Client-Side Protection Against DOM-based XSS Done Right (TM)

Ben Stock, Sebastian Lekies, Martin Johns

About us

- **Ben Stock, Sebastian Lekies, Martin Johns**
- **Security Researcher at Uni Erlangen, Uni Bochum and SAP**
- **More and stuff at http://kittenpics.org**

About this talk

- Results of a practical evaluation of client-side XSS filtering
- Presentation of numerous bypasses for Chrome's XSSAuditor
- New concept to combat client-side XSS

Cross-Site Scripting

a.k.a. XSS (duh)

The Same-Origin Policy

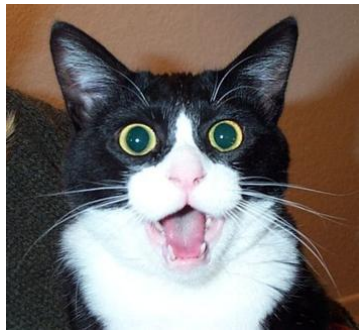
- **Question: why can't attacker.org read the visitors emails from GMail?**

- **Answer: Same-Origin Policy**
  - Application boundaries by origin: protocol, domain and port
  - Attacker's code runs in different *origin*

Bypassing the Same-Origin Policy

- **Applications process user-provided data**
  - May be stored or echoed back
- **Data `<script>alert(1)</script>` is actually Code**
  - .. interpreted by the victim's browser, executed in the *origin* of vulnerable application
- **Attacker's script code is executed on flawed site**
  - ➔ Cross-Site Scripting!
- **➔ We can read your GMails ☺**

XSS – what an attacker can do



- **Open an alert box!**
- **Hijack a session**
  - Oldest trick in the book: steal their cookies
  - Control victim's browser as he wishes
- **Alter content**
  - Display fake content or spoof login forms
- **Steal your password manager's passwords**
  - See our BlackHat EU Talk for more information ☺

Do everything with the Web app, that you could do – under your ID

Types of XSS

	Reflected	Stored
Server	`<?php echo "Hello ".$_GET['name']; ?>`	`<?php $res = mysql_query("INSERT…".$_GET['message']); […] $res = mysql_query("SELECT…"); $row = mysql_fetch_assoc($res); echo $row['message']; ?>`
Client	`<script> var name = location.hash.slice(1)); document.write("Hello " + name); </script>`	`<script> var html= location.hash.slice(1); localStorage.setItem("message", html); […] var message = localStorage.getItem("message"); document.write(message); </script>`

DOM-based / Client-Side XSS

- **Flaws in client-side code**
  - Data from attacker-controlled source flows to security-sensitive sink
  - Eventually, attacker-controlled data is interpreted as code

```
<script>
  var name = location.hash.slice(1));
  document.write("Hello " + name);
</script>
```

- **Detection of client-side XSS**
  - Dynamic analysis: use taint tracking
    - Commercial product DOMinator
  - Static analysis: no idea, we don't do static analysis ☺

Stopping XSS attacks

- **If you are the application's owner:**
  - Don't use user-provided data in an unencoded/unfiltered way
  - Use secure frameworks or other magic
  - Use Content Security Policy, sandboxed iframes, …

Stopping XSS attacks

- **If you are the application's owner:**
  - Don't use user-provided data in an unencoded/unfiltered way
  - Use secure frameworks or other magic
  - Use Content Security Policy, sandboxed iframes, …
- **If you are the application's user:**
  - Turn of JavaScript
  - **Use client-side XSS filter**
    - NoScript for Firefox
    - IE ships one
    - Chrome (the "XSS Auditor")

Quick digression: finding a lot of DOMXSS vulns

Finding and exploiting DOMXSS vulnerabilities automatically at scale

- **byte-level taint tracking in Chromium**
  - each character in a string has its source information attached to it
- **Chrome crawling extension**
  - also the interface between taint engine and central server
- **An exploit generator**
  - Taint information + HTML/JavaScript syntax rules
  - Generates exploits automatically

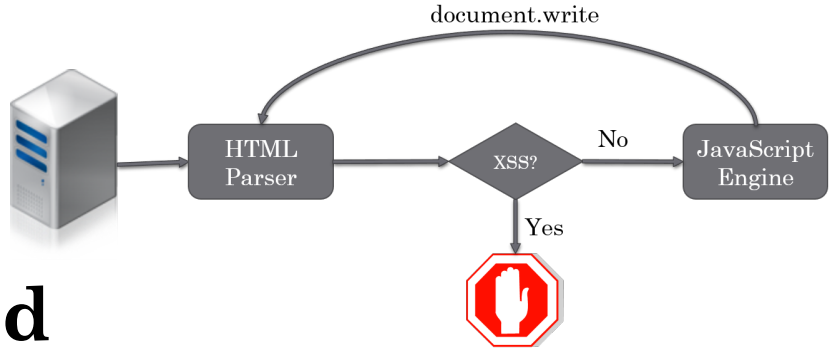
Results (many many ~~cats~~ XSS)

- **Ran experiment against Alexa Top 10k**
  - Found a total of **1,602 unique vulnerabilities**
  - .. On **958** domains
- **Auditor turned off at that point**
  - Vulnerability exists even if caught
- **Reran experiment with Auditor**
  - Auditor did not catch all exploits
  - Conducted in-depth analysis into the WHY

Bypassing the XSSAuditor

How the XSS Auditor works

- **HTTP response is parsed**
- **Auditor invoked if dangerous HTML construct is encountered**
  - Only during initial parsing process
  - Only if certain chars are in the request (<,>," and ')
- **HTTP request is checked for existence of construct**
  - Matching algorithm depends on HTML construct
- **If match is found, payload is "neutered"**



Auditor Matching Rules (simplified) **Inline Scripts**

- `<script>alert(1)</script>`
- **Matching rule**
  - Check whether content of script is contained in the request
  - ... skipping initial comments and whitespaces
  - ... only up to 100 characters
  - ... stops if "terminating character" is encountered (#, ?, //, ..

Auditor Matching Rules (simplified) **HTML attributes**

- **Event handlers**

```
<img onerror="alert(1)" src="//doesnot.exist">
```

- **Attributes with JavaScript URLs**

```
<iframe src="javascript:alert(1)"></iframe>
```

- **For each parsed attribute**
  - … check if the attribute contains a JavaScript URL
  - … or whether the attribute is an event handler
  - If so, check if the complete attribute is contained in the request

Auditor Matching Rules (simplified) **Referencing external content**

- `<script src="//attacker.org/script.js"></script>`
- `<embed src="//attacker.org/flash.swf"></embed>`

- **Matching rule**
  - … check if tag name
  - … and the complete attribute is contained in the request

How the XSS Auditor works

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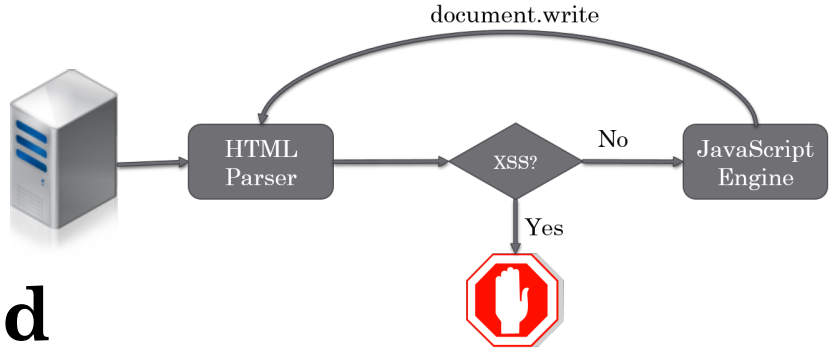

Invocation

Matching

Blocking

How to bypass the XSS Auditor

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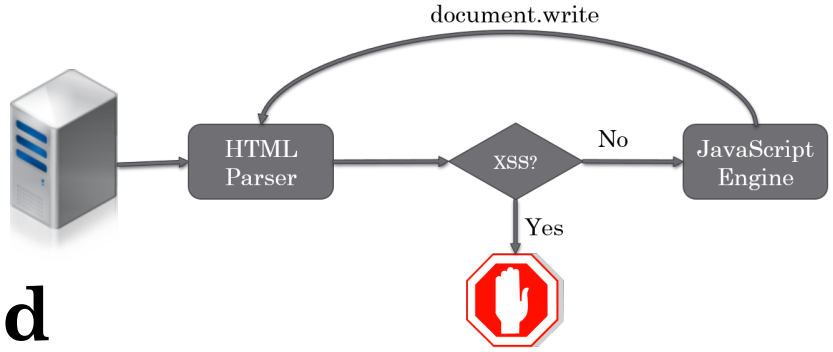

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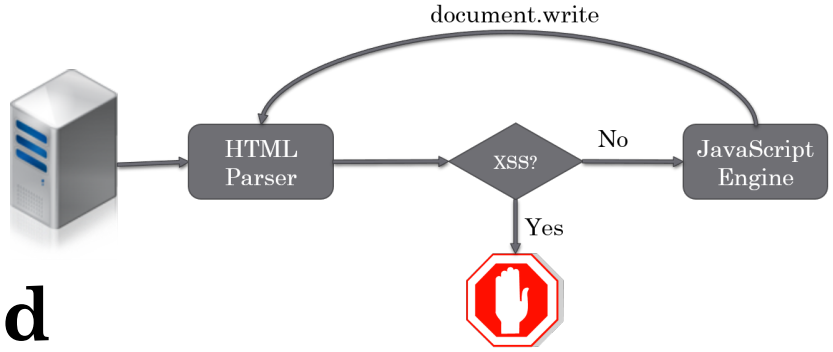

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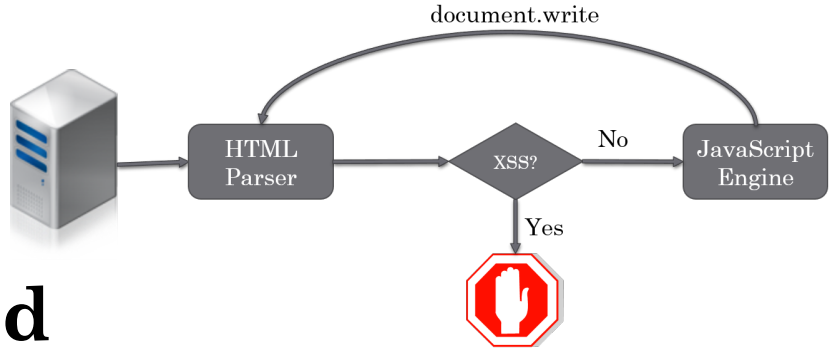

Invocation

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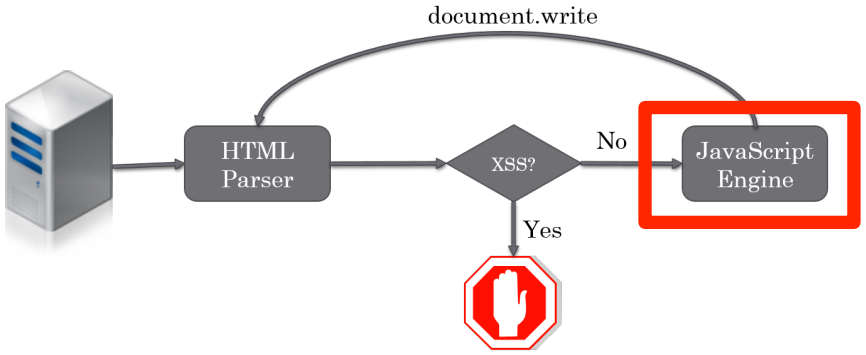
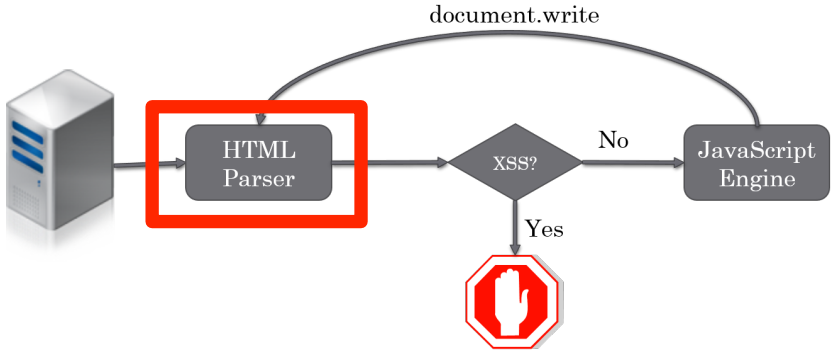
Avoiding Auditor Invocation

Bypassing Auditor Invocation

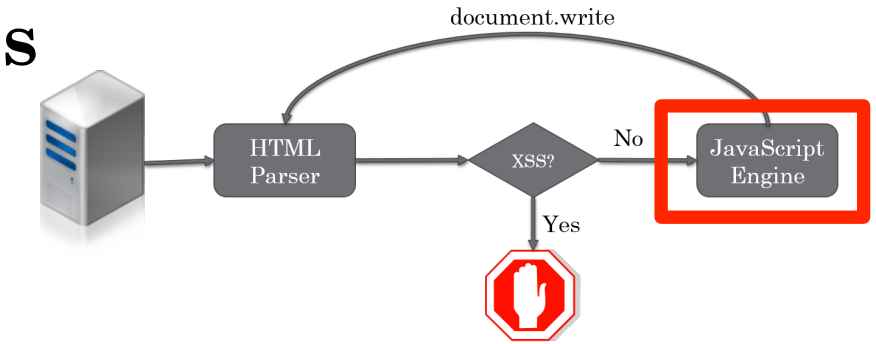




- **Filter works only for injected HTML**
  - not for injected JavaScript
  - `eval`, `setTimeout`, ...
- **Parsing document fragments**
  - `innerHTML`, `insertAdjacentHTML`, ..
  - Auditor is off for performance
- **Unquoted attribute injection** (no <,>," or ')

Bypassing Auditor Invocation (cntd.)

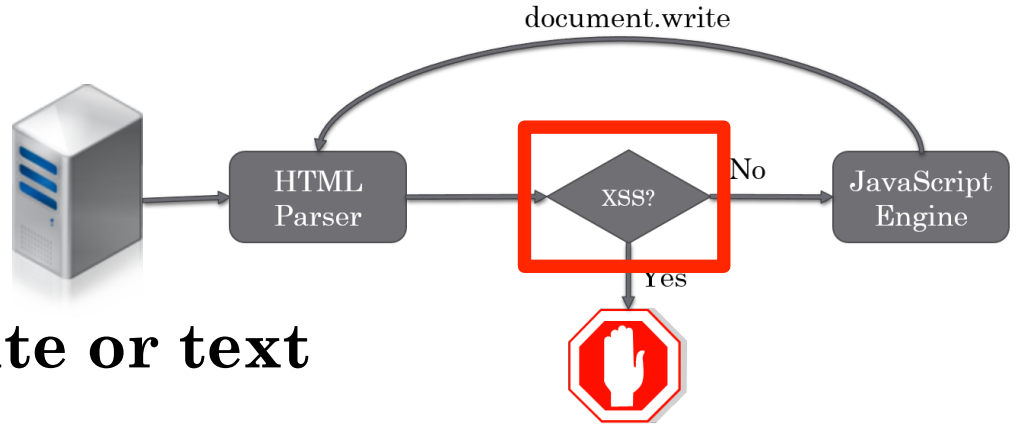
- **Various injection techniques do not require HTML**
  1. **DOM bindings**
     - e.g., assigning `script.src`
     - injection into already parsed DOM
  2. **Second-order flows**
     - e.g. cookies or Web Storage
     - injection vector cannot be found in the request
  3. **Alternative data sources**
     - e.g. postMessages
     - Attack vector enters the page through non-request channel



String-matching issues

Create situations, in which the injected vector does not match the parsed JavaScript

Partial Injections



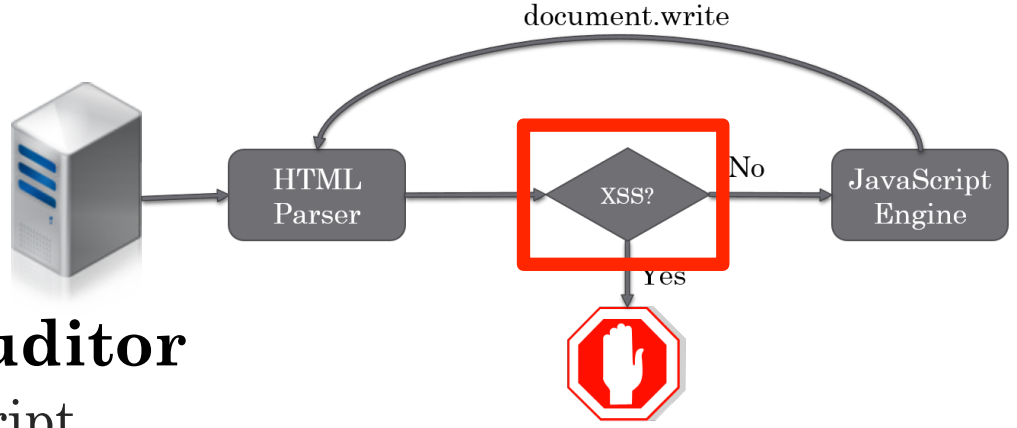
- **Hijack an existing tag, attribute or text**

```
document.write("<scr"+"ipt>var urlhash='" +
location.hash.slice(1) +"'</scr"+"ipt>");
```

- **http://vuln.com/partial.html#someValue'; alert(1); //**

```
<script>var urlhash='someValue'; alert(1); //'</script>
```

Trailing Content



- **Use existing content to fool Auditor**
  - … while still resulting in valid JavaScript
  - where "valid" means "will not cause compile-time errors"

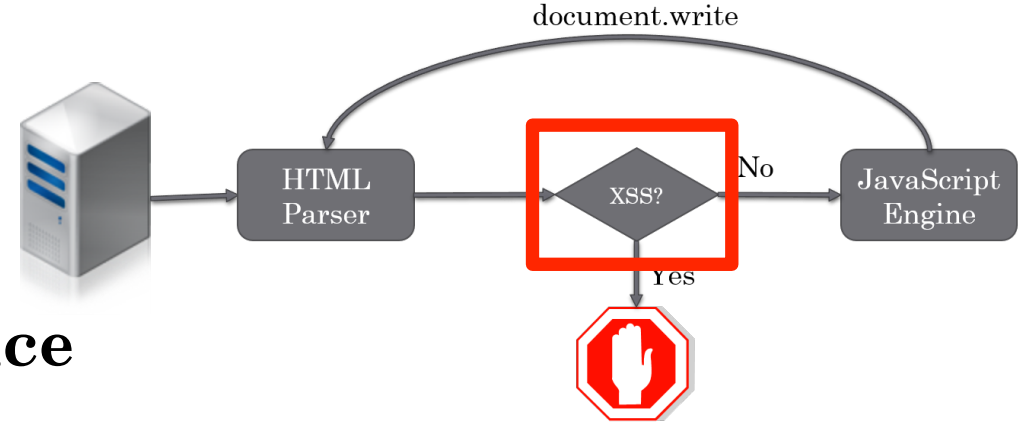
```
var width = location.hash.slice(1);
document.write("<img src='img.jpg' width='" + width + "px'/>");
```

- **http://vuln.com/trailing.html#' onload='alert(1);**

```
<img src='img.jpg' width='' onload='alert(1);px'/>
```

- **Other bypasses**
  - using trailing slashes (Auditor stops search after second slash)
  - Trailing SVG (using semicolon)

Double Injections



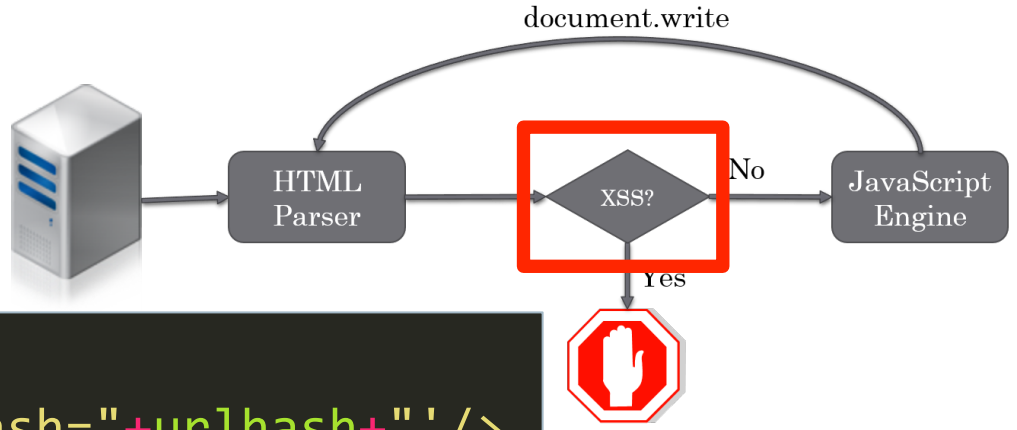
- **User input used more than once**

```
var urlhash = location.hash;
document.write("<img src='1.jpg?hash="+urlhash+"'/>
<img src='2.jpg?hash="+urlhash+"'/>");
```

- **...double.html#'>")</script>...l); void("**

WHAT???

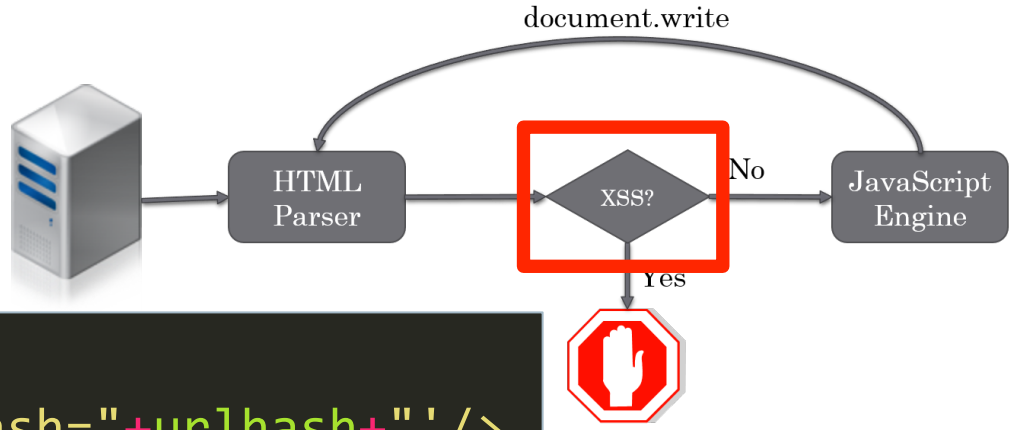
Double Injections




```
var urlhash = location.hash;
document.write("<img src='1.jpg?hash="+urlhash+"'/>
<img src='2.jpg?hash="+urlhash+"'/>");
```

```
<img src='1.jpg?hash=#foo' /><img src='2.jpg?hash=#foo' />
```

Double Injections




```
var urlhash = location.hash;
document.write("<img src='1.jpg?hash="+urlhash+"'/>
<img src='2.jpg?hash="+urlhash+"'/>");
```

```
<img src='1.jpg?hash=#'>")
</script>
<script>
  alert(1);
  void("'/><img src='2.jpg?hash=#'>")
</script>
<script>alert(1);void("'/>
```

Bypasses in the wild

- **Using our existing infrastructure, we found**
  - … **1,602** DOM-based XSS vulnerabilities
  - … on **958** domains
- **We enhanced our exploit generator to target bypassable vulnerabilities**
  - Not targeting DOM bindings, second-order flows or alternative attacks
- **Result: 776 of 958 domains susceptible to Auditor bypasses**

Doing it the right way

The Auditor's problems

- **Problem #1: approximation of data flow**
  - string matching
- **Problem #2: HTML parser**
  - after all, XSS is JavaScript injection
- **Problem #3: Never designed to tackle client-side XSS**
  - let's fix that

Our proposed solution

- **Approximation unnecessarily imprecise for local flows**
  - we can use taint tracking instead
- **Position inside JavaScript parser**
  - after all, XSS is JavaScript injection
- **XSS: data is interpreted as code**
  - "data" in JavaScript: Literals (Numeric, String, Boolean)
- **➔ Only allow tainted data to generate Literals**

Example

userdata

```
var userinput = location.hash.slice(1)
eval("var a='" + userinput + "';")
```

```
Declaration

  Identifier: a

  StringLiteral: 'userdata'
```

```
var a='userdata';
```

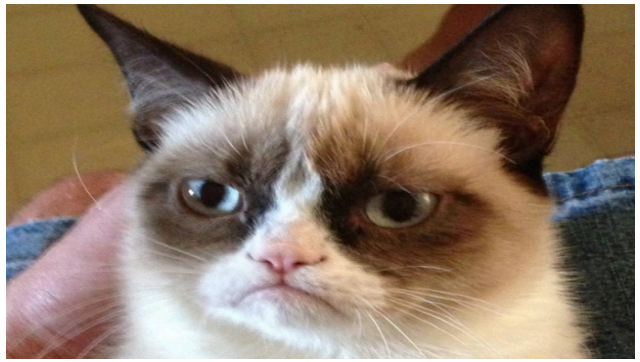
Example

userdata';alert(1);//

```
var userinput = location.hash.slice(1)
eval("var a='" + userinput + "';")
```

```
Declaration
  Identifier: a
  StringLiteral: 'userdata'
ExpressionStmt
  Type: CallExpression
  Callee:
    Identifier: alert
    Arguments:
      Literal: 1
```

```
var a='userdata'; alert(1);//';
```



Block policies

- **No tainted value may generate anything other than a Literal in the JavaScript engine**
- **No element that references external resources may have a tainted *origin***
  - enforced in HTML parser and DOM bindings
  - single exception: same origin as including page

Evaluation

False positives

- **Compatibility crawl of Alexa Top10k with policies in place**
  - **981,453** URLs, **9,304,036** frames

Blocking component	documents
JavaScript	5,979
HTML	8,805
DOM API	182
Sum	14,966 (0.016%)

False positives

- **Compatibility crawl of Alexa Top10k with policies in place**
  - **981,453** URLs, **9,304,036** frames

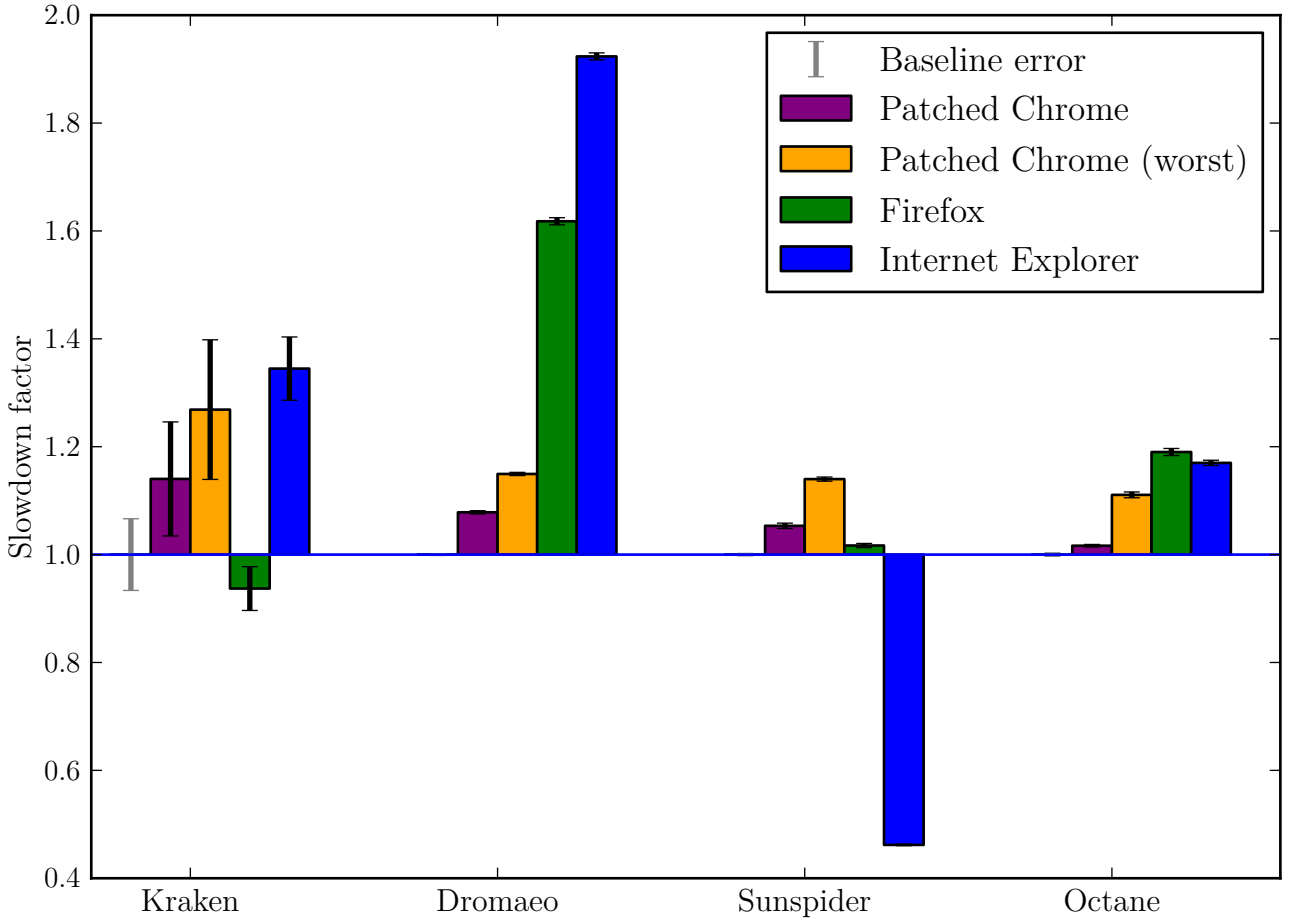
Blocking component	documents	domains
JavaScript	5,979	50
HTML	8,805	73
DOM API	182	60
Sum	14,966 (0.016%)	183 (1.83%)

False positives

- **Compatibility crawl of Alexa Top10k with policies in place**
  - **981,453** URLs, **9,304,036** frames

Blocking component	documents	domains	exploitable domains
JavaScript	5,979	50	22
HTML	8,805	73	60
DOM API	182	60	8
Sum	14,966 (0.016%)	183 (1.83%)	90

Performance

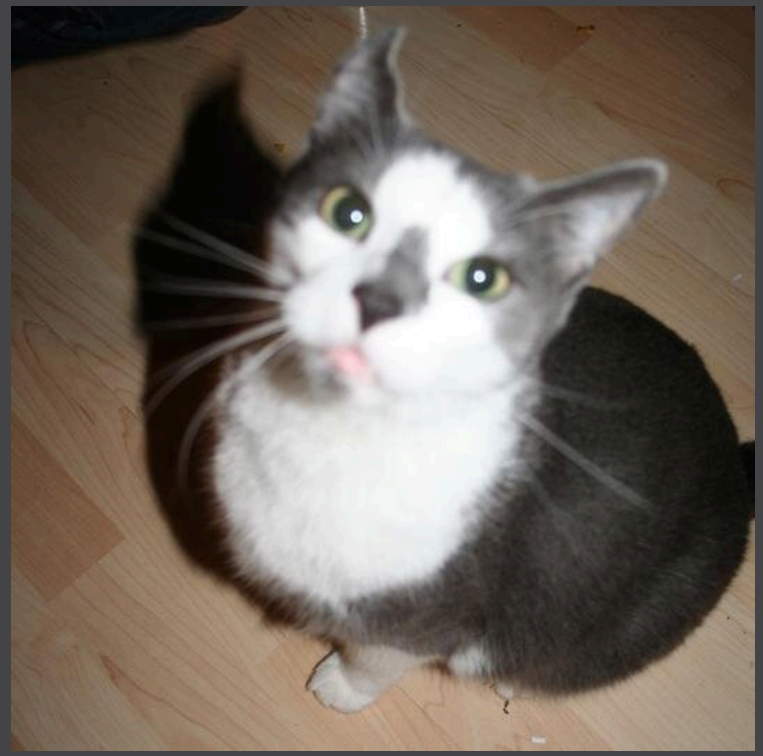


What to take away?

- **XSS still is a problem**
  - DOM-based XSS on about 10% of the Alexa Top 10k domains
- **Browsers deploy countermeasure to protect users**
  - Chrome arguably best filter
- **Security analysis of the Auditor shows that**
  - … there are many bypasses, related to both
  - ... invocation and
  - … string-matching issues
- **We propose new approach to client-side XSS filters**
  - using exact taint information
  - low false positives, some overhead (improvable)

Thank you

visit us at kittenpics.org



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