Vulnerability Discovery

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Vulnerability Discovery Project

Increase **assurance** of DoD software through enhanced vulnerability discovery techniques
Team

- Edward Schwartz, PhD, CERT
- David Warren, CERT
- Allen Householder, CERT

- David Brumley, PhD
- Thanassis Avgerinos, PhD
- Tyler Nighswander
Agenda

Revisiting Widely Held Beliefs about Black-Box Fuzzing

SMART Fuzzing: How to Intelligently Combine a Fuzzer with a Concolic Executor
Revisiting Widely Held Beliefs About Black-Box Fuzzing
Testing of programs by randomly mutating program inputs (seeds)
Challenge: How Many Software Vulnerabilities Are There?

Crash
Problem: Distinguishing One Vulnerability From Another

I don’t know how to *specify* a vulnerability, but I know how to *fix* one.
The Idea: Patches Define Vulnerabilities

Any crash that is fixed by the patch is also affected by vulnerability V.
Example Ground Truth
Patching software

- Fuzzed each program for 1 week with BFF fuzzer
- Manually patched all vulnerabilities to collect ground truth

<table>
<thead>
<tr>
<th></th>
<th>Flasm</th>
<th>ImageMagick</th>
<th>Jasper</th>
<th>OpenJpeg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crashes (BFF)</td>
<td>253</td>
<td>64</td>
<td>93</td>
<td>145</td>
</tr>
<tr>
<td>Vulnerabilities</td>
<td>6</td>
<td>31</td>
<td>12</td>
<td>36</td>
</tr>
</tbody>
</table>
Revisiting Common Beliefs about Black-Box Fuzzing

Belief 1: Stack backtrace hashing always accurately counts vulnerabilities.
   • Used by BFF and other fuzzers.

Belief 2: Sanitization never harms fuzzing performance.
   • Detects vulnerabilities that do not cause a crash.

Belief 3: The AFL fuzzer always finds more vulnerabilities than non-guided fuzzers.
   • Newer is better.
Belief 1: Stack Backtrace Hashing Always Accurately Counts Vulnerabilities

Undercount (UC)
- # vulnerabilities missed by stack backtrace hashing on average
- We never see these vulnerabilities

Overcount (OC)
- # times a vulnerability is included more than once by stack backtrace hashing on average
- We see these vulnerabilities more than once

<table>
<thead>
<tr>
<th>Program</th>
<th># Vuls</th>
<th>UC</th>
<th>%</th>
<th>OC</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flasm</td>
<td>6</td>
<td>1.8</td>
<td>29%</td>
<td>410.9</td>
<td>6,848%</td>
</tr>
<tr>
<td>ImageMagick</td>
<td>31</td>
<td>1.9</td>
<td>6%</td>
<td>67.9</td>
<td>219%</td>
</tr>
<tr>
<td>Jasper</td>
<td>12</td>
<td>0.0</td>
<td>0%</td>
<td>226.4</td>
<td>1,887%</td>
</tr>
<tr>
<td>OpenJpeg</td>
<td>36</td>
<td>0.1</td>
<td>0%</td>
<td>267.5</td>
<td>743%</td>
</tr>
</tbody>
</table>
Belief 2: Sanitization Never Harms Fuzzing Performance
Belief 3: The AFL Fuzzer Always Finds More Vulnerabilities Than Non-Guided Fuzzers
Collaboration with ForAllSecure
DARPA Celebrates Cyber Grand Challenge

Winners

Top-scoring cyber reasoning system becomes first machine to be invited to participate in DEF CON Capture the Flag tournament

OUTREACH@DARPA.MIL
8/5/2016

(Updated August 7, 2016)

DARPA officials this morning released partial, audited results of yesterday’s all-day Cyber Grand Challenge (CGC) Final Event—the world’s first all-machine cyber hacking tournament—and confirmed that the top-scoring machine was Mayhem, developed by team ForAllSecure of Pittsburgh.
Background: Concolic Execution

```c
rows, cols = input()
if rows > 0 && cols > 0
p = malloc(rows*cols*4)
p[rows*cols-1] = 0xFF
exit
```

```
rows=0
cols=0
```

```
rows=5
cols=10
```

```
¬ (rows > 0 && cols > 0)
```
Background: Concolic Execution

```
rows, cols = input()
if rows > 0 && cols > 0
  p = malloc(rows*cols*4)
else
  rows = 0
  cols = 0

overflow = rows > 0 && cols > 0

f = (overflow)
t = false

exit
```

```
p[rows*cols - 1] = 0xFF
```

```
rows*cols - 1 >= rows*cols*4
rows = 0x11111110
cols = 0x0000000f
```
Background: Fuzzing

Most mutations do not trigger the overflow vulnerability.
Concolic Execution vs. Fuzzing

Concolic Execution
- Precise
- Slow
- Hard constraints

Fuzzing
- Blunt
- Fast
- Easy constraints
The Synergistic Mayhem AFL Research Tool

- Concolic execution: Mayhem (ForAllSecure+SEI)
- Fuzzing: AFL
- Periodically synchronize seed files between them

Challenges

How much should we use concolic execution?

- \( \sim 10^4 \) times slower than fuzzing
- Brute force vs. high cost
SMART evaluation

Edge Coverage After Two Days with Blank Seeds

readelf  objdump  convert-png  mplayer-mp3  pdf2svg-pdf

Mayhem  SMART
Summary

• Developing new techniques for discovering and mitigating vulnerabilities in the DoD

• Developed vulnerability uniqueness model and used ground truth to explore common fuzzing (mis-)beliefs

• ForAllSecure: Hybrid fuzzing and concolic tester

Team Members
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