Breaking privacy and security by abusing cross-origin resource size

by Tom Van Goethem

DistriNet

Overview

- Introduction
  - Web 101; same-origin policy
- Exposing cross-origin resource size
  - Browser-based timing attacks
  - Browser cache
  - TCP windows
- Defence mechanisms

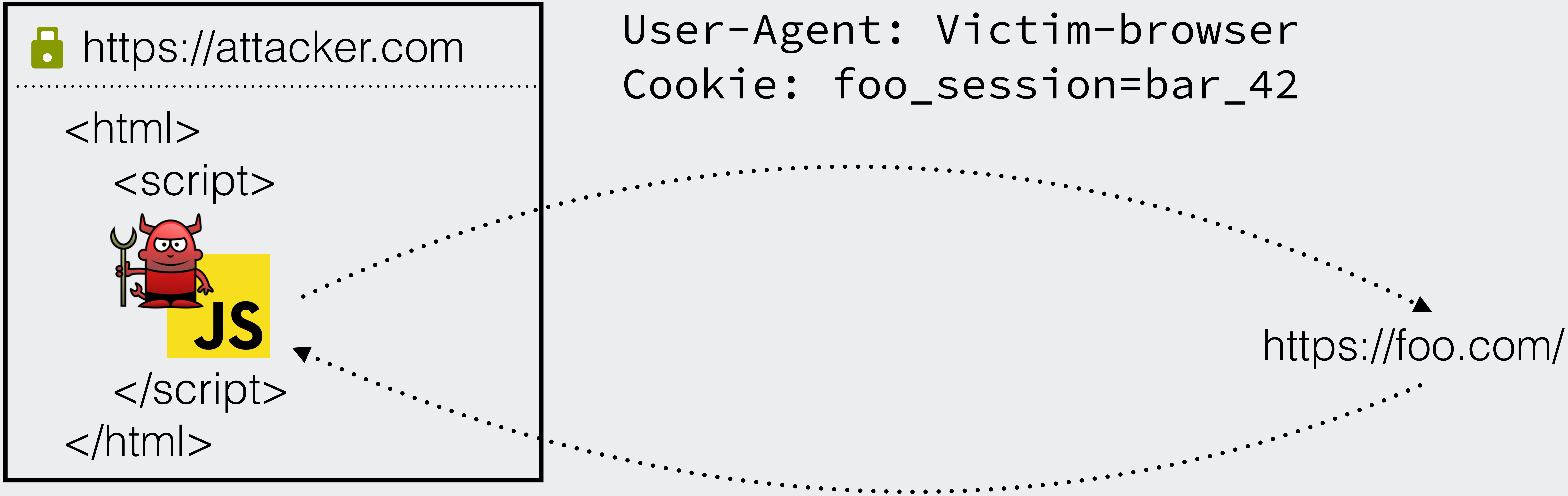
Introduction

- What happens when I open https://twitter.com/?
  - DNS resolution of twitter.com
  - TCP connection to 199.16.156.198:443
  - set up SSL connection
  - send `GET /` request with headers (`User-Agent`, `Cookie`, ...)
  - receive response for `/`
  - parse & render HTML
  - fetch other resources (JS, IMG, CSS, ...), possibly from other origins
  - cache resources
  - ???


I DON'T KNOW. WHAT DO I KNOW ABOUT IT?
ALL I KNOW IS WHAT'S ON THE INTERNET.
MARCH 13

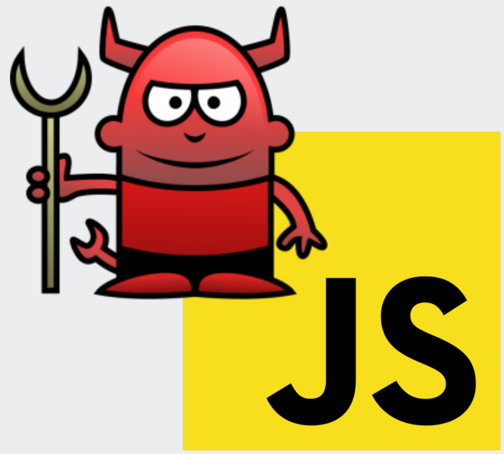
- What happens when I open https://attacker.com/?
  - DNS resolution of attacker.com
  - TCP connection to 13.33.33.37:443
  - set up SSL connection
  - send `GET /` request with headers (`User-Agent`, `Cookie`, ...)
  - receive response for `/`
  - parse & render HTML
  - **fetch other resources (JS, IMG, CSS, ...), possibly from other origins**
  - cache resources
  - **???**

```
GET / HTTP/1.1
Host: foo.com
User-Agent: Victim-browser
Cookie: foo_session=bar_42
```

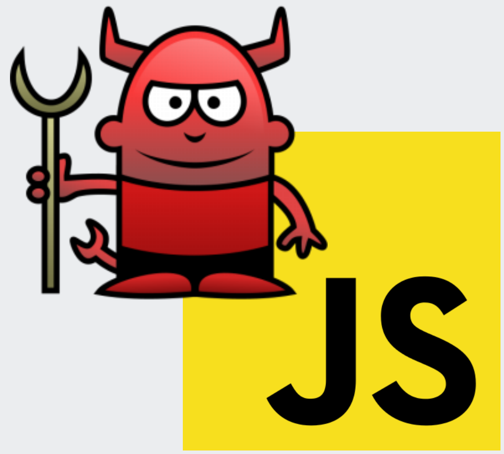



```
HTTP/1.1 200 OK
Content-Type: text/html
Content-Length: 6720

<html><head><title>...
```

```
// using <img>
let i = new Image();
i.src = 'https://foo.com/';

// using <video>
let v = document.createElement('video');
v.src = 'https://foo.com/'
```




```
// using Fetch API
let opts = {
    "mode": "no-cors",          // don't use CORS
    "credentials": "include"    // attach cookies
};
fetch('https://foo.com/', opts).then(function(resp) {
    console.log('yay! a response!');
});
```



Can not access content of cross-origin resources

```
GET / HTTP/1.1
Host: foo.com
User-Agent: Victim-browser
Cookie: foo_session=bar_42
```

John Smith

web server
for foo.com

```
HTTP/1.1 200 OK
Content-Type: text/html
Content-Length: 6720

<html>
  <head>
    <title>Welcome, Mr. Smith</title>
...
```


WHERE'S THE
BIRTH
CERTIFICATE

```
GET /search?q=delete+emails HTTP/1.1
Host: clinton-mail.com
User-Agent: Hillary
Cookie: sess=3727c5a4c0a97e98
```

clinton-mail.com

```
HTTP/1.1 200 OK
Content-Type: text/html
Content-Length: 536720

<html>
  <head>
    <title>8410 results</title>
...
```

```
GET /search?q=email+security HTTP/1.1
Host: clinton-mail.com
User-Agent: Hillary
Cookie: sess=3727c5a4c0a97e98
```

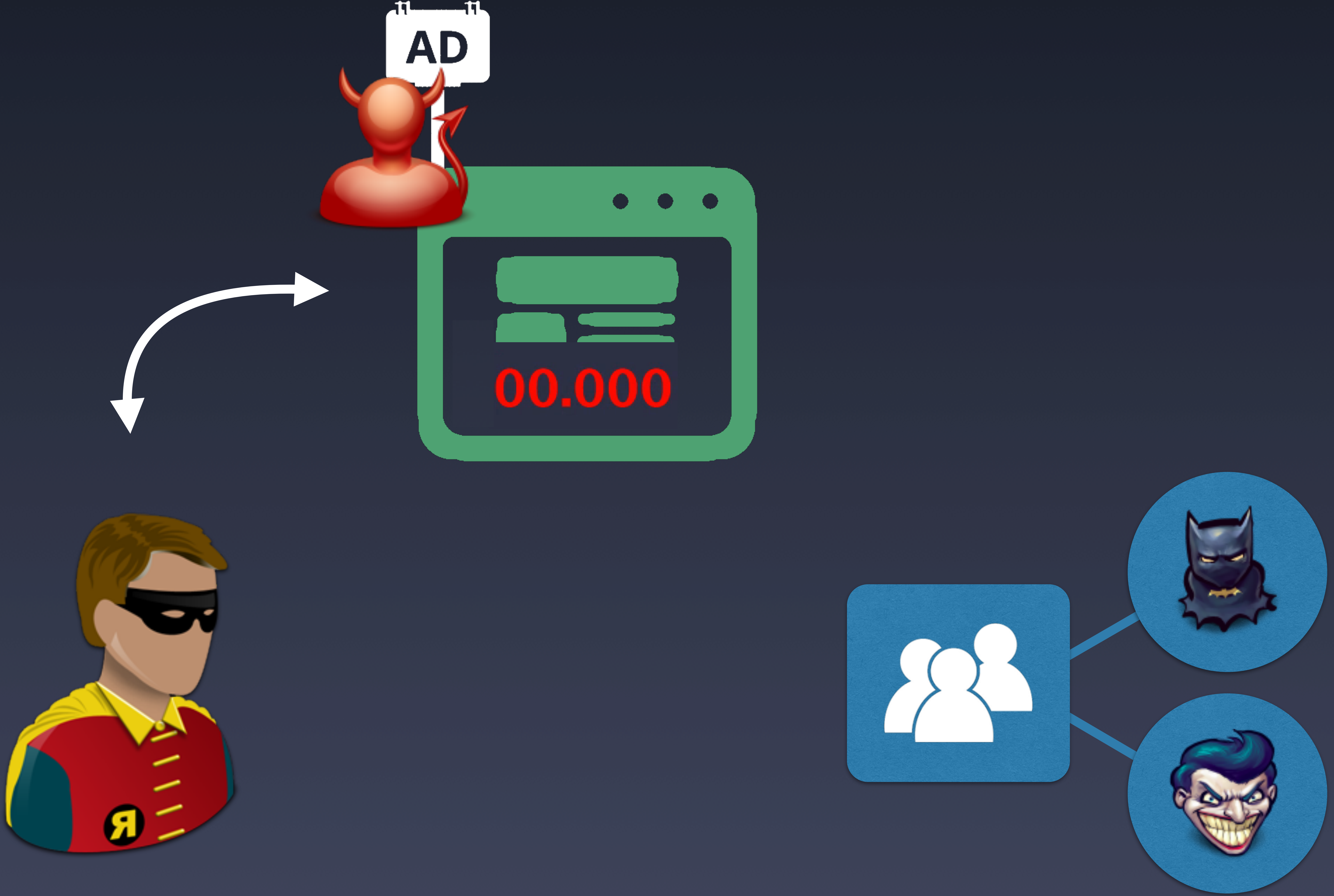
clinton-mail.com

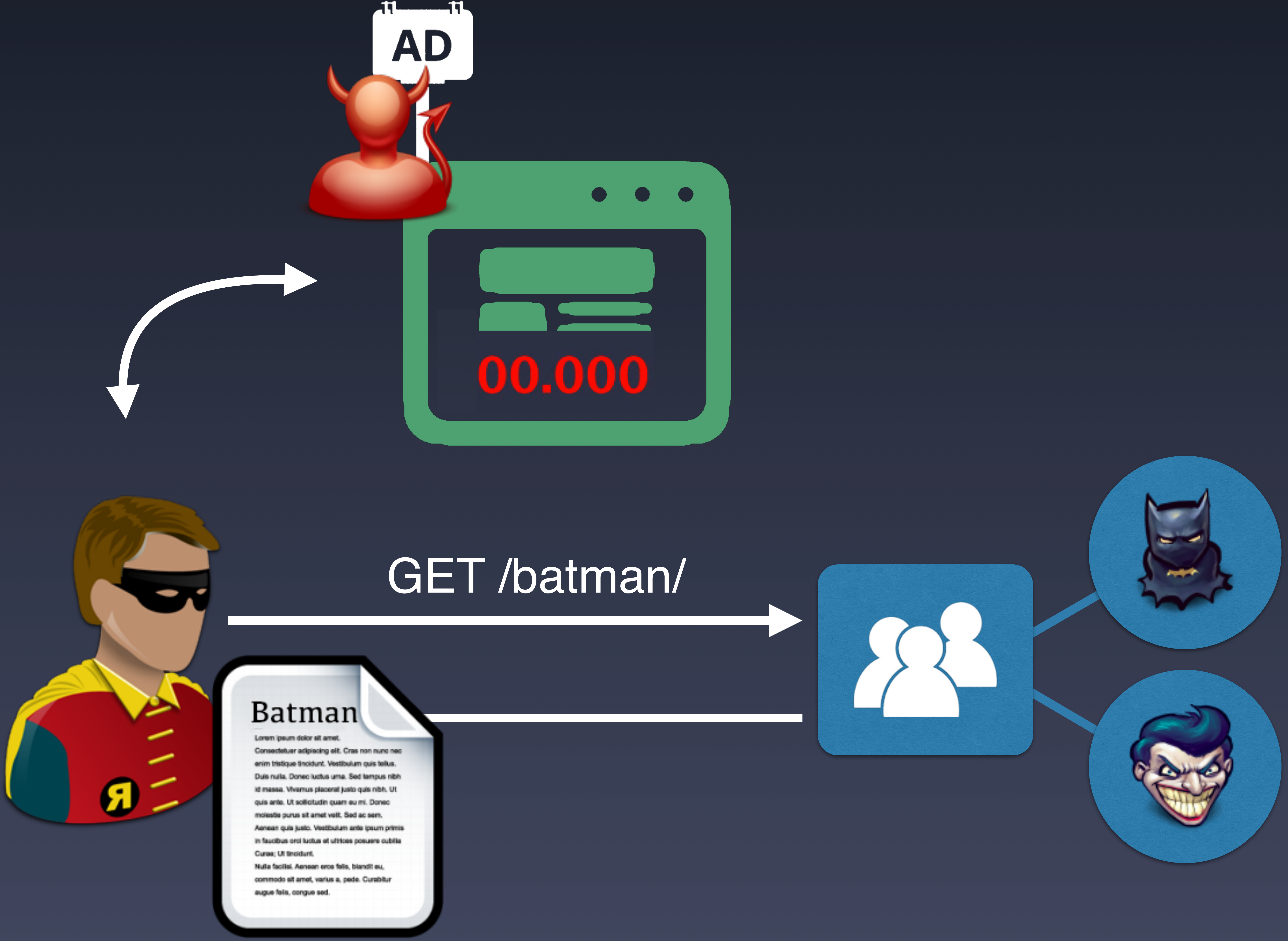
```
HTTP/1.1 200 OK
Content-Type: text/html
Content-Length: 29154

<html>
  <head>
    <title>5 results</title>
...
```

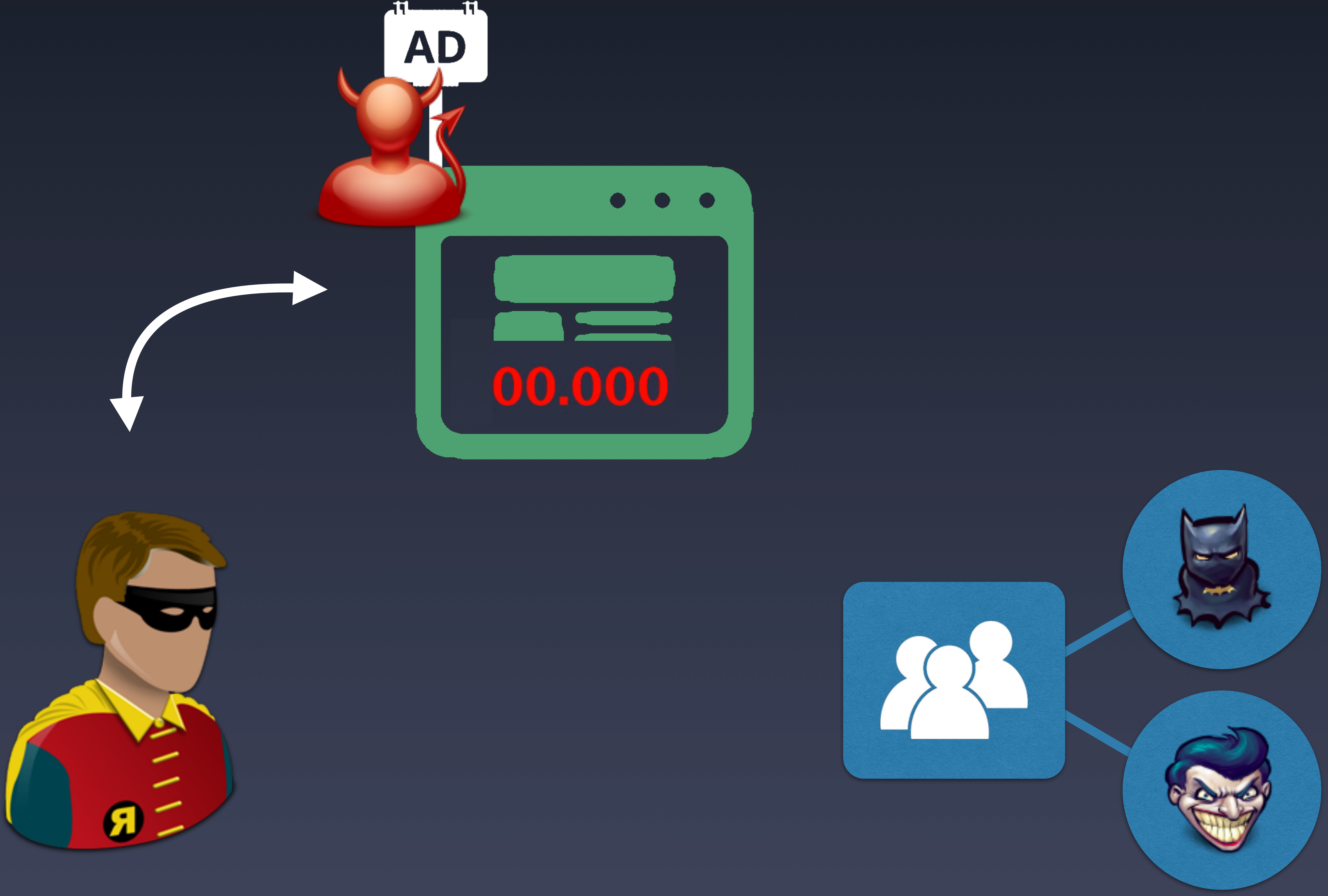
Content-Length: 29154

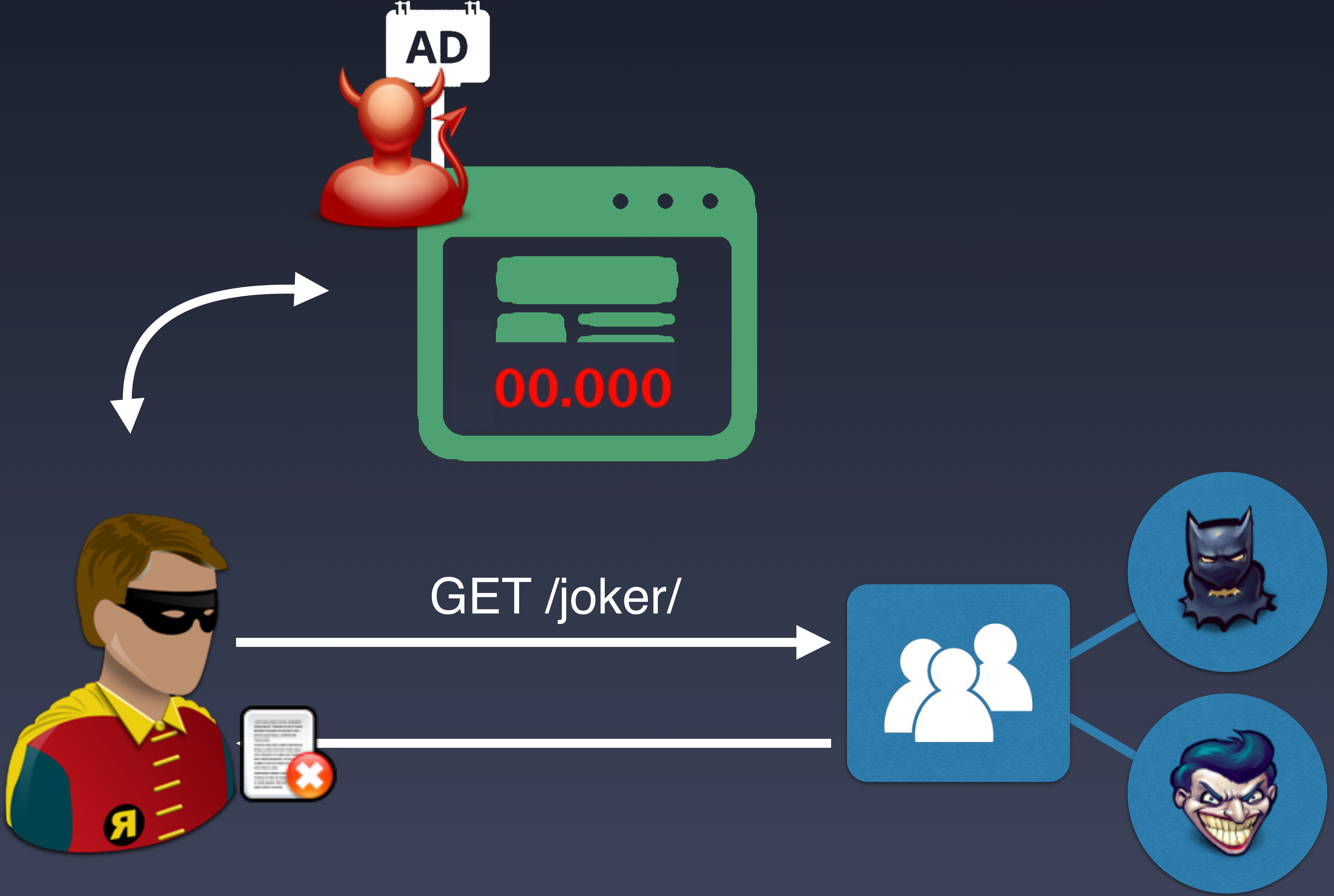
Exposing cross-origin resource size

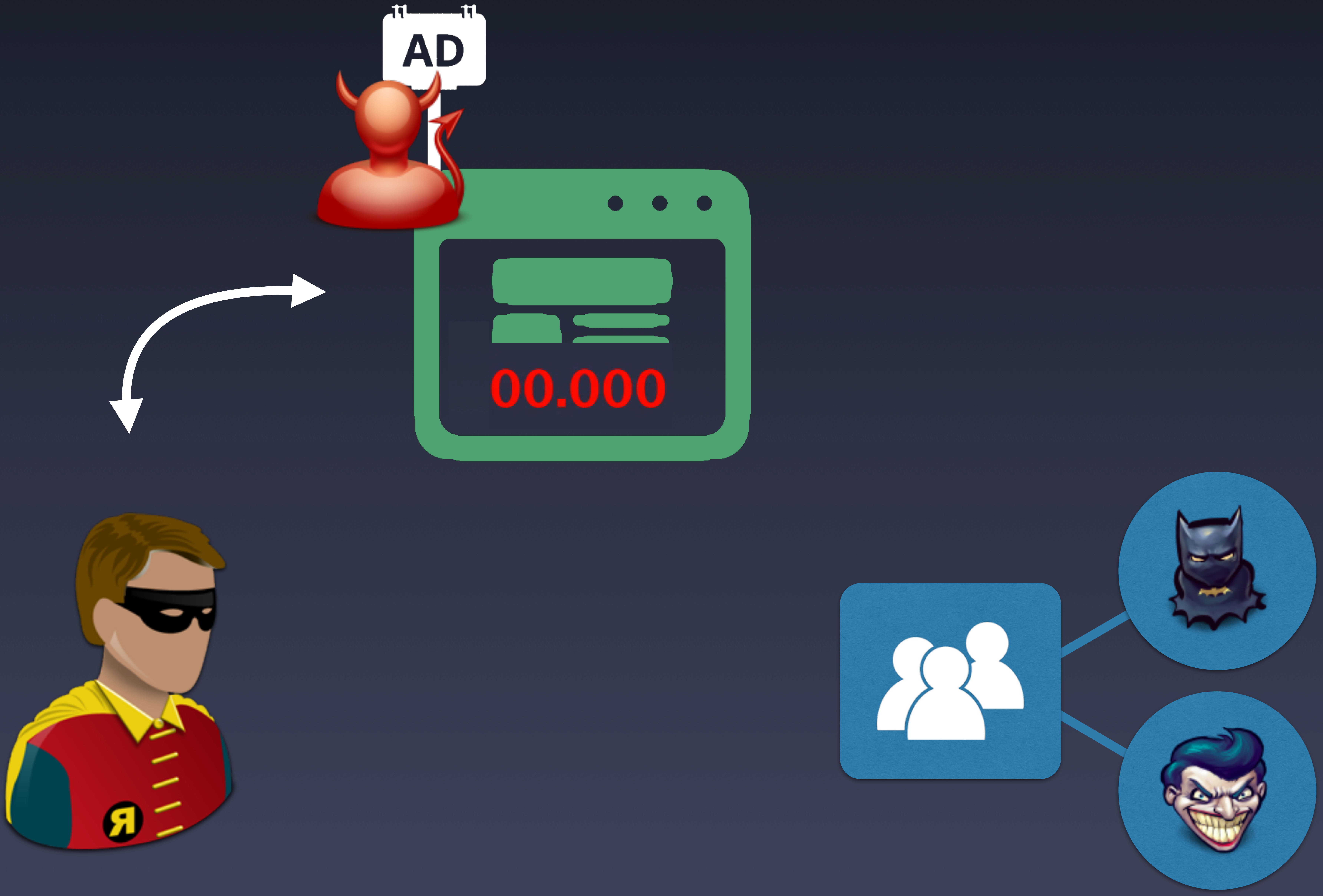
Timing attacks

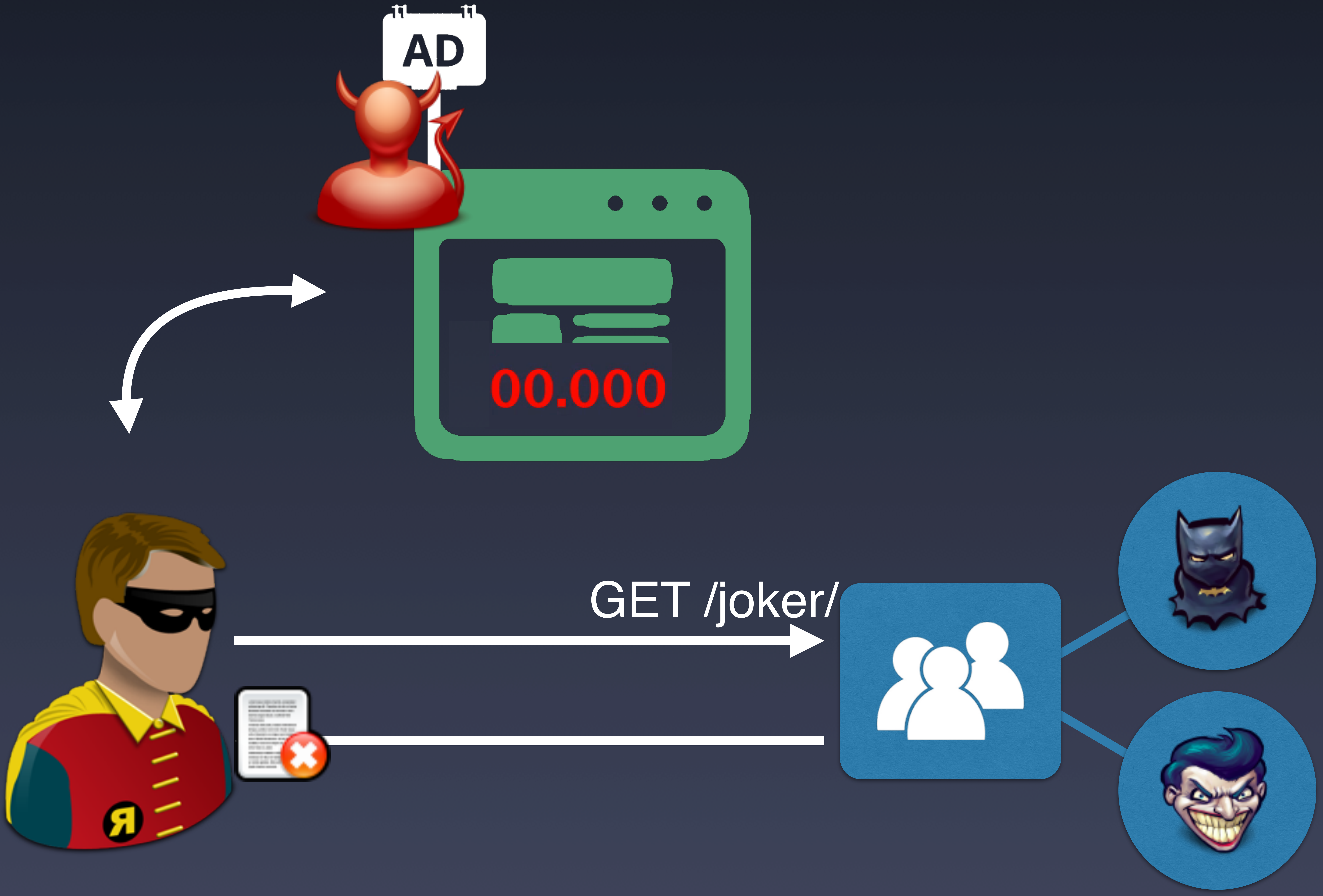

AD
00.000


AD
00.000
GET /batman/
Batman


AD
00.000


AD
00.000
GET /joker/


AD
00.000


AD
00.000
GET /joker/

Classic Cross-site Timing Attacks

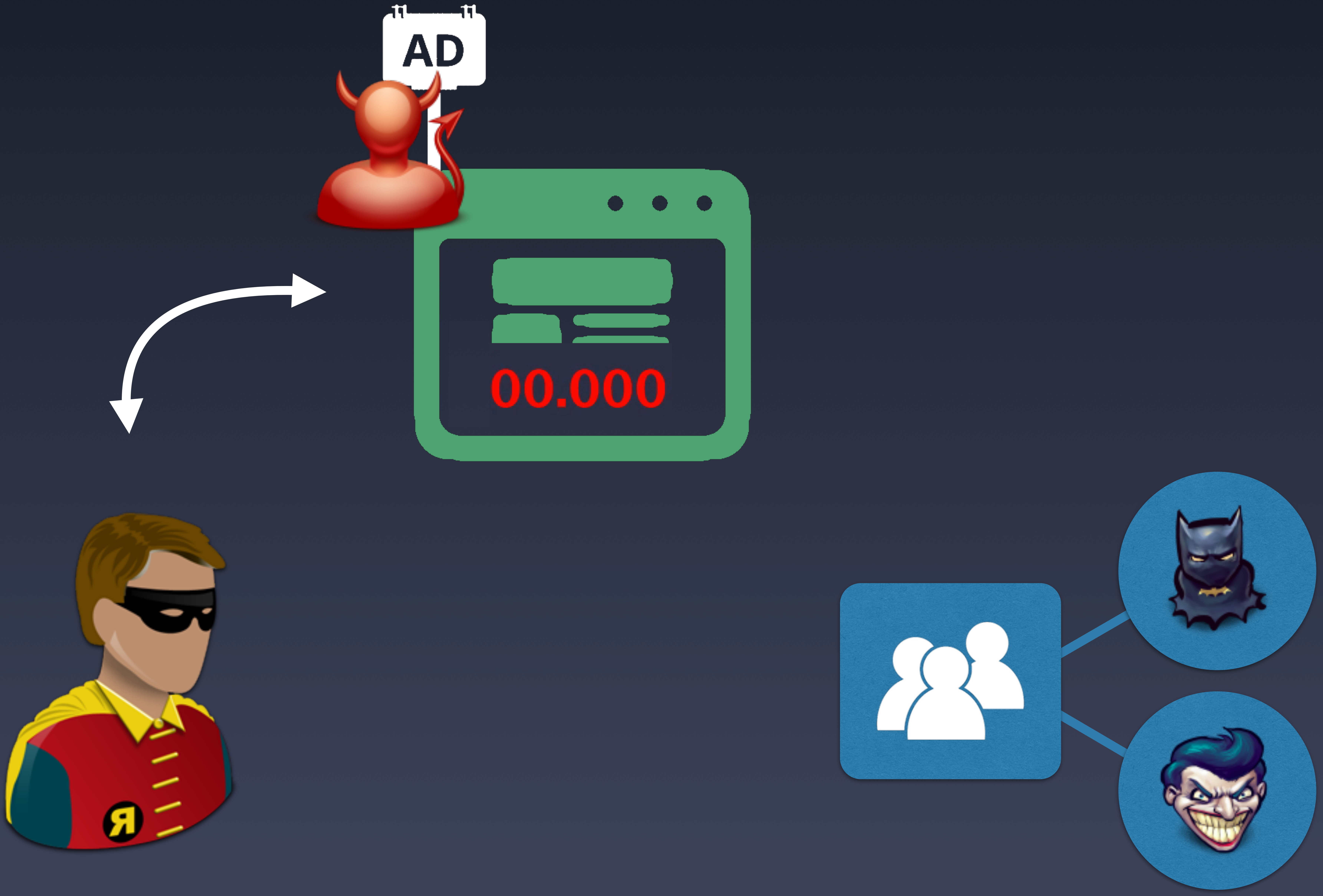
- Classic timing attacks have several limitations
  - Network irregularities
  - gzip compression
  - Round-trip for each measurement
  - Rate-limiting

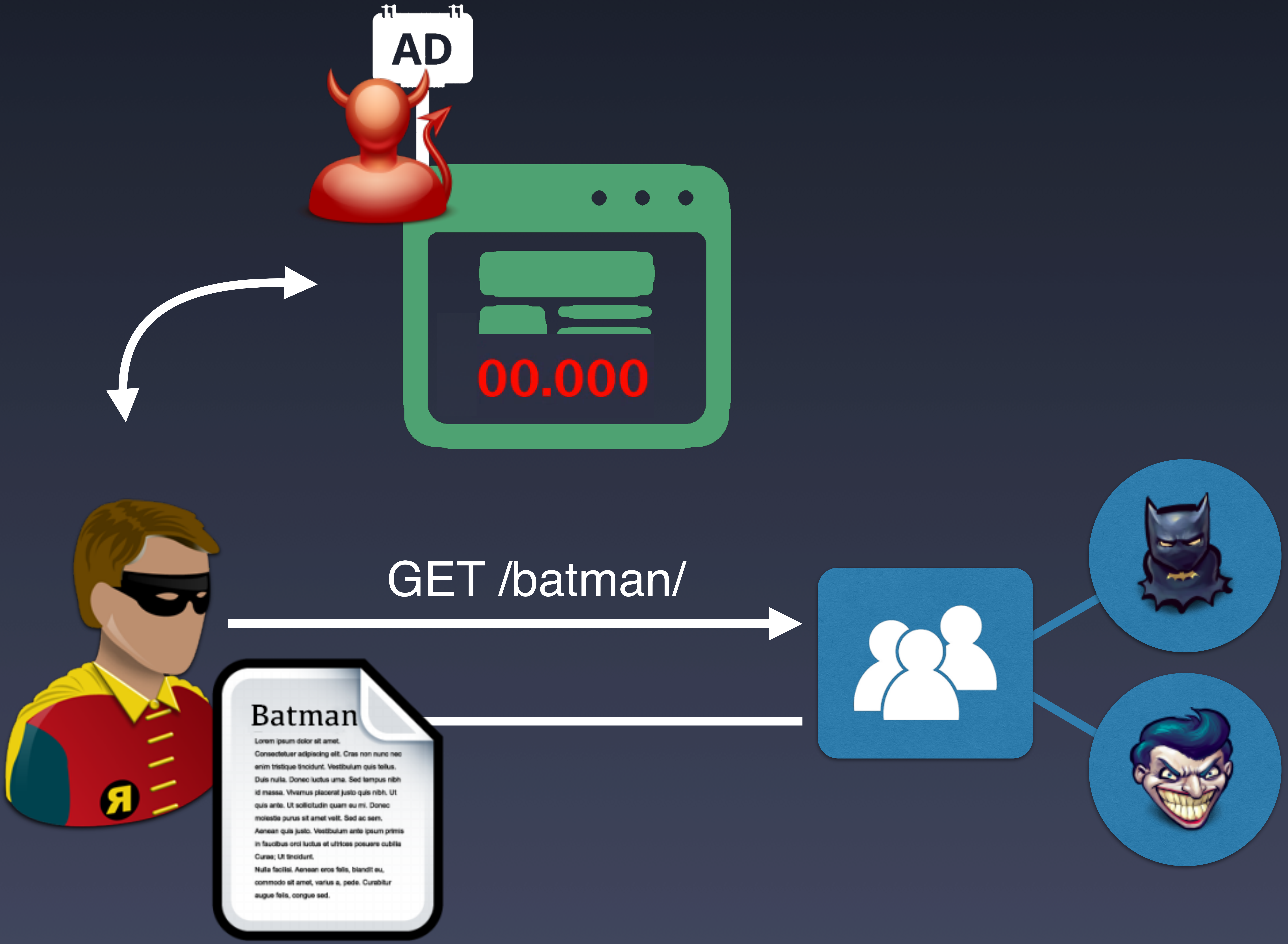
Browser-based Timing Attacks

- Timing attacks in browsers overcome these limitations
  - Timing measurement starts *after* resource is downloaded
  - Measurements are more accurate
  - For some attacks: resource is only downloaded once
  - Obtain multiple measurements in short interval

Exposing cross-origin resource size

Browser-based timing attacks


AD
00.000


AD
00.000
GET /batman/
Batman

Browser-based Timing Attacks

- Side-channels allow measuring time to process resource
  - Parse as specific format (~ CPU processing time)
  - Retrieve from cache (~ disk read time)
  - Store in cache (~ disk write time)

Video Parsing Attack

```
let video = document.createElement('video');

// suspend => download complete
video.addEventListener('suspend',function(){
    start = window.performance.now();
});

// error => parsing complete
video.addEventListener('error',function(){
    end = window.performance.now();
});

video.src = 'https://example.org/resource';
```

Video Parsing Attack

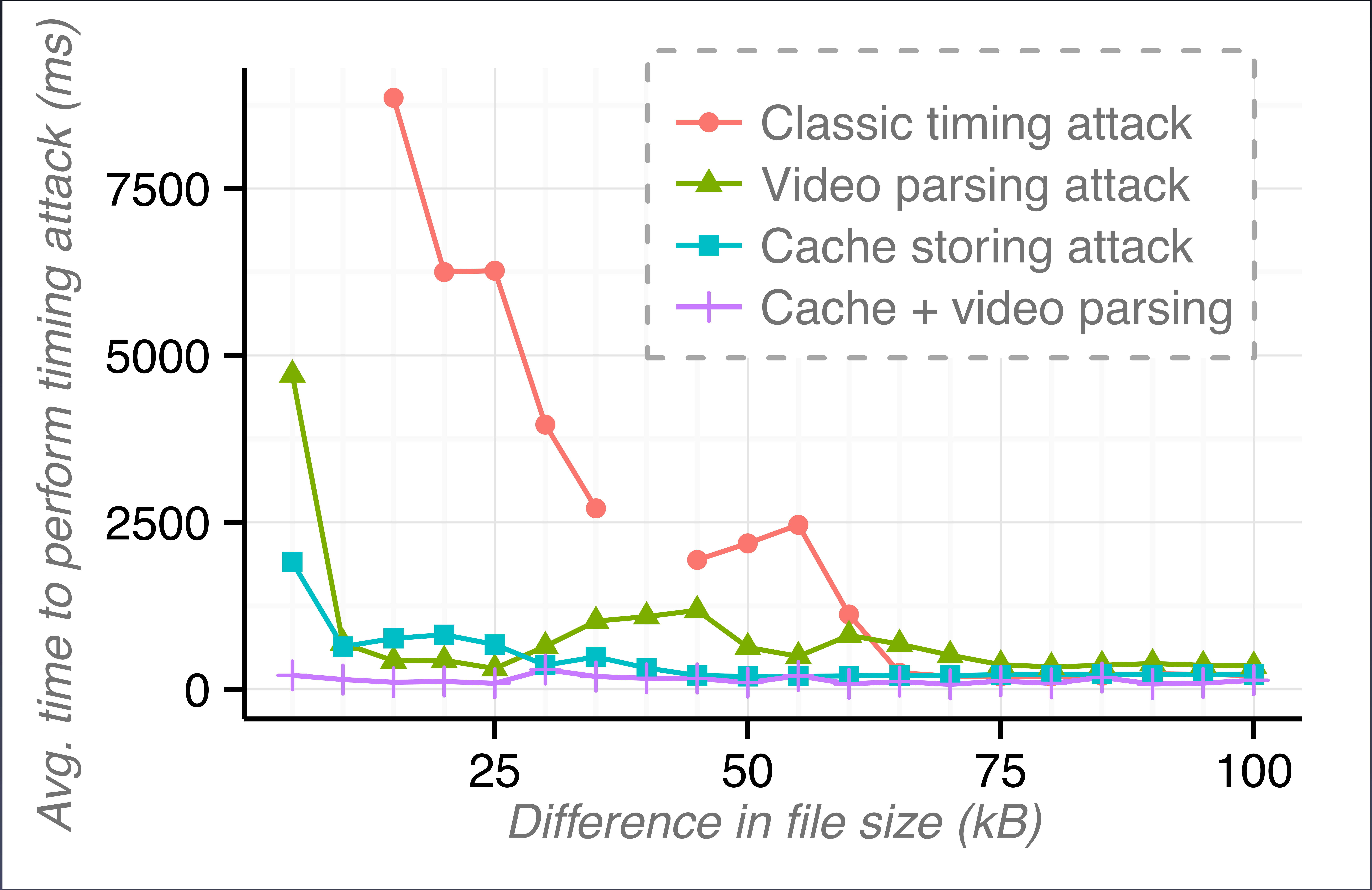
```
let video = document.createElement('video');

// suspend => download complete
video.addEventListener('suspend',function(){
    start = window.performance.now();
});

// error => parsing complete
video.addEventListener('error',function(){
    end = window.performance.now();
});

video.src = 'https://example.org/resource';
```

appcache.manifest

```
CACHE MANIFEST
CACHE:
https://example.org/resource
NETWORK:
*
```

Cache Storing Attack

```
let url = 'https://example.org/resource';
let opts = {credentials: "include", mode: "no-cors"};
let request = new Request(url, opts);
let bogusReq = new Request('/bogus');
fetch(request).then(function(resp) {
    // Resource download complete
    start = window.performance.now();
    return cache.put(foo, resp.clone())
}).then(function() {
    // Resource stored in cache
    end = window.performance.now();
});
```



Classic timing attack
Video parsing attack
Cache storing attack
Cache + video parsing
7500
5000
2500
0
25
50
75
100
Avg. time to perform timing attack (ms)
Difference in file size (kB)

Demo

Limit Visibility of this Post

Choose who can see your post on Facebook based on their demographic. For example, if you enter "Spanish" below, only people who have Spanish set as their language on Facebook or list Spanish as one of their languages on their Profile will be eligible to see your post on your Page, in News Feed and in Search. Learn more.

Locations: Enter country

- (•) Everywhere
- ( ) By State/Province
- ( ) By City

Gender:

- (•) All
- ( ) Men
- ( ) Women

Age: 13 - 65+

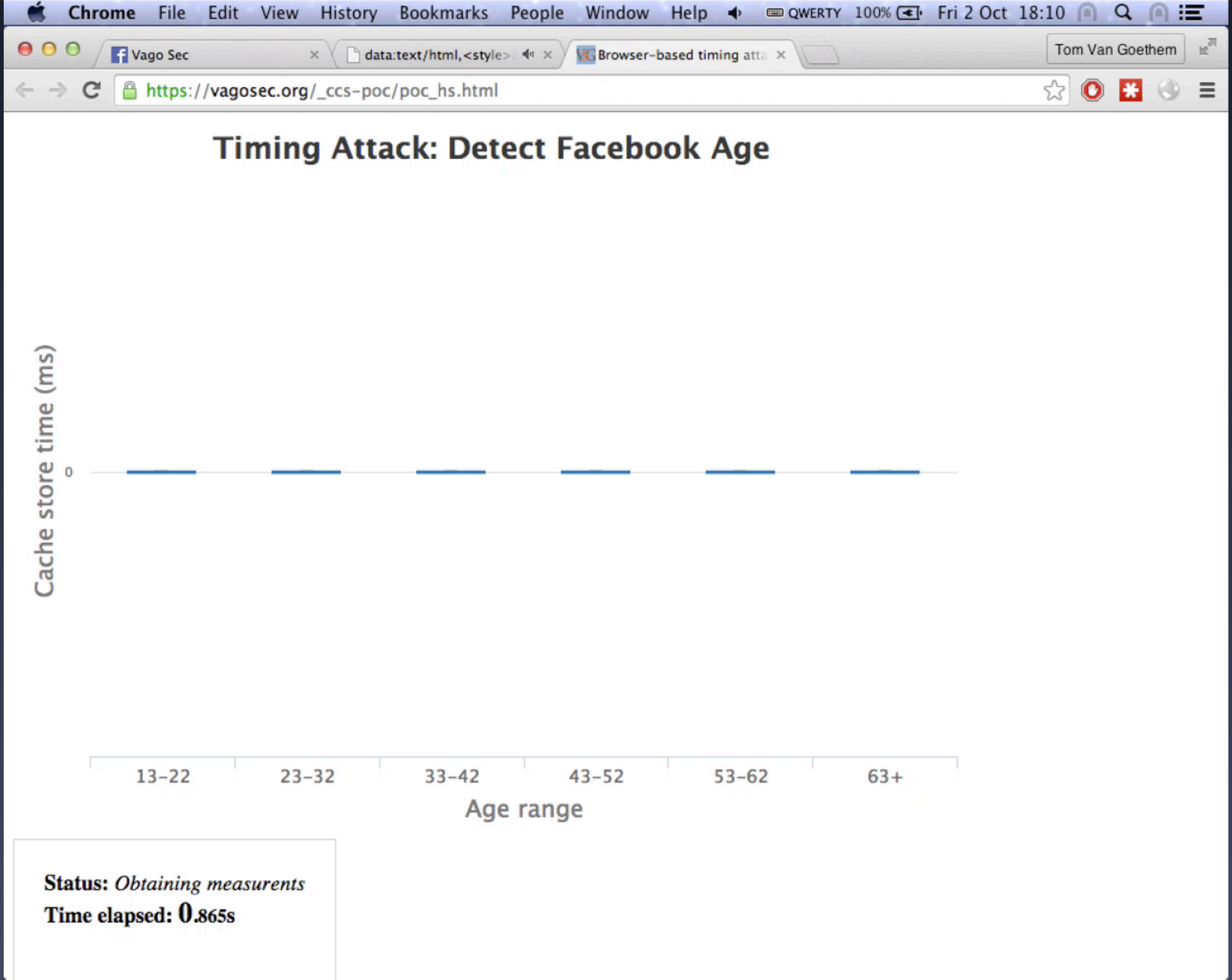
Languages: Enter language

Save Post Settings | Cancel

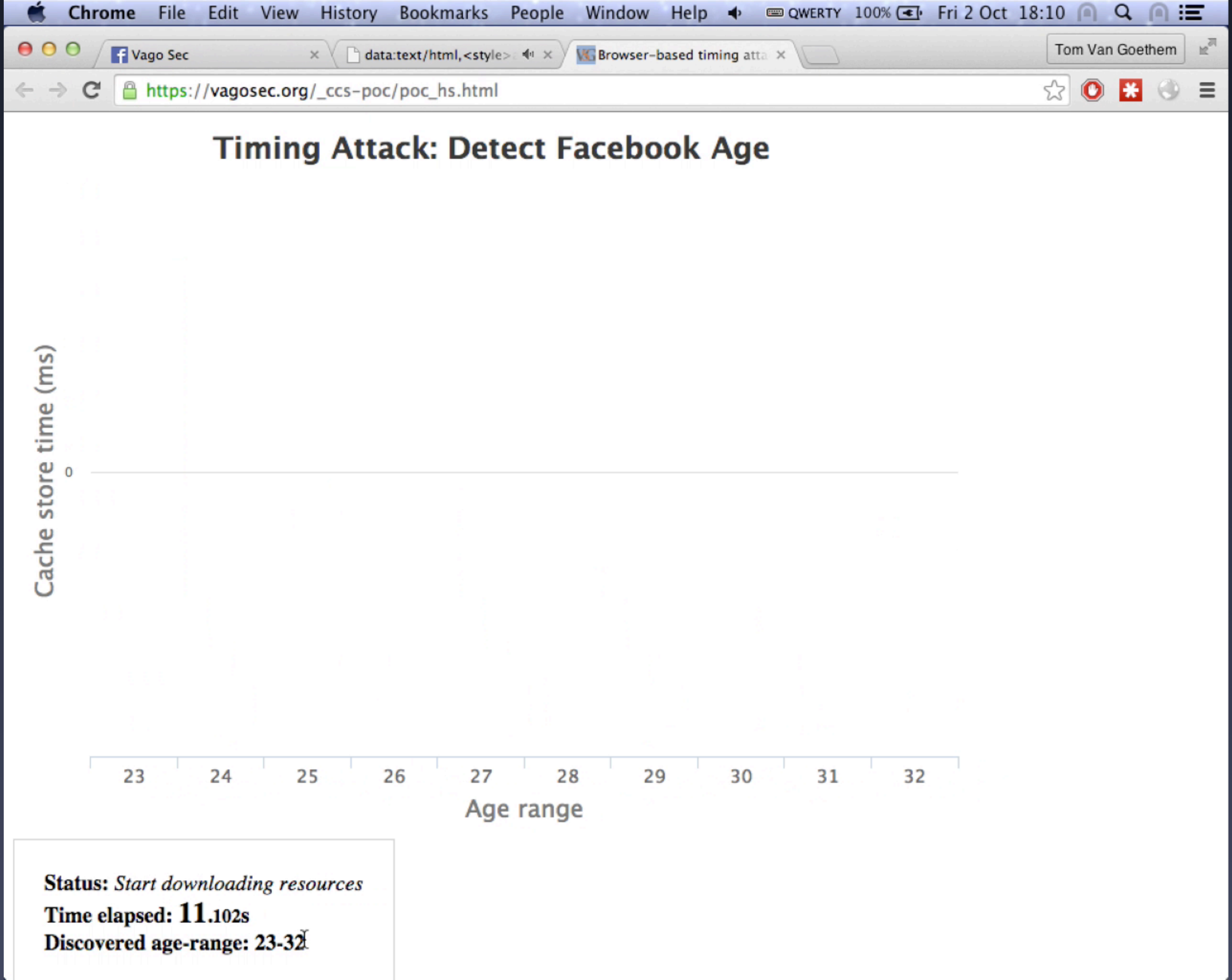
Age-discovery Attack

1. Create Facebook posts, each targeted to users of a specific age
2. Discover age-range of the user
    - Fetch corresponding resources
    - Obtain timing measurements
    - Determine age-range according to the value of timing measurements
3. Discover exact age of the user
    - Repeat (2) but for posts targeted to specific age

Chrome File Edit View History Bookmarks People Window Help
QWERTY 100% Fri 2 Oct 18:10
Vago Sec
data:text/html,<style>
Browser-based timing atta
Tom Van Goethem
https://vagosec.org/_ccs-poc/poc_hs.html
Timing Attack: Detect Facebook Age
Cache store time (ms)
0
13-22
23-32
33-42
43-52
53-62
63+
Age range
Status: Start downloading resources
Time elapsed: 0.52s



Chrome File Edit View History Bookmarks People Window Help
Fri 2 Oct 18:10
Vago Sec
data:text/html,<style>
Browser-based timing atta
Tom Van Goethem
https://vagosec.org/_ccs-poc/poc_hs.html
Timing Attack: Detect Facebook Age
Cache store time (ms)
0
13-22
23-32
33-42
43-52
53-62
63+
Age range
Status: Obtaining measurents
Time elapsed: 0.865s


Chrome File Edit View History Bookmarks People Window Help
QWERTY 100% Fri 2 Oct 18:10
Vago Sec
data:text/html,<style>
Browser-based timing atta
Tom Van Goethem
https://vagosec.org/_ccs-poc/poc_hs.html
Timing Attack: Detect Facebook Age
Cache store time (ms)
0
23
24
25
26
27
28
29
30
31
32
Age range
Status: Start downloading resources
Time elapsed: 11.102s
Discovered age-range: 23-32

https://labs.tom.vg/

Moar Attacks

- Facebook: demographics
- LinkedIn: connections, ...
- Twitter: following, identity, ...
- Google: search history
- Amazon: shopping history
- Gmail: inbox search
- ...

Exposing cross-origin resource size

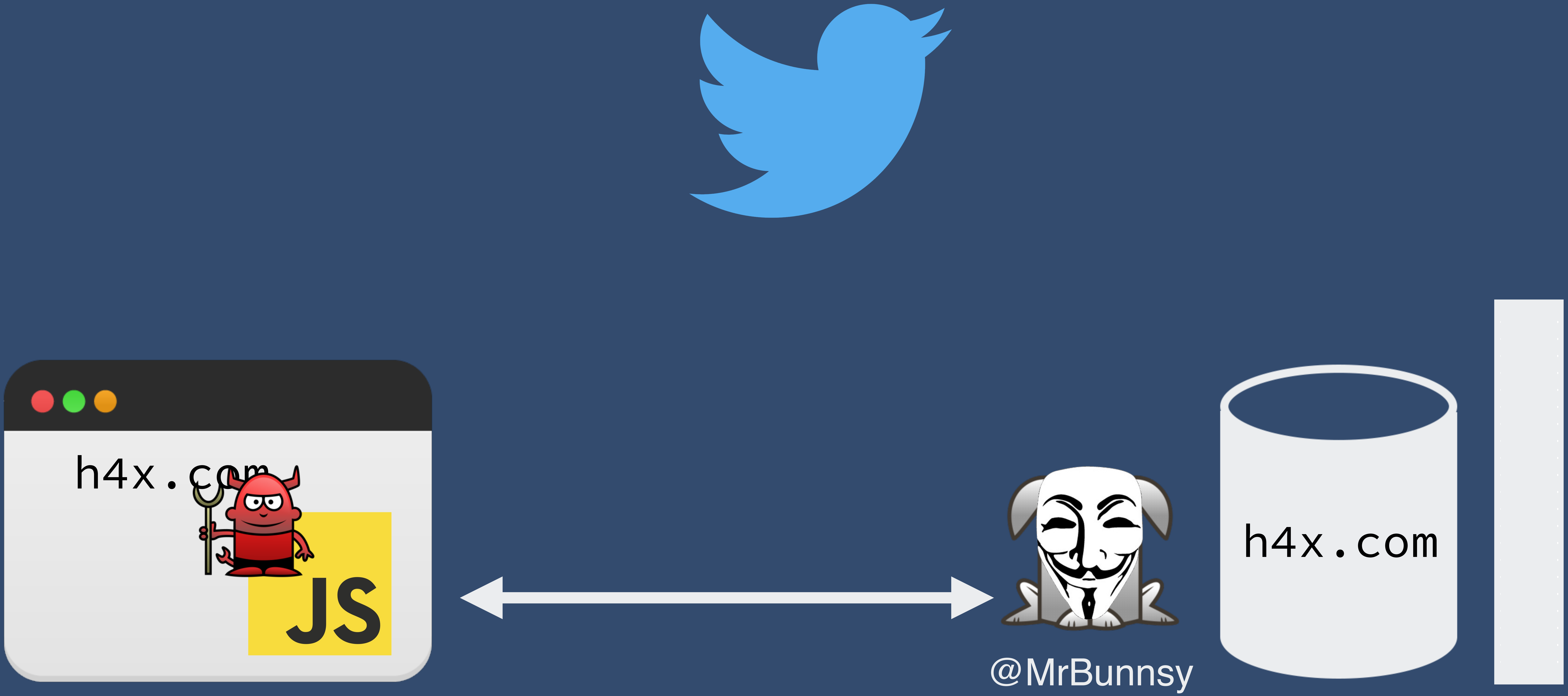
Browser cache

Browser Storage Side-Channel Attacks

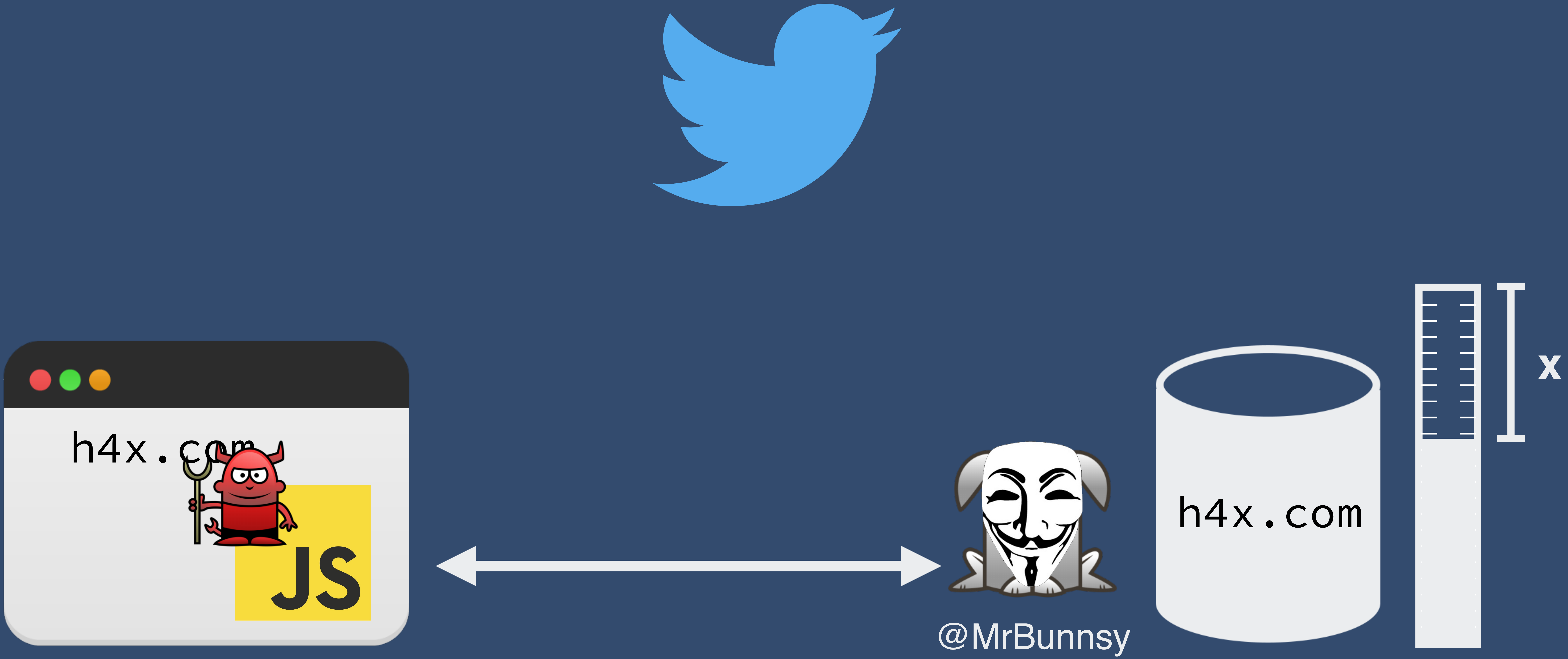
- Leverage browser's Cache API
  - Programmable cache
  - Store any (including cross-origin) resources in a cache
- Available space is limited per site
- Discovered 3 different attack techniques
  - Per-site quota, global quota, Quota Management/Storage APIs

Per-site quota

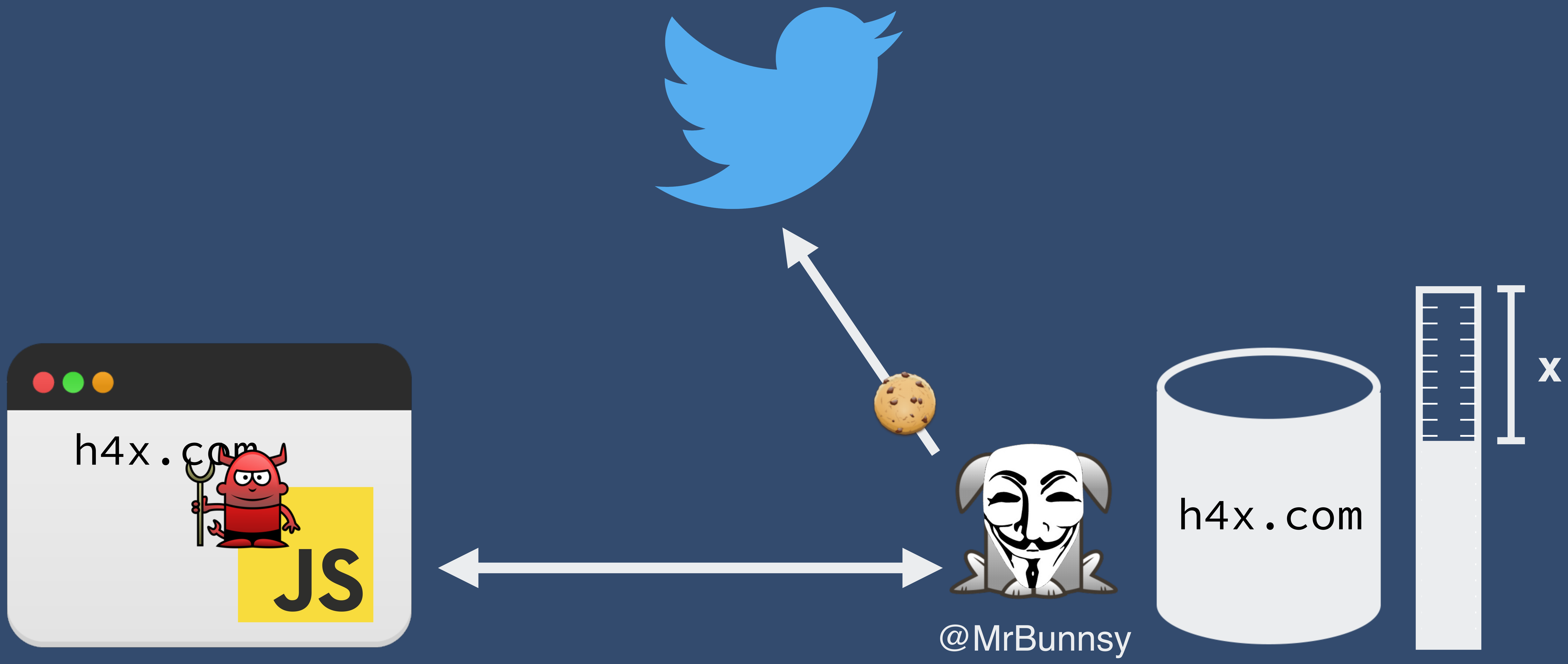
Per-site quota



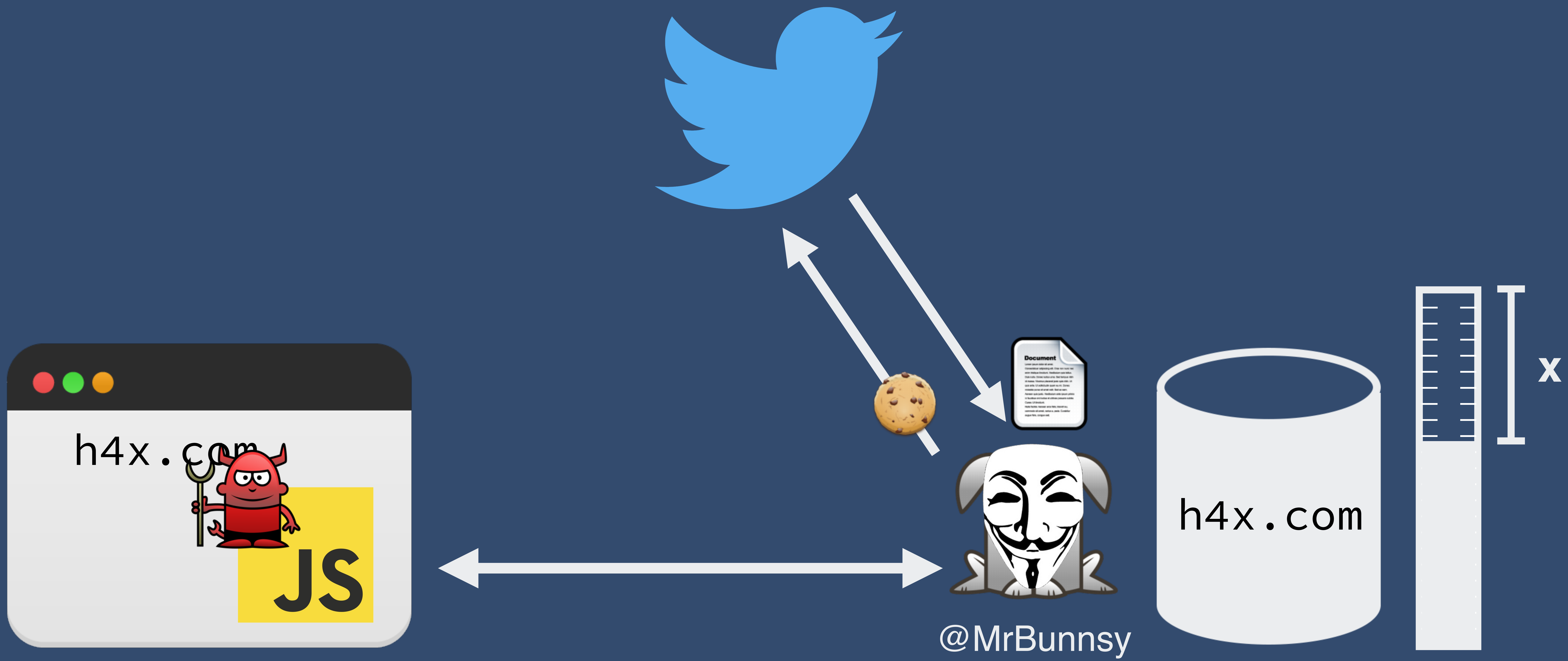
Per-site quota



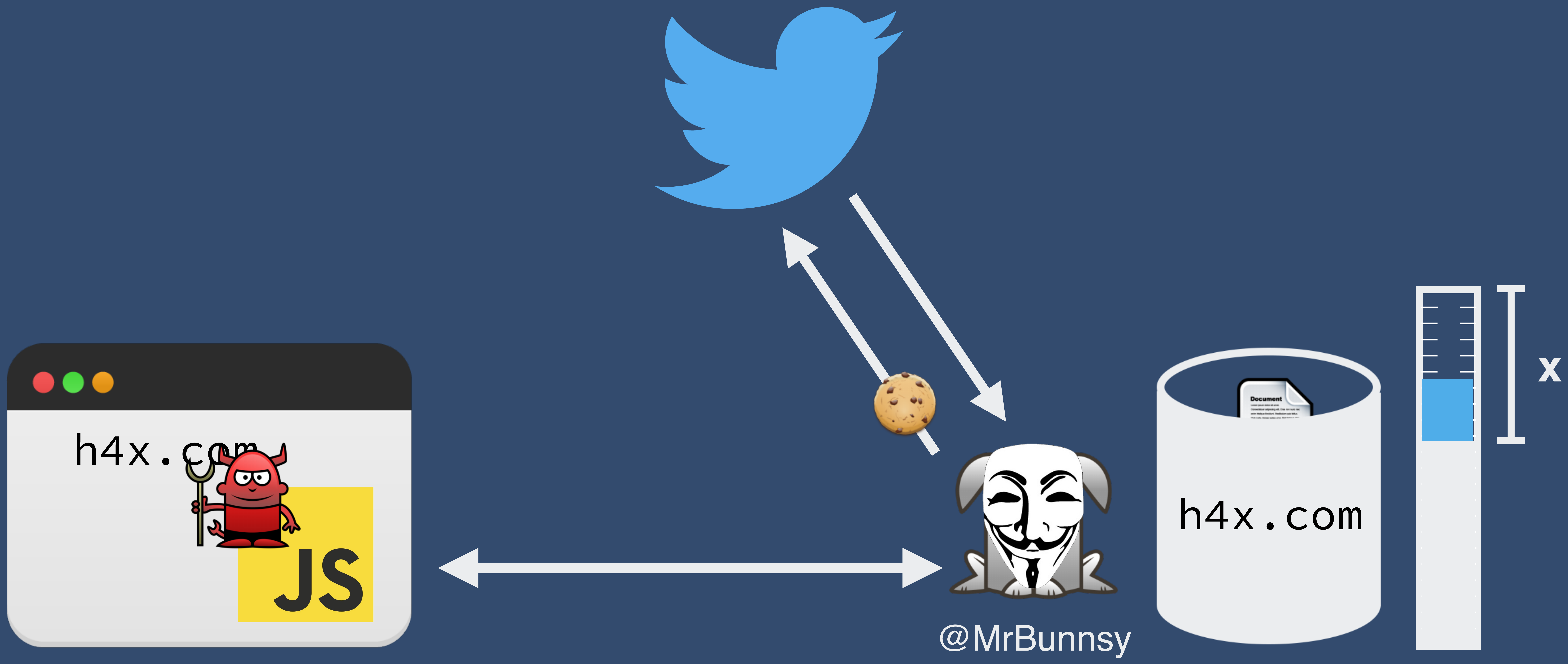
Per-site quota



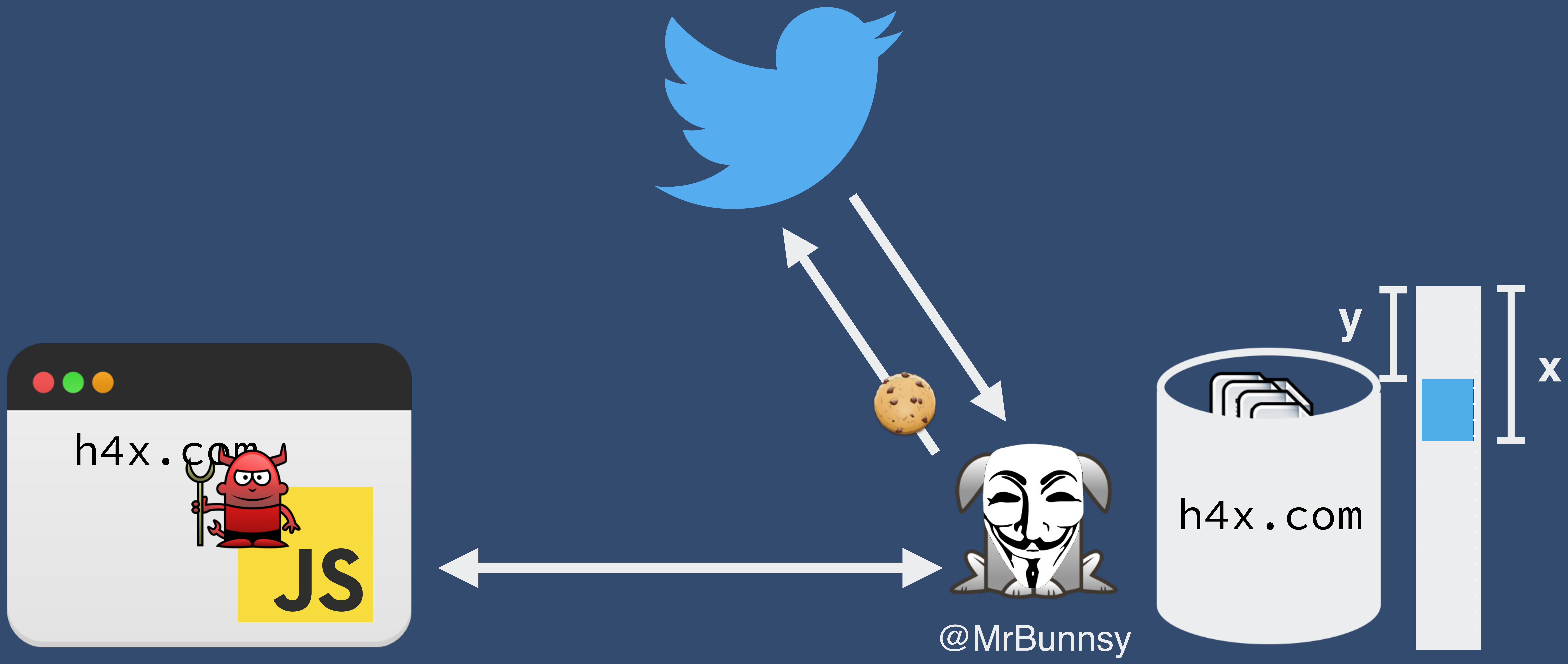
Per-site quota



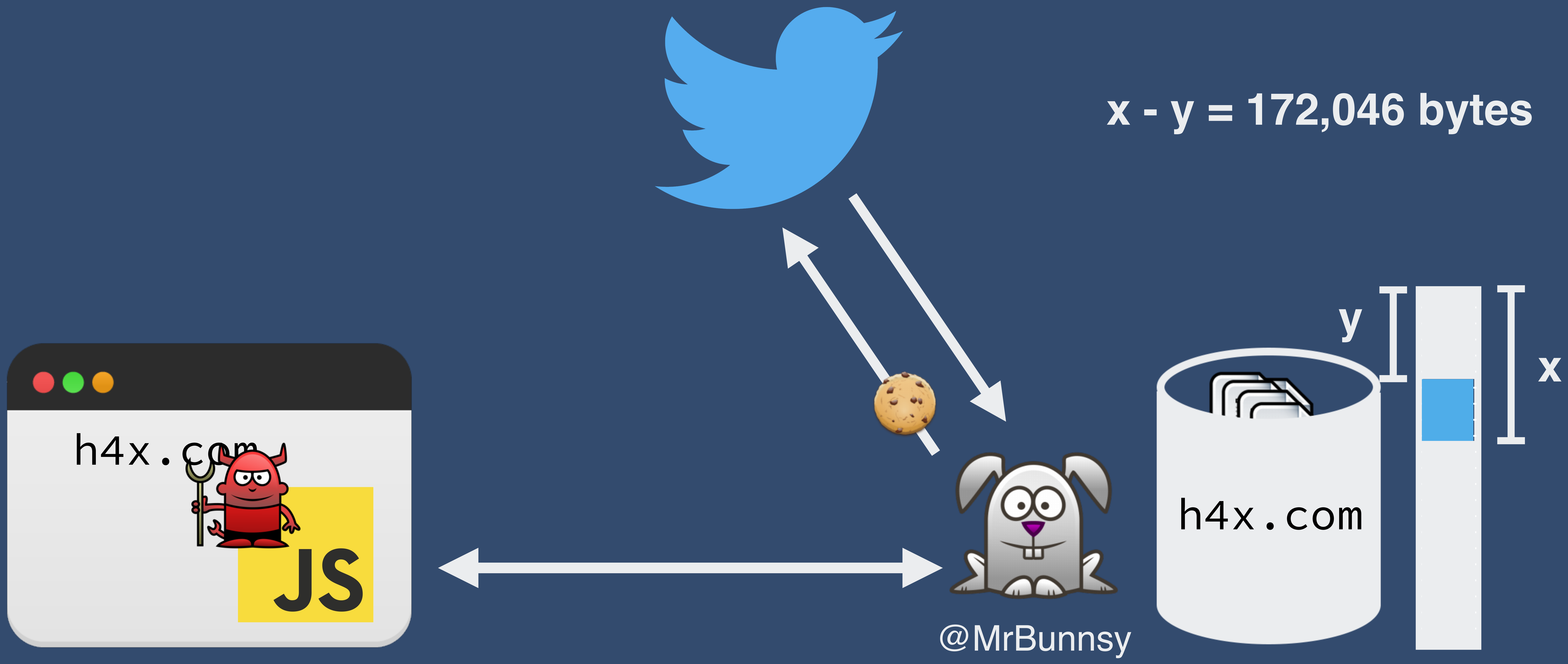
Per-site quota



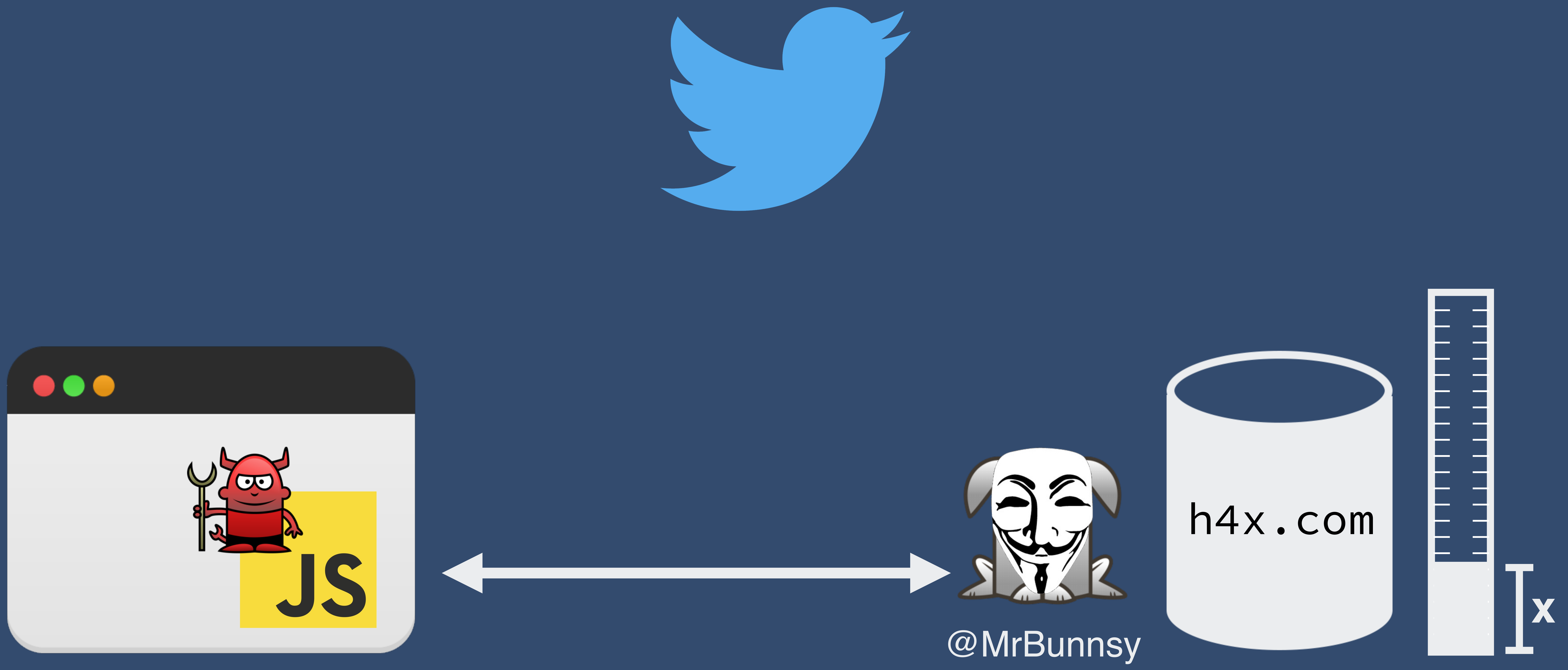
Per-site quota



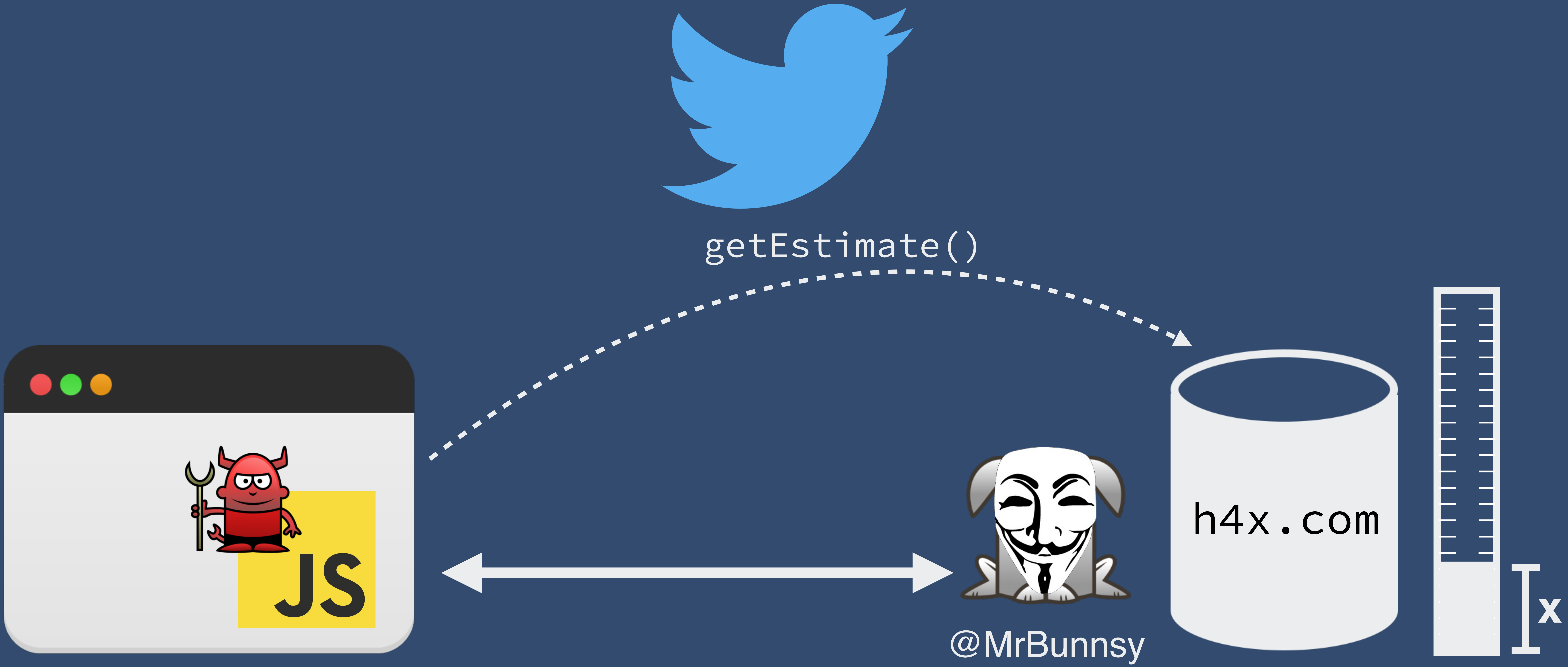
Per-site quota



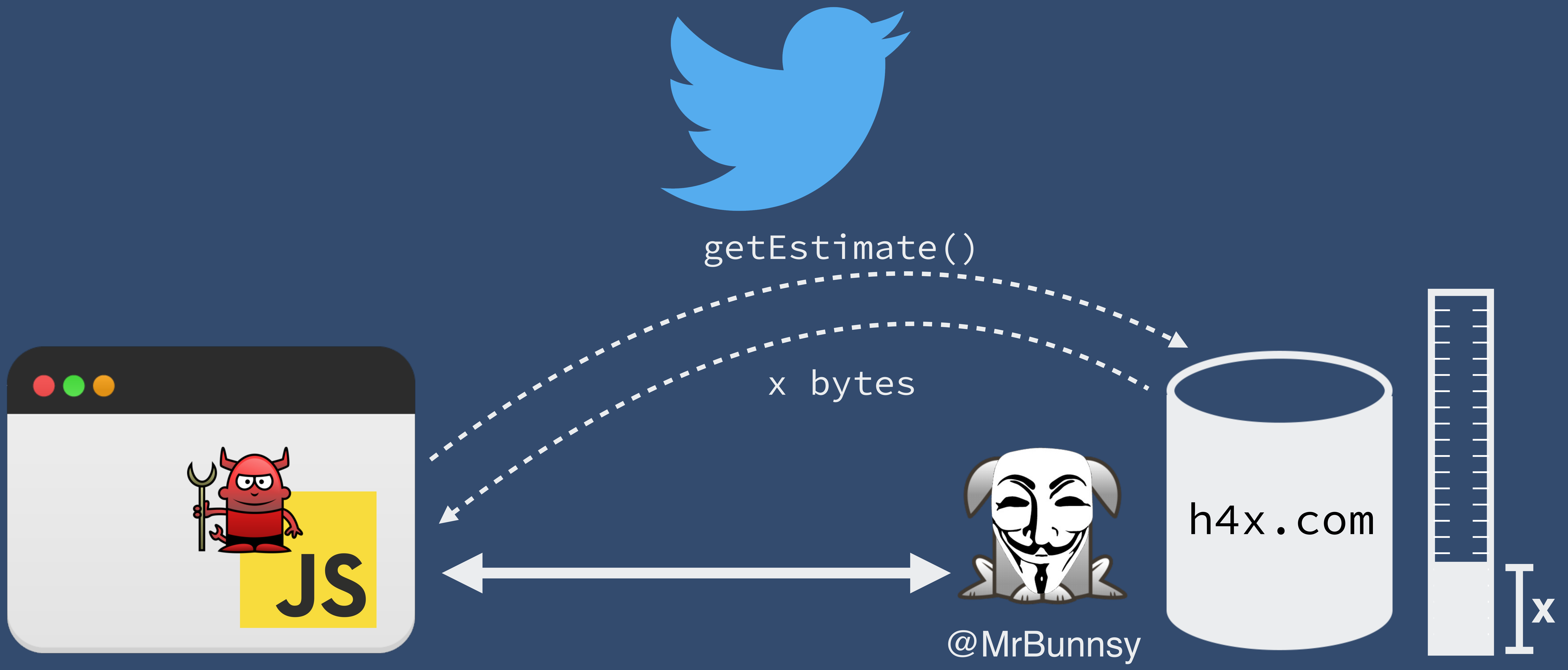
Quota Management/Storage APIs



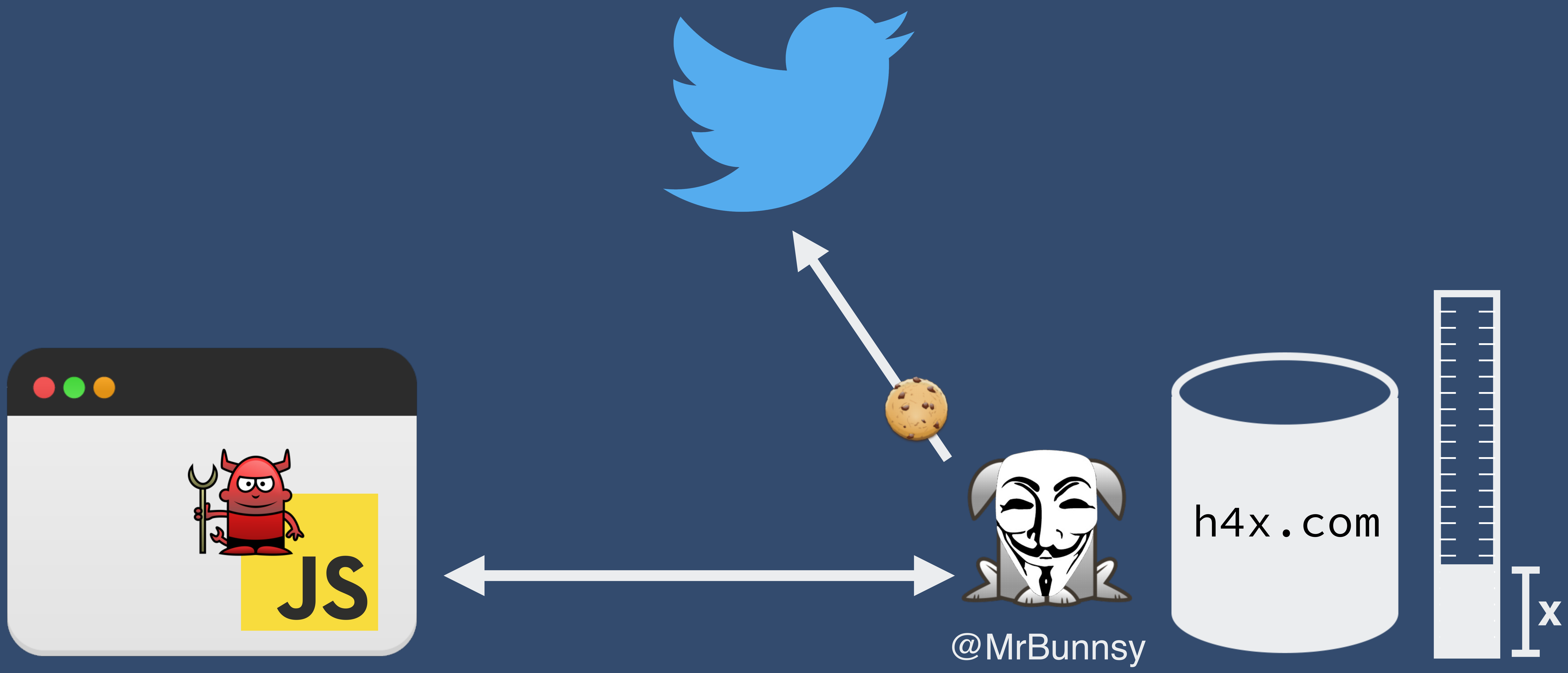
Quota Management/Storage APIs



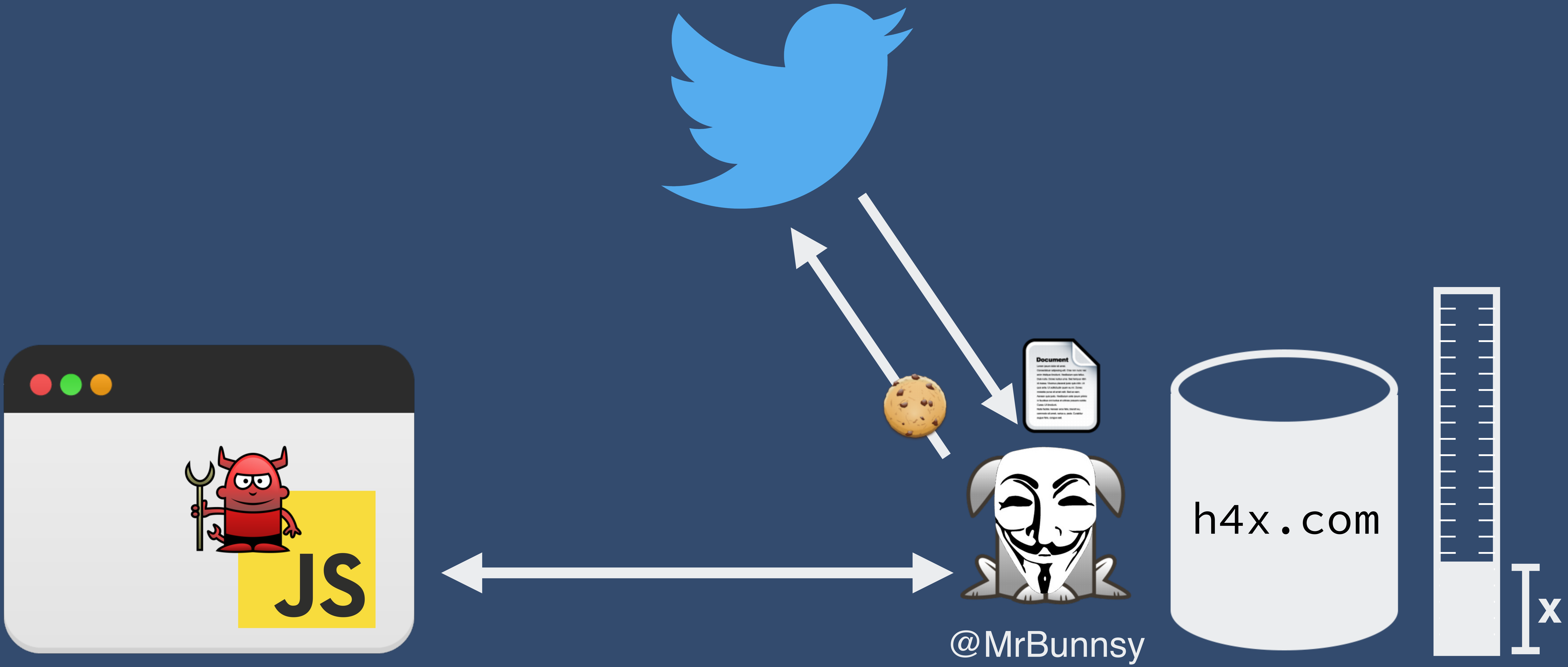
Quota Management/Storage APIs



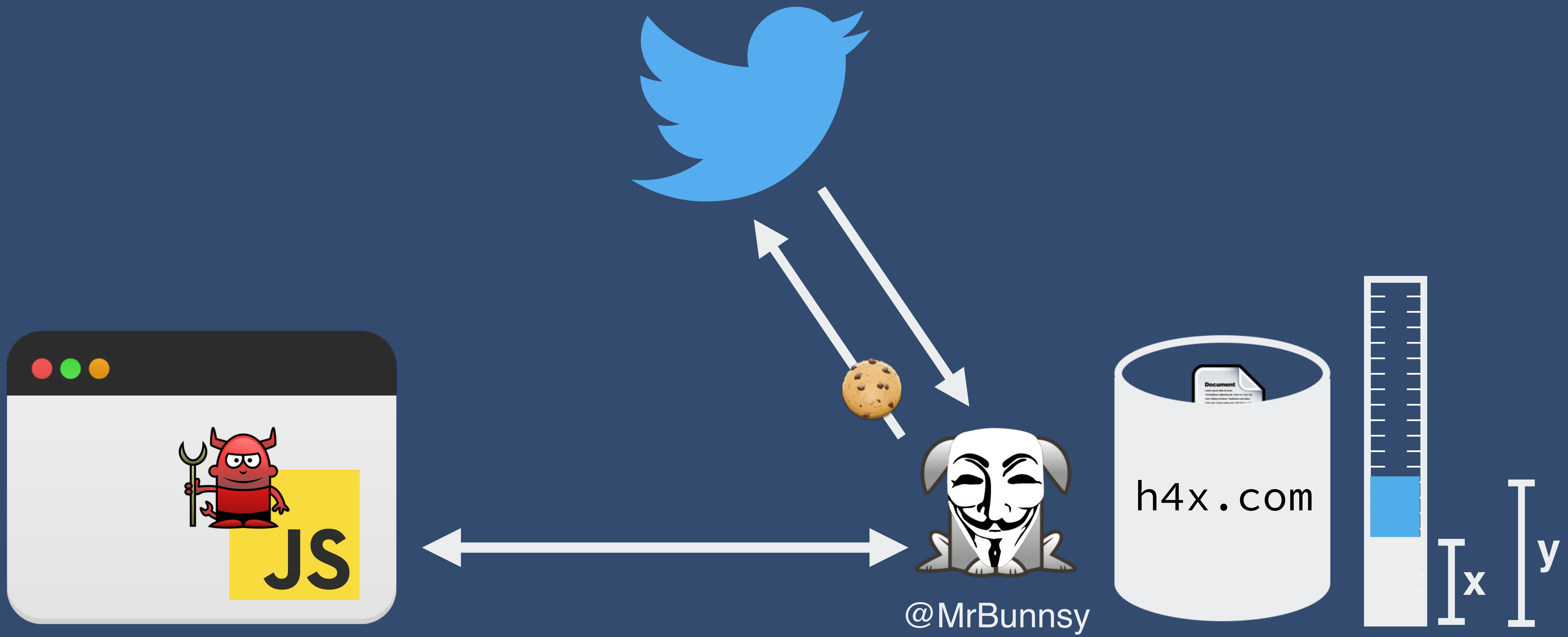
Quota Management/Storage APIs



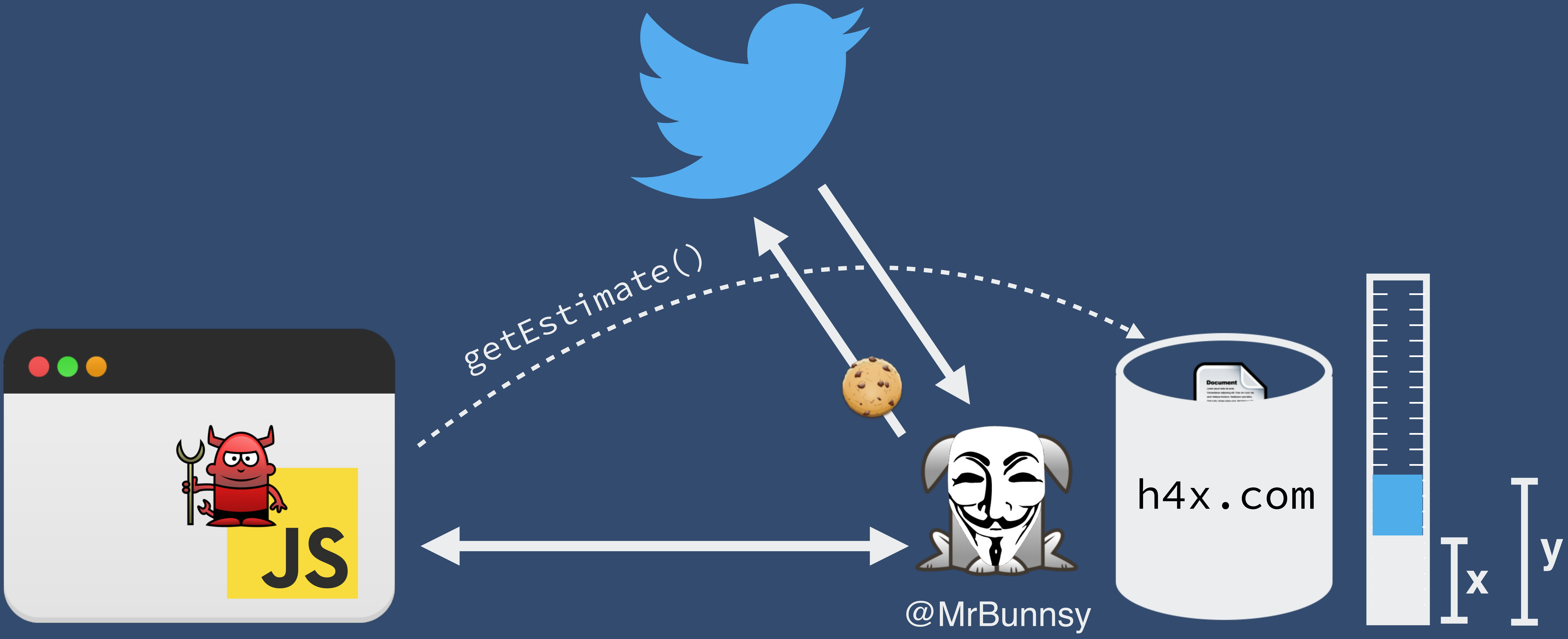
Quota Management/Storage APIs



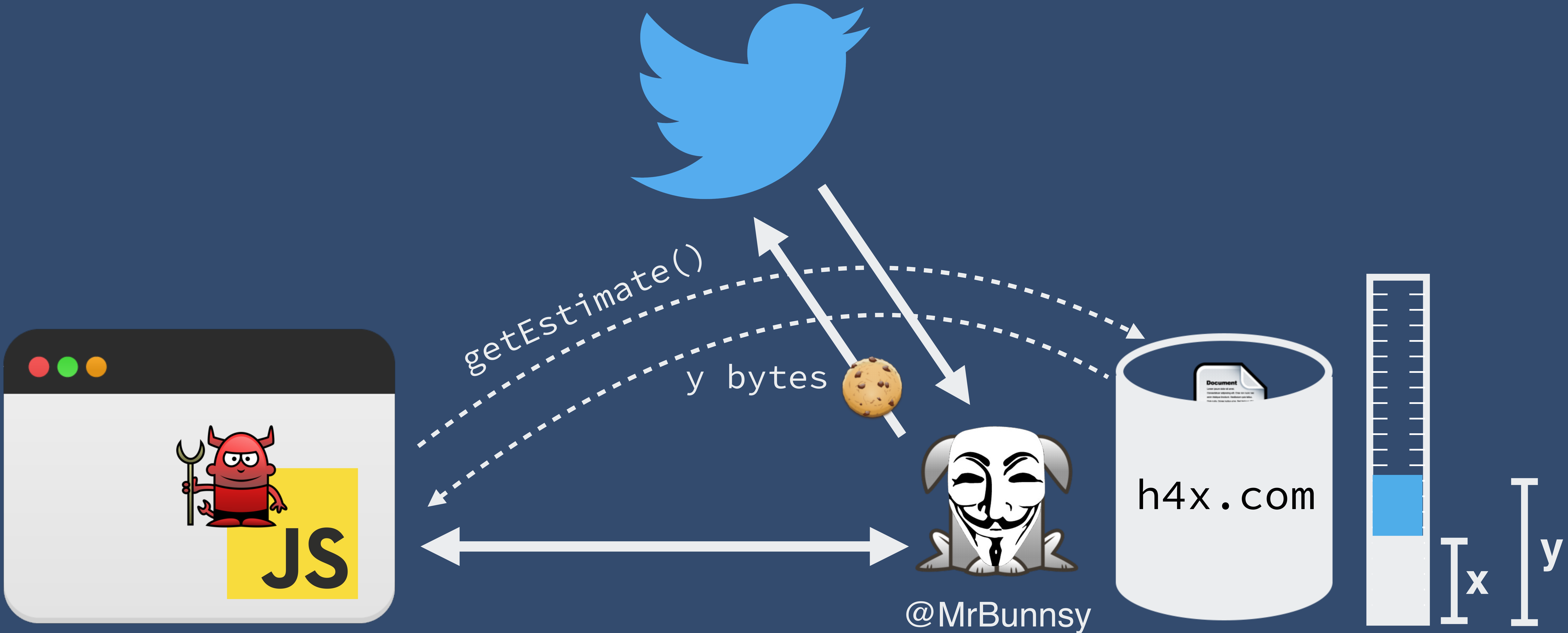
Quota Management/Storage APIs



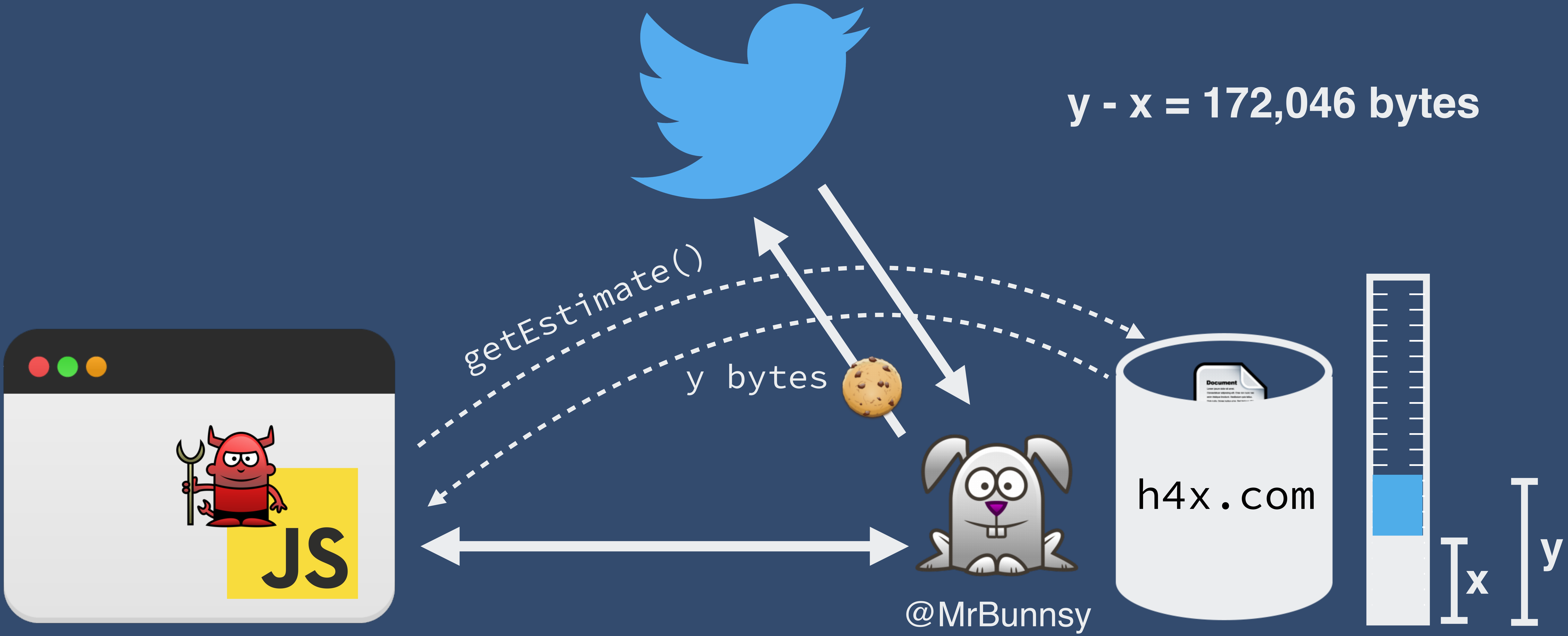
Quota Management/Storage APIs



Quota Management/Storage APIs



Quota Management/Storage APIs



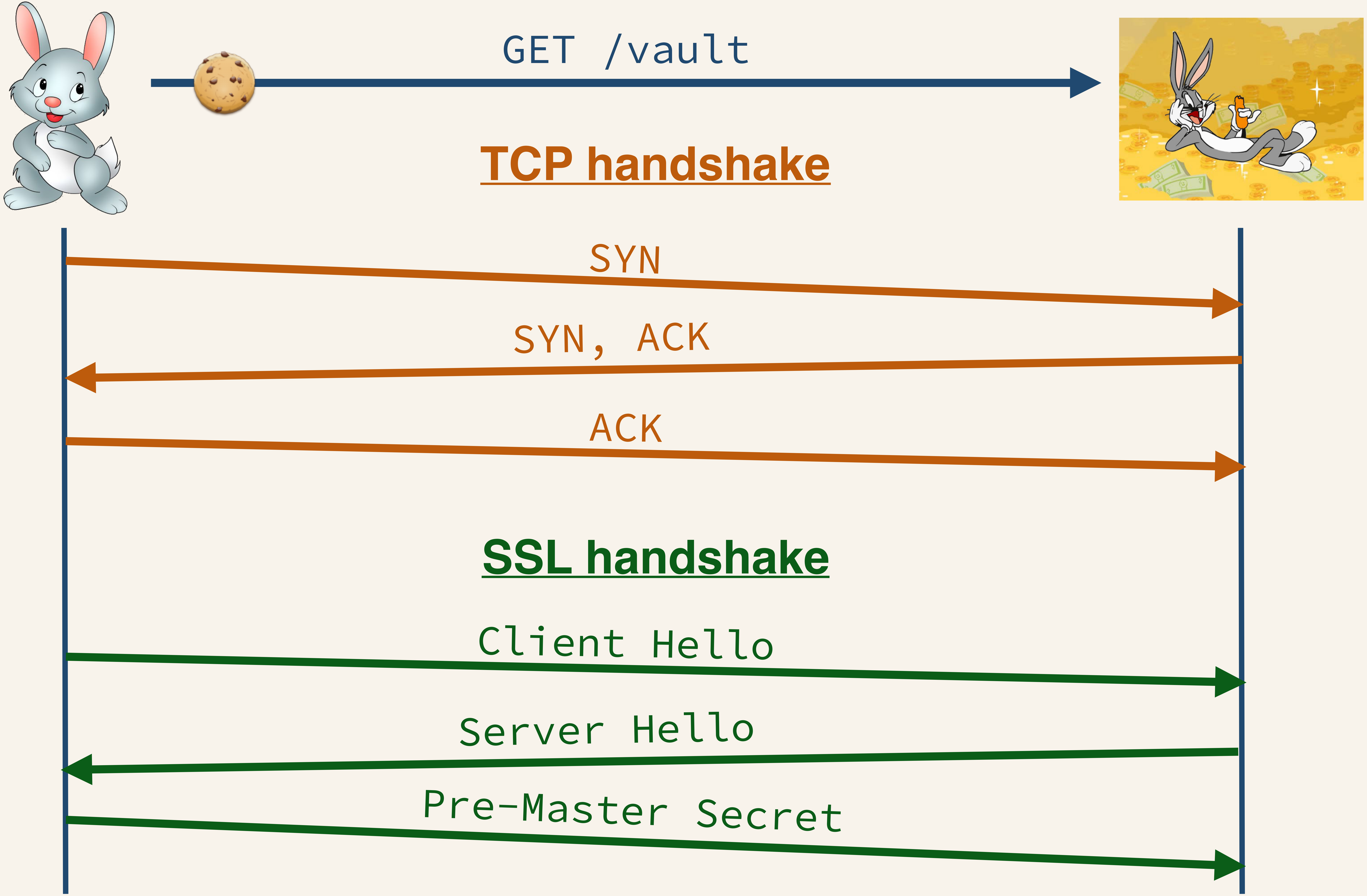
Real-world consequences

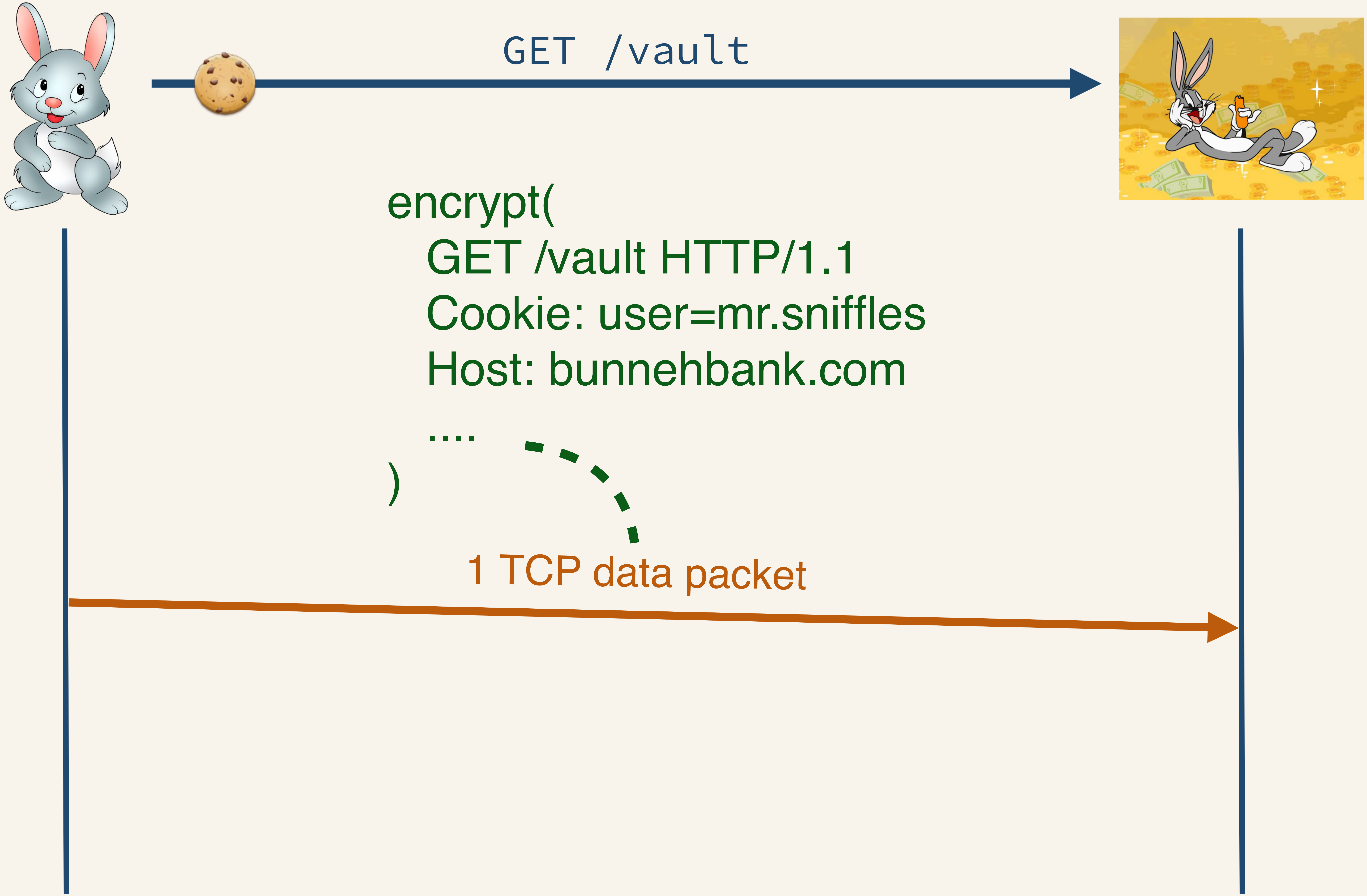
- User identification
  - e.g. by Twitter username
- Revealing private information
  - e.g. discover disease entered on WebMD
- Search-oriented information leakage
  - e.g. GMail search [Gelernter: CCS'15]
- Infer cross-origin cache operations
  - e.g. detect group membership on Telegram

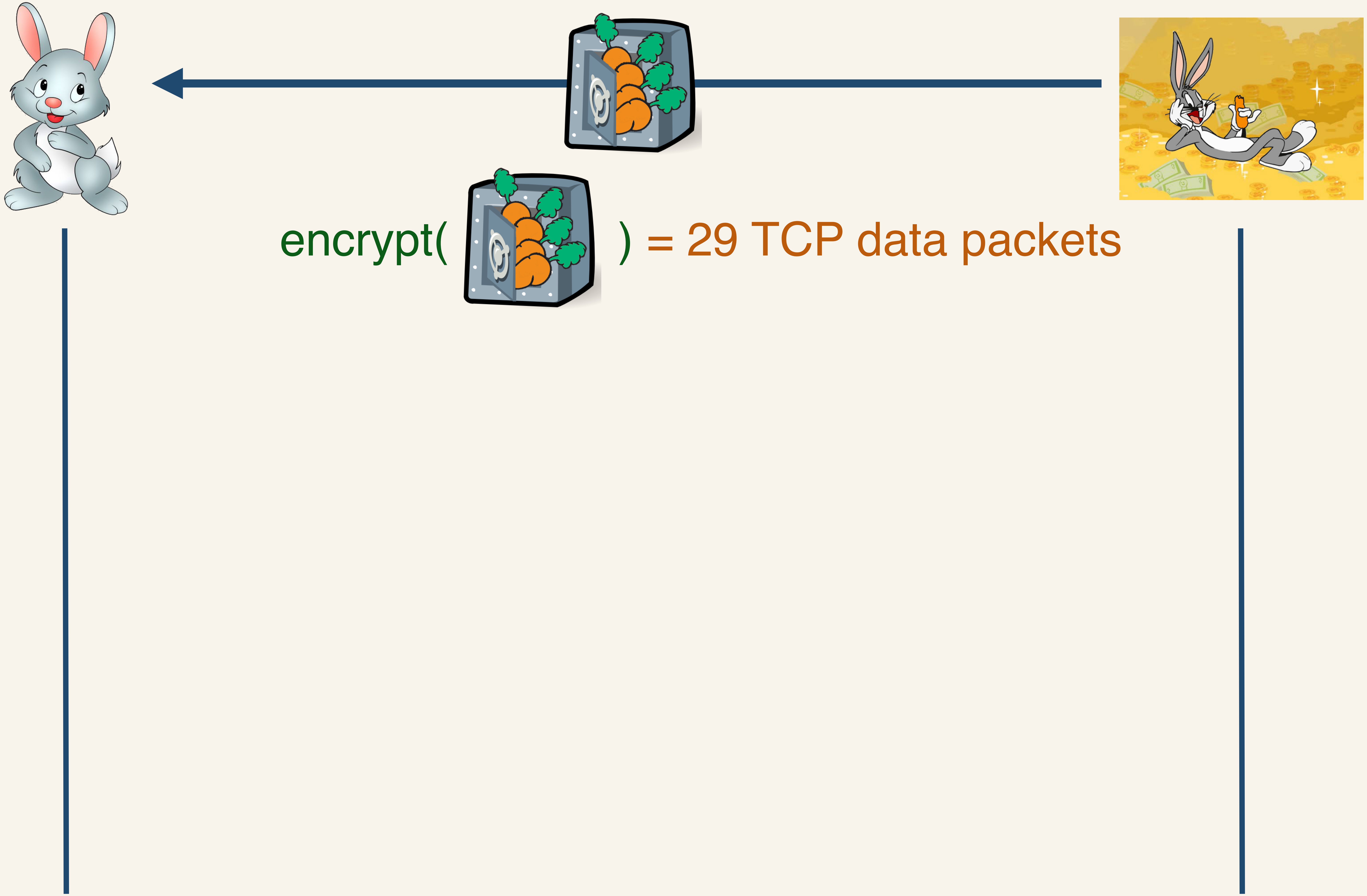
DEMO

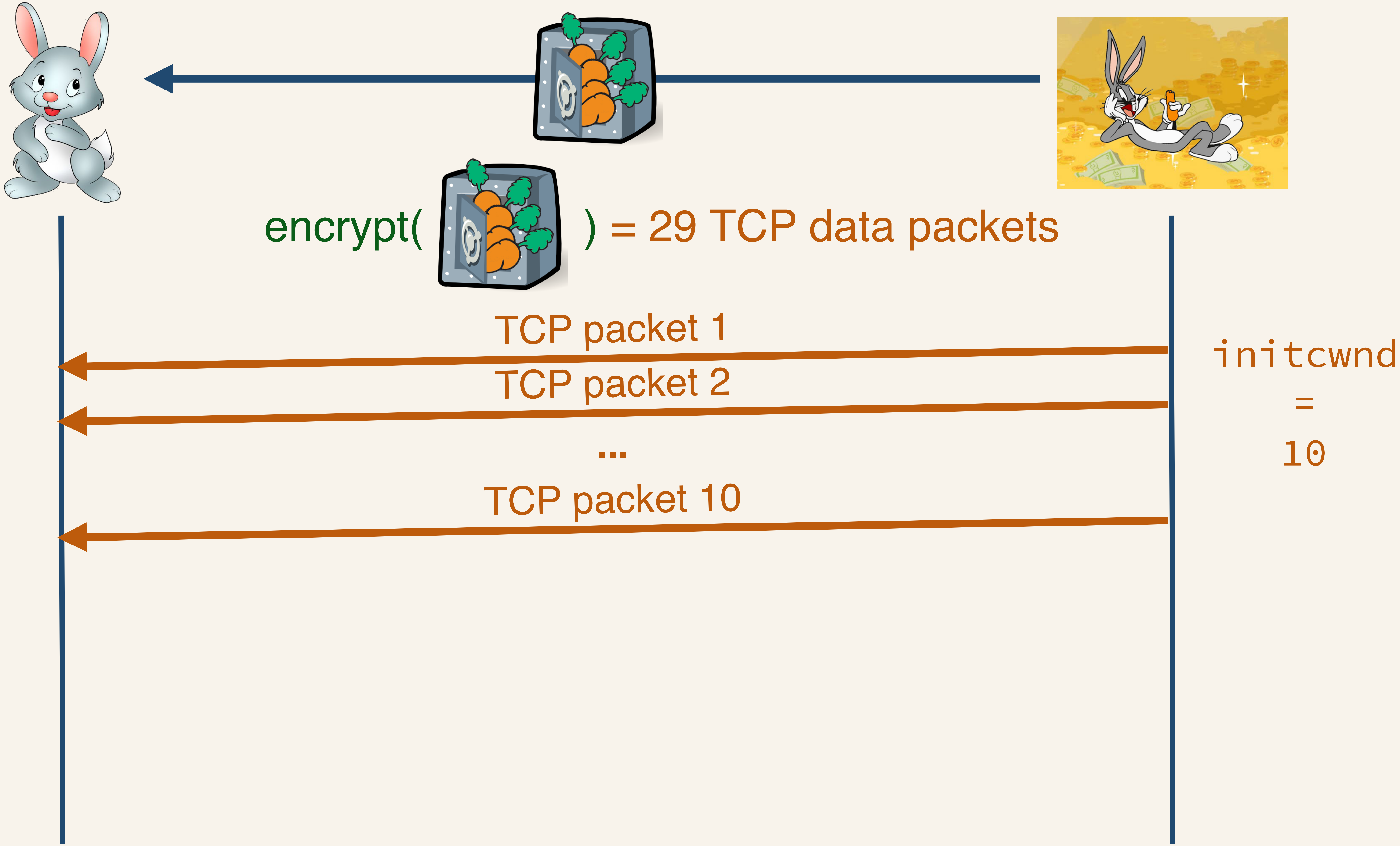
Exposing cross-origin resource size

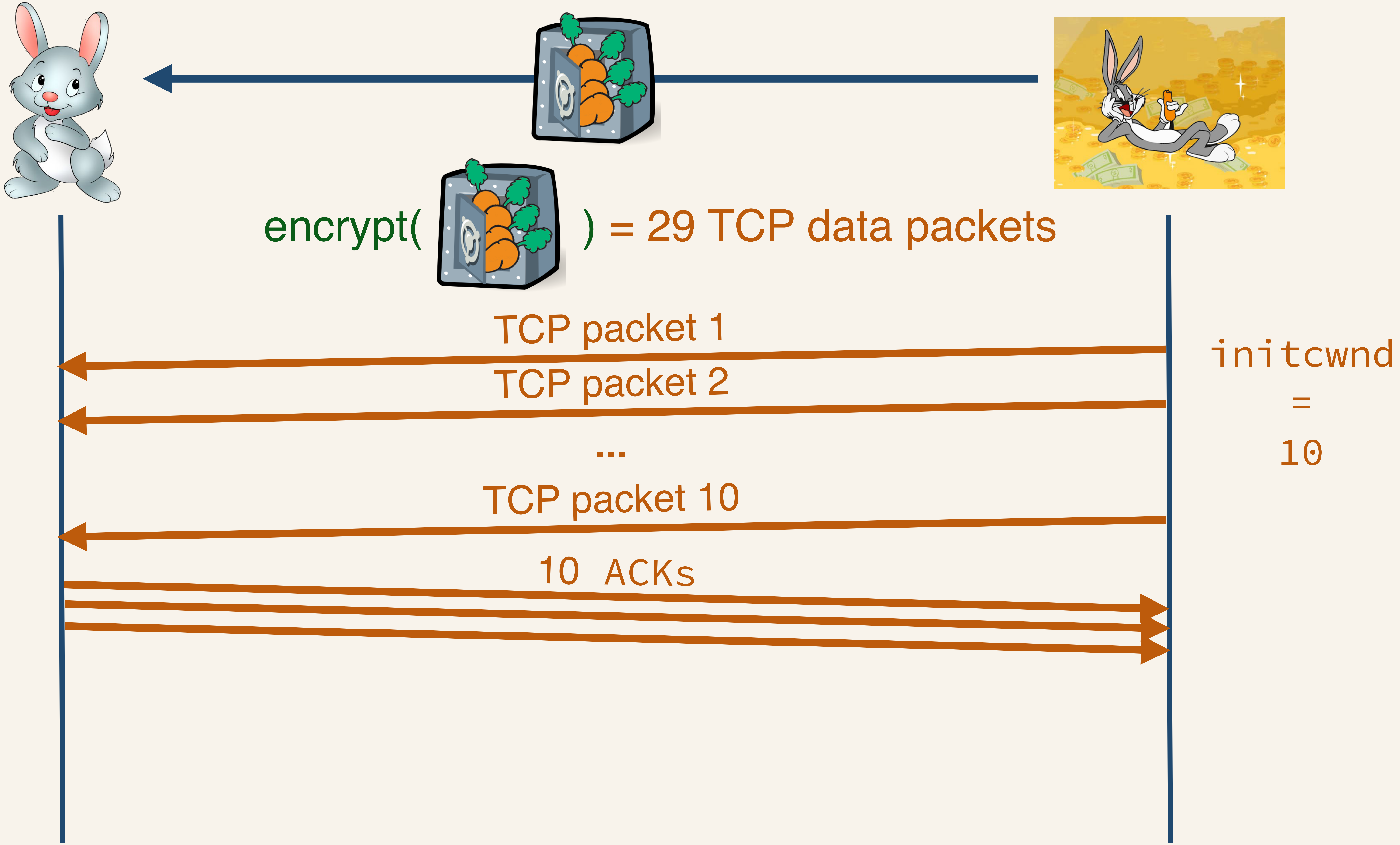
TCP windows


GET /vault
TCP handshake
SYN
SYN, ACK
ACK
SSL handshake
Client Hello
Server Hello
Pre-Master Secret

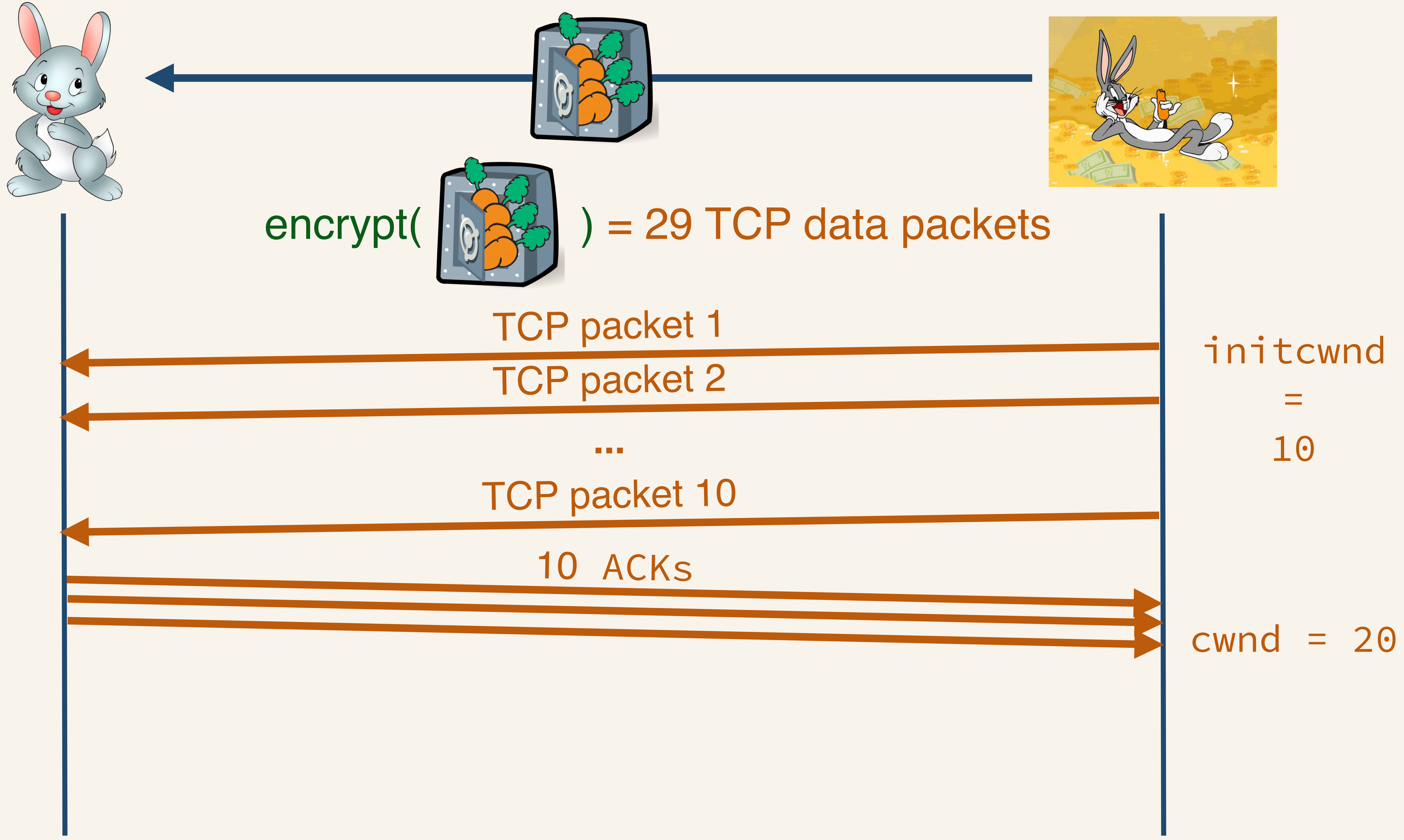

GET /vault
encrypt(
GET /vault HTTP/1.1
Cookie: user=mr.sniffles
Host: bunnehbank.com
....
)
1 TCP data packet


encrypt( ) = 29 TCP data packets

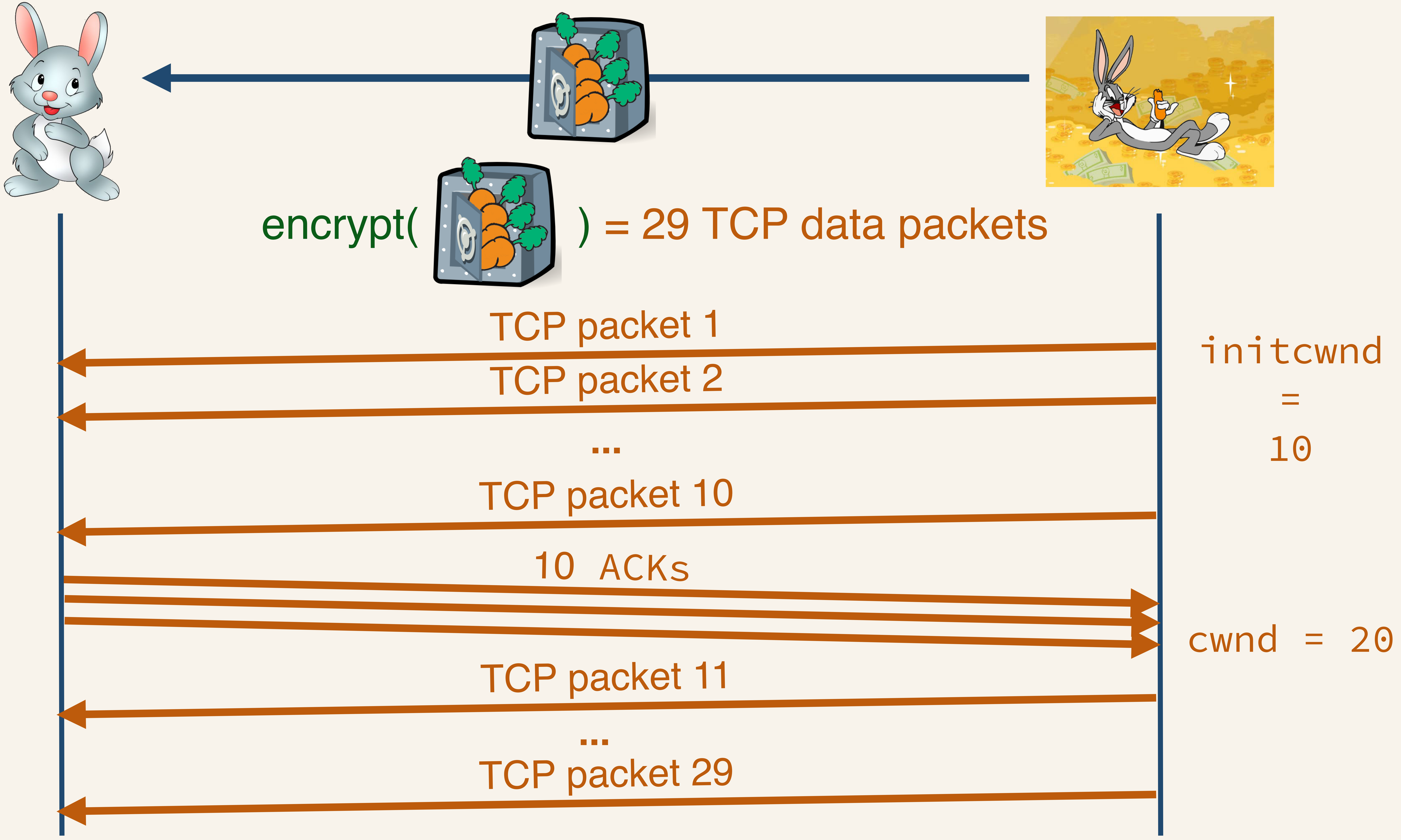

encrypt( ) = 29 TCP data packets
TCP packet 1
TCP packet 2
...
TCP packet 10
initcwnd
=
10



encrypt( ) = 29 TCP data packets
TCP packet 1
TCP packet 2
...
TCP packet 10
10 ACKs
initcwnd
=
10



encrypt( ) = 29 TCP data packets
TCP packet 1
TCP packet 2
...
TCP packet 10
10 ACKs
initcwnd
=
10
cwnd = 20


encrypt( ) = 29 TCP data packets
TCP packet 1
TCP packet 2
...
TCP packet 10
initcwnd
=
10
10 ACKs
cwnd = 20
TCP packet 11
...
TCP packet 29

HEIST

- A set of techniques that allow attacker to determine the exact size of a network response
- ... **purely in the browser**
- Can be used to perform compression-based attacks, such as CRIME and BREACH, in the browser

Browser Side-channels

- Send authenticated request to `/vault` resource

```
fetch('https://bunnehbank.com/vault',
        {mode: "no-cors", credentials:"include"})
```

- Returns a `Promise`, which resolves as soon as browser receives the first byte of the response

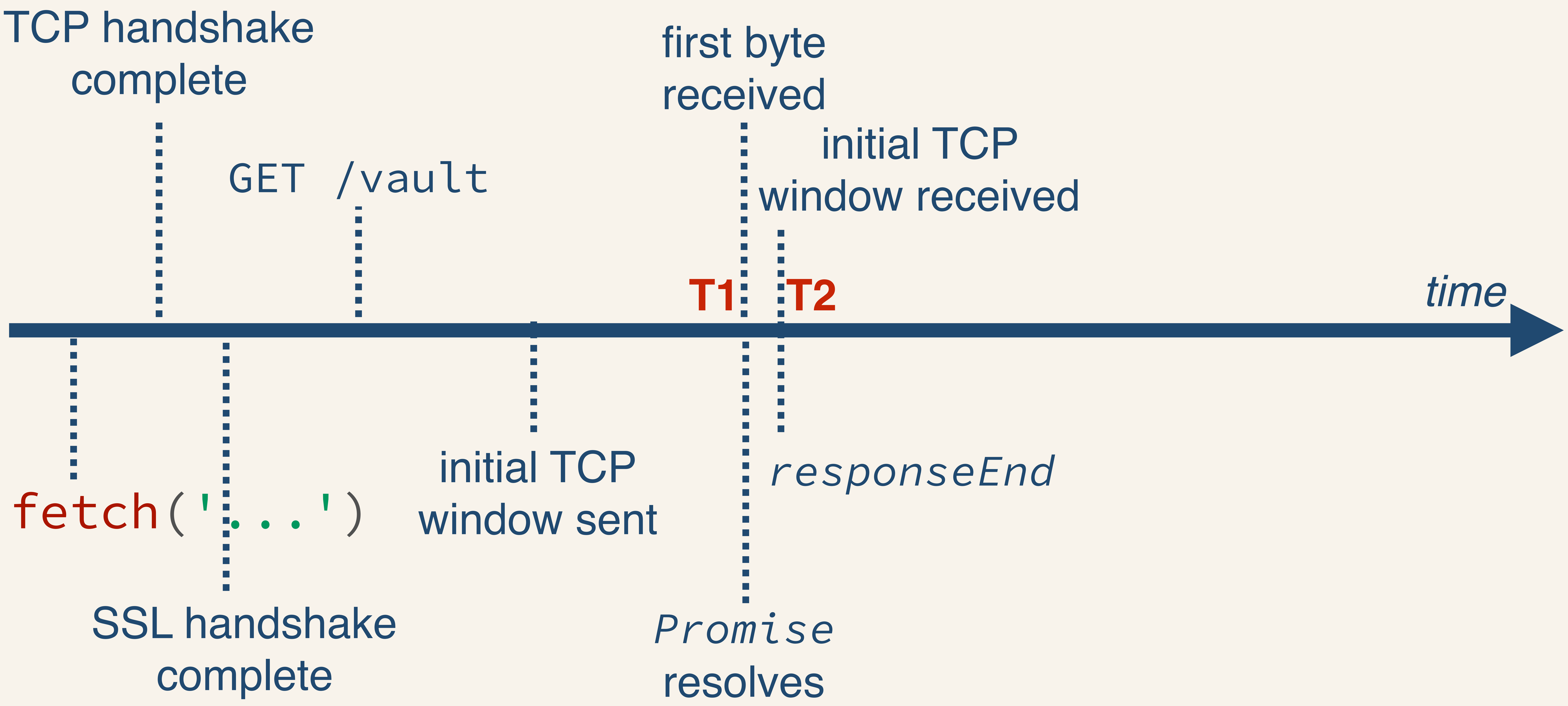
```
performance.getEntries()[-1].responseEnd
```

- Returns time when response was completely downloaded

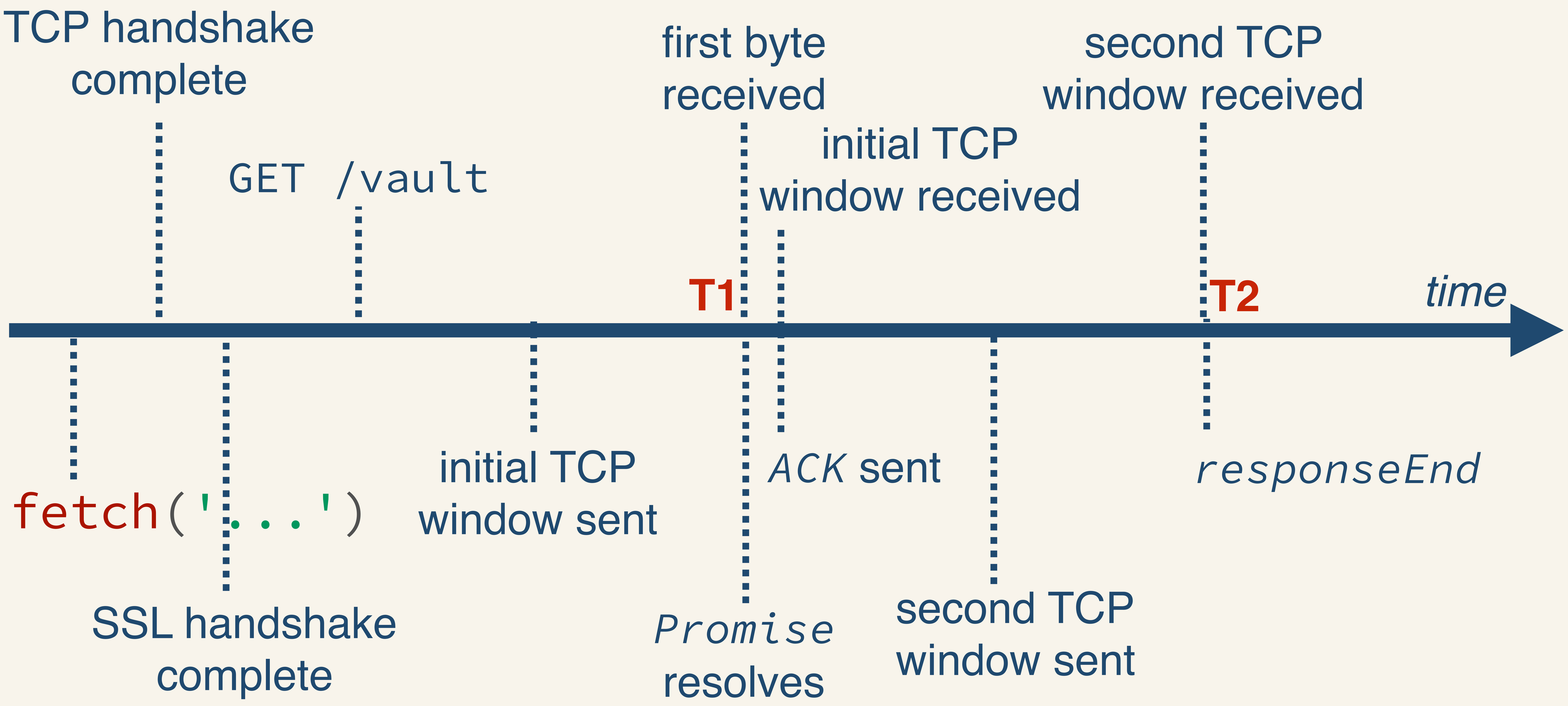
HEIST

- Step 1: find out if response fits in a single TCP window

Fetching small resource: T2 - T1 is very small



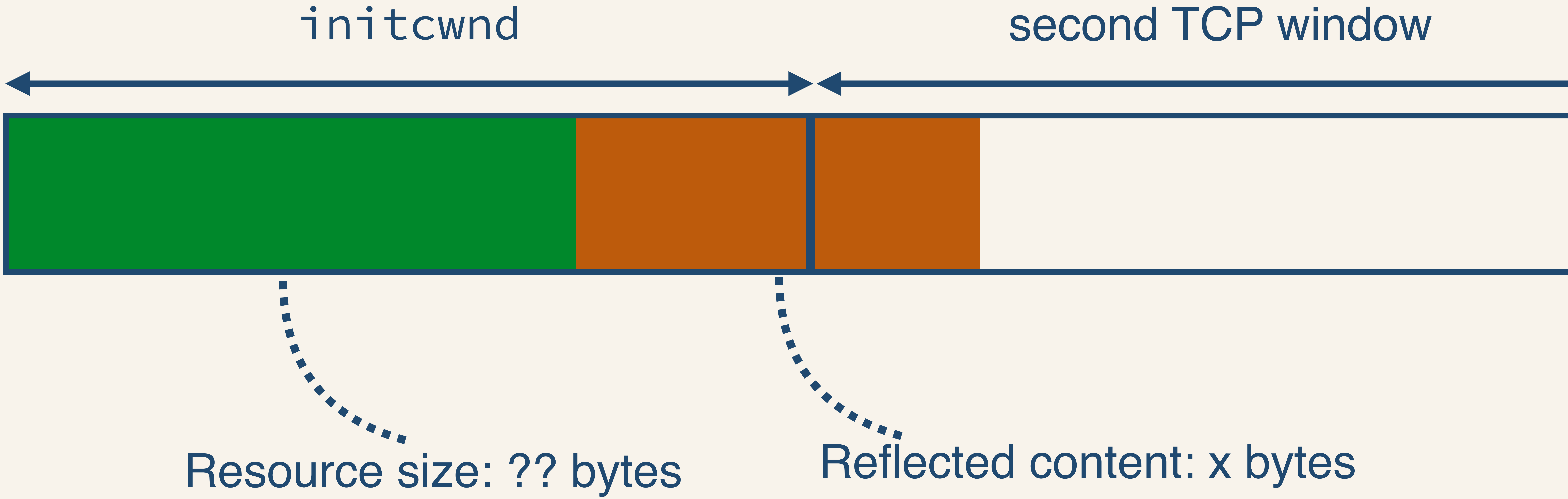
Fetching large resource: T2 - T1 is round-trip time



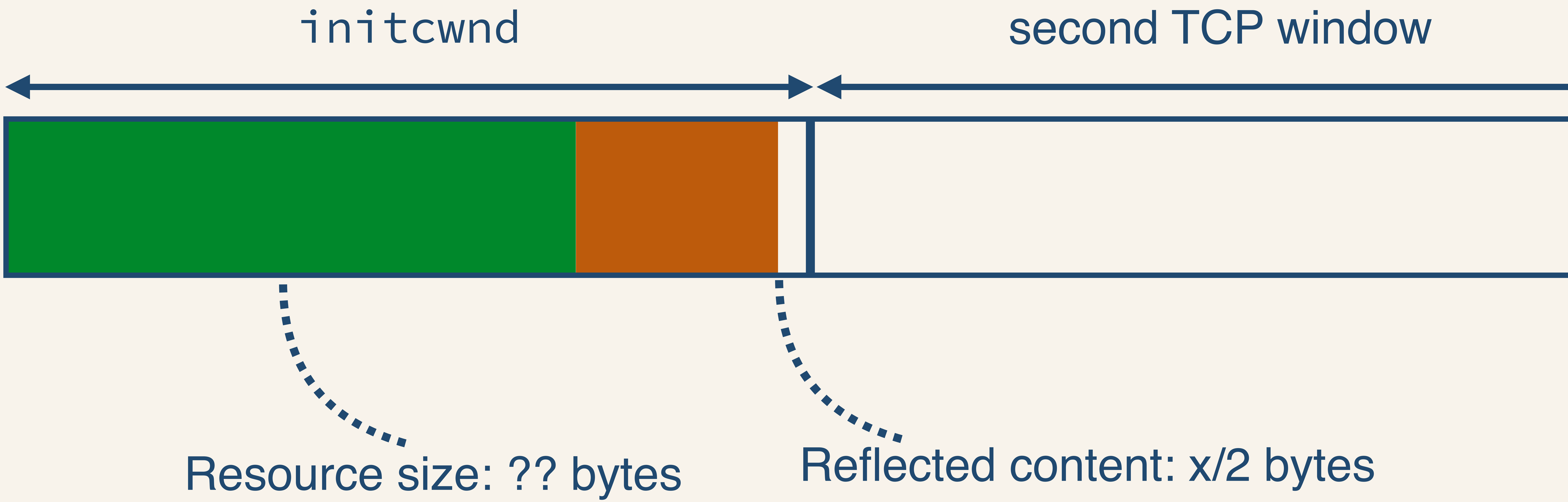
HEIST

- Step 1: find out if response fits in a single TCP window
- Step 2: discover exact response size

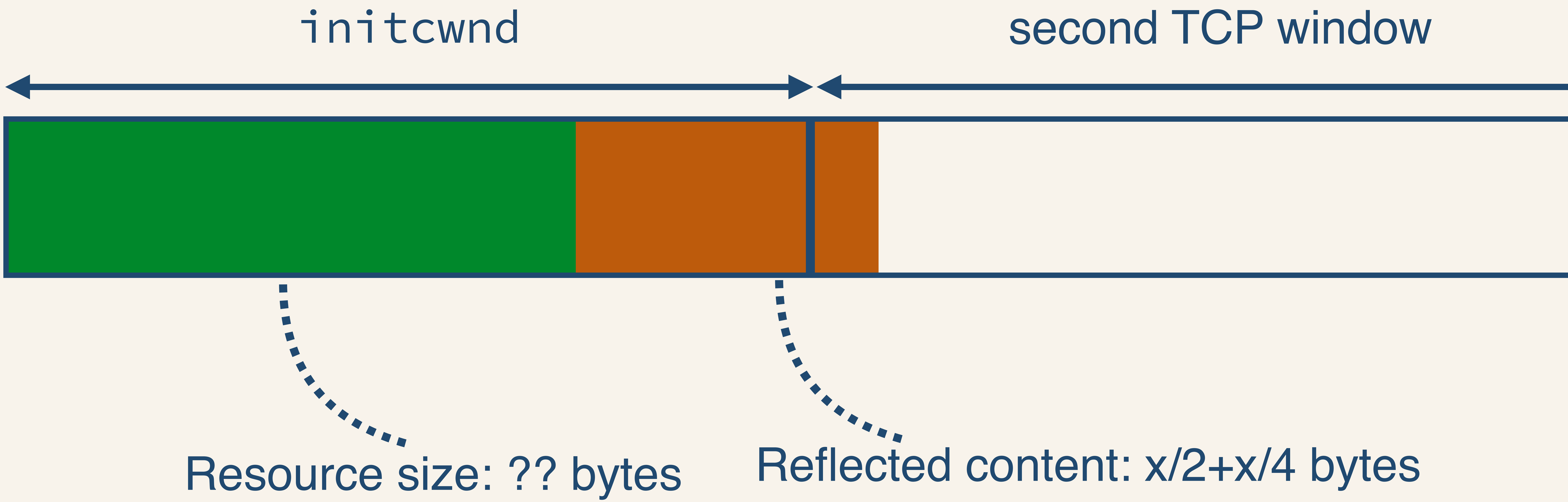
Discover Exact Response Size



Discover Exact Response Size



Discover Exact Response Size

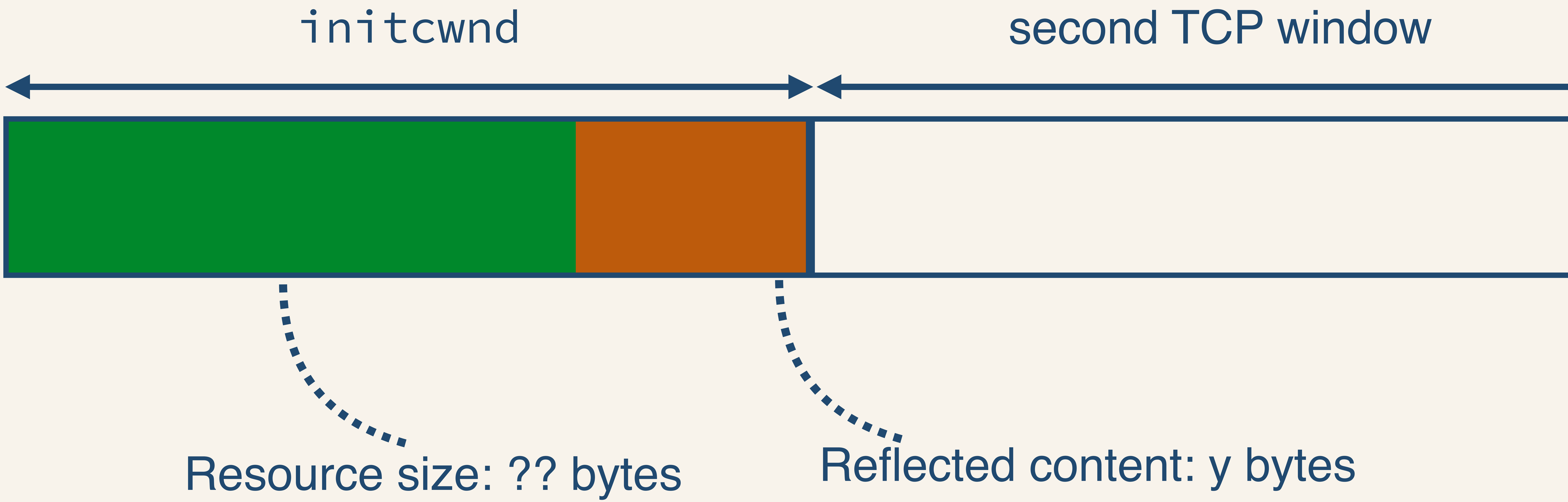


After *log(n)* checks, we find:

y bytes of reflected content = 1 TCP window

y+1 bytes of reflected content = 2 TCP windows

→ resource size = `initcwnd` - y bytes

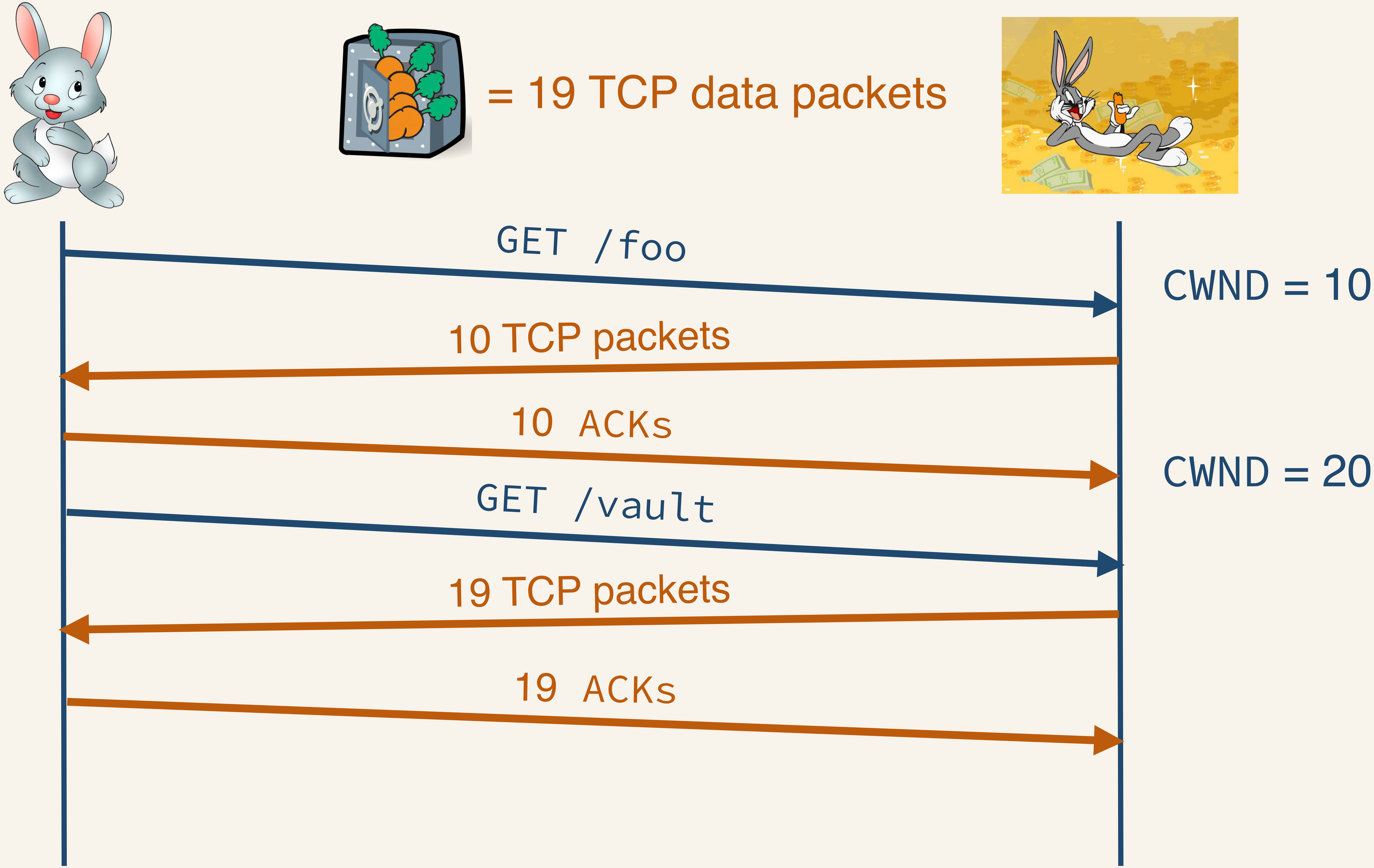


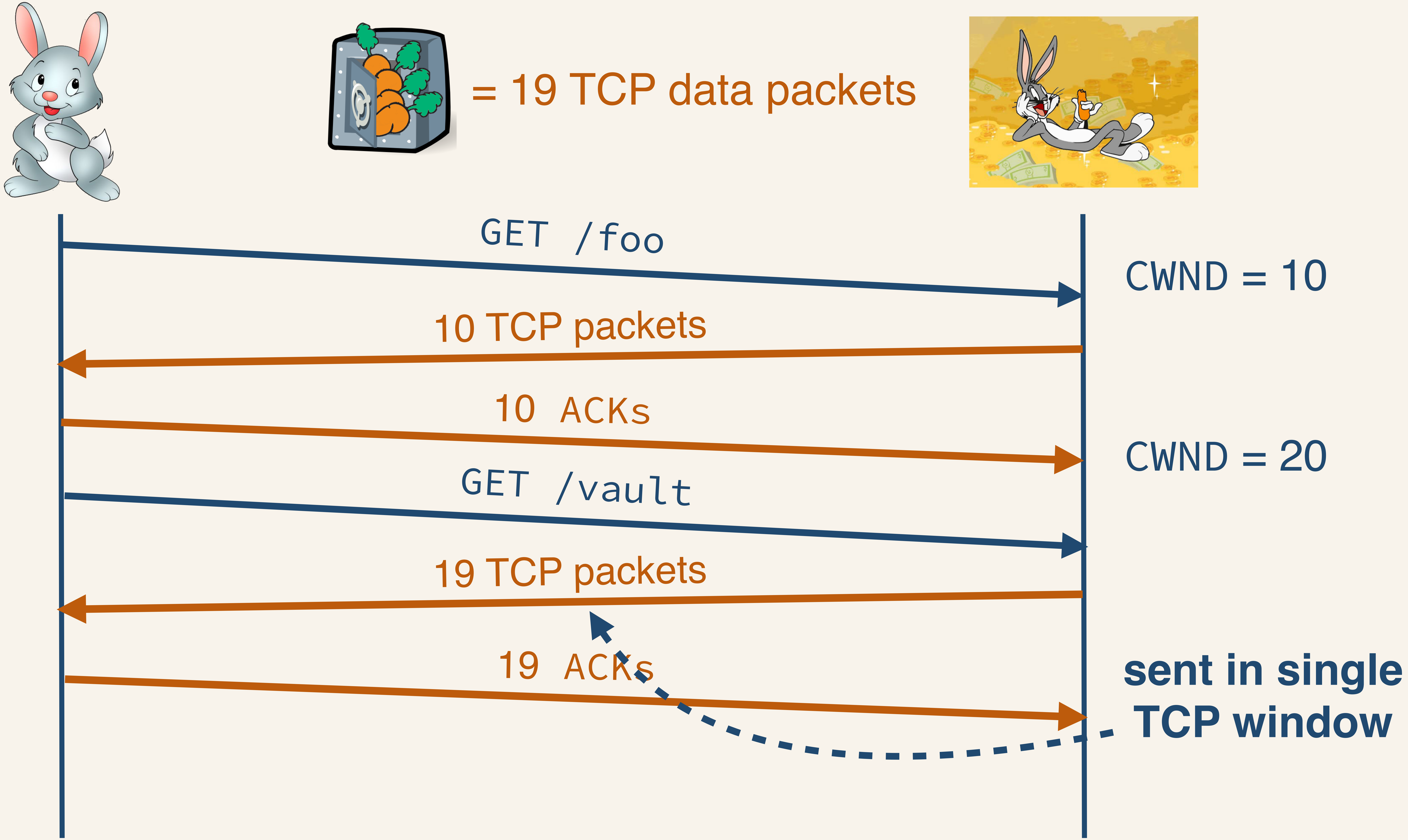
HEIST

- Step 1: find out if response fits in a single TCP window
- Step 2: discover exact response size
- Step 3: do the same for large responses (> `initcwnd`)

Determine size of large responses

- Large response = bigger than initial TCP window
- `initcwnd` is typically set to 10 TCP packets
  - ~14kB
- TCP windows grow as packets are acknowledged
- We can arbitrarily increase window size


= 19 TCP data packets
GET /foo
CWND = 10
10 TCP packets
10 ACKs
CWND = 20
GET /vault
19 TCP packets
19 ACKs


= 19 TCP data packets
GET /foo
CWND = 10
10 TCP packets
10 ACKs
CWND = 20
GET /vault
19 TCP packets
19 ACKs
sent in single
TCP window

HEIST

- Step 1: find out if response fits in a single TCP window
- Step 2: discover exact response size
- Step 3: do the same for large responses (> `initcwnd`)
- Step 4: if available, leverage HTTP/2

Leveraging HTTP/2

- HTTP/2 is the new HTTP version
  - Preserves the semantics of HTTP
- Main changes are on the network level
  - Only a single TCP connection is used for parallel requests

Leveraging HTTP/2

- Determine exact response size *without* reflected content in the same response
- Use (reflected) content in other responses on the same server
    - Note that BREACH still requires (a few bytes of) reflective content in the same resource


= 6 TCP packets
/reflect?x=... = 3 TCP packets
GET /reflect?x=...
CWND = 10
GET /vault
9 TCP packets
Promise resolves
9 ACKs
responseEnd
contains both /reflect and /vault

= 6 TCP packets
/reflect?x=... = 5 TCP packets
GET /reflect?x=...
CWND = 10
GET /vault
Promise resolves
10 TCP packets
10 ACKs
CWND = 20
1 TCP packet
responseEnd
1 ACK
contains both /reflect and part of /vault


40 50 60 70

Defence mechanisms

- The size of resources can leak at various layers
  - → Defence layers can be applied at various layers
- Very few defences work properly
- Often a tradeoff between performance/usability and security
- What “security grade” do we want?
  - Does a rough estimation of the resource size already leak information?

- Network layer
  - Add random padding
    - Not resilient against statistical attacks
    - Increases bandwidth
  - Add random delays
    - Affects performance
  - Randomize TCP window size
    - Is the possible variability sufficient?

- HTTP layer
  - Block requests triggered by attacker.com
    - Hard to determine originator of the request
  - Disable compression
    - Only prevents compression-based attacks
    - Affects network bandwidth
    - Only disable compression for secret/private information?

- Browser layer
  - Add random padding to cached `Response` objects
    - Work in progress (~ 9 months, and counting)
    - Reduces accuracy of exposed resource size
  - Disable third-party cookies
    - Breaks (a small part of) the web :-(
  - `SameSite` cookies
    - Cookies only included in same-site requests
    - Promising feature (when adopted)

Conclusion

- Resource size can leak sensitive information
- Various techniques exist that can reveal the size of cross-origin resources
  - Browser-based, network-based
- Variety of defence methods, few that work properly
  - Disable third-party cookies by default?

Questions?

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