See [PF] 4.1, 4.2, 4.3

Lecture 10: Web Security

10.1 Background

10.2 Security issues and threat models

10.3 Vulnerabilities in the “secure” communication channel (SSL/TLS)

10.4 Mislead the user

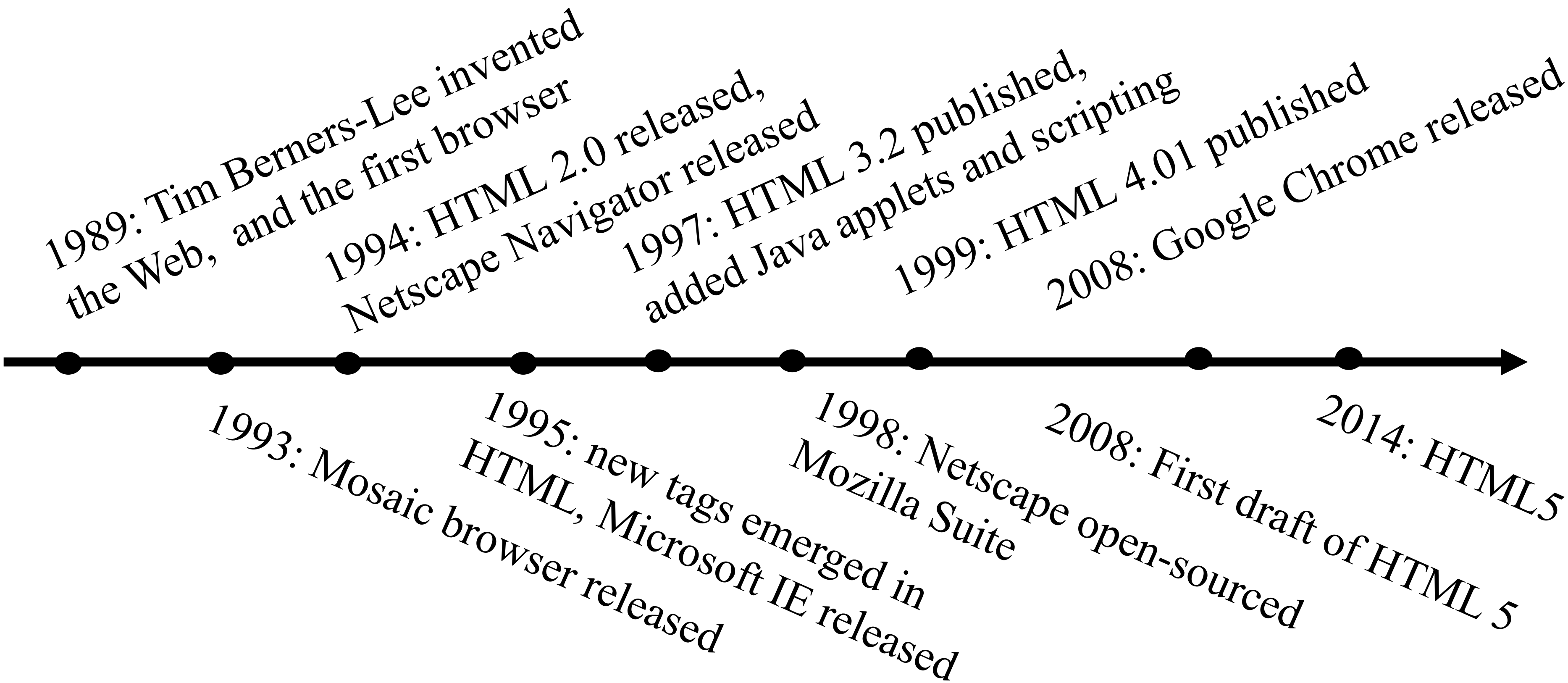
10.5 Cookies and the same-origin policy

10.6 Cross-site scripting (XSS) attacks

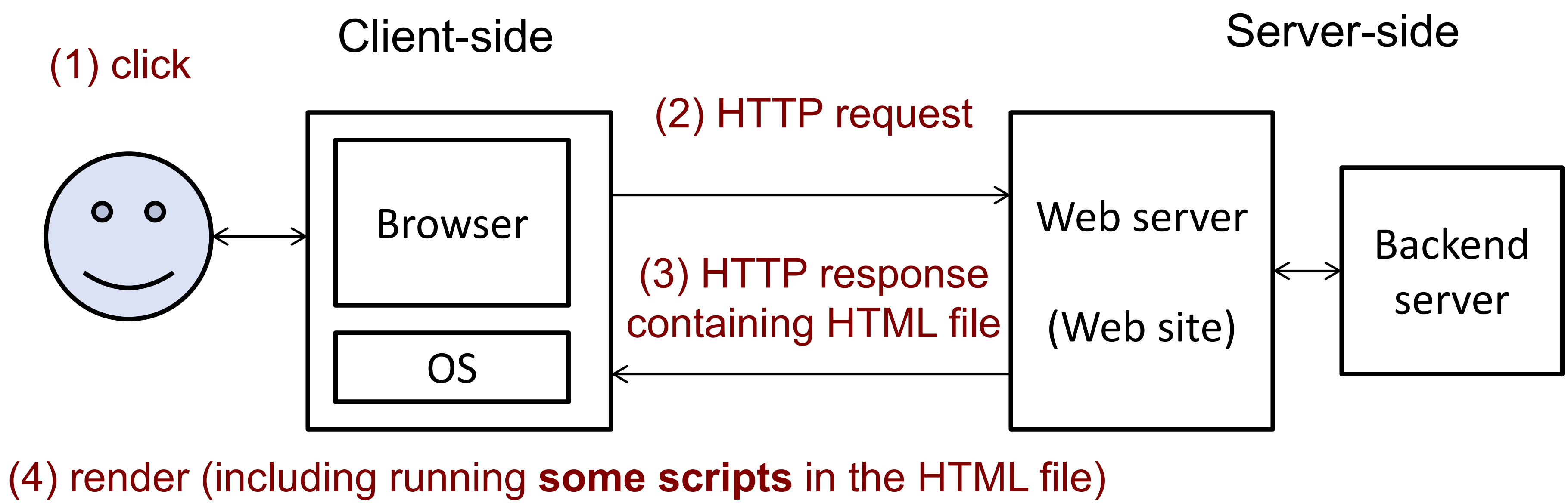
10.7 Cross-site request forgery (CSRF) attacks

10.1 Background

Evolution of the Web



Overview of HTTP: A Web-Page Access Process

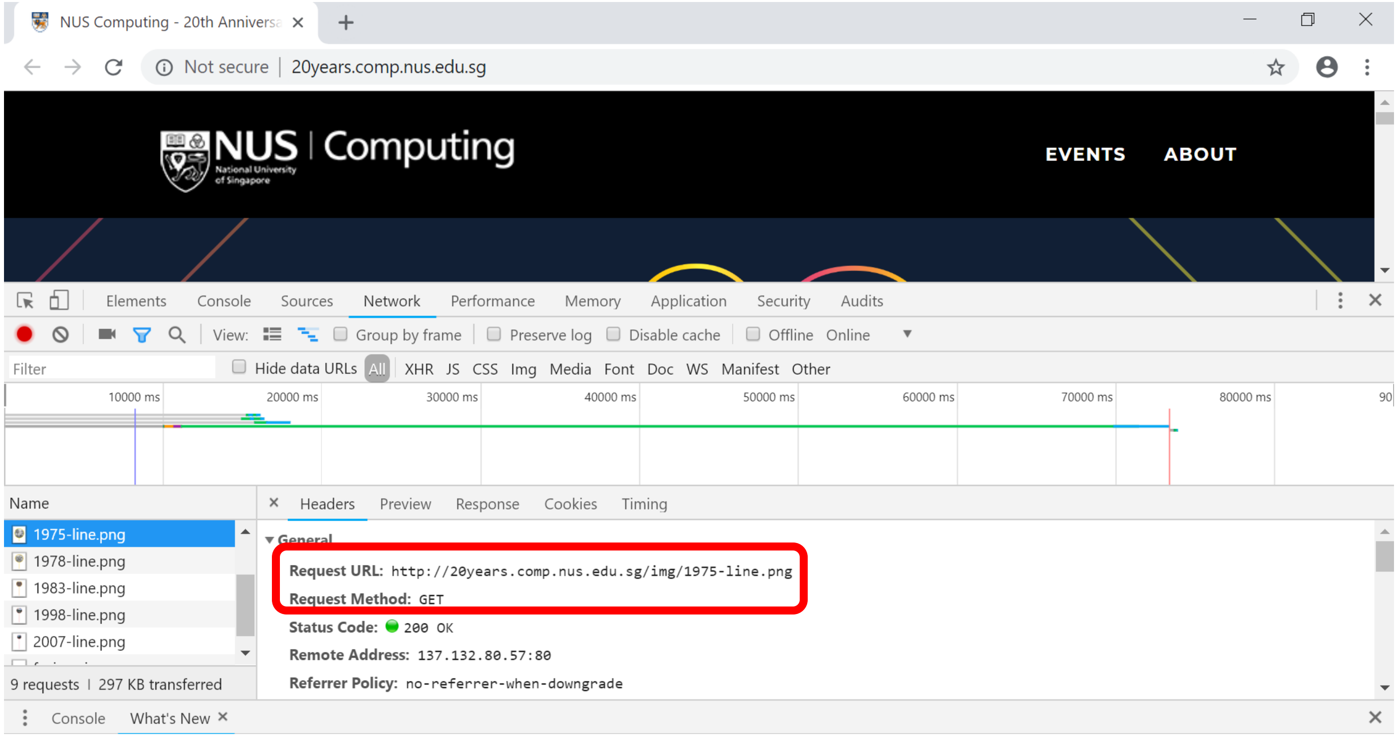


1. User clicks on a **URL "link"**, for example `luminus.nus.edu.sg/`
2. A **HTTP request** is sent to the server (with cookies if any)
3. Server constructs and include a **"HTML" file** inside its **HTTP response** to the browser, likely with **cookies**
4. The browser **renders the HTML file**, which describes the layout to be rendered and presented to the user, and the cookies are stored in the browser

Notes: To view **(the raw form of) the HTML file** sent from the server to the browser:
right-click a page, choose **"View page source"** (in Firefox); View->Developer->**"View Source"** (in Chrome).
Note that there are many occurrences of the tag "`<script>`", which marks the beginning of a **script**.

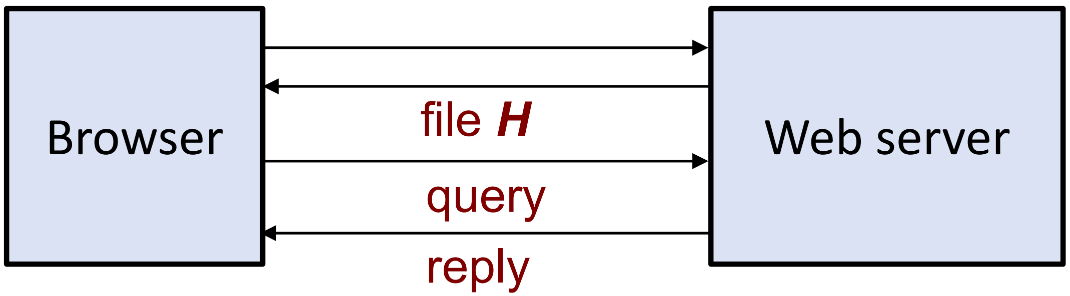
Sub-Resources of A Web Page

- A HTML page may contain **sub-resources** (e.g. images, multimedia files, CSS, scripts) including from **external/third-party** web sites
- When parsing a page with sub-resources, browser also contacts the **respective server** for each sub-resource
- A **separate HTTP request** for **every single file** on a page: since each file requires its own HTTP request



A Closer Look into an Interactive Query-Page Example

1) Browser visits **Google Search page** (`www.google.com.sg`).
   A HTML file ***H*** is sent by the server to the browser.
   The browser renders ***H***.



2) Browser user enters the search **keywords** "CS2017 NUS"

3) The browser, by running *H*, constructs a **query**, for instance:
   https://www.google.com.sg/webhp?sourceid=chrome-instant&ion=1&espv=2&ie=UTF-8#q=CS2107+NUS

4) Note that additional information is added as **URL parameters**.
   These info is useful for the server.
   The info could even be in the form of **script**.

5) The server constructs a **reply**.
   (Notice that in some cases, the reply **contain substrings** sent in Step 3.)

HTTP Request and Response Messages

- Note that various **request** and **response headers** are used

```
GET / HTTP 1.1
Host: www.example.com
User-Agent: Mozilla/…
...
```

```
HTTP/1.1 200 OK
Date: Thu, 13 Oct2011
Server: Apache/1.3.41
Content-Type: text/html
...
```

HTTP Request and Response Formats

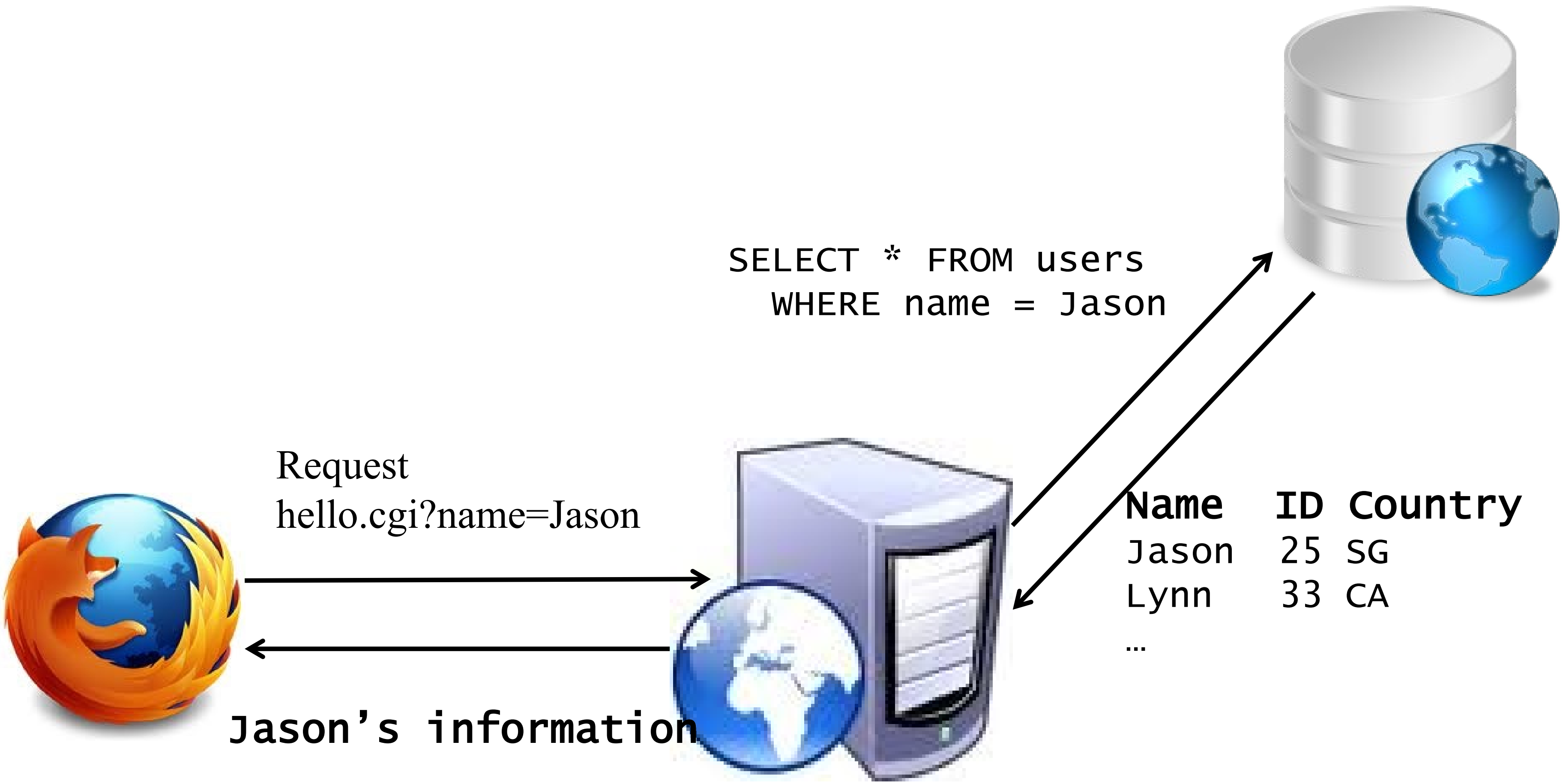
- **HTTP Request** contains:
  - **Request line**, e.g.: `GET /test.html HTTP/1.1`
  - **Request headers**, such as:
    ```
    Accept: image/gif, image/jpeg, */*
    Accept-Language: us-en, fr, cn
    Cookie: theme=light; sessionToken=abc123;
    ```
  - An empty/blank line
  - An optional message body

- **HTTP Response** contains:
  - **Status line** containing *status code* & *reason phrase*, e.g.:
    ```
    HTTP/1.1 200 OK
    HTTP/1.0 404 Not Found
    ```
  - **Response headers**, such as:
    ```
    Content-Type: text/html
    Content-Length: 35
    Set-Cookie: theme=light
    Set-Cookie: sessionToken=abc123; Expires=Wed, 09 Jun 2021 10:18:14 GMT
    ```

Web Client and Server Components

- Client-side components:
  - Hypertext Markup Language (**HTML**): webpage **content**
  - Cascading Style Sheets (**CCS**): webpage **presentation**
  - **JavaScript**: webpage **behavior**, making pages “active” (interactive and responsive)
- Server-side components:
  - **Web server**: nowadays a scripting language is typically used as well, e.g. PHP
  - **Database server**

Three-tiered Web Applications with Database Server



JavaScript for “Active” Pages

- Example of JavaScript in HTML:
  ```
  <script type="text/javascript"> document.write(’Hello World!’);
  </script>
  ```
- What **can JavaScript do** in a browser?
  - **Write a** (variable) **text** into an HTML page:
    ```
    document.write("<h1>" + studentname + "</h1>")
    ```
  - **Read and change HTML elements**:
    ```
    var doc = document.childNodes[0];
    ```
  - **React to events**, such as when a page has finished loading or when a user clicks on an HTML element:
    ```
    <a href="someURL.html" onclick="alert(’User just clicked me!’)">
    ```
  - **Validate user data**, e.g. form inputs
  - **Access cookies**!
    ```
    var doccookie = document.cookie;
    ```
  - Interact with the server, e.g. using **AJAX** (**A**synchronous **J**avaScript **A**nd **X**ML)

PHP: A Popular Server-Side Scripting Language

- **PHP**: a widely used, free server scripting language for making **dynamic** web pages
- Sample PHP page:

```
<!DOCTYPE html>
<html>
<body>

<?php
echo "My first PHP script!";
?>

</body>
</html>
```

10.2 Security Issues and Threat Models

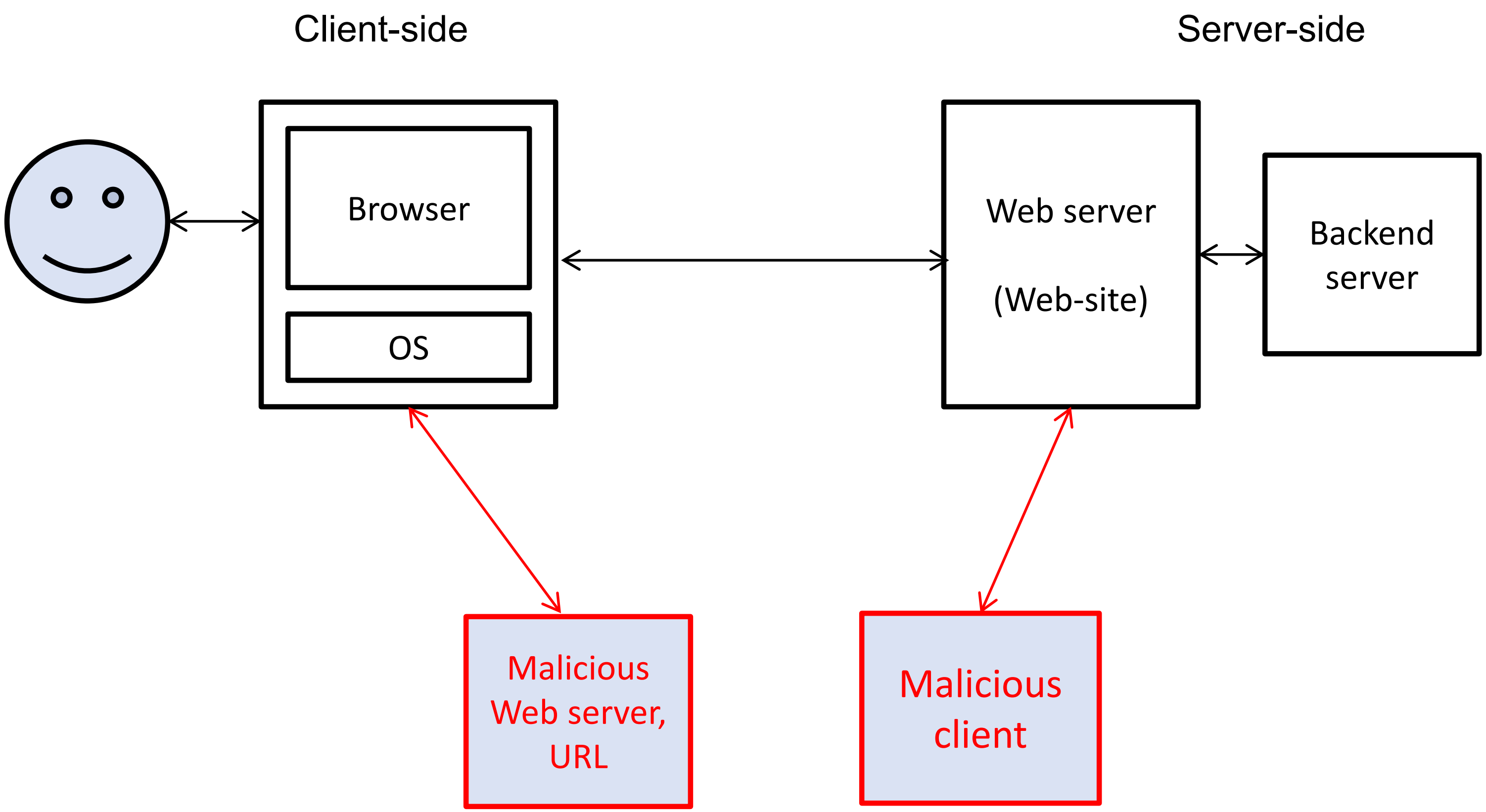
Complications of Web Security: Browsers

- Browsers run with the **same privileges** as the user: the browsers therefore can access the **user's files**
- At any particular instance, **multiple servers** (with different domain names) could provide the content: **access isolation** among sites is thus required
- Browsers support a **rich *command* set** and **controls** for content providers to render the **content**
- Browsers keep **user's info & secrets**: e.g. stored in cookies
- For enhanced functionality, many browsers support **plugins**, **add-ons**, **extensions** by third parties (Note: the definitions and differences of plugins, add-ons, extensions may not be clear & depends on the developers.)

Complications of Web Security: Browser Usage

- Users could **update content** in the server:
  e.g. forum, social media sites,
  where names are to be displayed
- More and more users' **sensitive data** is stored in the Web/cloud
- For PC, the browser is becoming the **main/super application**: in some sense, **the browser "*is*" the OS**

Threat Model 1: Attackers as Another *End Systems*



- In this scenario, the attackers are just another **end systems**
- Examples: a **malicious web server** that lures the victim to visit it; or a **malicious web client** who has access to the targeted server

Attacker Types in Threat Model 1

- **1A: Forum poster**:
  - The weakest attacker type
  - A **user** of an existing web app
  - **Doesn’t** register domains or host application content

- **1B: Web attacker**:
  - Owns a **valid domain & web server** with an SSL certificate
  - Can **entice** a victim to visit his site:

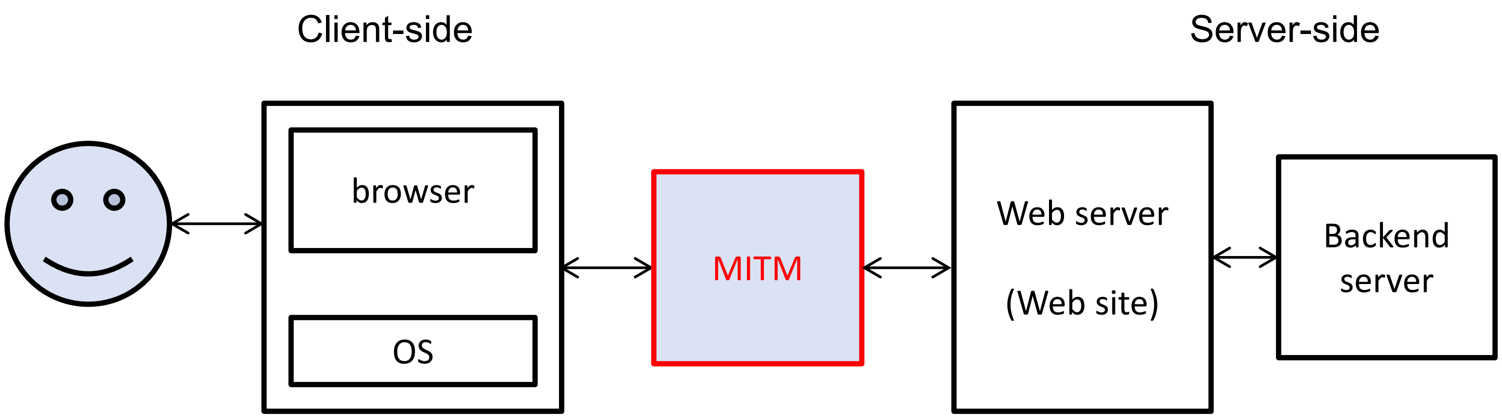
    Say via “Click Here to Get a Free iPad” link

    Or, via an advertisement (no clicks needed)
  - **Can’t** intercept/read traffic for other sites
  - The most **commonly-assumed** attacker type. *Why?*

Attacker Types in Threat Model 1

- **1C: Related-domain attacker**:
  - A web attacker who is able to host content in a **related domain** of the target web application
  - Host on a **sibling or child domain** of the target app
  - E.g. attacker.target.com or attacker.app.target.com, which target app.target.com
- **1D: Related-path attacker**:
  - A web attacker who is able to host an application on a **different path** than the target application, but **within the same origin**
  - E.g. www.comp.nus.edu.sg/~attacker, which targets www.comp.nus.edu.sg/~target

Threat Model 2: Attackers as a *MITM*



- Here, the attacker is a **Man-in-the-Middle** (at the IP layer)
- Example: a **malicious café-owner** who provides the free WiFi services in our previous examples

Attacker Types in Threat Model 2

- **2A: Passive network attacker:**
  - Eve who can **passively eavesdrop** on network traffic, but cannot manipulate or spoof traffic
  - Can **additionally act** as a web attacker
- **2B: Active network attacker:**
  - Mallory who can launch **active attacks** on a network
  - Can **additionally act** as a web attacker
  - The **most powerful** threat model
  - Yet, it is **not** generally considered to be capable of **presenting valid certificates** for HTTPS sites that are not under his control. *Why not?*

Web Attacks and Classification

- Yet, it can be **difficult** to clearly classify web attacks
- Many attacks uses a **combination** of other attacks
- This lecture describe some **web attacks** and relevant common **protection mechanisms**

10.3 Attacks on the “Secure” Communication Channel (SSL/TLS)

HTTPS

Review

- **HTTPS** protocol:
  - HTTPS = HTTP + TLS/SSL
  - Netscape SSL 2.0 [1993] ... TLS 1.3 [2018]
- Provisions a ***secure channel***, which establishes between 2 programs a **data channel** that has **confidentiality**, **integrity** and **authenticity**, against a computationally-bounded "network attacker"
- How does HTTPS work?
  - Ciphers negotiation
  - Authenticated key exchange (AKE)
  - Symmetric key encryption and MAC

Attacks on a Secure Channel by a MITM

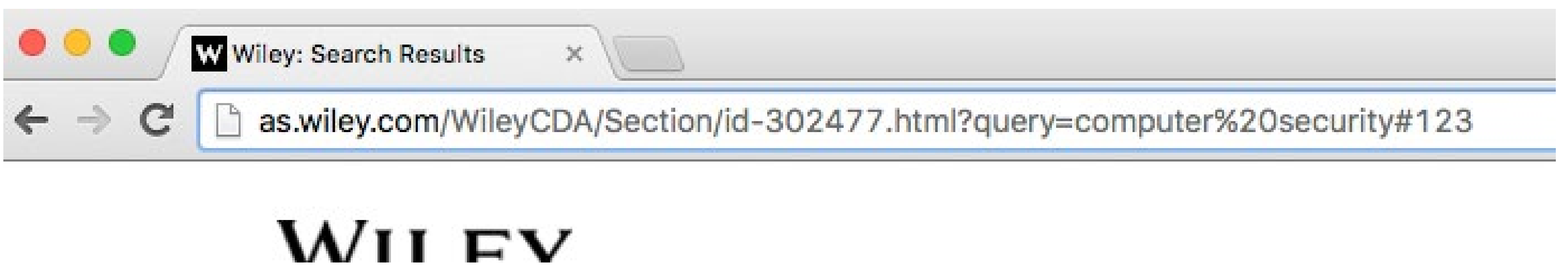
- Two **pre-conditions** of a MITM attack:
  - The attacker is a MITM in between the browser and web server
  - The attacker is able to sniff & spoof packets at the TCP/IP layers
- Note that if the connection is HTTPS, such MITM is **unable** to compromise both confidentiality & authenticity, ***unless***:
  - Web user accepts a **forged certificate** or a **rouge CA**
- Yet, this might not be the case when **there exist vulnerabilities** in the protocol or its **implementation**
- We have already covered some **HTTPS attack** examples: FREAK attack, Superfish, Heartbleed, re-negotiation attack (attack on protocol design)
- Other well-known attacks (*not required in this module*): BEAST attacks (attack on cryptography)

10.4 Mislead the User

URL (Uniform Resource Locator)

- A **URL** consists of a few components (see https://en.wikipedia.org/wiki/Uniform_Resource_Locator):
  1. Scheme
  2. Authority (a.k.a the hostname)
  3. Path
  4. Query
  5. Fragment

- Example:
  http://www.wiley.com/WileyCDA/Section/id-302477.html?query=computer%20security#12



Question: Why the URL is typically displayed with **two levels** of intensity?

URL: Possible Source of Confusion

- Suppose there is ***no*** clear visual distinction between the “hostname” and “path” of a URL
- The **delimiter** that separates hostname & the path can be a character **in the hostname or path**

```
www.wiley.com/WileyCDA/Section/id-302477.html?query=computer%20security
```

Hostname path

- Example: a malicious Website whose hostname contains the targeted hostname followed by a character resembling the **delimiter “/”** (e.g. www.wiley.com.lwiley.in/Section/id-302477.html)
- Another example: nuslogin.789greeting.co.uk (from phishing email)
- The displayed different intensities could help user **spot** the attack

Address Bar Spoofing

- **Address bar** is an important browser's component to protect: the ***only*** **indicator** of what URL the page is actually rendering
- *What if the address bar can be "modified" by a webpage?*
- An attacker could trick the user to **visit** a malicious URL ***X***, while making the user **wrongly believe** that the URL is ***Y***
- A poorly-designed browser may allow attacker to achieve the attack

Address Bar Spoofing: Example

- In the early design of some browsers, a web page could render objects/pop-ups in **an arbitrary location**
- This allows a malicious page to **overlay a spoofed address bar** on top of **the actual address bar**
- Current versions of popular browsers have mechanisms to prevent this issue
- Yet, a recent attack, e.g.: **Android Browser All Versions - Address Bar Spoofing Vulnerability - CVE-2015-3830** (https://www.rafaybaloch.com/2017/06/android-browser-all-versions-address.html)

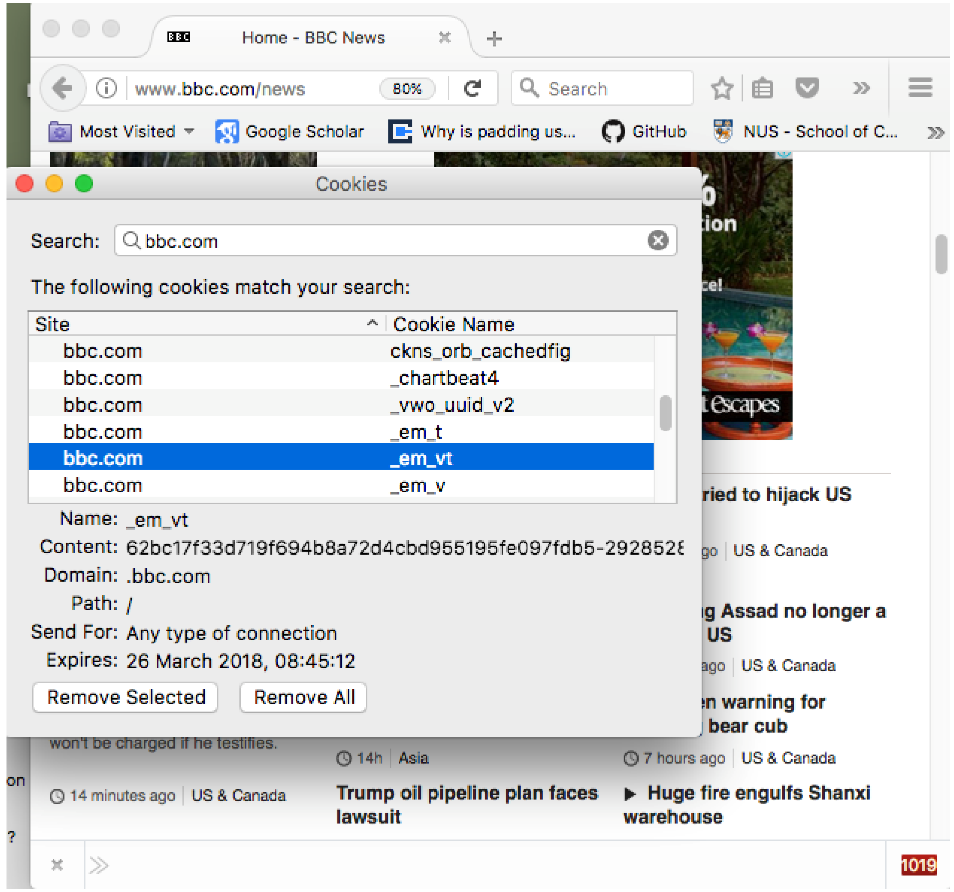
10.5 Cookies and the Same-Origin Policy

Remark:
The same-origin policy (SOP) is **not** an attack, but is a protection mechanism to protect cookies.

Cookies

- A **HTTP cookie**: a piece of textual data sent by a Web server and stored on the user's web browser while the user is browsing
- A cookie sent by the **web server**:
  in an HTTP response's "**Set-Cookie**" header field
- A cookie consists of a **name-value pair**: can be used to indicate a **user preference**, shopping cart content, a server-based ***session identifier***, etc
- Whenever a client revisits the Website (i.e. submit another HTTP request), the browser **automatically** sends all **"in-scope" cookies** back to the server in its HTTP request's "**Cookie**" header
- Note that cookies are sent back only to the "**same cookie origin**": to the server that is the "origin" of the cookies
  (Note: the scheme/protocol checking *may* be optional)

Viewing Cookies



On **Firefox**:

- Right-click → View Page Info → Security → View Cookies; or
- Tools → Web developer → Developer toolbar → Storage

On **Chrome**: chrome://settings/content/cookies

Cookies: Usage

- There are **a few types** of cookie, such as:
  - ***Session cookie***: deleted after the browsing session ends
  - ***Persistent cookie***: expires at a specific date or after a specific length of time
  - ***Secure cookie***: can only be transmitted over **HTTPS**

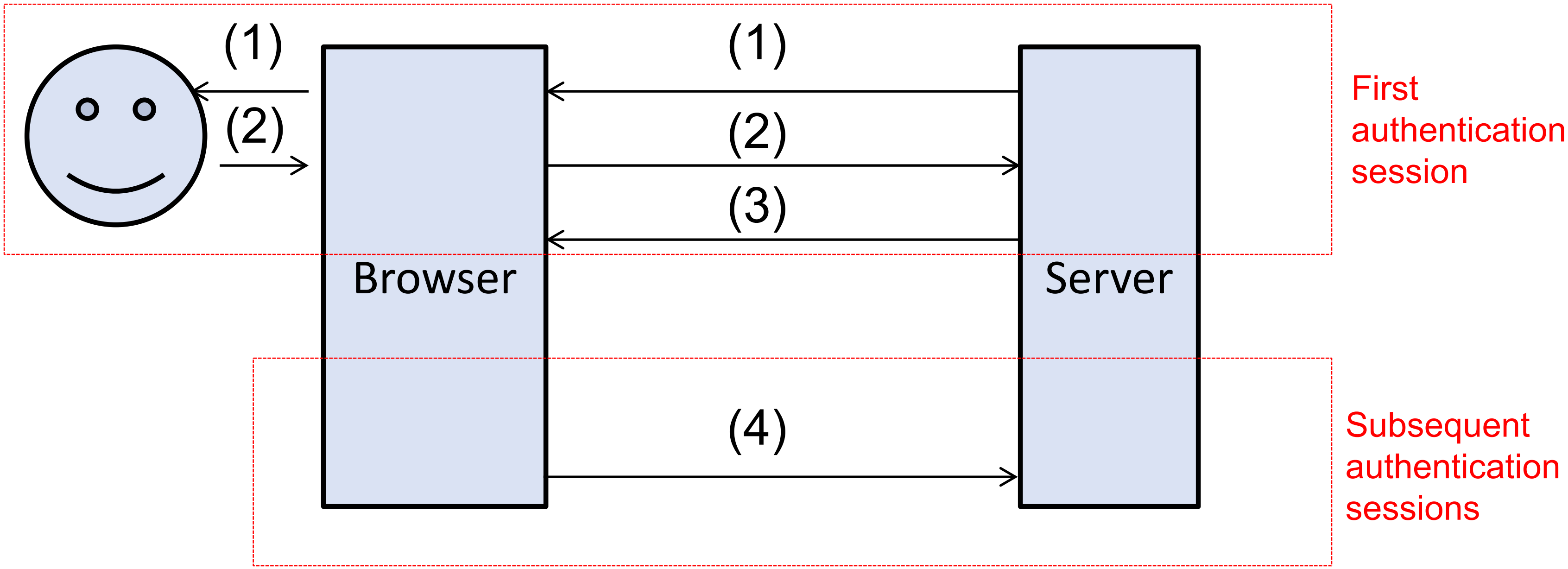
  See https://en.wikipedia.org/wiki/HTTP_cookie#Terminology
- Note: the checking on scheme in the "same origin" for cookies is **optional**, except for **secure cookies** which strictly require HTTPS
- Since HTTP is **stateless**, there is a need to keep track of a **web session**
- Cookie is commonly used to **set** and **indicate** a **session ID**
- **Cookie** is a better approach than attaching the session ID as a **URL-encoded parameter** in the HTTP request or as a **form field**, but it has its own issues too

Token-based Authentication and Cookie

- To ease a web user's tedious task of repeated logins, many web sites use "**token-based" authentication**:
  1. After a user *A* is **authenticated** (for e.g. **password verified**), the server sends a value ***t***, known as the **token**, to *A*
  2. In subsequent connections, whoever presents the **correct token** is thus **accepted** as the authentic user *A*

- **Remarks**:
  - A token typically has an **expiry date**
  - A token can identify a **session**:
    hence, the token is also called **session ID (SID)**
  - In web applications, a token is often stored in a **cookie**

Token-based Authentication: Diagram



(1) Authentication challenge (e.g. asking for password)

(2) Authentication response that involves the user

(3) Server sends a token ***t***, and Browser keeps the token ***t***

(4) Browser presents the token ***t*** with HTTP request, and Server verifies the token ***t***

Note: We assume that the **communication channel is secure**: it is done over HTTPS (with server being authenticated) and the HTTPS is free from vulnerabilities.

Storage Requirement and Choices of Token

- A token ***t*** needs to be **random** and sufficiently **long**
- Suppose token ***t*** is a **randomly chosen number**, then the server has to keep a **table** storing all issued tokens
- To **avoid** storing the table, one could use:
  - (**Insecure**) The cookie is some meaningful information concatenated with a **predictable** sequence number

    E.g ***t*** = "alicetan:16/04/2015:128829"

  - (**Secure**) The cookie consists of **two parts**:
    a randomly chosen value or meaningful information like the expiry date; and concatenated with the **message authentication code (MAC)** computed using the server's secret key

    E.g ***t*** = "alicetan:16/04/2015:adc8213kjd891067ad9993a"

Storage Requirement and Choices of Token

- For both methods, when the server finds out that the token is ***not*** in the correct format (or ***not*** the correct MAC), the server **rejects** the token
- The **first** method is **insecure***:* an attacker, who knows how the token is generated (e.g. by observing its own token), can **forge it**
- This illustrates the weakness of "security by obscurity": a wrong assumption that attackers don't know the format
- The **second** method is **secure**: it relies on the security of MAC

Scripts & Same-Origin Policy (SOP): Browser Access Control

- A **script** that runs in the browser could access **cookies**
- Important question: **which scripts can access what cookies?**
- Due to security concern, browser employs the following **access control** mechanism
- The **script** in a web page *A* (identified by its URL) can access **cookies** stored by another web page *B* (identified by its URL), only if both *A* and *B* have the ***same origin***
- **Origin** is defined as the combination of: **protocol, hostname, and port number**
- The above is simple and thus seemingly safe
- However, there are a number of possible **complications**

Same-Origin Policy (SOP): Some Complications

- Example of **origin determination rules**:
  URLs with the same origin as http://www.example.com
  (from http://en.wikipedia.org/wiki/Same-origin_policy)

Compared URL	Outcome	Reason
http://www.example.com/dir/page2.html	Success	Same protocol, host and port
http://www.example.com/dir2/other.html	Success	Same protocol, host and port
http://username:password@**www.example.com**/dir2/other.html	Success	Same protocol, host and port
http://www.example.com:**81**/dir/other.html	Failure	Same protocol and host but different port
https://www.example.com/dir/other.html	Failure	Different protocol
http://**en.example.com**/dir/other.html	Failure	Different host
http://**example.com**/dir/other.html	Failure	Different host (exact match required)
http://**v2.www.example.com**/dir/other.html	Failure	Different host (exact match required)
http://www.example.com:**80**/dir/other.html	Depends	Port explicit. Depends on implementation in browser.

- **Limitation:** there are many exceptions, and exceptions of exceptions: very confusing and thus prone to errors
- An example: unlike other browsers, **Microsoft IE** does ***not*** include the port in the calculation of the origin, using the **Security Zone** in its place
  (See https://blogs.msdn.microsoft.com/ieinternals/2009/08/28/same-origin-policy-part-1-no-peeking/.)

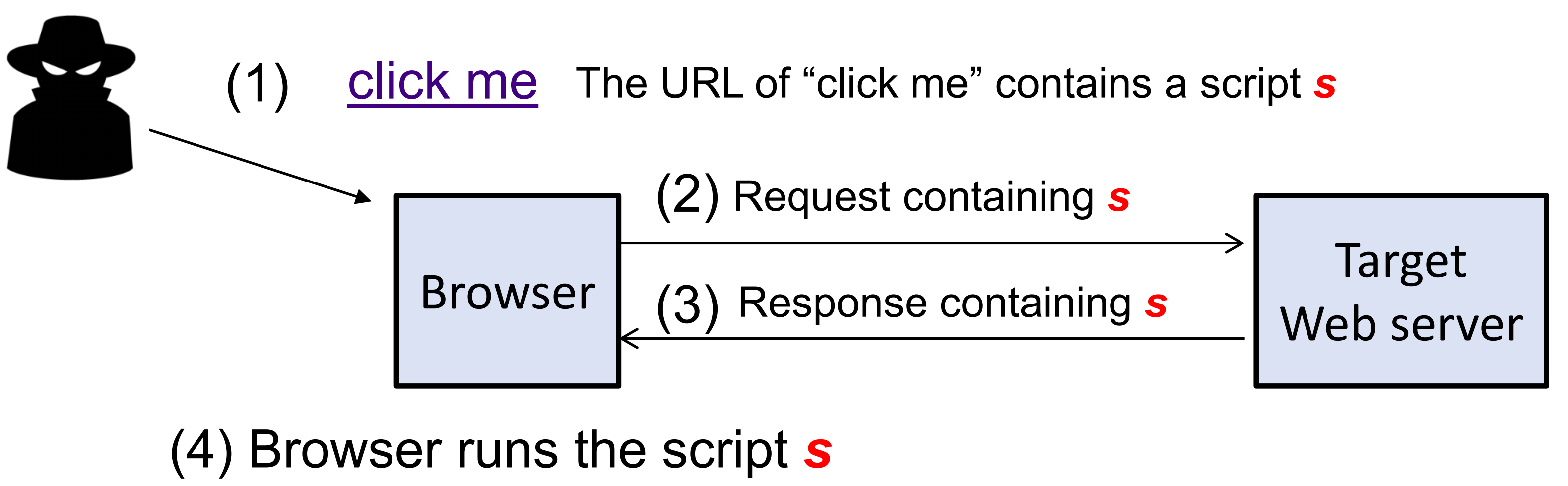
10.6 Cross Site Scripting (XSS) Attacks

Reflected (Non-Persistent) XSS Attack: Background

- In many web sites, the client can enter a string ***s*** in the browser, which is to be sent to the server
- The server then responses with a HTML **containing *s*,** which is then rendered and displayed by the client's browser
- Examples:
  - Enter a wrong address: http://www.comp.nus.edu.sg/nonsense_test
  - Search for a book in library: http://nus.preview.summon.serialssolutions.com/#!/search?q=heeheeheee
- Important question: what if the string ***s*** contains a **script**?
  - Example: http://www.comp.nus.edu.sg**/<script>alert("heehee!");</script>**
- Note that the attack above **won't** work if the server performs **HTML (entity) encoding**: replaces the special character "<" with <

Reflected (Non-Persistent) XSS Attack: Attack

1. The attacker tricks a user to **click** on a URL, which contains the target website and a malicious script ***s*** (For example, the link could be sent via email with "click me", or a link in a malicious website.)
2. The request is **sent to the server**
3. The server constructs a **response HTML**: the server doesn't check the request carefully, and its response **contains *s***
4. The browser renders the HTML page, and **runs** the script ***s***



Why is This an Attack?

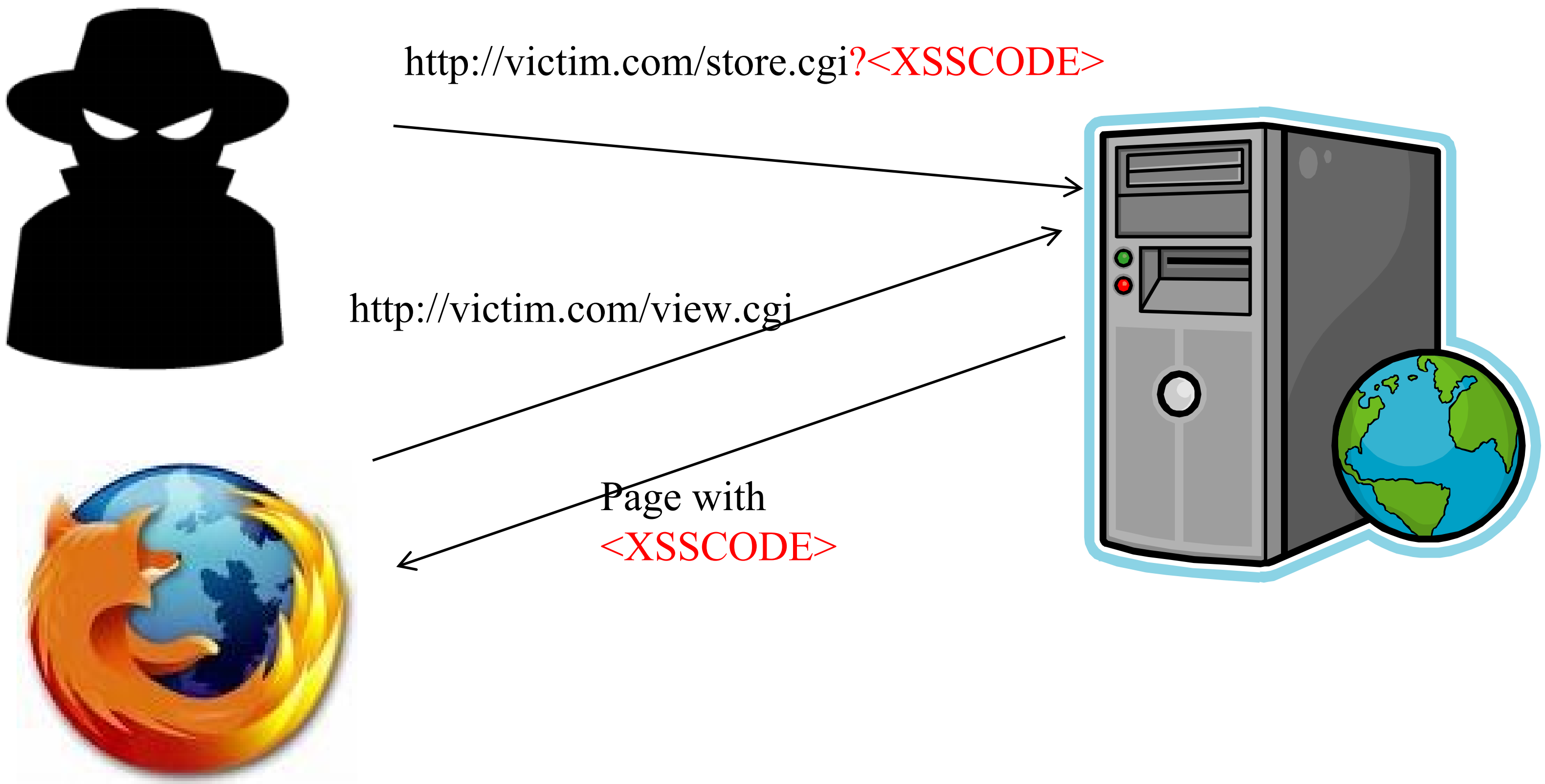
- A script can be **benign**
- However, a **malicious** script could:
  1. Deface the original Webpage
  2. Steal cookies
- Recall the same-origin policy:
  Because the script comes from the **target web server**,
  it can **access cookies** previously sent by the web server
- This is an example of **privilege escalation**:
  a malicious script from the attacker has the privilege of
  the web server and read the cookies
- The attack above exploits the **client's trust of the server**:
  the browser believes that the injected script is from the server

Stored (Persistent) XSS

- The script ***s*** is **stored** in the target web server
- For instance, it is stored in a **forum page**:
  the attacker is a **malicious forum poster**
- Another example: **Samy XSS worms** on Myspace.com,
  where Samy became a friend of 1M users in less than 20 hours!
  (See https://en.wikipedia.org/wiki/Samy_(computer_worm))

- **More dangerous** than reflected XSS attacks:
  - The malicious script is **rendered automatically**,
    without the need to lure target victims to a 3rd-party web site
  - The victim-to-script ratio is **many:1**

Stored (Persistent) XSS



XSS Attacks: Summary

- What is **XSS** in short?
  - "A type of **injection attack** on web apps, whereby a **forum poster** or **web attacker** attacks **another web user** by causing the latter run a (malicious) script from the former in the **execution context** of a page from **an involved web server**, thus subverting the Same Origin Policy."
- The attack works by exploiting **the victim's trust of the involved server**:
  - In reflected XSS: **the web server** that **returns** a page reflecting the injected script
  - In persistent XSS: **the web server** that **stores** a page containing the injected script

Defenses

- Most defense rely on mechanisms carried out in the **server-side**:
  - The server **filters and removes** any malicious script in a **HTTP request** while constructing its response page
  - The server **filters and removes** any malicious script in a **user's post** before it is saved into the forum database
- Some example techniques:
  - Script filtering
  - Noscript region:
    do not allow JavaScript to appear in certain region of a Web page.
- However, this defense is **not** a fool-proof method
- To additionally detect reflected XSS attack, some browsers employ a **client-side** detection mechanism: e.g. **XSS auditor**

10.7 Cross Site Request Forgery (CSRF) Attacks

CSRF Attack: *With* the Victim Clicking on a URL

A.k.a. "**sea surf**", **cross-site reference forgery**, session riding

An attack **example** (**with** the victim clicking on a URL):

- Suppose a client Alice is **already** authenticated by a target website ***S***, say www.bank.com, and ***S*** accepts an **authentication-token cookie**
- The attacker Bob tricks Alice to click on **a URL** of *S*, which maliciously **requests** for a service, say transferring $1,000 to Bob:

  www.bank.com/transfer?account=Alice&amount=1000&to=Bob

- Alice's cookie will also be **automatically sent** to *S*, indicating that the request comes from already-authenticated Alice
- Hence, the transaction will be **carried out**

(For more details, see https://en.wikipedia.org/wiki/Cross-site_request_forgery.)

CSRF Attack: *Without* the Victim Clicking on a URL

A **web attacker** can also performs a CSRF attack ***without*** any victim user's UI actions

An attack **example** (**without** the victim clicking a URL):

- Again, suppose Alice is **already** authenticated by a target website *S* (www.bank.com), and ***S*** accepts an authentication-token cookie
- **Alice visits the attacker's site**, whose page contains the following:
  <IMG SRC="www.bank.com/transfer?account=Alice&amount=1000&to=Bob" WIDTH="1" HEIGHT="1" BORDER="0">
- Alice's browser issues **another HTTP request** to obtain the image
- Alice's cookie will also be **automatically sent** to *S*
- Hence, the transaction will be **carried out**

CSRF Attacks

- What is the **CSRF** in short?
  "A type of **authorization attack** on web apps,
  whereby a **web attacker** attacks **a web user** by issuing
  a **forged request** to **a vulnerable web server** ‘on behalf’ of
  the victim user.”

- The attack disrupts the **integrity** of the target user’s session

- This is, in a way, the reverse of XSS:
  it exploits **the server’s trust of the client**
  (the server believes that the request is from the client)

Defenses

- **Relatively easier** to prevent compared to XSS
- The **SID/authentication-token cookie** automatically sent by the browser is ***insufficient***:
  the server must issue and require an **extra information**, i.e. ***anti-CSRF token***
- For example, the server **includes** a (dynamic) anti-CSRF token in its **money-transfer request** page
- The anti-CSRF token can be included in a **URL**:
  www.bank.com/transfer?account=Alice&amount=1000&to=Bob&
  Token=xxk34n890ad7casdf897e324
- It is also possible to include the anti-CSRF token inside a HTTP **request header** or a **hidden form field**

Other Web Attacks and Terminologies

- **Drive-by download**
- **Web bug** (aka Web beacon, tracking bug, tag, page tag).
- **Clickjacking** (User Interface redress attack)
  See https://www.owasp.org/index.php/Clickjacking
- **CAPTCHA**
- **Click fraud**

Question: Could **merely visiting** a malicious web site (for e.g. by clicking on a phishing email) make a web user become a subject to web attacks?