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
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
<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
<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>
```


- 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>
```


- 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>
```


- 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>
```


- 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>
```


- 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;
```

• 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>

<redacted>
<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
  • 1\textsuperscript{st} page load: script from ads.com $\rightarrow$ fancy-cars.com
  • 2\textsuperscript{nd} page load: script from ads.com $\rightarrow$ cheap-ads.net $\rightarrow$ 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'

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

appendChild is not "parser-inserted"

```html
<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 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

```json
{
  "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",
  "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
    • 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

\[
\text{<object data="//evil.com/evil.swf">}
\text{<paramname="allowscriptaccess" value="always">}
\text{</object>}
\]

- Problem #4: allowing objects from self
  - By default, Flash can always access \textbf{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"

\[
\text{<object data="//vuln.com/xss.html?inject=FWS..."/>}</object>
\]

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

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

<table>
<thead>
<tr>
<th>Data Set</th>
<th>Total</th>
<th>Report Only</th>
<th>Unsafe Inline</th>
<th>Missing object-src</th>
<th>Wildcard in Whitelist</th>
<th>Unsafe Domain</th>
<th>Trivially Bypassable Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unique CSPs</td>
<td>26,011</td>
<td>2,591</td>
<td>21,947</td>
<td>3,131</td>
<td>5,763</td>
<td>19,719</td>
<td>24,637</td>
</tr>
<tr>
<td></td>
<td></td>
<td>9.96%</td>
<td>84.38%</td>
<td>12.04%</td>
<td>22.12%</td>
<td>75.81%</td>
<td>94.72%</td>
</tr>
<tr>
<td>XSS Policies</td>
<td>22,425</td>
<td>0</td>
<td>19,652</td>
<td>2,109</td>
<td>4,816</td>
<td>17,754</td>
<td>21,232</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0%</td>
<td>87.63%</td>
<td>9.4%</td>
<td>21.48%</td>
<td>79.17%</td>
<td>94.68%</td>
</tr>
<tr>
<td>Strict XSS</td>
<td>2,437</td>
<td>0</td>
<td>348</td>
<td>14.28%</td>
<td>0%</td>
<td>1,015</td>
<td>1,243</td>
</tr>
<tr>
<td>Policies</td>
<td></td>
<td>0%</td>
<td>0%</td>
<td>41.65%</td>
<td>0%</td>
<td>51.05%</td>
<td>51.05%</td>
</tr>
</tbody>
</table>
Using script gadgets to bypass CSP

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

```html
<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

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

```php
<?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

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

```
<!-- attacker provided -->
<div data-role="button" data-text="&lt;script src='//attacker.org/js'&gt;&lt;/script&gt;"</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='&lt;script&gt;alert(1)&lt;/script&gt;'></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!
More sophisticated Clickjacking

• Follow the mouse movement with the iframe

• Gamify being Clickjacked

```javascript
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

https://google.com
https://attacker.com
https://google.com

X-Frame-Options: SAMEORIGIN
Clickjacking: Double Framing

Montag, 11. Dezember 2006


The grand Hillhilly Bank Robbery

Last Friday a team from our research group ("the ClInsects") participated at the annual ICF, a Capture the Flag contest held UCSB. As always it was a blast.

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

- finally!

CSP - Enforcing TLS connections

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  - Effectively blocks any HTTP resources from being loaded
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  - Will not load HTTP resources when page itself is run via HTTPS
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- Option 3: upgrade-insecure-requests
  - Browser automatically rewrites all HTTP URLs to HTTPS
  - seamless migration from HTTP to HTTPS

CSP - Adoption in the Wild

![Graph showing CSP adoption in the wild](image)

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Credits

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