SecBench.js

An Executable Security Benchmark Suite for Server-Side JavaScript

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Why Do We Want Benchmarks?

- **Fuels progress in a research community**
  - E.g., MNIST in machine learning, SPEC CPU in compilers
- **Avoids duplicate work**
  - Gathering and setting up a dataset takes time
- **Makes approaches comparable**
  - Head-to-head comparison, instead of “we believe we are better because ...”

Focus: JavaScript Vulnerabilities

- **Scope**
  - JavaScript packages on npm
  - Server-side code
  - Vulnerable (not malicious) code
- **Importance**
  - $>$ 2 million npm packages
  - Thousands of vulnerabilities
  - Dozens of new vulnerability-related techniques each year

Example: Command Injection

Vulnerable code (bestzip package):

```
const command = `zip --quiet --recurse-paths ${
      options.destination
    } ${sources}`;
const zipProcess = cp.exec(command, {
      stdio: "inherit",
      cwd: options.cwd
    });
```

Untrusted string becomes part of an OS-level command

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Untrusted string becomes part of an OS-level command

Attack code:

```
zip({
    source: "",
    destination: "./; touch bestzip",
  })
```

Attacker can execute arbitrary commands

Desired Properties of a Benchmark

- Realistic
- Executable
- Two-sided
- Vetted

Desired Properties of a Benchmark

- **Realistic** →
- **Executable**
- **Two-sided**
- **Vetted**

- Diverse, real-world software
- Unmodified code
- Why?
  - Success on benchmark

    ⇒ Success on reality

Desired Properties of a Benchmark

- **Realistic**
- **Executable** →
- **Two-sided**
- **Vetted**

- Proof-of-concept attack that exploits the vulnerability
- Why?
  - Evidence that exploitable
  - Basis for evaluating mitigation techniques

Desired Properties of a Benchmark

- **Realistic**
- **Executable**
- **Two-sided** →
- **Vetted**

- Both vulnerable and fixed code
- Why?
  - Evaluate false positives
  - Study and learn from fixes

Desired Properties of a Benchmark

- **Realistic**
- **Executable**
- **Two-sided**
- **Vetted** →
  - Manually checked
  - Why?
    - Avoid noise of large-scale, automated data gathering

Existing Benchmarks

Benchmark/dataset	Language	Vulns.	Realistic	Exec. exploits	Two-sided	Vetted
CGC	C	590	✗	✓	✗	✓
Juliet	C/C++, Java, C#	121,922	✗	✓	✓	✓
LAVA-M	C	2,265	✗	✓	✓	✗
BigVul	C/C++	3,745	✓	✗	✓	✗
Ferenc et al. ’19	JavaScript	1,496	✓	✗	✓	✗
VulinOSS	various	17,738	✓	✗	✗	✗
Magma	C	118	✓	✗	✓	✓
Ghera	Java/Android	25	✓	✓	✗	✓
Ponta et al.	Java	624	✓	✗	✓	✓

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SecBench.js	JavaScript	600	✓	✓	✓	✓

SecBench.js

- **600 JavaScript vulnerabilities**
  - Code injection
  - Command injection
  - Path traversal
  - Prototype pollution
  - ReDoS
- **Three applications**

See ICSE'23 paper and https://github.com/cristianstaicu/SecBench.js

Methodology

Three data sources:
Snyk, GitHub Advisories, Huntr.dev

↓

Filter: Available, installable, reproducible

↓

Create exploits

↓

Search for CVE and fixing commit

Creating Exploits

- **Validate that code is vulnerable and can be exploited**
- **Two steps:**
  1) Perform security-relevant action
  2) Check success with exploit oracle

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Example: Code and command injection

1) Create file
2) Check whether file exists

Creating Exploits

- **Validate that code is vulnerable and can be exploited**
- **Two steps:**
  1) Perform security-relevant action
  2) Check success with exploit oracle

Example: ReDoS

1) Trigger expensive regexp matching
2) Check that processing time $>$ threshold

Creating Exploits

- **Validate that code is vulnerable and can be exploited**
- **Two steps:**
  1) Perform security-relevant action
  2) Check success with exploit oracle

Example: Prototype polution

1) Add special property to prototype of all objects
2) Check that property exists

Example: Prototype Pollution

```
test("prototype pollution in lodash", () => {
  // setup
  const mergeF = require("lodash").defaultsDeep;
  const payload = '{"constructor": {"prototype": {"polluted": "yes"}}}';
  // sanity check
  expect({}.polluted).toBe(undefined);
  // exploit
  mergeF({}, JSON.parse(payload));
  // oracle check
  expect({}.polluted).toBe("yes");
  // cleanup
  delete Object.prototype.polluted;
});
```

Overview of Benchmark

Type of vulnerability	Nb. exploits	Has fix	Has CVE
Code injection	40	21	20
Command injection	101	41	90
Path traversal	169	19	80
Prototype pollution	192	126	158
ReDoS	98	78	59
Total	600	285	407

Installation and Execution

- **One folder per vulnerability**
  - package.json to install vulnerable package and its dependencies
  - Executable exploit as a test case
  - JSON file with meta-data
- **12 minutes to install entire benchmark**
- **13 minutes to execute all exploits**

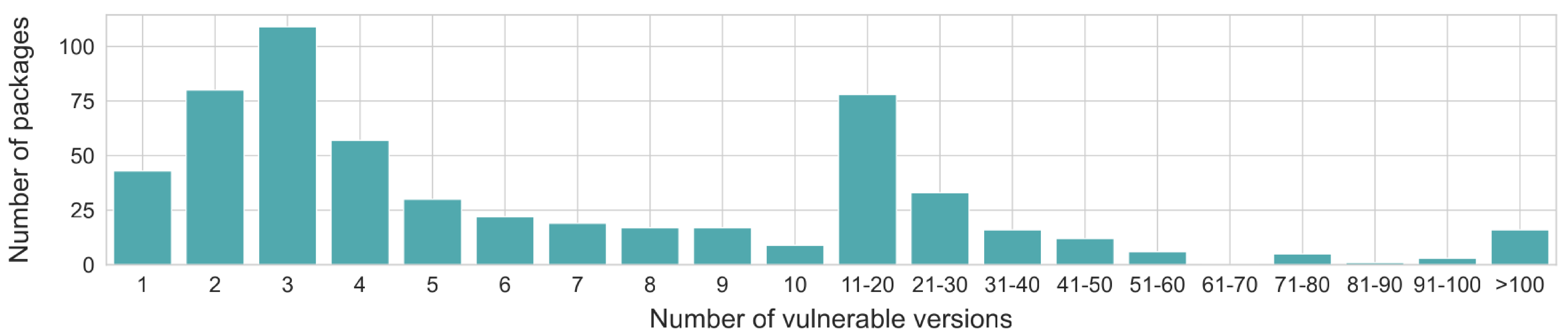
Applications

- Finding mislabeled vulnerable versions
- Finding flawed fixes
- Localizing sink calls (see paper)
- Evaluate detection and mitigation techniques

Finding Vulnerable Versions

- Which versions of a package are affected?
- For each version of the vulnerable package
  - Install package in this version
  - Try to run exploit

Number of Vulnerable Versions



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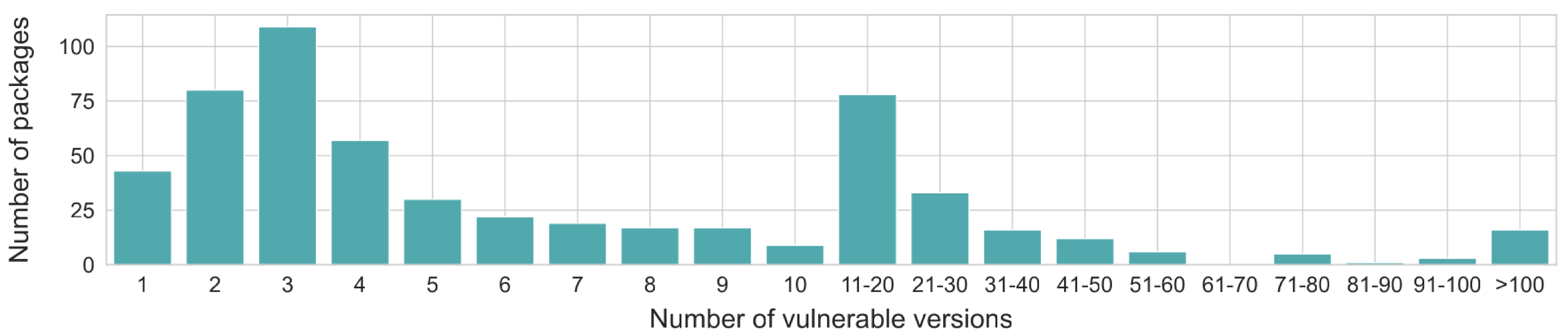
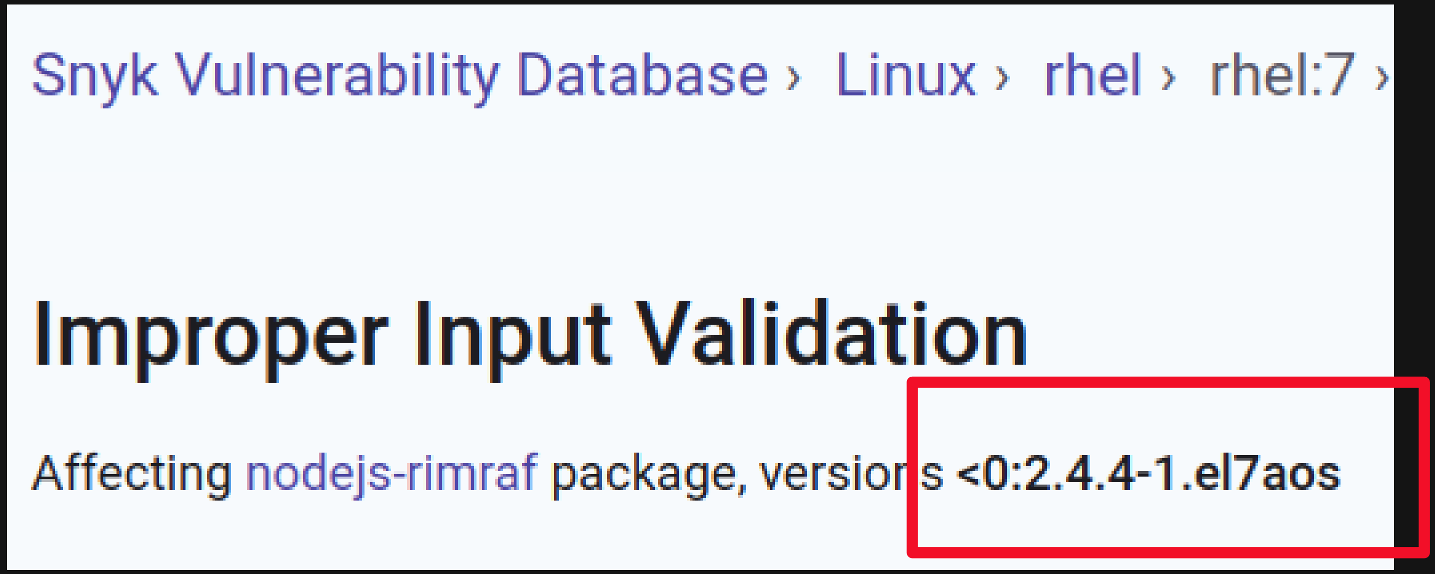


Some vulnerabilities affect only a few versions

Others affect many versions (maximum: 1,487)

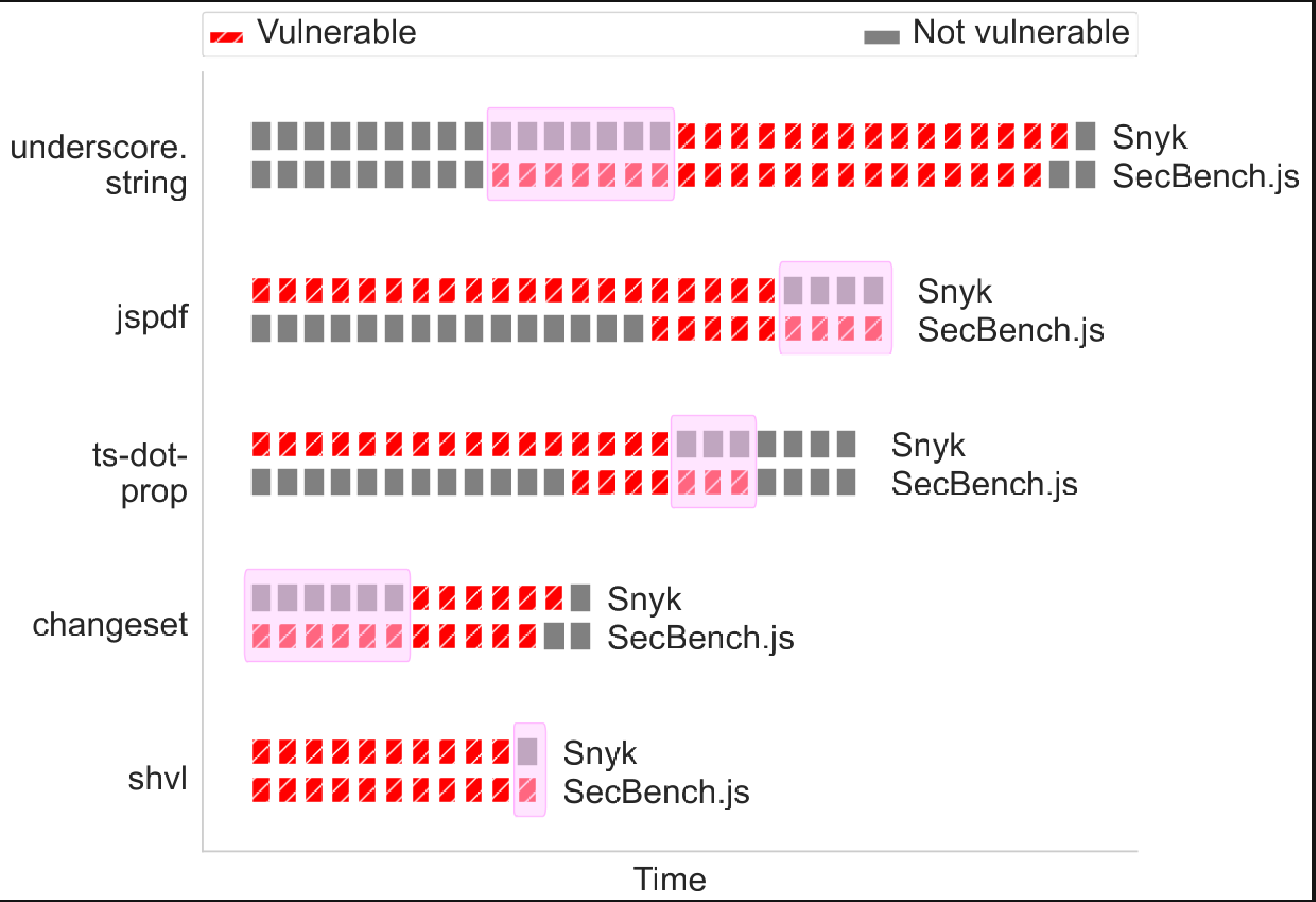
Mislabeled Version Ranges

- **Vulnerability databases indicate range of affected versions**
  - Basis, e.g., for npm's security warnings

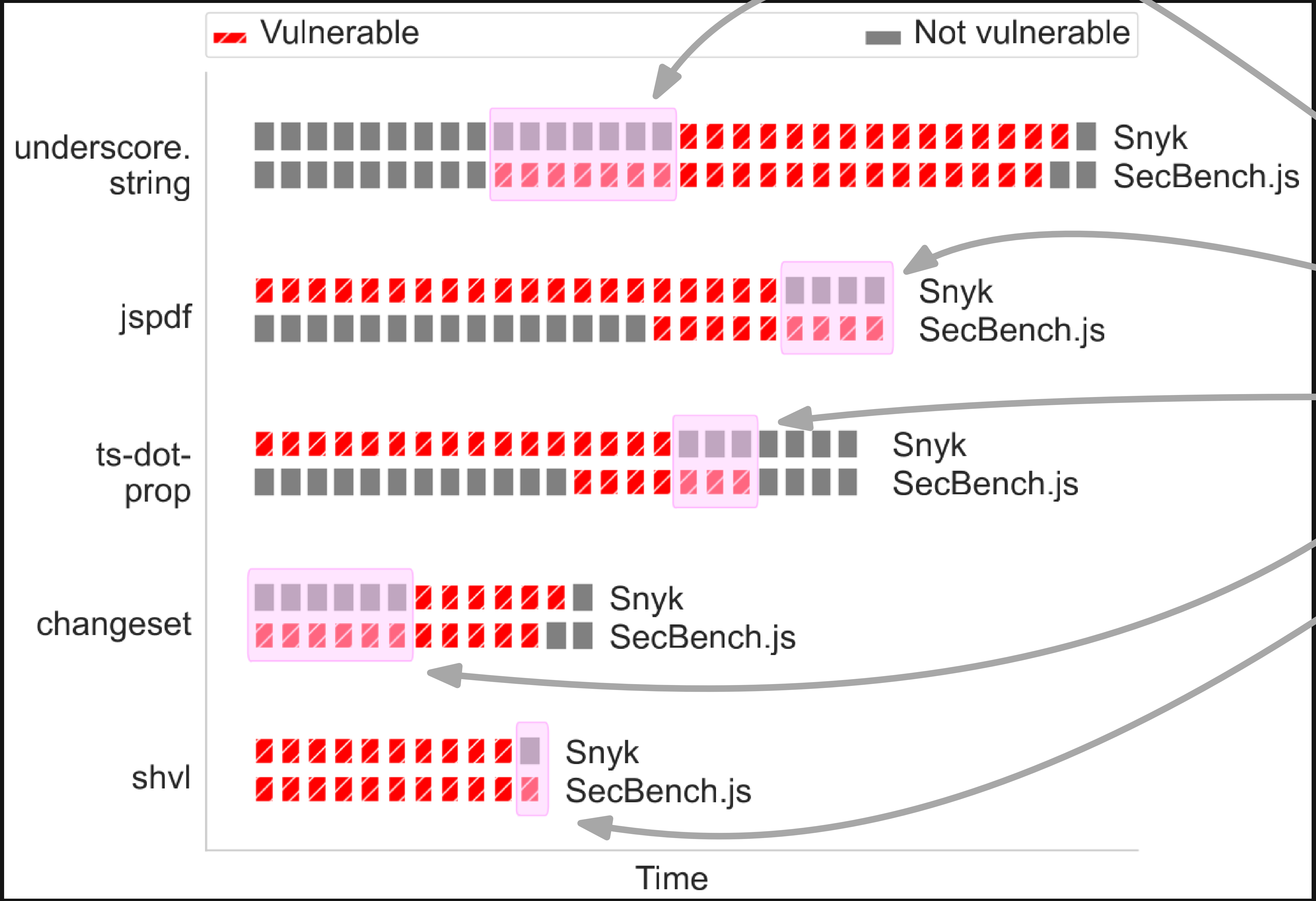


- **Are these ranges correct?**
  - 168 versions in 19 packages are incorrectly labeled as non-vulnerable

Examples

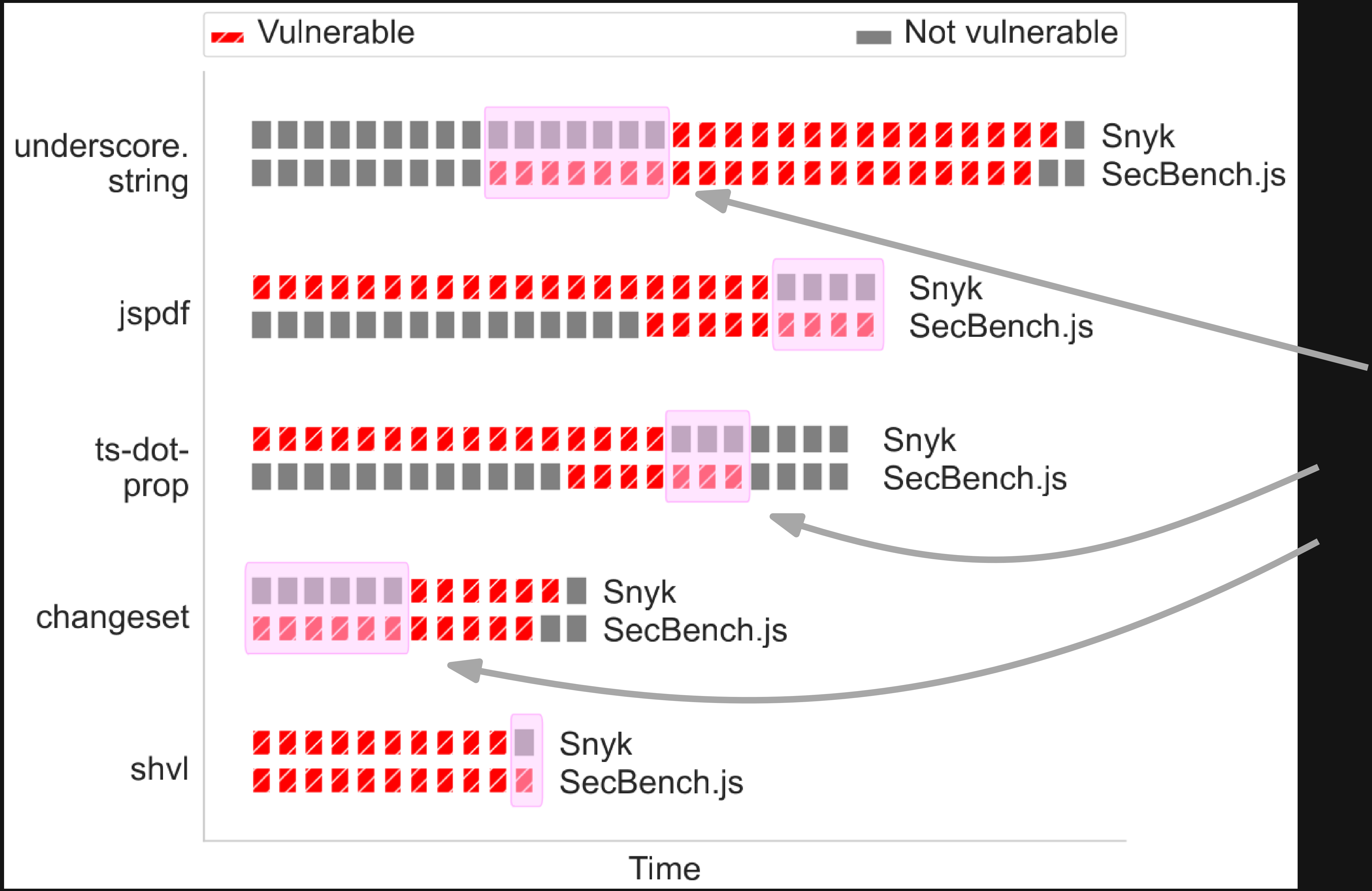

Vulnerable
Not vulnerable
underscore.
string
Snyk
SecBench.js
jspdf
Snyk
SecBench.js
ts-dot-
prop
Snyk
SecBench.js
changeset
Snyk
SecBench.js
shvl
Snyk
SecBench.js
Time

Examples



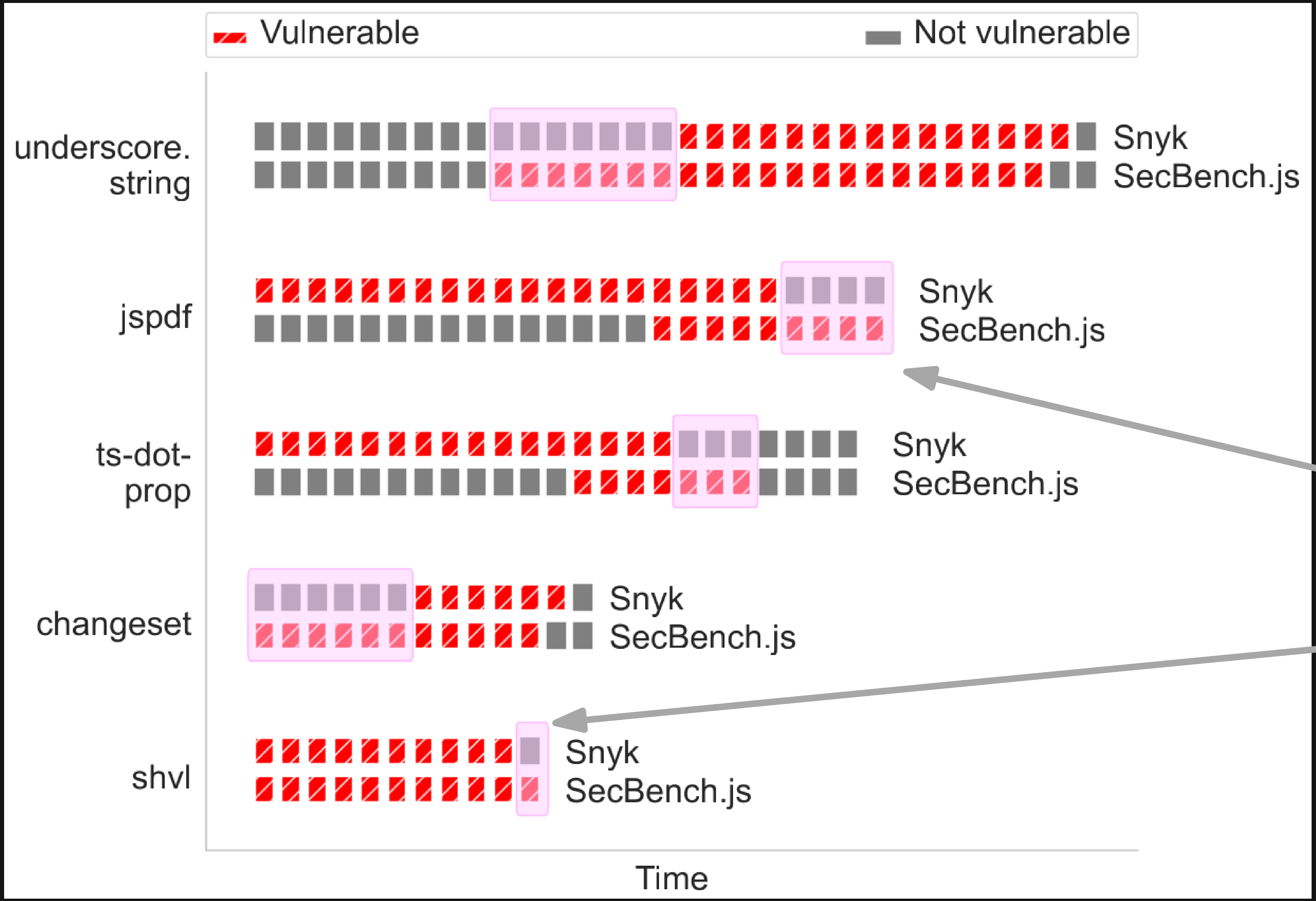
Mislabeled as non-vulnerable, but actually can be exploited!

Examples



Affects legacy versions

Examples



Affects the latest available version: Zero-day!

Finding Flawed Fixes

- **Fix may overfit to a proof-of-concept attack**
- **E.g., prototype pollution**
  - Can inject properties via `obj.__proto__` and `obj.constructor.prototype`
- **For each vulnerability**
  - Update to latest version
  - If exploit not successful:
    Check if simple mutations of exploit work

Results

- **18 successful exploits of “fixed” versions**
  - Twelve new CVEs
- **Surprisingly simple way of finding zero-day vulnerabilities**

Example

“Fixed” version of Mozilla’s *convict* package:

```
const path = k.split('.')
const childKey = path.pop()
const pKey = path.join('.')
if (!(pKey == '__proto__' ||
      pKey == 'constructor' ||
      pKey == 'prototype')) {
 const parent = walk(this._instance, pKey, true)
 parent[childKey] = v
}
```

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Works for the original exploit, but fails to prevent writes to, e.g., `constructor.prototype.x`

Other Applications of SecBench.js

- **Evaluation of vulnerability detection techniques**
  - How many of all vulnerabilities can they find?
  - E.g. evaluation of "Bimodal Taint Analysis" (ISSTA'23)
- **Evaluation of mitigation techniques**
  - How many of all exploits can they prevent?
- **Empirical studies**
  - Static and dynamic properties of vulnerabilities, exploits, and fixes

SecBench.js – Conclusion

- **First benchmark of JavaScript vulnerabilities that is**
  - Realistic
  - Executable
  - Two-sided
  - Vetted
- **Side product: 20 zero-day vulnerabilities**

See ICSE'23 paper and https://github.com/cristianstaicu/SecBench.js