定向覆盖模糊测试工具的设计与实现

毕业设计中期检查

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What Fuzzing is?

Defination[1]

- **Fuzzing** Fuzzing is the execution of the PUT using input(s) sampled from an input space (the “fuzz input space”) that protrudes the expected input space of the PUT.
  - PUT: Program Under Test
- **Fuzz testing** Fuzz testing is the use of fuzzing to test if a PUT violates a correctness policy.
- **Fuzzer** A fuzzer is a program that performs fuzz testing on a PUT.
- **Bug Oracle** A bug oracle is a program, perhaps as part of a fuzzer, that determines whether a given execution of the PUT violates a specific correctness policy.
- **Fuzz Configuration** A fuzz configuration of a fuzz algorithm comprises the parameter value(s) that control(s) the fuzz algorithm.
- **Seed** A seed is a (commonly well-structured) input to the PUT, used to generate test cases by modifying it.

What Fuzzing is?

Fuzz Testing

Input: $\mathbb{C}$, $\mathsf{t}_{\text{limit}}$

Output: $\mathbb{B}$ // a finite set of bugs

$\mathbb{B} \leftarrow \varnothing$

$\mathbb{C} \leftarrow \texttt{Preprocess}(\mathbb{C})$

while $\mathsf{t}_{\texttt{elapsed}} < \mathsf{t}_{\texttt{limit}} \wedge \texttt{Continue}(\mathbb{C})$ **do**

  $\texttt{conf} \leftarrow \texttt{Schedule}(\mathbb{C}, \mathsf{t}_{elapsed}, \mathsf{t}_{limit})$

  $\texttt{tcs} \leftarrow \texttt{InputGen}(conf)$

  // O_{bug} is embedded in a fuzzer

  $\mathbb{B}', \texttt{execinfos} \leftarrow \texttt{InputEval}(conf, tcs, \mathsf{O}_{bug})$

  $\mathbb{C} \leftarrow \texttt{ConfUpdate}(\mathbb{C}, conf, execinfos)$

  $\mathbb{B} \leftarrow \mathbb{B} \cup \mathbb{B}'$

return $\mathbb{B}$

Fuzzing Algorithm

```
Input: ℂ, t_limit
Output: 𝔹 // a finite set of bugs
𝔹 ← ∅
ℂ ← Preprocess(ℂ)
while t_elapsed < t_limit ∧ Continue(ℂ) do
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    𝔹′, execinfos ← InputEval(conf, tcs, O_bug)
    ℂ ← ConfUpdate(ℂ, conf, execinfos)
    𝔹 ← 𝔹 ∪ 𝔹′
return 𝔹
```

- $\mathbb{C}$:a set of fuzz configurations
- t_{limit}: timeout
- $\mathbb{B}$: a set of discovered bugs

Fuzzing Algorithm

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PREPROCESS ($\mathbb{C}$) $\rightarrow \mathbb{C}$

- **Instrumentation**
  - grey-box and white-box fuzzers
  - static/dynamic(INPUTEVAL)
- **Seed Selection**
  - weed out potentially redundant configurations
- **Seed Trimming**
  - reduce the size of seeds
- **Preparing a Driver Application**
  - library Fuzzing, kernal Fuzzing

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Stop Condition

- $t_{\text{elapsed}} < t_{\text{limit}}$
- CONTINUE ($\mathbb{C}$)$\rightarrow$ {True, False}
  - Determine whether a new fuzz iteration should occur

Fuzzing Algorithm

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SCHEDULE ($\mathbb{C}$, $t_{elapsed}$, t_{limit}) $\rightarrow$ conf

- **Function**
  - Pick important information(conf)
- **FCS Problem**
  - *exploration*:Spent time on gathering more accurate information on each configuration to inform future decisions
  - *exploitation*:Spent time on fuzzing the configurations that are currently believed to lead to more favorable outcomes

Fuzzing Algorithm

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return 𝔹
```

InputGen (conf) ⟶ tcs

- **function**
  - Generate testcases
- **classification**
  - Generation-based(*Model-based*)
  - Mutation-based(*Model-less*)
  - White-box Fuzzers: symbolic execution

Fuzzing Algorithm

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```

$\textsc{InputEval}\,(\texttt{conf}, \texttt{tcs}, O_{\text{bug}}) \rightarrow \mathbb{B}', \texttt{execinfos}$

- **Fuzzing PUT**
  - tcs
  - $\mathbb{B}'$
- **Feedback Information**
  - conf, tcs
  - execinfos (tcs,crashes,stack backtrace hash,edge coverage,etc.)

Fuzzing Algorithm

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```

- ConfUpdate $(\mathbb{C}$, conf, execinfos$) \to \mathbb{C}$
  - Update Fuzz Configuration(distinguishablity)
  - Seed Pool Update
- $\mathbb{B} \cup \mathbb{B}' \to \mathbb{B}$
  - Update Bugs Set

Fuzzing Algorithm

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- $\mathsf{t}_{\text{elapsed}} < \mathsf{t}_{\text{limit}}$
- $\textsc{Continue}(\mathbb{C}) \rightarrow \{\texttt{True}, \texttt{False}\}$
  - Determine whether a new fuzz iteration should occur

1 Background
- Pre-Knowledge
- Motivation
- Research Status

2 Theory

3 Work

4 References

Classification

The amount of collected information defines the color of a fuzzer[1].

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- **program instrumentation**
  - static
  - dynamic
- processor traces
- system call usage
- etc.

Classification

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Program Instrumentation

- Static
  - source code
  - intermediate code
  - binary-level
- Dynamic

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Program Instrumentation

- Static
- Dynamic
  - dynamically-linked libraries
  - execution feedback: branch coverage, new path, etc.
  - race condition bugs: thread scheduling

Classification

Classification of Fuzzing

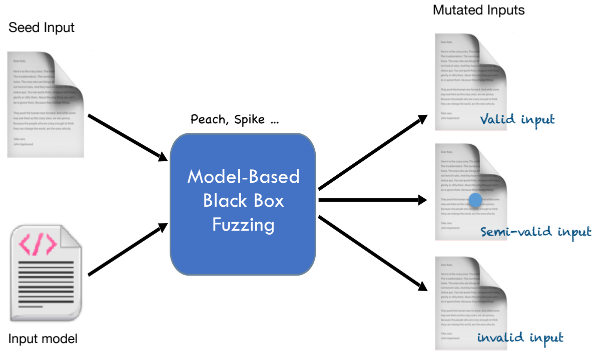
- **Black-box Fuzzing**
  - no program analysis, no feedback
- **White-box Fuzzing**
  - mostly program analysis
- **Grey-box Fuzzing**
  - no program analysis, but feedback

Why Grey-box Fuzzing ?

- Black-box Fuzzing

Defination: techniques that do not see the internals of the PUT,and can observe only the input/output behavior of the PUT, treating it as a black-box[1].

-No program analysis, no feedback



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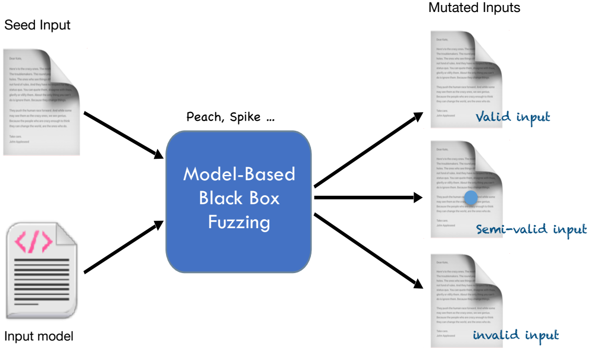


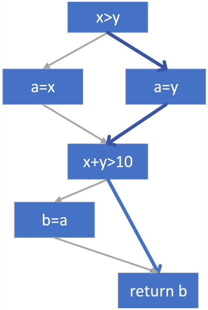
- You have no view of the PUT,but have some view of the input/output domain
- Fuzzing congfigurations are not changed according to some feedback
  - some fuzzer may add the testcases to seed pool
- Not effective

Why Grey-box Fuzzing ?

- White-box Fuzzing

  Defination: techniques that generates test cases by analyzing the internals of the PUT and the information gathered when executing the PUT[1].

  - Requires heavy-weight program analysis and constraint solving.



Cover more paths

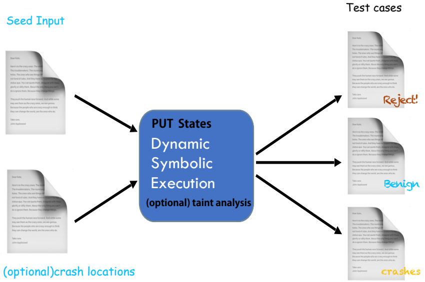
x≤y∧x+y≤10

x≤y∧¬x+y≤10

¬x≤y

Program Analysis

- **Symbolic Excution**
- **Constrains Satisfation**



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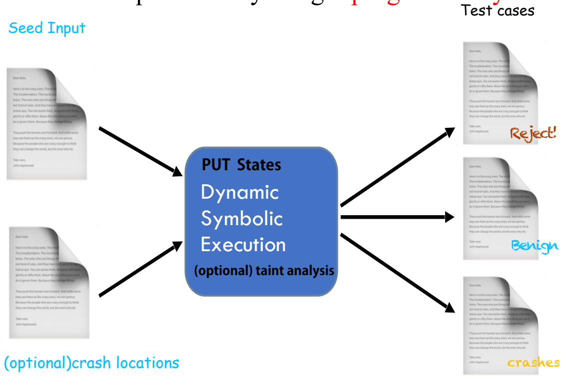


- You have the view of the PUT state(CFG,CG)
- Heavy-weight Program analysis (effective but not efficient!)

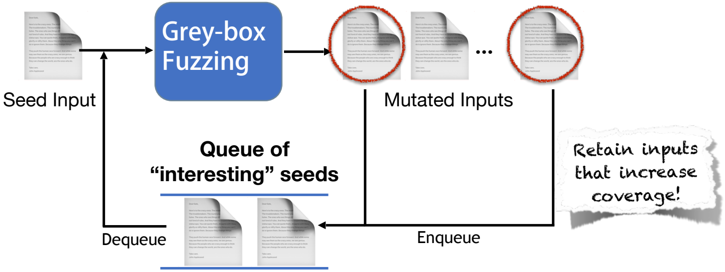
Why Grey-box Fuzzing ?

- Grey-box Fuzzing

  Defination: techniques that can obtain *some* information internal to the PUT and/or its executions to generates test cases[1].

  - Uses only lightweight instrumentation to glean some program structure

  - And coverage feedback



Why Grey-box Fuzzing ?

Grey-box Fuzzing is frequently used

- **State-of-the-art** in automated vulnerability detection
- **Extremely efficient** coverage-based input generation
  - All program analysis before/at instrumentation time.
  - Start with a seed corpus, choose a seed file, fuzz it.
  - Add to corpus only if new input increases coverage.

Why Directed Grey-box Fuzzing ?

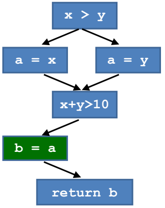
Directed Fuzzing has many applications

- **Patch Testing**: reach changed statements
- **Crash Reproduction**: exercise stack trace
- **SA Report Verification**: reach “dangerous” location
- **Information Flow Detection**: exercise source-sink pairs

Why Directed Grey-box Fuzzing ?

Directed Fuzzing

- **Goal:reach a specific target**
  - **Target Locations**: the line number in the source code or the virtual memory address at the binary level[2].
  - **Target Bugs**: use-after-free vulnerabilities, etc.
- **DSE:classical constraint satisfaction problem**
  - uses program analysis and constraint solving to generate inputs that systematically and effectively explore the state space of feasible paths[3].
  - **Program analysis** to identify **program paths** that reach given program locations.
  - **Symbolic Execution** to derive **path conditions** for any of the identified paths.
  - **Constraint Solving** to find an input

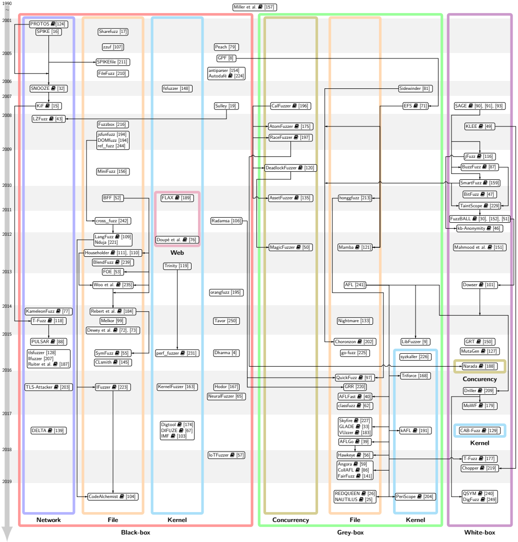


$$\varphi_1 = (x>y) \wedge (x+y>10)$$
$$\varphi_2 = \neg(x>y) \wedge (x+y>10)$$

Why Directed Grey-box Fuzzing ?

- **Effectiveness comes at the cost of efficiency**
- **Heavy-weight program analysis**

Genealogy tracing significant fuzzers' lineage[1]



[1] paper[1]-Figure1

Representative Work

- **AFLGo(2017)**[4]
- **Hawkeye(2018)**[5]

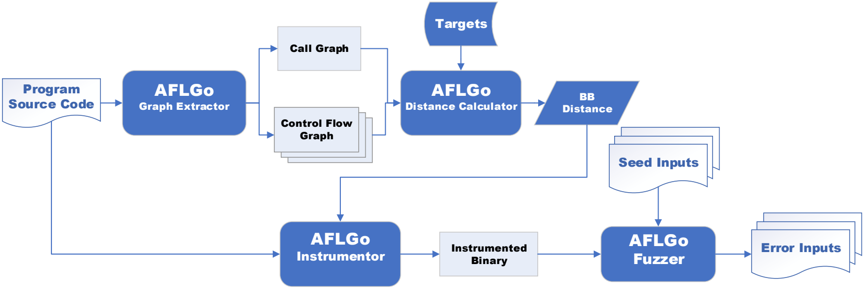
OverView

Directed Fuzzing as optimisation problem!

- **Instrumentation Time**
  1. Extract **call graph** (CG) and **control-flow graphs** (CFGs).
  2. For each **BB**, compute **distance** to target locations.
  3. Instrument program to **aggregate distance values**.
- **Runtime**
  1. collect coverage and distance **information**, and
  2. decide **how long to be fuzzed** based on distance.
     - If input is **closer** to the targets, it is fuzzed for **longer**.
     - If input is **further away** from the targets, it is fuzzed for **shorter**.

OverView

AFLGo Architecture



Algorithm

Directed Grey-box Fuzzing

```
Input: 𝕊 // a finite set of seeds
Input: 𝕋 // a finite set of targer sits
Output: 𝕊′ // a finite set of buggy seeds
𝕊′ ← ∅
SeedQueue ← 𝕊
Graphs ← GraphExt(Code)
BBdistance ← DisCalcu(𝕋, Graphs)
while !siganl do
    s ← Dequeue(SeedQueue)
    e ← AssinEnergy(s, t_elapsed, BBdistance)
    for i ← 1 to e do
        s′ ← Mutation(s)
        trace ← Execution(s′)
        if s′ crashes then 𝕊′ ← 𝕊′ ∪ s′
        if IsIntersting(s′) then
            distance ← SeedEva(trace, BBdistance)
            SeedQueue ← SortInser(distance, s′, SeedQueue)
return 𝕊′
```

Instrumentation

```
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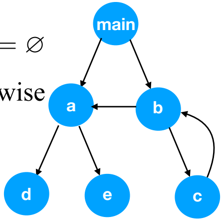
return 𝕊′
```

Instrumentation

- **Function-level target distance**[2]:using call graph (CG)

$$d_f(n,T_f)=\begin{cases}\text{undefined}, & \text{if } R(n,T_f)=\varnothing\\ [\sum_{t_f\in R(n,T_f)} d_f(n,t_f)^{-1}]^{-1}, & \text{otherwise}\end{cases}$$

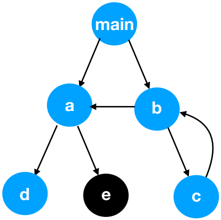


[2] R(n,Tf) is the set of all target functions that are reachable from n in CG

Instrumentation

- **Function-level target distance**:using call graph (CG)

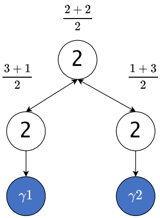
1. Identify **target functions** in CG



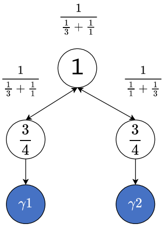
Instrumentation

- **Function-level target distance**:using call graph (CG)

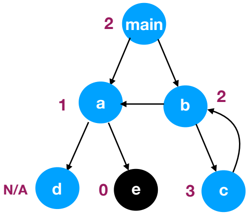
1. Identify **target functions** in CG
2. For each **function**, compute the **harmonic mean** of the **length of the shortest path** to targets



(a)arithmetic mean



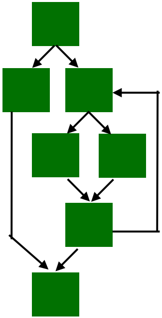
(b)harmonic mean



Instrumentation

- **Function-level target distance**:using call graph (CG)
- **BB-level target distance**:using control-flow graphs (CFG)

$$d_b(m, T_b) = \begin{cases} 0, & \text{if } m \in T_b \\ c \cdot \min_{n \in N(m)} (d_f(n, T_f)), & \text{if } m \in T \\ [\sum_{t \in T} (d_b(m,t) + d_b(t, T_b))^{-1}]^{-1}, & \text{otherwise} \end{cases}$$

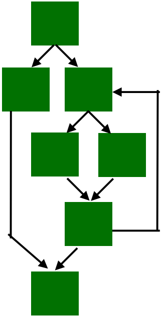


CFG for function b

Instrumentation

- **Function-level target distance**:using call graph (CG)
- **BB-level target distance**:using control-flow graphs (CFG)

1. Identify **target BBs** and assign distance 0 (none in function b)

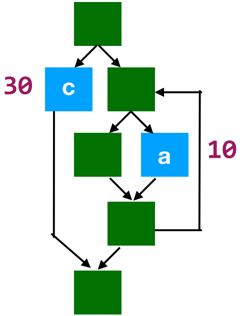


CFG for function b

Instrumentation

- **Function-level target distance**:using call graph (CG)
- **BB-level target distance**:using control-flow graphs (CFG)

1. Identify **target BBs** and assign distance 0
2. Identify BBs that **call function** and assign **10*FLTD**



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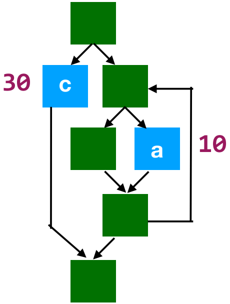
Instrumentation

- **Function-level target distance**:using call graph (CG)
- **BB-level target distance**:using control-flow graphs (CFG)

1. Identify **target BBs** and assign distance 0
2. Identify BBs that **call function** and assign **10*FLTD**
3. For each BB, compute harmonic mean of (length of shortest path to any function-calling BB + 10*FLTD).

$[(1+30)^{-1}+(2+10)^{-1}]^{-1}$



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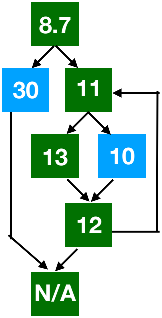
1. Identify **target BBs** and assign distance 0
2. Identify BBs that **call function** and assign **10*FLTD**
3. For each BB, compute harmonic mean of (length of shortest path to any function-calling BB + 10*FLTD).



CFG for function b

1. Background
2. Theory
3. Work
4. References

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Thanks!