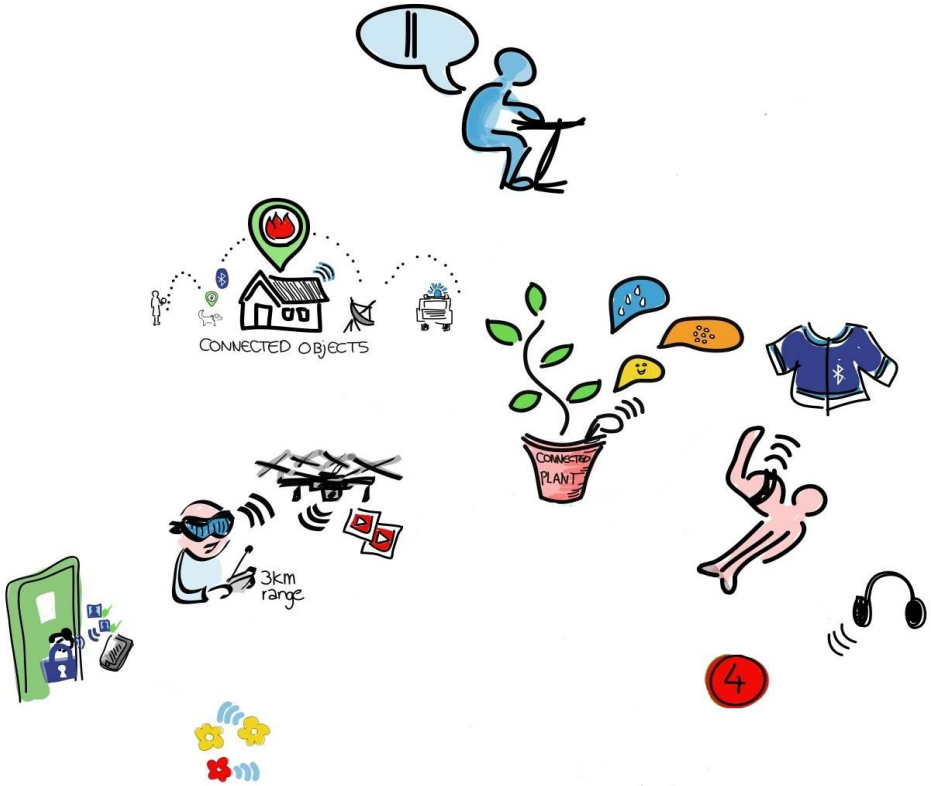
black hat EUROPE 2014

A Large Scale Analysis of the Security of Embedded Firmwares

A. Costin, *J. Zaddach*, A. Francillon, D. Balzarotti
•EURECOM, France

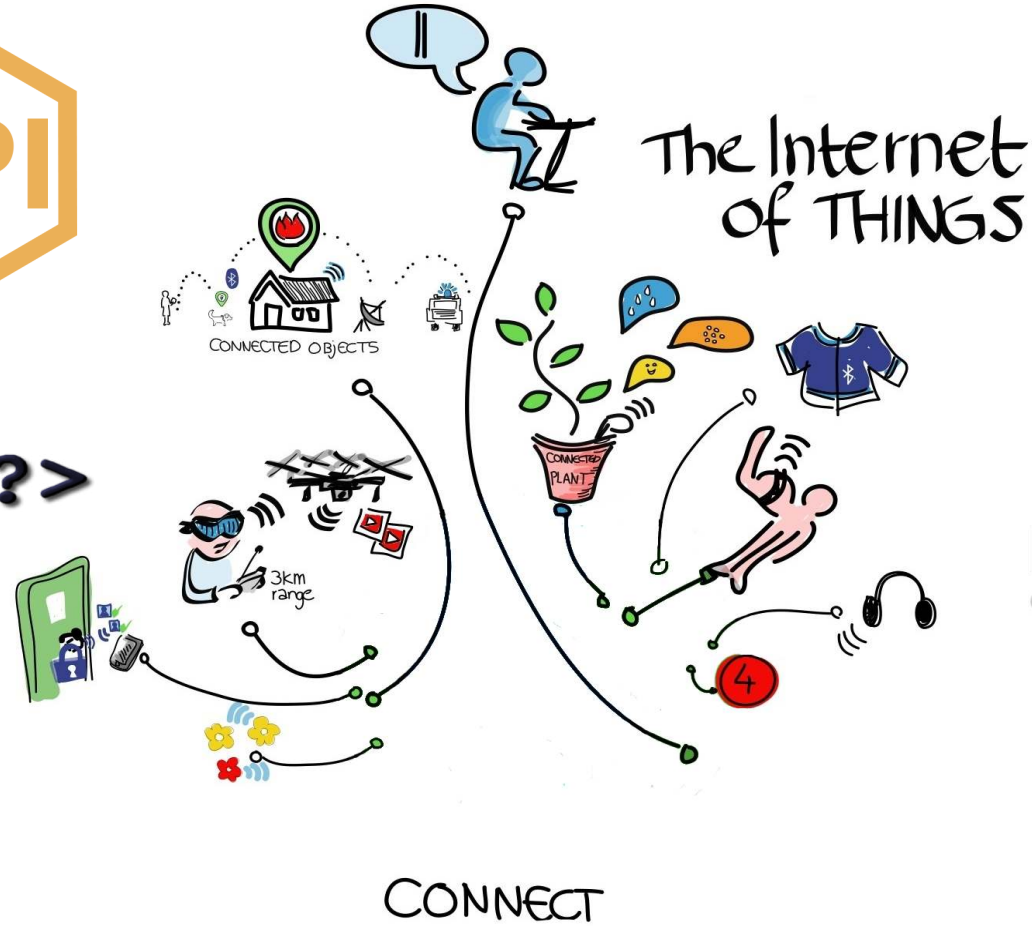
Embedded Systems Are Everywhere



Smarter & More Complex

API

<?xml?>

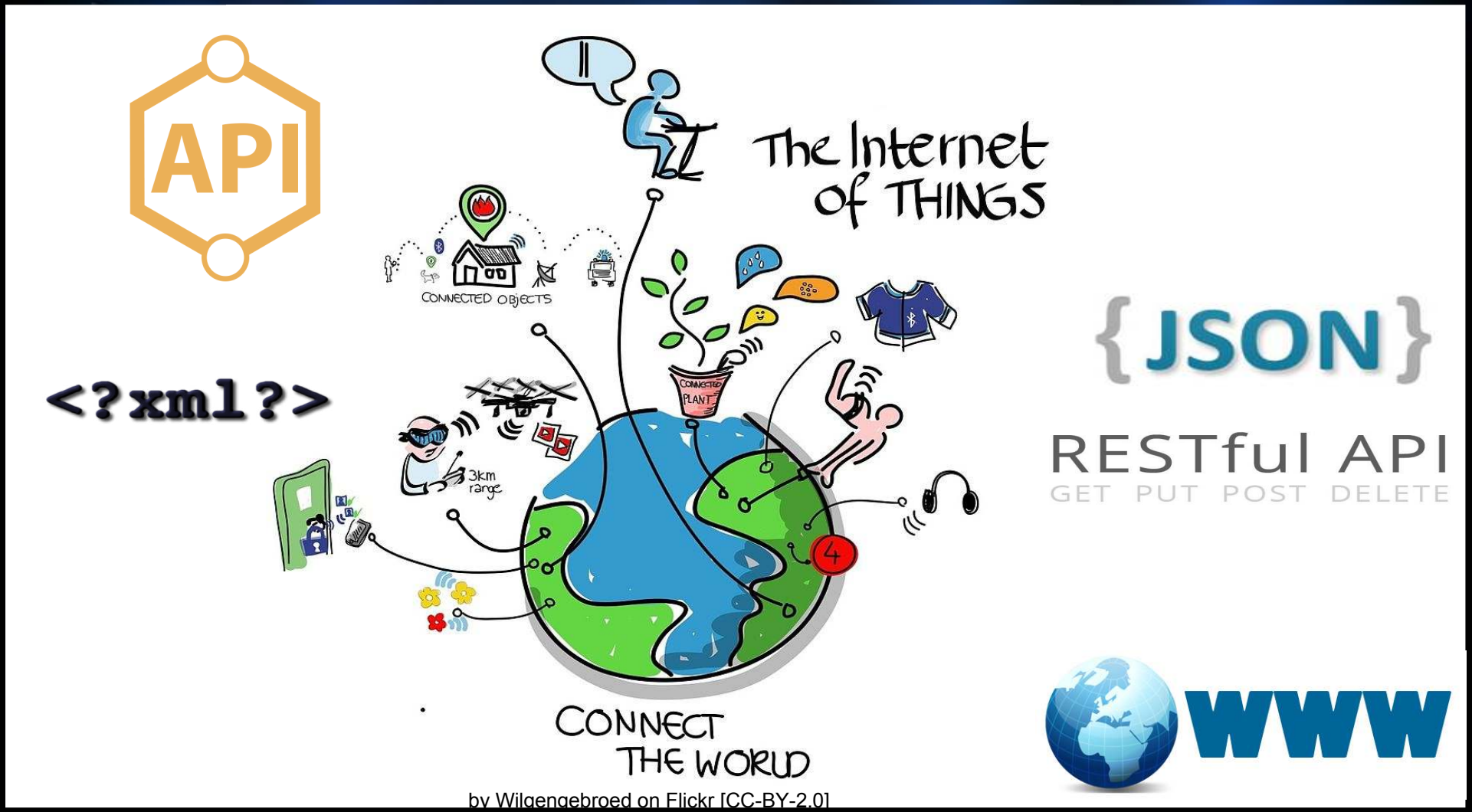


{JSON}

RESTful API

GET PUT POST DELETE

Interconnected



by Wilgengebroed on Flickr [CC-BY-2.0]

Many Examples of Insecure Embedded Systems

- Routers
- Printers
- VoIP
- Cars

Hackers Reveal Nasty New Car Attacks – With Me Behind The Wheel (12/08/2013, Forbes)

Many Examples of Insecure Embedded Systems

- Routers

Firefox | Reverse Engineering a D-Link B...

www.devttys0.com/2013/10/reverse-engineering-a-d-link-backdoor/

Based on the source code of the HTML pages and some Shodan search results D-Link devices are likely affected:

- DIR-100
- DIR-120
- DI-624S
- DI-524UP
- DI-604S
- DI-604UP
- DI-604+
- TM-G5240

Additionally, several Planex routers also appear to use the same firmware:

- BRL-04R
- BRL-04UR
- BRL-04CW

You stay classy, D-Link.

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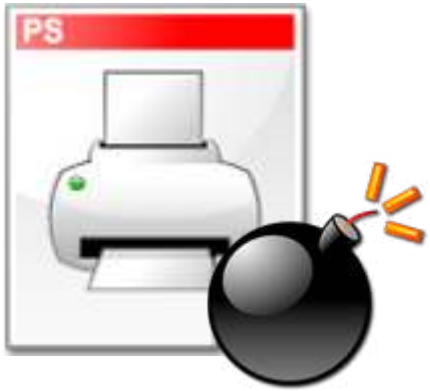
Networked printers at risk
(30/12/2011, McAfee Labs)



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Cisco VoIP Phones Affected By On Hook Security Vulnerability (12/06/2012, Forbes)

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- Printers
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- Cars
- Drones

Hacker Releases Software to Hijack Commercial Drones

by BRYANT JORDAN on DECEMBER 9, 2013

Like 489 people like this. Be the first of your friends.

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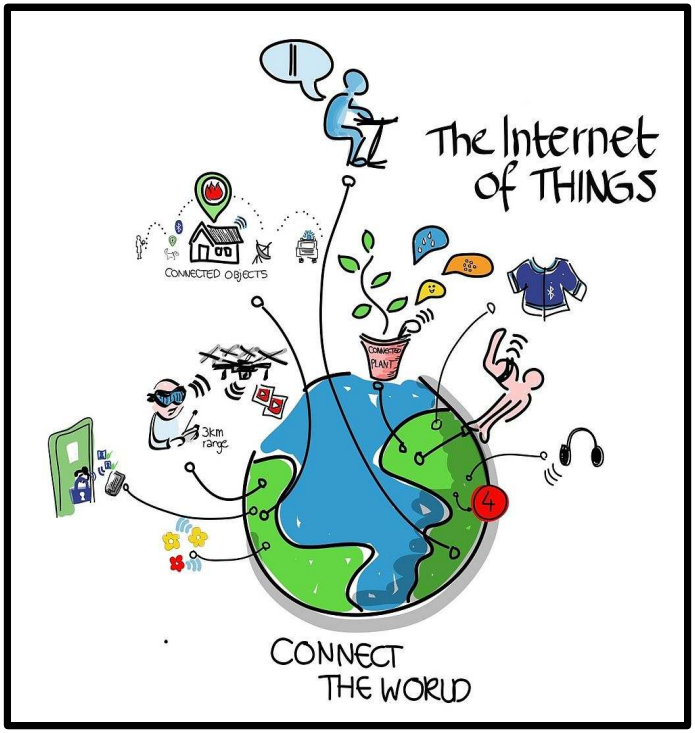

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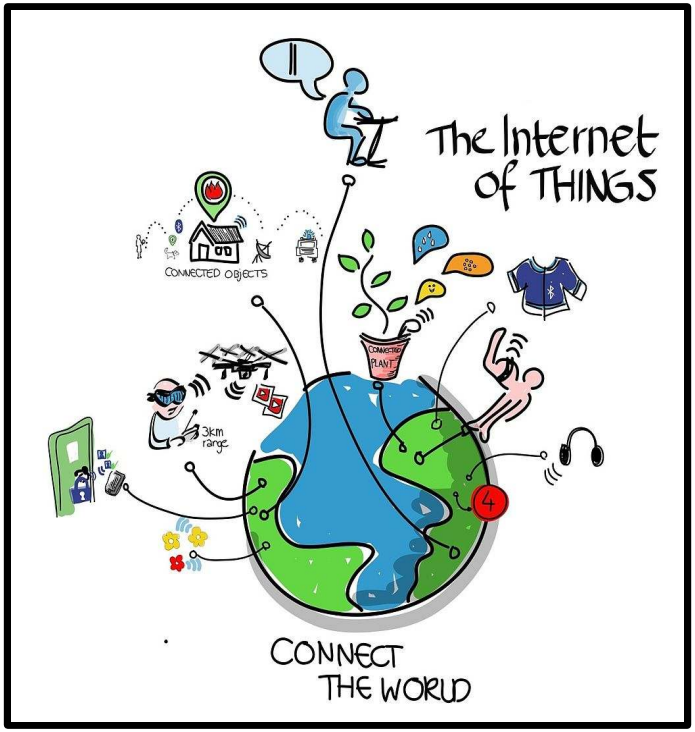

- **Each of the above is a result of individual analysis**
- **Manual and tedious efforts → Does not scale**

The Goal

Perform a large scale analysis to gain a better understanding of firmware problems

The Problem With Large Scale Analysis

- Heterogeneity of
  - Hardware, architectures, OSes
  - Users, requirements
  - Security goals

The Problem With Large Scale Analysis

- Heterogeneity of
  - Hardware, architectures, OSes
  - Users, requirements
  - Security goals
- Manual analysis does not scale, it requires
  - Finding and downloading firmware
  - Unpacking and initial analysis
  - **Re**-discovering a similar bugs

Previous Approaches

- Test on real devices [Bojinov09CCS]
  - Accurate results
  - Does not scale well

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- Test on real devices [Bojinov09CCS]
  - Accurate results
  - Does not scale well
- Scan devices on the Internet
  - Large scale testing [Cui10ACSAC]
    - Can only test for known vulnerabilities
    - Blackbox approach
  - More is too intrusive [Census2012]

Our Approach to The Large Scale Analysis

- Collect a large number of firmware images

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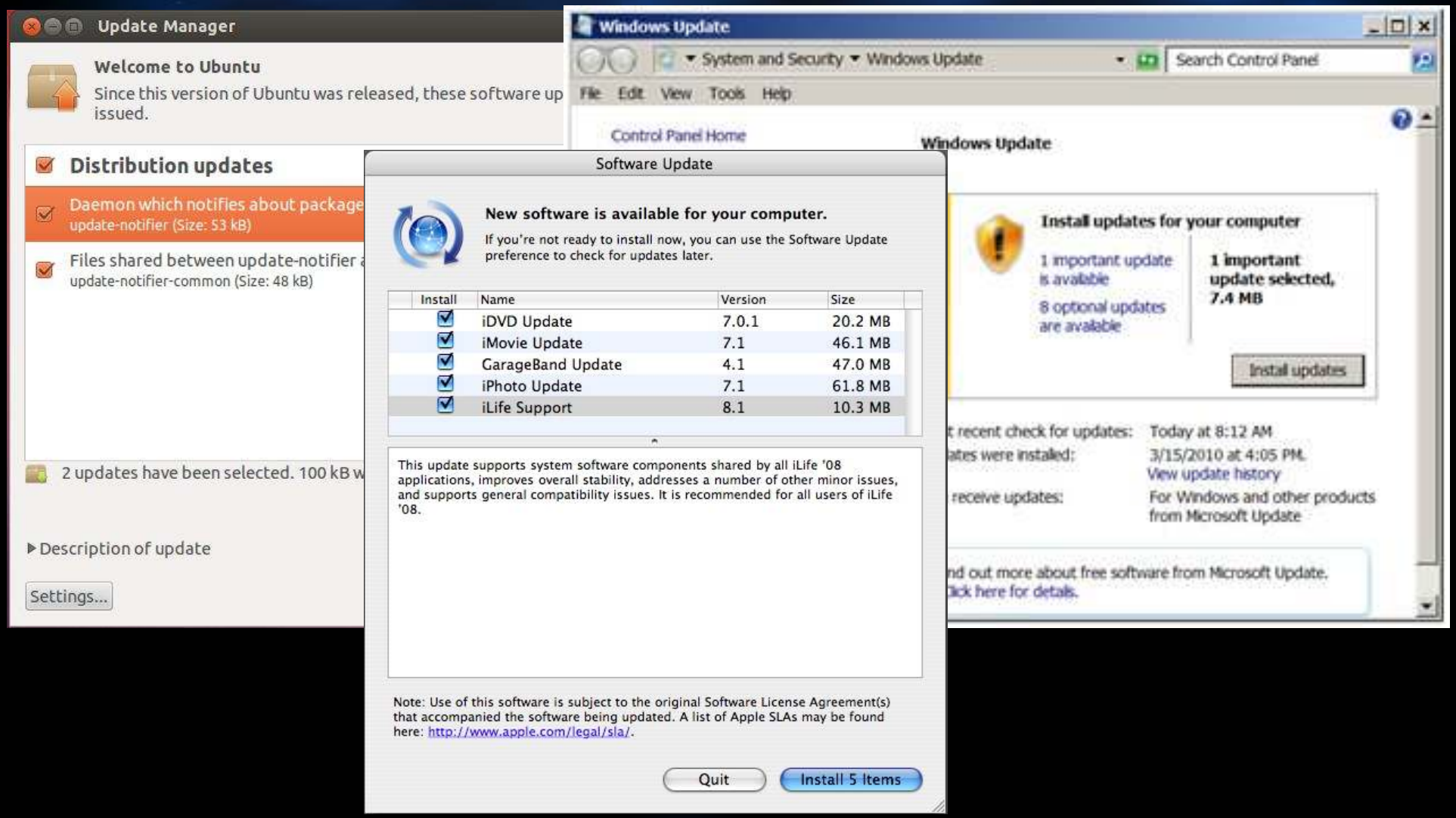
- Many challenges remain

Mainstream Systems Have Centralized Updates



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Challenge: Embedded Systems Update Sources are diverse

- Public site
  - Manufacturer web site
  - FTP site
- Hidden site
  - Accessed by firmware update utility
- Restricted site
- Request-only updates
- Delivery on other media (CD-Rom, …)
- Firmware only delivered on device

Challenge: Embedded Systems Update Mechanisms are diverse

Collecting a Dataset

- No large scale firmware dataset yet
  - As opposed to existing datasets in security or other CS research areas

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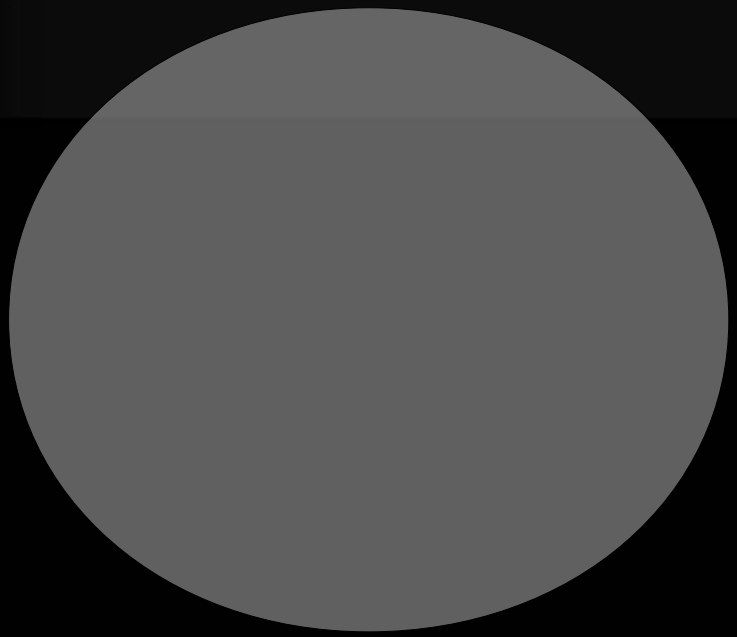
- www.firmware.re project

Challenge: Firmware Identification

← Clearly a Firmware



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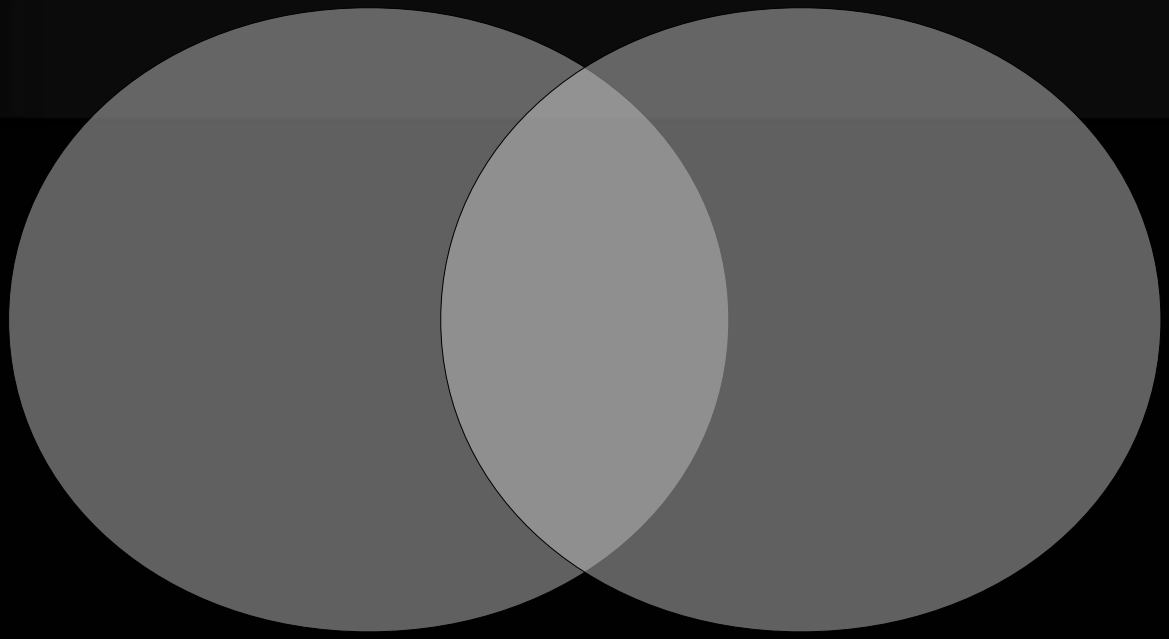

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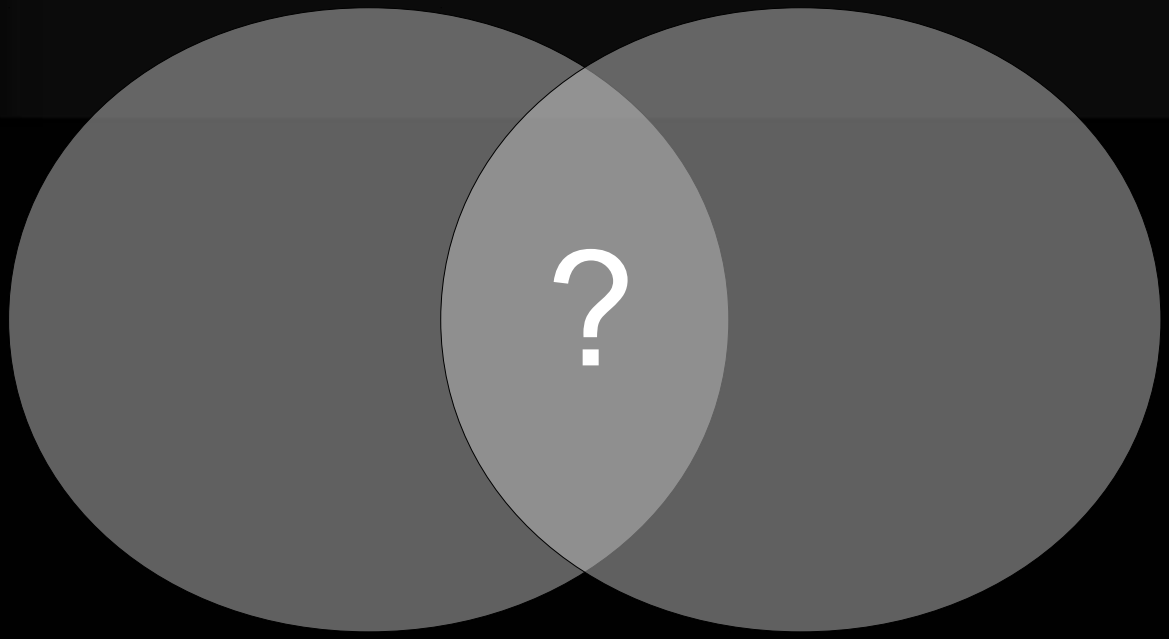

Challenge: Firmware Identification

- E.g., upgrade by printing a PS document

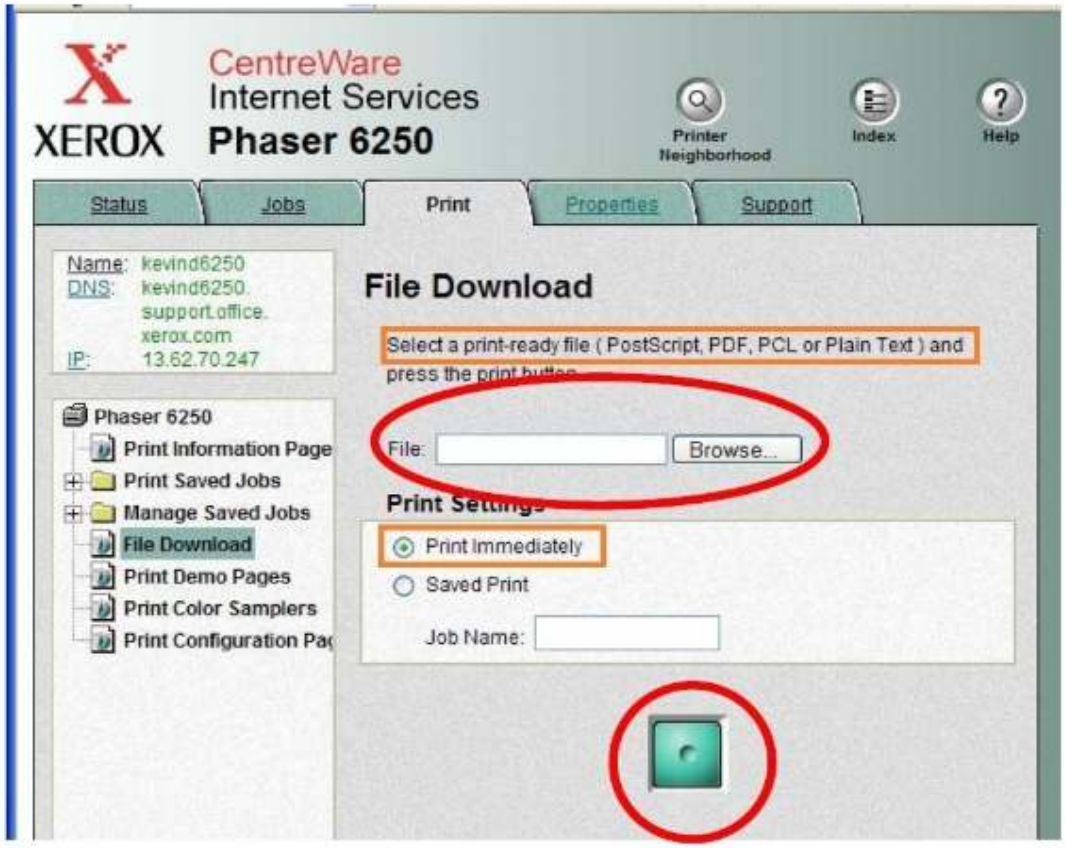

Figure 4: Select the firmware update file and press the green button to send it.

Challenge: Unpacking & Custom Formats

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ZIP

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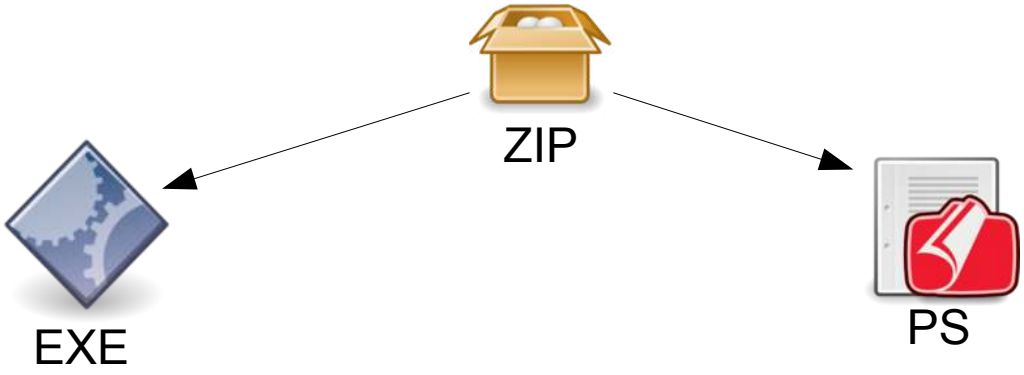

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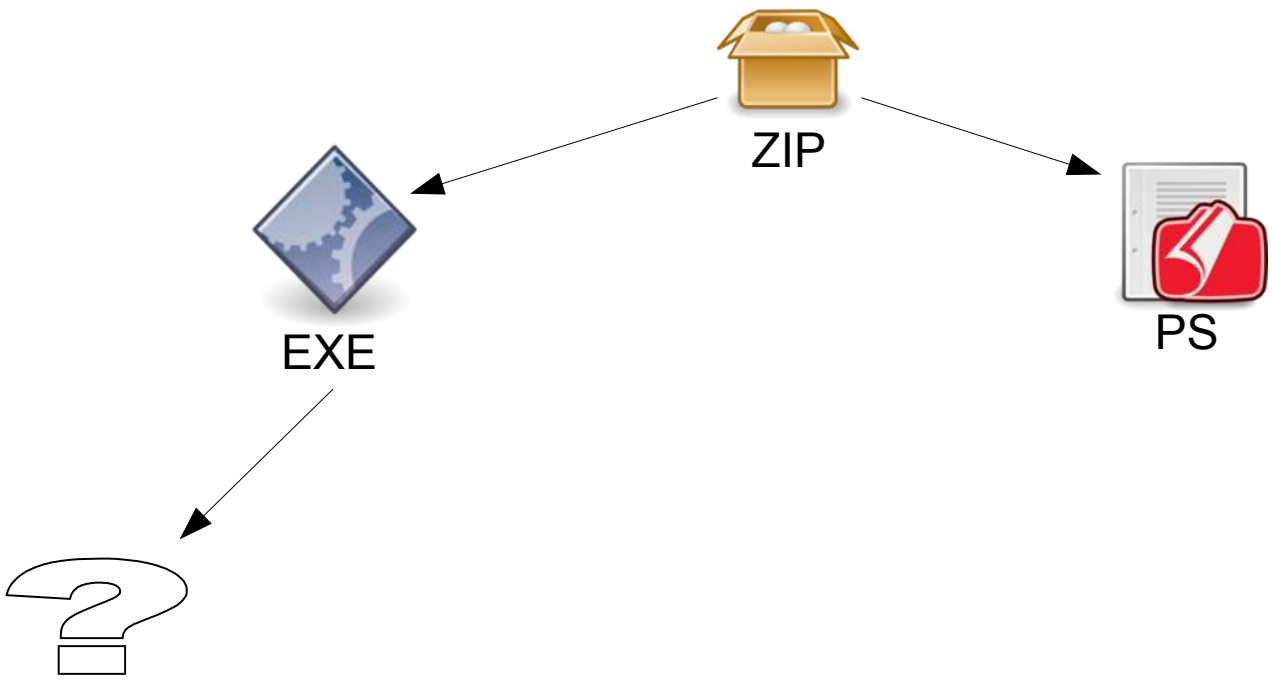

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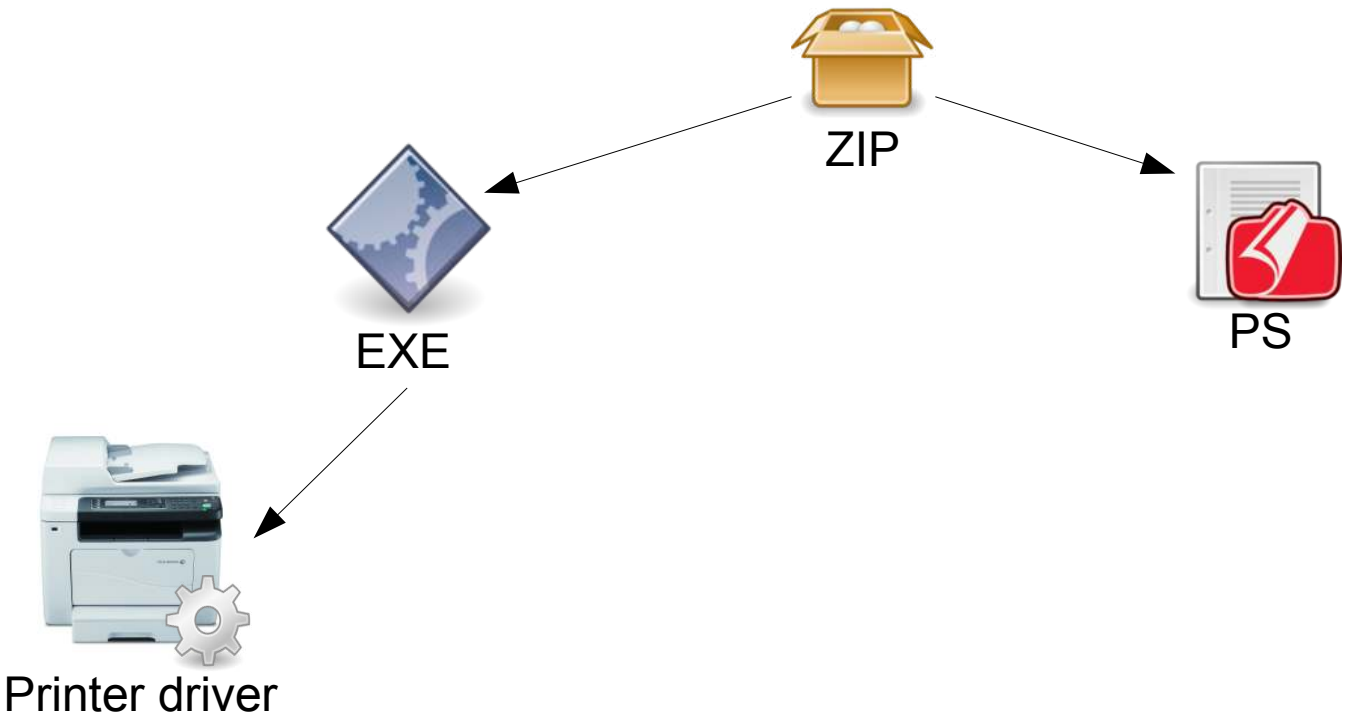

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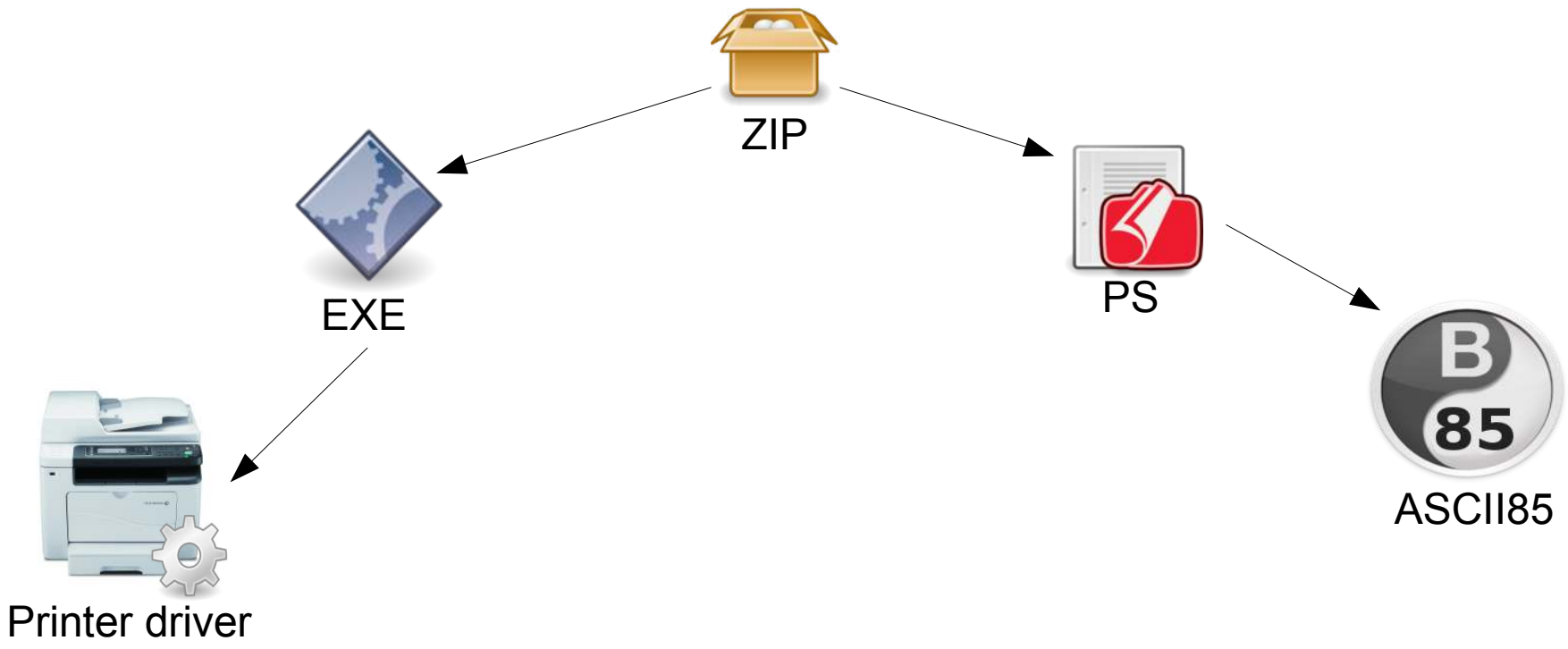

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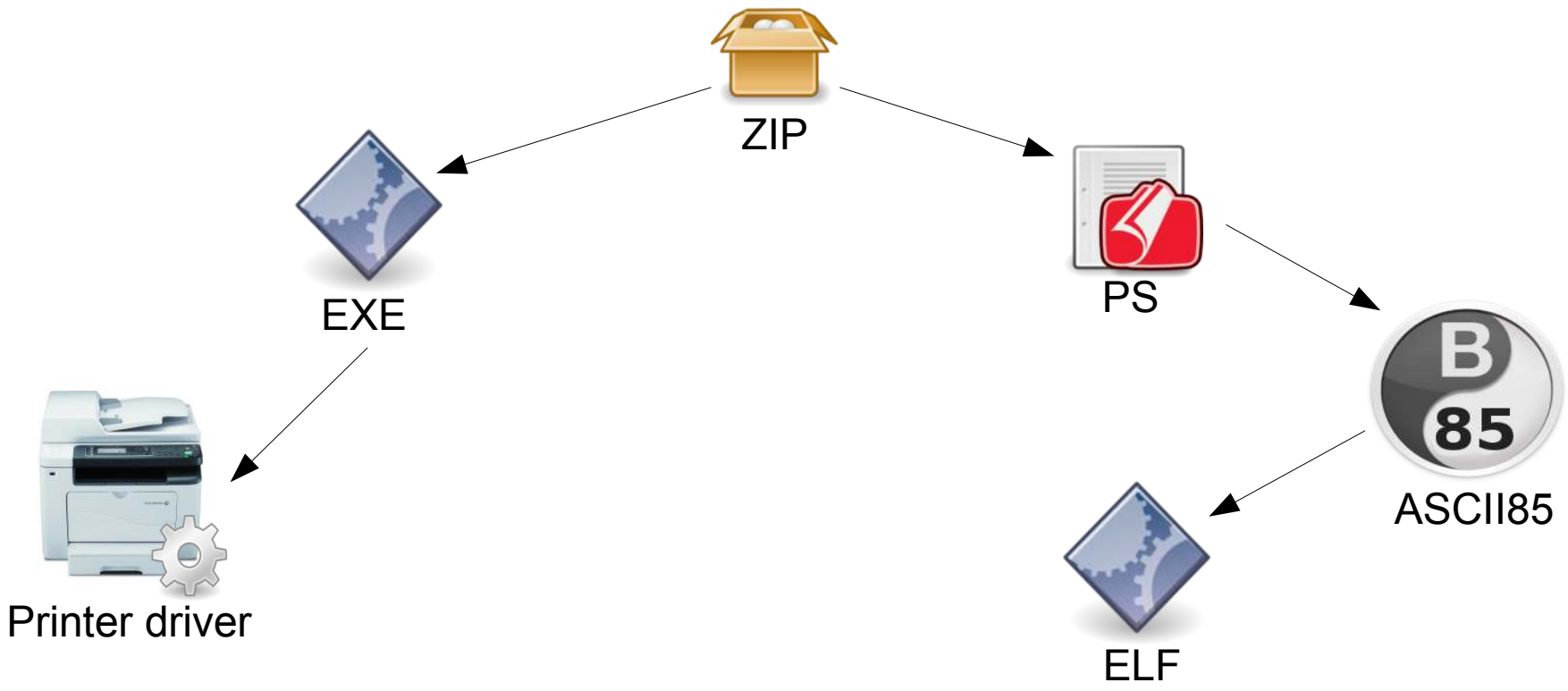

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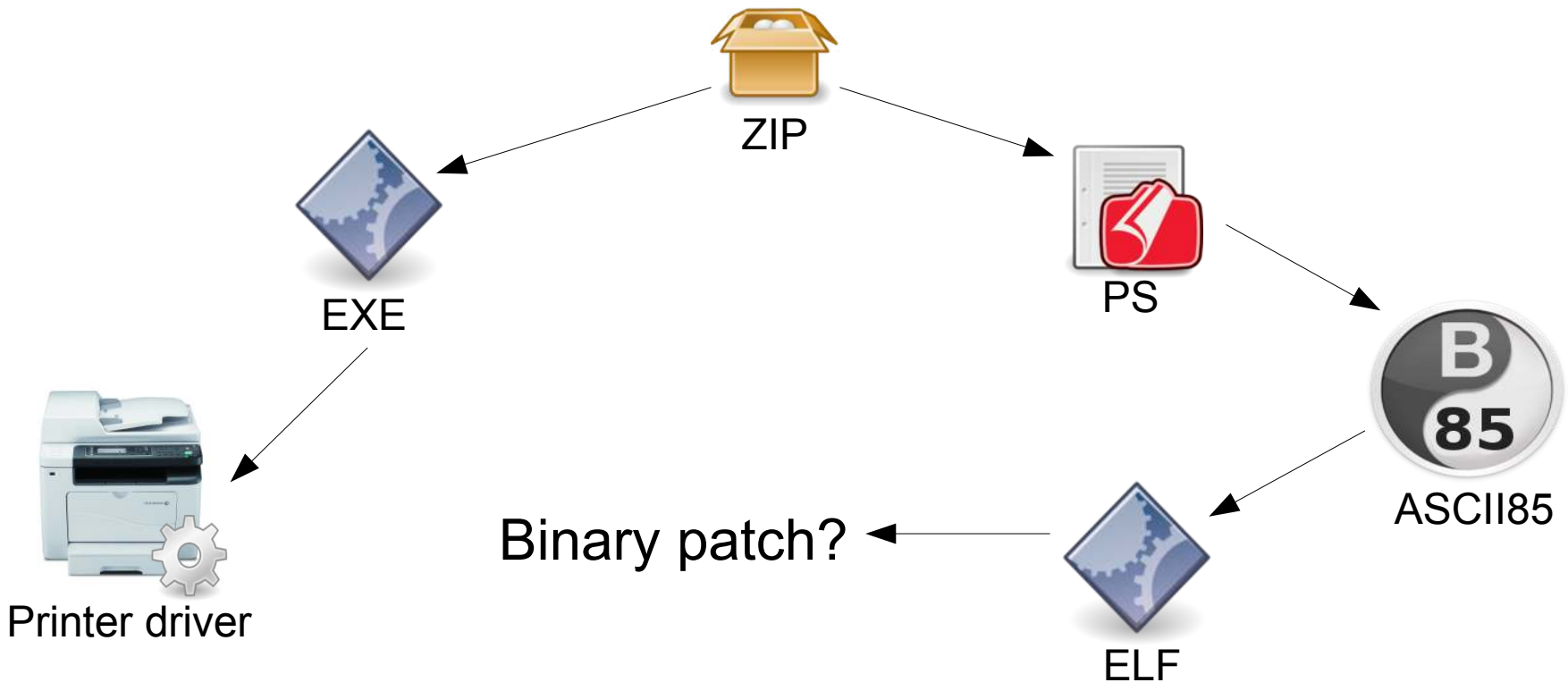

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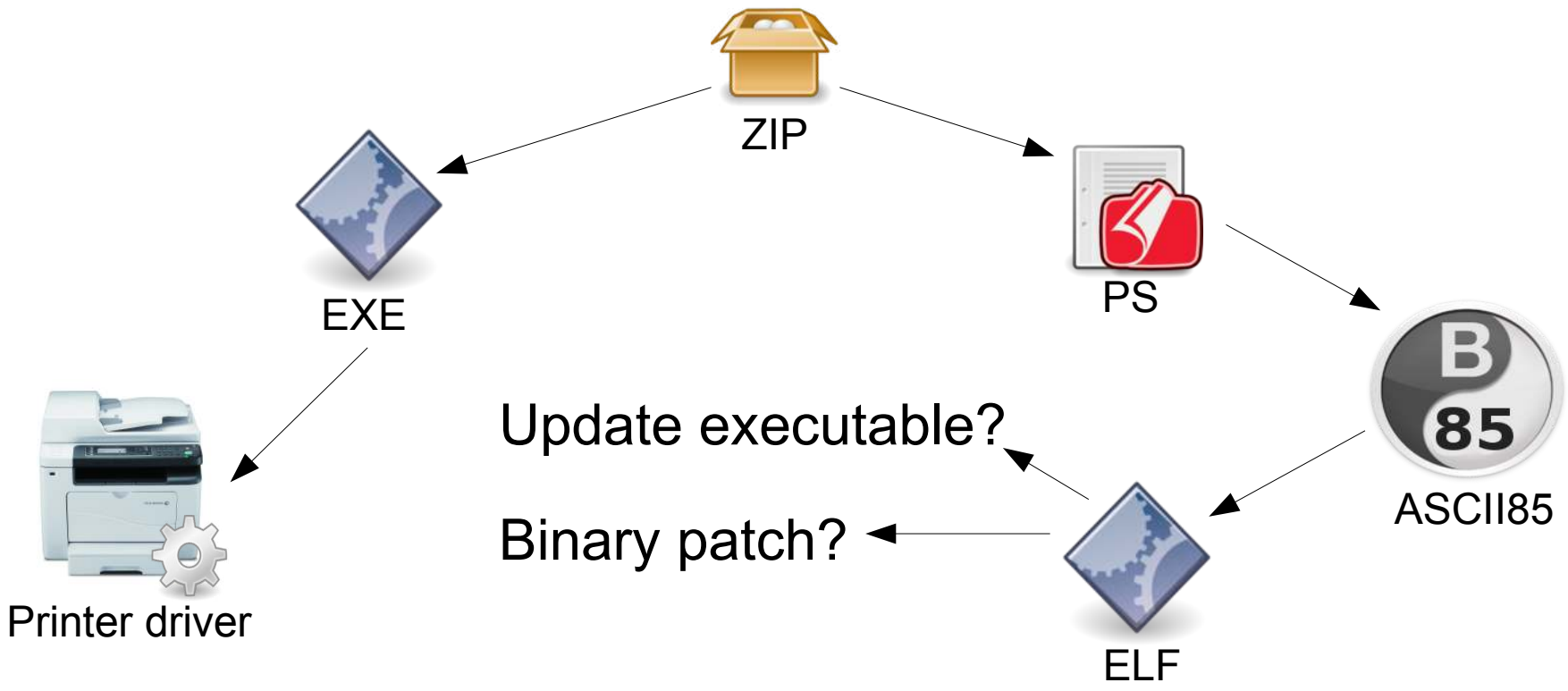

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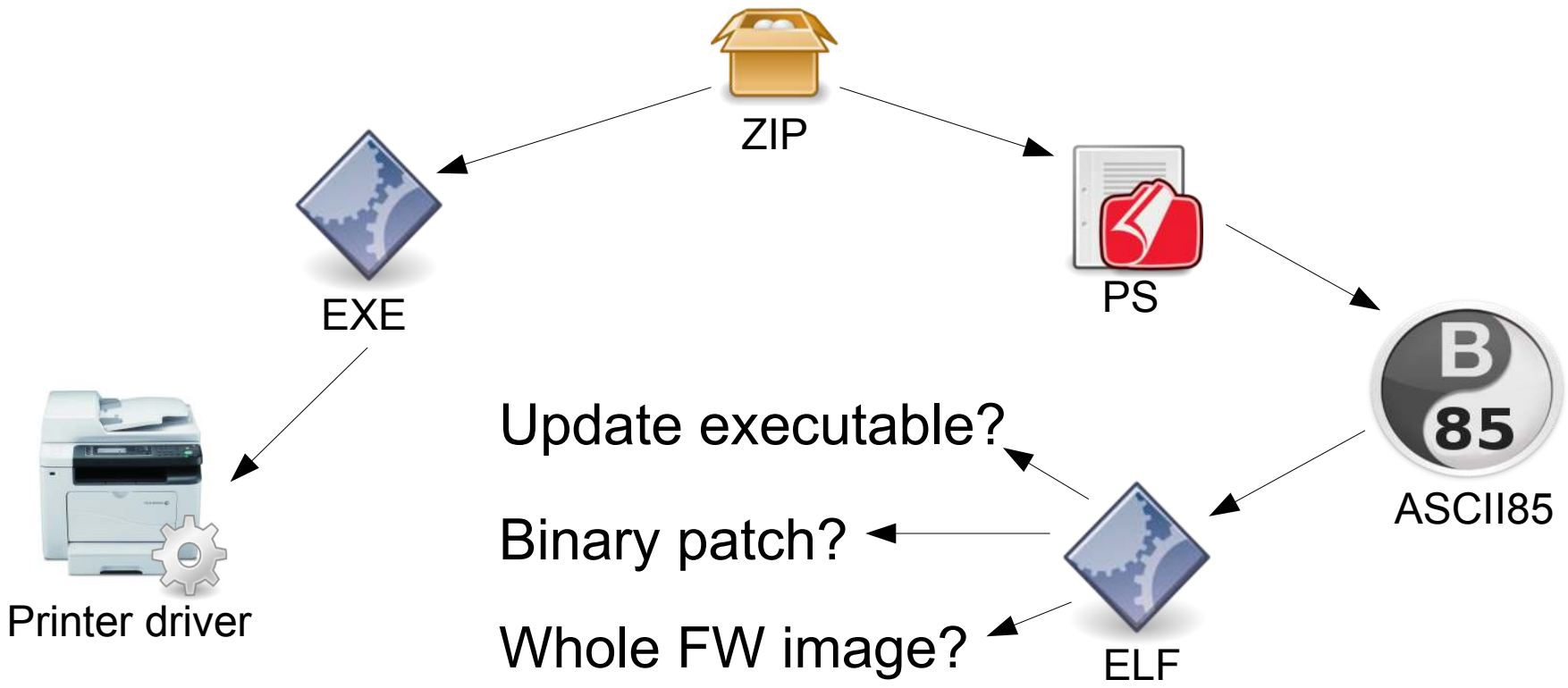
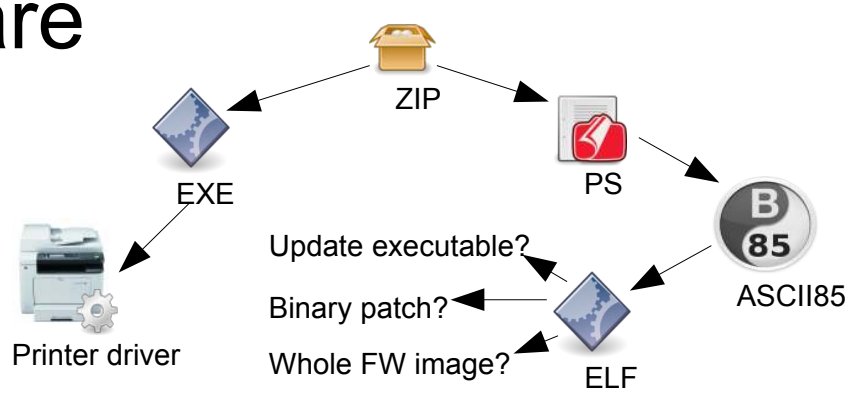


Challenge: Unpacking & Custom Formats

- How to reliably unpack and learn formats?
- Firmware updates often are ”russian dolls”
- Sometimes result of unpacking is just a binary data blob



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- Often, a firmware image→just 'data' binary blob
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  - Bruteforce at every offset with all known unpackers
- Heuristics for detecting when to stop

Challenge: Scalability & Computational Limits

- Unpacking and file carving is very CPU intensive

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- Unpacking and file carving is very CPU intensive
- Results in millions of unpacked files
  - Manual analysis infeasible
  - One-to-one fuzzy hash comparison is CPU intensive

Challenge: Results Confirmation

- An issue found statically
  - May not apply to a real-device
  - Cannot guarantee exploitability
  - E.g., vulnerable daemon present but never started

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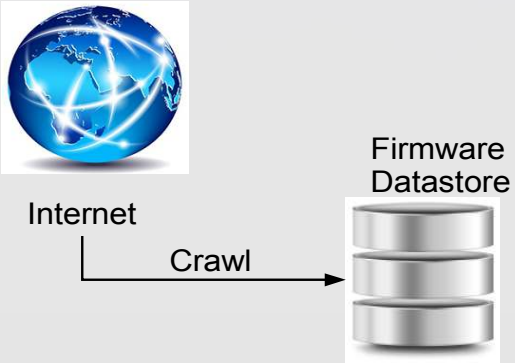
- An issue found statically
  - May not apply to a real-device
  - Cannot guarantee exploitability
  - E.g., vulnerable daemon present but never started
- Issue confirmation is difficult
  - Requires advanced analysis (static & dynamic)
  - Often requires real embedded devices
  - Does not scale well in heterogeneous environments

Architecture



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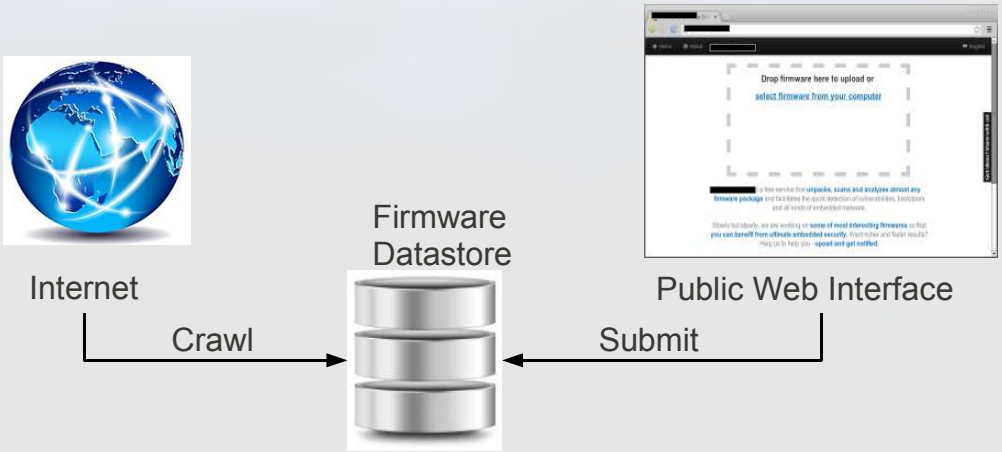

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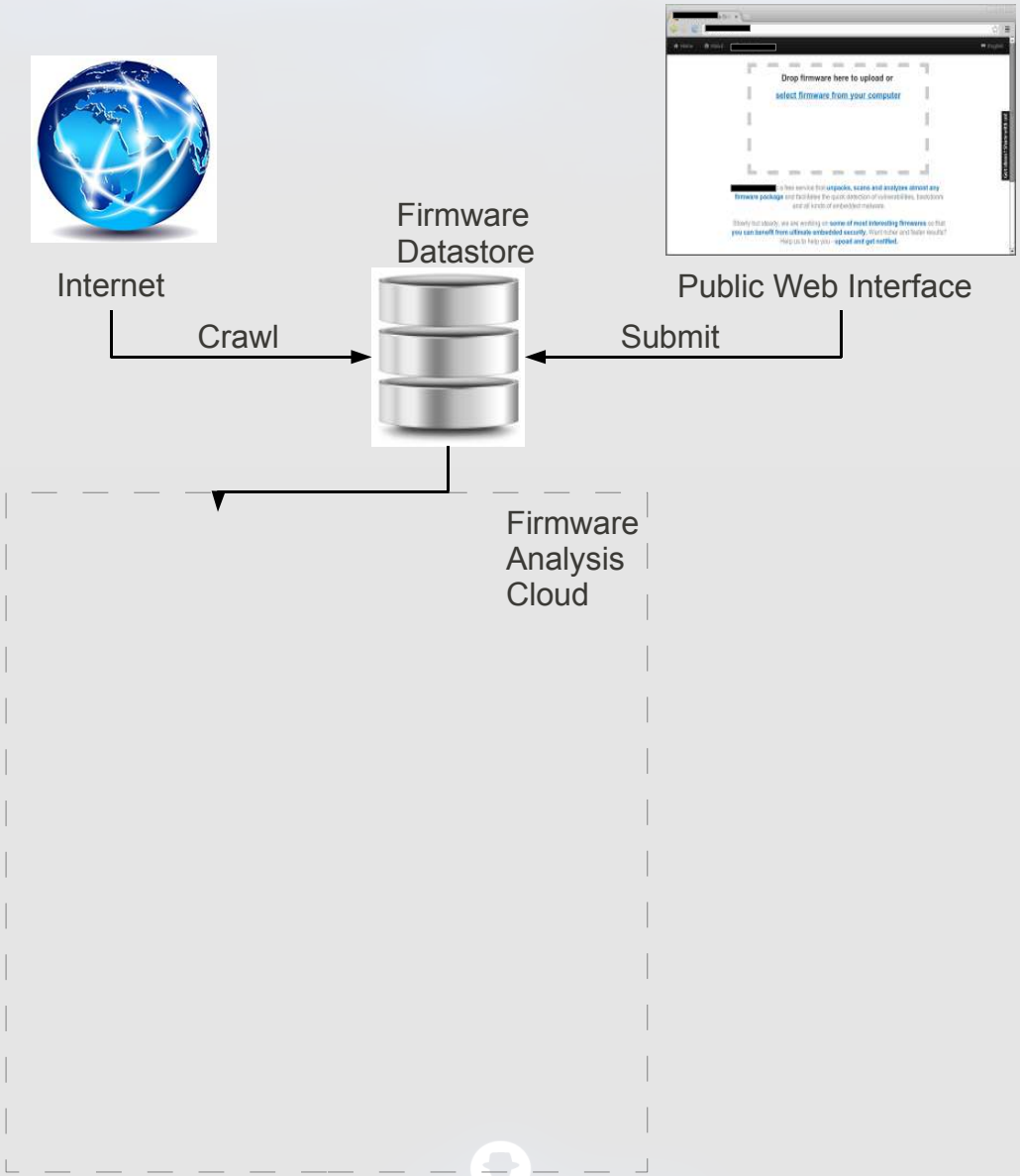

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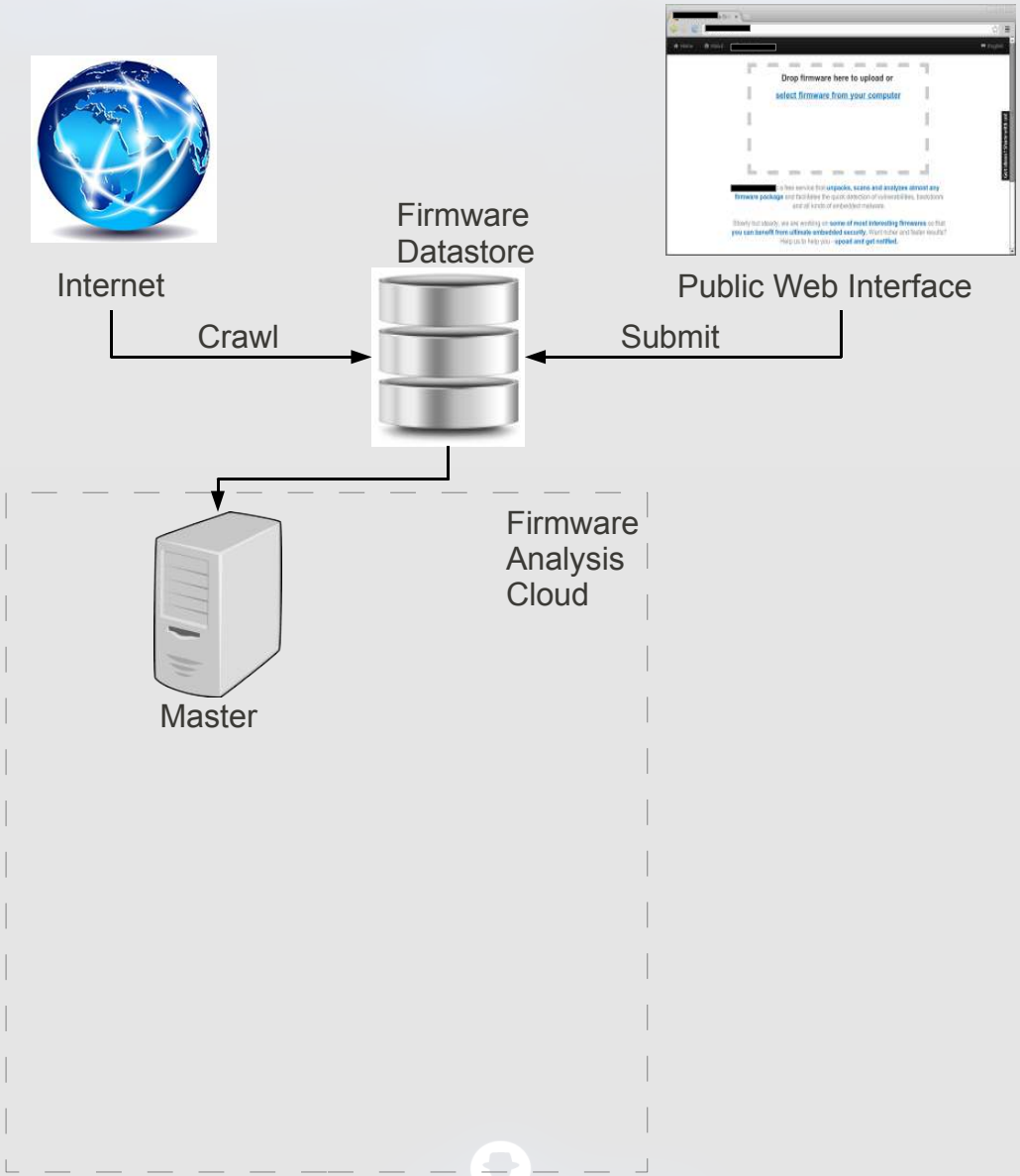

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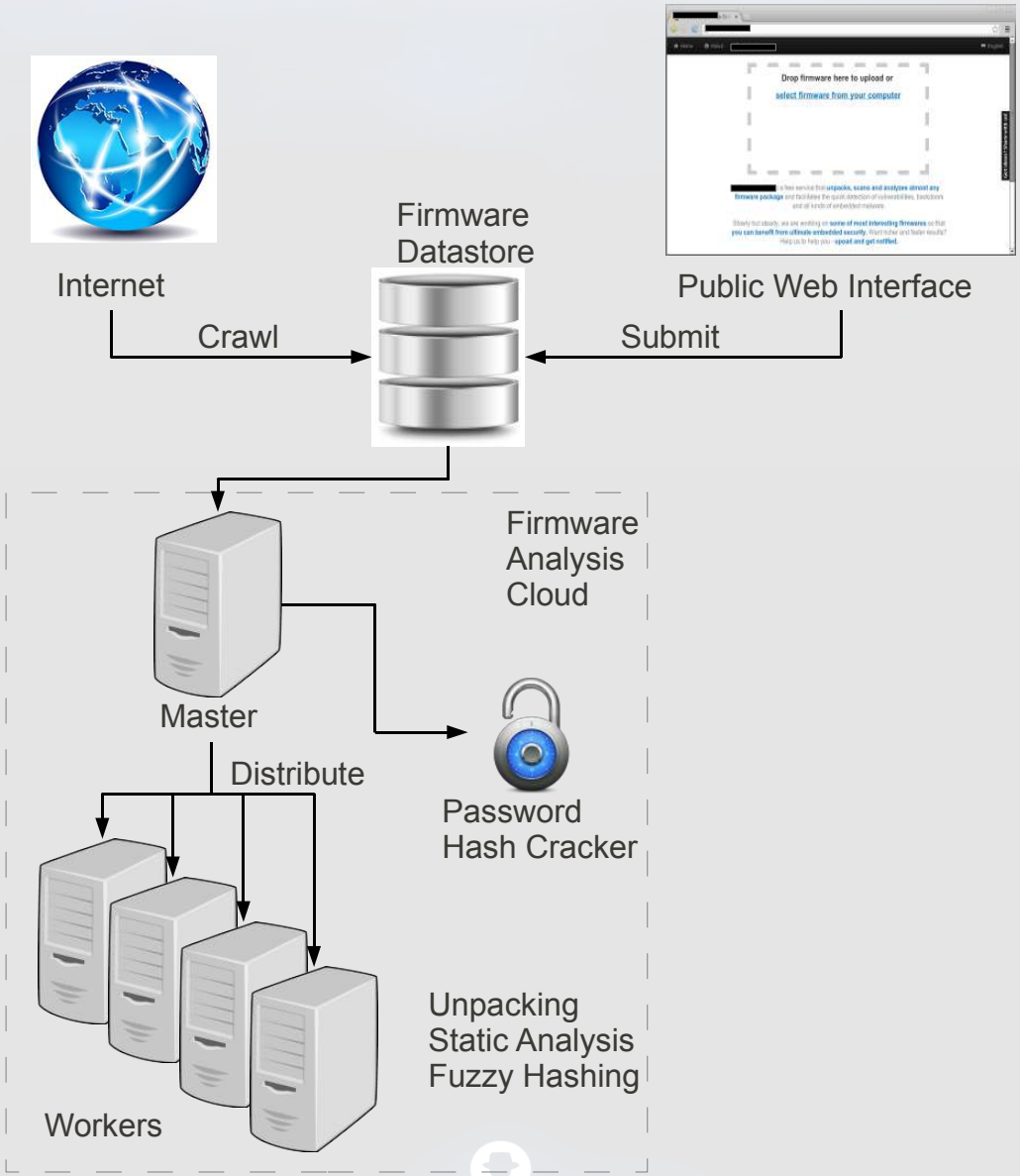

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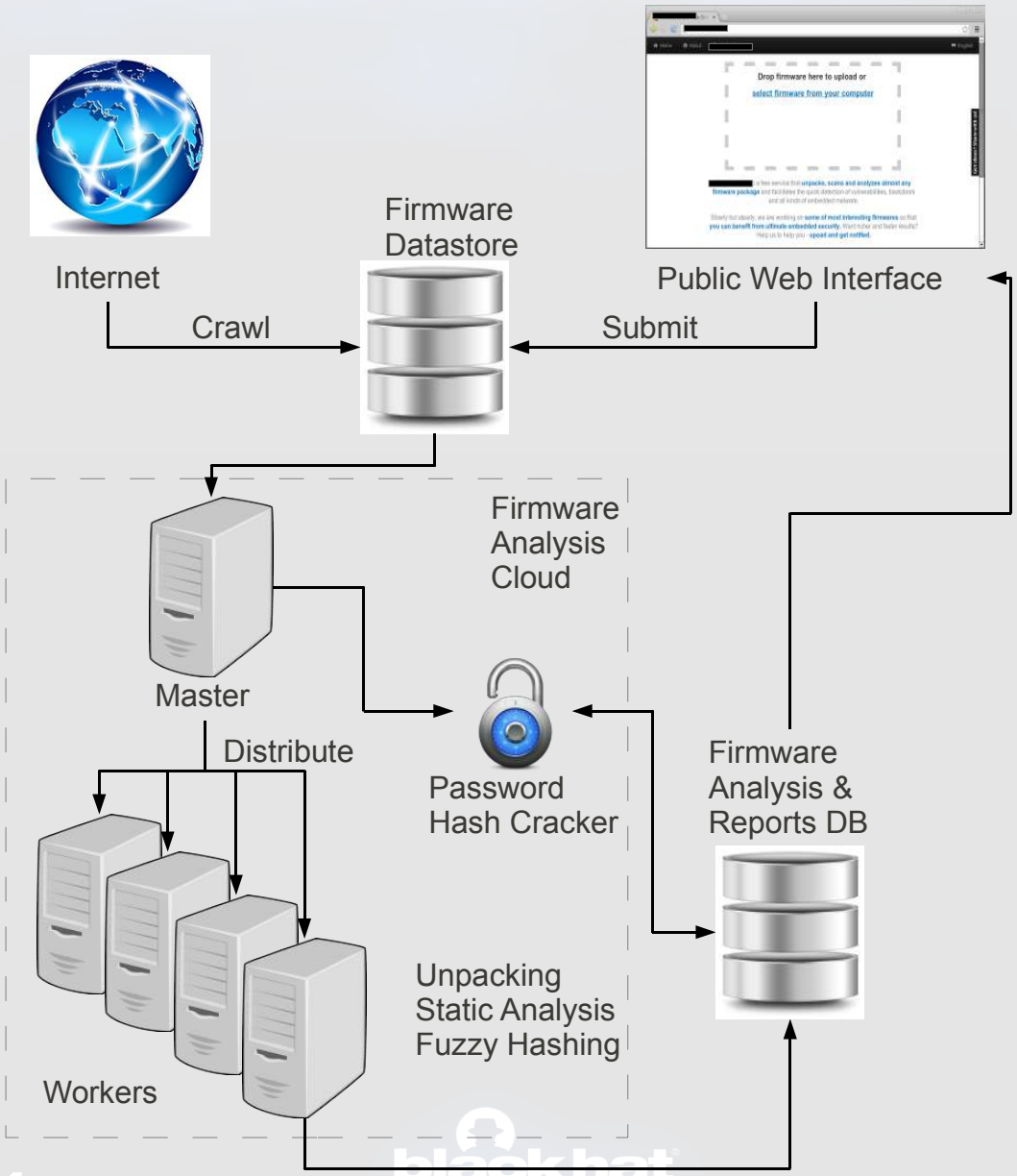

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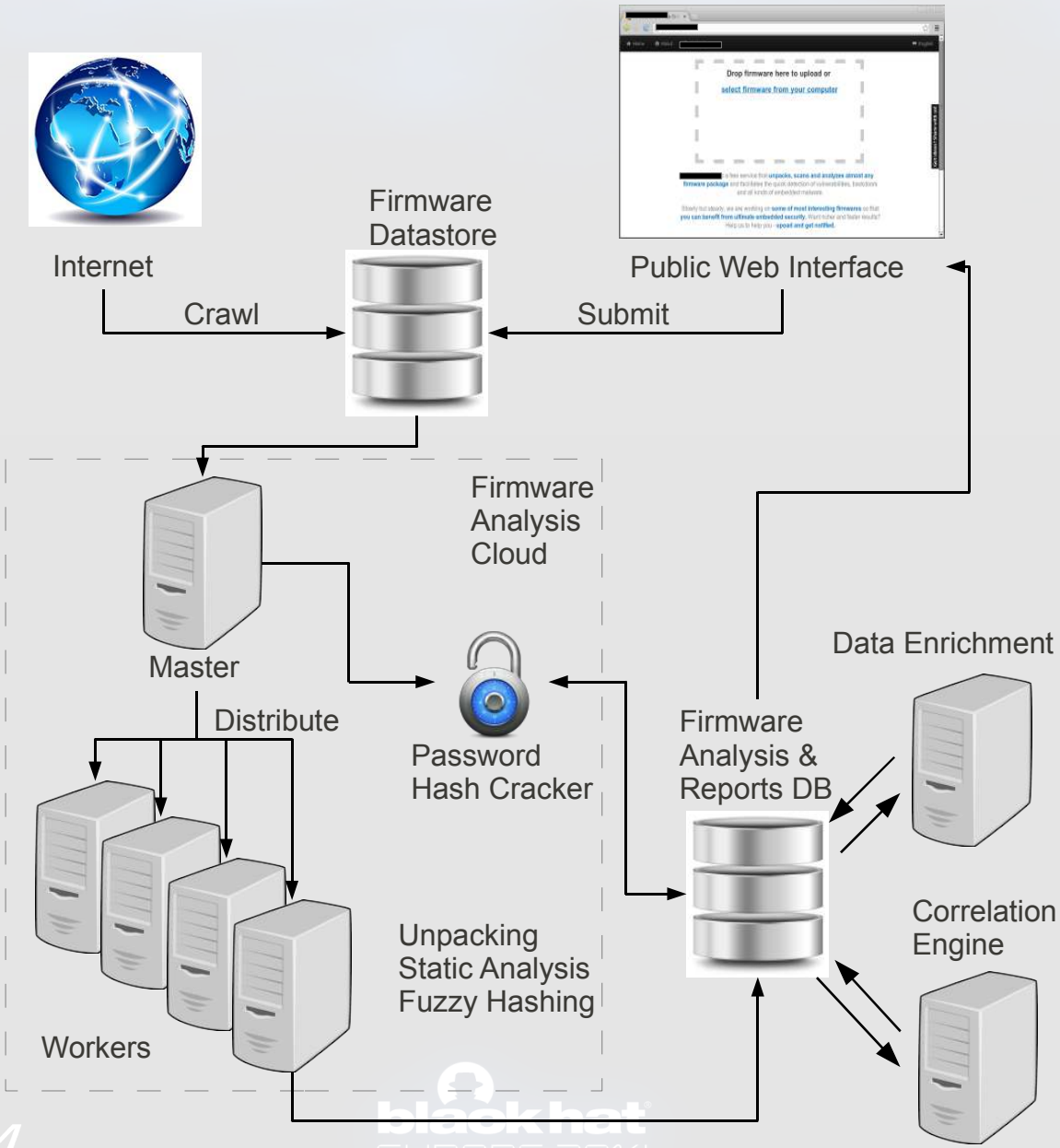


Crawler

- Multiple seeds
  - FTP-index engines
  - Google Custom search engines
- Several download techniques
  - WGET scripts
  - Beautiful Soup scripts
- 759 K collected files, 1.8 TB of disk space

www.Firmware.RE (beta)
Will provide Unpacking and Analysis

Firefox | firmware · ǝɹ - Free Online Firm...

www.firmware.re

firmware · ǝɹ (beta)

USENIX Security '14 | BH13US | About | English

Upload

Info

Examples

To start, drag-n-drop firmware here or

select firmware from your computer

Got ideas? Share with us!

Blog | Twitter | contact@firmware.re | Google groups | ToS | Privacy policy

Unpacking

- 759 K total files collected

  ↓ Filter non firmware

- 172 K filtered interesting files

  ↓ Random selection

- 32 K analyzed

  ↓ Successful unpack

- 26 K unpacked (fully or partially)

  ↓ Unpacked files

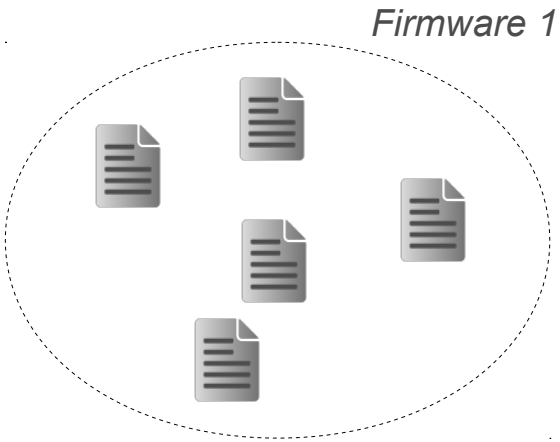
- 1.7 M resulted files after unpacking

Static Analysis

- Correlation/clustering
  - Fuzzy hashes, Private SSL keys, Credentials
- Misconfigurations
  - Web-server configs, Credentials, Code repositories
- Data enrichment
  - Version banners
  - Keywords (e.g., telnet, shell, UART, backdoor)

Example: Correlation

- Correlation via fuzzy-hashes (ssdeep, sdhash)



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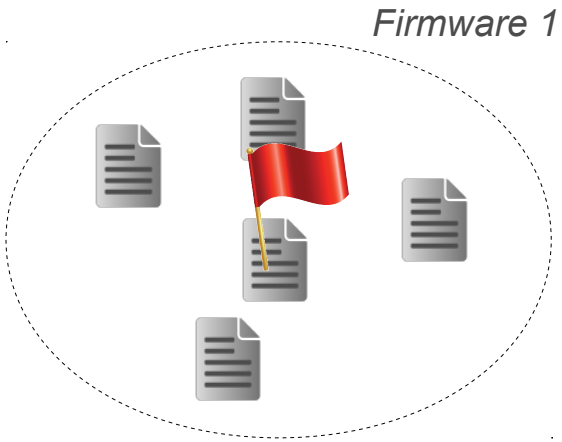

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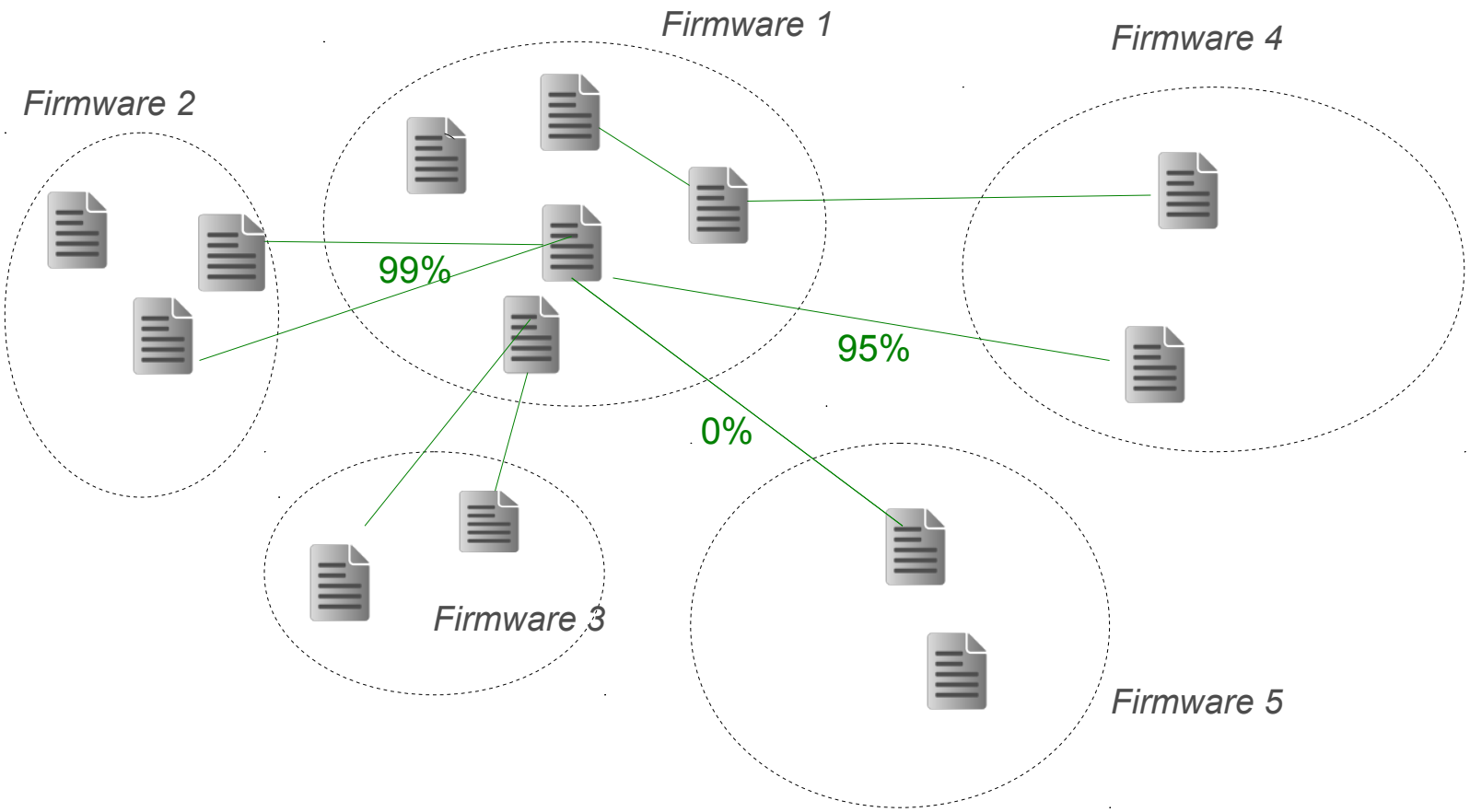

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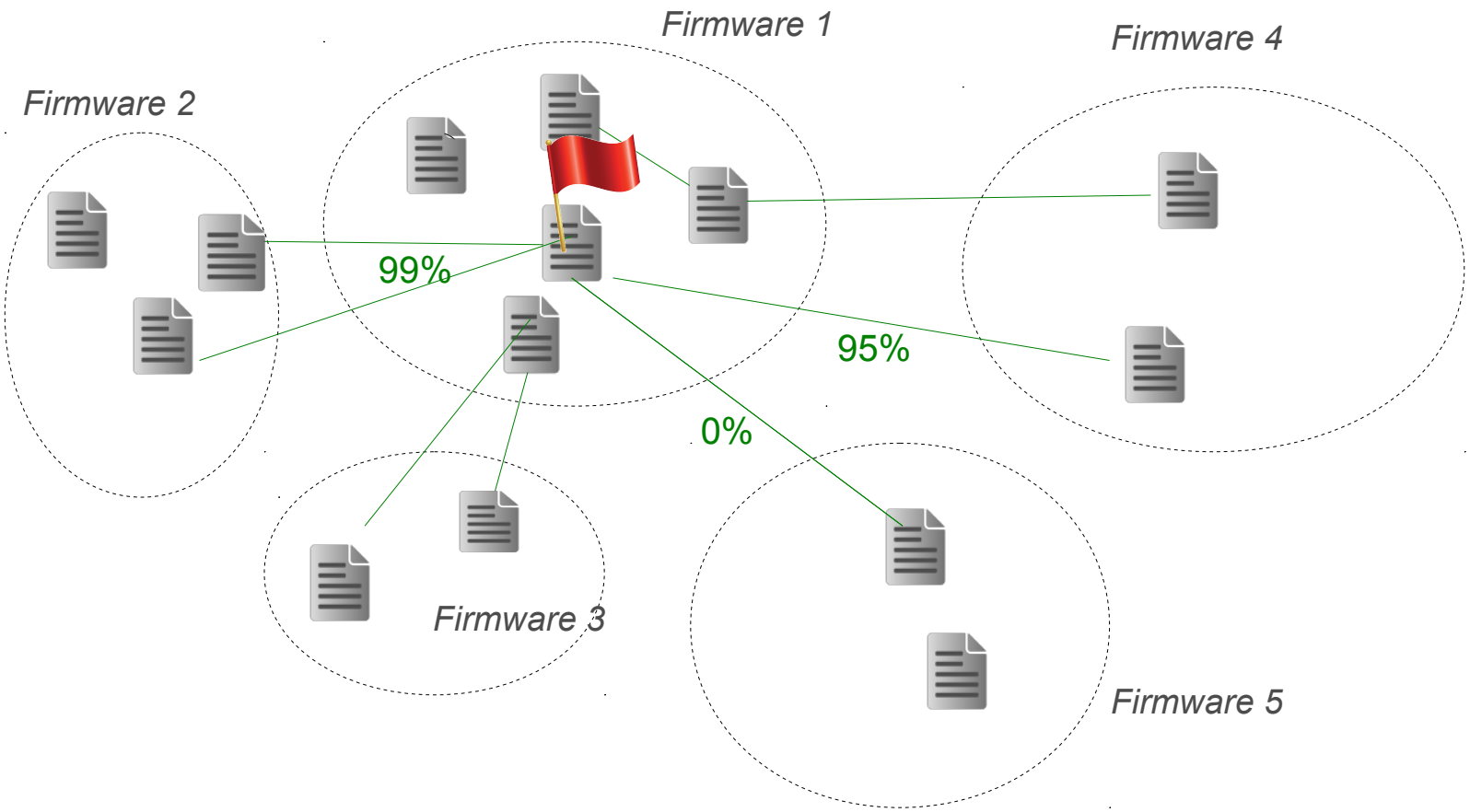

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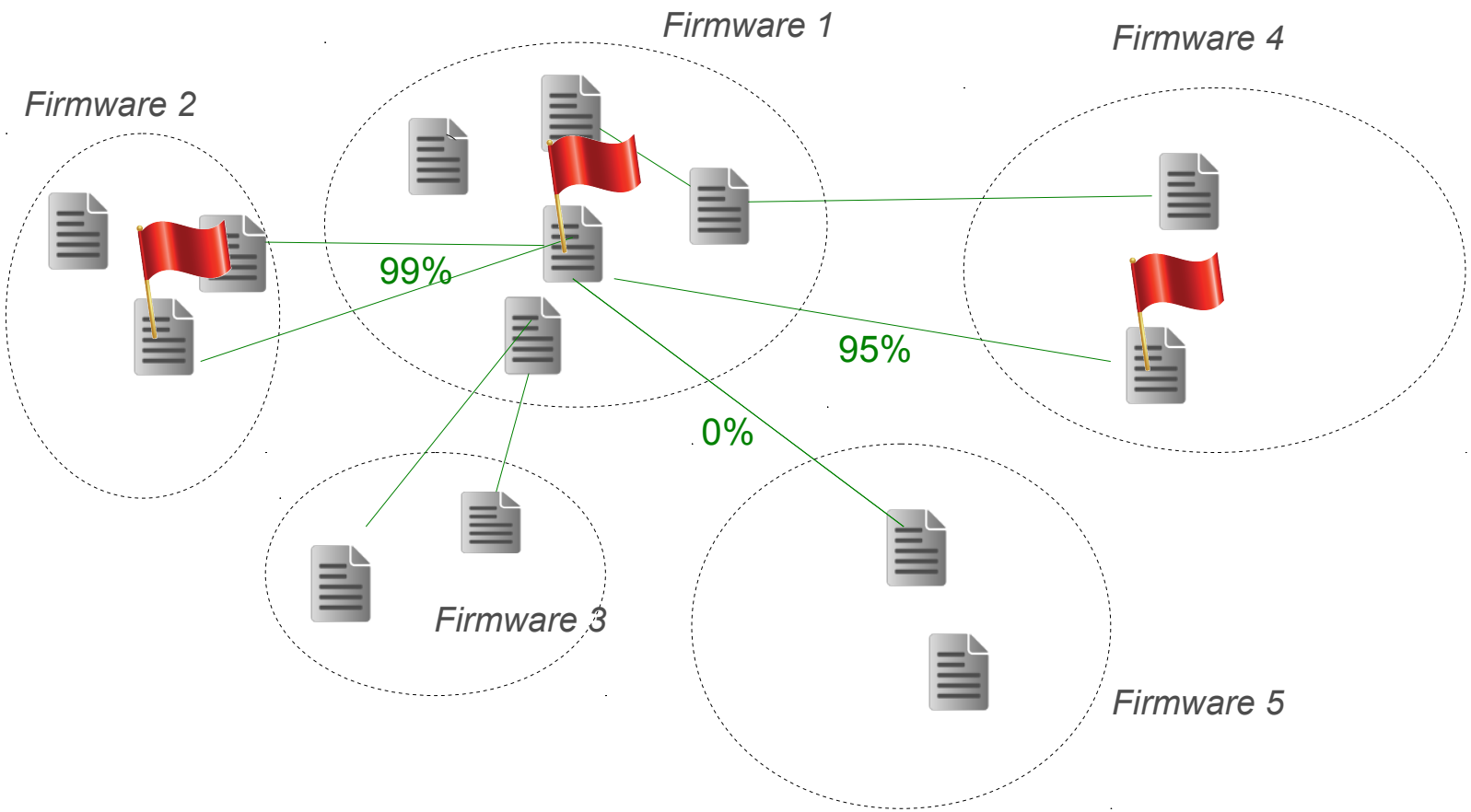

Example: RSA Keys

- SSL keys correlation + vulnerability propagation

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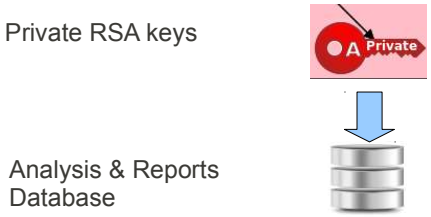

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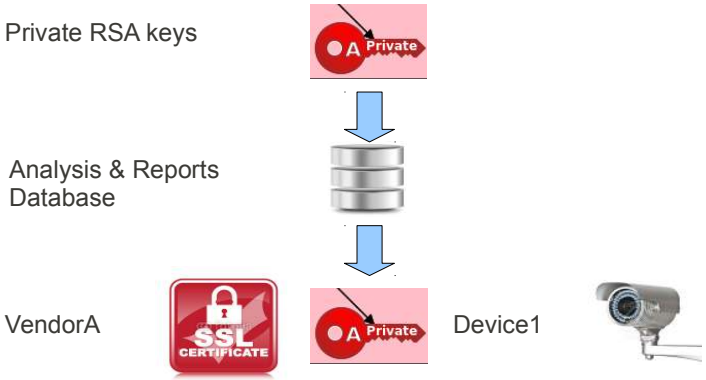

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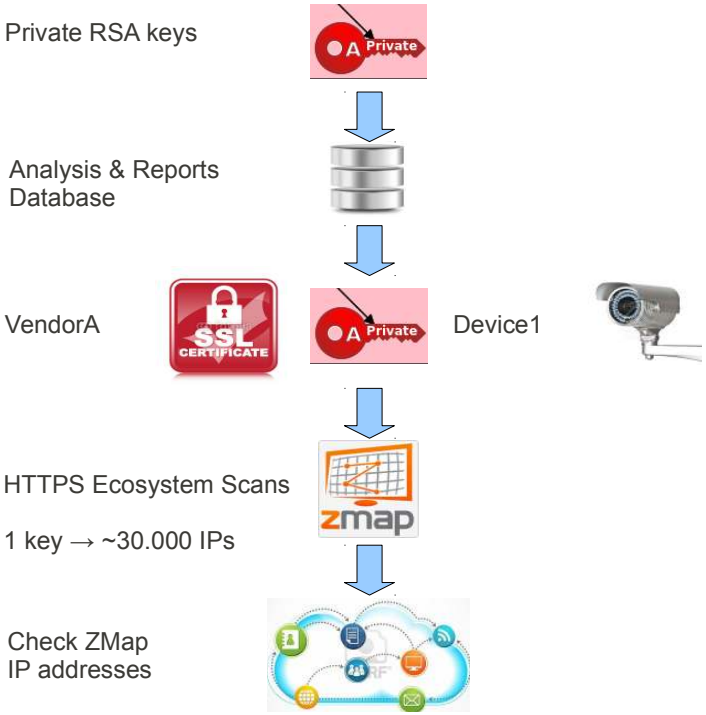

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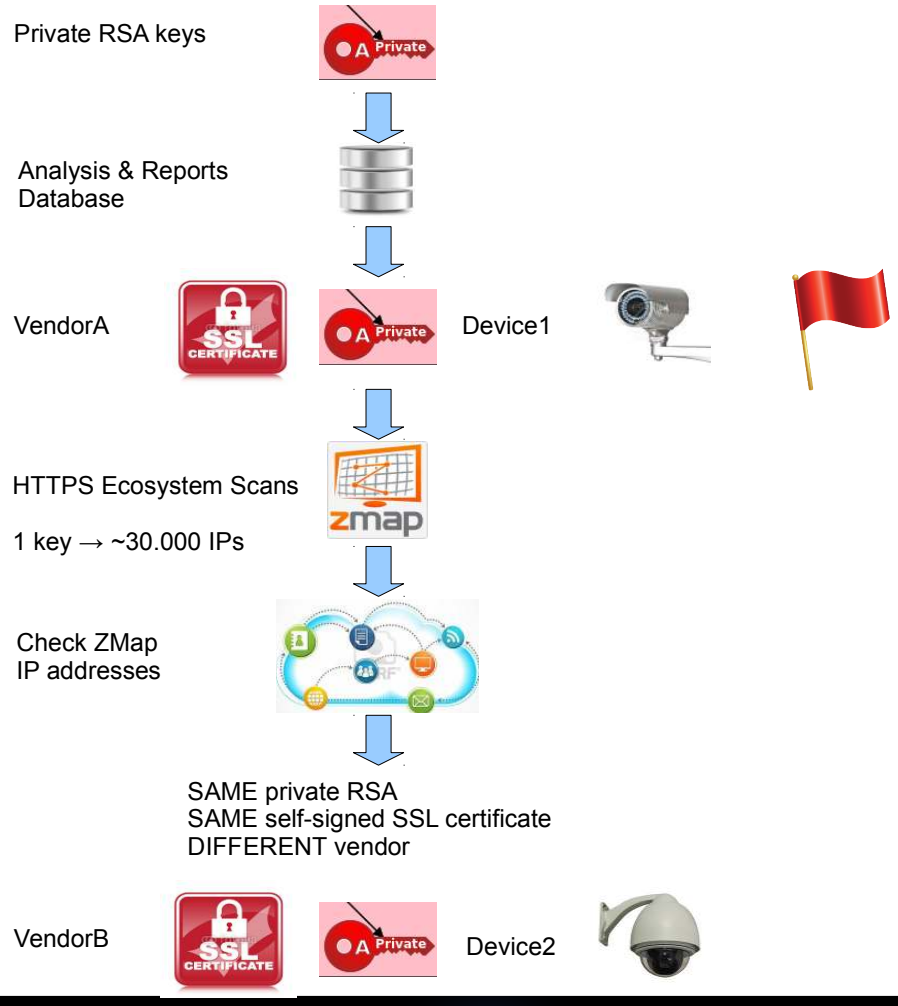

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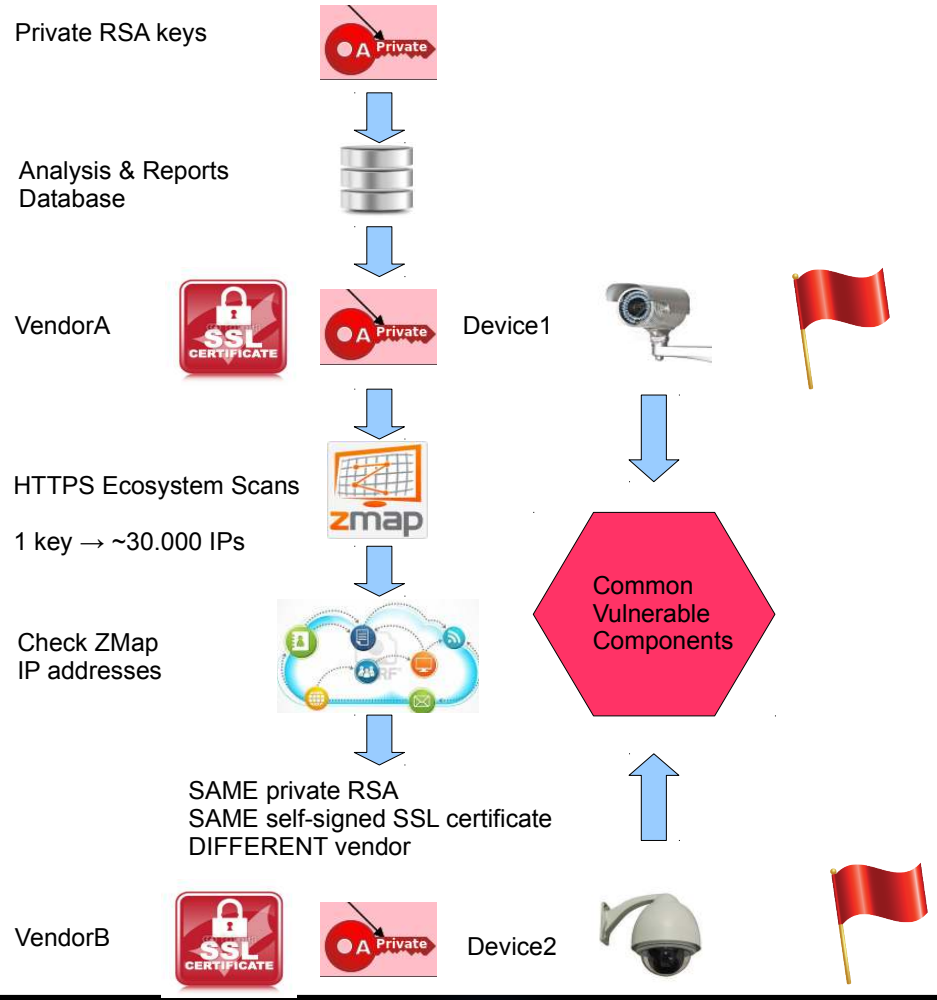

Results: Summary

- 38 new vulnerabilities (CVE)
- Correlated them to 140 K online devices
- Affected 693 firmware files by at least one vuln

”Chamber of Horrors”

- Several recently build images with linux kernels, busybox older than 9 years
- Similar ”debug” backdoor daemon in networking, home automation equipment
- Forgotten or backdoor entries in `authorized_keys` files

”Chamber of Horrors”

- Linux kernel older than 4 years compiled by root on a machine with public IP accepting SSH connections (GPS/Aerospace manufacturer)
- Discovered vulnerability in wireless fireworks system, implemented PoC attack [3]

Contributions Summary

- First large-scale static analysis of firmwares
- Described the main challenges associated
- Shown the advantages of performing a large-scale analysis of firmware images
- Implemented a framework and several efficient static techniques

Conclusions

- A broader view on firmwares
  - Not only beneficial
  - But necessary for discovery and analysis of vulnerabilities
- Correlation reveals firmware relationship
  - Shows how vulnerabilities reappear across different products
  - Could allow seeing how firmwares evolve

Conclusions

- There are plenty of latent vulnerabilities
- Security
  - Tradeoff with cost and time-to-market
  - Clearly not a priority for some vendors

Thank You!

Questions?

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References

- [1] A. Costin, J. Zaddach, A. Francillon, D. Balzarotti, *"A Large-Scale Analysis of the Security of Embedded Firmwares"*, In Proceedings of the 23rd USENIX Conference on Security (to appear)
- [2] A. Costin, J. Zaddach, *"Poster: Firmware.RE: Firmware Unpacking and Analysis as a Service"*, In Proceedings of the ACM Conference on Security and Privacy in Wireless Mobile Networks (WiSec) '14
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