Analysis of Incomplete Programs

a.k.a Programs with *closed-box* components

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Indian Institute of Technology Kanpur

Incomplete programs

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main() {
  input (a,b);
  …
  If (...)
     x = foo(a, b);
  …
  assert(...);
}
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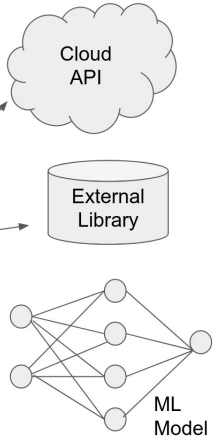

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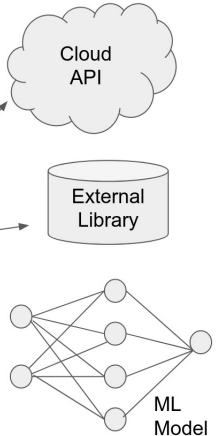

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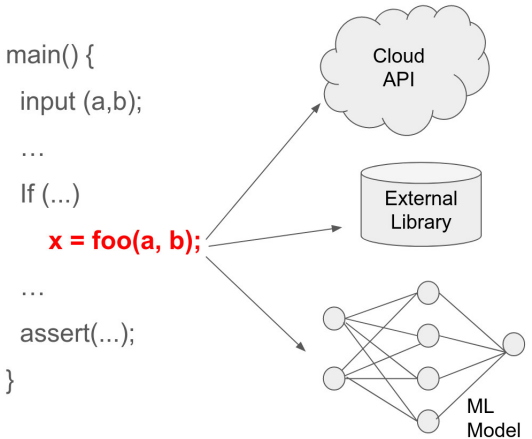

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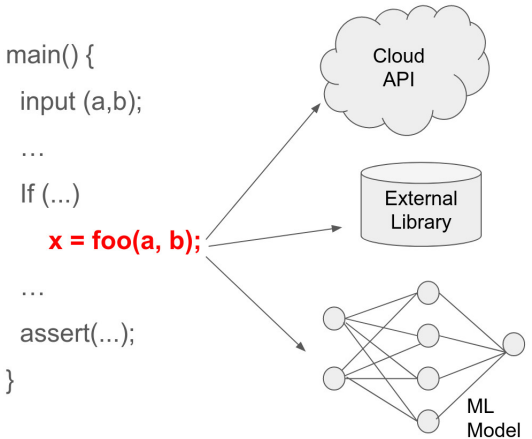

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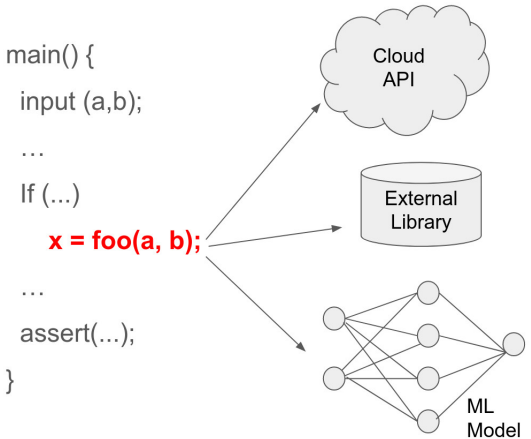

- *Unknown* (ongoing)
- *Closed-box* or Oracle access (ISSTA'19, ISSTA'22, OOPSLA'22a, **OOPSLA'22b**)
- Knowledge of probabilistic distribution (S&P(Oakland)'21, CAV'22, OOPSLA'22c)

Solution

Tests + Proofs

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Tests + Proofs

(fuzzing, random sampling) (SMT solving, Computer Algebra Systems)

COLOSSUS: Deferred Concretization (*Awanish Pandey et al. ISSTA'19*)

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int main( ) {
  read (x) ;
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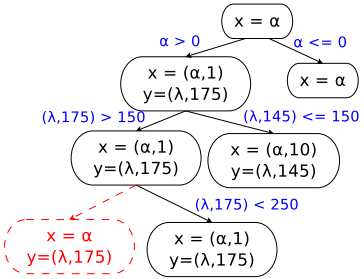

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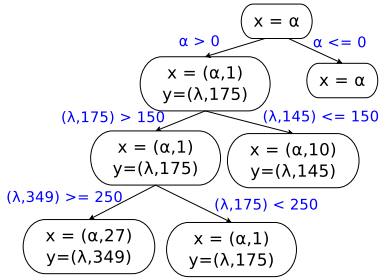

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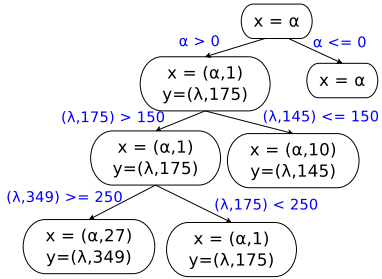

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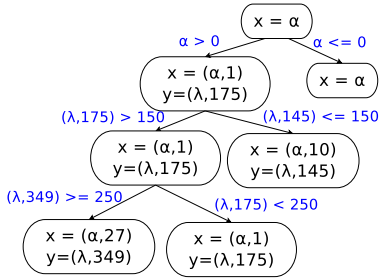

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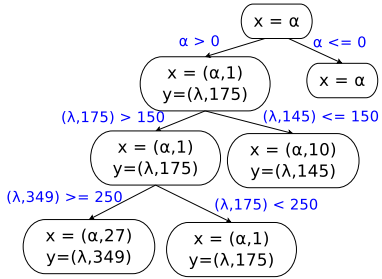

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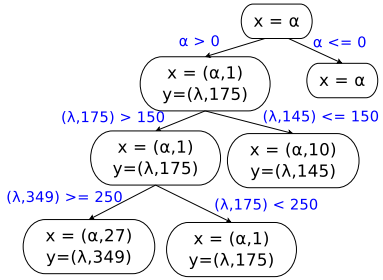

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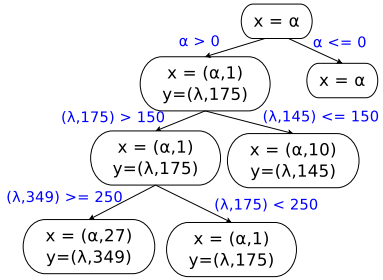

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(Solution : $\alpha_1 = 1, \alpha_2 = 3, \alpha_3 = 3, \alpha_4 = 6, \alpha_5 = 216$)

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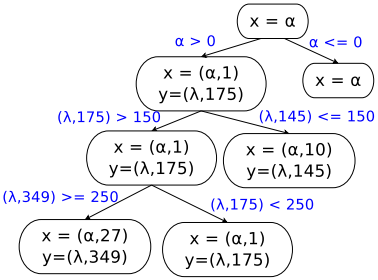

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COLOSSUS improves branch coverage by 66.94% over concretization and 115% over full symbolic return.

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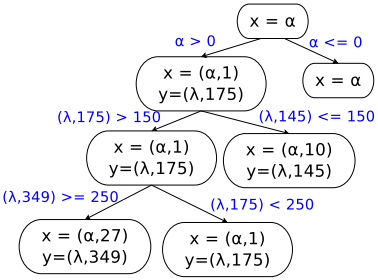

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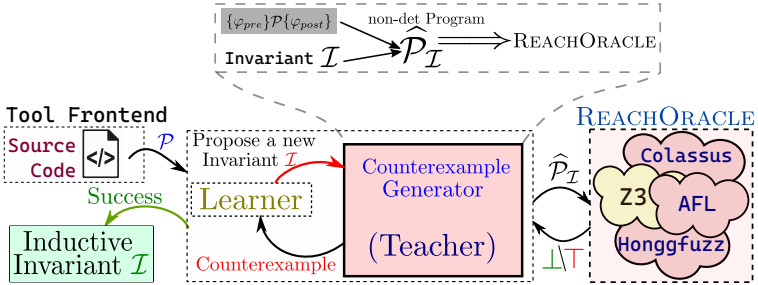
COLOSSUS improves branch coverage by 66.94% over concretization and 115% over full symbolic return. COLOSSUS explores 38.6% extra execution tree missed due to concretization.

ACHAR: Almost Correct Invariants (*Sumit Lahiri et al. ISSTA'22*)



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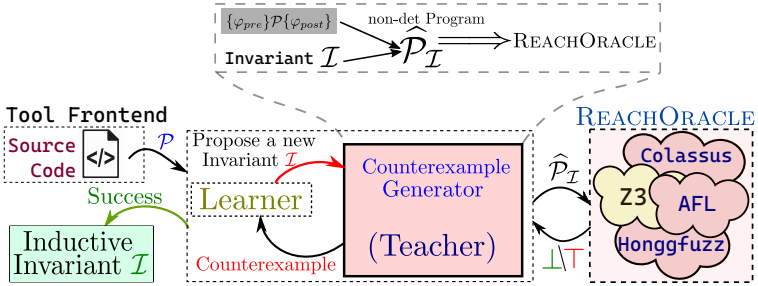

Proof Fuzzing

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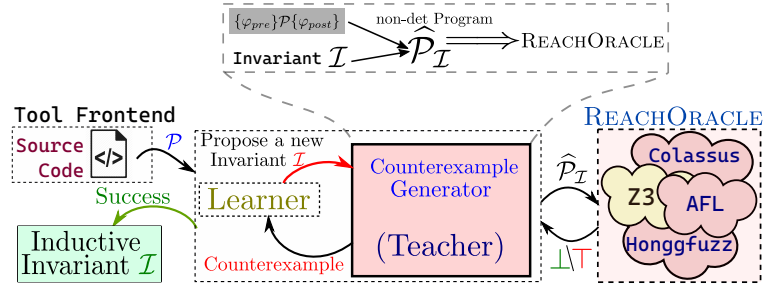

Proof Fuzzing

- **Theorem**: If a "goal" location in $\widehat{\mathrm{P}}_{\mathcal{I}}$ is *unreachable*, $\mathcal{I}$ is a *valid invariant* for $\{\varphi_{\mathrm{pre}}\}\mathcal{P}\{\varphi_{\mathrm{post}}\}$.

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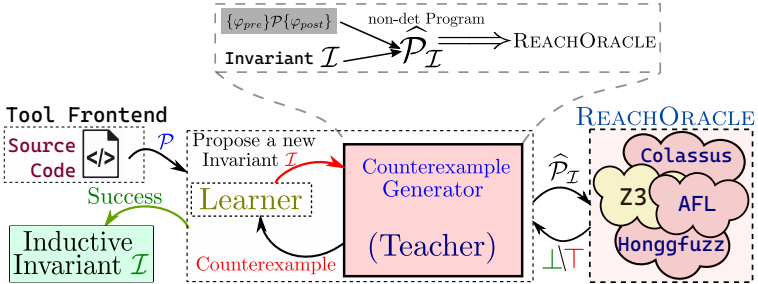

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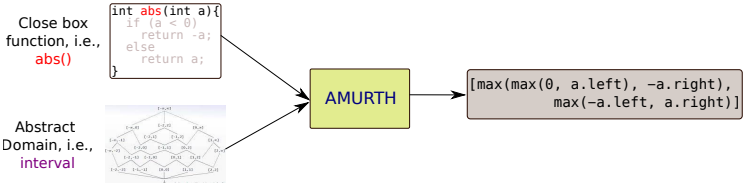
- **Theorem**: If a "goal" location in $\widehat{\mathrm{P}}_{\mathcal{I}}$ is *unreachable*, $\mathcal{I}$ is a *valid invariant* for $\{\varphi_{\mathrm{pre}}\}\mathcal{P}\{\varphi_{\mathrm{post}}\}$.
- Use fuzzing to test for reachability in $\hat{\mathrm{P}}_{\mathcal{I}}$.

AMURTH: Synthesizing Abstract Transformers (*Pankaj Kalita et al. OOPSLA'22*)



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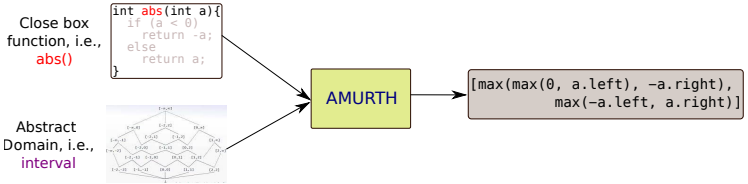

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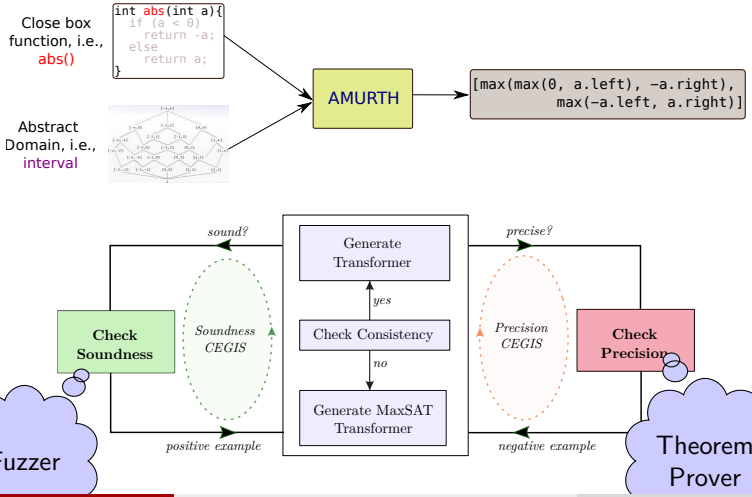
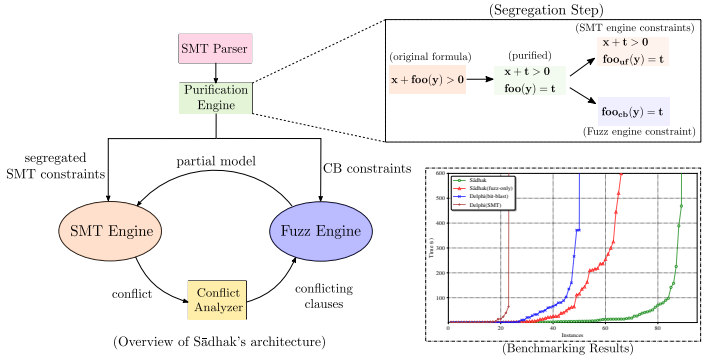


Today's Focus: SĀDHAK

SĀDHAK: Satisfiability Modulo Fuzzing (*Sujit Muduli et al. OOPSLA'22*)



(Overview of Sādhak's architecture)

(Benchmarking Results)

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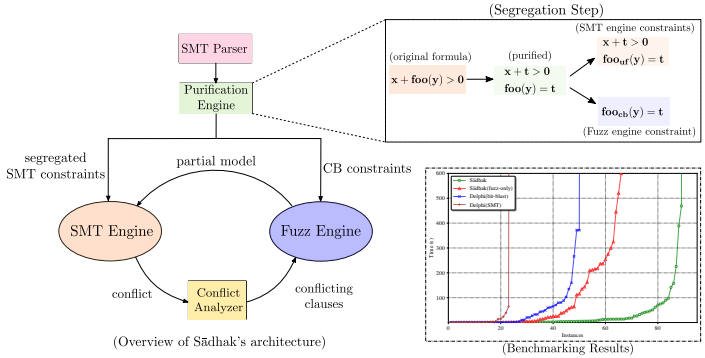

Conflict Driven Fuzz Loop (CDFL)

- We introduce the theory of **Closed-box (CB) functions**;

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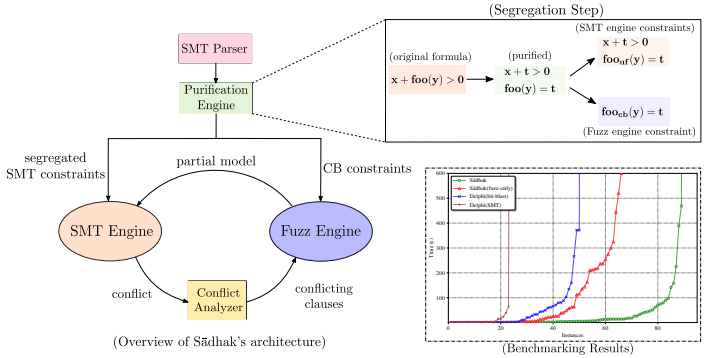

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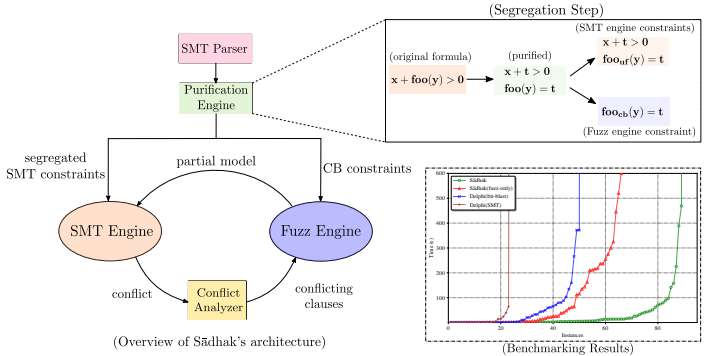

Conflict Driven Fuzz Loop (CDFL)

- We introduce the theory of **Closed-box (CB) functions**;
- The procedure is sound but not complete.

Introduction

$$(\mathfrak{u} = 6) \wedge (\mathfrak{bar}(\mathfrak{u}, \mathfrak{v}) = 42)$$

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$$(u = 6) \wedge (\mathtt{bar}(u, v) = 42)$$

- External library call
- Web API call

Introduction

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Closed-box (CB) Function

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Test satisfiability of first-order logic constraints containing closed-box (CB) functions

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Closed-Box (CB) Function

1. It must be functional
2. An input-output oracle interface is available

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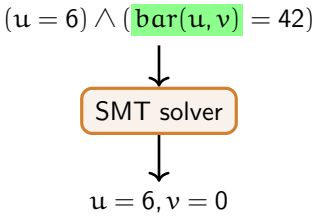
Test satisfiability of first-order logic constraints containing closed-box (CB) functions

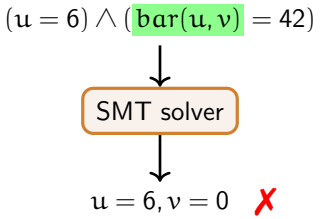
Closed-Box (CB) Function

1. It must be functional
2. An input-output oracle interface is available

Constraint Solving with UF Theory



Constraint Solving with UF Theory




```
u32 bar(u32 u, u32 v) {
   return u * v;
}
```

Core Idea

1. **Reduce satisfiability of a formula to reachability in a program**

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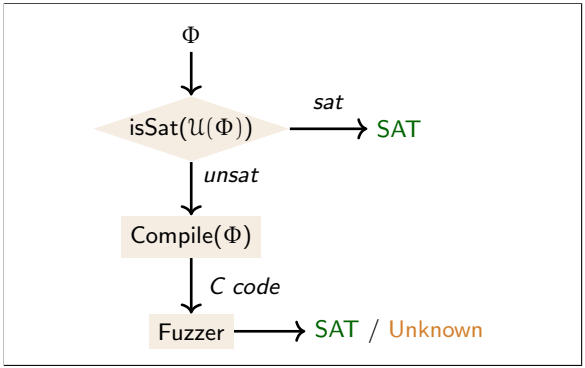
1. **Reduce satisfiability of a formula to reachability in a program**
2. **Use fuzzing to solve the reachability problem**

Prior Works

Colossus

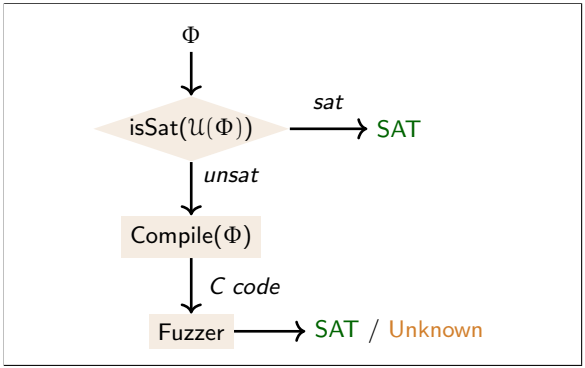
Prior Works

COLOSSUS



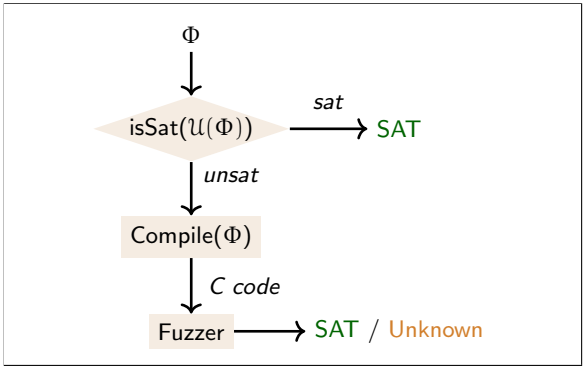
Prior Works

COLOSSUS



Prior Works

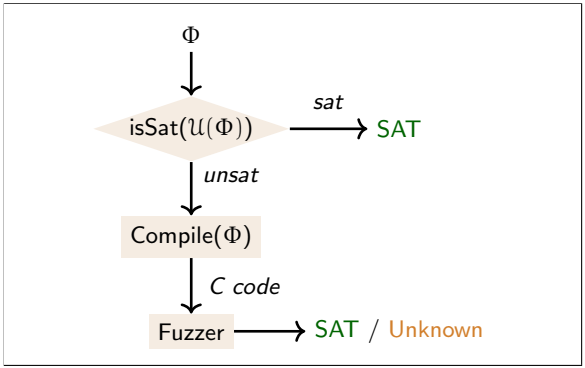
Colossus



- Underapproximate the input formula and check for satisfiability

Prior Works

Colossus



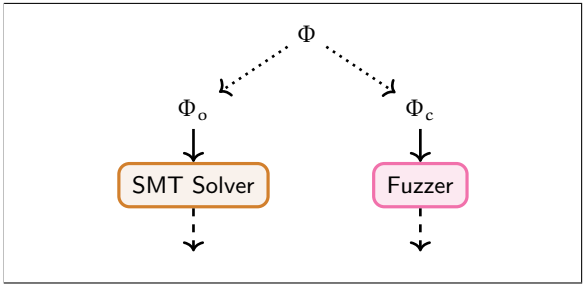
- Underapproximate the input formula and check for satisfiability
- If the underapproximated formula is UNSAT, Colossus uses fuzzing

Prior Works

ACHAR

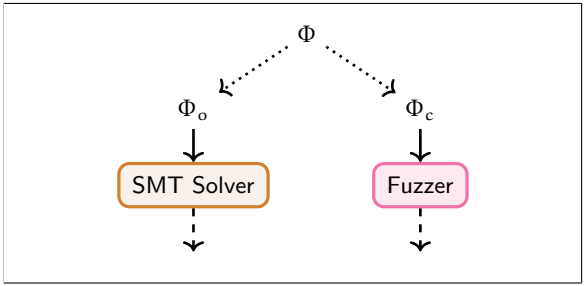
Prior Works

ACHAR



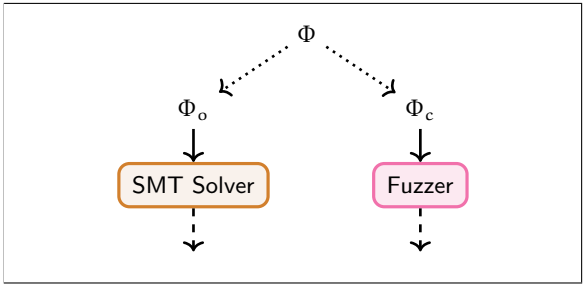
Prior Works

ACHAR



Prior Works

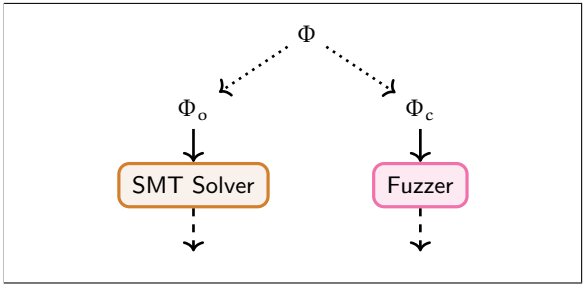
ACHAR



- Create a disjunctive partition of open-box and closed-box components

Prior Works

ACHAR



- Create a disjunctive partition of open-box and closed-box components
- Use SMT for open-box and fuzzing for closed-box

Contributions

1. Introduced CB theory to support closed-box functions in SMT solvers

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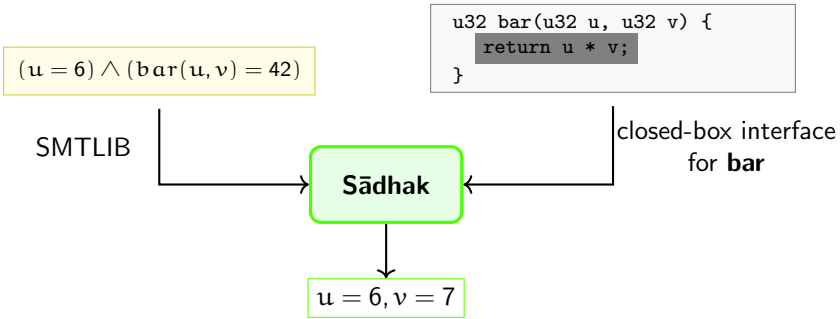
1. Introduced CB theory to support closed-box functions in SMT solvers
2. A conflict-driven fuzz loop (CDFL) algorithm for solving CB constraints

Synergistic Combination of SMT Solving and Fuzzing

In SĀDHAK SMT solver and fuzzer communicate with each other, exchanging information for efficient solving of CB constraints.



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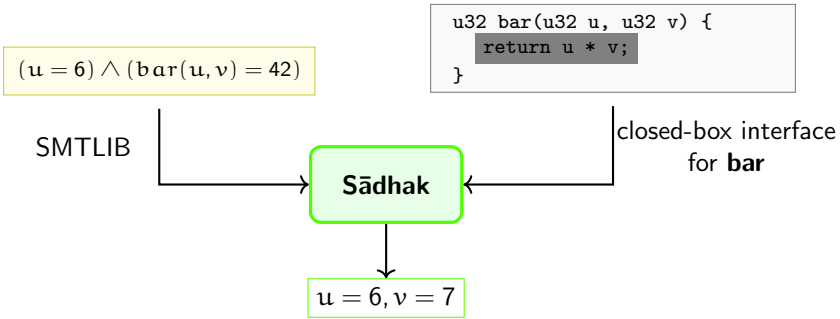

SĀDHAK is sound but not complete

SMTLIB Encoding

$$(u = 6) \wedge (bar(u, v) = 42)$$

(SMTLIB encoding of above constraint with closed-box function)

```
1 (declare-const u (_ BitVec 32))
2 (declare-const v (_ BitVec 32))
3 (declare-cb bar ((_ BitVec 32) (_ BitVec 32)) (_ BitVec 32))
4 (assert (= u (_ bv6 32)))
5 (assert (= (bar u v) (_ bv42 32)))
6 (check-sat)
7 (get-model)
```

CB Theory

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$$\sum_{CB}\{T_1,T_2,\ldots\} = \langle S, C, F, F^{CB}, B, R\rangle$$

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- S : set of sorts in theories

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- C : set of (sorted) constants in theories

CB Theory

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- S : set of sorts in theories
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CB Theory

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- B : predicates from theories

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- R : schema for translating sorts and expressions into a program

CB Theory

$$\sum_{CB}\{T_1,T_2,\ldots\} = \langle S, C, F, F^{CB}, B, R\rangle$$

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- F : set of all (sorted) function symbols
- F^{CB} : set of (sorted) closed-box functions
- B : predicates from theories
- R : schema for translating sorts and expressions into a program

Example

closed-box function

$$\mathbf{f}(x, y) > 255 \wedge \mathbf{f}(x, y) < 65536$$
$$\wedge\ (x > y) \wedge (p > 1) \wedge (q > 1) \wedge (r > 1)$$
$$\wedge\ \mathrm{isPow2}(p) \wedge \mathrm{isPow2}(q) \wedge \mathrm{isPow2}(r) \wedge (p \times q \times r = 64)$$

Segregation

Purification

$$\mathbf{f}(x, y) > 255 \wedge \mathbf{f}(x, y) < 65536$$
$$\wedge\ (x > y) \wedge (p > 1) \wedge (q > 1) \wedge (r > 1)$$
$$\wedge\ \mathrm{isPow2}(p) \wedge \mathrm{isPow2}(q) \wedge \mathrm{isPow2}(r) \wedge (p \times q \times r = 64)$$

$$\mathbf{z} = \mathrm{f}(x, y) \wedge \mathbf{z} > 255 \wedge \mathbf{z} < 65536$$
$$\wedge\ (x > y) \wedge (p > 1) \wedge (q > 1) \wedge (r > 1)$$
$$\wedge\ \mathrm{isPow2}(p) \wedge \mathrm{isPow2}(q) \wedge \mathrm{isPow2}(r) \wedge (p \times q \times r = 64)$$

(Purification)

Segregation

Separation

$$z = f(x, y) \wedge z > 255 \wedge z < 65536$$
$$\wedge\ (x > y) \wedge (p > 1) \wedge (q > 1) \wedge (r > 1)$$
$$\wedge\ \mathrm{isPow2}(p) \wedge \mathrm{isPow2}(q) \wedge \mathrm{isPow2}(r) \wedge (p \times q \times r = 64)$$

SMT Engine

$$z = f_{uf}(x, y) \wedge z > 255 \wedge z < 65536$$
$$\wedge\ (x > y) \wedge (p > 1) \wedge (q > 1) \wedge (r > 1)$$
$$\wedge\ \mathrm{isPow2}(p) \wedge \mathrm{isPow2}(q) \wedge \mathrm{isPow2}(r)$$
$$\wedge\ (p \times q \times r = 64)$$

Fuzz Engine

$$z = f_{cb}(x, y)$$

(Separation)

Conflict-driven Fuzz Loop (CDFL)

Iteration - 1

SMT Engine

$$z = f_{uf}(x, y) \wedge z > 255 \wedge z < 65536$$
$$\wedge\ (x > y) \wedge (p > 1) \wedge (q > 1) \wedge (r > 1)$$
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Fuzz Engine

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$$\wedge\ (p \times q \times r = 64)$$

Fuzz Engine

$$z = f_{cb}(x, y)$$

$x = 0, y = 0, z = 0$

(partial model)

Conflict-driven Fuzz Loop (CDFL)

Iteration - 1

SMT Engine

$$z = f_{uf}(x, y) \wedge z > 255 \wedge z < 65536$$
$$\wedge\ (x > y) \wedge (p > 1) \wedge (q > 1) \wedge (r > 1)$$
$$\wedge\ isPow2(p) \wedge isPow2(q) \wedge isPow2(r)$$
$$\wedge\ (p \times q \times r = 64)$$

Fuzz Engine

$$z = f_{cb}(x, y)$$

propagate

$x = 0, y = 0, z = 0$

(partial model)

Conflict-driven Fuzz Loop (CDFL)

Iteration - 1

SMT Engine

$z = f_{uf}(x, y) \wedge z > 255 \wedge z < 65536$
$\wedge \boxed{(x > y)} \wedge (p > 1) \wedge (q > 1) \wedge (r > 1)$
$\wedge\ isPow2(p) \wedge isPow2(q) \wedge isPow2(r)$
$\wedge\ (p \times q \times r = 64)$

Fuzz Engine

$z = f_{cb}(x, y)$

$x = 0, y = 0, z = 0$

(partial model)

(conflict)

Conflict-driven Fuzz Loop (CDFL)

Iteration - 1

SMT Engine

$z = f_{uf}(x, y) \wedge z > 255 \wedge z < 65536$

$\wedge$ $(x > y)$ $\wedge$ $(p \geq 1) \wedge (q > 1) \wedge (r > 1)$

$\wedge$ $isPow2(p) \wedge isPow2(q) \wedge isPow2(r)$

$\wedge$ $(p \times q \times r = 64)$

lemma

Fuzz Engine

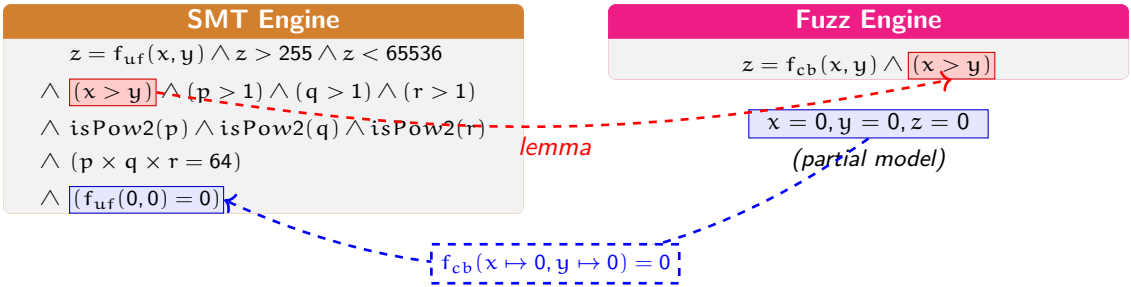
$z = f_{cb}(x, y) \wedge (x > y)$

$x = 0, y = 0, z = 0$

(partial model)

Conflict-driven Fuzz Loop (CDFL)

Iteration - 1



Conflict-driven Fuzz Loop (CDFL)

Iteration - 2

SMT Engine

$$z = f_{uf}(x, y) \wedge z > 255 \wedge z < 65536$$
$$\wedge\ (x > y) \wedge (p > 1) \wedge (q > 1) \wedge (r > 1)$$
$$\wedge\ isPow2(p) \wedge isPow2(q) \wedge isPow2(r)$$
$$\wedge\ (p \times q \times r = 64)$$
$$\wedge\ (f_{uf}(0, 0) = 0)$$

Fuzz Engine

$$z = f_{cb}(x, y) \wedge (x > y)$$

Conflict-driven Fuzz Loop (CDFL)

Iteration - 2

SMT Engine

$$z = f_{uf}(x, y) \wedge z > 255 \wedge z < 65536$$
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Fuzz Engine

$$z = f_{cb}(x, y) \wedge (x > y)$$

$x = 1, y = 0, z = 0$

(partial model)

Conflict-driven Fuzz Loop (CDFL)

Iteration - 2

SMT Engine

$$z = f_{uf}(x, y) \wedge z > 255 \wedge z < 65536$$
$$\wedge\ (x > y) \wedge (p > 1) \wedge (q > 1) \wedge (r > 1)$$
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$$\wedge\ (p \times q \times r = 64)$$
$$\wedge\ (f_{uf}(0, 0) = 0)$$

Fuzz Engine

$$z = f_{cb}(x, y) \wedge (x > y)$$

propagate

$x = 1, y = 0, z = 0$

(partial model)

Conflict-driven Fuzz Loop (CDFL)

Iteration - 2

SMT Engine

$z = f_{uf}(x, y) \wedge \boxed{z > 255} \wedge z < 65536$
$\wedge\ (x > y) \wedge (p > 1) \wedge (q > 1) \wedge (r > 1)$
$\wedge\ isPow2(p) \wedge isPow2(q) \wedge isPow2(r)$
$\wedge\ (p \times q \times r = 64)$
$\wedge\ (f_{uf}(0, 0) = 0)$

(conflict)

Fuzz Engine

$z = f_{cb}(x, y) \wedge (x > y)$

$\boxed{x = 1, y = 0, z = 0}$

(partial model)

Conflict-driven Fuzz Loop (CDFL)

Iteration - 2

SMT Engine

$z = f_{uf}(x, y) \wedge \boxed{z > 255} \wedge z < 65536$
$\wedge\ (x > y) \wedge (p > 1) \wedge (q > 1) \wedge (r > 1)$
$\wedge\ isPow2(p) \wedge isPow2(q) \wedge isPow2(r)$
$\wedge\ (p \times q \times r = 64)$
$\wedge\ (f_{uf}(0, 0) = 0)$

Fuzz Engine

$z = f_{cb}(x, y) \wedge (x > y) \wedge \boxed{(z > 255)}$

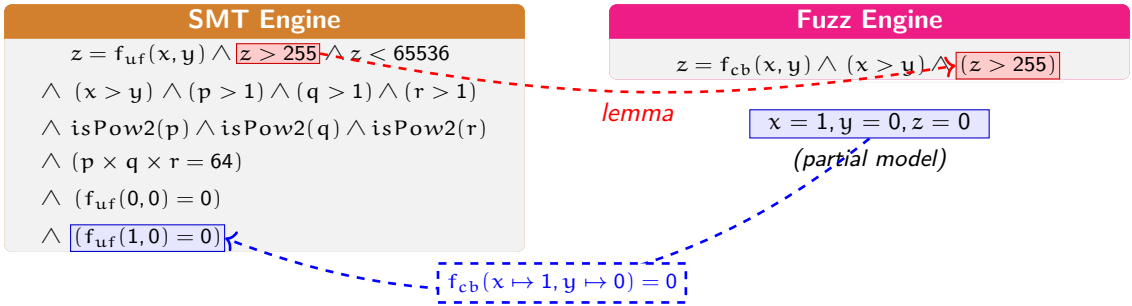
lemma

$x = 1, y = 0, z = 0$

(partial model)

Conflict-driven Fuzz Loop (CDFL)

Iteration - 2



Conflict-driven Fuzz Loop (CDFL)

Iteration - 3

SMT Engine

$$z = f_{uf}(x, y) \wedge z > 255 \wedge z < 65536$$
$$\wedge\ (x > y) \wedge (p > 1) \wedge (q > 1) \wedge (r > 1)$$
$$\wedge\ isPow2(p) \wedge isPow2(q) \wedge isPow2(r)$$
$$\wedge\ (p \times q \times r = 64)$$
$$\wedge\ (f_{uf}(0, 0) = 0)$$
$$\wedge\ (f_{uf}(1, 0) = 0)$$

Fuzz Engine

$$z = f_{cb}(x, y) \wedge (x > y) \wedge (z > 255)$$

Conflict-driven Fuzz Loop (CDFL)

Iteration - 3

SMT Engine

$$z = f_{uf}(x, y) \wedge z > 255 \wedge z < 65536$$
$$\wedge\ (x > y) \wedge (p > 1) \wedge (q > 1) \wedge (r > 1)$$
$$\wedge\ isPow2(p) \wedge isPow2(q) \wedge isPow2(r)$$
$$\wedge\ (p \times q \times r = 64)$$
$$\wedge\ (f_{uf}(0, 0) = 0)$$
$$\wedge\ (f_{uf}(1, 0) = 0)$$

Fuzz Engine

$$z = f_{cb}(x, y) \wedge (x > y) \wedge (z > 255)$$

$x = 65536, y = 1, z = 65536$

(partial model)

Conflict-driven Fuzz Loop (CDFL)

Iteration - 3

SMT Engine

$$z = f_{uf}(x, y) \wedge z > 255 \wedge z < 65536$$
$$\wedge\ (x > y) \wedge (p > 1) \wedge (q > 1) \wedge (r > 1)$$
$$\wedge\ isPow2(p) \wedge isPow2(q) \wedge isPow2(r)$$
$$\wedge\ (p \times q \times r = 64)$$
$$\wedge\ (f_{uf}(0, 0) = 0)$$
$$\wedge\ (f_{uf}(1, 0) = 0)$$

Fuzz Engine

$$z = f_{cb}(x, y) \wedge (x > y) \wedge (z > 255)$$

propagate

$x = 65536, y = 1, z = 65536$

(partial model)

Conflict-driven Fuzz Loop (CDFL)

Iteration - 3

SMT Engine

$z = f_{uf}(x, y) \wedge z > 255 \wedge \boxed{z < 65536}$

$\wedge\ (x > y) \wedge (p > 1) \wedge (q > 1) \wedge (r > 1)$

$\wedge\ isPow2(p) \wedge isPow2(q) \wedge isPow2$

$\wedge\ (p \times q \times r = 64)$

$\wedge\ (f_{uf}(0, 0) = 0)$

$\wedge\ (f_{uf}(1, 0) = 0)$

(conflict)

Fuzz Engine

$z = f_{cb}(x, y) \wedge (x > y) \wedge (z > 255)$

$x = 65536, y = 1, z = 65536$

(partial model)

Conflict-driven Fuzz Loop (CDFL)

Iteration - 3

SMT Engine

$$z = f_{uf}(x, y) \wedge z > 255 \wedge \boxed{z < 65536}$$
$$\wedge\ (x > y) \wedge (p > 1) \wedge (q > 1) \wedge (r > 1)$$
$$\wedge\ isPow2(p) \wedge isPow2(q) \wedge isPow2(r)$$
$$\wedge\ (p \times q \times r = 64)$$
$$\wedge\ (f_{uf}(0, 0) = 0)$$
$$\wedge\ (f_{uf}(1, 0) = 0)$$

lemma

Fuzz Engine

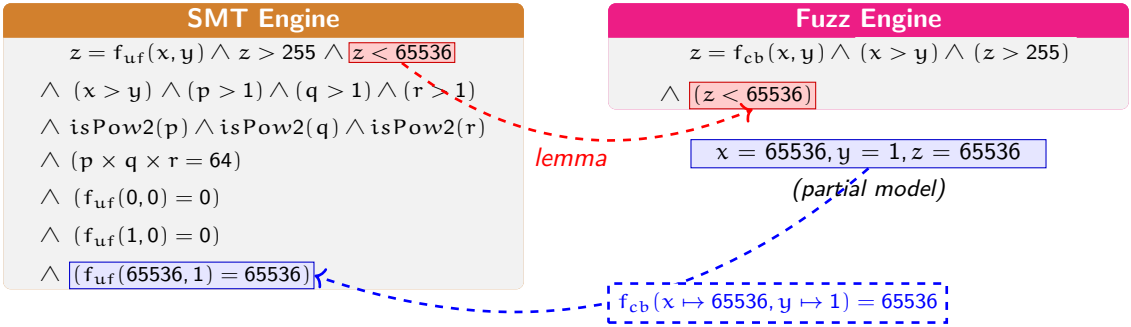
$$z = f_{cb}(x, y) \wedge (x > y) \wedge (z > 255)$$
$$\wedge\ \boxed{(z < 65536)}$$

$$x = 65536, y = 1, z = 65536$$

(partial model)

Conflict-driven Fuzz Loop (CDFL)

Iteration - 3



Conflict-driven Fuzz Loop (CDFL)

Iteration - 4

SMT Engine

$$z = f_{uf}(x, y) \wedge z > 255 \wedge z < 65536$$
$$\wedge\ (x > y) \wedge (p > 1) \wedge (q > 1) \wedge (r > 1)$$
$$\wedge\ isPow2(p) \wedge isPow2(q) \wedge isPow2(r)$$
$$\wedge\ (p \times q \times r = 64)$$
$$\wedge\ (f_{uf}(0, 0) = 0)$$
$$\wedge\ (f_{uf}(1, 0) = 0)$$
$$\wedge\ (f_{uf}(65536, 1) = 65536)$$

Fuzz Engine

$$z = f_{cb}(x, y) \wedge (x > y) \wedge (z > 255)$$
$$\wedge\ (z < 65536)$$

Conflict-driven Fuzz Loop (CDFL)

Iteration - 4

SMT Engine

$$z = f_{uf}(x, y) \wedge z > 255 \wedge z < 65536$$
$$\wedge\ (x > y) \wedge (p > 1) \wedge (q > 1) \wedge (r > 1)$$
$$\wedge\ isPow2(p) \wedge isPow2(q) \wedge isPow2(r)$$
$$\wedge\ (p \times q \times r = 64)$$
$$\wedge\ (f_{uf}(0, 0) = 0)$$
$$\wedge\ (f_{uf}(1, 0) = 0)$$
$$\wedge\ (f_{uf}(65536, 1) = 65536)$$

Fuzz Engine

$$z = f_{cb}(x, y) \wedge (x > y) \wedge (z > 255)$$
$$\wedge\ (z < 65536)$$

$x = 256, y = 1, z = 256$

(partial model)

Conflict-driven Fuzz Loop (CDFL)

Iteration - 4

SMT Engine

$$z = f_{uf}(x, y) \wedge z > 255 \wedge z < 65536$$
$$\wedge\ (x > y) \wedge (p > 1) \wedge (q > 1) \wedge (r > 1)$$
$$\wedge\ isPow2(p) \wedge isPow2(q) \wedge isPow2(r)$$
$$\wedge\ (p \times q \times r = 64)$$
$$\wedge\ (f_{uf}(0, 0) = 0)$$
$$\wedge\ (f_{uf}(1, 0) = 0)$$
$$\wedge\ (f_{uf}(65536, 1) = 65536)$$

Fuzz Engine

$$z = f_{cb}(x, y) \wedge (x > y) \wedge (z > 255)$$
$$\wedge\ (z < 65536)$$

propagate

$x = 256, y = 1, z = 256$

(partial model)

Conflict-driven Fuzz Loop (CDFL)

Iteration - 4

SMT Engine

$$z = f_{uf}(x, y) \wedge z > 255 \wedge z < 65536$$
$$\wedge\ (x > y) \wedge (p > 1) \wedge (q > 1) \wedge (r > 1)$$
$$\wedge\ isPow2(p) \wedge isPow2(q) \wedge isPow2(r)$$
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$$\wedge\ (f_{uf}(0, 0) = 0)$$
$$\wedge\ (f_{uf}(1, 0) = 0)$$
$$\wedge\ (f_{uf}(65536, 1) = 65536)$$

Fuzz Engine

$$z = f_{cb}(x, y) \wedge (x > y) \wedge (z > 255)$$
$$\wedge\ (z < 65536)$$

$x = 256, y = 1, z = 256$

(partial model)

(consistent)

Conflict-driven Fuzz Loop (CDFL)

Iteration - 4

SMT Engine

$$z = f_{uf}(x, y) \wedge z > 255 \wedge z < 65536$$
$$\wedge\ (x > y) \wedge (p > 1) \wedge (q > 1) \wedge (r > 1)$$
$$\wedge\ isPow2(p) \wedge isPow2(q) \wedge isPow2(r)$$
$$\wedge\ (p \times q \times r = 64)$$
$$\wedge\ (f_{uf}(0, 0) = 0)$$
$$\wedge\ (f_{uf}(1, 0) = 0)$$
$$\wedge\ (f_{uf}(65536, 1) = 65536)$$

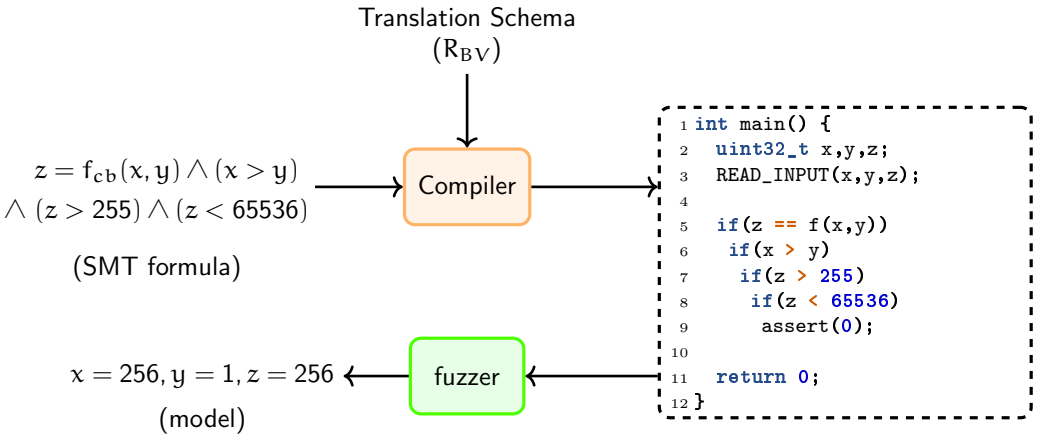
$$x = 256, y = 1, z = 256,$$
$$p = 2, q = 8, r = 4$$

Fuzz Engine

$$z = f_{cb}(x, y) \wedge (x > y) \wedge (z > 255)$$
$$\wedge\ (z < 65536)$$

```
u32 f(u32 x, u32 y) {
  return x * y;
}
```

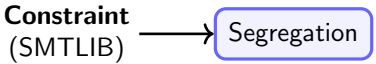
Fuzz Engine


Translation Schema
(R_{BV})
$z = f_{cb}(x, y) \wedge (x > y)$
$\wedge\ (z > 255) \wedge (z < 65536)$
(SMT formula)
Compiler
1 int main() {
2 uint32_t x,y,z;
3 READ_INPUT(x,y,z);
4
5 if(z == f(x,y))
6 if(x > y)
7 if(z > 255)
8 if(z < 65536)
9 assert(0);
10
11 return 0;
12 }
fuzzer
$x = 256, y = 1, z = 256$
(model)

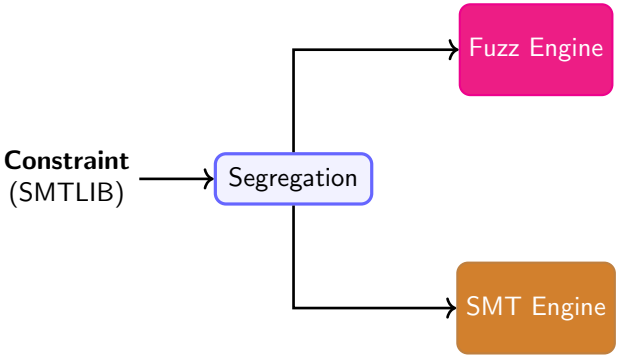
SĀDHAK: An SMT Solver for CB Constraints

Constraint
(SMTLIB)

SĀDHAK: An SMT Solver for CB Constraints



SĀDHAK: An SMT Solver for CB Constraints



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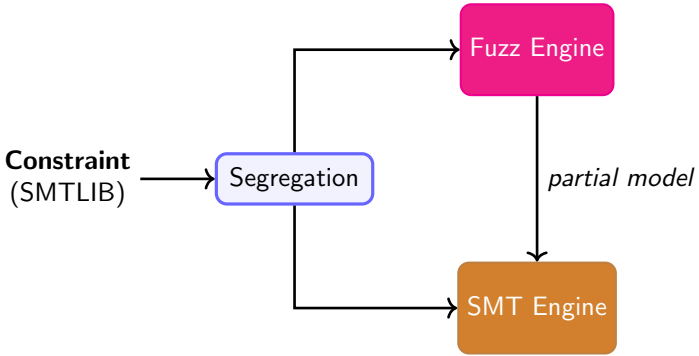

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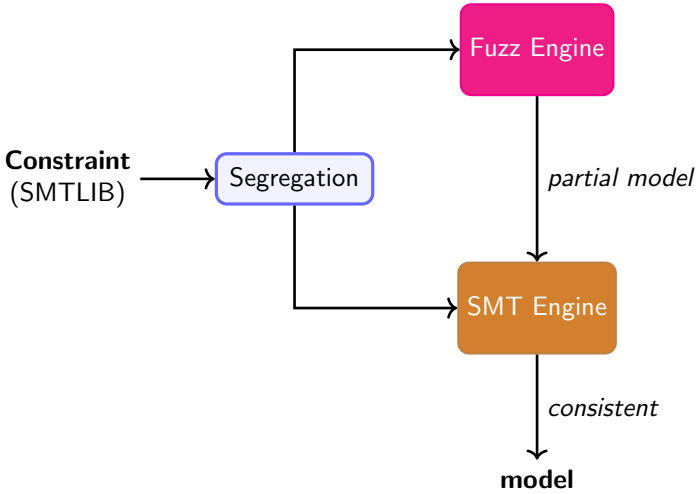

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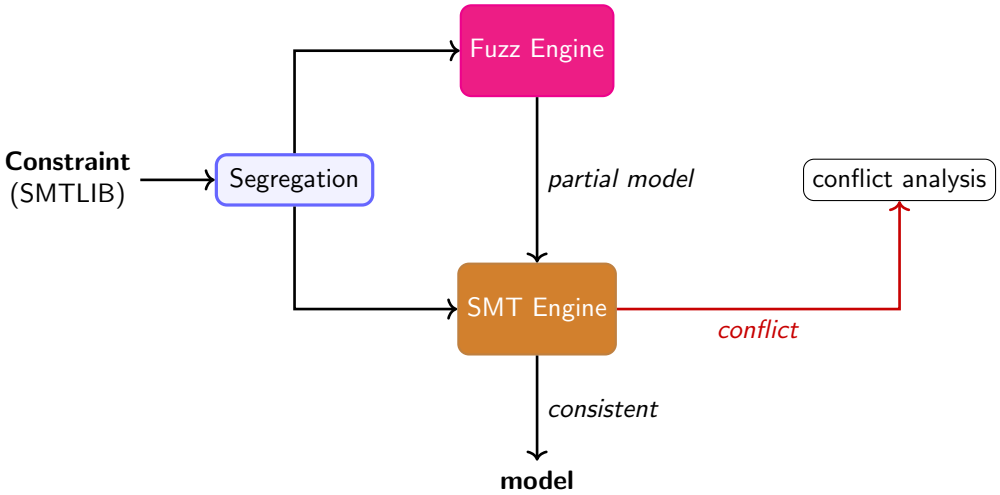

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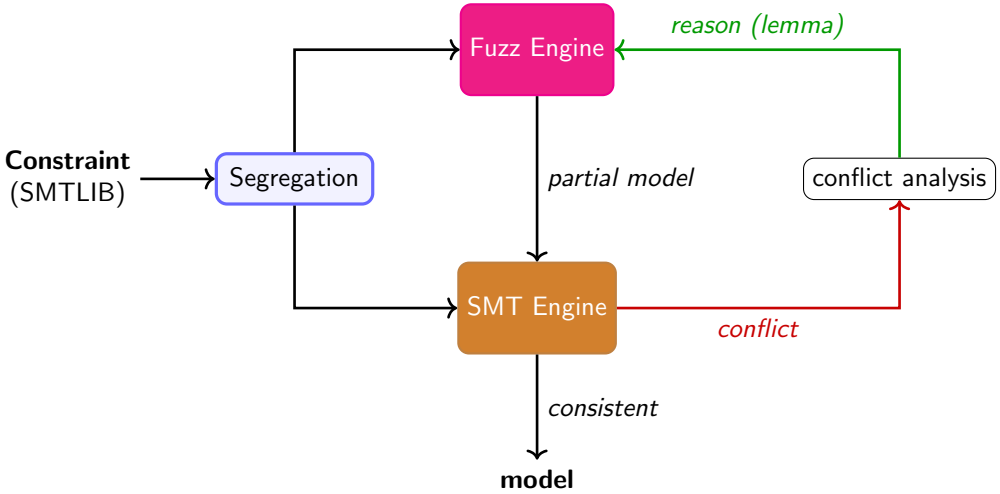
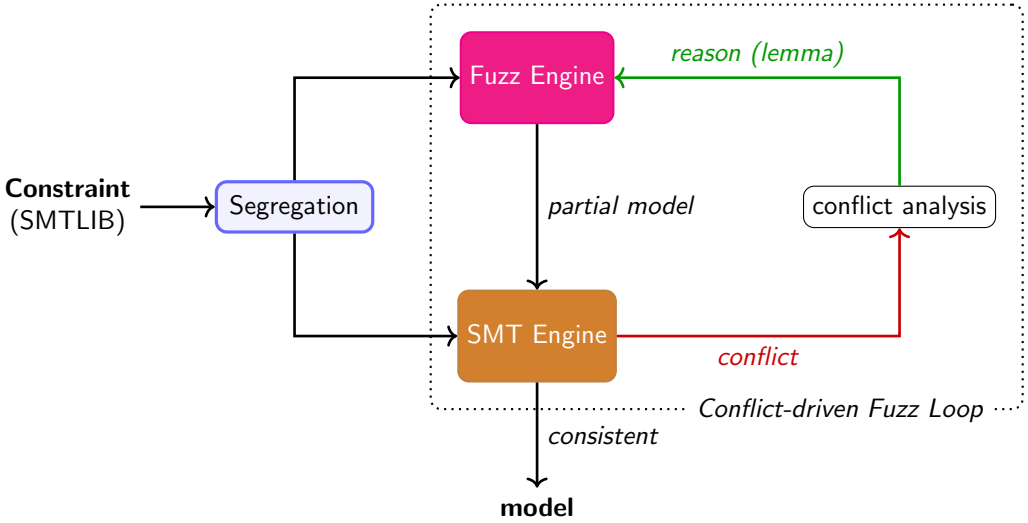


SĀDHAK: An SMT Solver for CB Constraints



Related Work

DELPHI [*Polgreen et al. VMCAI'22*]

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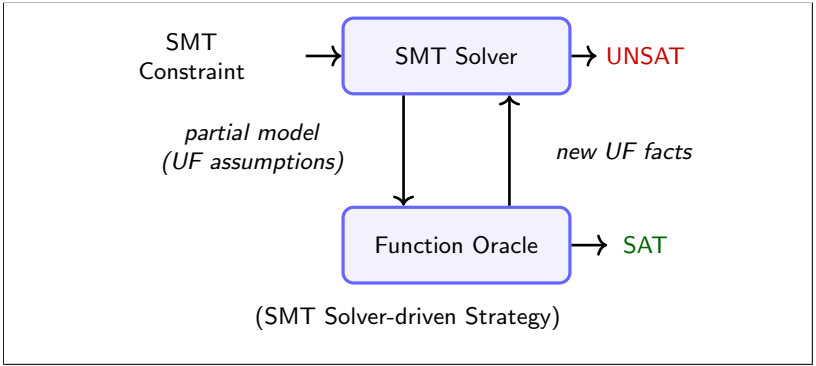
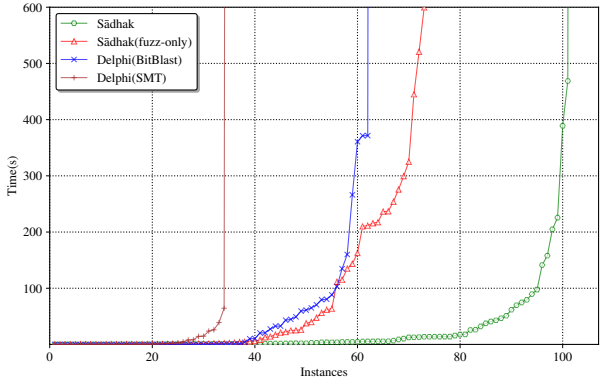


Evaluation



	Sādhak		Delphi	
	Fuzz only	CDFL	SMT	BitBlast
# solved	73	**101**	34	62

Conclusion

- Introduced closed-box function theory (CB theory)

(paper and artifact)

(Thanks to Sujit for letting me steal his slides :))

Conclusion

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- Conflict-driven fuzz loop (CDFL) for using fuzzing in synergy with the SMT solving

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Conclusion

- Introduced closed-box function theory (CB theory)
- Conflict-driven fuzz loop (CDFL) for using fuzzing in synergy with the SMT solving
- Sādhak is built on top of CVC4 SMT solver.
- A set of 95 new benchmarks (SMTLIB queries with closed-box constraints)

(paper and artifact)

(Thanks to Sujit for letting me steal his slides :))

CHIRON: A framework to teach program analysis [ASE'23]

Fun Source Language, Simple IR, Plug-and-play Architecture, Small code-base

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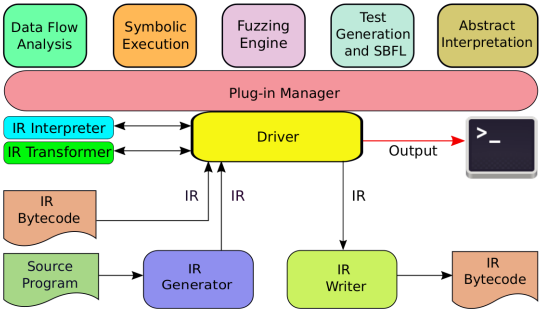
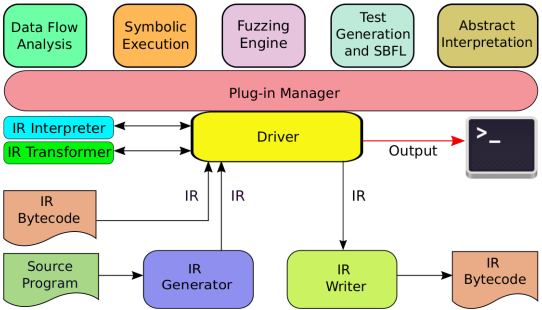


CHIRON: A framework to teach program analysis [ASE'23]

Fun Source Language, Simple IR, Plug-and-play Architecture, Small code-base



Module	Module Size[#]	Module Effort	Student Codesize[*]
CORE FRAMEWORK	0.77	8	-
DATA FLOW ANALYSIS	0.14	2	0.2–0.3
FUZZING	0.11	2	0.06–0.1
SYMBOLIC EXECUTION	0.31	3	0.15–0.17
ABSTRACT INTERPRETATION	0.15	2	0.1–0.3
SBFL FRAMEWORK	0.24	2	0.03–0.12

[*]Code written by students for the assignments. [#]Code written by CHIRON developers for framing the assignments.

Example: Abstract Interpretation with CHIRON

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```
input(:vara, :varb, :varc)
goto (0, 0)
pendown
repeat 6 [
  if (:vara != :varb) [
    if ( :vara > :varb) [ right :vara ] else [ left :varb ]
  ]
  else [
    if ((:vara <= :varc) || (:varb <= :varc)) [
      :vara = :varc / :vara
      :varb = :varb / :varc
      :varc = :varb
    ]
  ]
  forward :vara
  right :varb
  forward :varc
  left :varc
]
penup
```

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input(:vara, :varb, :varc)
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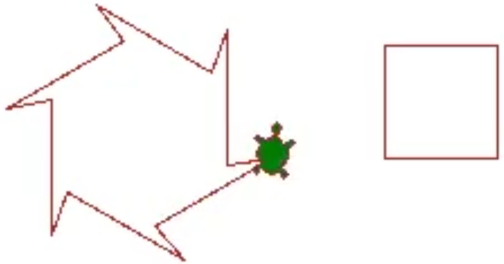
        :varc = :varb
      ]
   ]
   forward :vara
   right :varb
   forward :varc
   left :varc
]
penup
```



Questions?