Freezing the Web: A Study of ReDoS Vulnerabilities in JavaScript-based Web Servers

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TU Darmstadt

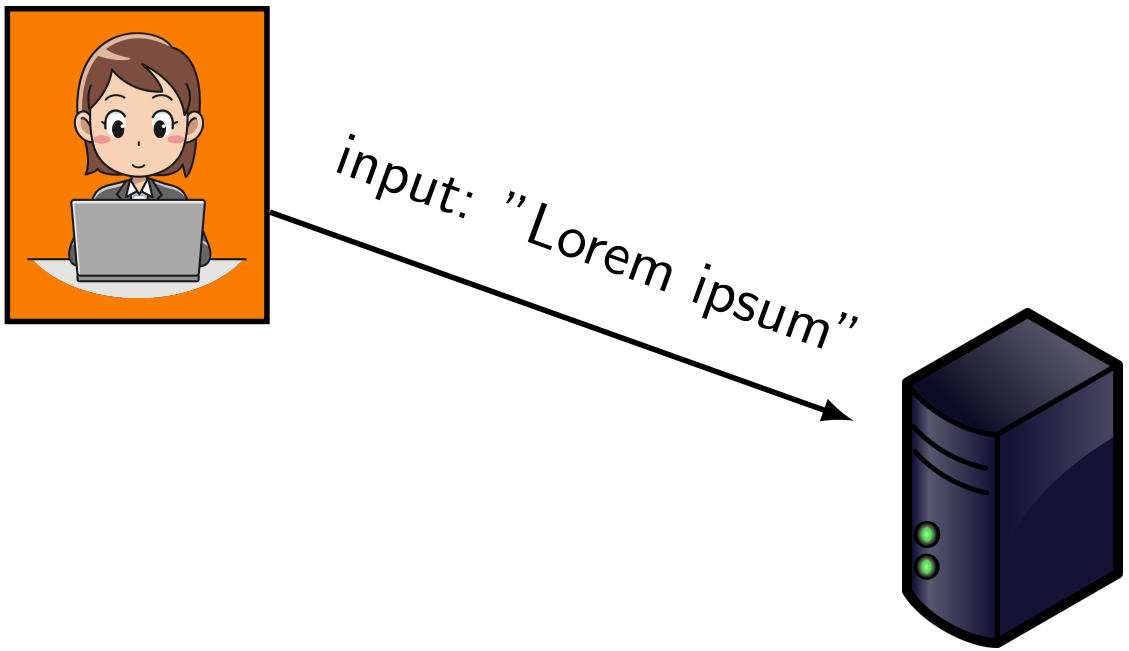
www.software-lab.org

15th August 2018

TECHNISCHE UNIVERSITÄT DARMSTADT

SOLA SoftwareLab

Regular Expression Denial of Service (ReDoS)



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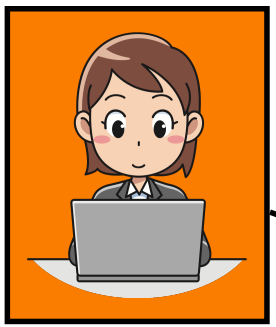

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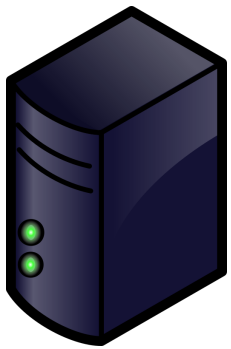

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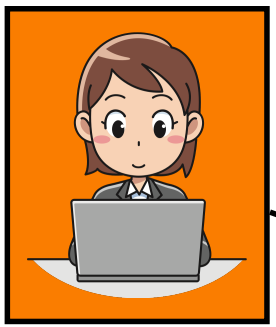

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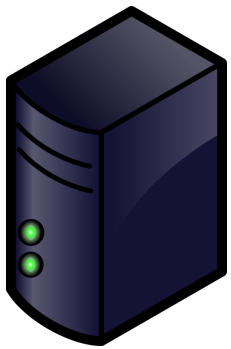

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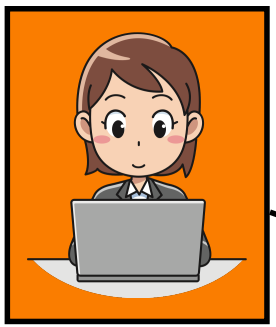

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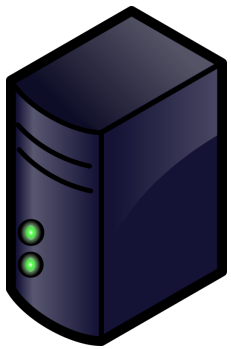

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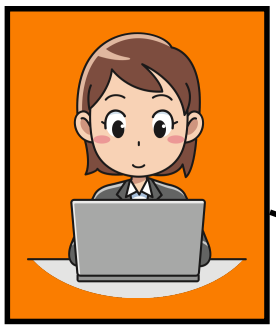

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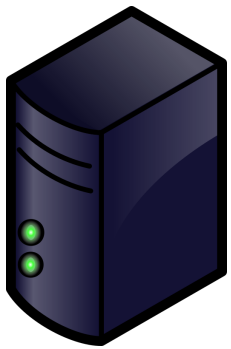
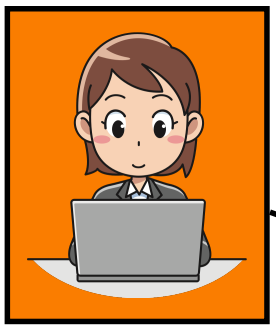


input.match(regexp);

input: "ǎóÁs̩" × 1000

Regular Expression Denial of Service (ReDoS)



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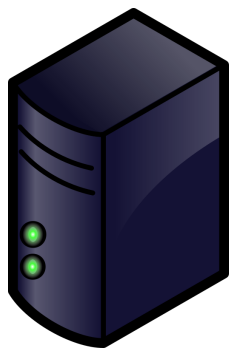

input.match(regexp);

input: "ăóÁș" x 1000

processing time: $\mathcal{O}(n^x), x > 1$

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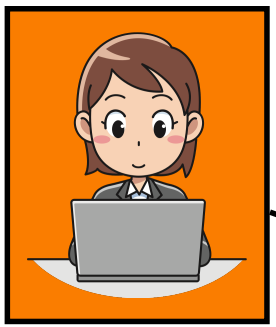

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we identify 25 vulnerabilities in popular npm modules

This Talk

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ReDoS affects websites

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Novel methodology

library vulnerability $\rightarrow$ website vulnerability

Backtracking-based Matching

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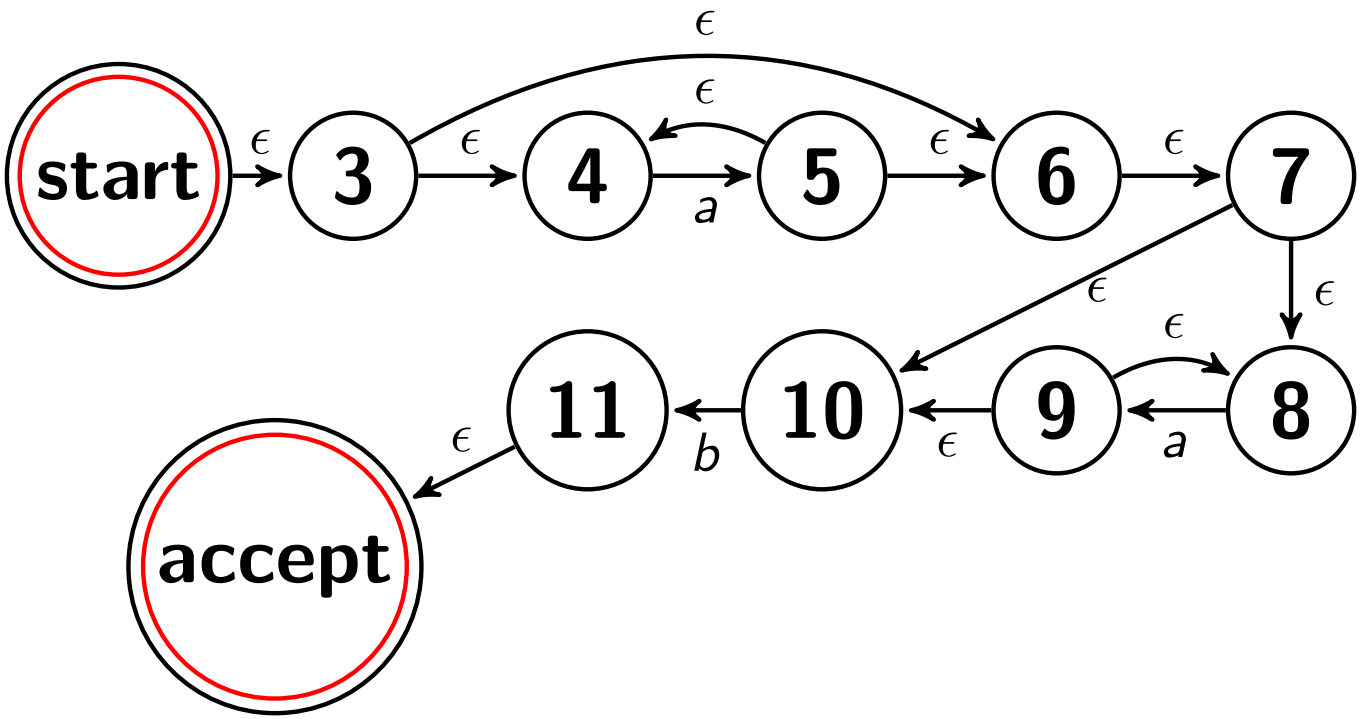

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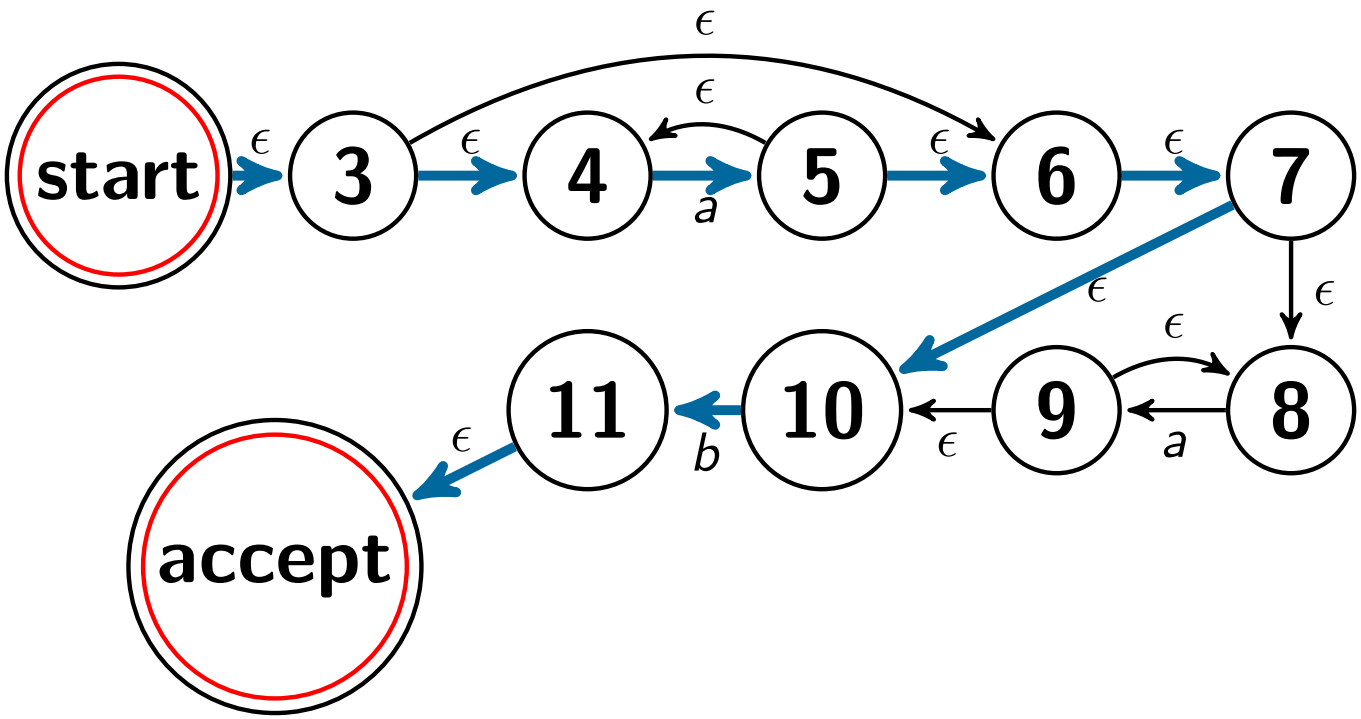

input: "ab"

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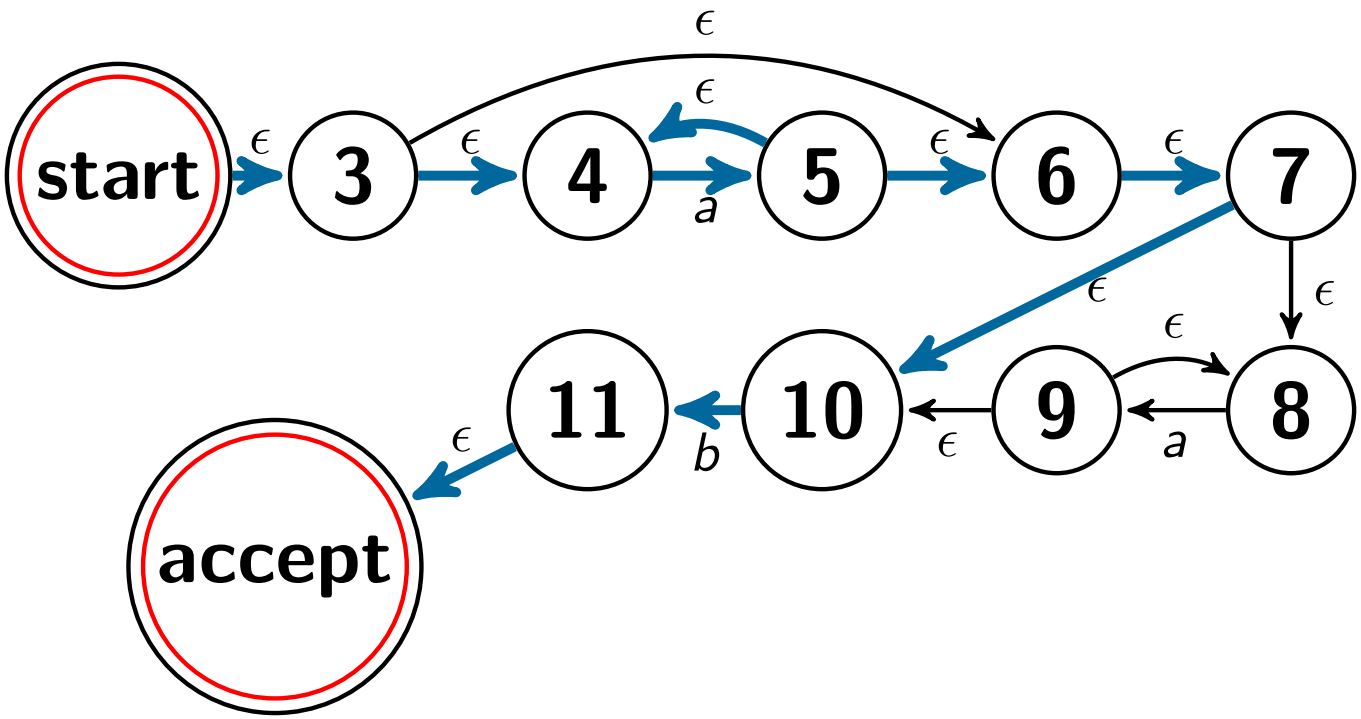

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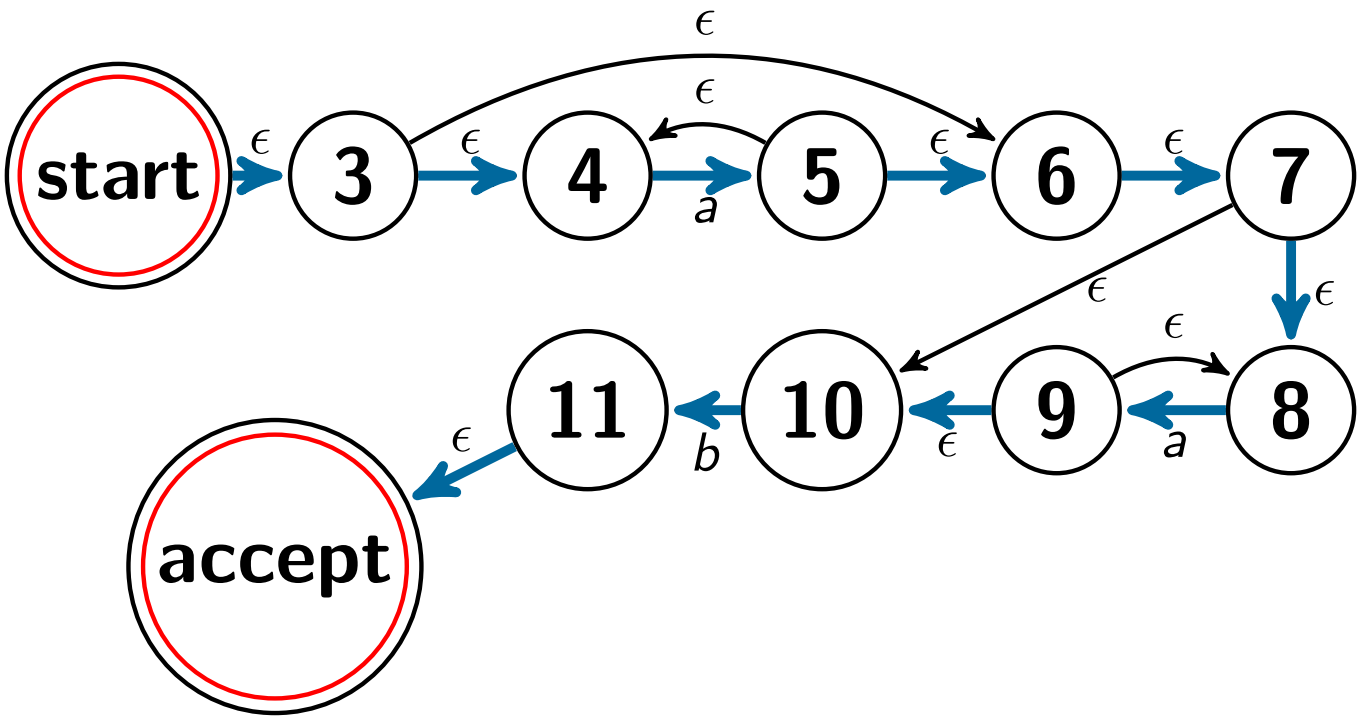

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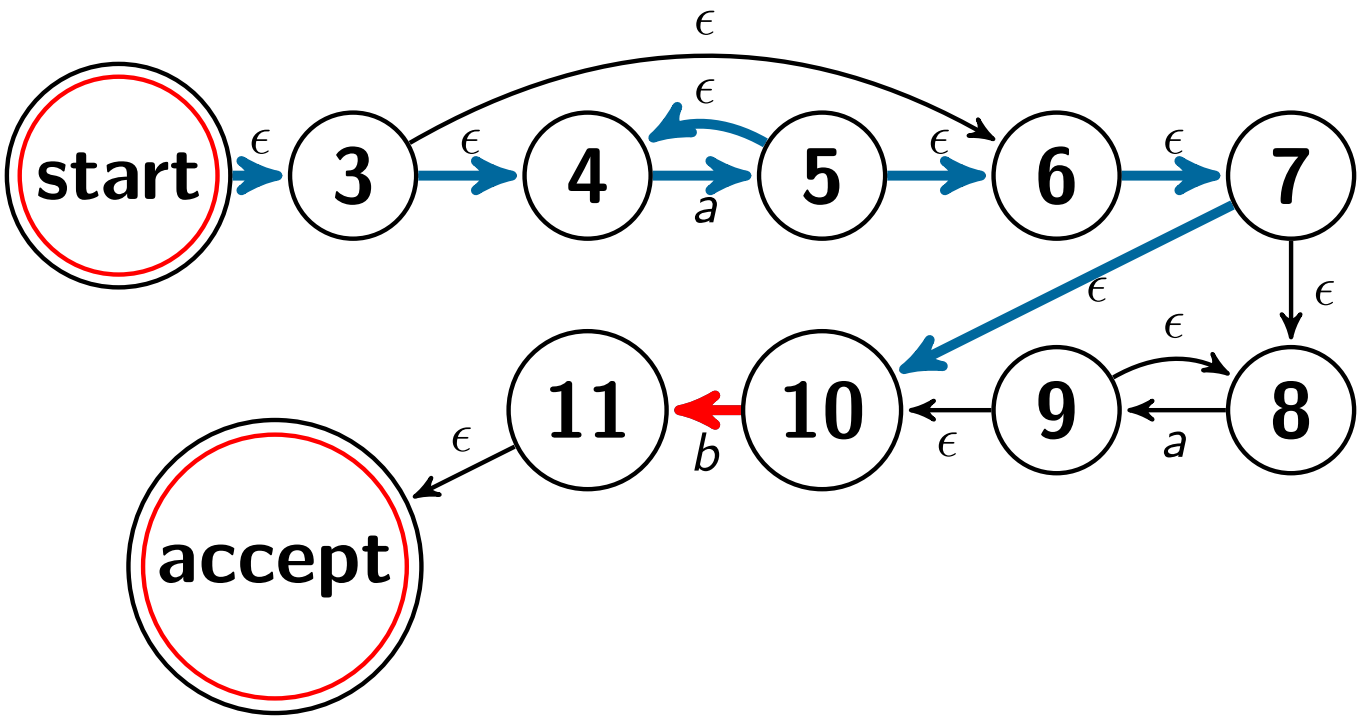

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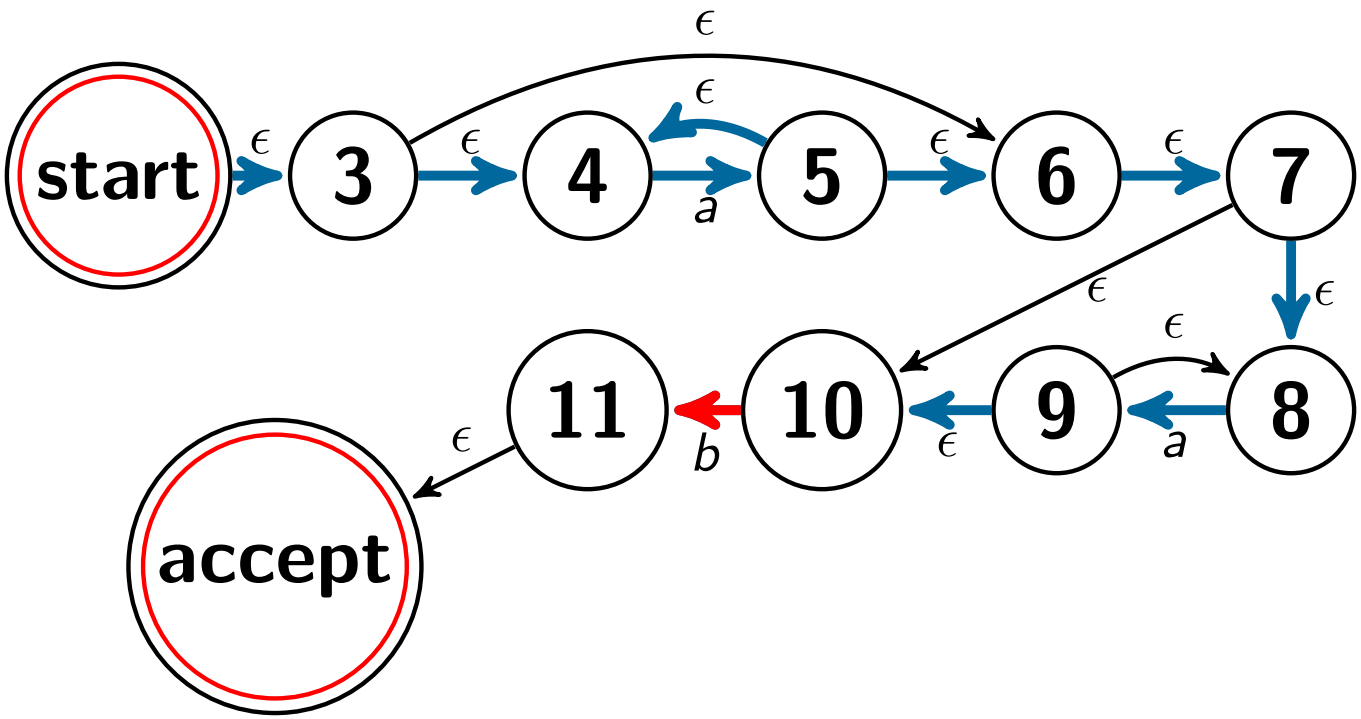

input: "aaaaaaaaaaaaaaaaaaaa"

Overview

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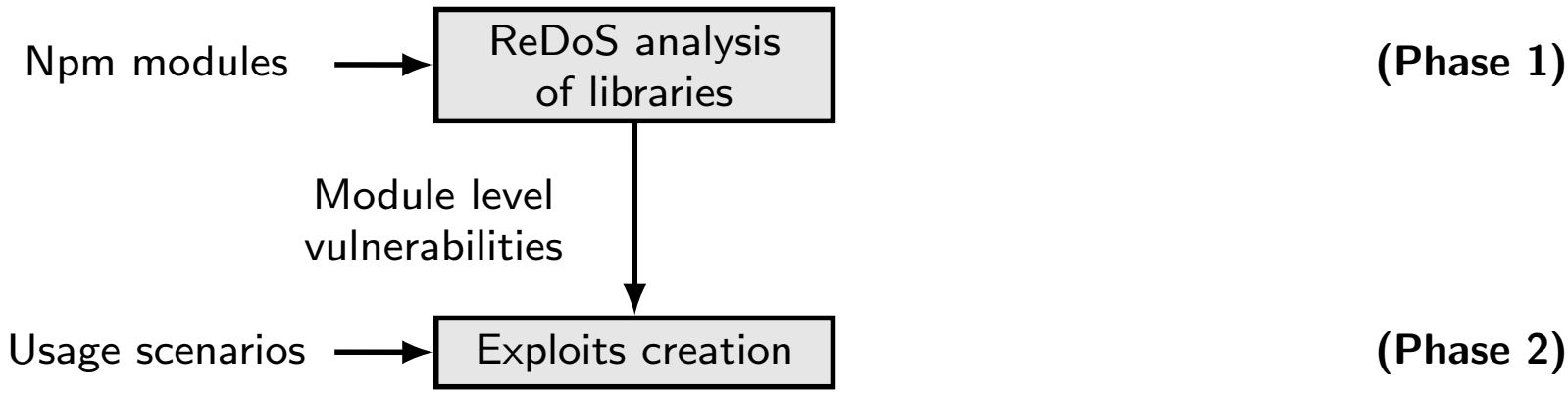
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ReDoS analysis of libraries
(Phase 1)
Module level vulnerabilities
Usage scenarios
Exploits creation
(Phase 2)

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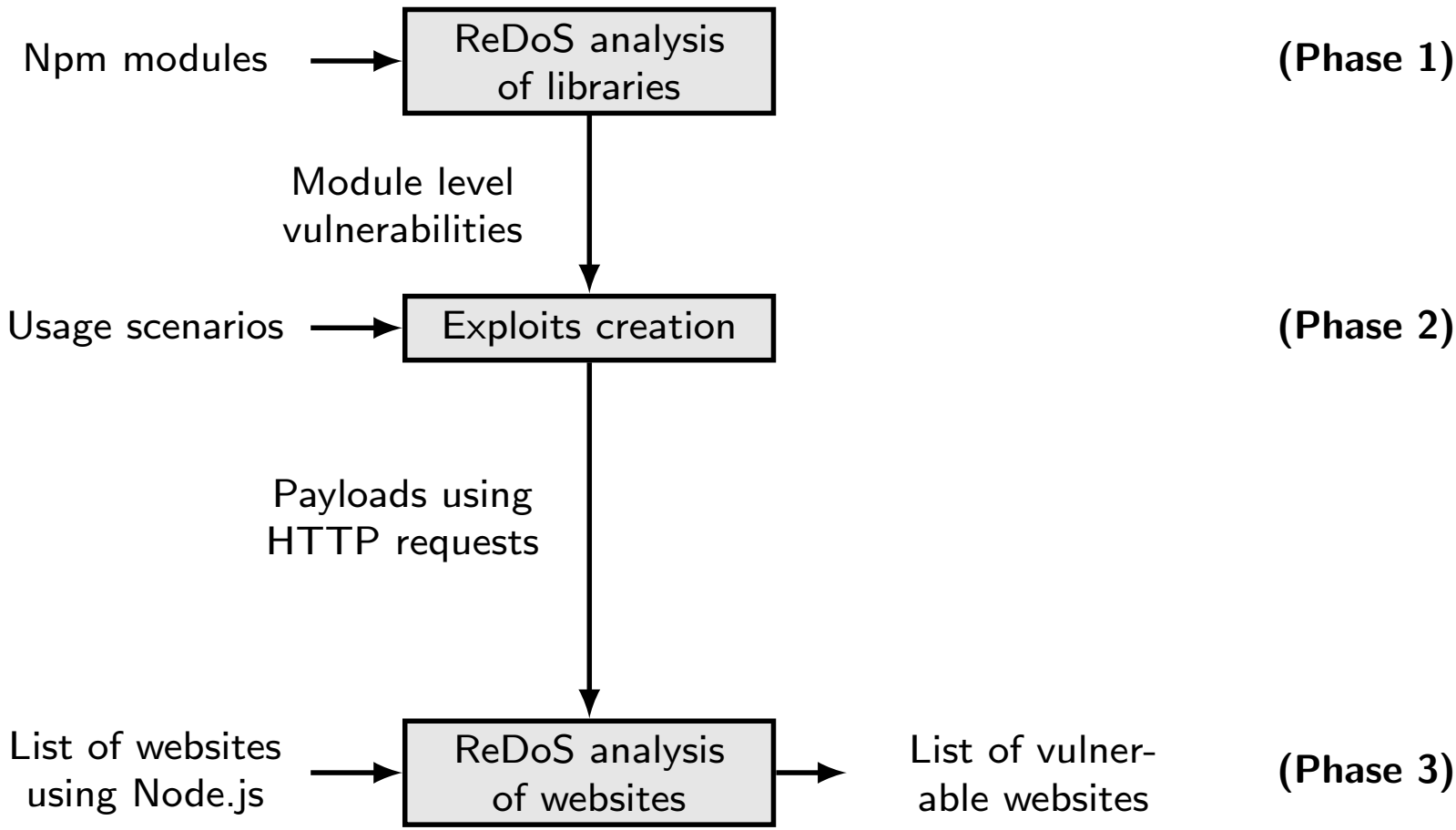
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List of websites using Node.js
ReDoS analysis of websites
List of vulnerable websites
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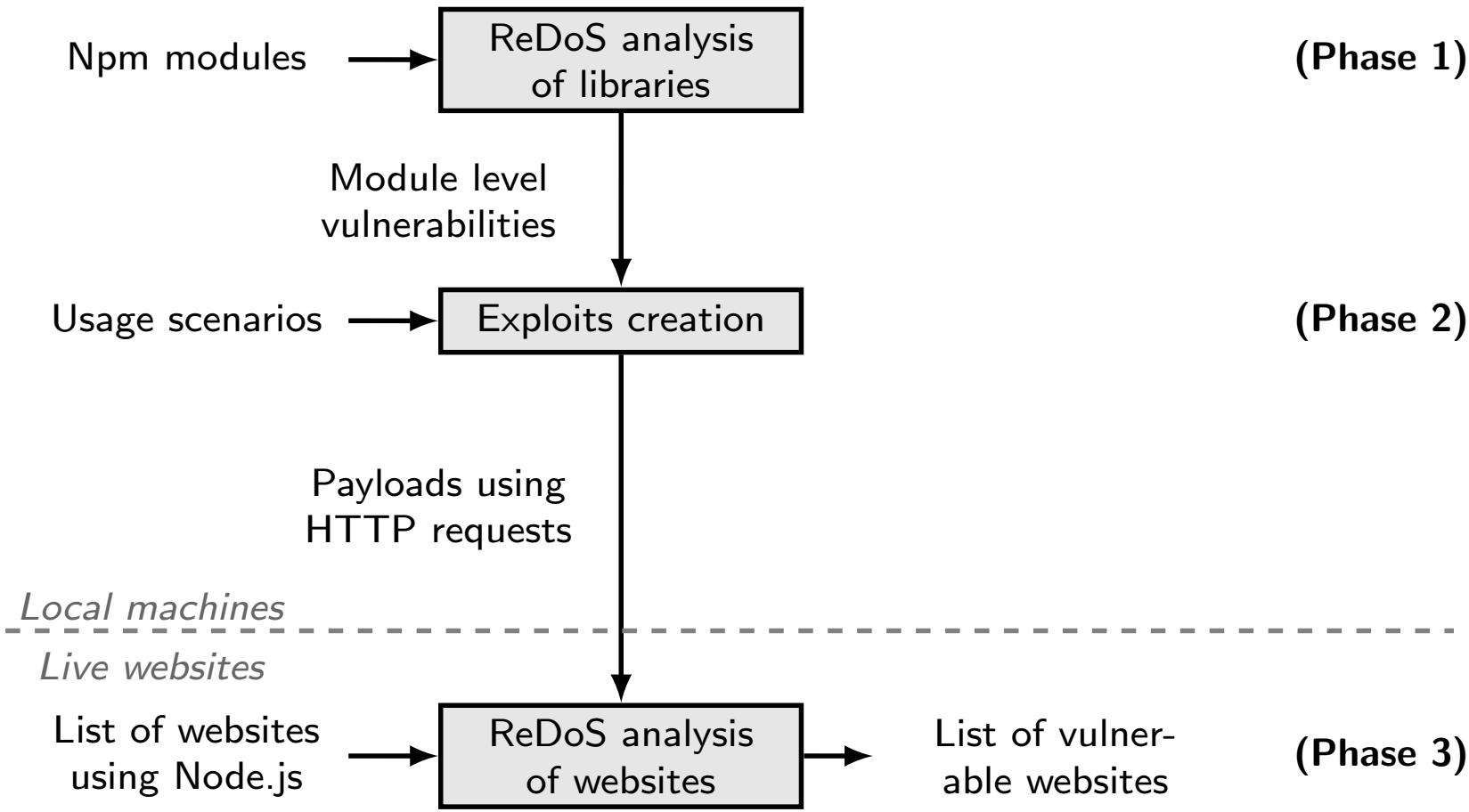
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Setup

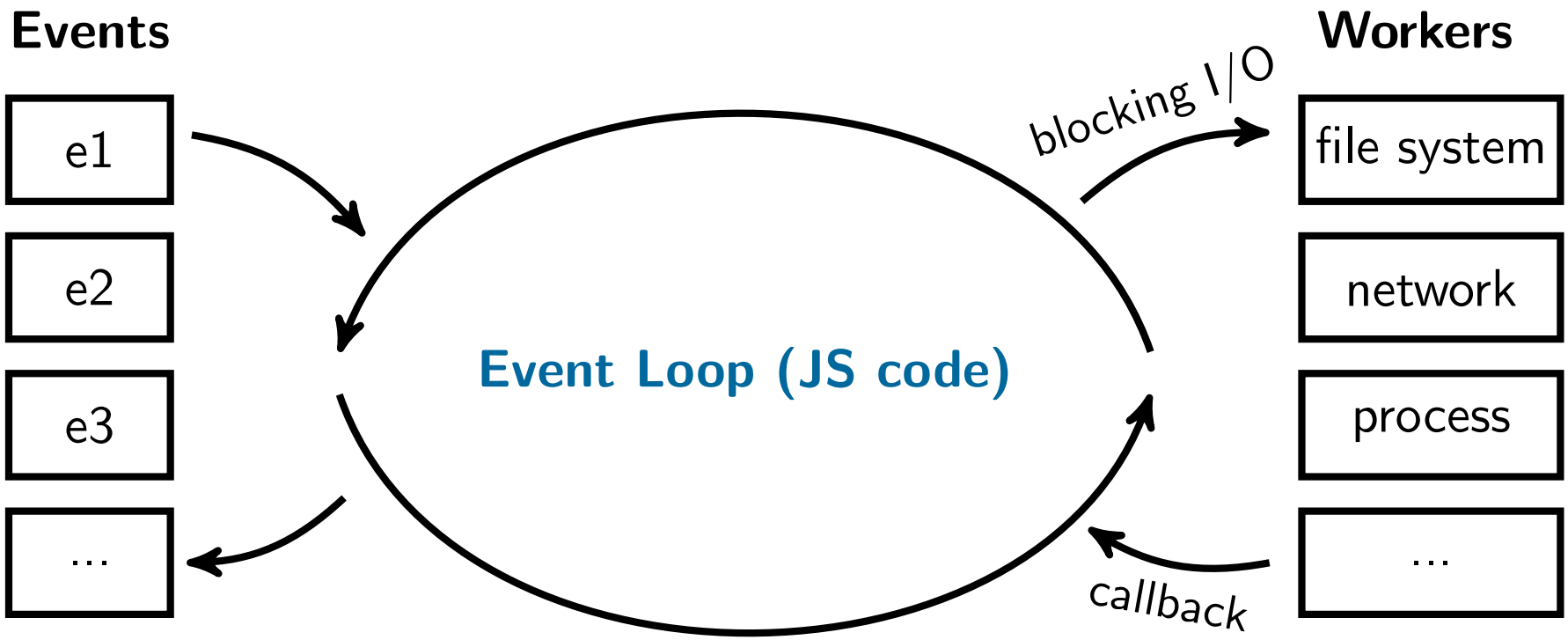
measure in single instance setup

manually analyze popular packages

analyze 2,800 websites from Top 1 million

fifth most-dependent upon npm package

Node.js Particularities



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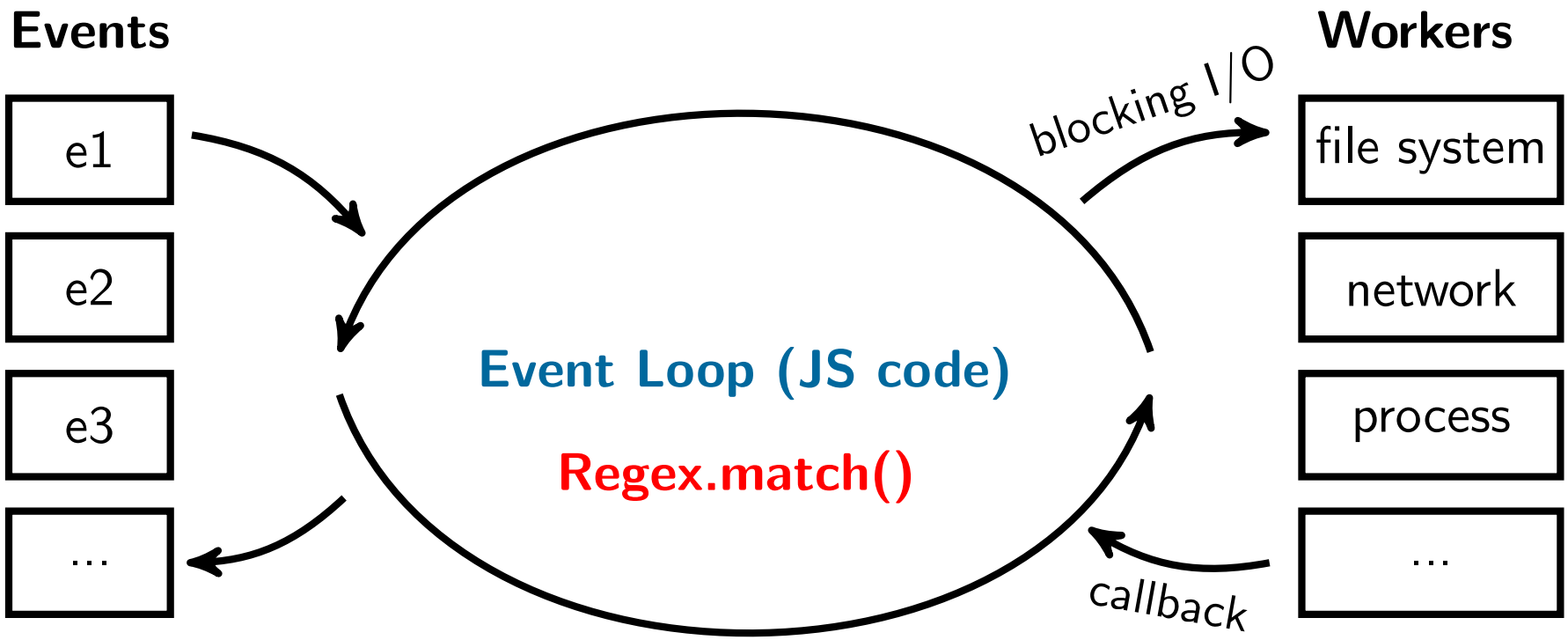
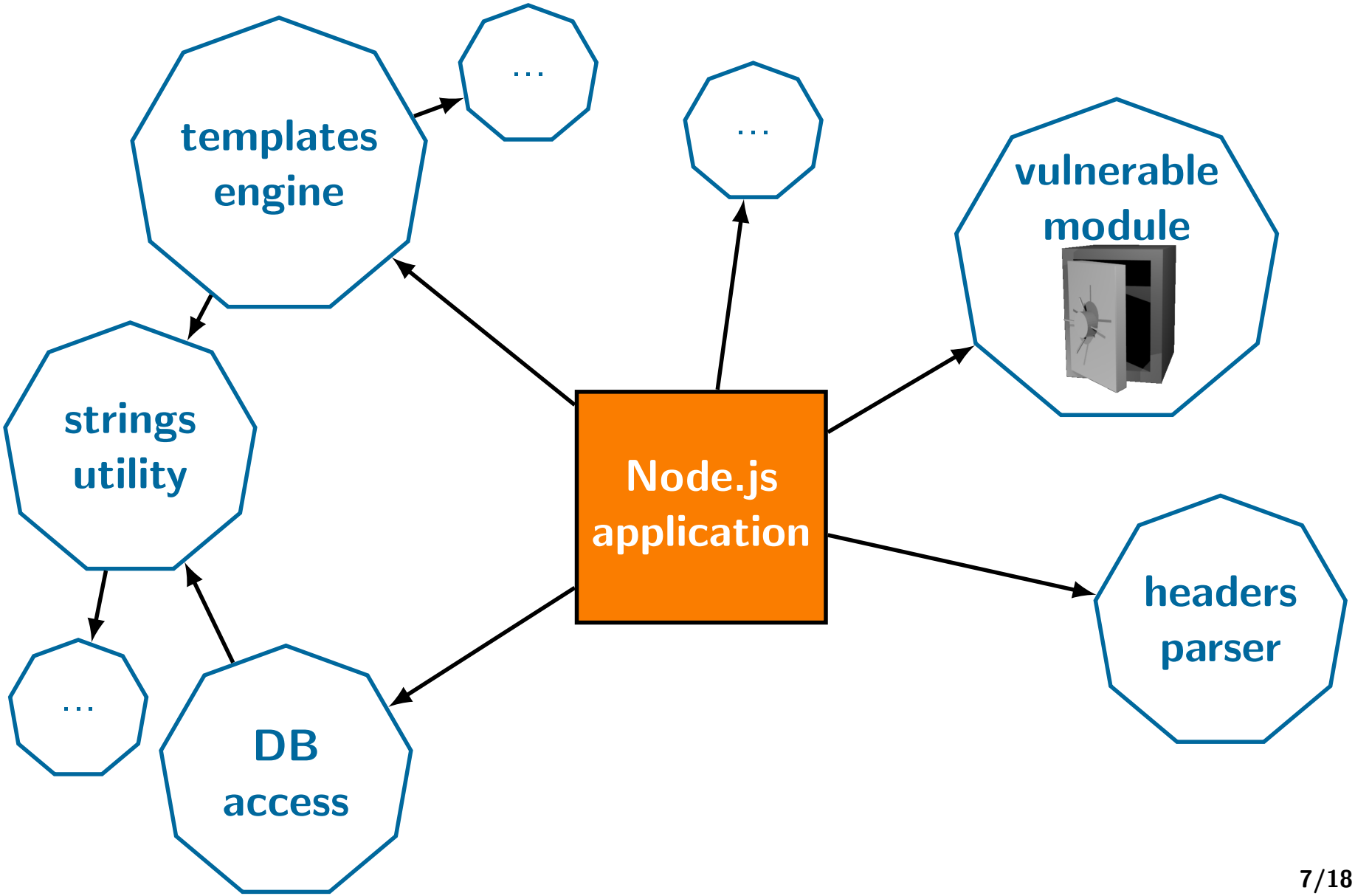


Node.js Particularities (2)



Ethical Considerations

Few payloads

80 requests in total

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Vulnerabilities disclosure

the majority of them have been fixed

Phase 1: Npm Analysis

Criterion for vulnerable libraries

We consider a module to be vulnerable iff we find an input that

- is at most 80,000 characters long,
- whose **matching time takes more than 5 seconds.**

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- Manual analysis of regular expressions and information flow
- Manually written exploits

Phase 1: Vulnerable Regular Expressions

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- **Example 1**: content

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/^([^\/]+\/[^\s;]+)(?:(?:\s*;\s*boundary=(?:"([^"
    ]+)"|([^;"]+)))|(?:\s*;\s*[^=]+=(?:(?:"(?:[^"
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```

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```

- **Example 2**: ua-parser-js

```
/ip[honead]+(.*os\s([\w]+)*\slike\smac|;\sopera)/
```

Phase 2: HTTP-level Payload Creation

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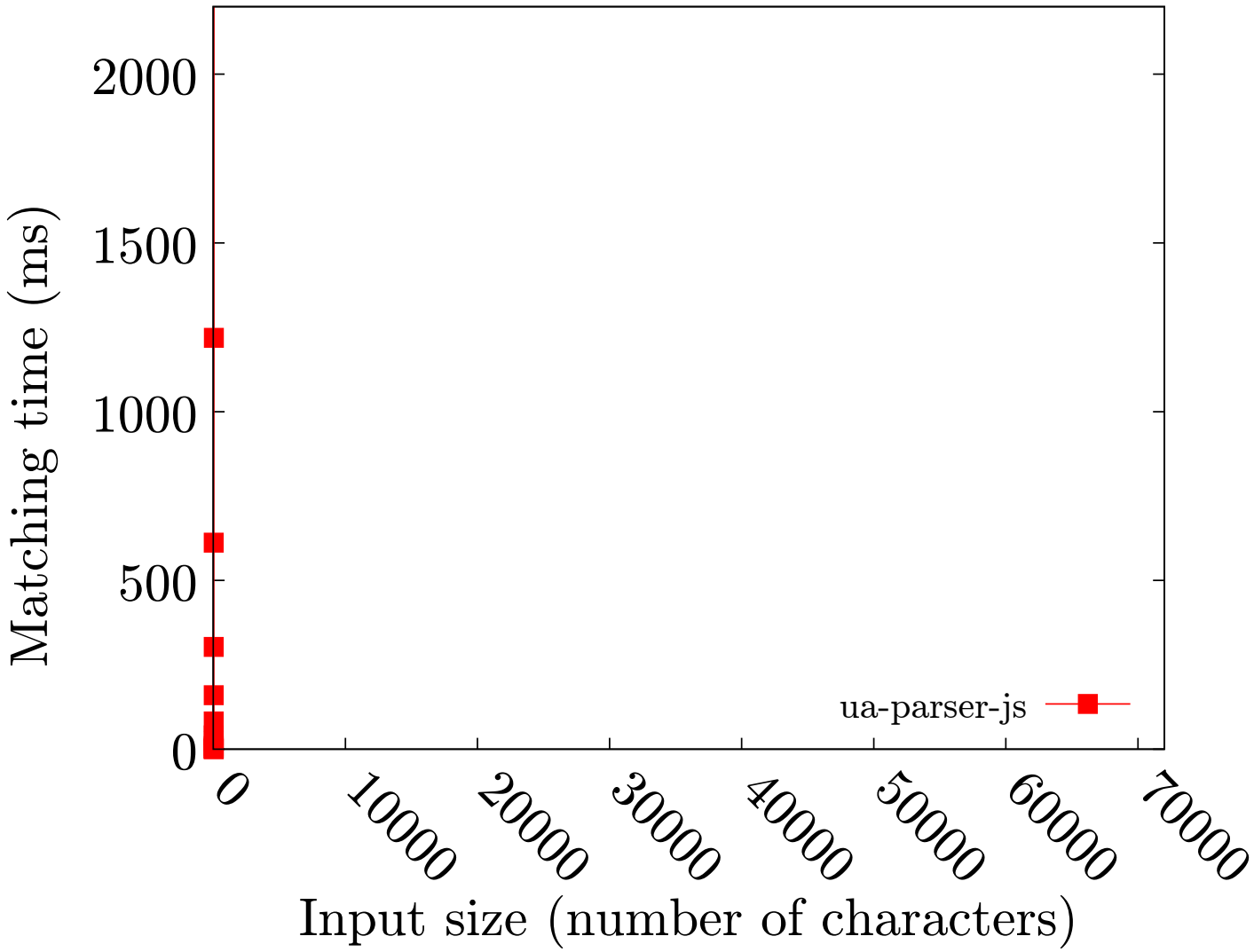
- In total **8 payloads** corresponding to 8 popular modules

Phase 2: Input Dependency



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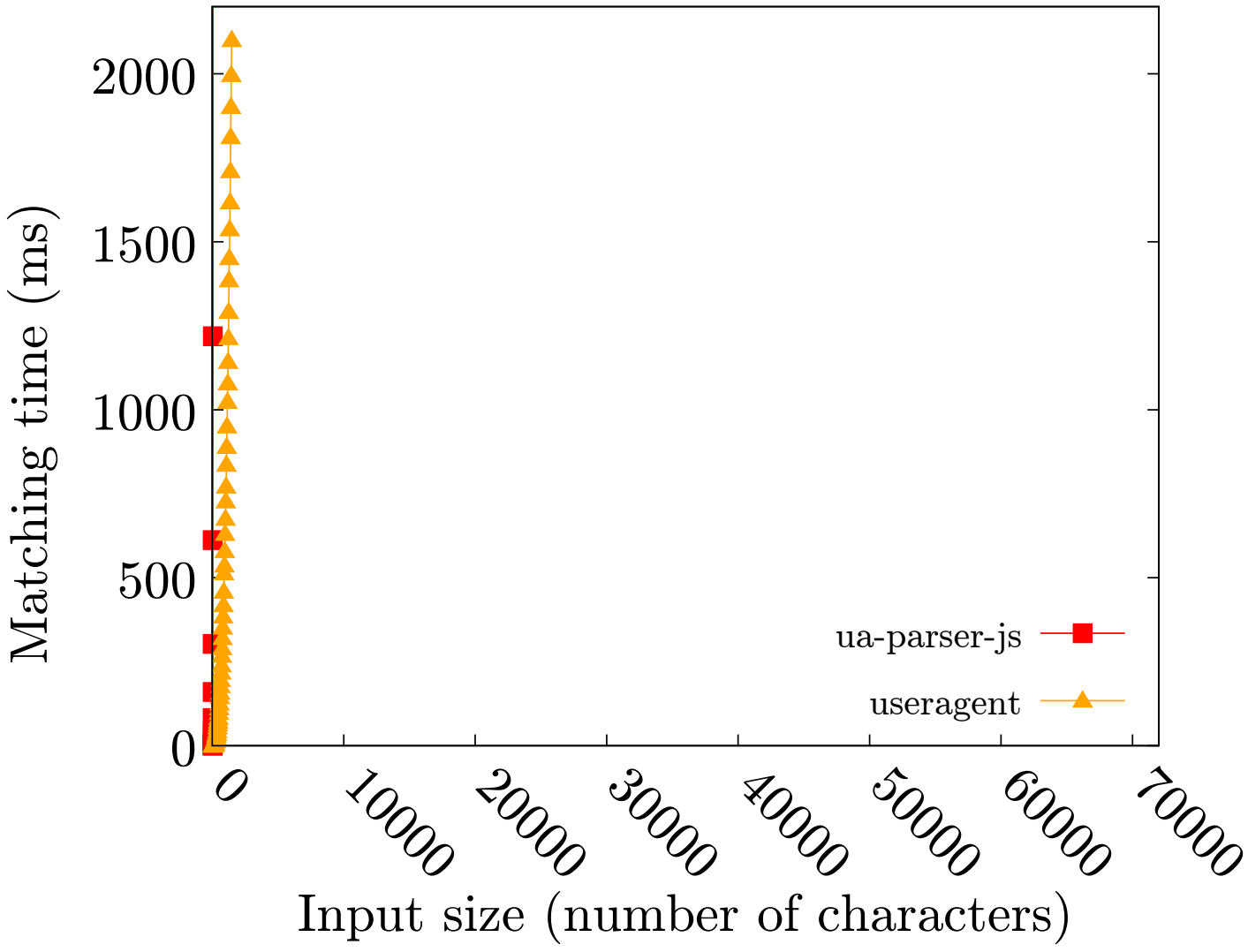

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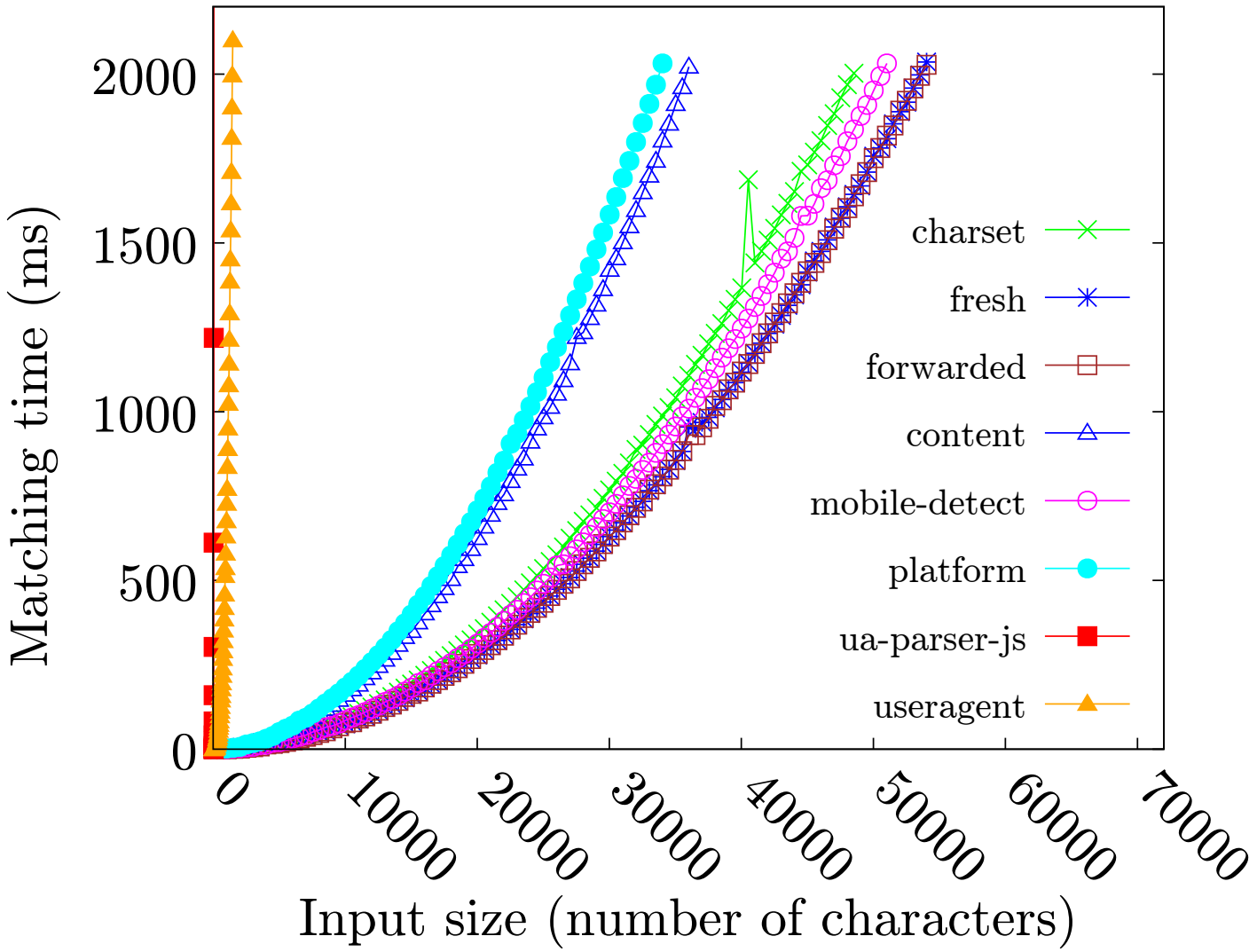

Phase 3: Websites Analysis

P1

100ms

3x 5x

3x 5x

Phase 3: Websites Analysis

P1		**P2**	
100ms		200ms	
3x	5x	3x	5x
3x	5x	3x	5x

Phase 3: Websites Analysis

P1	**P2**	**P3**	**P4**	**P5**
100ms	200ms	500ms	1s	2s
3x 5x	3x 5x	3x 5x	3x 5x	3x 5x
3x 5x	3x 5x	3x 5x	3x 5x	3x 5x

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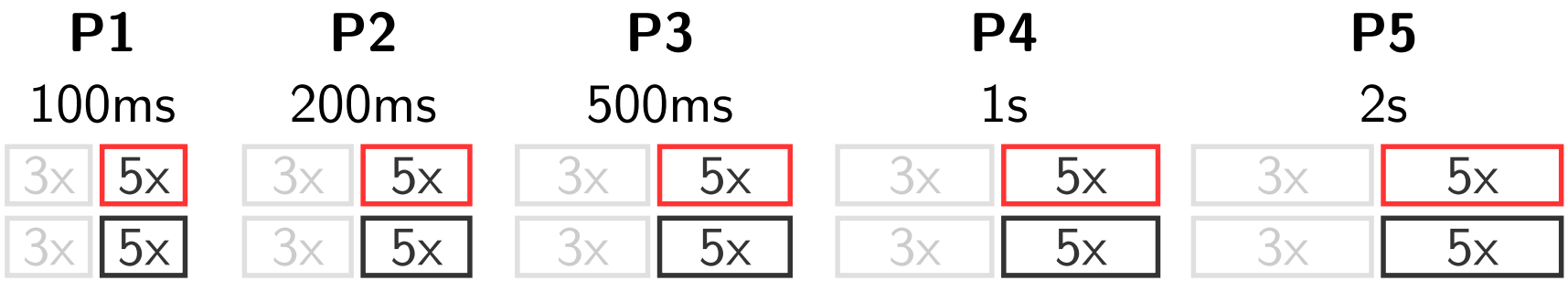
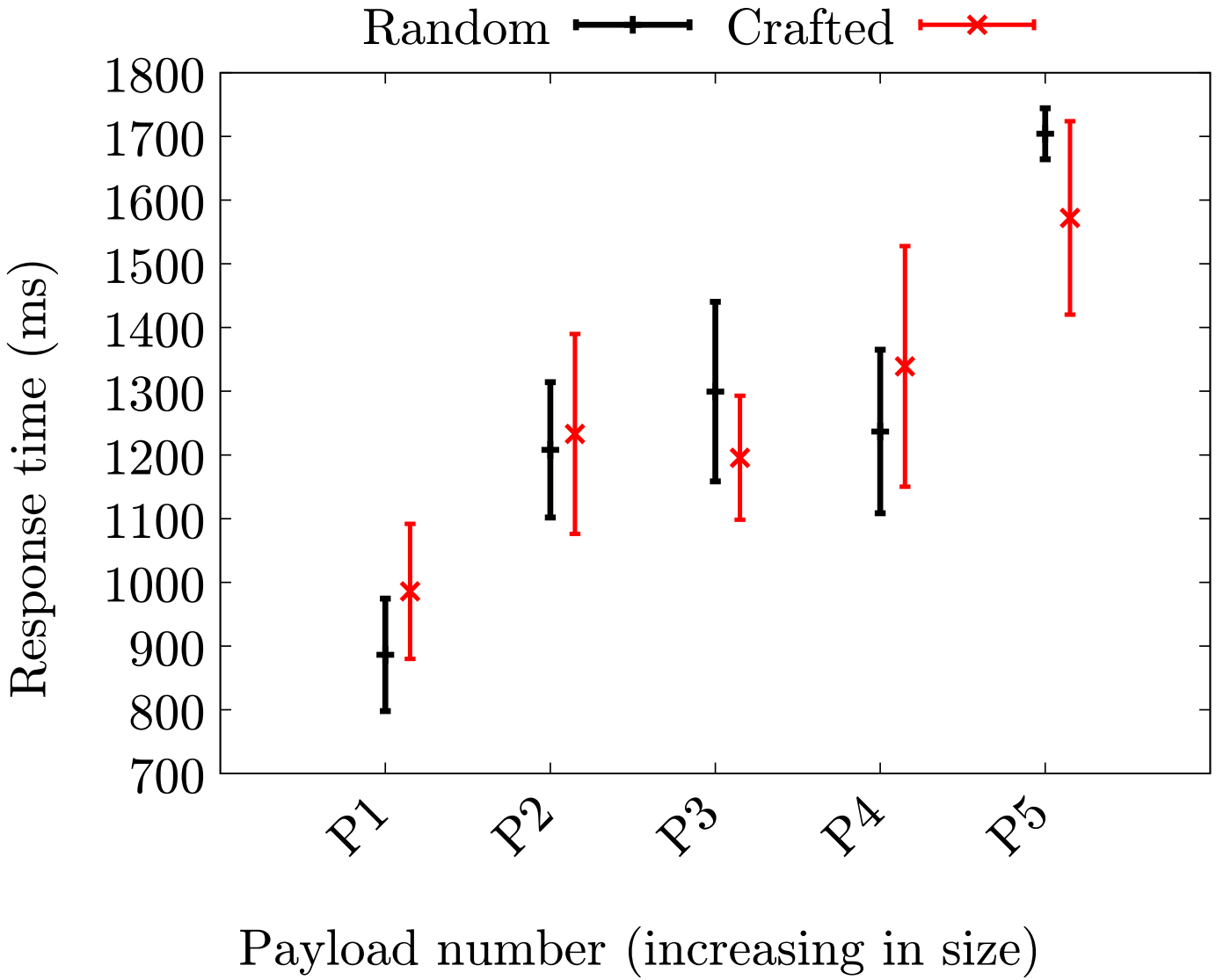


Criterion for vulnerable websites

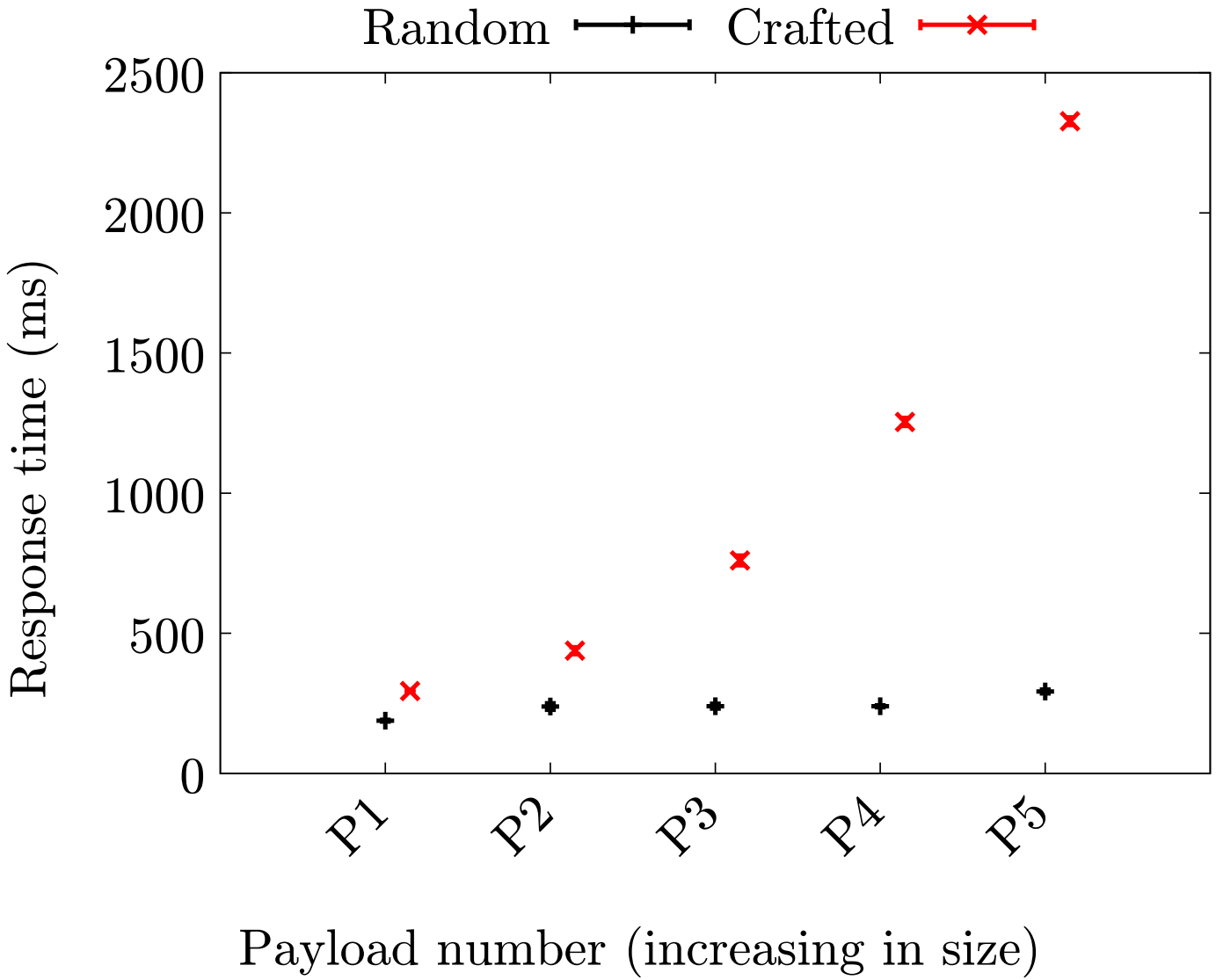
We consider a website to be vulnerable iff:

- statistically significant difference between the response times to **random** and **crafted** inputs,
- this difference increases when the input size increases.

Phase 3: Response Time of a Non-Vulnerable Website



Phase 3: Response Time of a Vulnerable Website

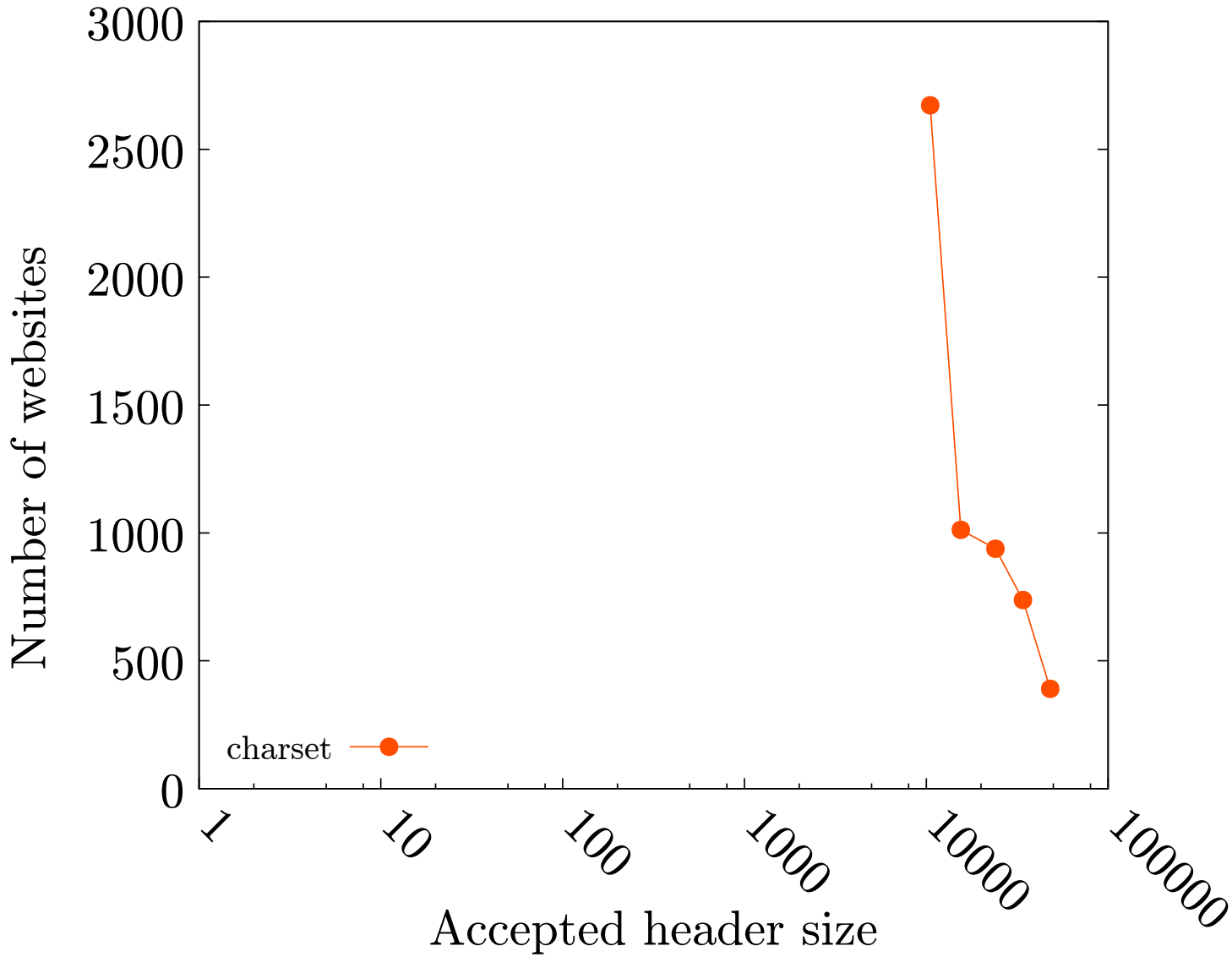


Phase 3: Number of Vulnerable Websites

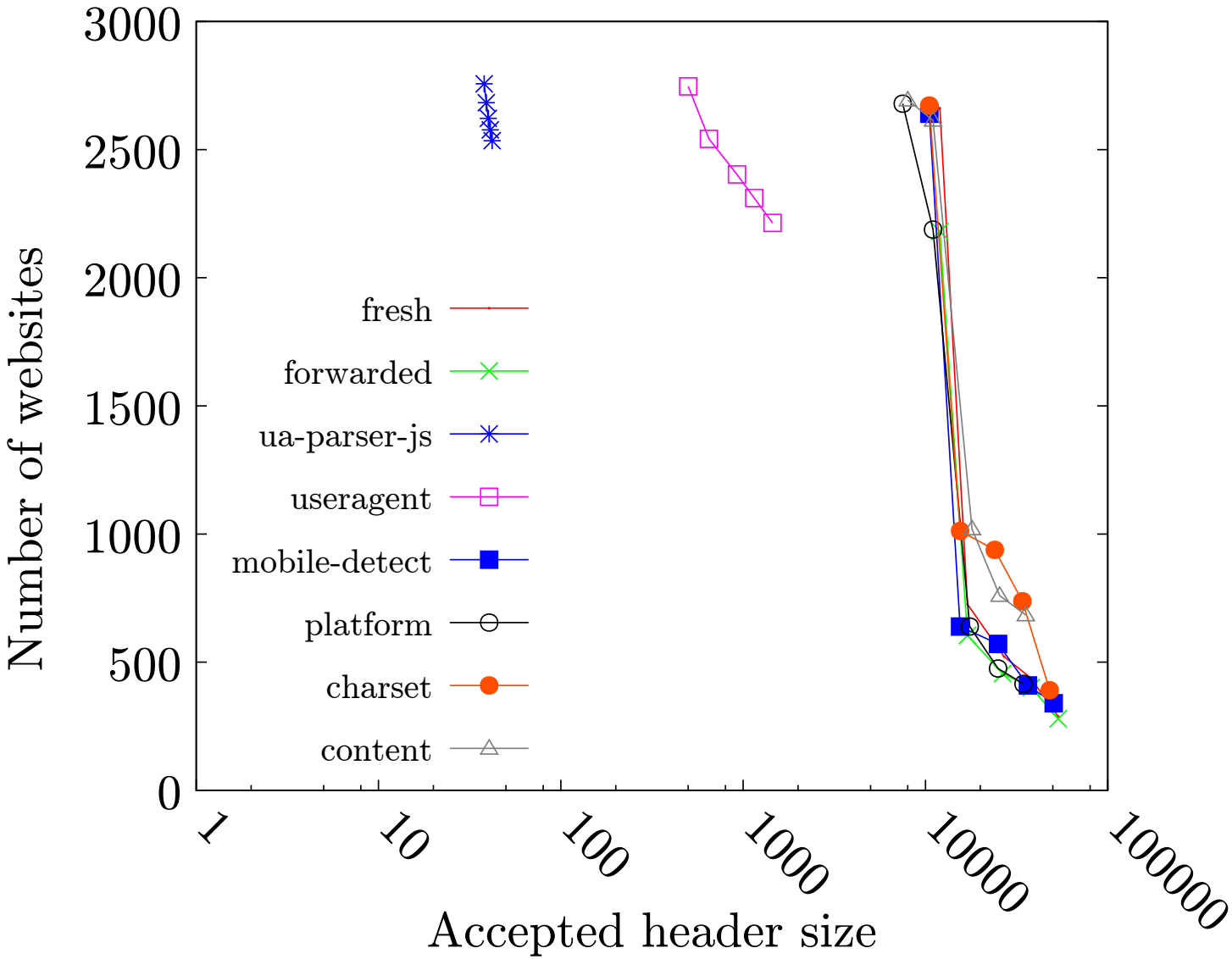
Exploit	Number of sites affected
fresh	241
forwarded	99
ua-parser-js	41
useragent	16
mobile-detect	9
platform	8
charset	3
content	0

In total: 339 (11%) websites are vulnerable

Defenses


3000
2500
2000
1500
1000
500
0
Number of websites
charset
1
10
100
1000
10000
100000
Accepted header size

Defenses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Defenses (2)

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  Rust programming language
- **Timeout on matching regular expressions**
  [Davis et al., USENIX Security, 2018], .NET framework
- **Tooling support for identifying ReDoS**
  Java programming language [Wüstholz et al., TACAS, 2017]

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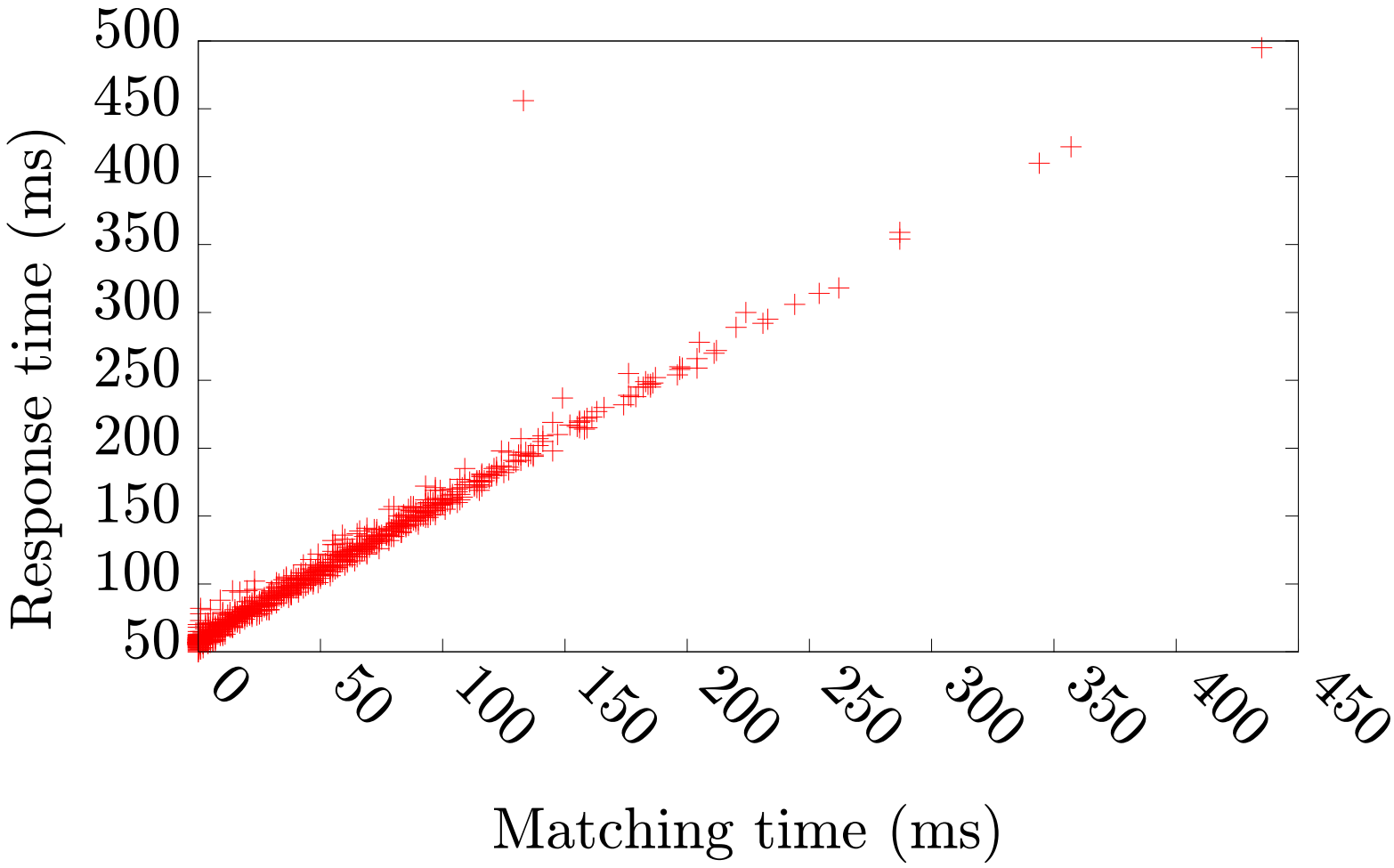
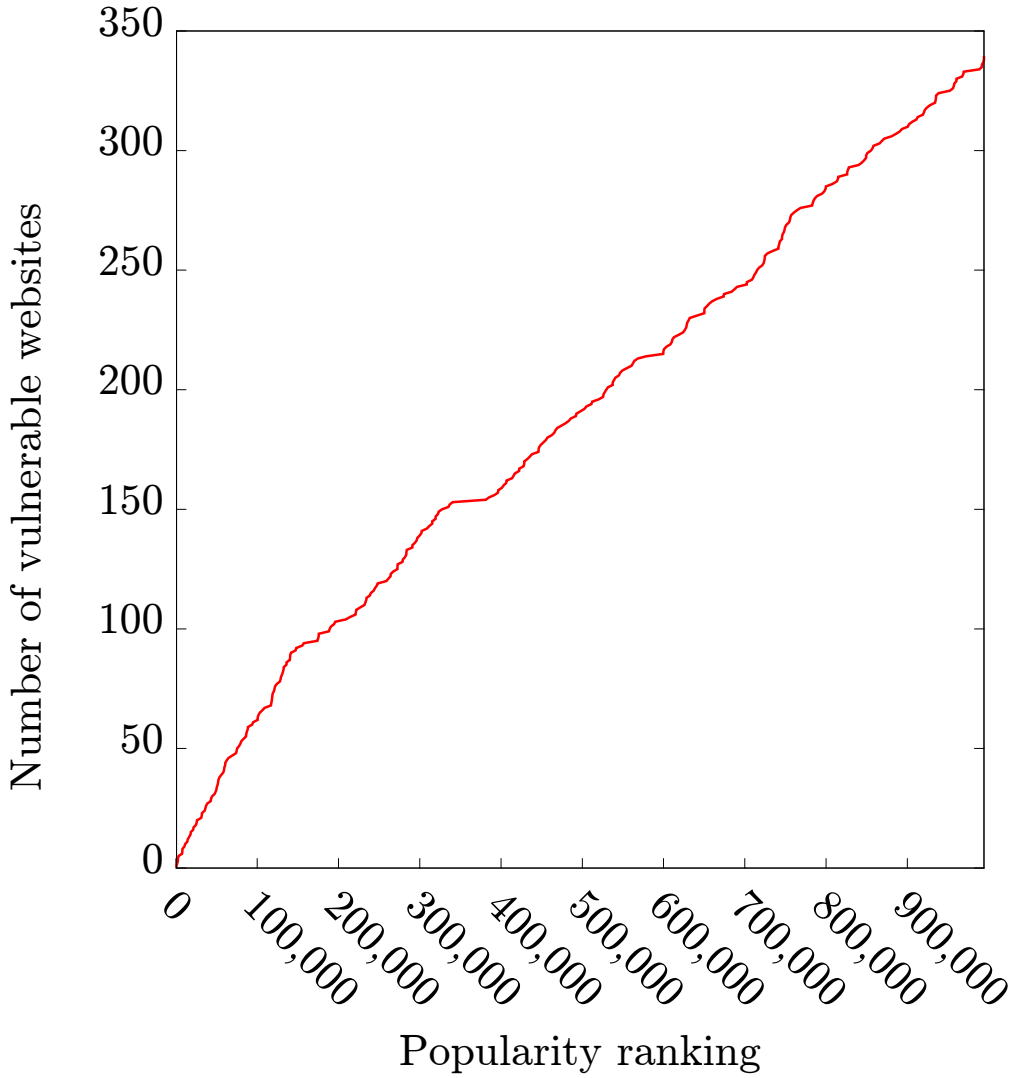
Is Response Time a Good Estimator?



Popularity of Vulnerable Websites



Dimensioning Payloads

Module	P1 100ms	P2 200ms	P3 500ms	P4 1s	P5 2s
fresh	12,000	17,000	27,000	37,500	**53,500**
forwarded	12,000	17,000	26,500	38,000	53,500
useragent	500	650	925	1,150	1,450
ua-parser-js	**38**	**39**	**40**	**41**	**42**
mobile-detect	10,500	15,500	25,000	36,500	50,500
platform	7,500	11,000	17,500	25,000	34,500
charset	10,500	15,500	24,000	34,000	48,000
content	8,000	11,000	18,000	25,500	35,500