

InputFinder: Reverse Engineering Closed Binaries using Hardware Performance Counters

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Introduction

- ▶ Dynamic program analysis techniques necessitate test suites
- ▶ Test suite availability and completeness issues
- ▶ Analysis dependencies:
 - ▶ platform
 - ▶ architecture
 - ▶ binary format
 - ▶ source code availability
 - ▶ ...

Background

Fuzzing

Black-box fuzzing

- ▶ Randomly generated input
- ▶ Advantages
 - ▶ easy to implement
 - ▶ previous success
- ▶ Disadvantages
 - ▶ poor code coverage
 - ▶ slow

Background

Fuzzing

White-box fuzzing

- ▶ Systematically generated input
- ▶ Advantages
 - ▶ improved effectiveness
- ▶ Disadvantages
 - ▶ limitations of constraint solver (if symbolic execution is used)
 - ▶ source code dependencies (if instrumentation is used, i.e. afl-fuzz)

Background

Symbolic Execution

- ▶ Execution of a program with symbols as input
- ▶ Build path conditions
- ▶ Advantages
 - ▶ code coverage
 - ▶ good results
- ▶ Disadvantages
 - ▶ Constraint-solver limitations
 - ▶ non-linear constraints
 - ▶ scalability (path explosion)
- ▶ *Concolic execution*

DARPA Cyber Grand Challenge

Mission: Design and build autonomous security systems which are capable of finding and patching vulnerabilities in unknown, closed source binaries.

DARPA Cyber Grand Challenge

- ▶ Architecture (32 bit, x86)
- ▶ Binary format
- ▶ System calls
 - ▶ *allocate()*
 - ▶ *deallocate()*
 - ▶ *terminate()*
 - ▶ *fdwait()*
 - ▶ *random()*
 - ▶ *receive()*
 - ▶ *transmit()*
- ▶ No standard libraries

Problem Statement

Platform, architecture, format, source-code **independent** method
for generating input for programs.

Programs will normally

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- ▶ provide output (possibly)

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Use this observation to identify valid input

Proposed Approach

Leverage information exposed by the hardware [performance counters] during the program's execution

1. Analyze the number of instructions retired to incrementally build input strings
2. Use discovered input and dynamically generated traces to identify the expected protocol

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- ▶ No inter dependencies between fields of a single input.
- ▶ Input is not altered prior to validation.

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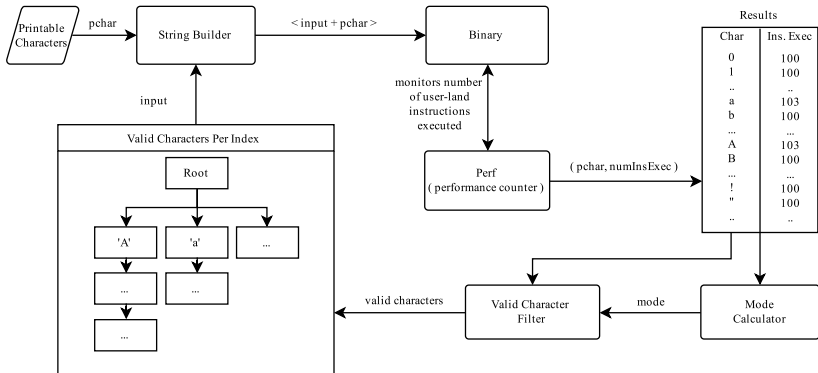
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4. Valid characters for the current index of the input are characters for which the number of user-land instructions retired is not within the range of mode \pm threshold
5. Append one of the discovered valid characters to the current input string and repeat steps 2-5 (until no more valid characters are identified).



Finding Input Size

Idea: Work done by processor to read input is a function of the input size and the input buffer size

1. Send three short inputs (e.g. 3,4,5 characters long)
2. Record delta (difference in number of instructions retired between consecutive length inputs)
3. Increase input size exponentially and send three inputs of consecutive lengths (e.g. 100,101,102 characters long)
4. Compare current deltas with expected delta
5. Repeat steps 3-4 until change is observed

Classifying Input

Determine type of accepted characters even when the program does not have predefined input/commands.

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Help fuzzers achieve better results, faster.

Protocol State Machine Generation

To discover the expected protocol:

1. Generate every permutations of input strings
2. Discover arguments for input strings
3. Test permutations with instrumented binary
4. Compare execution traces

Execution Traces

Instrument binary using PIN to record every basic block (defined by its starting address) executed in order of execution

```
0x8049522  
0x8049528  
0x8049530  
0x8049536  
0x8049542  
0x8049506  
0x80480B3  
0x904954D  
0x80480BB  
0x8049824  
0x8049658  
0x8049661  
0x804966B  
0x8049542  
0x8049506
```

...

Example

Valid input strings: HELLO, AUTH, SET, CALL, BYE

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Arguments: check arguments for HELLO; send HELLO, check arguments for AUTH; send HELLO, check arguments for CALL ...

Compare traces: [HELLO, AUTH] vs. [CALL, AUTH] vs. [SET, AUTH], vs. [BYE, AUTH] ...

Evaluation

- ▶ 24 DARPA Cyber Grand Challenge (CGC) binaries
- ▶ 1 cyber security interview challenge (password cracking program)

Results

Binary	Input	Number of Inputs	Input Size	Crash Input	Protocol State Machine
06459301	yes (8 min)	8 out of 8	yes	no	-
06b71301	no	-	yes	no	-
07a9a901	-	-	yes	yes	-
0b32aa01	yes (2 min)	1 out of 1	yes	yes	-
11dc8e01	no	-	yes	no	-
1877a601	yes (11 min)	6 out of 6	yes	no	-
250d1101	yes (20 min)	5 out of 5	yes	no	yes
2eca0101	yes (42 min)	7 out of 7	no	no	-
37e97201	yes (38 min)	6 out of 6	yes	no	-
3dcf1a01	yes (6 min)	6 out of 6	yes	yes	-
48b9cf01	yes (50 min)	9 out of 9	yes	no	-
65884701	no	-	no	no	-
701b7301	-	-	yes	no	-
7262d006	yes (5 min)	4 out of 5	yes	no	-
7fa39f01	no	-	yes	yes	-
b8993403	yes (12 min)	1 out of 1	yes	no	-
badd9e01	no	-	yes	no	-
caea9c01	no	-	yes	no	-
cc366801	yes (60 min)	10 out of 10	no	no	-
d476cd01	no	-	yes	no	-
df9df201	no	-	yes	no	-
e7cd3901	-	-	no	yes	-
f14eb101	yes (53 min)	11 out of 11	no	no	yes
f658d801	yes (2 min)	1 out of 4	yes	no	-
interview challenge	yes (2 min)	1 out of 1	yes	-	-

Results

- ▶ CGC
 - ▶ Binaries with well defined input: 21 out of 24
 - ▶ Found some input strings 13 out of 21 (62%)
 - ▶ Found all input strings 11 out of 13 (85%)
- ▶ Interview challenge password cracked

Case Study

250d1101

Binary implements a simple protocol which allows the user to perform base 64 encoding/decoding and utilize an obfuscation scheme.

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The protocol dictates that the user must first authenticate before being able to execute any commands.

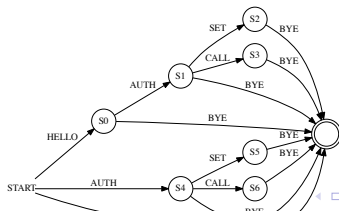
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250d1101

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- ▶ 5/5 input strings discovered
- ▶ Correct protocol identified, including hidden authentication backdoor



Future Work

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- ▶ Use hardware counters for protocol state machine generation (vs. PIN instrumentation)

Thank you!

Questions?