REDOCS2020 - Automatic exploit generation

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Subject by: Jules Villard

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Problem Overview

Context

- Codebases are bigger than ever
- More bugs than ever!

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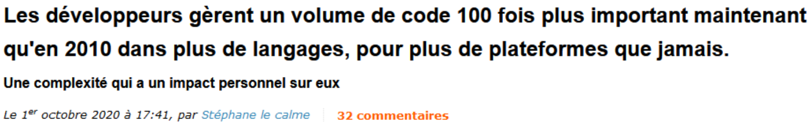

Les développeurs gèrent un volume de code 100 fois plus important maintenant qu'en 2010 dans plus de langages, pour plus de plateformes que jamais.

Une complexité qui a un impact personnel sur eux

Le 1^er octobre 2020 à 17:41, par Stéphane le calme | **32 commentaires**

Problem Overview

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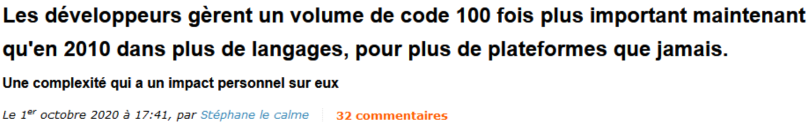

Les développeurs gèrent un volume de code 100 fois plus important maintenant qu'en 2010 dans plus de langages, pour plus de plateformes que jamais.

Une complexité qui a un impact personnel sur eux

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Facebook runs on at least 64 millions of line of code. Imagine the debugging.

Background

Static Analysis

- Processes the code of the program
- Don't execute it !

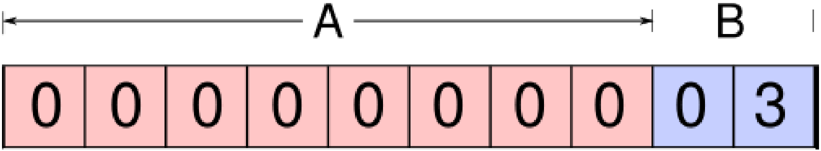
Formal challenge

"Can we automatically turn static analysis reports into executable confirming the vulnerability of a program ?" - Jules Villard, Facebook

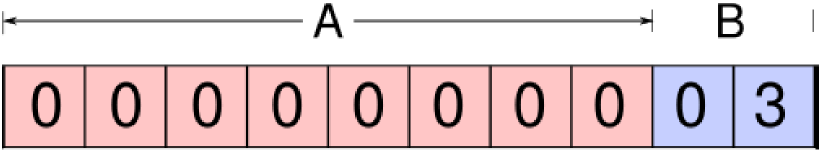
Weakness example: the Buffer Overflow

- Classic attack
- Allow to modify other variables in memory
- A lot of consequences
    - Crash the program (e.g. Segfault)
    - Hijack the execution (e.g. Cracks)
    - Privilege escalation (e.g. Root Shells),
    - ...

The Buffer Overflow – Technically

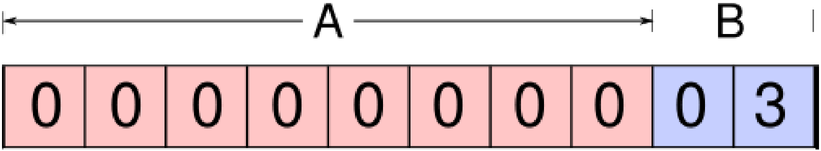


The Buffer Overflow – Technically

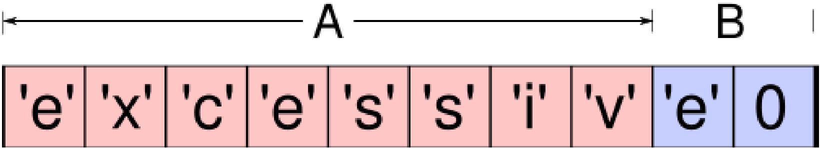


```
strcpy(A, "excessive")
```

The Buffer Overflow – Technically



`strcpy(A, "excessive")`



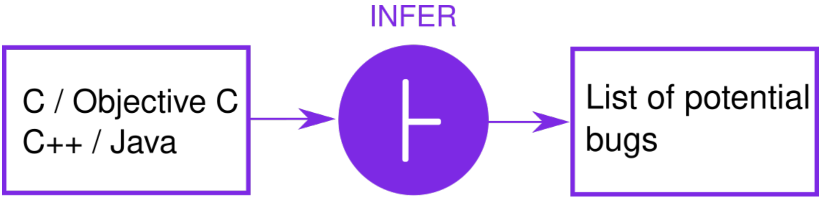
Weakness example: the Buffer Overflow

```c
int main() {
    short valid = 0;
    char buf[8];
    strcpy(buf, "excessive");
    printf("%d", valid); // Overflow !!!
}
```

Program bug example

- Example of vulnerability – 101 Buffer overflow
- Exploit it manually
- Automatize it through Infer later!

Infer tool



INFER

C / Objective C
C++ / Java

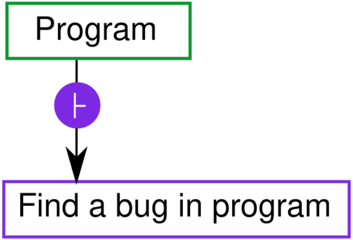
List of potential bugs

- Static analysis tool from Facebook
- **Capture** phase, then **Analysis** phase

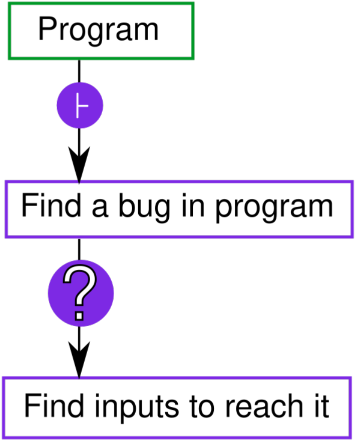
Practical approach

Program

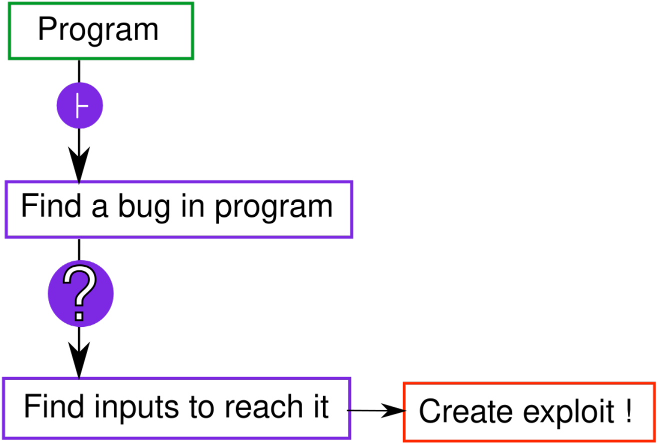
Practical approach



Practical approach



Practical approach



Program

Find a bug in program

Find inputs to reach it

Create exploit !

Practical approach

This week's challenge

Given the Infer information about bugs of a program A, find a **set of inputs** that **crashes** A

Table of content

Proposed approaches

Model checking

Overview

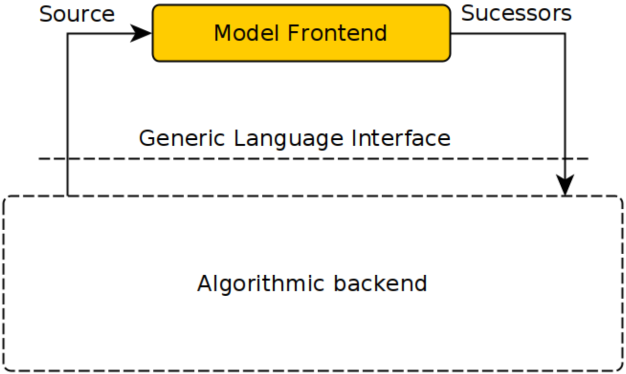
- ■ Formal
- ■ Intuitive
- ■ Automated
- ■ Provides counter-examples
- × State-space explosion

Obelix : Modular Model-Checker

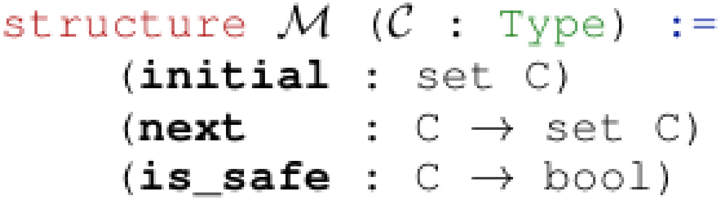
Highlights

- Modular model-checker
- 3 languages : DVE, EMI-UML, C/C++
- 12+ algorithms
- Bitstate hashing
- Swarm model-checking

Obelix : Generic Language Interface

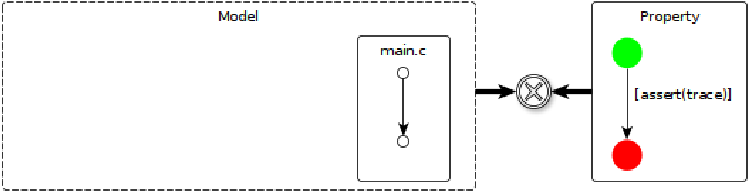


Obelix : Generic Language Interface

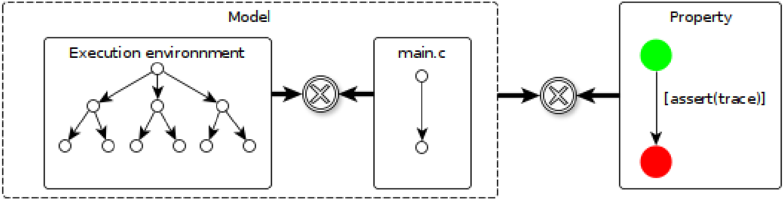


```
structure ℳ (𝒞 : Type) :=
     (initial : set C)
     (next    : C → set C)
     (is_safe : C → bool)
```

Application : How ?



Application : How ?



A few results

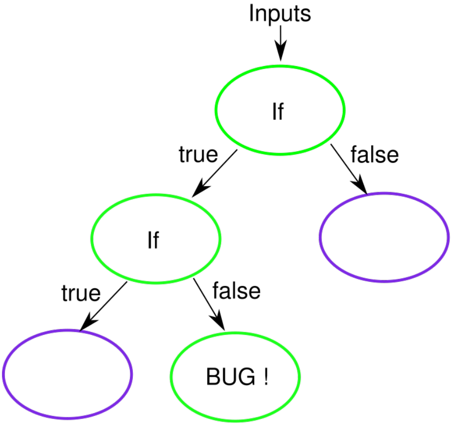
Results

- Custom model-checker
- 16 reachability algorithms supported

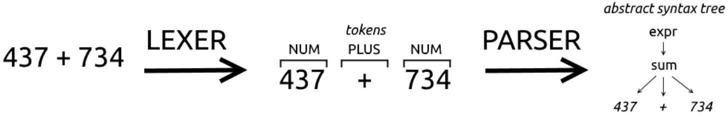
Symbolic approach : SMT

Find output using a logic formula

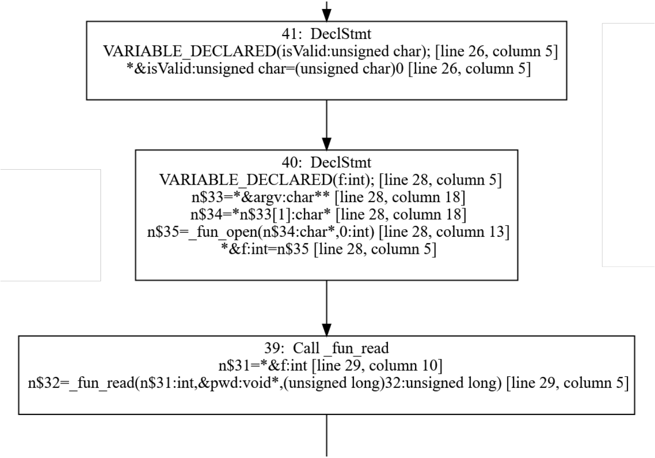
CFG and BFS



Compiler


437 + 734
LEXER
tokens
NUM
437
PLUS
+
NUM
734
PARSER
abstract syntax tree
expr
sum
437
+
734

Smallfoot Intermediate Language

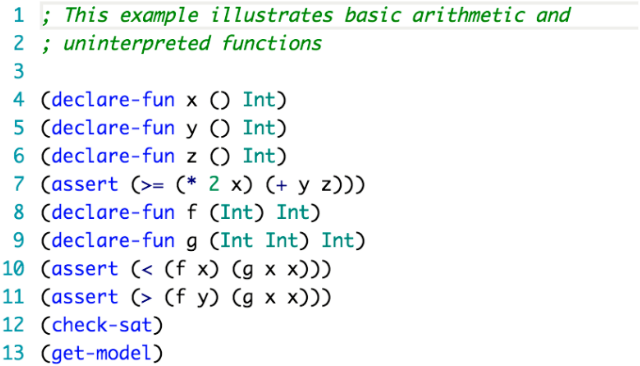


```
41: DeclStmt
VARIABLE_DECLARED(isValid:unsigned char); [line 26, column 5]
*&isValid:unsigned char=(unsigned char)0 [line 26, column 5]
```

```
40: DeclStmt
VARIABLE_DECLARED(f:int); [line 28, column 5]
n$33=*&argv:char** [line 28, column 18]
n$34=*n$33[1]:char* [line 28, column 18]
n$35=_fun_open(n$34:char*,0:int) [line 28, column 13]
*&f:int=n$35 [line 28, column 5]
```

```
39: Call _fun_read
n$31=*&f:int [line 29, column 10]
n$32=_fun_read(n$31:int,&pwd:void*,(unsigned long)32:unsigned long) [line 29, column 5]
```

Formula



```
; This example illustrates basic arithmetic and
; uninterpreted functions

(declare-fun x () Int)
(declare-fun y () Int)
(declare-fun z () Int)
(assert (>= (* 2 x) (+ y z)))
(declare-fun f (Int) Int)
(declare-fun g (Int Int) Int)
(assert (< (f x) (g x x)))
(assert (> (f y) (g x x)))
(check-sat)
(get-model)
```

Input Language

Restriction :

- No pointer
- Only int
- No exterior function
- Only use argv as a vector of int

Buffer Overflow example

Does not fit our example :

- Array
- char* (String)
- Standard functions : memcpy

Compiler

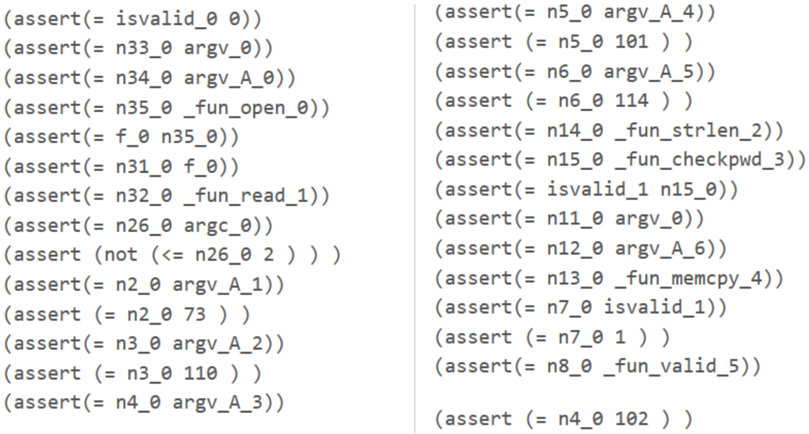
Does not fit our example :

- Array
- char* (String)
- Standard functions : memcpy

Principle

What we won't understand won't hurt us.

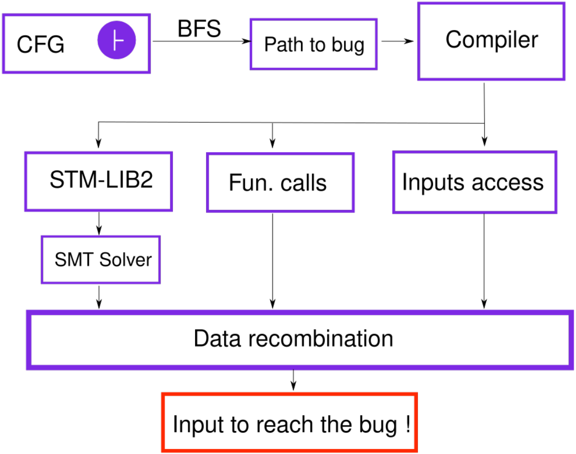
SMT Output



```
(assert(= isvalid_0 0))
(assert(= n33_0 argv_0))
(assert(= n34_0 argv_A_0))
(assert(= n35_0 _fun_open_0))
(assert(= f_0 n35_0))
(assert(= n31_0 f_0))
(assert(= n32_0 _fun_read_1))
(assert(= n26_0 argc_0))
(assert (not (<= n26_0 2 ) ) )
(assert(= n2_0 argv_A_1))
(assert (= n2_0 73 ) )
(assert(= n3_0 argv_A_2))
(assert (= n3_0 110 ) )
(assert(= n4_0 argv_A_3))
```

```
(assert(= n5_0 argv_A_4))
(assert (= n5_0 101 ) )
(assert(= n6_0 argv_A_5))
(assert (= n6_0 114 ) )
(assert(= n14_0 _fun_strlen_2))
(assert(= n15_0 _fun_checkpwd_3))
(assert(= isvalid_1 n15_0))
(assert(= n11_0 argv_0))
(assert(= n12_0 argv_A_6))
(assert(= n13_0 _fun_memcpy_4))
(assert(= n7_0 isvalid_1))
(assert (= n7_0 1 ) )
(assert(= n8_0 _fun_valid_5))

(assert (= n4_0 102 ) )
```

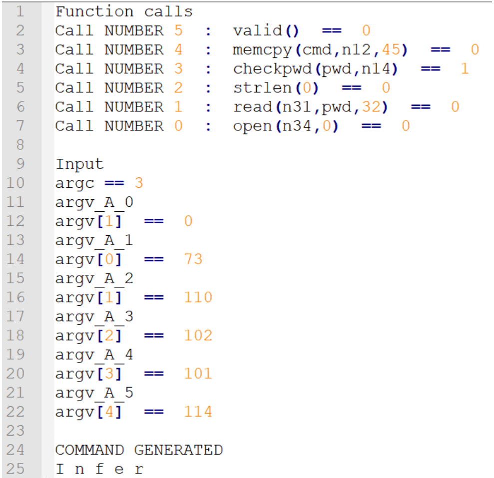


CFG
⊦
BFS
Path to bug
Compiler
STM-LIB2
Fun. calls
Inputs access
SMT Solver
Data recombination
Input to reach the bug !

SMT Solver Response

```
{
  'argc_0': 3, '_fun_valid_5': 0, 'n8_0': 0, 'n7_0': 1,
  'isvalid_1': 1, '_fun_memcpy_4': 0, 'n13_0': 0,
  'argv_A_6': 0, 'n12_0': 0, 'argv_0': 0, 'n11_0': 0,
  'n15_0': 1, '_fun_checkpwd_3': 1, '_fun_strlen_2': 0,
  'n14_0': 0, 'n6_0': 114, 'argv_A_5': 114, 'n5_0': 101,
  'argv_A_4': 101, 'n4_0': 102, 'argv_A_3': 102,
  'n3_0': 110, 'argv_A_2': 110, 'n2_0': 73,
  'argv_A_1': 73, 'n26_0': 3,'_fun_read_1': 0,
  'n32_0': 0, '_fun_open_0': 0, 'n31_0': 0, 'f_0': 0,
  'n35_0': 0, 'argv_A_0': 0, 'n34_0': 0,
  'n33_0': 0, 'isvalid_0': 0, 'pwd_0': 0
}
```

Evaluation



```
Function calls
Call NUMBER 5  :  valid()  ==  0
Call NUMBER 4  :  memcpy(cmd,n12,45)  ==  0
Call NUMBER 3  :  checkpwd(pwd,n14)  ==  1
Call NUMBER 2  :  strlen(0)  ==  0
Call NUMBER 1  :  read(n31,pwd,32)  ==  0
Call NUMBER 0  :  open(n34,0)  ==  0

Input
argc == 3
argv_A_0
argv[1]  ==  0
argv_A_1
argv[0]  ==  73
argv_A_2
argv[1]  ==  110
argv_A_3
argv[2]  ==  102
argv_A_4
argv[3]  ==  101
argv_A_5
argv[4]  ==  114

COMMAND GENERATED
I n f e r
```

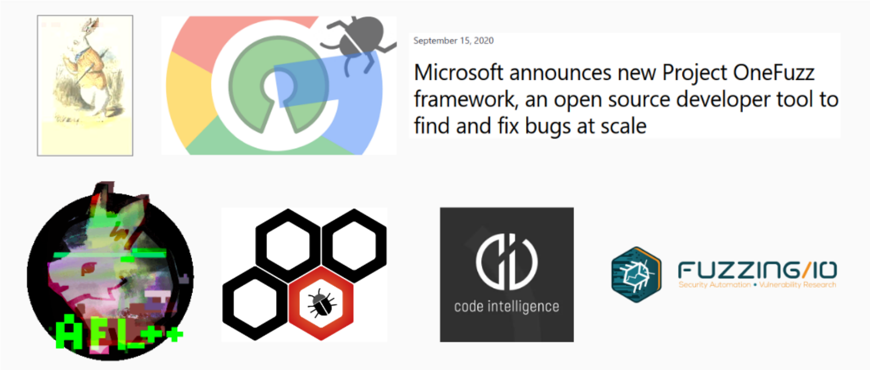
- ≈ 0.30 seconds

Fuzzing Technique

Third approach: Directed Fuzzing

Fuzzing technique

Idea: Generate random inputs in the hope of crashing programs

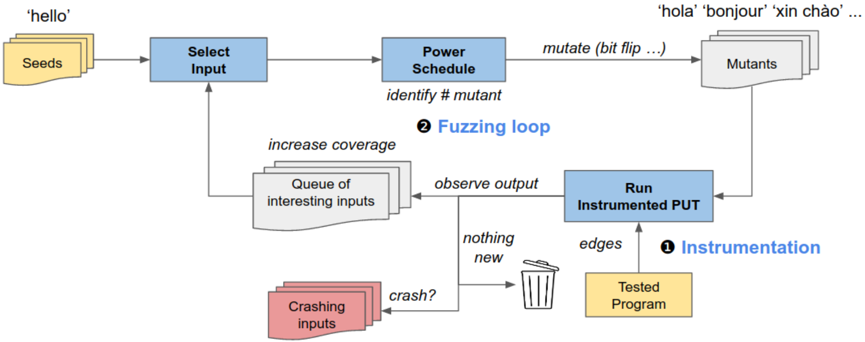


September 15, 2020

Microsoft announces new Project OneFuzz framework, an open source developer tool to find and fix bugs at scale

> **100 fuzzers** (Google, Facebook, Microsoft) in recent years

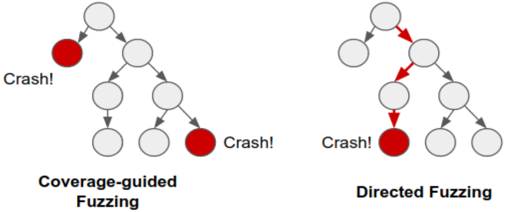
Coverage-guided greybox fuzzing [AFL, libFuzzer]



Goal: Cover as many paths as possible

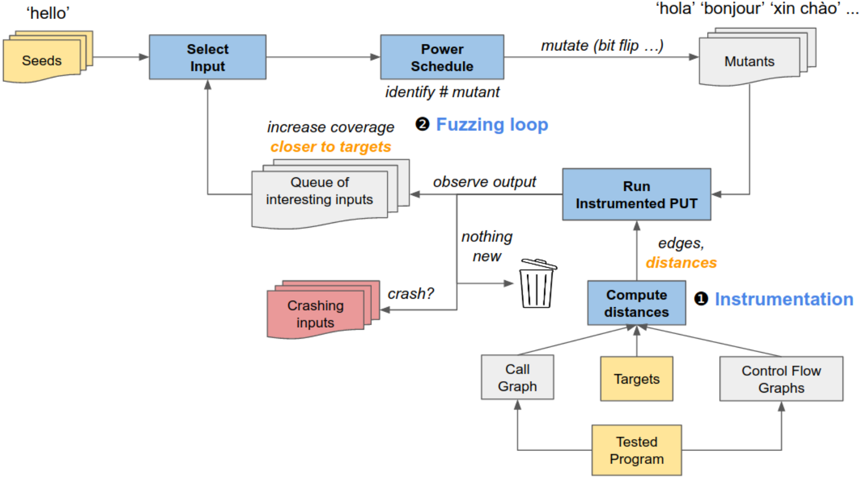
- Feedback: code coverage (e.g., lines, branches)
- Mutation operators: bitflip, insert/delete/overwrite bytes ...

Intuitions of directed approach



- **Goal**: Reach predefined targets (e.g., recent code changes, vulnerable functions, patches, static reports)
- New distance-based input metric
- Favor inputs that are "closer" to targets
  - Select them more often
  - Produce more mutants from those inputs

Directed greybox fuzzing [AFLGo]

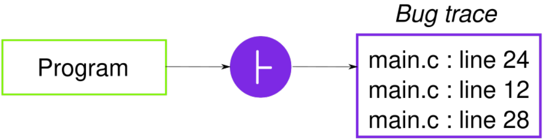


"Directed Greybox Fuzzing", M. Böhme et al, CCS'17

Putting it all together

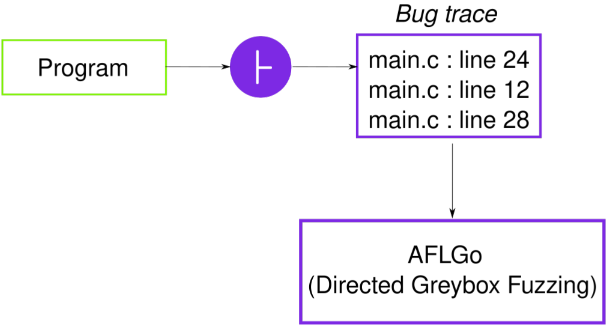
Program

Putting it all together



main.c : line 24
main.c : line 12
main.c : line 28

Putting it all together



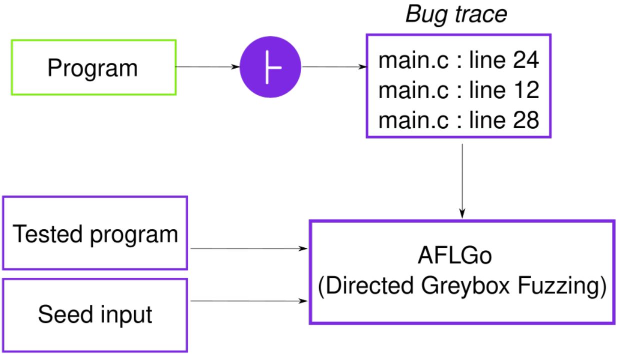
Program

Bug trace

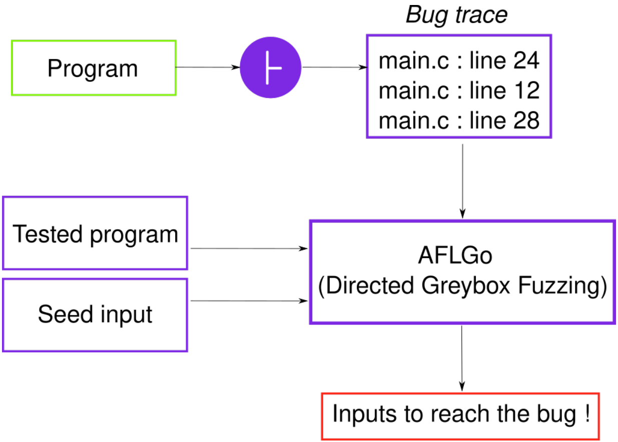
main.c : line 24
main.c : line 12
main.c : line 28

AFLGo
(Directed Greybox Fuzzing)

Putting it all together



Putting it all together



Program

Bug trace

main.c : line 24
main.c : line 12
main.c : line 28

Tested program

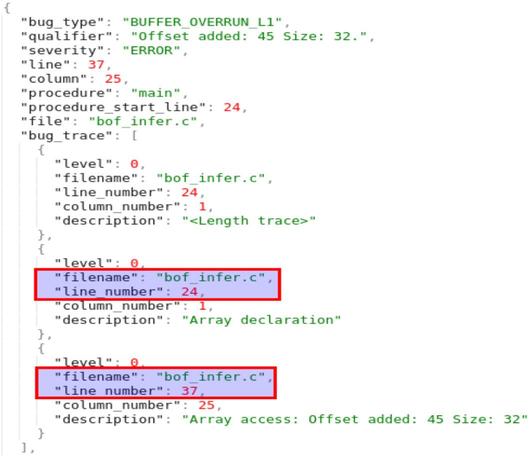
Seed input

AFLGo
(Directed Greybox Fuzzing)

Inputs to reach the bug !

Implementation

- Python script to parse Infer's output “report.json"
  - Targets: ['bof_infer.c:24', 'bof_infer.c:37']
- Generate a script to run AFLGo `https://github.com/aflgo/aflgo`



```
{
  "bug_type": "BUFFER_OVERRUN_L1",
  "qualifier": "Offset added: 45 Size: 32.",
  "severity": "ERROR",
  "line": 37,
  "column": 25,
  "procedure": "main",
  "procedure_start_line": 24,
  "file": "bof_infer.c",
  "bug_trace": [
    {
      "level": 0,
      "filename": "bof_infer.c",
      "line_number": 24,
      "column_number": 1,
      "description": "<Length trace>"
    },
    {
      "level": 0,
      "filename": "bof_infer.c",
      "line_number": 24,
      "column_number": 1,
      "description": "Array declaration"
    },
    {
      "level": 0,
      "filename": "bof_infer.c",
      "line_number": 37,
      "column_number": 25,
      "description": "Array access: Offset added: 45 Size: 32"
    }
  ],
```

Evaluation

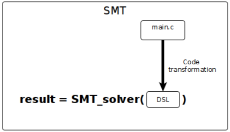
Run the fuzzer 5 times against the buffer overflow example (due to randomness)

Run	**Time-to-Exposure**
1	4m 44s
2	18m 4s
3	17m 11s
4	14m 50s
5	18m 13s
Average	14 m 36 s

Conclusions and perspectives

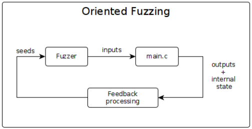
Results comparison

SMT



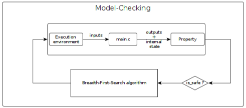
- + Quick
- + Function complexity
- – Semantic limitations

Fuzzing



- + Can be efficent
- – Does not always find the solution

Model Checking



- + Respect the semantic
- – Combinatorial explosion

Other Approaches – Hybrid methods

- Hybrid methods
  - Prune interesting branches with Fuzzing + Heuristics
  - SMT on subproblems

Future Work – Automatic exploit generation

- We can trigger bugs
- How to automatize their exploits?
- Create an attack model
- Find all possible exploits
- → FULLY AUTOMATED EXPLOITS!

Convert vulnerabilities to bug

```
void onBufferOverflow(env, bufsz, entrypoint)
  if(canOverWriteRip())
    addExploit("Can rewrite on rip!");
  for(var=0 to env.nb_vars)
    if( var.rewrittable && var.used)
      addExploit("Can Hijack the program!");
  /* [...]  */
```

Next steps to improve the framework

- General
  - Test on code with several path to the same bug
- Fuzzing
  - Resolve magic-bytes comparisons, (e.g. `strcmp`)
  - Distance computation is long with large programs
- SMT
  - Add more types
  - Support arbitrary memory accesses
  - Improve function with hooks
- Model Checker
  - Partial order reduction
  - Hardware model-checking

It works on my machine

Thank you !