Hand Sanitizers in the Wild

A Large-scale Study of Custom JavaScript Sanitizer Functions

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Motivation

Client Side XSS: Root Cause

```
1  let name = location.hash.substr(1);
2  let greeting = "Hello, " + name;
3  /*
4     Application code
5  */
6  div.innerHTML = greeting;
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Visiting:
foo.com#RuhrSec

Hello, RuhrSec

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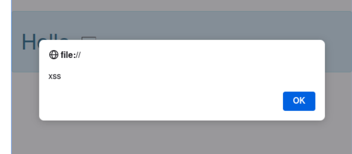

Client Side XSS: Root Cause

No difference between data and markup in HTML

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2 let greeting = "Hello, " + name;
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Client Side XSS: Root Cause

Source: Attacker controlled data

Source

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Client Side XSS: Root Cause

Sink: Turned into (executable) code

```
let name = location.hash.substr(1);
let greeting = "Hello, " + name;
/*
   Application code
*/
div.innerHTML = greeting;
```

Sink

Client Side XSS: Root Cause

Unprotected data flow from source to sink

Source

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1 let name = location.hash.substr(1);
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Sink

Client Side XSS: Protection

- Solution: Sanitizer

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1  let name = location.hash.substr(1);
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3  /*
4      ...
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6  greeting = sanitize(greeting); Sanitizer
7  /*
8      ...
9  */
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- Solution: Sanitizer
- Removes "dangerous chars" from input
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Sanitizer

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Figure: HTML Sanitizer

Visiting:

foo.com#<img src=x onerror=alert('xss')>

Hello, img src=x onerror=alert('xss')

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How to sanitize?

- We have 3 injection contexts
  - HTML, HTML attribute and JavaScript

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Characters to be encoded per injection context

<table>
<tr><th>Context</th><th>OWASP Recommendations</th></tr>
<tr><td>HTML</td><td><>'"& except HTML encoded chars</td></tr>
<tr><td>HTML Attr.</td><td>The quote characters (" and ') as well as characters usable to break out of unquoted attribute values (including: [space] % * + , - / ; < = > ^ and |), properties and event handlers</td></tr>
<tr><td>JavaScript</td><td>non-alphanumeric except ,._ whitespace or hex/unicode encoded</td></tr>
</table>

Challenges for Developers

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What now?

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⇒ None do what's required…

- They all encode a subset of "dangerous" characters

What now?

Hey, folks know regex!

Regular Expressions to the Rescue!

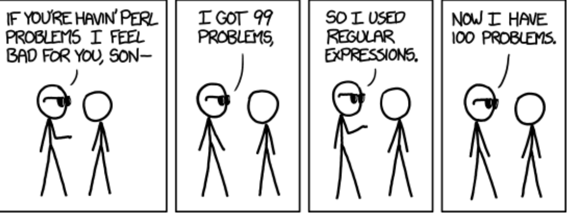

Figure: https://xkcd.com/1171/

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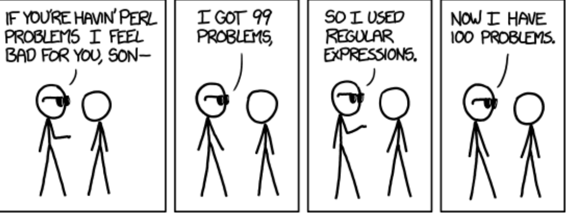

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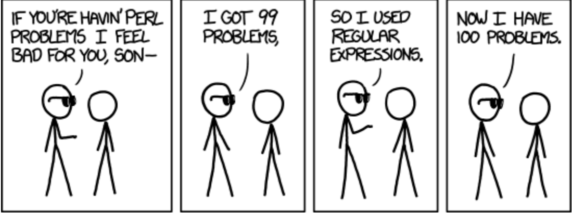
HTML is not a regular language...

Regular Expressions to the Rescue!



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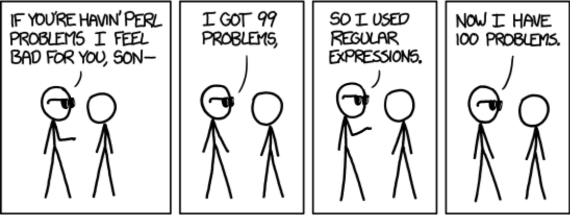

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HTML is not a regular language...

⇒ Regular Expressions unsuited to parse it

- Parsing it requires to build and manipulate a DOM while traversing the input

Sanitizing: Difficulties

Very difficult to get right...

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Very difficult to get right. . .

> *More than half of the DOM XSS root causes were due to bugs in HTML sanitizers*
>
> —*Google Research: Trusted Types - mid 2021 report*

Large Scale Study

State of Sanitization on the Web

We asked ourselves two questions:

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Q1: How prevalent are sanitizers?

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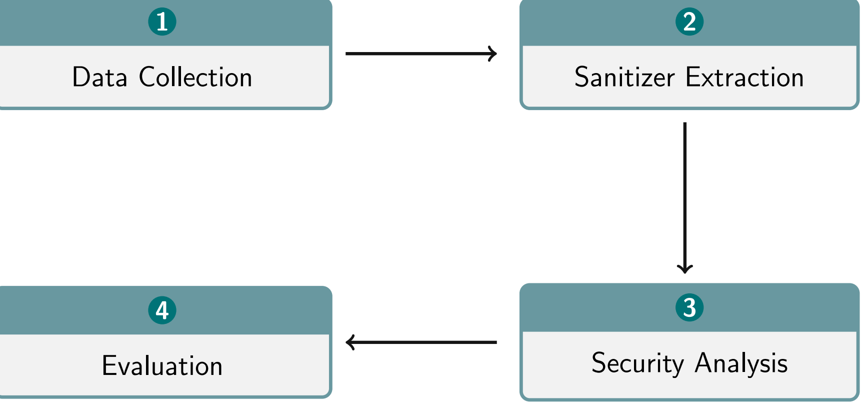
Q1: How prevalent are sanitizers?

Q2: Are they actually secure?

Study: Setup



Project Foxhound

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- Firefox fork enhanced with taint-tracking capabilities
- Also records all operations that occurred on tainted values
  - Deep insight into inner working of web application
- Open source, actively maintained and compatible with Playwright

  $\Rightarrow$ good addition to security testing toolbelt

1 Data Collection

- Take our taint browser

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- Take our taint browser
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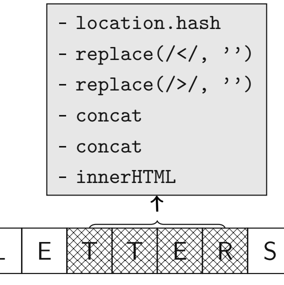
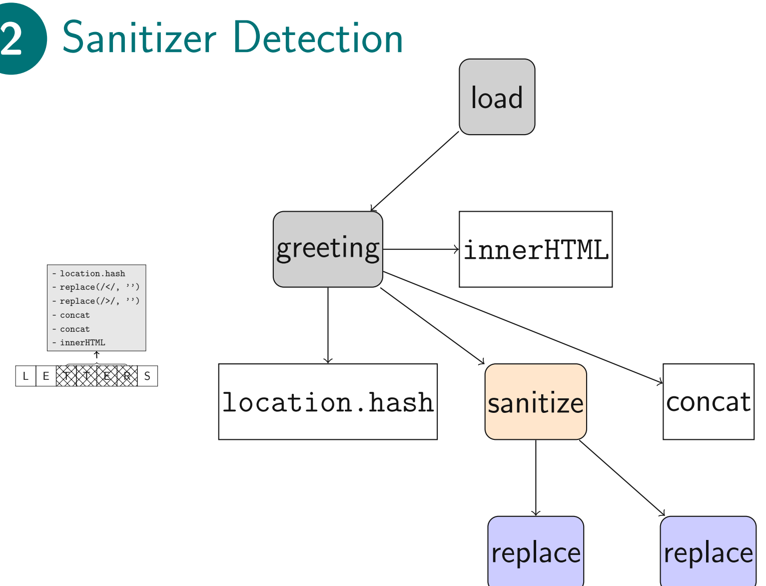
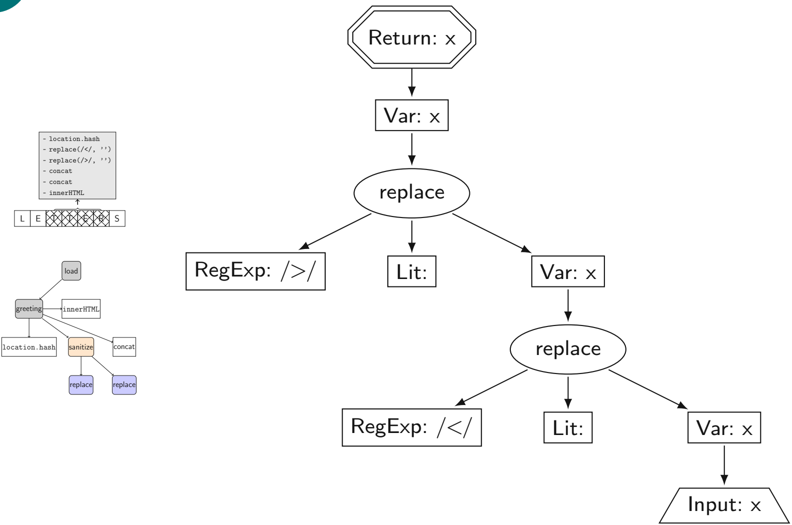
- Record data flows relevant to Client-Side XSS
  - Occurred on 3887 domains

2 Sanitizer Detection

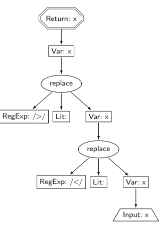



2
Sanitizer Detection
load
greeting
innerHTML
location.hash
sanitize
concat
replace
replace
- location.hash
- replace(/</, '')
- replace(/>/, '')
- concat
- concat
- innerHTML
L E T T E R S

2 Sanitizer Detection



3 Sanitizer Analysis



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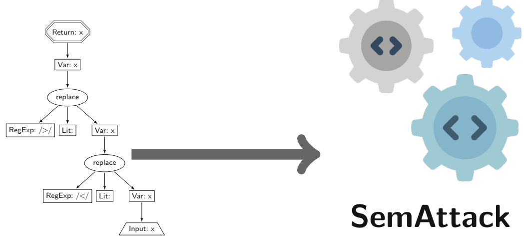


3 Sanitizer Analysis

Return: x

Var: x

replace

RegExp: />/ Lit: Var: x

replace

RegExp: /</ Lit: Var: x

Input: x

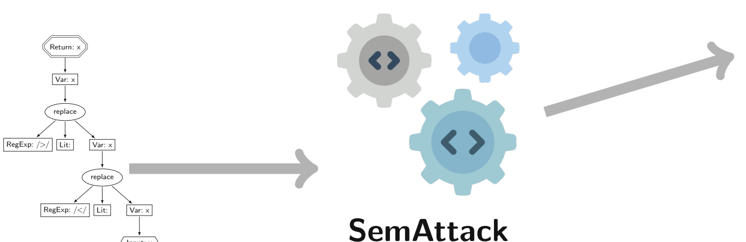
SemAttack

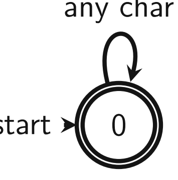
any char

start 0

Post Image

3 Sanitizer Analysis





Post Image

`<img src=x onerror=alert('XSS')>`

XSS Payload

3 Sanitizer Analysis

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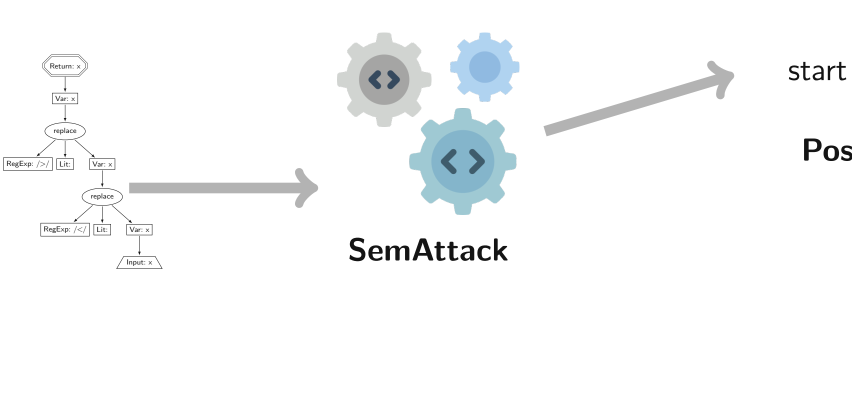

start

0

Post Image

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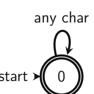
XSS Payload

4 Validation

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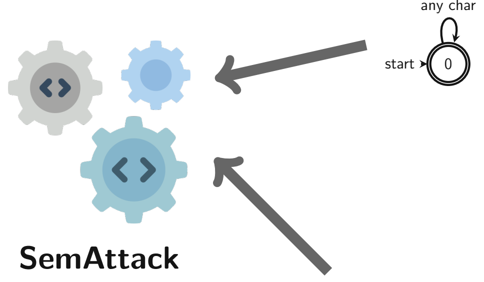

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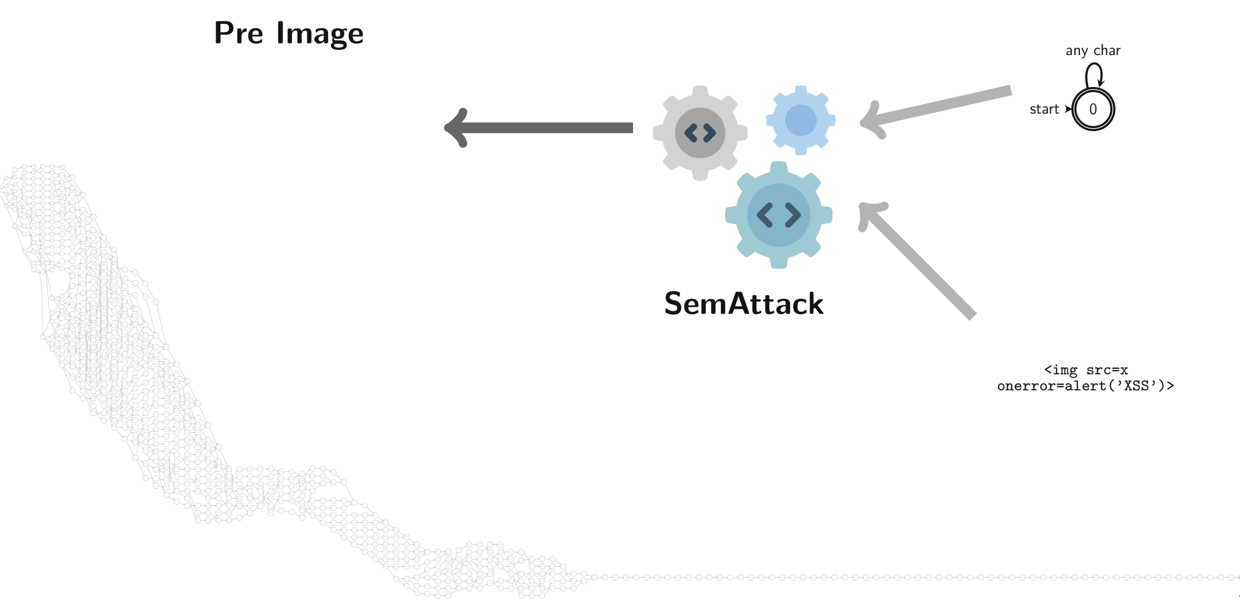

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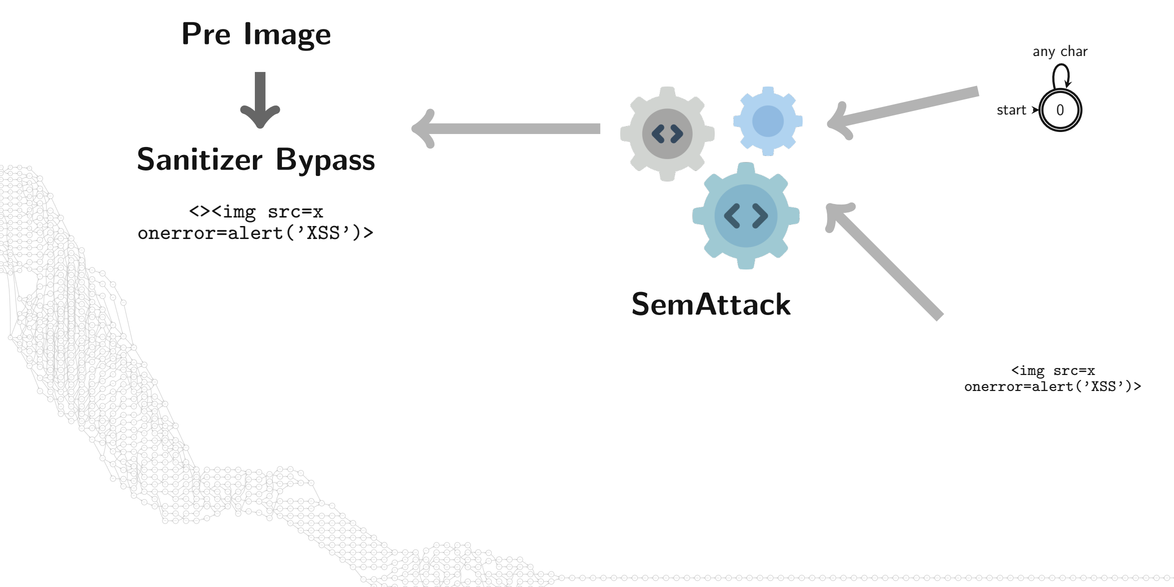

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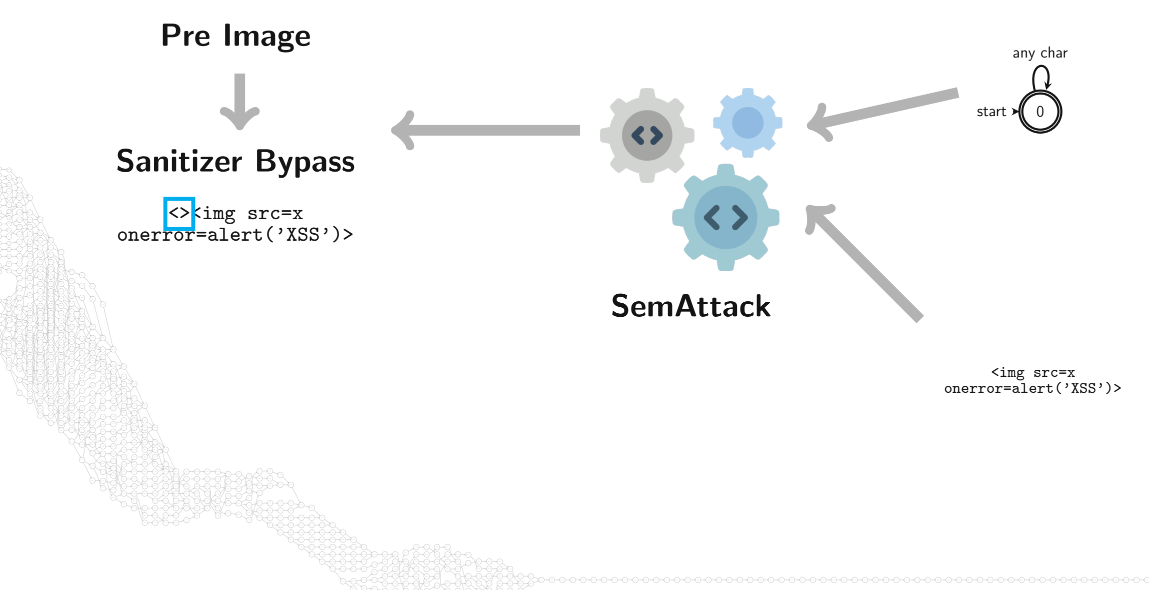

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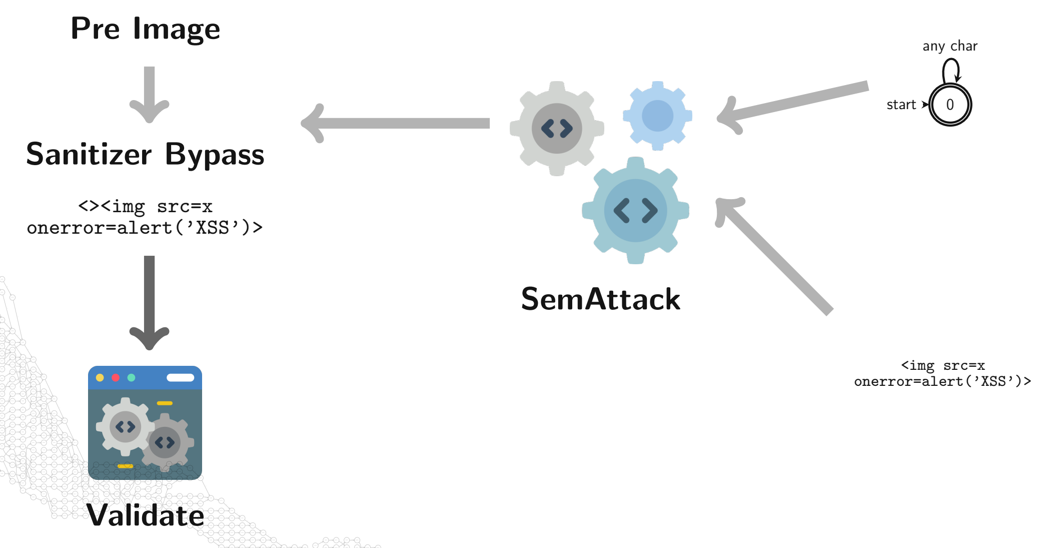

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- 88 sanitizers on 102 domains detected as insecure by SemAttack.

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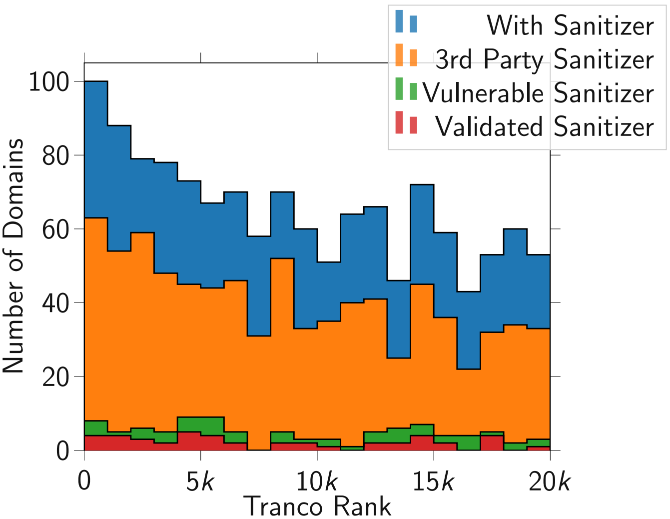

Cabinet of Horrors

Effective against germs, but not against XSS payloads!

Optimized for specific Payload

```
1 function f(v) {
2   return v.replace(/'/g, "").replace(/\(/g, "")
3   .replace(/\)/g, "").replace(/alert/g, "");
4 }
```

Optimized for specific Payload

Delete all Single Quotes

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1  function f(v) {
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```

Delete all Parentheses

Optimized for specific Payload

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1   function f(v) {
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Delete dangerous payload

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- Removing Parentheses to prevent function calls seems reasonable?
  - But... JavaScript is crazy
  - `` confirm`xss` `` works as well

Wrong Context

```
function sanitize(v) {
  return v.replace(/</g, "&lt;")
    .replace(/>/g, "&gt;");
}
var url = 'http://example.org;cat=' +
    sanitize(cat) + '?';
document.write('<iframe src="' + url + '" style="display:none"></iframe>');
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Issues:

- Encoding angle brackets generally a good idea!

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Injection Context

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```

Issues:

- Encoding angle brackets generally a good idea!
  - But... context is inside an attribute
  - No angle brackets required to break out and inject payload
  - Example: `" onload=alert(1) foo=`

Blocklisting

```
v = decodeURIComponent(location.hash.replace('#', '').split('/')[2]);
v = v.replace(/<img(.*)?(\/)?>(.*)?(<\/img>)?/gi, '')
  .replace(/<a(.*)?(\/)?>(.*)?(<\/a>)?/gi, '')
  .replace(/<script(.*)?(\/)?>(.*)? (<\/script>)?/gi, '');
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Issues:

Blocklisting

Delete all `img` tags with content

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```

Delete all `script` tags with content

Issues:

Blocklisting

```
1  v = decodeURIComponent(location.hash.replace('#', '').split('/')[2]);
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Issues:

- Blocklisting is brittle by nature

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Issues:

- Blocklisting is brittle by nature
- Several other tags can be used to inject payloads:

Blocklisting

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Issues:

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  - E.g., `<image>` behaves exactly the same as `<img>`

Blocklisting

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```

Matching closing tags

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- Blocklisting is brittle by nature
- Several other tags can be used to inject payloads:
  - E.g., `<image>` behaves exactly the same as `<img>`

Small aside:

- HTML parsers accept attributes in end tags (and ignore them)

Regular Expressions Limitations

```
1  var url = location.href.replace(/<script[\S\s]*?\1>|<\/?(a|img)[^>]*>/gi, "")
2    .replace('"', "")
3    .replace(">", "")
4    .replace("#", "")
5    .replace("<", "");
6  document.write('<script type="text/javascript" src="example.org?url='+url+'"
   ↪  ></script>');
```

Issues:

Regular Expressions Limitations

Delete all `script`, `a` and `img` tags

```
1 var url = location.href.replace(/<script[\S\s]*?\1>|<\/?(a|img)[^>]*>/gi, "")
2   .replace('"', "")
3   .replace(">", "")
4   .replace("#", "")
5   .replace("<", "");
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Issues:

- Regular Expressions do a single scan over the input

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   ↪  ></script>');
```

Issues:

- Regular Expressions do a single scan over the input
  - E.g., `<sc<a>ript>` would only have the inner tag removed

Regular Expressions Limitations

```
1  var url = location.href.replace(/<script[\S\s]*?\1>|<\/?(a|img)[^>]*>/gi, "")
2    .replace('"', "")
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```

Remove dangerous characters

Issues:

- Regular Expressions do a single scan over the input
- The JavaScript API for `replace()` is somewhat unintuitive

Regular Expressions Limitations

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1   var url = location.href.replace(/<script[\S\s]*?\1>|<\/?(a|img)[^>]*>/gi, "")
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Regular Expressions Limitations

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  .replace(">", "")
  .replace("#", "")
  .replace("<", "");
document.write('<script type="text/javascript" src="example.org?url='+url+'"
↪ ></script>');
```

Issues:

- Regular Expressions do a single scan over the input
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  - `replace("<", "")` replaces only the first occurrence of <
  - To replace all, `replace(/</g, "")` has to be used

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- Regular Expressions do a single scan over the input
- The JavaScript API for `replace()` is somewhat unintuitive
  - `replace("<", "")` replaces only the first occurrence of <
  - To replace all, `replace(/</g, "")` has to be used
  - One of the most frequent errors we encountered!

Mitigations

HTML Parser to Sanitize

I'll just use a HTML parser library to sanitize my input!

HTML Parser to Sanitize

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- Does this HTML parser actually behave like your visitor's browsers do?

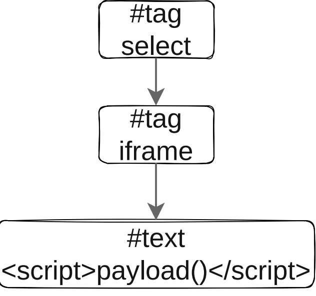
Parser Confusion to Sanitizer Bypass

Payload: `<select><iframe><script>payload()`

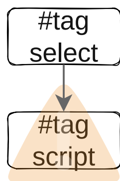
Parser Confusion to Sanitizer Bypass

Payload: `<select><iframe><script>payload()`

Parsed by Google Caja



Parsed by Google Chrome



Parser Confusion to Sanitizer Bypass: Root Cause

4.8.5 The `iframe` element

Categories:

Flow content.
Phrasing content.
Embedded content.
Interactive content.
Palpable content.

Contexts in which this element can be used:

Where embedded content is expected.

Content model:

Nothing.

Parser Confusion to Sanitizer Bypass: Root Cause

The ”nothing” content model

When an element's content model is nothing, the element must contain no Text nodes (other than inter-element whitespace) and no element nodes.

Parser Confusion to Sanitizer Bypass: Root Cause

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However. . .

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However... the parsing specification says content of `iframe` should be parsed as text...

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However... the parsing specification says content of `iframe` should be parsed as text...

```
div.innerHTML = `<iframe><img src=x onerror=alert(1)>`;
```

: no code execution

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When an element's content model is nothing, the element must contain no Text nodes (other than inter-element whitespace) and no element nodes.

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So the sanitizer is actually correct, but...

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When an element’s content model is nothing, the element must contain no Text nodes (other than inter-element whitespace) and no element nodes.

However. . . the parsing specification says content of `iframe` should be parsed as text. . .

`` div.innerHTML = `<iframe><img src=x onerror=alert(1)>`; `` : no code execution

So the sanitizer is actually correct, but. . .

Where has the `iframe` gone actually?

The missing `iframe`

Recall the payload: `<select><iframe><script>payload()`

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the `select` element

Content model:

Zero or more `option`, `optgroup`, and script-supporting elements.

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Recall the payload: `<select><iframe><script>payload()`

> the `select` element
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“script-supporting elements” are `script` and `template` tags

Thus, an `iframe` can't be a child of `select`

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Recall the payload: `<select><iframe><script>payload()`

> the `select` element
>
> **Content model:**
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> *Zero or more `option`, `optgroup`, and script-supporting elements.*

"script-supporting elements" are `script` and `template` tags

Thus, an `iframe` can't be a child of `select`, and Chrome drops it

Parser Confusion to Sanitizer Bypass: Summary

Sanitization based on a “full” HTML parser needs to take into account:

- All subtleties of the HTML specification
  - It’s a 1300+ page document...
- How browsers diverge from it

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Sanitization based on a “full” HTML parser needs to take into account:

- All subtleties of the HTML specification
  - It’s a 1300+ page document...
- How browsers diverge from it

⇒ This also applies to server-side HTML sanitization!

How to protect yourself then?

Protection

1. Avoid the need to sanitize!

Protection

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   - Minimize putting user data into the DOM

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   - This allows to “just” encode everything
   - Please recall the DOM clobbering talk!
3. Use a well tested library
   - E.g., DOMPurify
   - Keep it up to date!

Way Forward?

Two upcoming browser features:

- Sanitizer API
- Trusted Types

Sanitizer API

- Buy in by Mozilla, Google and Microsoft. Safari has not implemented it (yet?)

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Goal: Adding a robust and secure by default HTML sanitizer

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Goal: Adding a robust and secure by default HTML sanitizer

- Updated with the browser, so any bypasses are fixed automatically

Sanitizer API: Usage

```
1  let node = document.createElement('div');
2  let sanitizer = new Sanitizer(); Create Sanitizer object
3  let payload = '<img src=x onerror=alert(1)>';
4  node.setHTML(payload, sanitizer);
5  let sanitized = sanitizer.sanitizeFor('div', payload);
6  node.replaceChildren(...sanitized.childNodes);
7  // innerHTML of node is: <img src="x"> after both calls
```

Figure: Usage of the Sanitizer API

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Option 2

Figure: Usage of the Sanitizer API

Sanitizer API: Takeaways

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Still under development

- Not yet ready for productive use

Trusted Types

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Idea: Ensure sanitization via strong typing

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Buy in only by Google, Microsoft

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Idea: Ensure sanitization via strong typing

Buy in only by Google, Microsoft

- Make sinks accept Trusted values instead of strings
- Assigning strings gives a type error

Trusted Types: Enforcement

Changing API for `.innerHTML` hugely invasive!

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Add a Content Security Policy (CSP) directive!

```
require-trusted-types-for 'script';
```

Trusted Types: Usage

```
1  const p = '<img src=x onerror=alert(1)>';
2  htmlPolicy = trustedTypes.createPolicy('sanitize', {
3      createHTML: s => s.replace(/\</g, '&lt;')
4  });
5  node.innerHTML = htmlPolicy.createHTML(p);
6  node.innerHTML = p;
```

Figure: Creating and Using a Trusted Types Policy

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Create a Trusted Types Policy

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Define a Sanitizer for HTML sinks

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Use Policy to create TrustedHTML

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Secure Assignment

Figure: Creating and Using a Trusted Types Policy

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6  node.innerHTML = p;  Insecure Assignment
```

Figure: Creating and Using a Trusted Types Policy

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Enforcing sanitization fantastic idea!

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- No suggestions about sanitization itself
- The broken ones shown before could be used as policy $\rightarrow$ false sense of security
- Requires a “generic” sanitizer
- Usability Issues
  - Do you know about the undocumented parameters?

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Google and Microsoft only technology

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Google and Microsoft only technology

→ Idea is you get Trusted Types for free when using frameworks such as Angular

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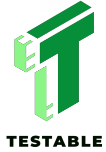
- First party sanitizers more likely to be vulnerable than third party ones
- Developers misunderstand key aspects of JavaScript, including:
  - URL encoding functionality: `escape`, `encodeURI(Component)`
  - Regular expression usage
  - Parts of the standard library

Thank you for your attention!



Resources

github.com/SAP/project-foxhound
github.com/ias-tubs/hand_sanitizer

Contact

david.klein@tu-braunschweig.de
david-klein-b2aa80254
twitter.com/ncd_leen

Summary

- 3887 out of 20 000 websites contained interesting data flows.
- We found 705 unique sanitizers on 1415 out of those 3887 domains.
- 88 sanitizers on 102 domains detected as insecure by SemAttack.

- Client-Side XSS still an issue
- Deployed sanitizers are neither generic nor minimal
- First party sanitizers more likely to be vulnerable than third party ones
- Developers misunderstand key aspects of JavaScript