Understanding the Reproducibility of Crowd-reported Security Vulnerabilities

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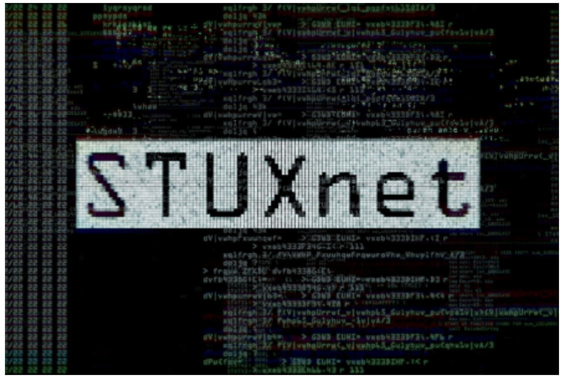
Real World Effects of Security Vulnerabilities



CVE-2010-2772
STUXnet

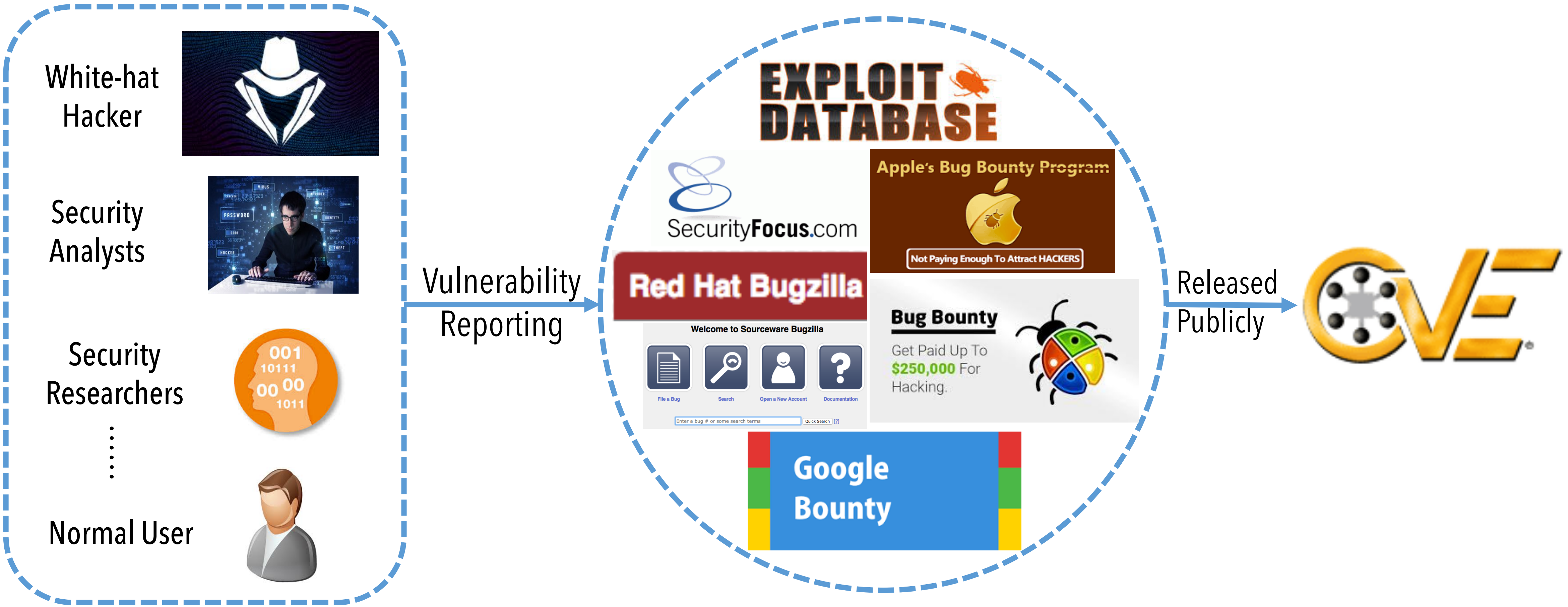
CVE-2014-0160
HeartBleed

CVE-2014-6271
ShellShock

CVE-2017-0144
WannaCry

It is infeasible for in-house teams to identify all possible vulnerabilities before a software release

Massive Crowd-reported Vulnerabilities Over Time



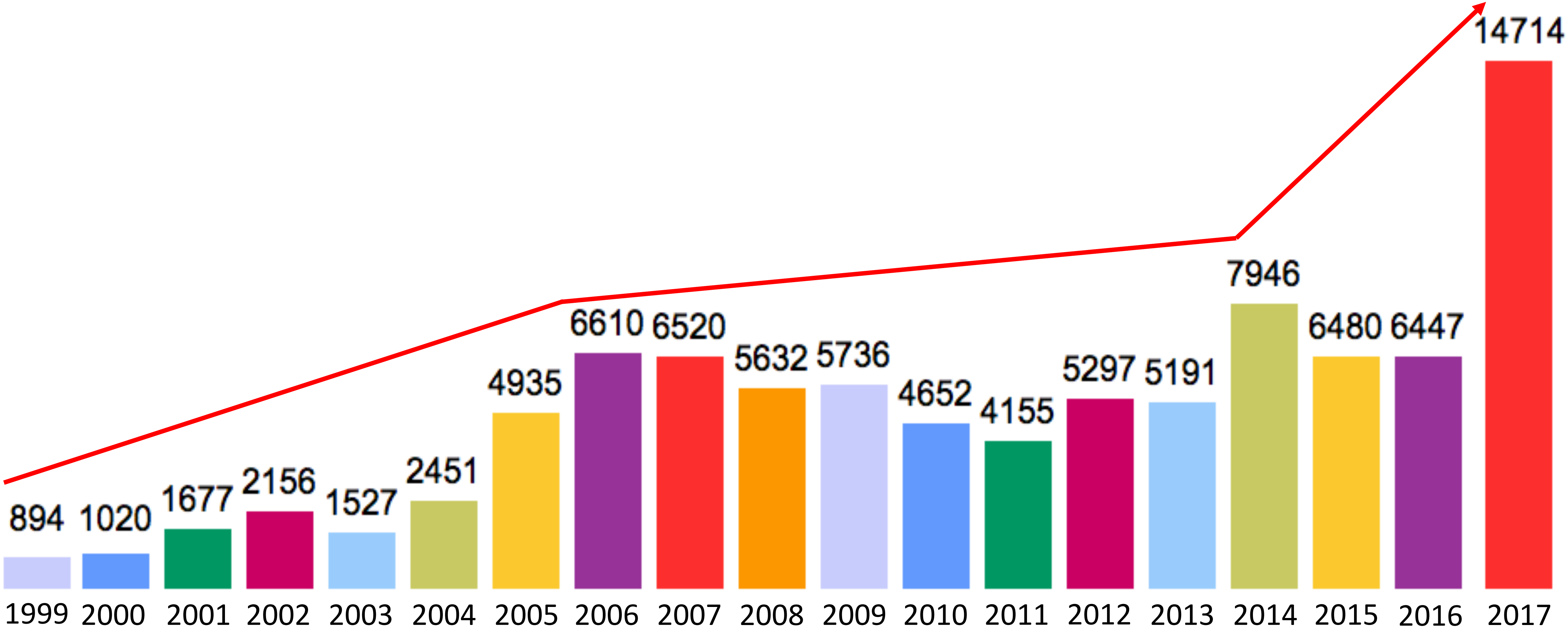
The Crowd

Vulnerability Reporting Websites

CVE[1] Website

[1] Common Vulnerabilities and Exposures

Massive Crowd-reported Vulnerabilities Over Time



Number of vulnerabilities reported to CVE[1] by year

[1] Common Vulnerabilities and Exposures

Vulnerability Reproduction Can Be Challenging

Nick Clifton 2016-12-01 10:31:40 UTC

```
Hi Thuan,

I am unable to reproduce this problem as you reported it. :-(

> binutils was checked out from


How were the binutils configured ?

> Its commit is  268ebe95201d2ebdcf68cad9dc67ff6d1e25be9e
> (Fri Nov 18 14:15:12 2016
```

Vulnerability Reproduction Can Be Challenging

Nick Clifton 2017-08-09 16:37:39 IST

Hi Zhihua,

I am sorry, but I am unable to reproduce this failure.

Please co

1. The c

2. The o

3. Which
you u
in th

t. :-(

Nick Clifton 2017-06-15 11:14:04 UTC Comment 4

Hi Aadamski,

I could not reproduce this failure. Please could you check again to see if it is still present ? I suspect that one of the recent patches to fix the other problems you detected may have fixed this problem as well.

nozz_ posted a comment.

Hello @Jouko,

Thank you again for your rep

rahul 2008-08-08 04:38:16 UTC Comment 8

That is odd, I couldn't reproduce it, could you please post your httpd.conf in full (and logs with debug on)?

customers, drivers and Grab.

Unfortunately we did not consider possible to perform any code execution even with your additional information. We tried to reproduce your PoC against our systems but this one is not working mainly because of that environments are not totally similar and our instance is hardened.

Consequences of Poor Reproducibility

Software vendors

Poor reproducibility delays the patching of vulnerability

Symantec

FireEye

Security Firms

Poor reproducibility prevents analysts from assessing potential threats to their customers in a timely fashion

Security Researchers

Poor reproducibility makes it hard to thoroughly evaluate security solutions

Consequences of Poor Reproducibility

Research Papers that use public vulnerabilities for evaluation	# of Vulnerability
SP'2018	9
Usenix'2017	8
Usenix'2015	6
NDSS'2015	7
Usenix'2015	8
NDSS'2011	14
SP'2008	5
Usenix'2005	4
Usenix'1998	8

Security Researchers

Poor reproducibility makes it hard to thoroughly evaluate security solutions

This Work

Q1: How reproducible are public security vulnerability reports?

Q2: What makes vulnerability reproduction difficult?

Q3: How to improve the efficiency of vulnerability reproduction?

We answer three questions **by manually reproducing vulnerabilities**

Roadmap

- Methodology
- Findings
- ~~Survey~~
- Suggestions
- Conclusion

We surveyed 48 external security professionals from both academia and industry to examine people's perceptions towards the vulnerability reports and their usability

Vulnerability Report Dataset

- We randomly selected a large collection of reported vulnerabilities
  - We focused on Memory Error Vulnerabilities due to their high severity (Average CVSS Score 7.6 > Overall Average CVSS Score 6.2) and significant real-world impact
  - We focused on Open Source Linux Software due to debugging and diagnosing capabilities

CVSS Score	Rating
0.1 - 3.9	Low
4.0 - 6.9	Medium
7.0 - 8.9	High
9.0 - 10.0	Critical

- We collected two datasets including,
  - A primary dataset of 291 vulnerabilities with CVE IDs
  - A complementary dataset for 77 vulnerabilities without CVE ID

Vulnerability Report Dataset (cont.)

We collect vulnerability reports by crawling the references listed in the CVE website.

❖ *6044 vulnerability reports in total*

CVE-ID

CVE-2008-5314 | Learn more at National Vulnerability Database (NVD)
• CVSS Severity Rating • Fix Information • Vulnerable Software Versions • SCAP Mappings • CPE Information

Description

Stack consumption vulnerability in libclamav/special.c in ClamAV before 0.94.2 allows remote attackers to cause a denial of service (daemon crash) via a crafted JPEG file, related to the cli_check_jpeg_exploit, jpeg_check_photoshop, and jpeg_check_photoshop_8bim functions.

References

Note: References are provided for the convenience of the reader to help ... Th

- EXPLOIT-DB:7330
- URL:https://www.exploit-db.com/exploits/7330
- MLIST:[clamav-announce] 20081126 announcing ClamAV 0.94.2
- URL:http://lurker.clamav.net/message/20081126.150241.55b1e092.en.html
- MLIST:[oss-security] 20081201 CVE request: clamav 0.94.2
- URL:http://www.openwall.com/lists/oss-security/2008/12/01/8

Information source websites

CVE-2008-5314

EDB-ID: 7330	**Author:** ilja van sprundel	**Published:** 2008-12-03
CVE: CVE-2008-5314	**Type:** Dos	**Platform:** Multiple
E-DB Verified: ✔	**Exploit:** Download / View Raw	**Vulnerable App:** N/A

« Previous Exploit

```
/*
There is a recursive stack overflow in clamav 0.93.3 and 0.94 (and probably
older versions) in the jpeg parsing code.
it scan's the jpeg file, and if there is a thumbnail, it'll scan that too. the
thumbnail itself is just another jpeg
file and the same jpeg scanning function gets called without checking any kind
of recurising limit. this can easely
lead to a recurisive stack overflow. the vulnerable code looks like:
clamav-0.94\libclamav\special.c
```

The crowd-sourced vulnerability reports

Vulnerability Report Dataset (cont.)

We collect vulnerab… in the CVE website.

- *6044 vulnerab…*

Top 5 source websites in our dataset

EXPLOIT DATABASE

SecurityFocus.com

Red Hat Bugzilla

Security tracker

Openwall

CVE-2008-5… …ulnerability reports

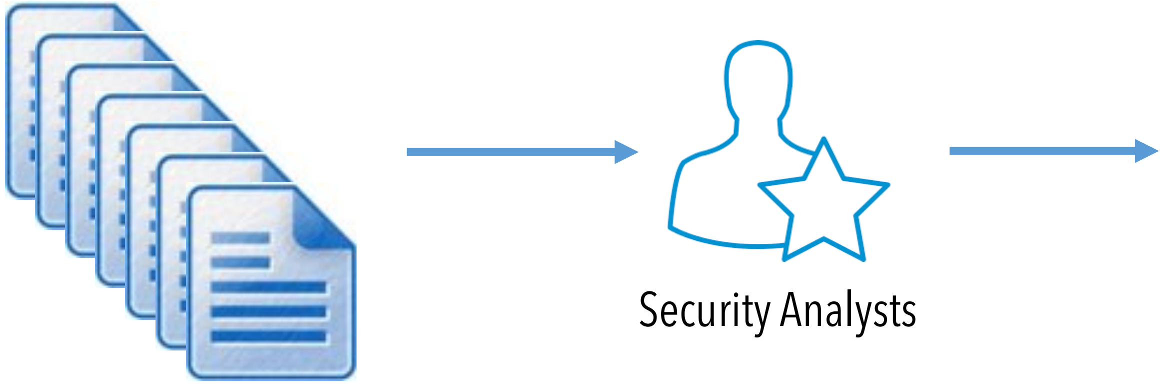
The Analyst Team

- We formed a team of 5 security analysts to carry out our experiments

Security Analysts

- In-depth knowledge of memory error vulnerabilities
- First-hand experience analyzing vulnerabilities, writing exploits, and developing patches
- Rich Catch-The-Flag experience, and have discovered and reported over 20 new vulnerabilities to CVE website

Reproduction Workflow



- Vulnerable Version
- Operating System
- Software Installation
- Software Configuration
- Proof-of-Concept File
- Trigger Method
- Vulnerability Verification

Default Setting for missing information

Reproduction Workflow (cont.)

- Set up the operating system for vulnerable software analysis

Information	Default Setting
Operating System	A Linux system that was released in (or slightly before) the year when the vulnerability was reported

- Vulnerable Version
- <u>Operating System</u>
- Software Installation
- Software Configuration
- Proof-of-Concept File
- Trigger Method
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Reproduction Workflow (cont.)

- Compile vulnerable software with the compilation options
- Install vulnerable software with the configuration options

Building System	Default Setting
automake	make; make install
autoconf & automake	./configure; make; make install
cmake	mkdir build; cd build; cmake ../; make; make install

- ✓ <u>Vulnerable Version</u>
- Operating System
- ✓ <u>Software Installation</u>
- ✓ <u>Software Configuration</u>
- Proof-of-Concept File
- Trigger Method
- Vulnerability Verification

Reproduction Workflow (cont.)

- Trigger the vulnerability by using the Proof-of-Concept File

Type of PoC	Default Setting
Shell commands	Run the commands with the default shell
Script program (e.g., python)	Run the script with the appropriate interpreter
C/C++ code	Compile code with default options and run it
A long string	Directly input the string to the vulnerable program
A malformed file (e.g., jpeg)	Input the file to the vulnerable program

- Vulnerable Version
- Operating System
- Software Installation
- Software Configuration
- ✓ <u>Proof-of-Concept File</u>
- ✓ <u>Trigger Method</u>
- Vulnerability Verification

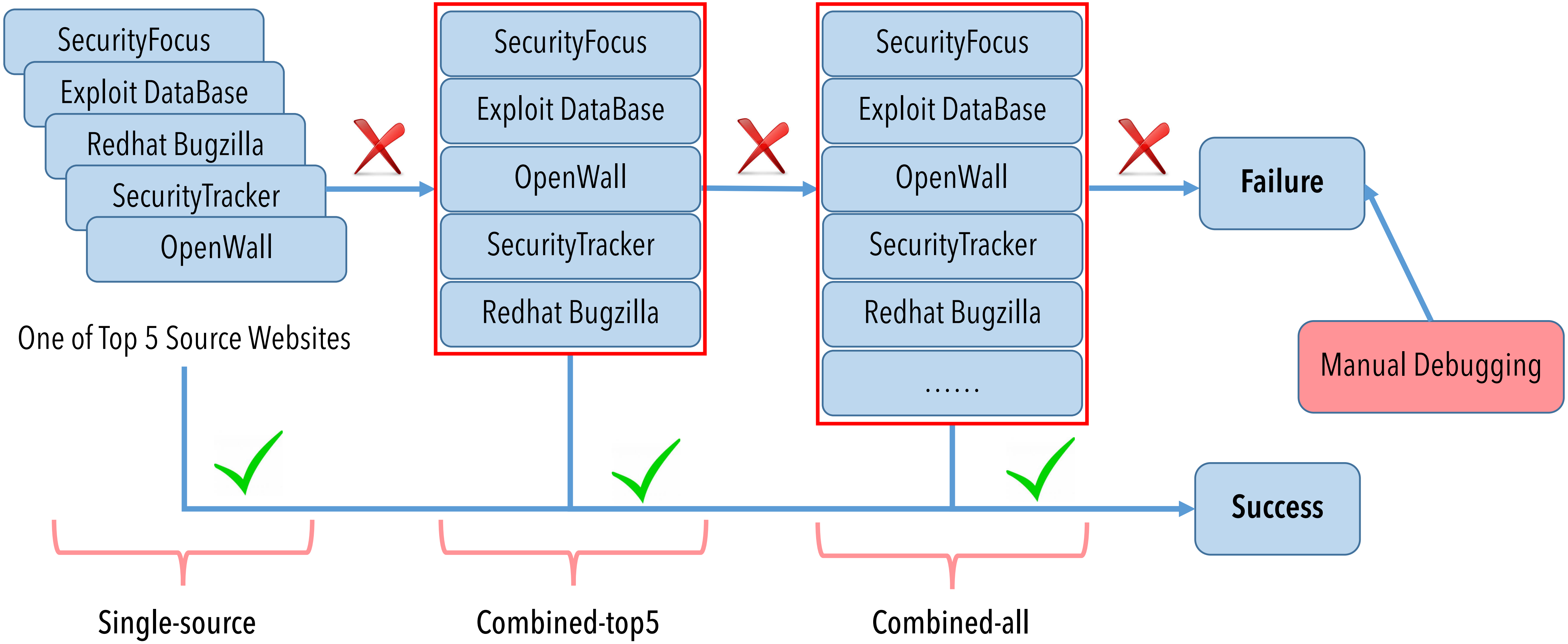
Reproduction Workflow (cont.)

- Verify the vulnerability with expected program behavior

Information	Default Setting
Vulnerability Verification	Unexpected program termination (or program "crash")

- Vulnerable Version
- Operating System
- Software Installation
- Software Configuration
- Proof-of-Concept File
- Trigger Method
- ✓ <u>Vulnerability Verification</u>

Reproduction Experiment: Controlled Information Source



Roadmap

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Finding 1: Vulnerability Is Difficult to Reproduce

Information Source	CVE Reproduction (N=291)		
	# of Case	# of Success	Success Rate (%)
SecurityFocus	256	32	12.6%
Redhat Bugzilla	195	19	9.7%
ExploitDB	156	46	29.5%
OpenWall	153	67	43.8%
SecurityTracker	89	4	4.5%
Combined-top5	287	126	43.9%
Combined-all	291	182	62.5%

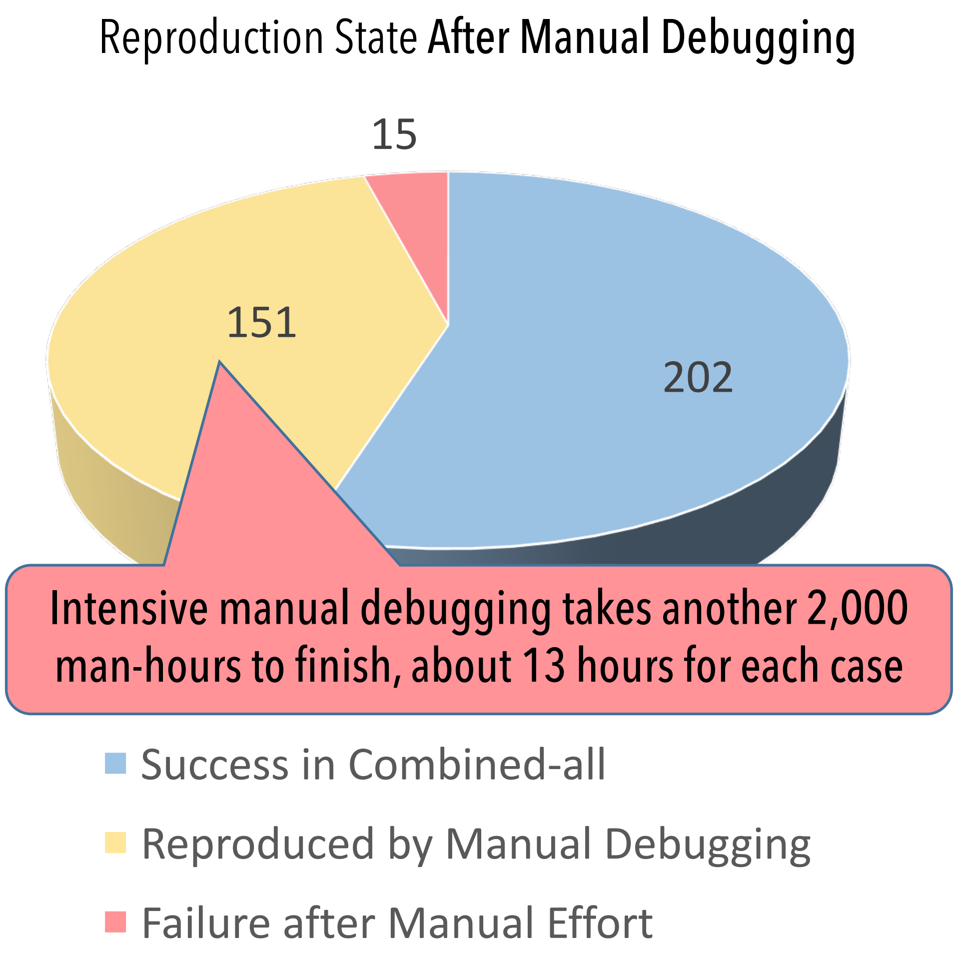
The single-source returns a low success rate

"Combined-top5" has clearly improved the success rate

The success rate is improved to 62.5% by "Combined-all"

Information Source	Non-CVE Reproduction (N=77)		
Combined-all	77	20 (25.6%)	25.6%

Finding 2: Key Factors Make Reproduction Difficult



Report Information	# of vulnerabilities addressed by Manual Debugging
Trigger Method	74
Software Installation	43
PoC File	38
Software Configuration	6
OS information	4
Software version	1
Vulnerability Verification	0

Finding 3: Useful Tips for Information Recovery

Priority of Information

1. Trigger method
2. Software Installation
3. PoC File
4. Software Configuration
5. Operating System

Correlation of Different Vulnerabilities

Recover missing information by reading reports of other similar vulnerabilities.

For 74 cases that failed on trigger method, we recovered 68 cases by reading other similar vulnerability reports

Roadmap

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Our Ideas of Making Vulnerability Reproduction Easier

Vulnerability Reporters → Bugzilla Reporting Websites → Reproducers

CVE-2007-1001 misses Trigger Method
CVE-2013-7226 misses Installation Options
CVE-2007-1465 misses Proof-of-Concept
……

Manually generating standardized reports is really time-consuming

With standardized reports, it's a waste of resource if we still reproduce vulnerability entirely by manual efforts

1. Standardize Vulnerability Reports
2. Develop Useful Automated Tools to Collection Information
3. Automate the Vulnerability Reproduction

VAGRANT docker

Conclusion

Vulnerability reproduction is difficult and requires extensive manual efforts

A crowdsourcing approach could increase the reproducibility

Apart from manual debugging based on experience, Internet-scale crowdsourcing and some heuristics could help recover missing information

There is an urgent need to automate vulnerability reproduction and overhaul current vulnerability reporting systems

Data Sharing

- DataSet : https://vulnreproduction.github.io/ (12 Virtual Machine Images)
- Github Repo : https://github.com/VulnReproduction/LinuxFlaw

Name: Dongliang Mu
Homepage: http://mudongliang.me/about/
Email: dzm77@ist.psu.edu

- We provide 300+ Reproducible Vul
- For each vulnerability, we have :
  - Fully-tested Proof-of-Concept
  - Pre-configured virtual machine or Docker Image
  - Detailed instructions on how to reproduce the vulnerability
  - Structured information fields (in HTML and JSON)

References

	Research Papers that use public vulnerabilities for evaluation	# of Vulnerability
Usenix'2005	Non-control-data attacks are realistic threats	4
SP'2008	Preventing memory error exploits with wit	5
Usenix'2015	Control-flow bending: on the effectiveness of control-flow integrity	6
NDSS'2015	Preventing Use-after-free with Dangling Pointers Nullification	7
Usenix'1998	StackGuard : automatic adaptive detection and prevention of buffer-overflow attacks	8
Usenix'2017	Towards efficient heap overflow discovery	8
Usenix'2015	Automatic Generation of Data-Oriented Exploits	8
SP'2018	Data-oriented programming : On the Expressiveness of Non-Control Data Attacks	9
NDSS'2011	AEG: Automatic exploit generation	14