z y)) 6.0)
                (+ 7.0 x))))
        (and (< (/ z x) v) (>= w v)
             (< (/ w v ) 0) (> (/ z x) 0))))
(assert (= z (* x y)))
(assert (= x (/ z y)))
(assert (= y (/ z x)))
```

UNSAT

```
% z3 example.smt2
sat
```

Semantic Fusion: an Example

```
(declare-fun x () Real)
(declare-fun y () Real)
(declare-fun w () Real)
(declare-fun v () Real)
(declare-fun z () Real)
(assert (or
        (not (= (+ (+ 1.0 (/ z y)) 6.0)
                (+ 7.0 x))))
        (and (< (/ z x) v) (>= w v)
             (< (/ w v ) 0) (> (/ z x) 0))))
(assert (= z (* x y)))
(assert (= x (/ z y)))
(assert (= y (/ z x)))
```

UNSAT

```
% z3 example.smt2
sat
```

https://github.com/Z3Prover/z3/issues/2391

Fusion Functions

Type	Fusion Function	Variable Inversion Functions	
		r_x	r_y
Int	$x + y$	$z - y$	$z - x$
	$x + c + y$	$z - c - y$	$z - c - x$
	$x * y$	$z \ div \ y$	$z \ div \ x$
	$c_1 * x + c_2 * y + c_3$	$(z - c_2 * y - c_3) \ div \ c_1$	$(z - c_1 * x - c_3) \ div \ c_2$
Real	$x + y$	$z - y$	$z - x$
	$x + c + y$	$z - c - y$	$z - c - x$
	$x * y$	z/y	z/x
	$c_1 * x + c_2 * y + c_3$	$(z - c_2 * y - c_3)/c_1$	$(z - c_1 * x - c_3)/c_2$
String	$x \ str{+}{+} \ y$	$str.substr \ z \ 0 \ (str.len \ x)$	$str.substr \ z \ (str.len \ x) \ (str.len \ y)$
	$x \ str{+}{+} \ y$	$str.substr \ z \ 0 \ (str.len \ x)$	$str.replace \ z \ x \ ""$
	$x \ str{+}{+} \ c \ str{+}{+} \ y$	$str.substr \ z \ 0 \ (str.len \ x)$	$str.replace \ (str.replace \ z \ x \ "") \ c \ ""$

Empirical Evaluation

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- Tool YinYang, our realization of Semantic Fusion

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- Bug hunting with YinYang (July-October 2019)

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Empirical Evaluation

- Tool YinYang, our realization of Semantic Fusion
- Bug hunting with YinYang (July-October 2019)
- Bug reduction with C-Reduce
- Bug reports on issue trackers of Z3 and CVC4

How many bugs can YinYang find?

Status	Z3	CVC4	Total
Reported	45	13	58
Confirmed	38	8	46
Fixed	36	6	42
Duplicate	4	1	5
Won't fix	2	0	2

Type	Z3	CVC4	Total
Soundness	24	6	30
Crash	11	1	12
Performance	1	2	3
Unknown	1	0	1

Logic	Z3	CVC4	Total
NIA	2	1	3
NRA	15	1	16
QF_NIA	0	1	1
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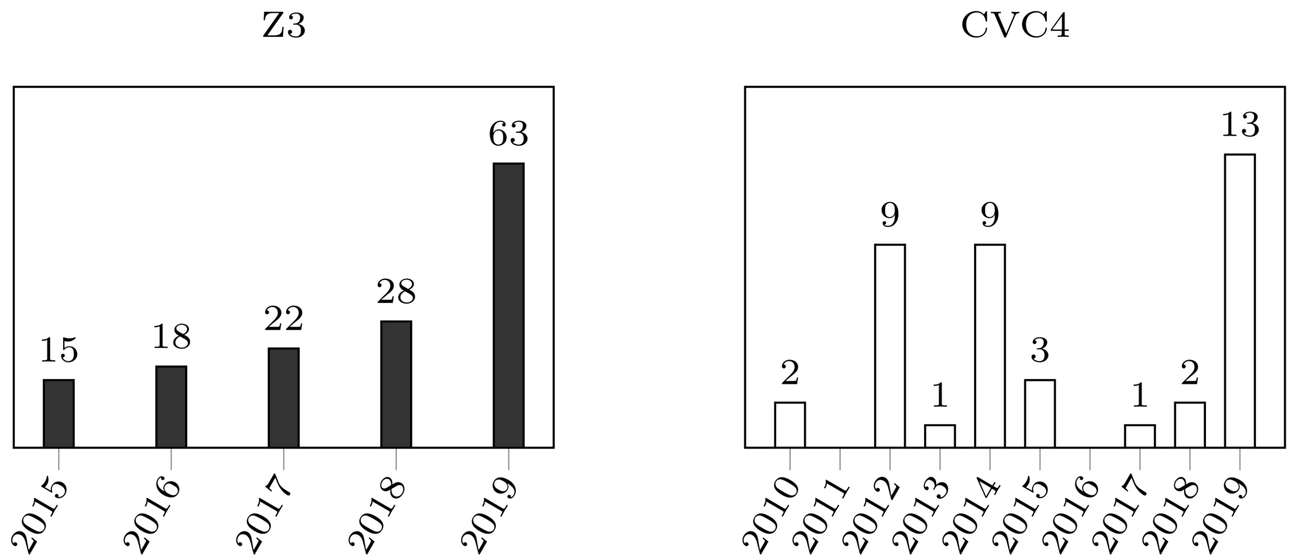
Significance of the bug finding results



Soundness bugs per year in Z3 and CVC4.

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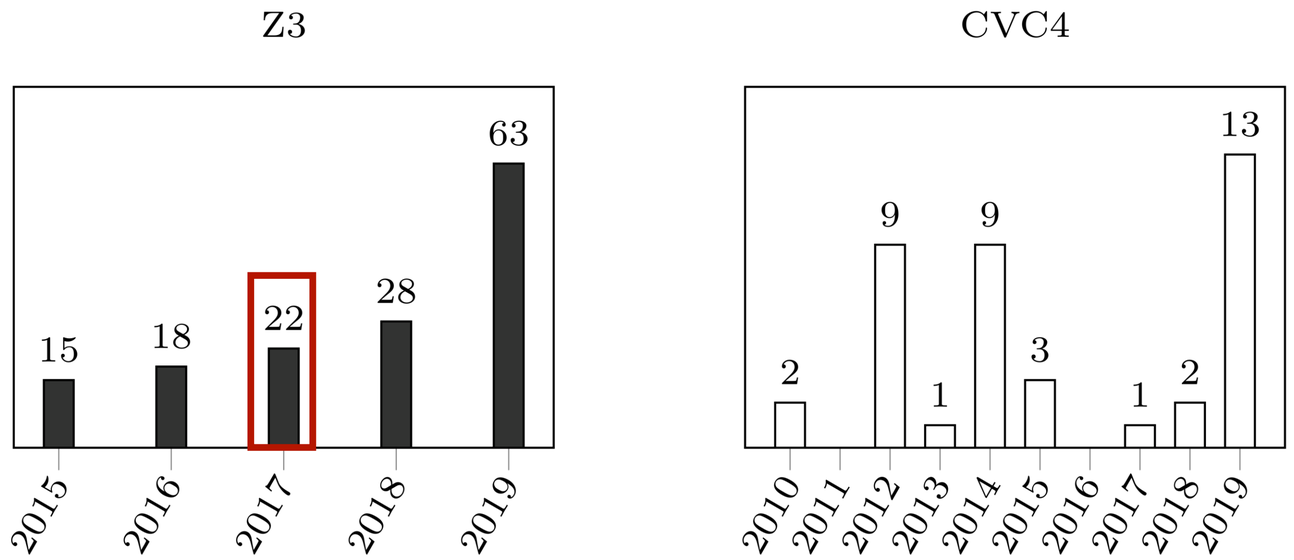

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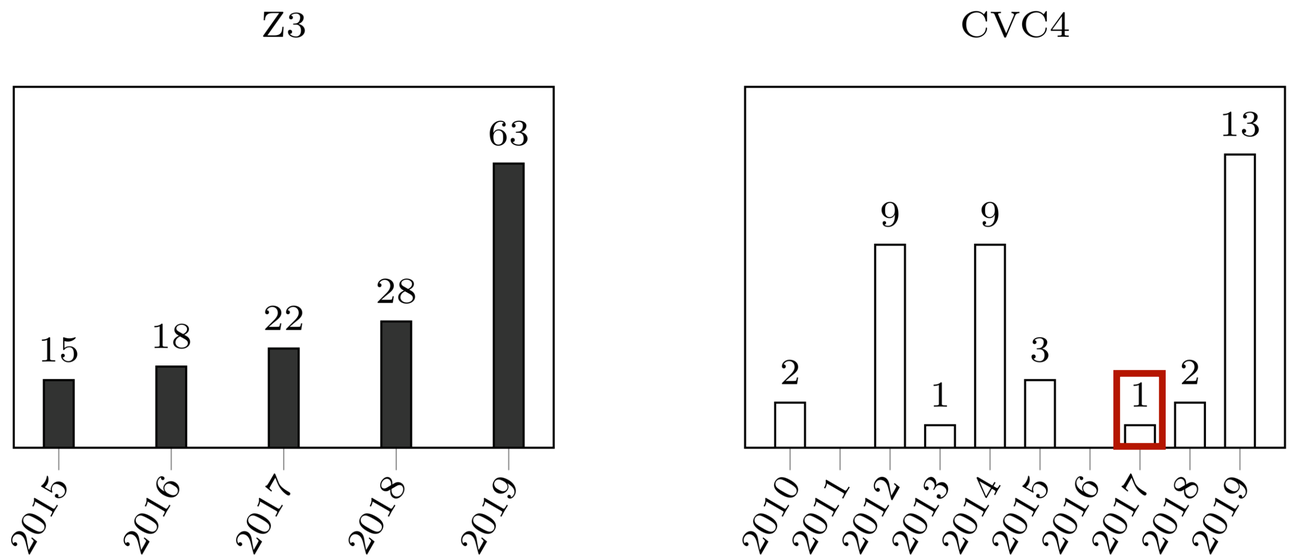

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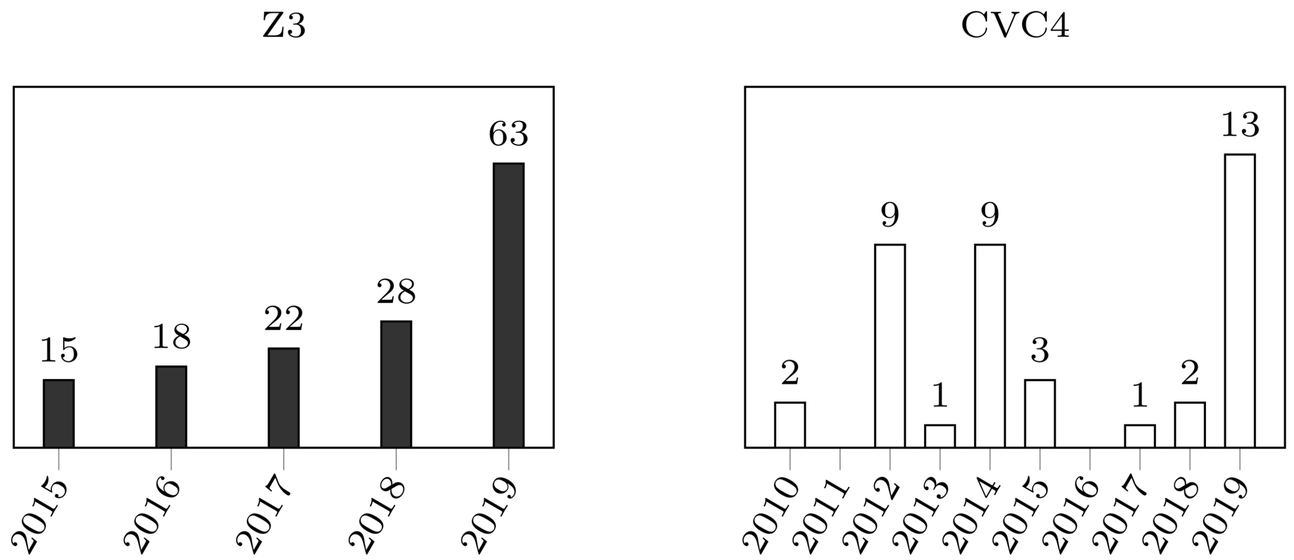
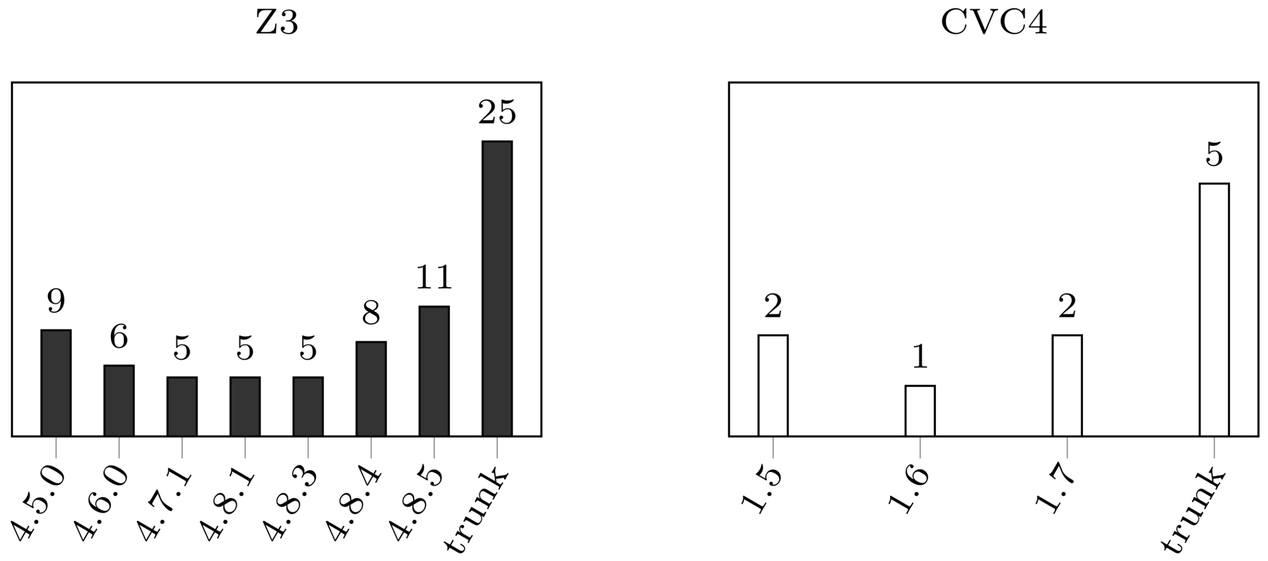


Soundness bugs per year in Z3 and CVC4.

YinYang found 24 in Z3, 5 in CVC4 in 4 months

Significance of the bug finding results



Soundness bugs in historical Z3 and CVC4 releases and the trunk.

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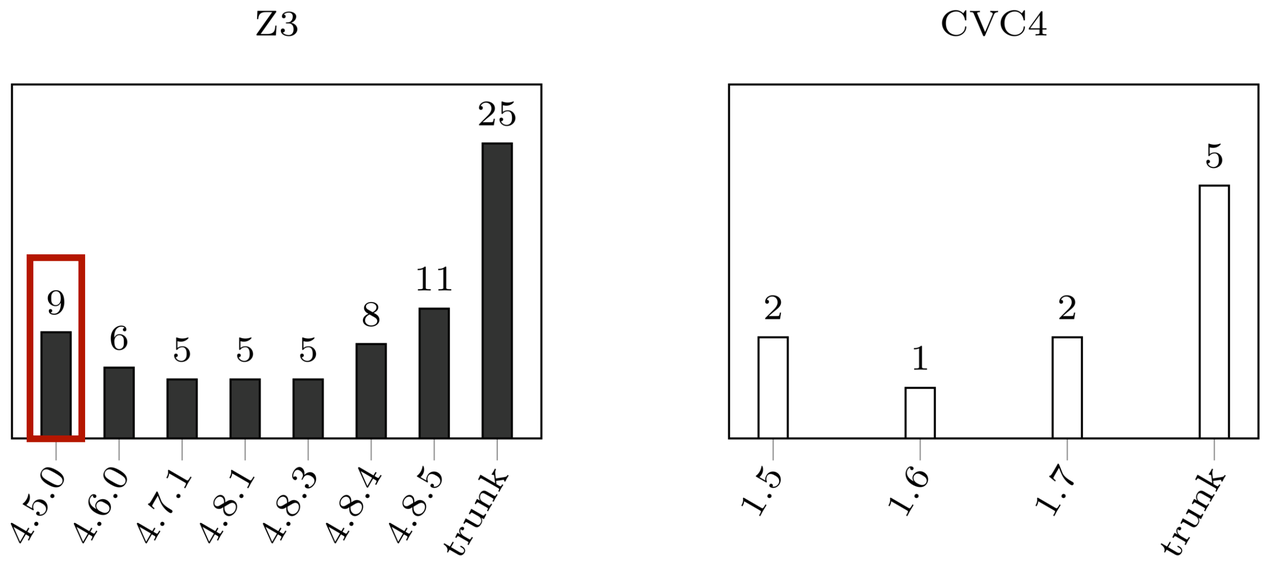

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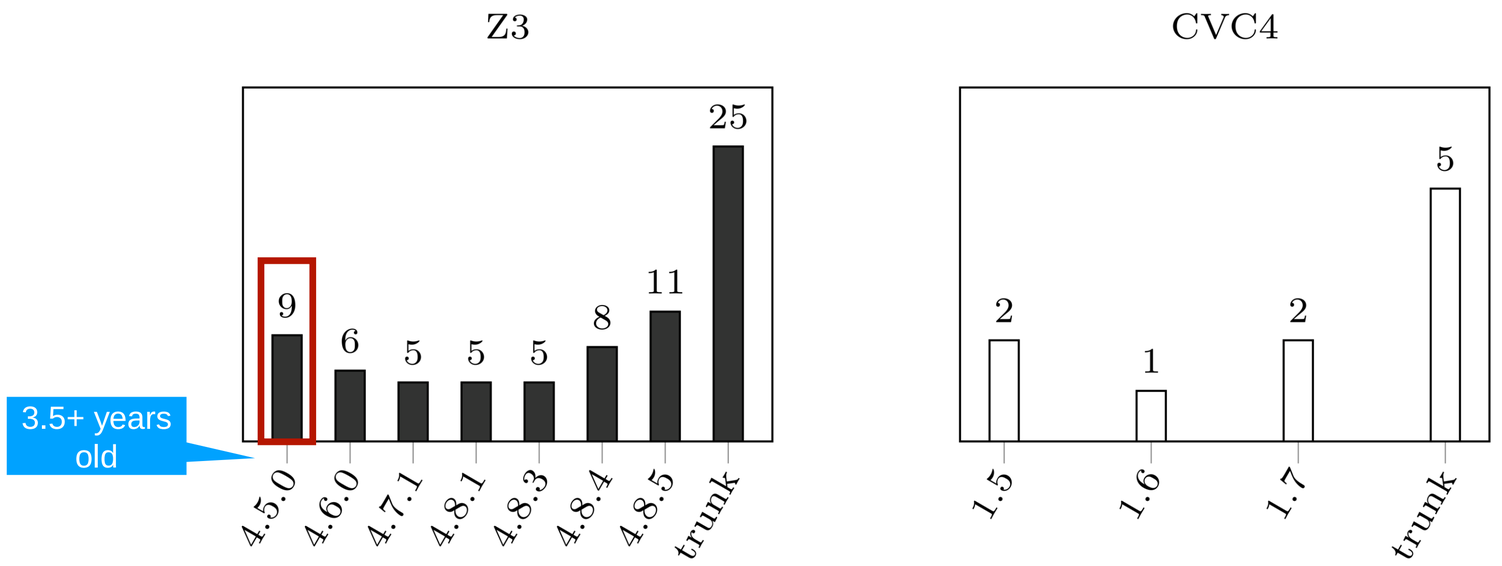

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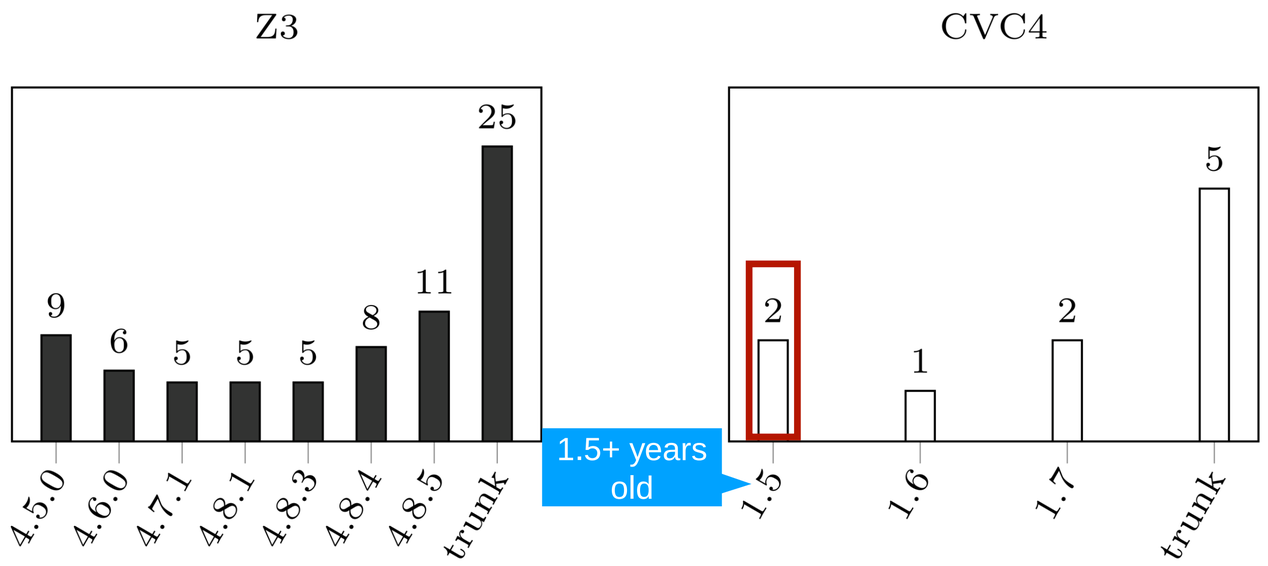

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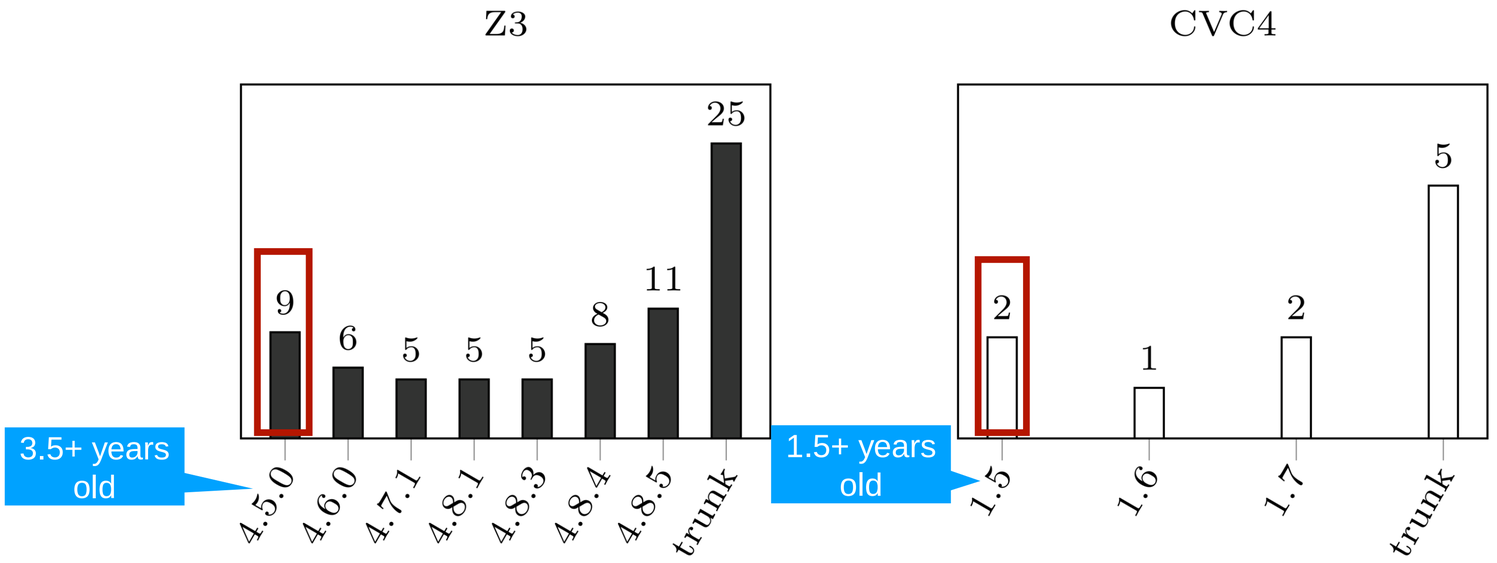

Soundness bugs in historical Z3 and CVC4 releases and the trunk.

YinYang found longstanding soundness bugs

Is Semantic Fusion necessary?

Is Semantic Fusion necessary?

ConcatFuzz

$\varphi_1 \quad \wedge \quad \varphi_2$

SAT **SAT**

$\varphi_1 \quad \vee \quad \varphi_2$

UNSAT **UNSAT**

Is Semantic Fusion necessary?

ConcatFuzz

$\varphi_1 \quad \wedge \quad \varphi_2$

SAT **SAT**

$\varphi_1 \quad \vee \quad \varphi_2$

UNSAT **UNSAT**

ConcatFuzz can only retrigger 5/50 bugs

Is Semantic Fusion necessary?

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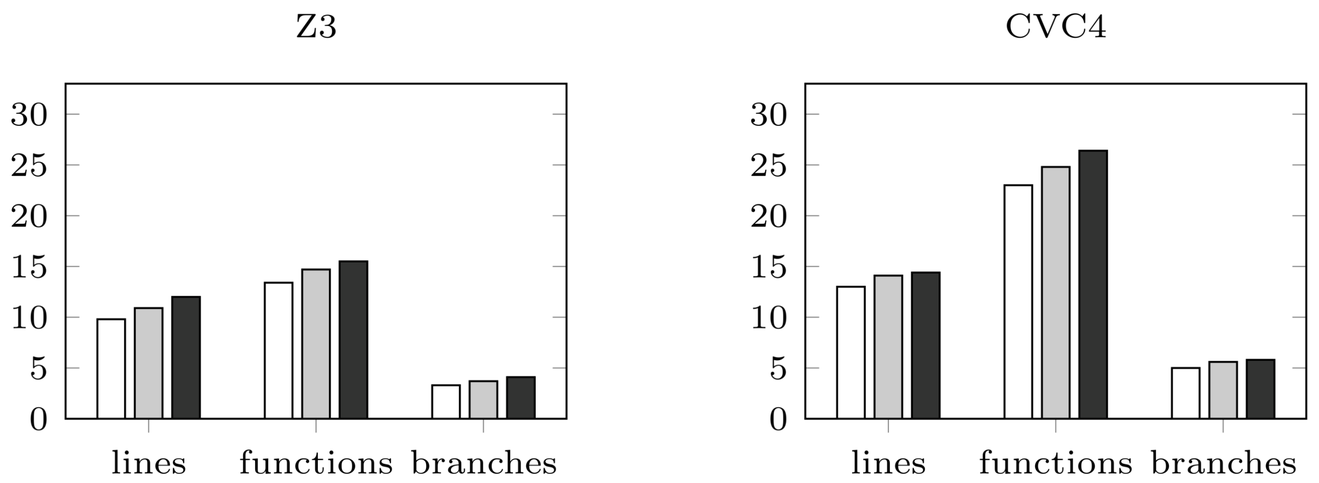

Code coverage comparison of Benchmark, ConcatFuzz and YinYang.

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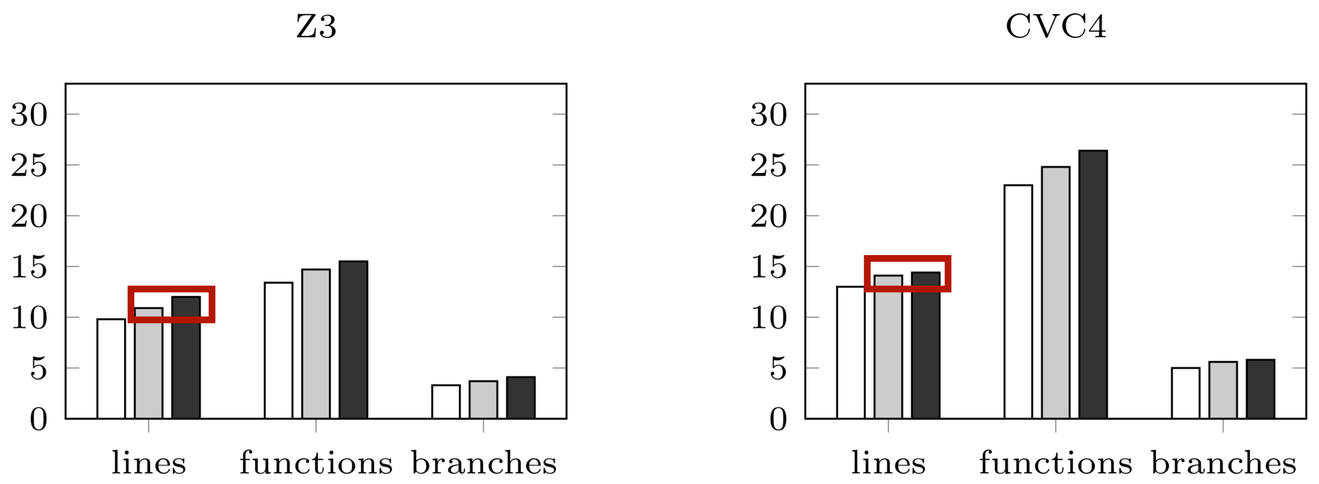

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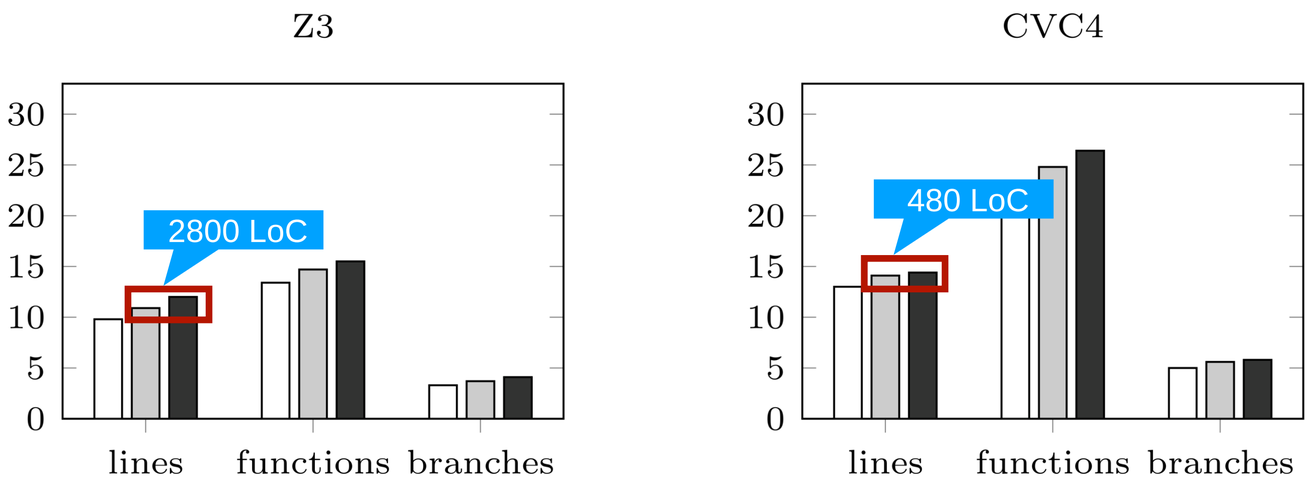

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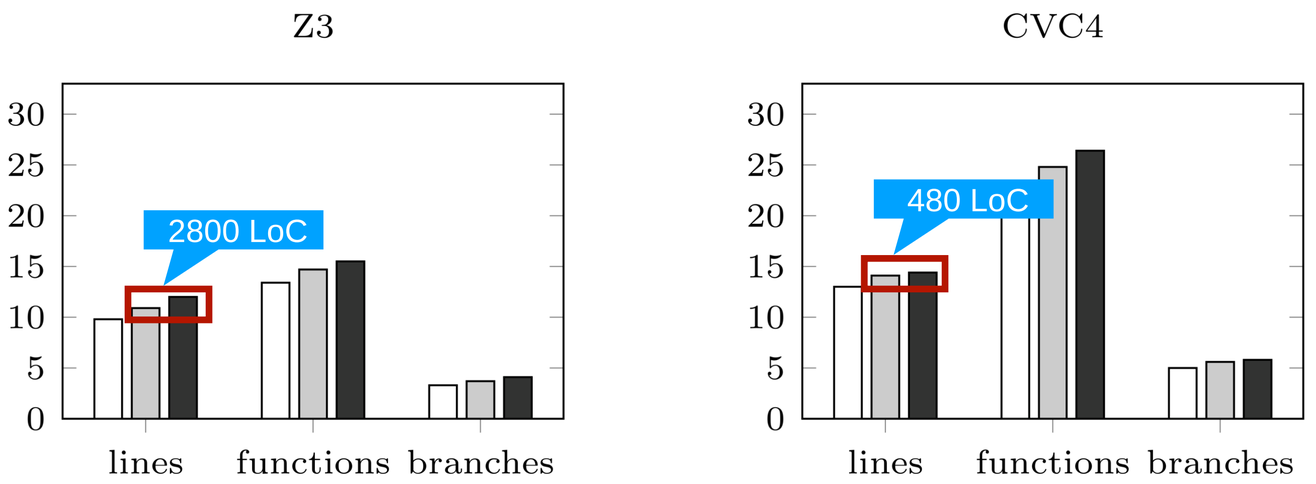

Code coverage comparison of Benchmark, ConcatFuzz and YinYang.

YinYang consistently achieves higher coverage

Z3 #2376

```
% cat formula.smt2
(declare-fun a () Real)
(declare-fun b () Real)
(declare-fun c () Real)
(declare-fun d () Real)
(declare-fun j () Real)
(declare-fun e () Real)
(assert (not (exists ((f Real))
(=> (and (< (/ 0 0) c) (< (/ 0 (* 2.0 b))
d))(= (= 0.0 a) (not (=> (<= f a) (<= e
j))))))))
(check-sat)

% cvc4 formula.smt2
unsat

%z3 formula.smt2
sat
```

Z3 #2376

```
% cat formula.smt2
(declare-fun a () Real)
(declare-fun b () Real)
(declare-fun c () Real)
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d))(= (= 0.0 a) (not (=> (<= f a) (<= e
j))))))))
(check-sat)

% cvc4 formula.smt2
unsat

%z3 formula.smt2
sat
```

NikolajBjorner commented on 5 Jul 2019

thanks, fixed

CVC4 #3412

```
% cat formula.smt2
(declare-fun a () Int)
(declare-fun b () Int)
(assert (= (div a b) (- 1)))
(check-sat)

% z3 formula.smt2
sat

% cvc4 formula.smt2
unsat
```

CVC4 #3412

```
% cat formula.smt2
(declare-fun a () Int)
(declare-fun b () Int)
(assert (= (div a b) (- 1)))
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```

```
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```

```
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```

CVC4 #3412

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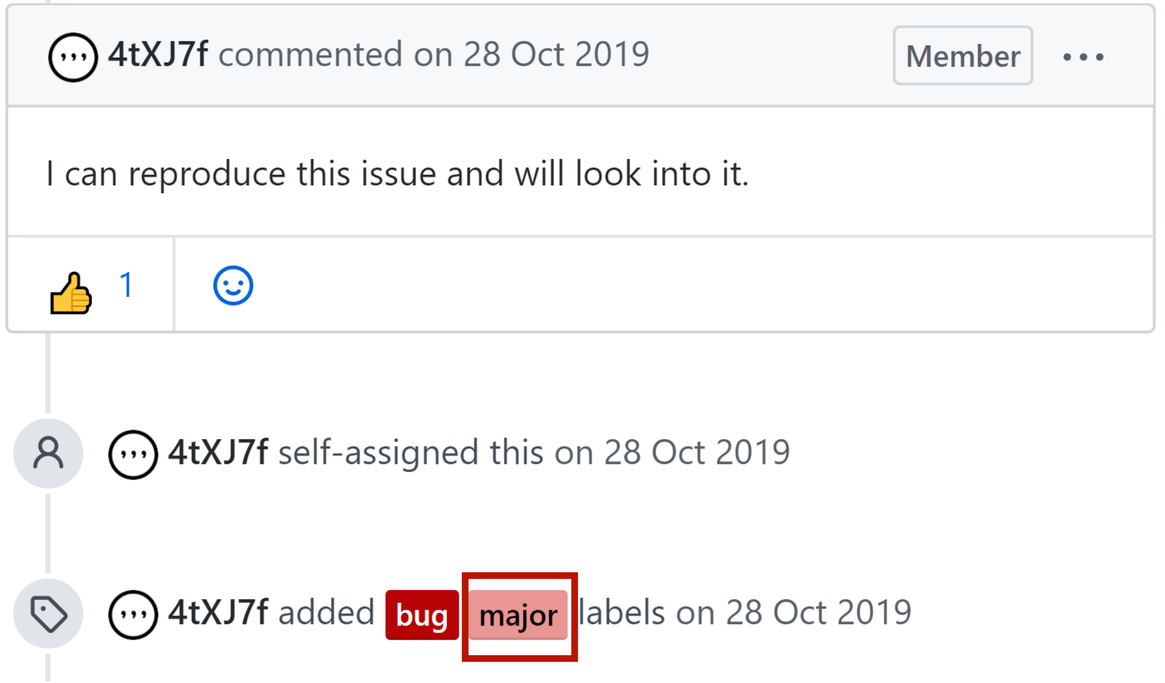
```



Z3 #4153

```
% cat formula.smt2
(declare-fun a () String)
(declare-fun b () String)
(assert (=
    (str.++ (str.substr "1" 0  (str.len a))
"0") b))
(assert (< (str.to.int b) 0))
(check-sat)

% z3-4.8-7 formula.smt2
unsat

% z3 formula.smt2
sat
```

Z3 #4153

```
% cat formula.smt2
(declare-fun a () String)
(declare-fun b () String)
(assert (=
    (str.++ (str.substr "1" 0  (str.len a))
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(assert (< (str.to.int b) 0))
(check-sat)

% z3-4.8-7 formula.smt2
unsat

% z3 formula.smt2
sat
```

NikolajBjorner commented on 29 Apr

exposed

- incomplete axiomatization of stoi
- more opportunities for rewriting

CVC4 #3217

```
% cat formula.smt2
(declare-fun a () String)
(declare-fun b () String)
(declare-fun c () String)
(declare-fun d () String)
(assert
    (or (not (= (str.suffixof "B"
                (str.replace "A" b "B"))
     (= ( str.substr a 0 (str.len b)) "A")))
        (not (= (not (= c "A")) (str.suffixof "A"
        (str.replace "A" c "B"))))))
(assert (= a (str.++ (str.++ b "") d)))
(check-sat)


% z3 formula.smt2
unsat

% cvc4 formula.smt2
sat
```

CVC4 #3217

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% cat formula.smt2
(declare-fun a () String)
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(assert
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        (not (= (not (= c "A")) (str.suffixof "A"
        (str.replace "A" c "B"))))))
(assert (= a (str.++ (str.++ b "") d)))
(check-sat)
```

ajreynol commented on 23 Aug 2019

Another excellent find, thanks a lot.

This is fixed in my latest PR.

ajreynol added **bug** **major** labels on 23 Aug 2019

```
% z3 formula.smt2
unsat

% cvc4 formula.smt2
sat
```

Z3 #2618 & CVC4 #3357

```
% cat formula.smt2
(declare-fun a () String)
(declare-fun b () String)
(declare-fun c () String)
(assert (str.in.re c
(re.* (re.union (str.to.re "aa")
(str.to.re ""))))))
(assert (= 0 (str.to.int
(str.replace a b (str.at a
(str.len a))))))
(assert (= a (str.++ b c)))
(check-sat)

% cvc4 formula.smt2
unsat

% z3 formula.smt2
sat
```

Z3 #2618 & CVC4 #3357

```
% cat formula.smt2
(declare-fun a () String)
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(declare-fun c () String)
(assert (str.in.re c
(re.* (re.union (str.to.re "aa")
(str.to.re ""))))))
(assert (= 0 (str.to.int
(str.replace a b (str.at a
(str.len a))))))
(assert (= a (str.++ b c)))
(check-sat)

% cvc4 formula.smt2
unsat

% z3 formula.smt2
sat
```

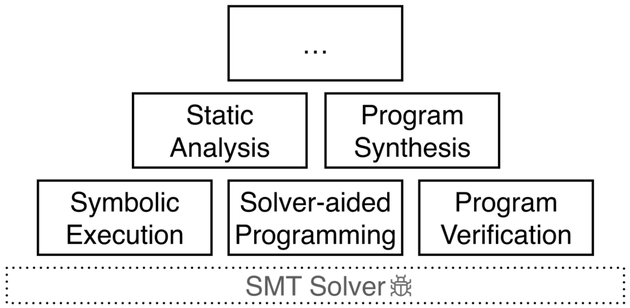
```
% z3 unreduced.smt2
sat
```

```
% cvc4 unreduced.smt2
sat
```

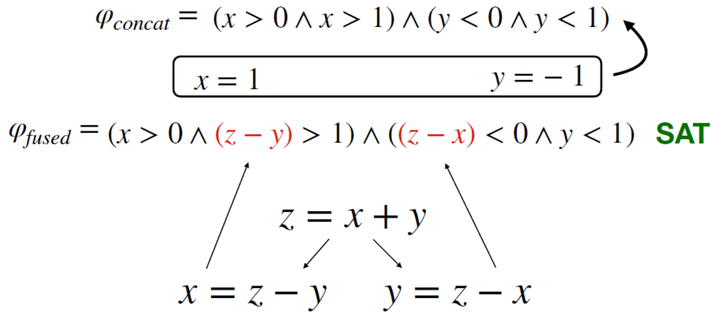
Z3 and CVC4 are both unsound on the unreduced test!

Summary

SMT Solver



Semantic Fusion



Testing SMT solvers is challenging

- How to generate test formulas?
- How to obtain the test oracles?
- It is challenging to find bugs.

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YinYang Release

YinYang will be released this summer.
Please stay tuned!

Statistics & Report links

https://github.com/Z3Prover/z3/issues/2530 Fixed
https://github.com/Z3Prover/z3/issues/2531 Fixed
https://github.com/Z3Prover/z3/issues/2533 Fixed
https://github.com/Z3Prover/z3/issues/2546 Fixed
https://github.com/Z3Prover/z3/issues/2548 Fixed
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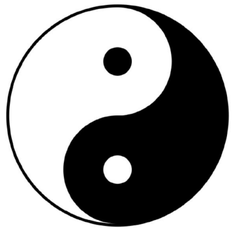
https://github.com/Z3Prover/z3/issues/2562 Fixed
https://github.com/Z3Prover/z3/issues/2563 Dup
https://github.com/Z3Prover/z3/issues/2566 Dup
https://github.com/Z3Prover/z3/issues/2567 Fixed
https://github.com/Z3Prover/z3/issues/2573 Fixed
https://github.com/Z3Prover/z3/issues/2578 Fixed
https://github.com/Z3Prover/z3/issues/2580 Fixed
https://github.com/Z3Prover/z3/issues/2612 Fixed

https://testsmt.github.io

Code



github.com/testsmt