A Large Scale Analysis of the Security of Embedded Firmwares

A. Costin, **J. Zaddach, A. Francillon, D. Balzarotti**

EURECOM, France

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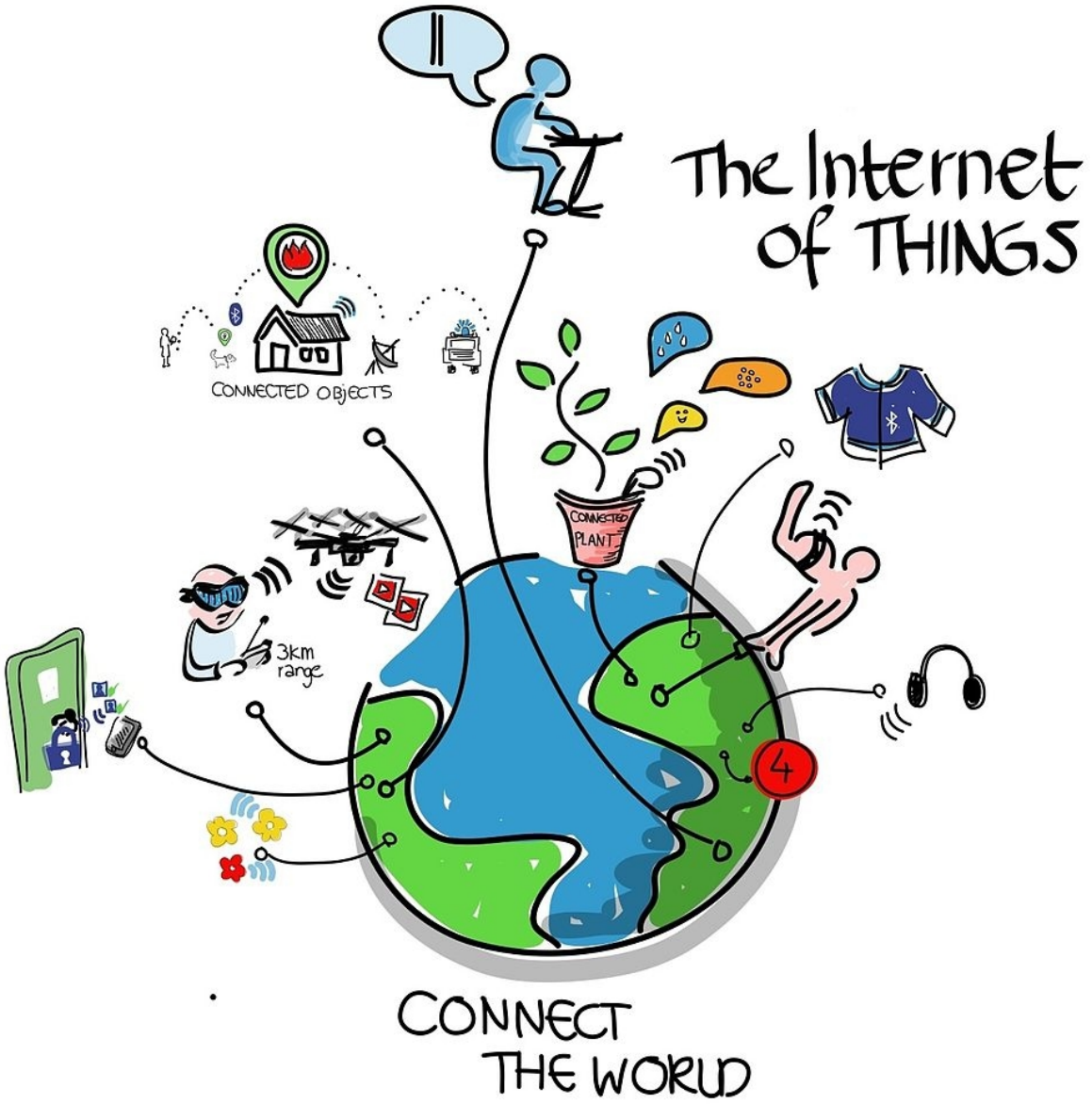
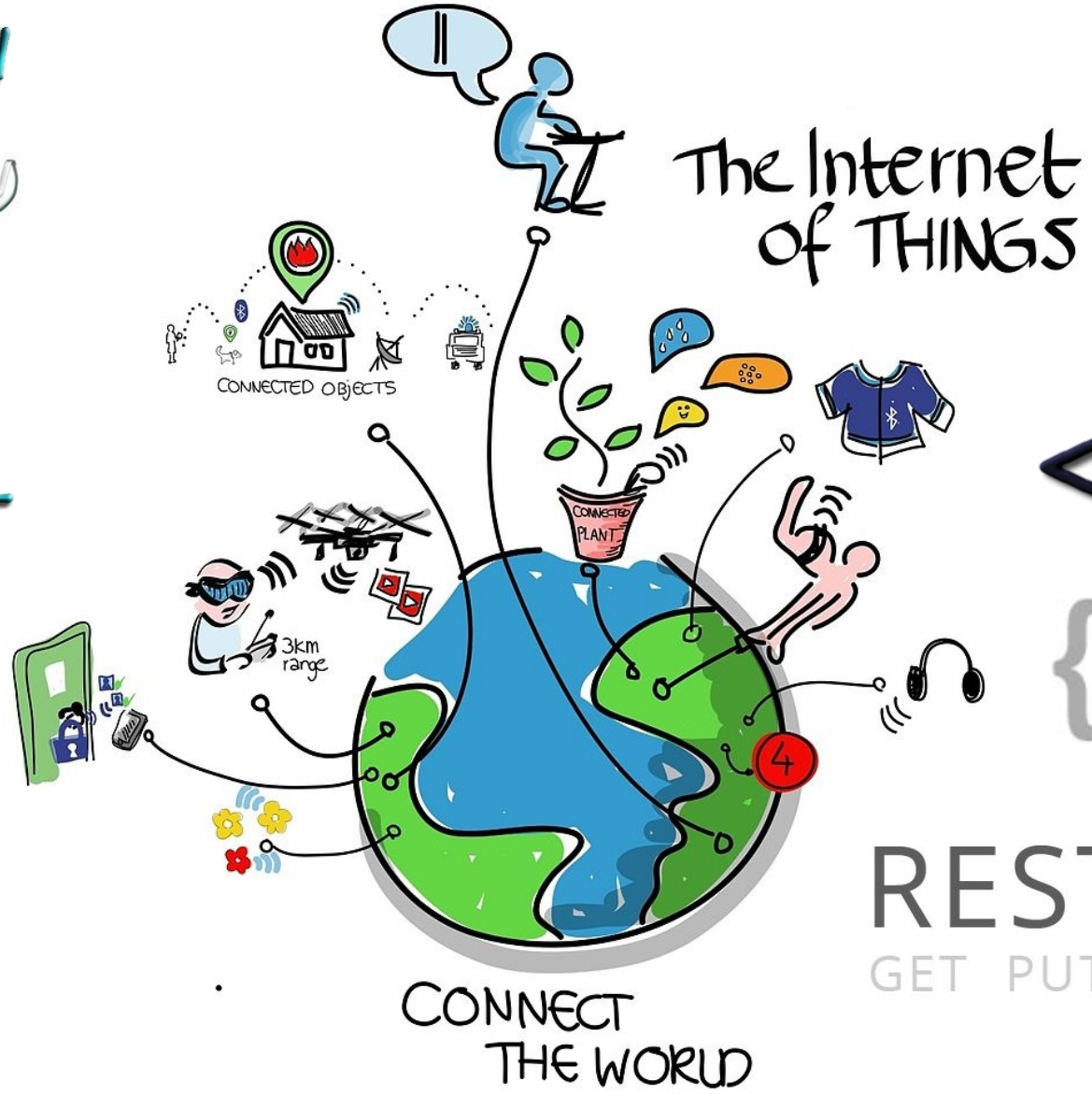
Embedded Systems Are Everywhere



By Wilgengebroed on Flickr [CC-BY-2.0]

Smarter & More Complex



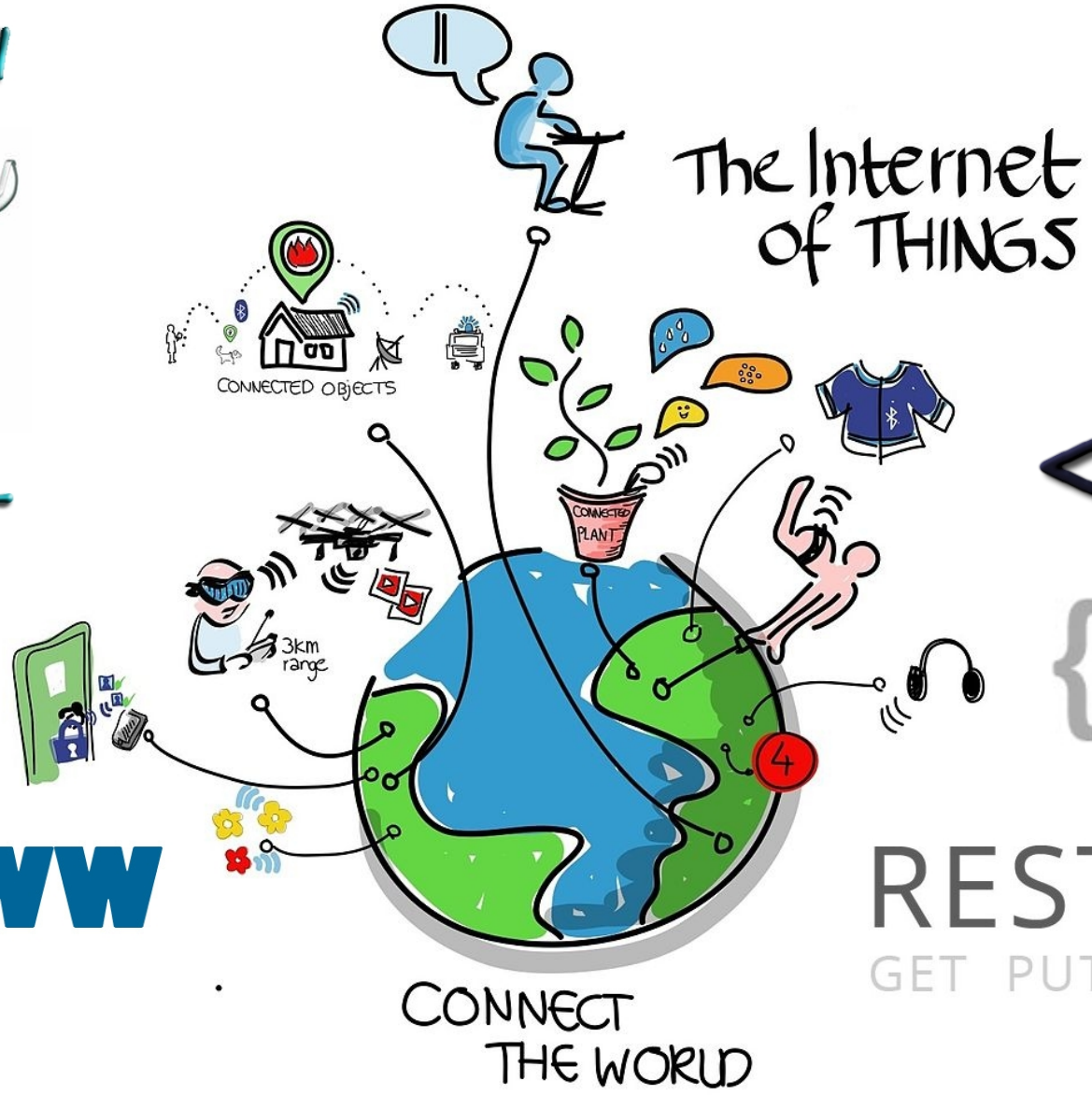
<?xml?>

{JSON}

RESTful API

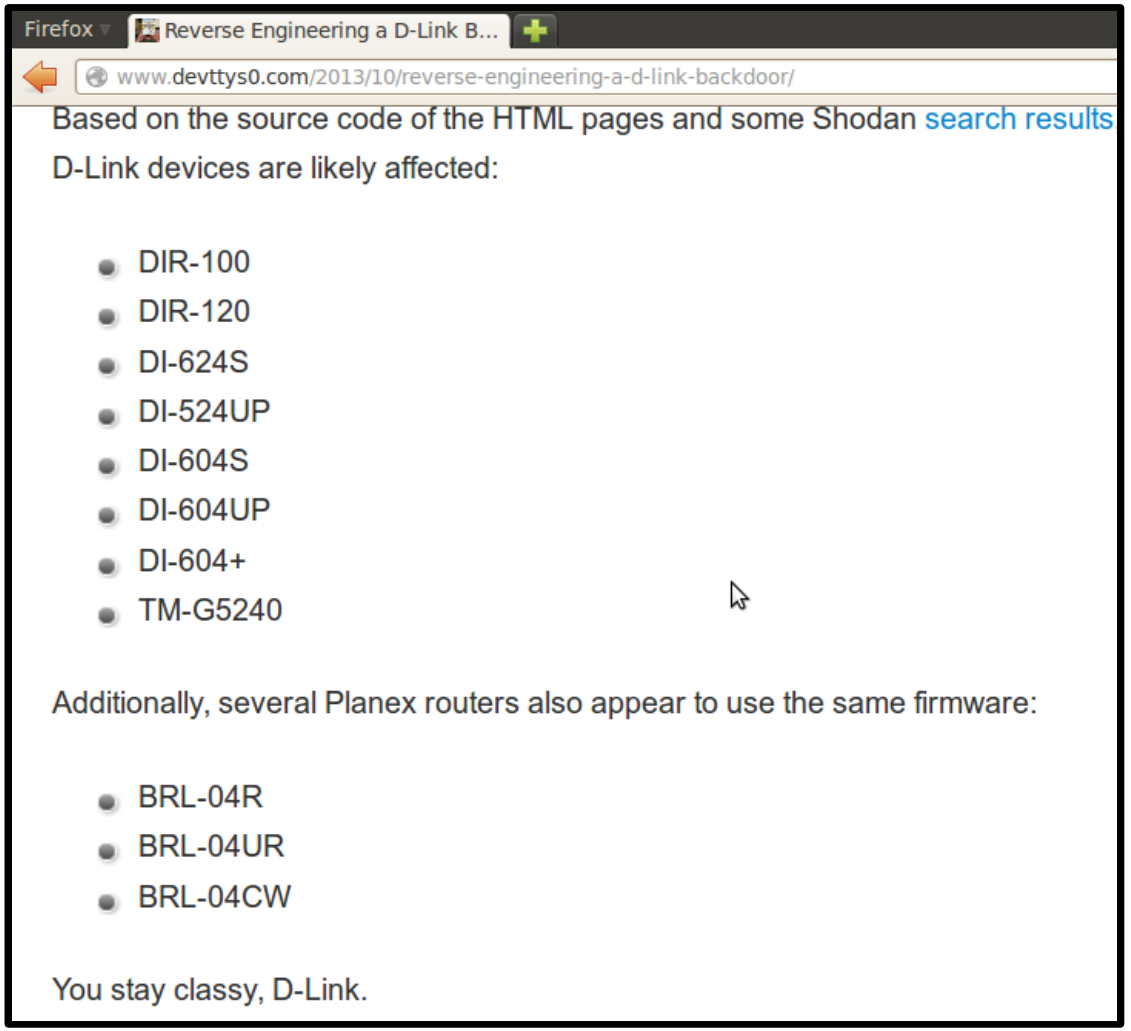
GET PUT POST DELETE

Heavily Interconnected



Many Examples of Insecure Embedded Systems

- Routers



Many Examples of Insecure Embedded Systems

- Routers
- Printers

Networked Printers at Risk

By Jimmy Shah on Dec 30, 2011

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Multifunction printers (MFPs) have been common in offices for years. They let employees print, scan, and copy documents. Two separate talks at the 28th Chaos Communications Congress (28c3) show how attackers can infect these trusted office devices.

Hacking MFPs

In Andrei Costin's presentation "Hacking MFPs," he covered the history of printer and copier hacks from the 1960s to today. The meat of the talk concerned executing remote code on an MFP using crafted PostScript. Just printing a particular document can get code to run on the machine. Previous research proof of concepts have done exactly that, once with a specially designed Word document and once with a Java applet.

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FBI: Criminals Auto-dialing With Hacked VoIP Systems

By Robert McMillan, IDG News Service Dec 5, 2008 5:50 PM

Criminals are taking advantage of a bug in the Asterisk Internet telephony system that lets them pump out thousands of scam phone calls in an hour, the U.S. Federal Bureau of Investigation warned Friday.

The FBI didn't say which versions of Asterisk were vulnerable to the bug, but it advised users to upgrade to the latest version of the software. Asterisk is an open-source product that lets users turn a Linux computer into a VoIP (Voice over Internet Protocol) telephone exchange.

In so-called vishing attacks, scammers usually use a VoIP system to set up a phony call center and then use phishing e-mails to trick victims into calling the center. Once there, they are prompted to give private information. But in the scam described by the FBI, they apparently are taking over legitimate Asterisk systems in order to directly dial victims.

Many Examples of Insecure Embedded Systems

- Routers
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- VoIP
- Cars

FORBES 7/24/2013 @ 9:00AM | 506,516 views

Hackers Reveal Nasty New Car Attacks--With Me Behind The Wheel (Video)

This story appears in the August 12, 2013 issue of Forbes.

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Many Examples of Insecure Embedded Systems

- Routers
- Printers
- VoIP
- Cars
- Drones

Hacker Releases Software to Hijack Commercial Drones

by BRYANT JORDAN *on* DECEMBER 9, 2013

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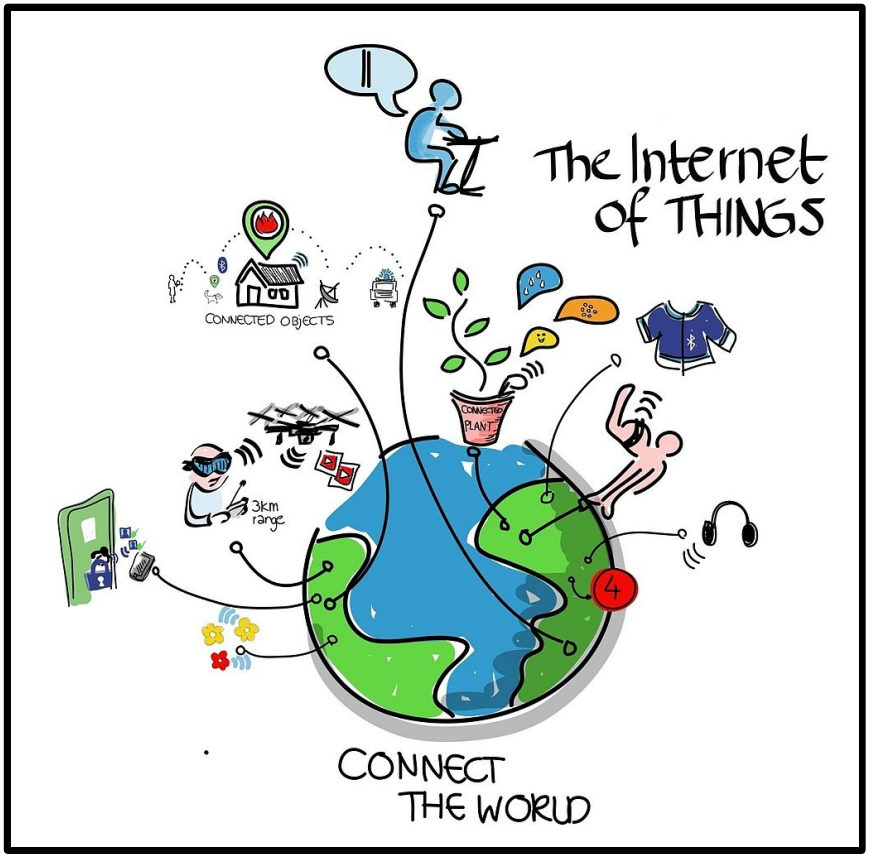

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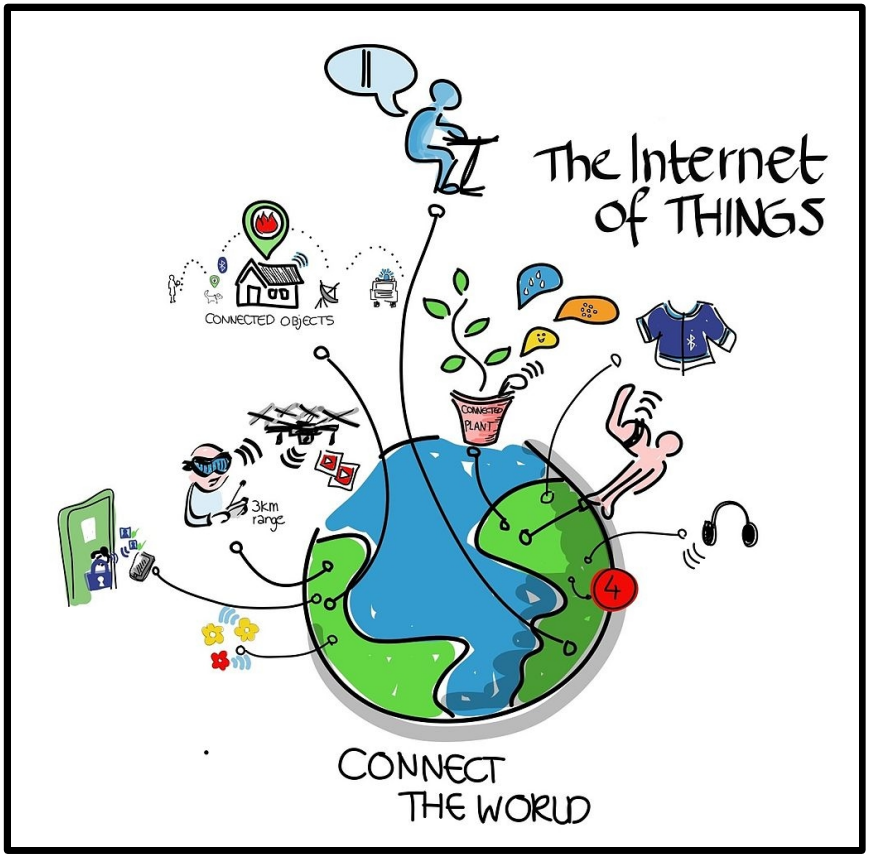

- **Each of above is a result of an individual analysis**
- **Manual and tedious efforts, Does not scale**

The Goal

Perform a large scale analysis to provide a better undestanding of the problem

The Problem With Large Scale Analysis

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

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- Heterogeneity of
  - Hardware, architectures, OSes
  - Users, requirements
  - Security goals
- Manual analysis does not scale, it requires
  - Finding and downloading the firmwares
  - Unpacking and performing initial analysis
  - **Re**-discovering the same or similar bug in other firmwares

Previous Approaches

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

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- 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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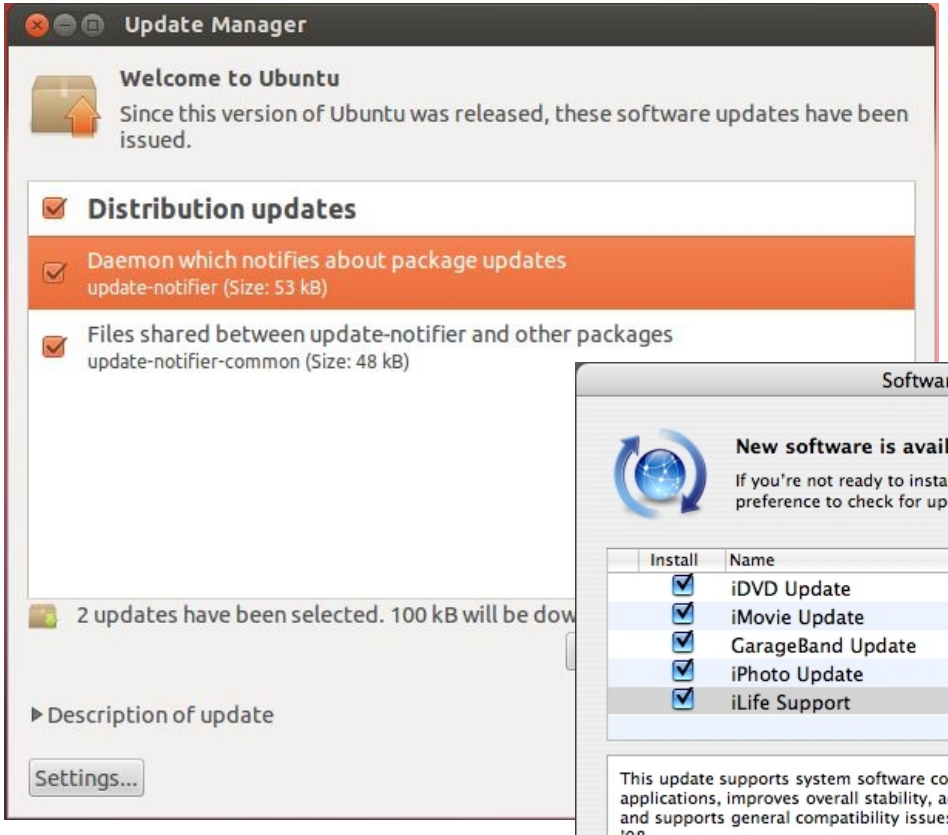
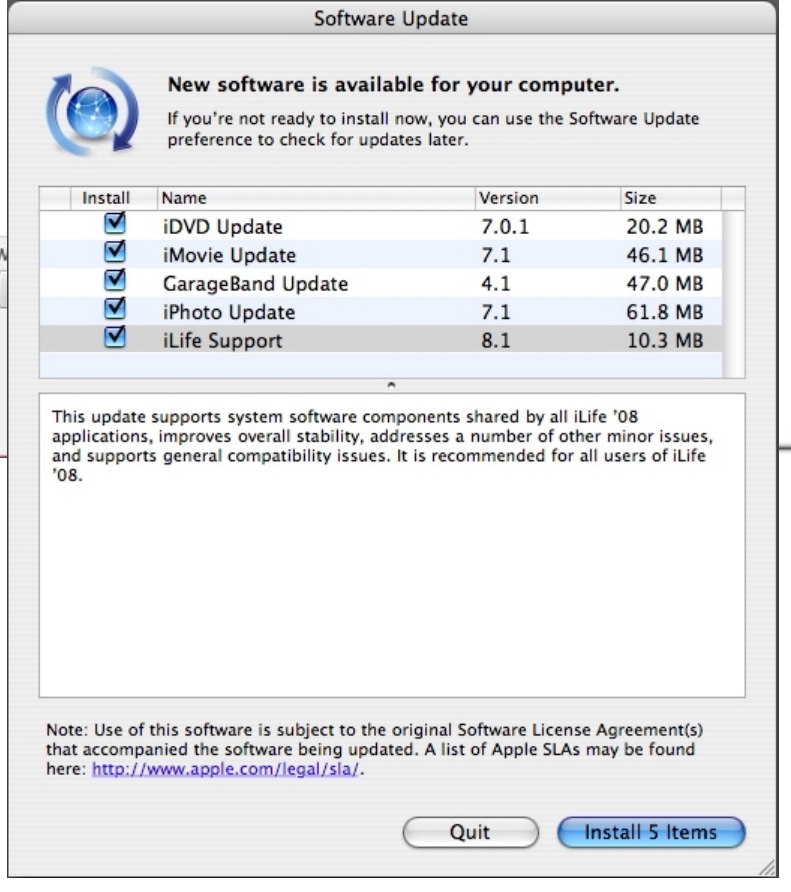
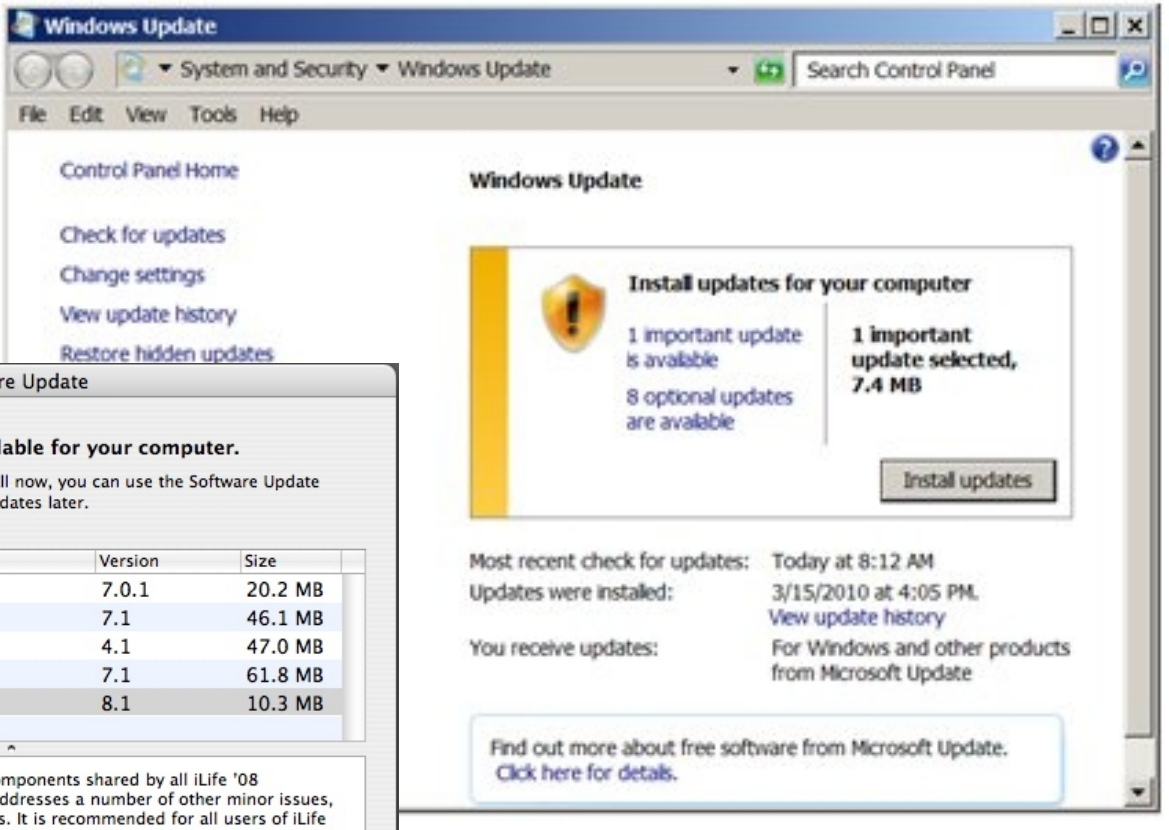
- But many challenges

Mainstream Systems Have Centralized Updates







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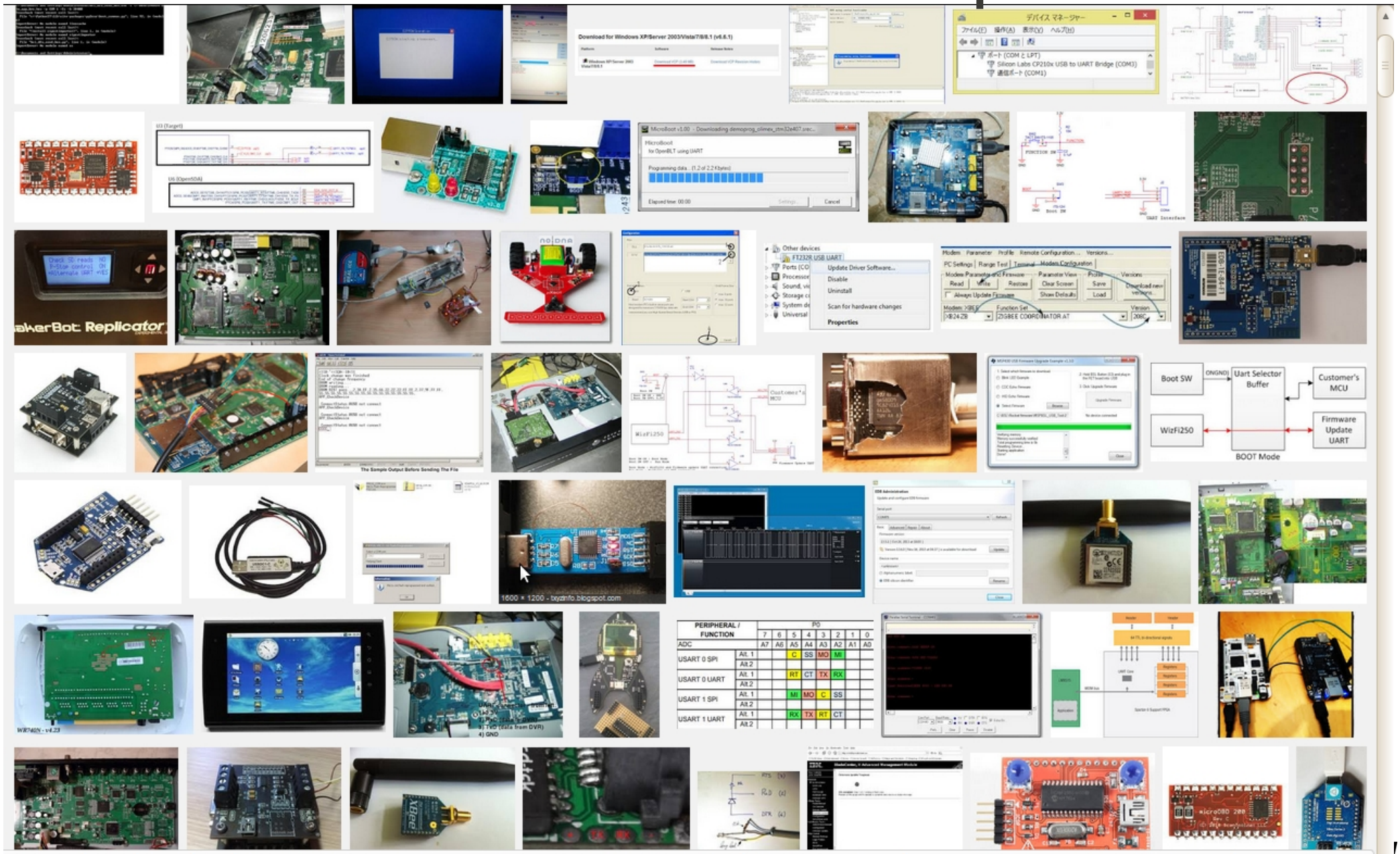
Challenge: Embedded Systems Have No Centralized Updates



www.google.com/imgres?imgurl=http://3.bp.blogspot.com/-eoyP93DWXHM/ULGN-zu9vpI...om=1&docid=5yINoC5G55MiVM&ei=E73oU4egAsim0QXZ14CICQ&tbm=isch&ved=0CEoQMygjMCM

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- No large scale firmware dataset yet
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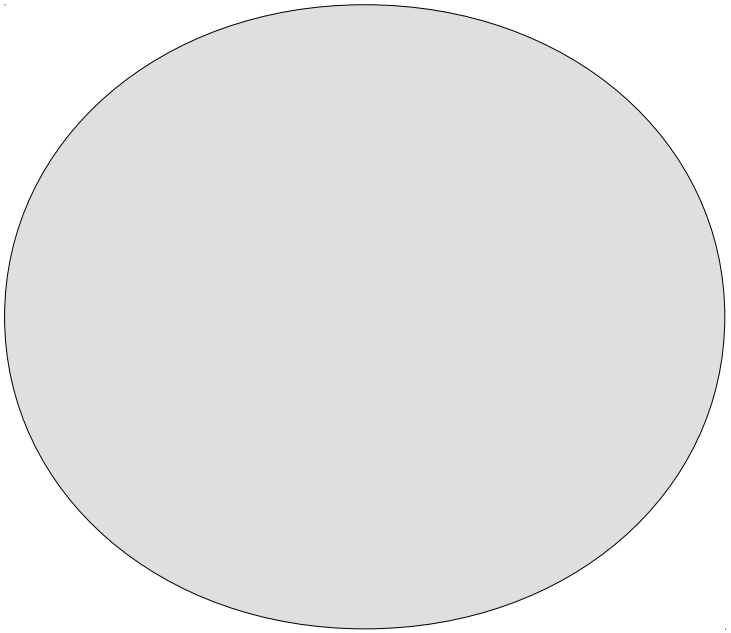
- www.firmware.re project

Challenge: Firmware Identification

Clearly a Firmware



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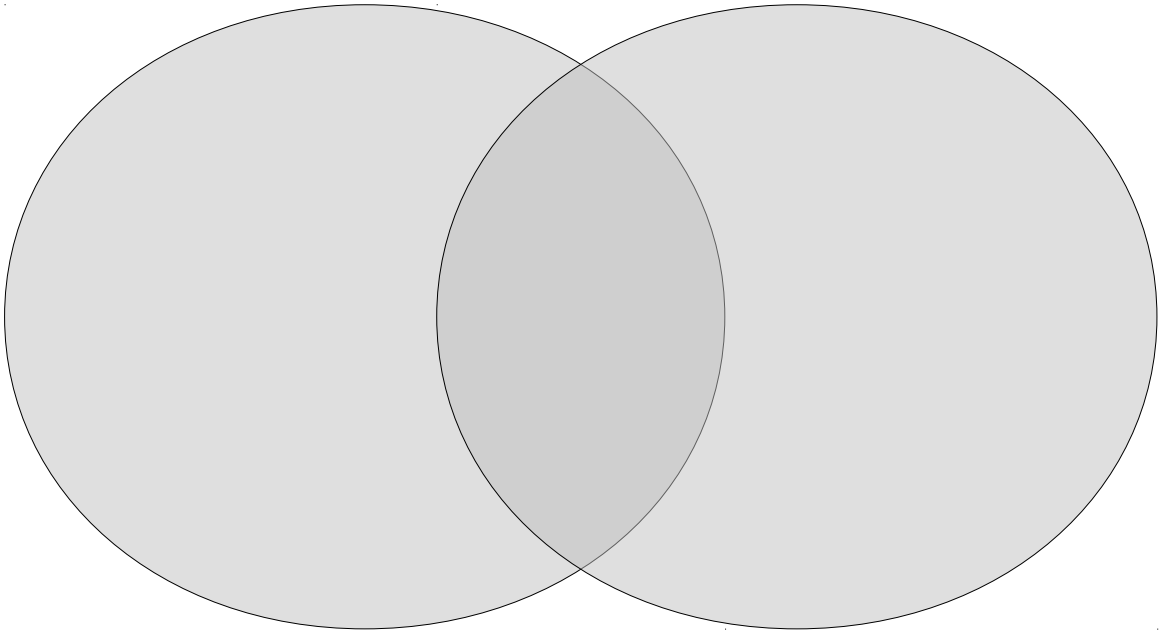

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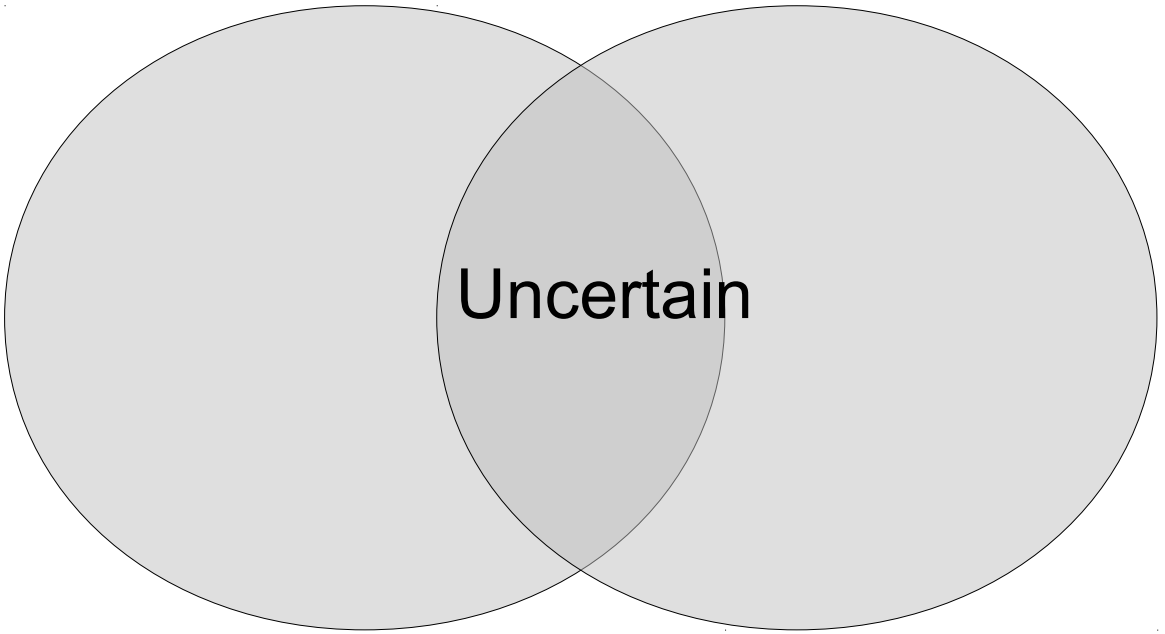

Challenge: Firmware Identification

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

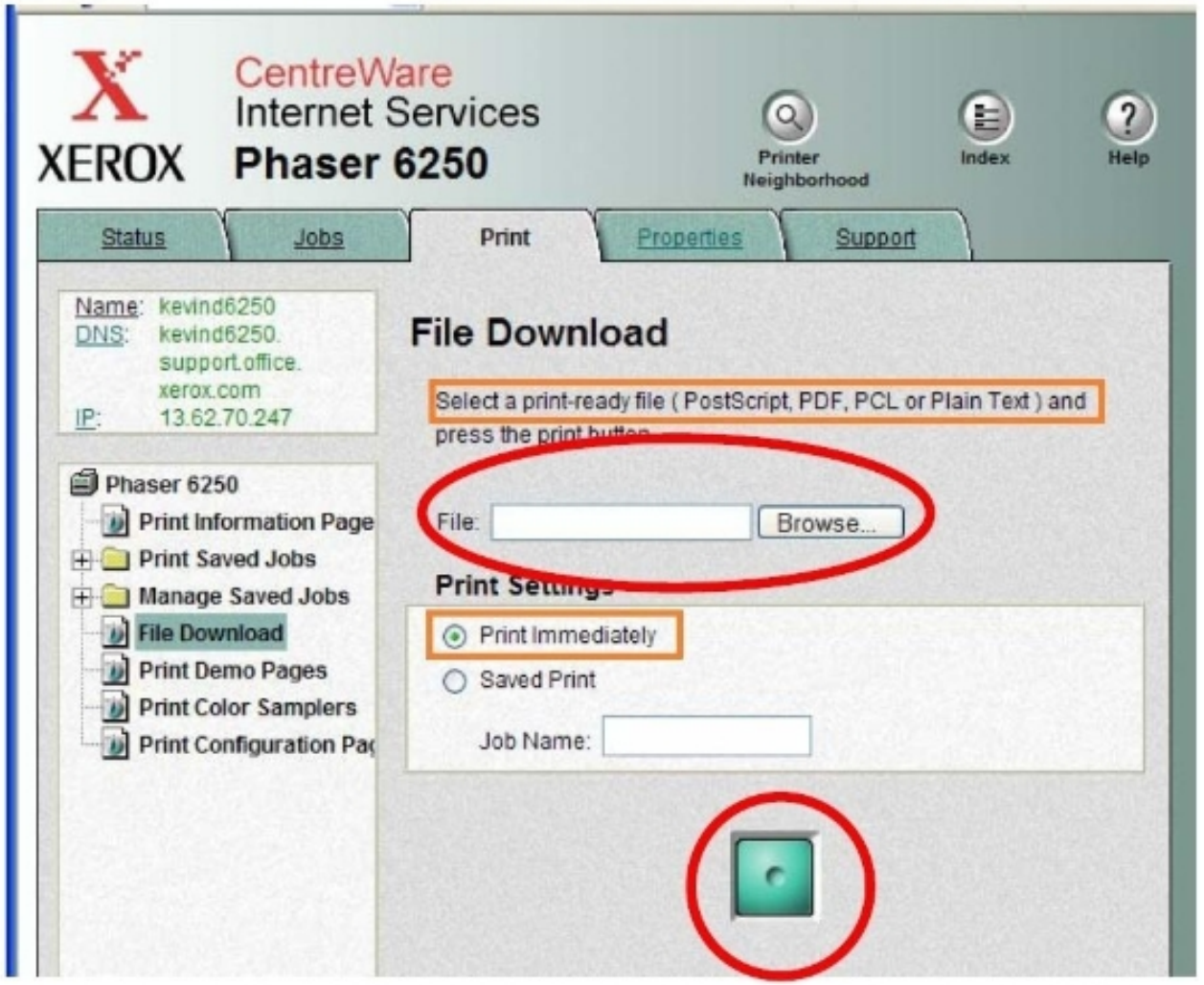

Figure 4: Select the firmware update file and press the green button to send it.

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- Heuristics for detecting when to stop

Challenge: Scalability & Computational Limits

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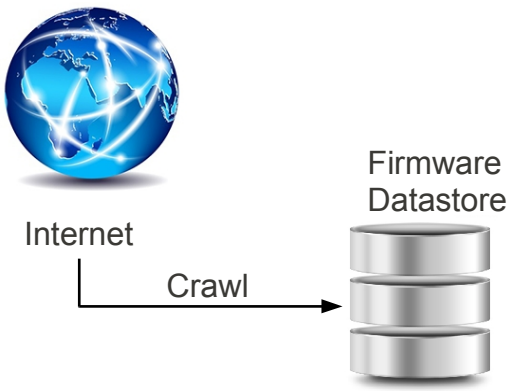
  - Cannot guarantee exploitability
  - E.g., vulnerable daemon present but never started
- Issue confirmation is difficult
  - Requires advanced analysis (static & dynamic)
  - Often requires real embedded devices
  - Does not scale well in heterogeneous environments

Architecture



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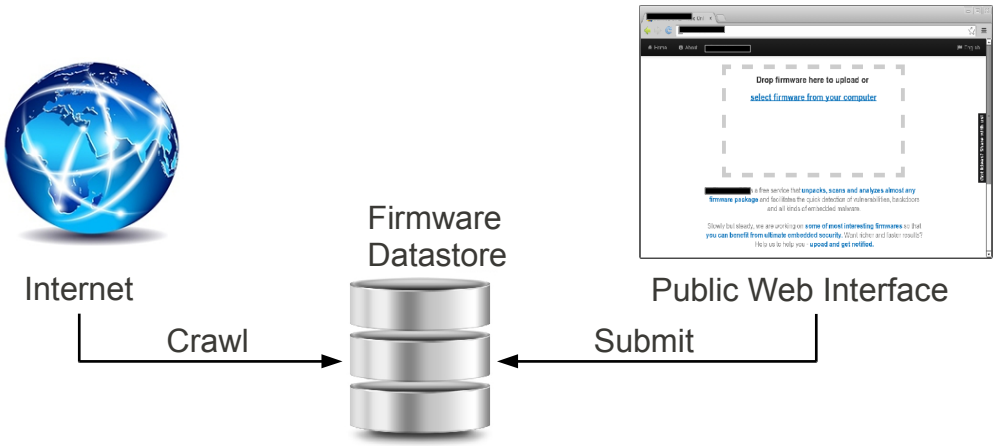

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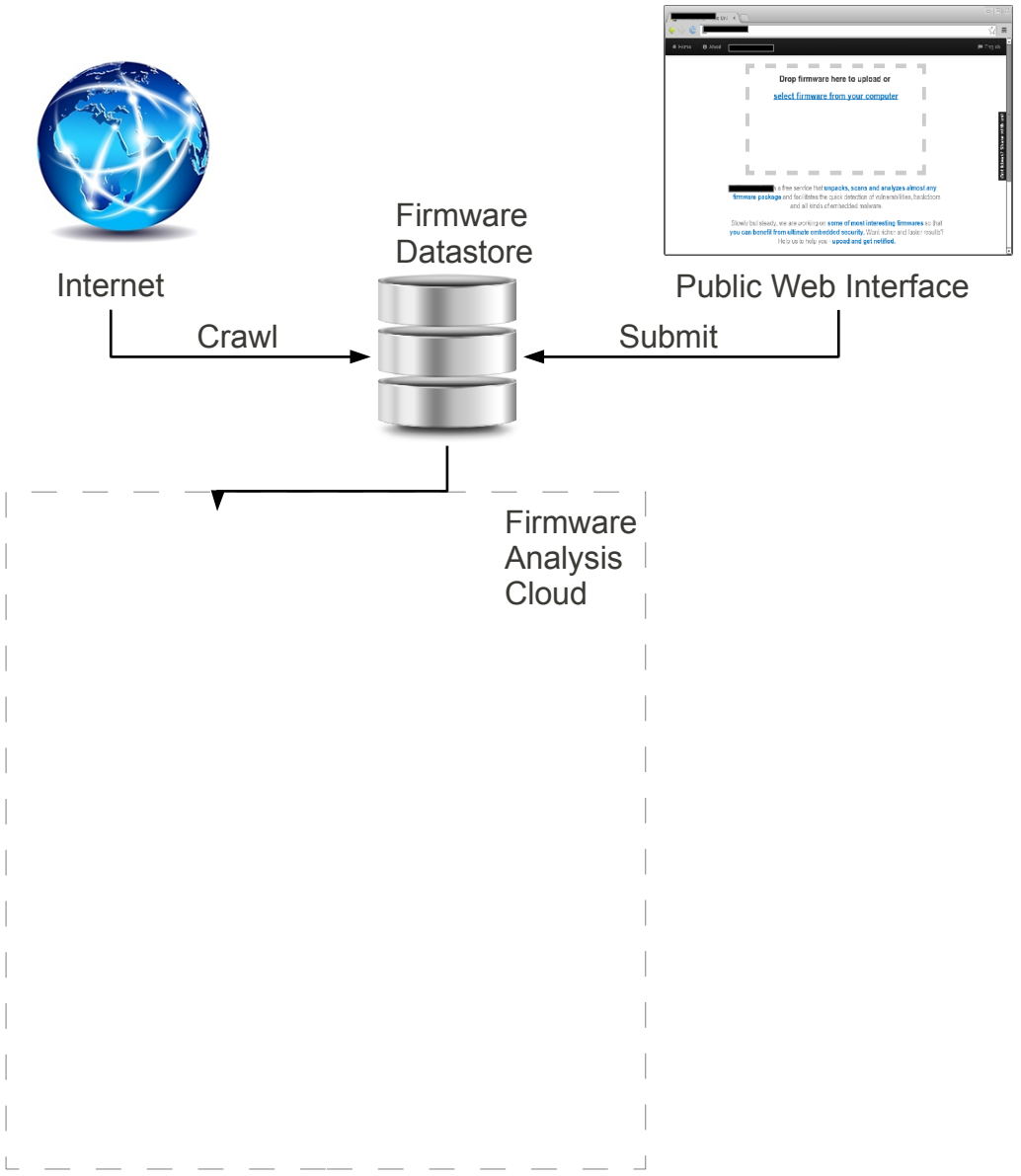

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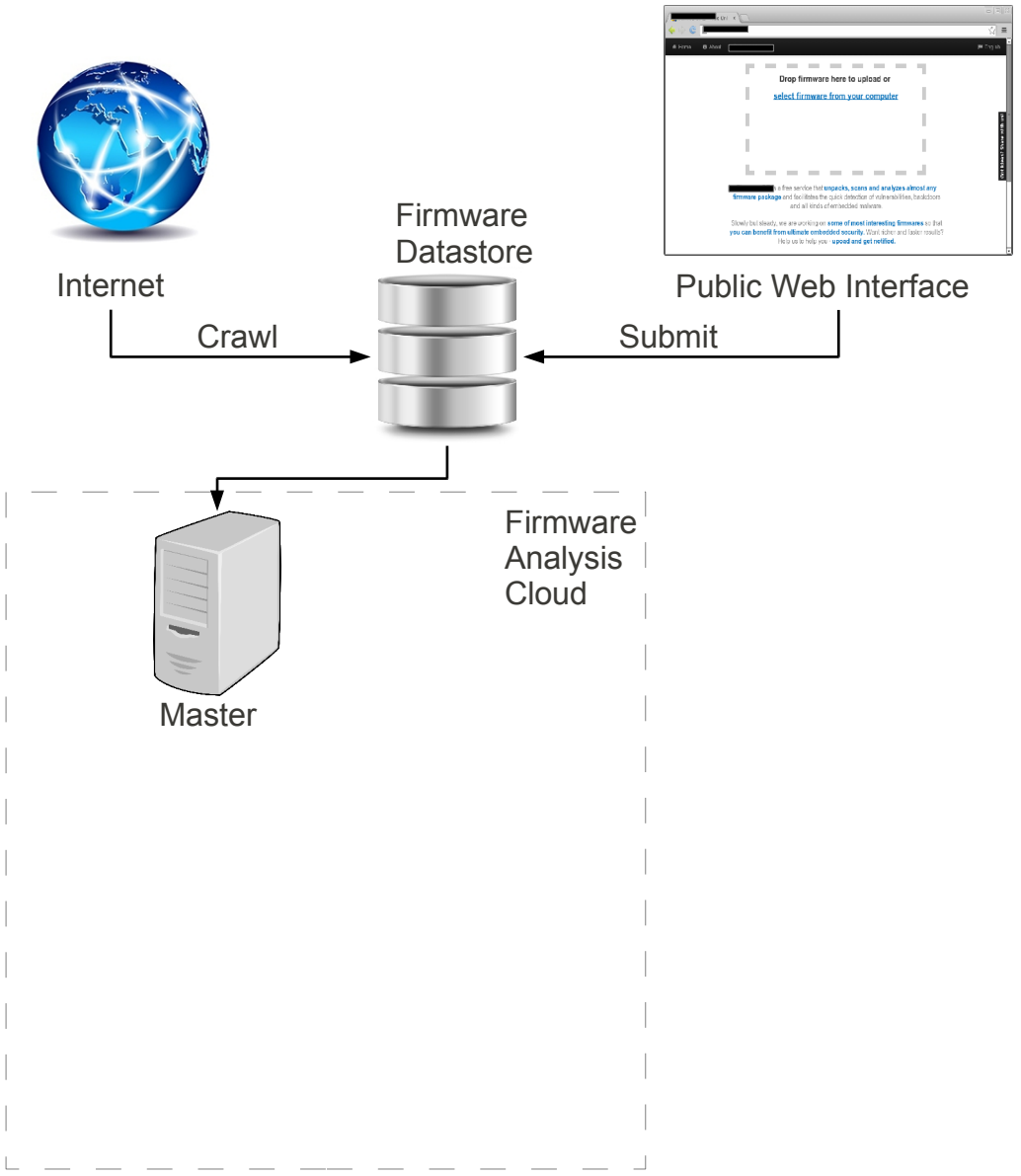

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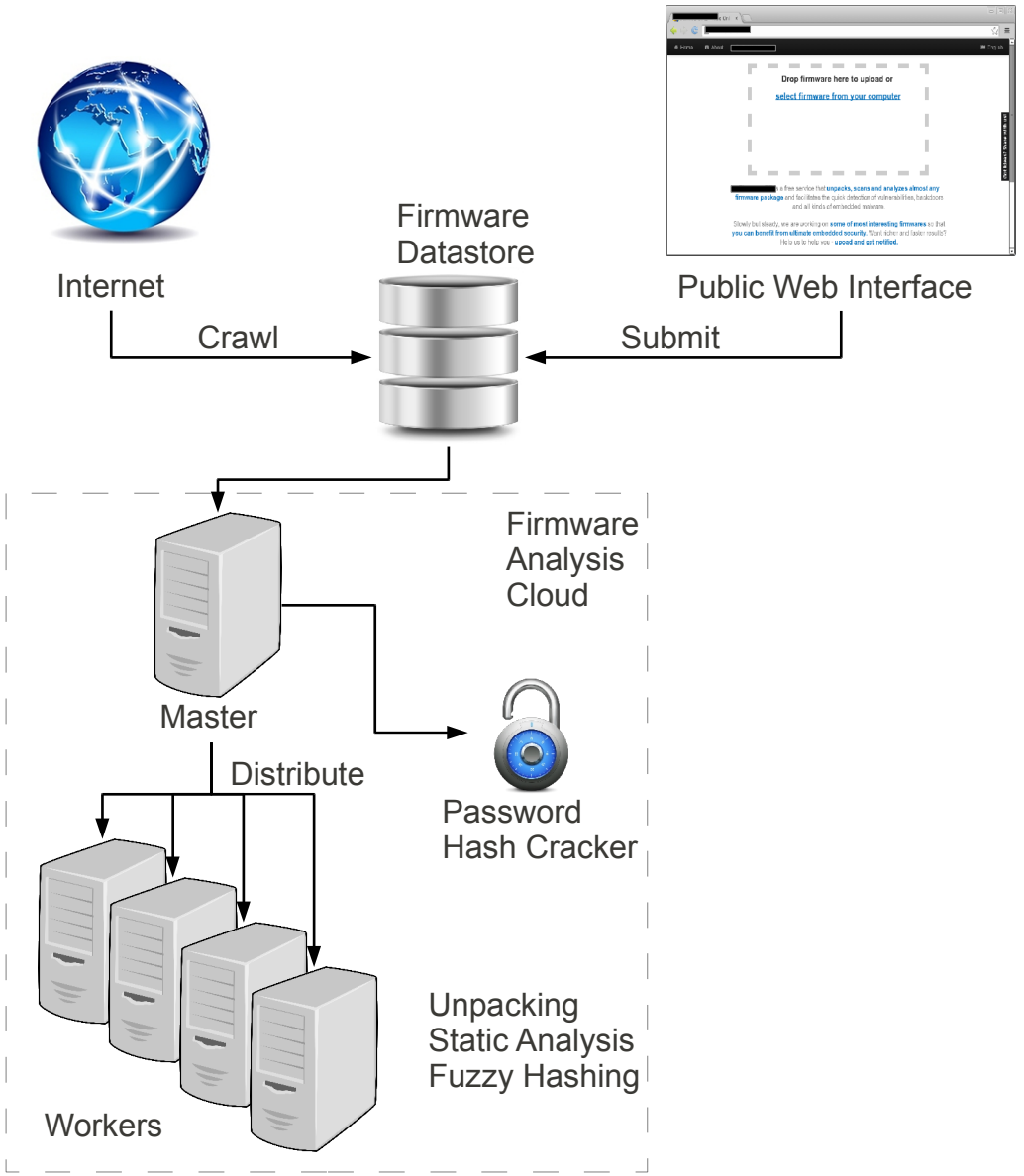

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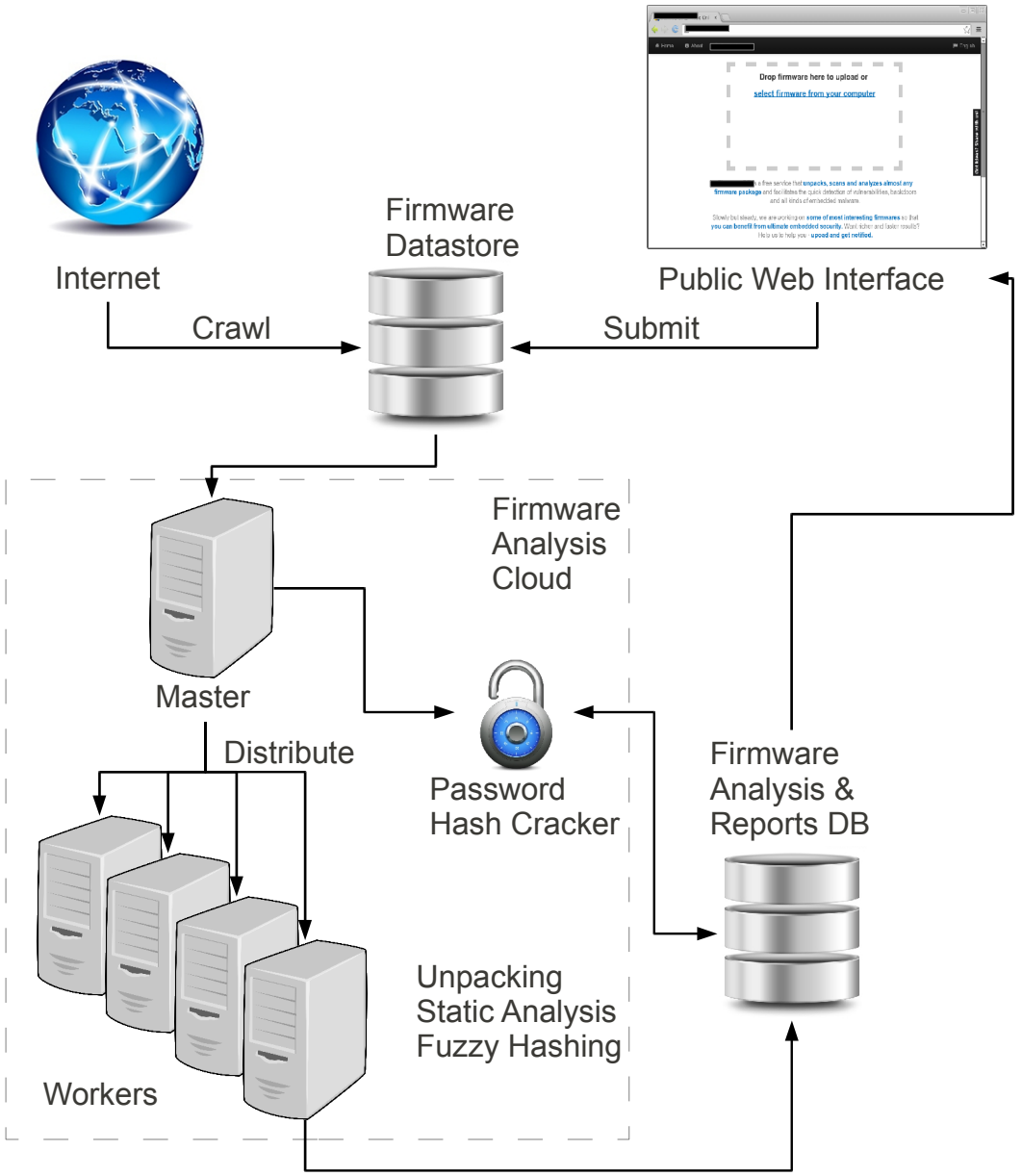

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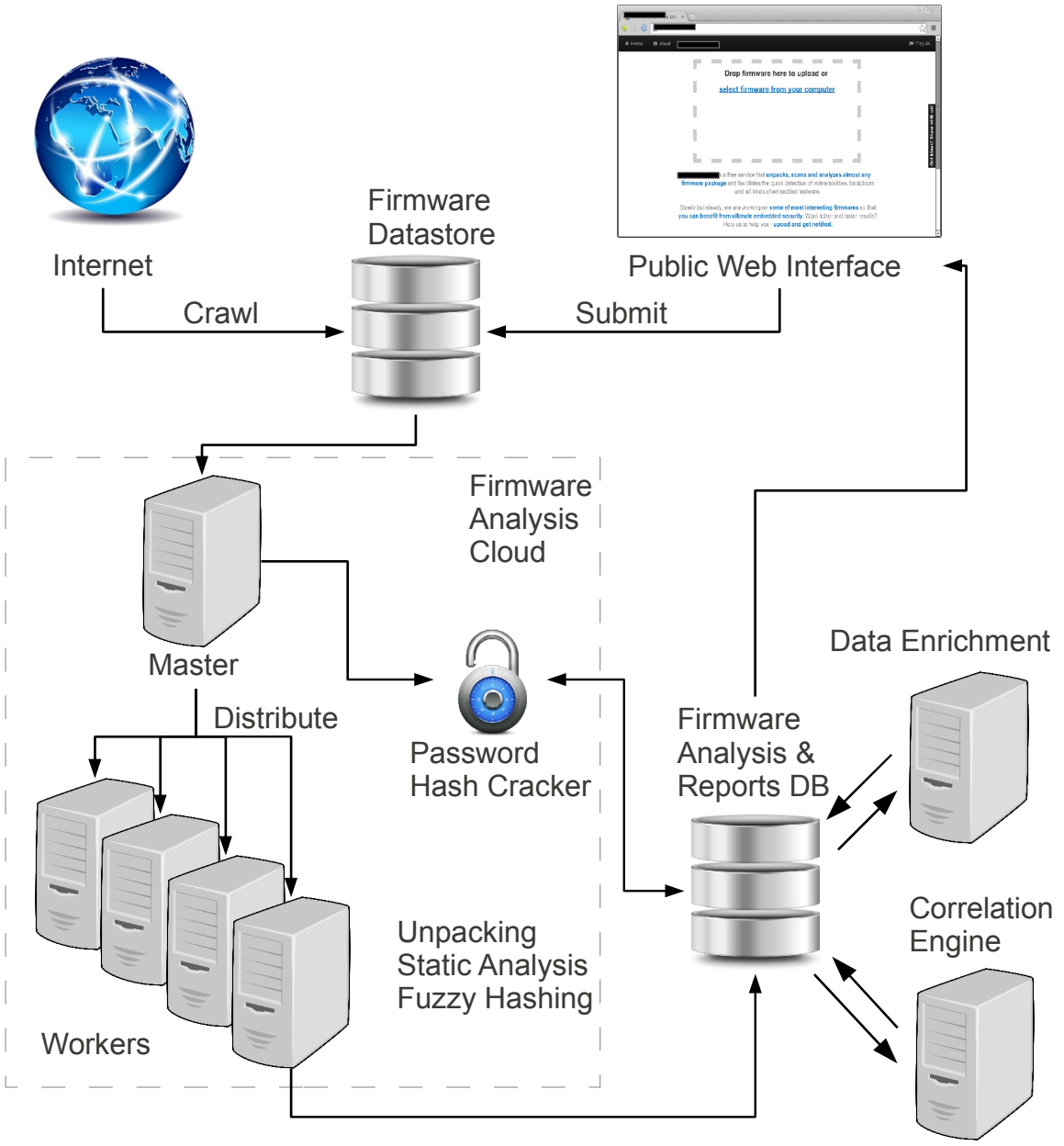

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Crawler

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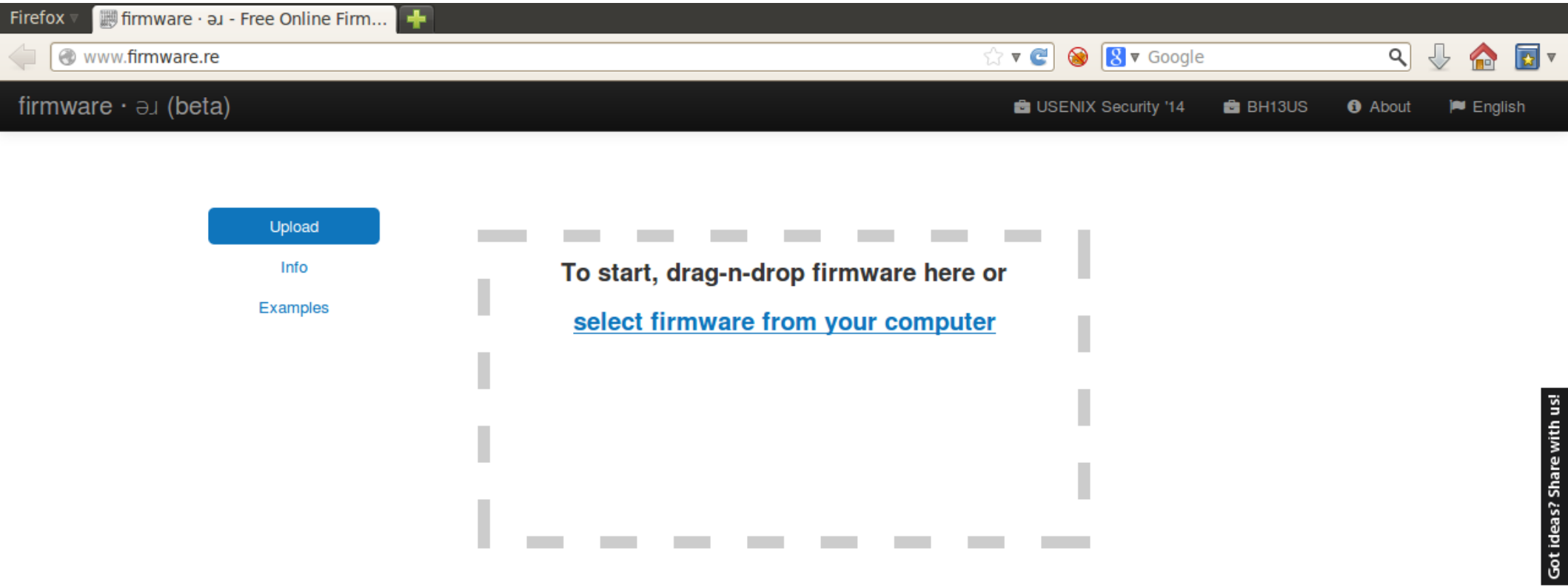
www.Firmware.RE (beta)
Will provide Unpacking and Analysis



Unpacking

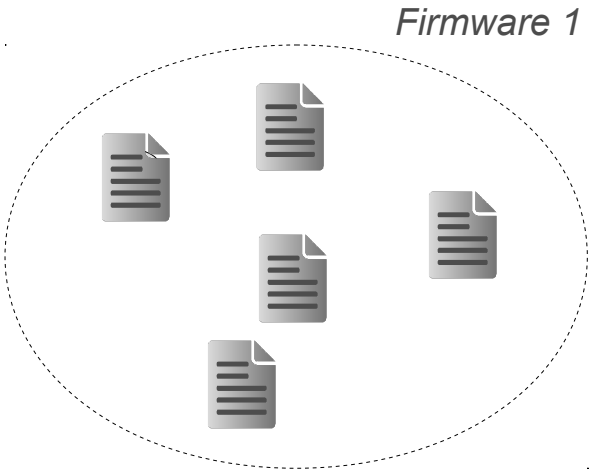
- 759 K total files collected
  - Filter non firmware
- 172 K filtered interesting files
  - Random selection
- 32 K analyzed
  - Successful unpack
- 26 K unpacked (fully or partially)
  - Unpacked files
- 1.7 M resulted files after unpacking

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)
  - E.g., Vulnerability Propagation



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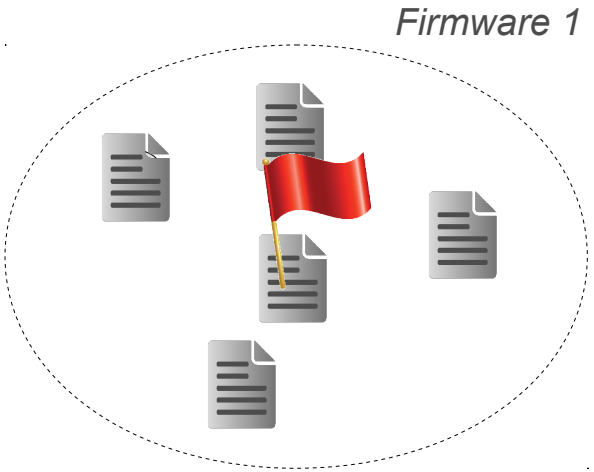

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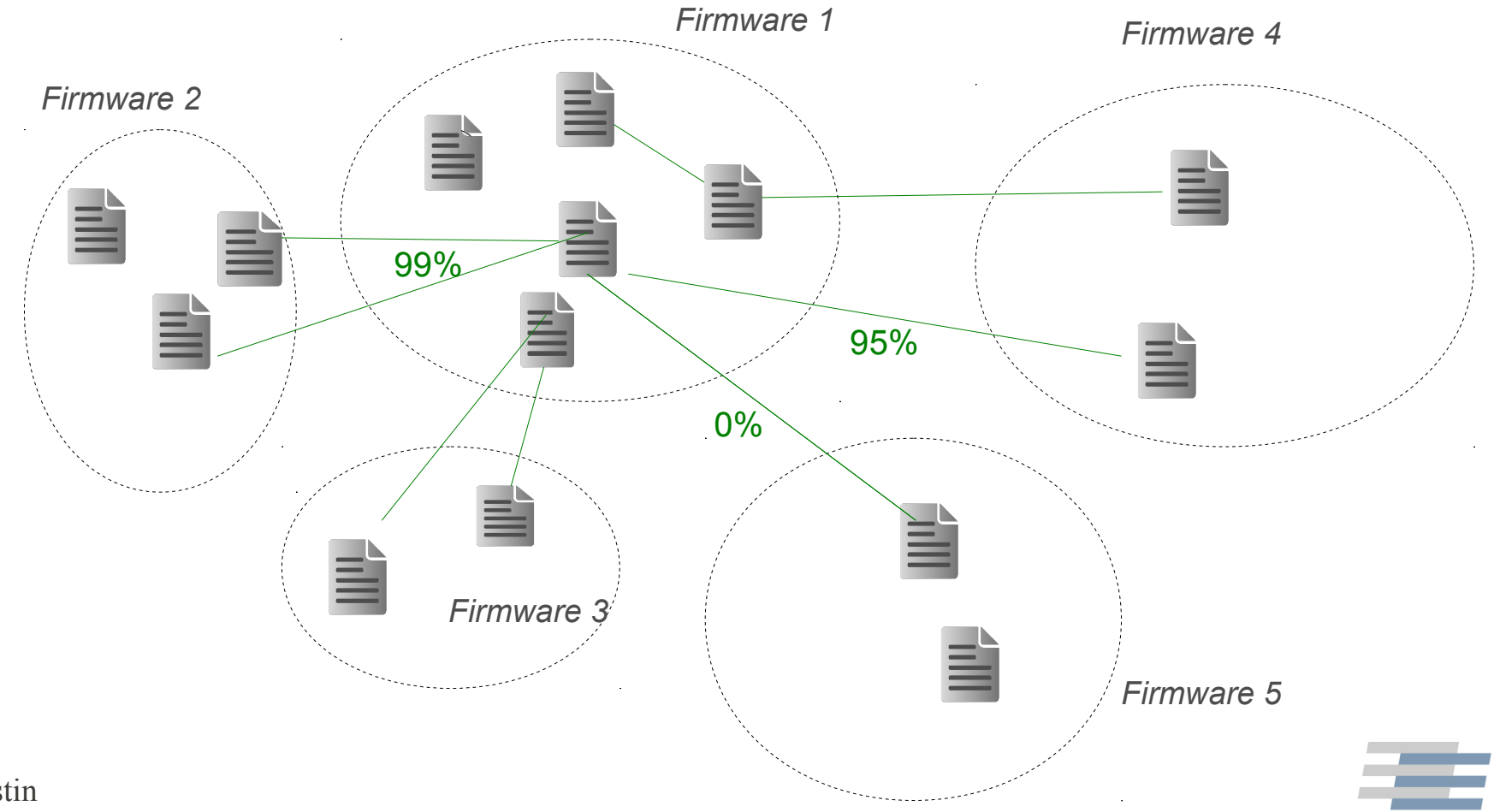

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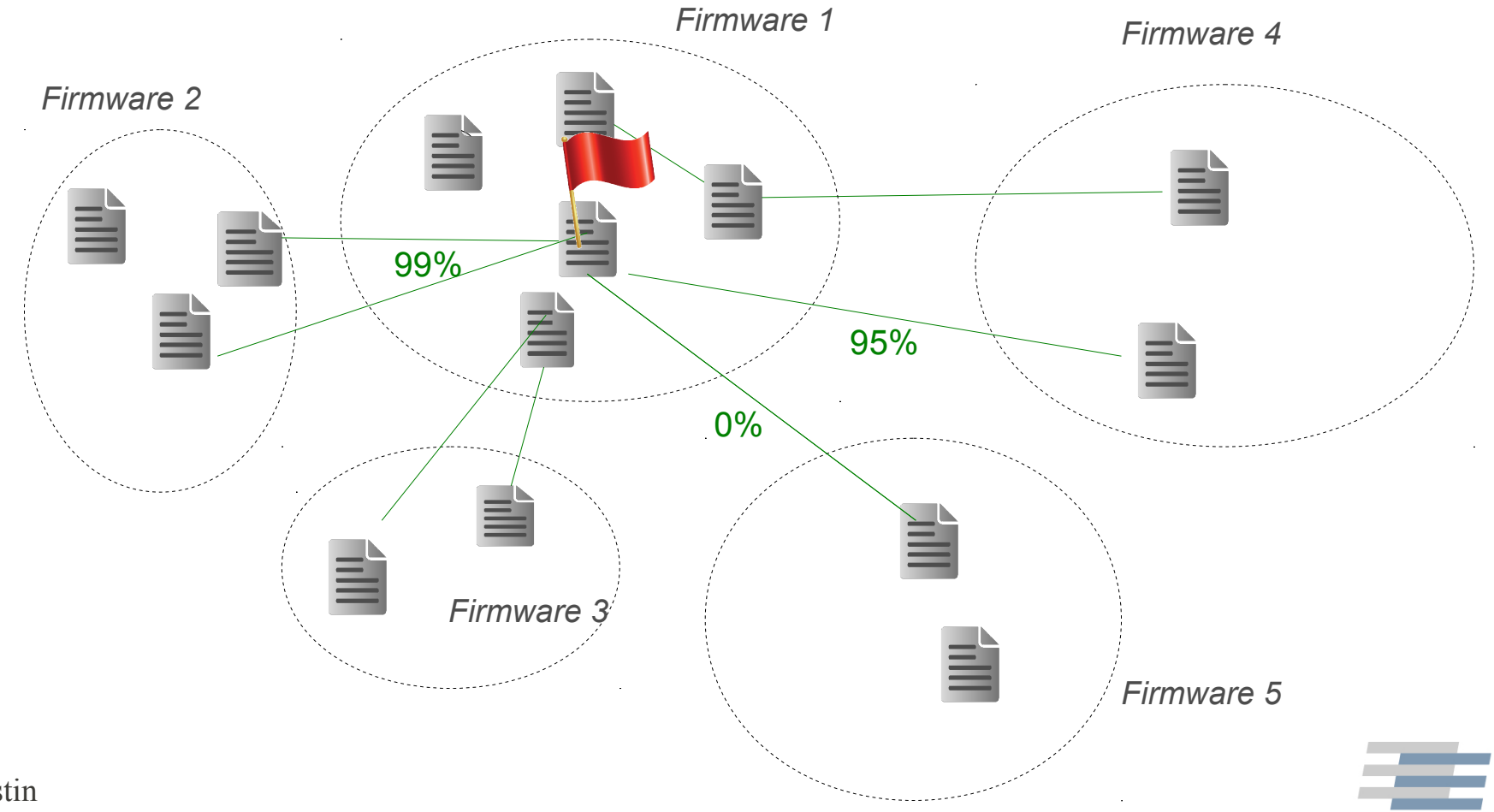

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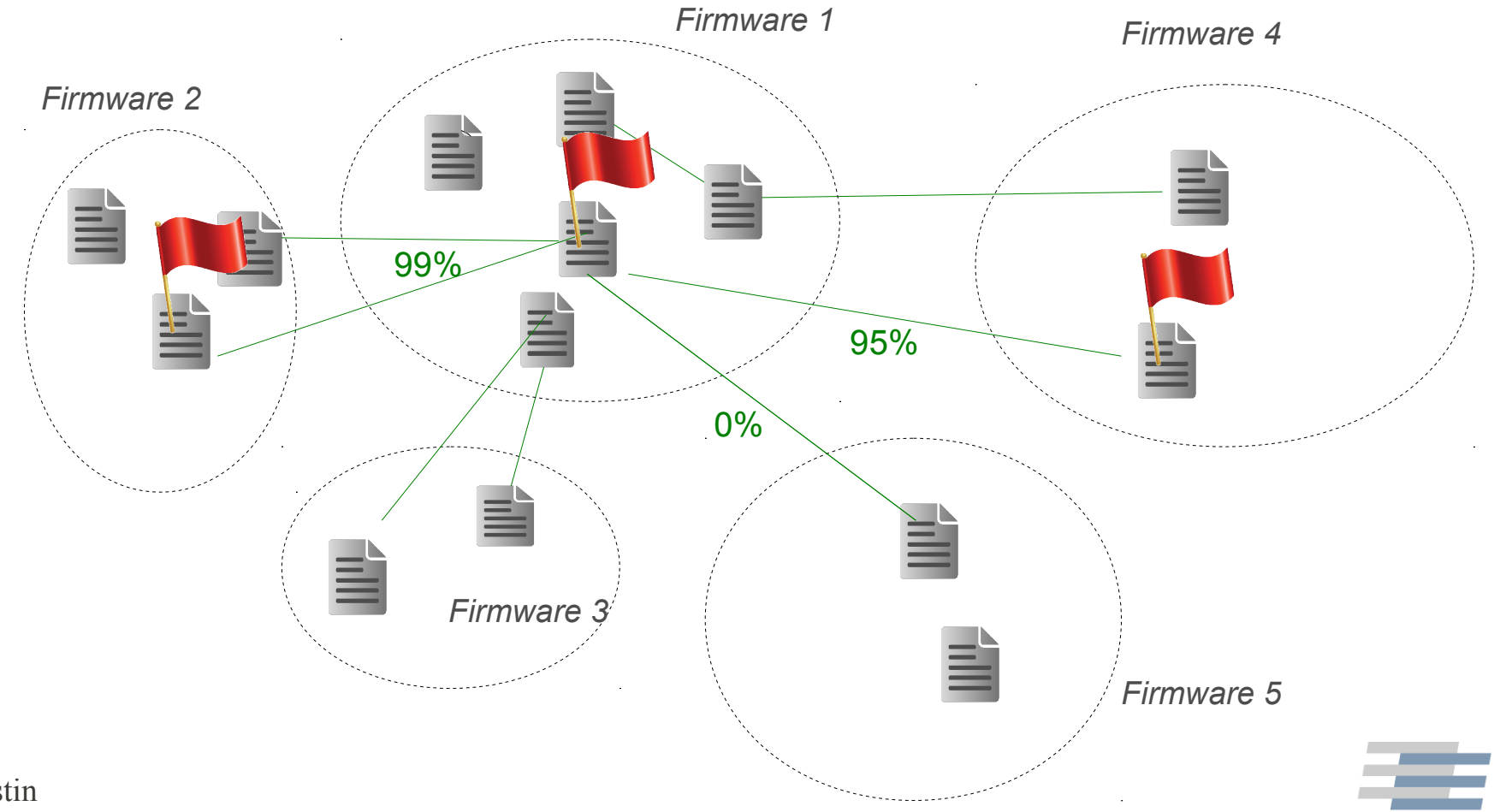

Example: RSA Keys

- SSL keys correlation + vulnerability propagation

Private RSA keys

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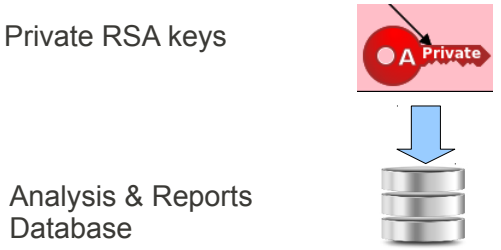

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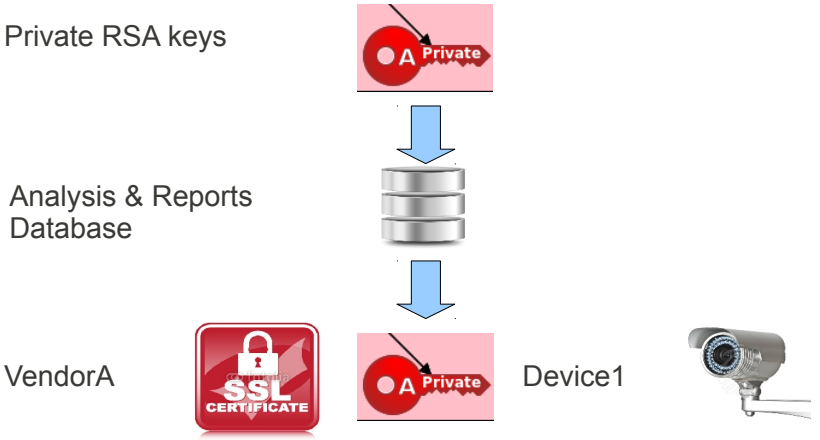

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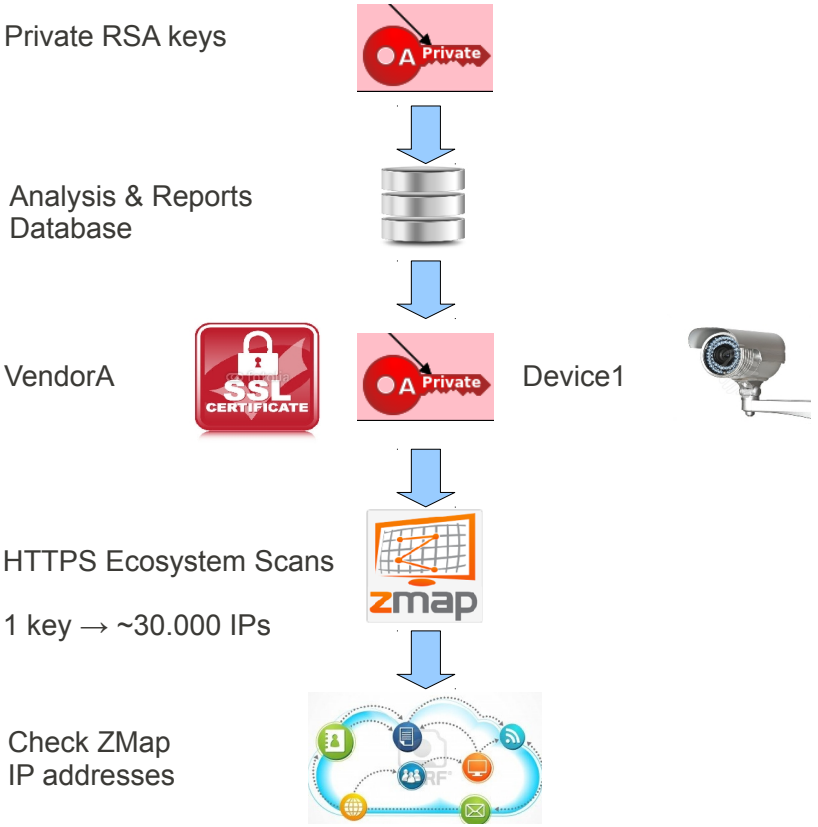

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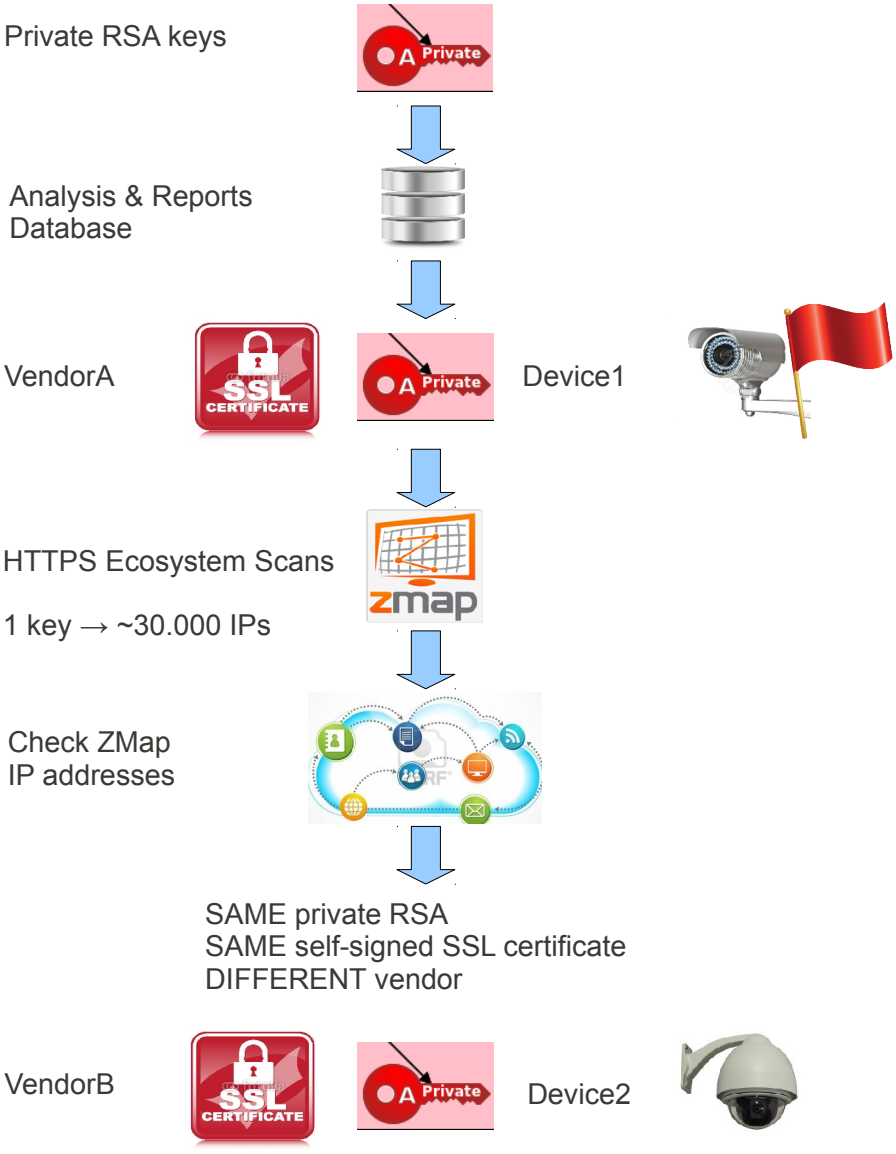

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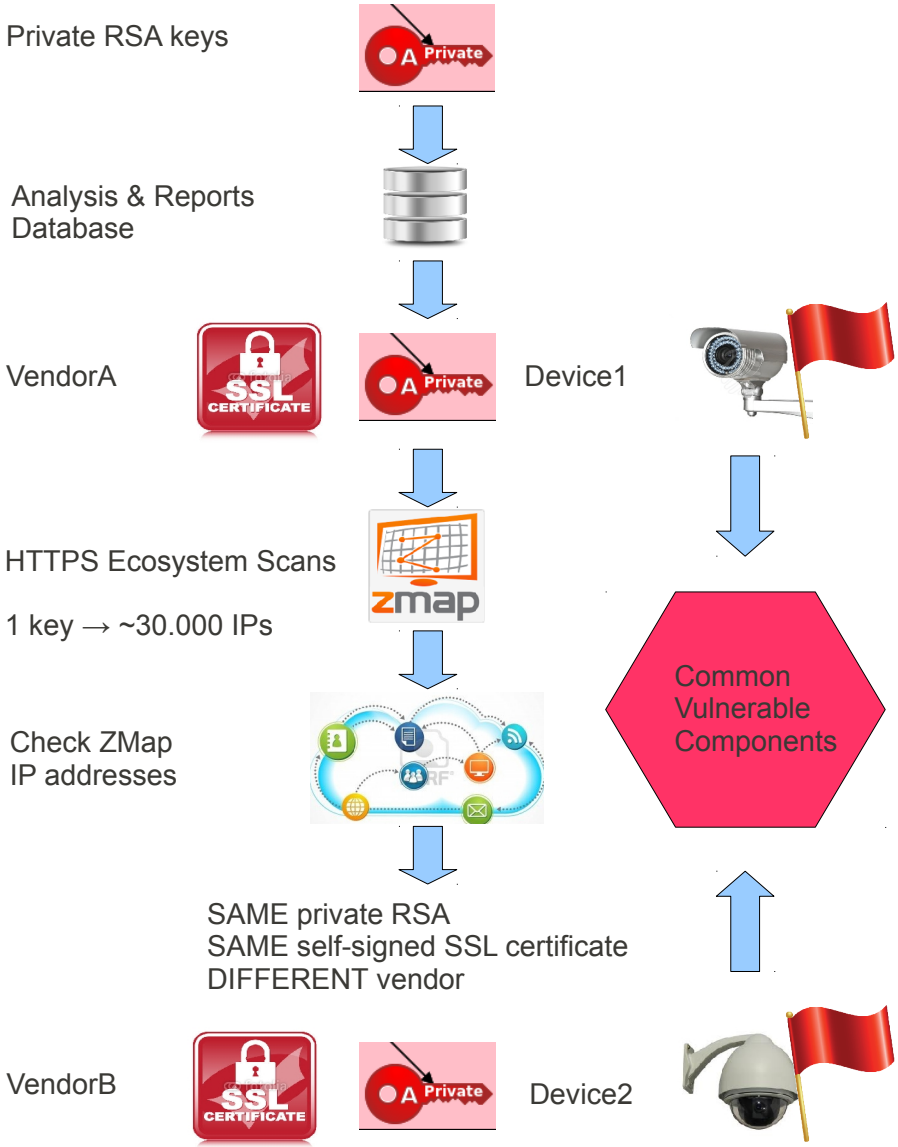

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Results: Summary

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

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 relatioship
  - Shows how vulnerabilities reappear across different products
  - Could allow seeing how firmwares evolve/get fixed

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?

{name.surname}@eurecom.fr

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)
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- [3] A. Costin, A. Francillon, *"Short paper: A Dangerous 'Pyrotechnic Composition': Fireworks, Embedded Wireless and Insecurity-by-Design"*, In Proceedings of the ACM Conference on Security and Privacy in Wireless Mobile Networks (WiSec) '14