Why do Internet Devices Remain Vulnerable? A Survey with System Administrators

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Introduction

- Long tail of vulnerable systems remain after a patch is issued.
- **A compromised system affects many, beyond owner!**
  - a compromise leaks a new data dimension --> user profiling.
  - attackers learn and improve as they compromise more devices
    - e.g., password reuse, and/or password-choosing habits.
  - For web, libraries means a vulnerability in any would have a ripple effect.
  - Compromised device can be used to damage other systems.

Related Work

- **Vulnerability notification effectiveness.**
  - Durumeric et al. [2] (2014): Heartbleed.
    - 13% remediation rate.
  - Li et al. [1] (2016): who to contact, email language, format.
    - 18% remediation rate (within 2 weeks).
  - Stock et al. [3] (2016): XSS vulnerabilities.
    - 10% remediation rate.
  - Zeng et al. [4] (2019): outdated ciphersuites/TLS.
    - 2-3% remediation rate (within 2 weeks).

Related Work

- **Factors affecting notification success.**
  - Ensuring delivery to the proper person/team:
    - not enough [2,5] (2014 and 2018).
  - Sender's reputation:
    - Cetin et al. [6] – unimportant (2016).
    - Stock et al. [5] – important (2018).
  - Notification method:
    - Stock et al. [5] -- social-media and phones not better than emails (2016).
    - Maass et al. [7] -- snail mail increased remediation by 42% (2021).
  - Providing a proof-of-concept of the vulnerability:
    - no significant improvement to remediation rates [8] (2017).

Related Work

- **Notification of compromised (vs. vulnerable) systems.**
  - Li et al. [9] (2016): notified *already hijacked* sites.
    - 50% remediation rate.
  - Vasek and Moore [10] (2012): malware-distributing websites.
    - 17% remediation rate.
  - Quarantining infected machines (e.g., ISP support).
    - 92% remediation rates for infected ISP machines [13].
    - 87% for end systems [14].

Related Work

- **Notification++: active engagement.**
  - Kührer et al. [15] (2014): active engagement with involved parties:
    - collaboration with security organizations.
    - creating technical advisories explaining how to remediate.
    - engaging with industry players (e.g., Cisco).
    - 90% remediation rate.

Next Step

- Why aren't notifications working?
  - We directly solicit the admins' input on the matter.

- Some of the previous literature surveyed [2], [1], [8], [5], [4] (or interviewed [13]) admins.
  - Surveys solicit input/feedback on research methodology
    - not designed to answer the main question.

Research Questions

RQ1. *what admins think are the main factors that prevent them from remediating a vulnerability?*

RQ2. *how such factors change with variables such as, severity, company size, administrator's team size?*

Study Design and Methodology

- Participant Recruitment.
  - Surveyed admins who have a known vulnerability in their systems
    - their input is more relevant to us at this stage.
  - Focused specifically on software vulnerabilities.

Study Design and Methodology

- Randomly chose 9 vulnerabilities from past 8 years.
  - Various severity levels.
  - Patches were available between 4 days (POODLE) and 47 days (Exim) from when the vuln. was made public.

Vulnerability	AKA	Severity
CVE-2019-6111	OpenSSH	5.9 (M)
CVE-2014-3566	POODLE	3.4 (L)
CVE-2018-3110	Java VM	9.9 (C)
CVE-2014-0160	Heartbleed	7.5 (H)
CVE-2019-15846	Exim vuln	9.8 (C)
CVE-2020-6287	SAP NetWeaver	10 (C)
CVE-2018-16845	Nginx	6.1 (M)
CVE-2017-3169	Apache vuln	9.8 (C)
CVE-2018-15599	Dropbear	5.3 (M)

Severity levels: C – Critical, H – High, M – Medium, L – Low.

Study Design and Methodology

- For each vulnerability:
  - used Censys to find devices running the specific vulnerable software version.

Vulnerability	AKA	Severity	#vuln devices
CVE-2019-6111	OpenSSH	5.9 (M)	671
CVE-2014-3566	POODLE	3.4 (L)	91,413
CVE-2018-3110	Java VM	9.9 (C)	1,382
CVE-2014-0160	Heartbleed	7.5 (H)	64,187
CVE-2019-15846	Exim vuln	9.8 (C)	618,866
CVE-2020-6287	SAP NetWeaver	10 (C)	9,684
CVE-2018-16845	Nginx	6.1 (M)	24,045
CVE-2017-3169	Apache vuln	9.8 (C)	1,048,405
CVE-2018-15599	Dropbear	5.3 (M)	2,040,824

Severity levels: C – Critical, H – High, M – Medium, L – Low.

Study Design and Methodology

- For each IP address:
  - queried the RIRs WHOIS databases for contact information
    - prioritizing abuse contact if found, and falling back to regular email contact otherwise.

Vulnerability	AKA	Severity	#vuln devices	#emails found in WHOIS
CVE-2019-6111	OpenSSH	5.9 (M)	671	587
CVE-2014-3566	POODLE	3.4 (L)	91,413	38,900
CVE-2018-3110	Java VM	9.9 (C)	1,382	1,047
CVE-2014-0160	Heartbleed	7.5 (H)	64,187	37,824
CVE-2019-15846	Exim vuln	9.8 (C)	618,866	401,722
CVE-2020-6287	SAP NetWeaver	10 (C)	9,684	2,574
CVE-2018-16845	Nginx	6.1 (M)	24,045	7,509
CVE-2017-3169	Apache vuln	9.8 (C)	1,048,405	440,305
CVE-2018-15599	Dropbear	5.3 (M)	2,040,824	668,513

Severity levels: C – Critical, H – High, M – Medium, L – Low.

Study Design and Methodology

- For each email address:
  - Remove redundant ones (keep unique).

Vulnerability	AKA	Severity	#vuln devices	#emails found in WHOIS	#unique emails
CVE-2019-6111	OpenSSH	5.9 (M)	671	587	117
CVE-2014-3566	POODLE	3.4 (L)	91,413	38,900	2,739
CVE-2018-3110	Java VM	9.9 (C)	1,382	1,047	89
CVE-2014-0160	Heartbleed	7.5 (H)	64,187	37,824	1,802
CVE-2019-15846	Exim vuln	9.8 (C)	618,866	401,722	1,835
CVE-2020-6287	SAP NetWeaver	10 (C)	9,684	2,574	262
CVE-2018-16845	Nginx	6.1 (M)	24,045	7,509	147
CVE-2017-3169	Apache vuln	9.8 (C)	1,048,405	440,305	4,143
CVE-2018-15599	Dropbear	5.3 (M)	2,040,824	668,513	1,464

Severity levels: C – Critical, H – High, M – Medium, L – Low.

Study Design and Methodology

- We do not test whether vulnerable systems were remediated after emailing admins.

Ethical Considerations

- Emphasize that participation is voluntary.
- Transparency about our activities.
  - web page explaining who we are, what we do, how we can be contacted.
    - on the same domain from which emails were sent.
- Opt-out option, e.g., from future studies, both in our email and in the web page.
- Limited the emails sent to each email address to one to avoid spamming.

Data Set

- Sent 13,191 emails. Received 92 responses.
- Discarded responses from 3 participants who selected *"I prefer not to answer"* for more than 90% of the questions.

Vulnerability	AKA	Severity	#vuln devices	#emails found in WHOIS	#unique emails	#participants (%)
CVE-2019-6111	OpenSSH	5.9 (M)	671	587	117	-
CVE-2014-3566	POODLE	3.4 (L)	91,413	38,900	2,739	4.5 ($n = 4$)
CVE-2018-3110	Java VM	9.9 (C)	1,382	1,047	89	-
CVE-2014-0160	Heartbleed	7.5 (H)	64,187	37,824	1,802	2.2 ($n = 2$)
CVE-2019-15846	Exim vuln	9.8 (C)	618,866	401,722	1,835	30.3 ($n = 27$)
CVE-2020-6287	SAP NetWeaver	10 (C)	9,684	2,574	262	2.2 ($n = 2$)
CVE-2018-16845	Nginx	6.1 (M)	24,045	7,509	147	2.2 ($n = 2$)
CVE-2017-3169	Apache vuln	9.8 (C)	1,048,405	440,305	4,143	50.6 ($n = 45$)
CVE-2018-15599	Dropbear	5.3 (M)	2,040,824	668,513	1,464	4.5 ($n = 4$)
	n/a					3.4 ($n = 3$)

Severity levels: C - Critical, H - High, M - Medium, L - Low.

IP Geolocation Lookup

Country	N	Country	N
United States	34	Japan	1
Canada	16	Netherlands	1
Australia	12	Norway	1
Austria	3	Philippines	1
France	2	Romania	1
United Kingdom	2	Switzerland	1
Belgium	1	Thailand	1
Germany	1	Turkey	1
India	1	Uzbekistan	1

Analysis Methodology

- Quantitative analysis
- Qualitative analysis
  - Within survey responses.
  - From email replies.
  - Thematic analysis.
    - Open coding
      - e.g., looked at participants' reasoning to remediate or forgo remediation, additional remediation barriers, remediation plans.

The Survey

- [..]
- What is the size of your organization?
- How many people are involved in addressing issues related to the Host's security/privacy vulnerabilities?
- [..]

Participant Demographics

Criteria	Percentage (%)
Size of organization	
At most 500 employees	61.8
501 to 5000 employees	20.2
5001+ employees	6.7
Prefer not to answer	11.2
Size of The Remediation Team	
Just me	23.6
2 to 10 people	64.0
11 to 20 people	4.5
21+	3.4
Prefer not to answer	4.5

The Survey

- [..]
- Were you previously aware of the vulnerability we detected?
- Have you already remediated, or previously attempted to remediate, the vulnerability we detected?
- If you have not, do you plan to remediate the vulnerability we detected?
- [..]

Results

Criteria	Percentage (%)
Aware $(n = 89)$	
Yes	46% $(n = 41)$
No	51% $(n = 45)$
Prefer not to answer	3% $(n = 3)$
Remediated $(n = 89)$	
Yes	45% $(n = 40)$
No	51% $(n = 45)$
Prefer not to answer	4% $(n = 4)$
Plan to remediate $(n = 45)$	
Yes	67% $(n = 30)$
No	27% $(n = 12)$
Prefer not to answer	6% $(n = 3)$

Results: Quantitative Analysis

Some are FPs

the server acts as a honeypot and does not include vulnerable data

Some other FPs

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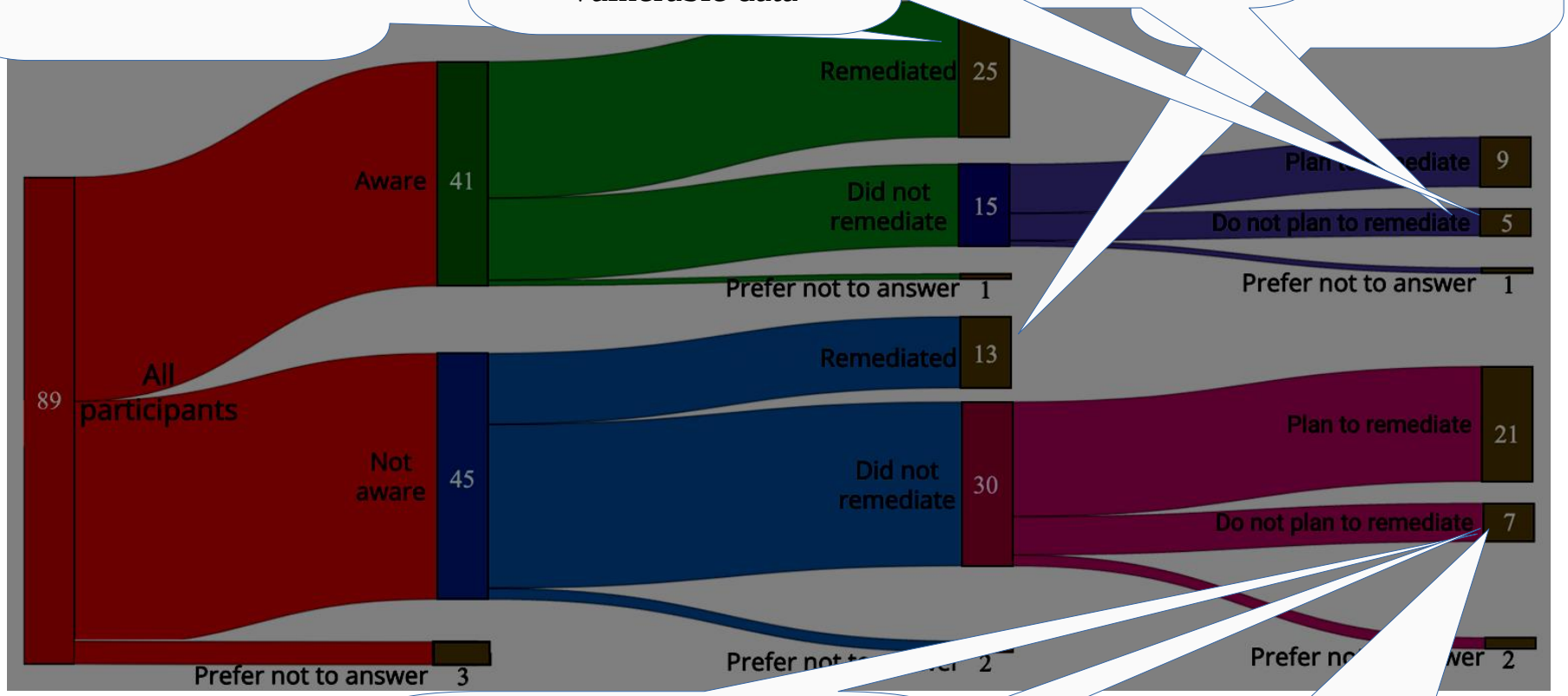
d the survey



the vulnerable server is old

its shutdown is planned

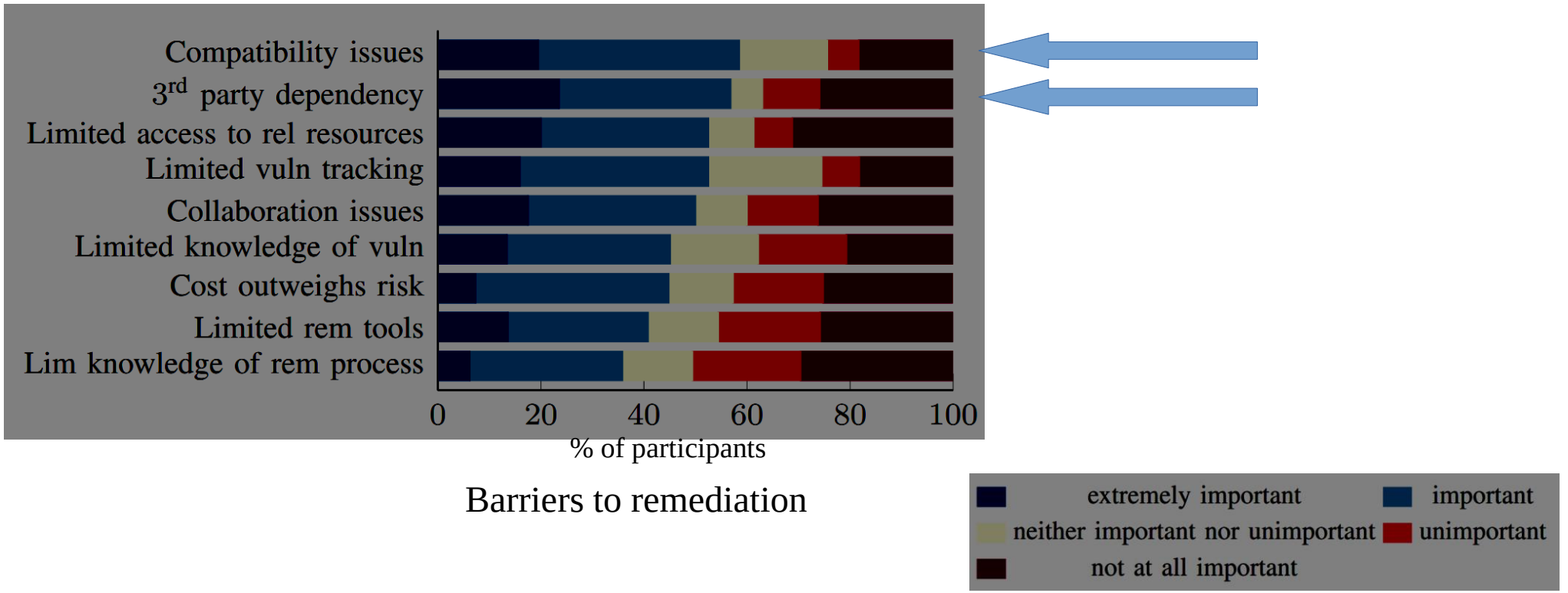
"no one is interested in fixing unused systems on that server"

Results: Quantitative Analysis

- No statistically significant association between awareness and vulnerability remediation response.

The Survey

- Cost of remediation outweighs risk
- Limited knowledge of vulnerability
- Limited knowledge of remediation process
- Issues impending the collaboration between The Remediation Team and other stakeholders
- Limited remediation tools
- Limited vulnerability tracking tools
- Third-party dependencies (e.g. hosting provider, certificate authority)
- Compatibility issues (e.g. backwards compatibility, legacy code, new libraries)
- Limited access to relevant resources that are not controlled by the Remediation Team (e.g. data, tools)



Barriers to remediation

Results: Quantitative Analysis

- We found:
  - statistically significant difference in the importance of different factors for participants.

  - ***Limited knowledge of remediation*** *process* was significantly less important than ***Compatibility issues.***

Results: Quantitative Analysis

- Dividing participants into two groups:
  - those who remediated
  - those who did not
- ... we found a significant difference between factors in both groups
- More data is needed to identify the most important factors for each group.
  - From post-hoc analysis.

Results: Quantitative Analysis

- Influential parameters for: awareness, remediation, remediation barriers
  - Organization size.
    - LEs more likely **aware** of vulnerability vs SMEs.
  - Vuln. Severity.
    - vulnerabilities with L-M severity levels more likely to have negative **remediation** response.
    - For the H-C group, Compatibility issues significantly more important than Limited knowledge of **remediation** process.
  - Size of admin team.
    - *"Issues impeding the collaboration within the remediation team or with other stakeholders"* was more important for bigger teams.

Results: Qualitative Analysis

- We identified 6 themes from open-ended responses
  - Lack of control over the vulnerable system.
  - Politics.
  - Benefit does not outweigh the cost.
  - Limited resources.
  - Complex remediation processes.
  - Legacy systems.

Results: Qualitative Analysis

- We identified 6 themes from open-ended responses
  - Lack of control over the vulnerable system.
    - *"[..] once we notify the responsible party of the vulnerability we allow 24 hours to remediate before traffic to the affected IP address will be blocked until remediation is completed."*
  - Politics.
  - Benefit does not outweigh the cost.
  - Limited resources.
  - Complex remediation processes.
  - Legacy systems.

Results: Qualitative Analysis

- We identified 6 themes from open-ended responses
  - Lack of control over the vulnerable system.
  - Politics.
    - having to go through bureaucratic processes with other departments
    - having to convince management and other stakeholders of the importance of remediating vulnerabilities.
    - *"Political/Business Infrastructure supportive of time and personnel [is an] extremely important [factor]"*.
  - Benefit does not outweigh the cost.
  - Limited resources.
  - Complex remediation processes.
  - Legacy systems.

Results: Qualitative Analysis

- We identified 6 themes from open-ended responses
  - Lack of control over the vulnerable system.
  - Politics.
  - Benefit does not outweigh the cost.
    - the impact of the remediation process on existing services (e.g., downtime).
    - the perceived risk and expected losses from a vulnerability exploitation.
    - their plans to decommission old vulnerable servers.
  - Limited resources.
  - Complex remediation processes.
  - Legacy systems.

Results: Qualitative Analysis

- We identified 6 themes from open-ended responses
  - Lack of control over the vulnerable system.
  - Politics.
  - Benefit does not outweigh the cost.
  - Limited resources.
    - lack of time to keep servers updated. lack of personnel. unavailability of vendor patches. lack of documentation from previous admins
      - *“I am the network administrator. The administrator of this system recently died. I was not completely aware that this server had a public network exposure [...]”.*
  - Complex remediation processes.
  - Legacy systems.

Conclusion: RQ1

- No one-size fits all solution.
  - no evidence that awareness of the existence of a vulnerability affects remediation plans
    - Demystifies results in previous literature.

Conclusion: RQ2

- Compatibility issues were more important than limited knowledge of remediation process.
- For L-M severity, we found that participants are more likely to have negative response to remediation.
- For company sizes
  - the importance of factors **does not** change with company size.
  - LEs are more likely to be aware than SMEs.
- Other factors that influence remediation decisions include politics, benefit vs cost, limited resources, and the maintenance of legacy systems.

Thank You!

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