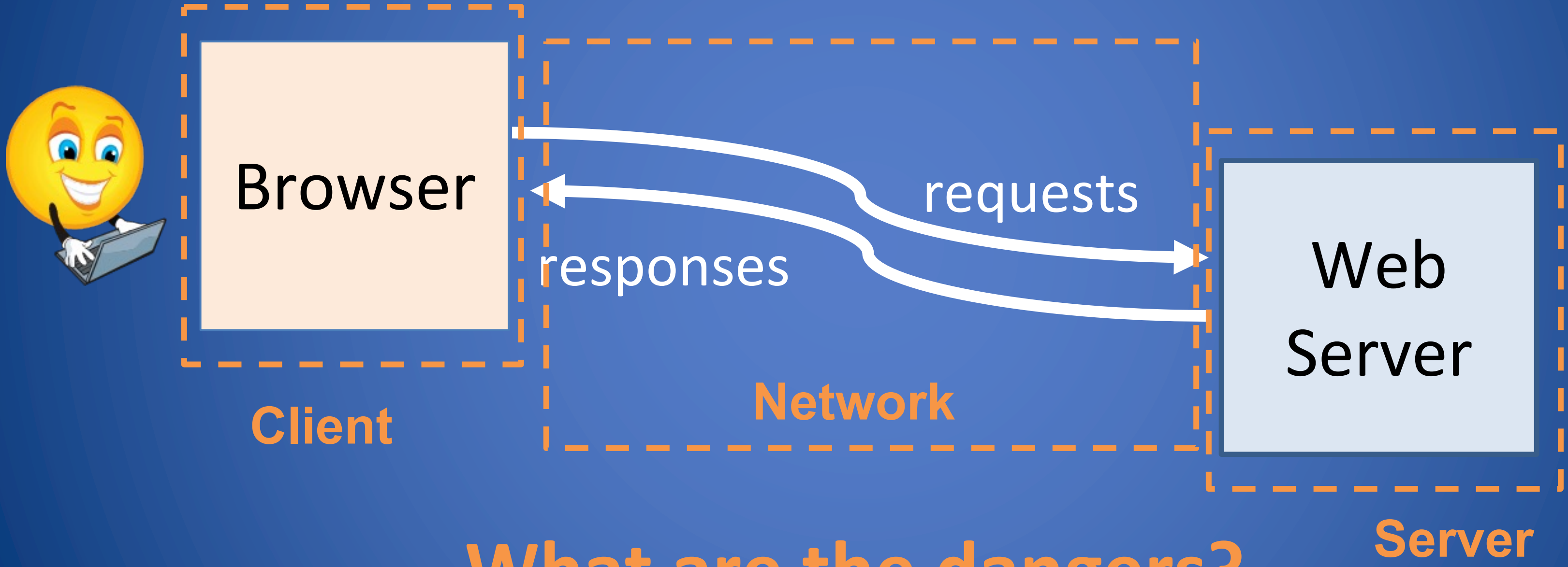
Web Security I

Web Security Models
Browser Security
Web Technologies and Protocols

Web Security Model

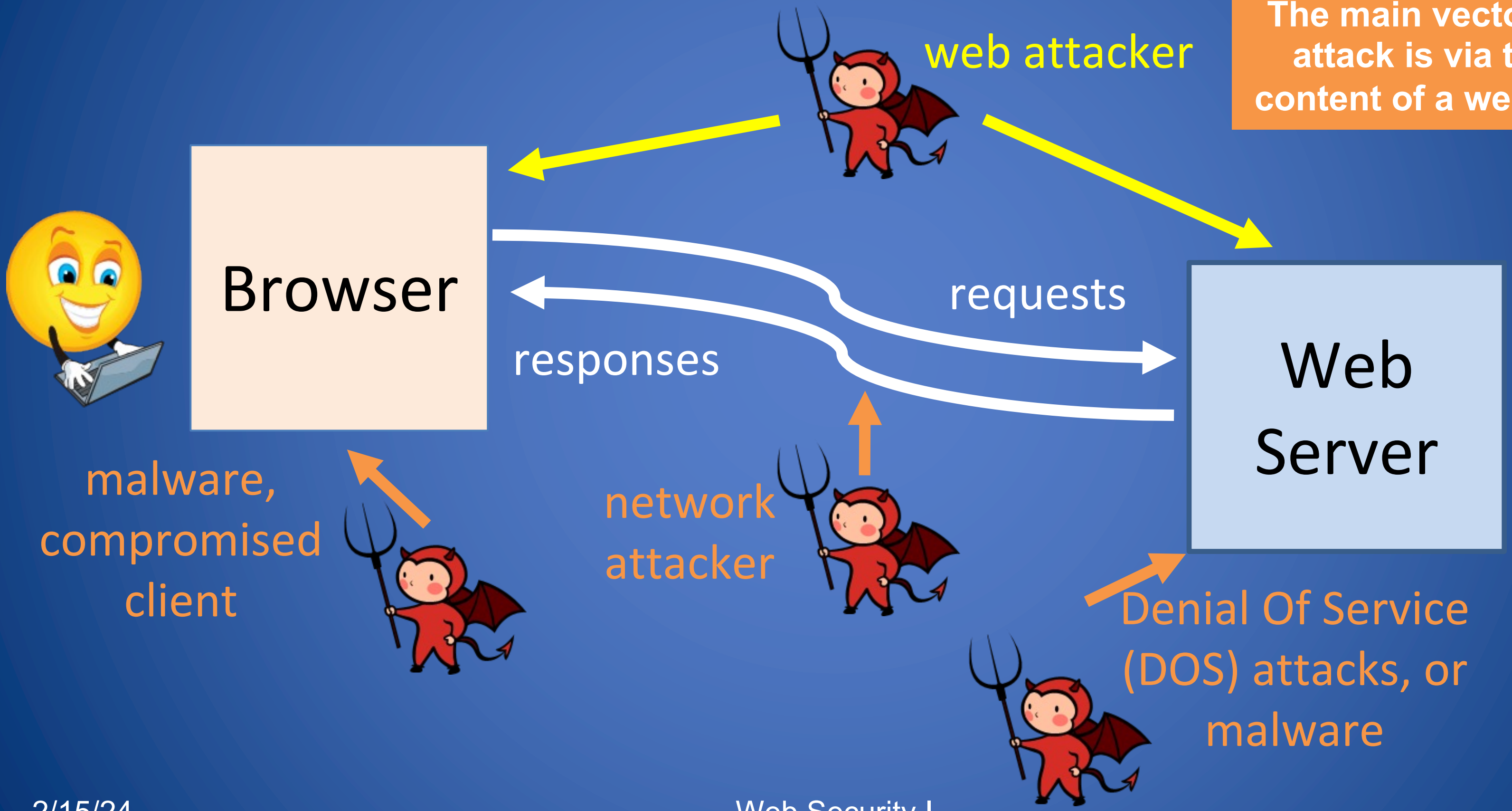
Web Applications



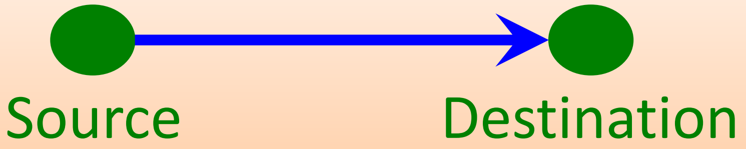
What are the dangers?

Threat Models

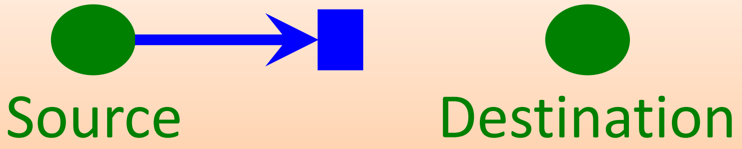
The main vector of attack is via the content of a website


web attacker
Browser
requests
responses
Web Server
malware, compromised client
network attacker
Denial Of Service (DOS) attacks, or malware

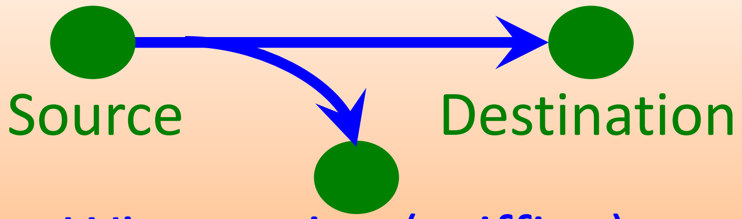
Network Attacks



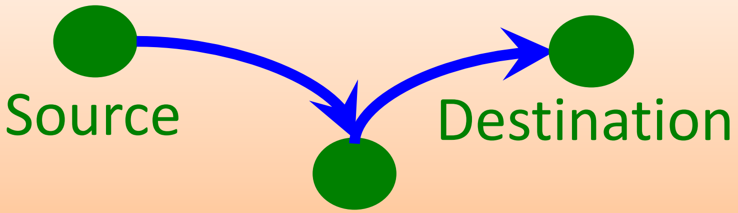
Standard Flow



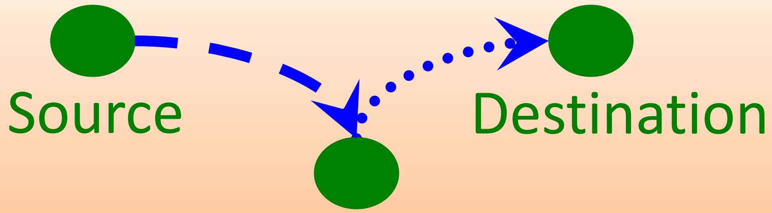
Block (DoS)



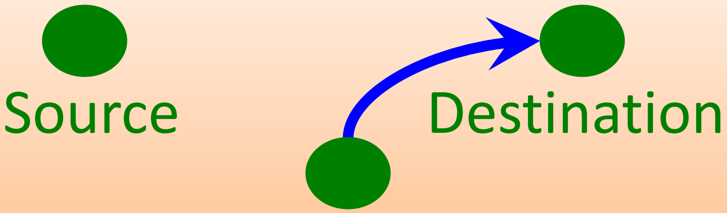
Wiretapping (sniffing)



Attacker in the Middle (passive)



Attacker in the Middle (active)



Creation (spoofing)

Web Attacker Capabilities

- Attacker controls malicious website
  - Website might look professional, legitimate, etc.
  - Attacker can get users to visit website (how?)
- Good website is compromised by attacker
  - Attacker inserts malicious content into website
  - Attacker steals sensitive data from website
  - …

Attacker does not have direct access to user's machine

Potential Damage

- An attacker gets you to visit a malicious website
  - Can they perform actions on other websites impersonating you?
  - Can they run evil code on your OS?
- Ideally, none of these exploits are possible ...

Attack Vectors

- Web browser (focus of this lecture)
  - Renders web content (HTML pages, scripts)
  - Responsible for confining web content
  - **Note:** Browser implementations dictate what websites can do
- Web applications
  - Server code (PHP, Ruby, Python, …)
  - Client-side code (JavaScript)
  - Many potential bugs (which you'll explore in Project 2 ☺)

Browser Security: Sandbox

- Goal: protect local computer from web attacker
  - Safely execute code on a website
  - … without the code accessing your files, tampering with your network, accessing other sites
- High stakes ($40K bounty for Google Chrome ; www.google.com/about/appsecurity/chrome-rewards/)
- We won't address attacks that break the sandbox
- But they **happen** check the **CVE list**
  - **https://cve.mitre.org/cgi-bin/cvekey.cgi?keyword=sandbox**
  - **https://support.apple.com/en-us/HT213635**

Domains, HTML and HTTP

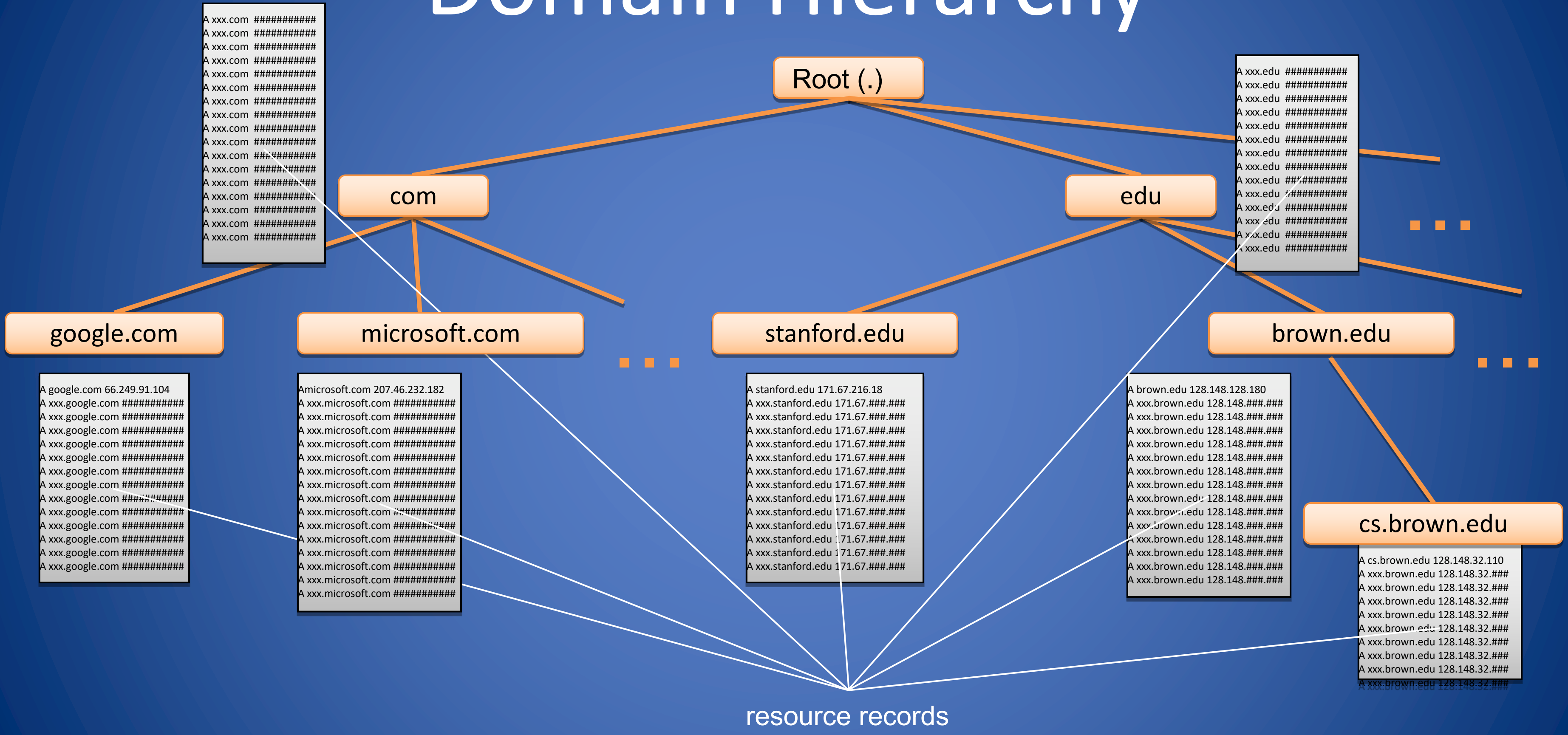
URL and FQDN

- URL Uniform Resource Locator
- https://cs.brown.edu/about/contacts.html
  - a protocol (e.g. https),
    a FQDN (e.g. cs.brown.edu)
  - a path and file name (e.g. /about/contacts.html).

- FQDN (Fully Qualified Domain Name)
  - [Host name].[Domain].[TLD].[Root]
  - Two or more labels, separated by dots (e.g., cs.brown.edu)
- Root name server

  It is a "." at the end of the FQDN
- Top-level domain (TLD)
  - Generic (gTLD), .com, .org, .net, …
  - Country-code (ccTLD), .ca, .it, …

Domain Hierarchy



Root (.)

com

edu

google.com

microsoft.com

stanford.edu

brown.edu

cs.brown.edu

. . .

. . .

. . .

A xxx.com ###########
A xxx.com ###########
A xxx.com ###########
A xxx.com ###########
A xxx.com ###########
A xxx.com ###########
A xxx.com ###########
A xxx.com ###########
A xxx.com ###########
A xxx.com ###########
A xxx.com ###########
A xxx.com ###########
A xxx.com ###########
A xxx.com ###########
A xxx.com ###########
A xxx.com ###########
A xxx.com ###########

A xxx.edu ###########
A xxx.edu ###########
A xxx.edu ###########
A xxx.edu ###########
A xxx.edu ###########
A xxx.edu ###########
A xxx.edu ###########
A xxx.edu ###########
A xxx.edu ###########
A xxx.edu ###########
A xxx.edu ###########
A xxx.edu ###########
A xxx.edu ###########
A xxx.edu ###########

A google.com 66.249.91.104
A xxx.google.com ###########
A xxx.google.com ###########
A xxx.google.com ###########
A xxx.google.com ###########
A xxx.google.com ###########
A xxx.google.com ###########
A xxx.google.com ###########
A xxx.google.com ###########
A xxx.google.com ###########
A xxx.google.com ###########
A xxx.google.com ###########
A xxx.google.com ###########
A xxx.google.com ###########

Amicrosoft.com 207.46.232.182
A xxx.microsoft.com ###########
A xxx.microsoft.com ###########
A xxx.microsoft.com ###########
A xxx.microsoft.com ###########
A xxx.microsoft.com ###########
A xxx.microsoft.com ###########
A xxx.microsoft.com ###########
A xxx.microsoft.com ###########
A xxx.microsoft.com ###########
A xxx.microsoft.com ###########
A xxx.microsoft.com ###########
A xxx.microsoft.com ###########
A xxx.microsoft.com ###########
A xxx.microsoft.com ###########
A xxx.microsoft.com ###########

A stanford.edu 171.67.216.18
A xxx.stanford.edu 171.67.###.###
A xxx.stanford.edu 171.67.###.###
A xxx.stanford.edu 171.67.###.###
A xxx.stanford.edu 171.67.###.###
A xxx.stanford.edu 171.67.###.###
A xxx.stanford.edu 171.67.###.###
A xxx.stanford.edu 171.67.###.###
A xxx.stanford.edu 171.67.###.###
A xxx.stanford.edu 171.67.###.###
A xxx.stanford.edu 171.67.###.###
A xxx.stanford.edu 171.67.###.###
A xxx.stanford.edu 171.67.###.###
A xxx.stanford.edu 171.67.###.###

A brown.edu 128.148.128.180
A xxx.brown.edu 128.148.###.###
A xxx.brown.edu 128.148.###.###
A xxx.brown.edu 128.148.###.###
A xxx.brown.edu 128.148.###.###
A xxx.brown.edu 128.148.###.###
A xxx.brown.edu 128.148.###.###
A xxx.brown.edu 128.148.###.###
A xxx.brown.edu 128.148.###.###
A xxx.brown.edu 128.148.###.###
A xxx.brown.edu 128.148.###.###
A xxx.brown.edu 128.148.###.###
A xxx.brown.edu 128.148.###.###
A xxx.brown.edu 128.148.###.###
A xxx.brown.edu 128.148.###.###

A cs.brown.edu 128.148.32.110
A xxx.brown.edu 128.148.32.###
A xxx.brown.edu 128.148.32.###
A xxx.brown.edu 128.148.32.###
A xxx.brown.edu 128.148.32.###
A xxx.brown.edu 128.148.32.###
A xxx.brown.edu 128.148.32.###
A xxx.brown.edu 128.148.32.###
A xxx.brown.edu 128.148.32.###
A xxx.brown.edu 128.148.32.###

resource records

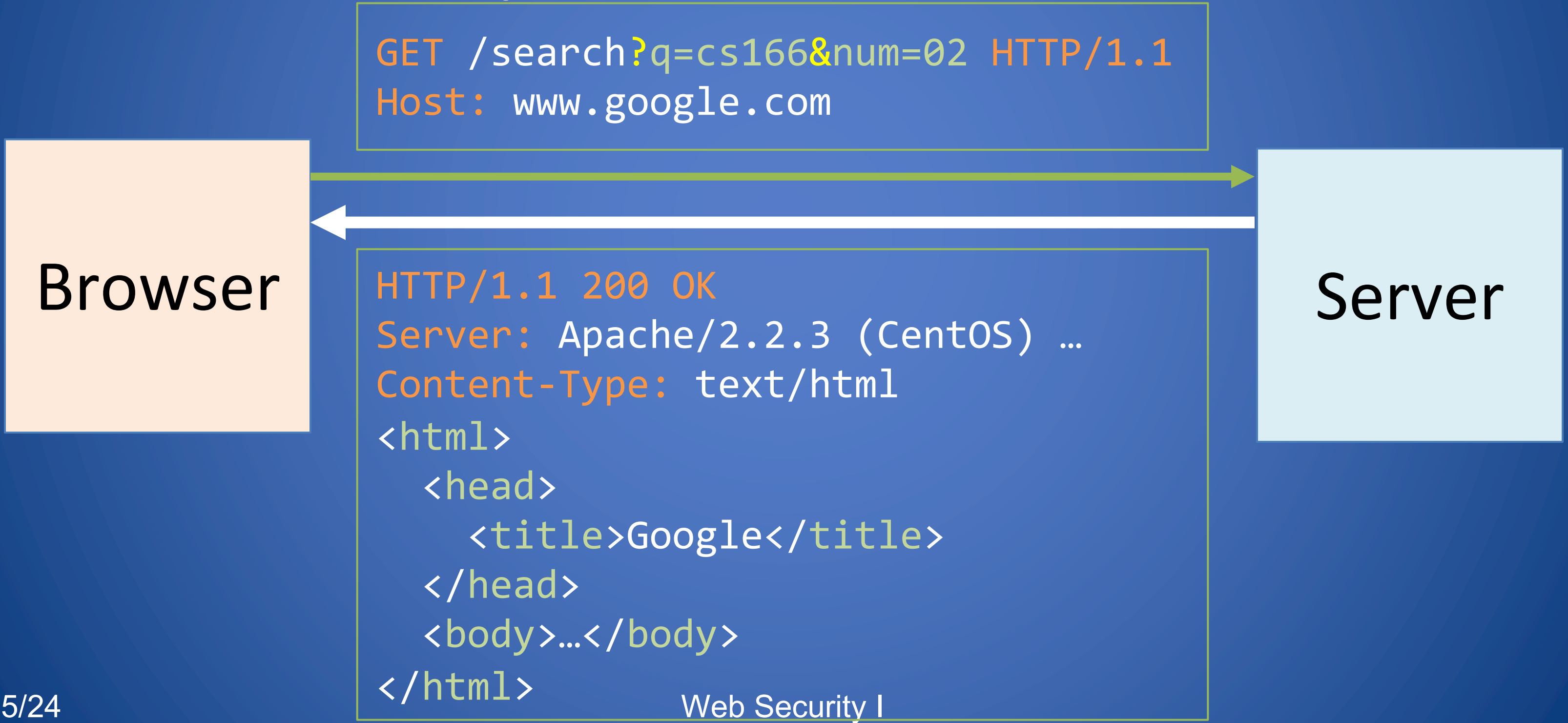
HTML

- Hypertext markup language (HTML)
  - Allows linking to other pages (href)
  - Supports embedding of images, scripts, other pages (script, iframe)
  - User input accepted in forms

```
<html>
  <head>
    <title>Google</title>
  </head>
  <body>
    <p>Welcome to my page.</p>
    <script>alert(“Hello world”);
    </script>
    <iframe src=“http://example.com”>
    </iframe
  </body>
</html>
```

HTTP (Hypertext Transport Protocol)

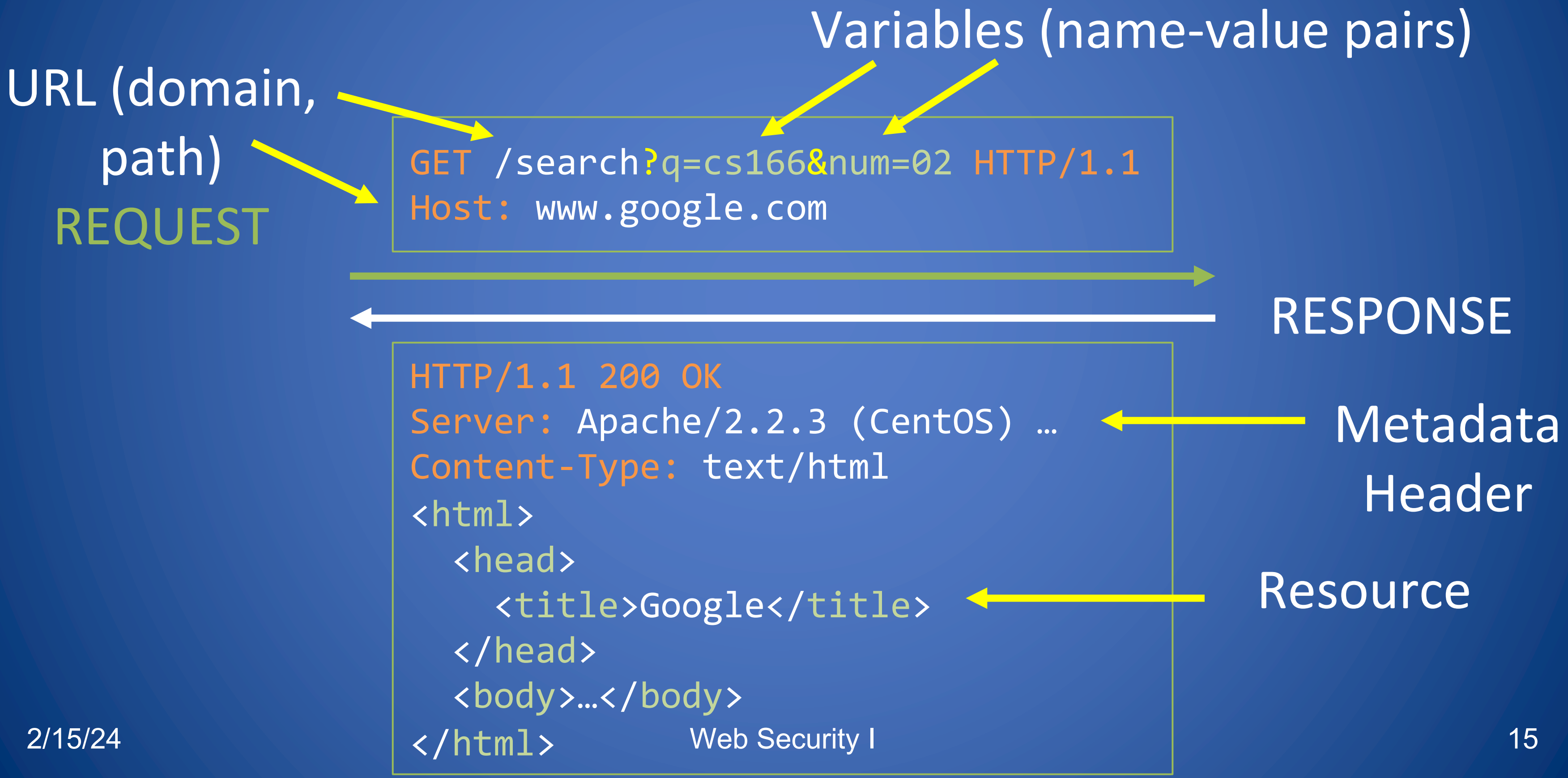
- Communication protocol between client and server



```
GET /search?q=cs166&num=02 HTTP/1.1
Host: www.google.com
```

```
HTTP/1.1 200 OK
Server: Apache/2.2.3 (CentOS) …
Content-Type: text/html
<html>
  <head>
    <title>Google</title>
  </head>
  <body>…</body>
</html>
```

What’s in a request (or response)?



URL (domain, path)

Variables (name-value pairs)

REQUEST

```
GET /search?q=cs166&num=02 HTTP/1.1
Host: www.google.com
```

RESPONSE

```
HTTP/1.1 200 OK
Server: Apache/2.2.3 (CentOS) …
Content-Type: text/html
<html>
  <head>
    <title>Google</title>
  </head>
  <body>…</body>
</html>
```

Metadata Header

Resource

Variables

- Key-value pairs obtained from user input into forms and submitted to server
- Submit variables in HTTP via GET or PUT
- GET request: variables within HTTP URL, e.g.,

  http://www.google.com/search?q=cs166&num=02

- POST request: variables within HTTP body, e.g.,

```
POST / HTTP/1.1
Host: example.com
Content-Type: application/x-www-form-urlencoded
Content-Length: 18

month=5&year=2024
```

Semantics: GET vs. POST

- GET
  - Request target resource
  - Read-only method
  - Submitted variables may specify target resource and/or its format

- POST
  - Request processing of target resource
  - Read/write/create method
  - Submitted variables may specify how resource is processed (e.g., content of resource to be created, updated, or executed)

GET vs. POST

	GET	POST
Browser history	√	X
Browser bookmarking	√	X
Browser caching	√	X
Server logs	√	X
Reloading page	immediate	warning
Variable values	Restricted	arbitrary

Moving from Browser Security to Web Application Security: Client-Side Controls

Client-Side Controls

- Web security problems arises because clients can submit arbitrary input
- **What about using client side controls to check the input?**
- **Which kind of controls?**

Client-Side Controls

- A standard application may rely on client-side controls to restrict user input in two general ways:
  - Transmitting data via the client component using a mechanism that should prevent the user from modifying that data
  - Implementing measures on the client side
- In this model the **Server does not trust the Client**

Bypassing Web Client-Side Controls

- In general a security flaw because it is easy to bypass
- The user:
  - has a full control over the client and the data it submits
  - Can bypass any controls that are client-side and not replicated on the server
- Why these controls are still useful?
  - E.g. for load balancing or usability
  - Often we can suppose that the vast majority of users are honest

Transmitting Data Via the Client

- A common developer bad habit is passing data to the client in a form that the end user cannot directly see or modify
- Why is it so common?
  - It removes or reduces the amount of data to store server side per-session
  - In a multi-server application it removes the need to synchronize the session data among different servers
  - The use of third-party components on the server may be difficult or impossible to integrate
- Transmitting data via the client is often the easy solution but unfortunately is not secure.

Common Mechanisms

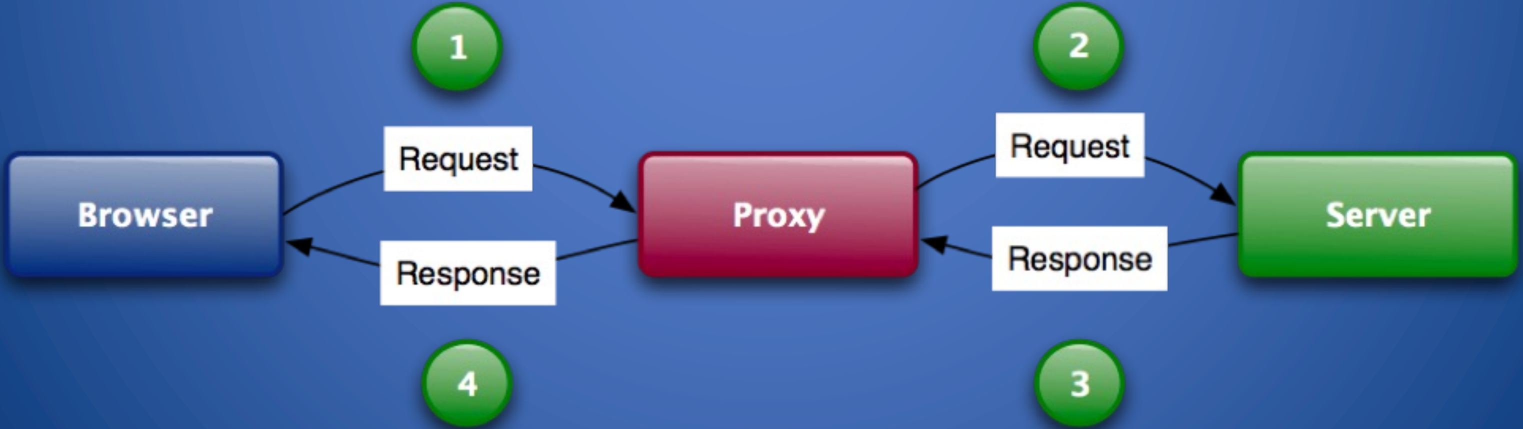
- HTML Hidden fields
  - A field flagged hidden is not displayed on-screen
- HTTP Cookies
  - Not displayed on-screen, and the user cannot modify directly
- Referer Header
  - An optional field in the http request that it indicates the URL of the page from which the current request originated
- If you use the proper tool you can tamper the data on the client-side

Web client tool

- Web inspection tool:
  - Firefox or Chrome web developer:
    - powerful tools that allow you to edit HTML, CSS and view the coding behind any website: CSS, HTML, DOM and JavaScript
- Web Proxy:
  - Burp, OWASP ZAP, etc.
    - Allow to modify GET or POST requests

HTTP Proxy

- An intercepting Proxy:
  - inspect and modify traffic between your browser and the target application
  - Burp Intruder, OWASP ZAP, etc.



WEBGOAT

Demos

- Owasp Webgoat https://github.com/WebGoat/WebGoat
  - – parameter injection
  - –Bypass html field restrictions
  - –Exploit hidden fields
  - –Bypass client side java script validation

BREAK!

5 4 3 2 1

Web Intro

In BROWSER we trust…

- Most of our trust on web security relies on information stored in the Browser:
  - –A Browser should be updated since Bugs in the browser implementation can lead to various attacks

https://us-cert.cisa.gov/ncas/current-activity/2023/02/14/mozilla-releases-security-updates-firefox-110-and-firefox-esr

  - –Add-ons too are dangerous
    - –Hacking Team flash exploits - goo.gl/syVwiD
    - –**github.com/greatsuspender/thegreatsuspender/issues/1263**
  - –Executing a browser with low privileges helps

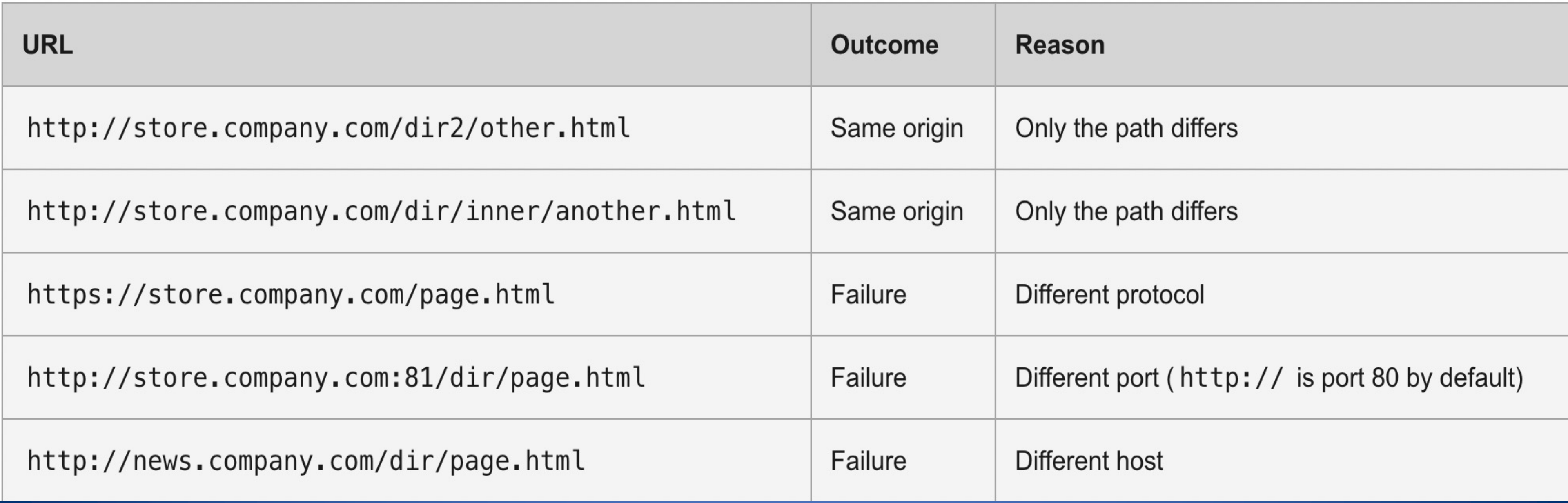
Browser Security: Same-Origin Policy

- Very simple idea: “Content from different origins should be isolated”
  - Website origin defined over tuple (protocol, domain, port)
- Very difficult to execute in practice…
  - Messy number of cases to worry about…
    - HTML elements?
    - Navigating Links?
    - Browser cookies?
    - JavaScript capabilities?
    - iframes?
    - etc.
  - Browsers didn’t always get this correct…

Browser Security: SOP

- Goal: Protect and isolate web content from other web content
  - Content from different origins should be isolated, e.g., mal.com should not interact with bank.com in unexpected ways
  - What about cs.brown.edu vs brown.edu or mail.google.com vs drive.google.com?
  - Lots of subtleties

SOP Example: (protocol, domain, port)
http://store.company.com/dir/page.html



URL	Outcome	Reason
`http://store.company.com/dir2/other.html`	Same origin	Only the path differs
`http://store.company.com/dir/inner/another.html`	Same origin	Only the path differs
`https://store.company.com/page.html`	Failure	Different protocol
`http://store.company.com:81/dir/page.html`	Failure	Different port (`http://` is port 80 by default)
`http://news.company.com/dir/page.html`	Failure	Different host

Source: https://developer.mozilla.org/en-US/docs/Web/Security/Same-origin_policy

Cookies

Cookies

- HTTP is a stateless protocol; cookies used to emulate state
- Servers can store cookies (name-value pairs) into browser
  - Used for user preferences (e.g., language and page layout), user tracking, authentication
  - Expiration date can be set
  - May contain sensitive information (e.g., for user authentication)
- Browser sends back cookies to server on the next connection

```
POST /login.php HTTP/1.1
Set-Cookie: Name: sessionid
            Value: 19daj3kdop8gx
            Domain: cs.brown.edu
            Expires: Wed, 21 Feb 2024 …
```

Cookie Scope

- Each cookie has a scope
  - Base domain, which is a given host (e.g., brown.edu)
  - Plus, optionally, all its subdomains (cs.brown.edu, math.brown.edu, www.cs.brown.edu , etc.)
- For ease of notation, we denote with . the inclusion of subdomains (e.g., .brown.edu)
  - This isn’t the real notation—it’s actually specified in HTTP with the "Domain:" attribute of a cookie

Same Origin Policy: Cookie Reads

Websites can only read cookies within their scope

- Example: browser has cookies with scope
  brown.edu
  .brown.edu,
  .math.brown.edu
  cs.brown.edu
  .cs.brown.edu,
  blog.cs.brown.edu

- Browser accesses cs.brown.edu
- Browser sends cookies with scope
  .brown.edu
  cs.brown.edu
  .cs.brown.edu

Same Origin Policy: Cookie Writes

A website can set cookies for (1) its base domain; or (2) a super domain (except TLDs) and its subdomains

- Browser accesses cs.brown.edu
- cs.brown.edu can set cookies for
  .brown.edu
  cs.brown.edu

- But not for
  google.com
  .com
  math.brown.edu
  brown.edu
  …

Clicker Question #1

If the browser accesses cs.brown.edu, the server can set cookies with which of the following scopes?

A. .brown.edu

B. only math.brown.edu

C. only help.cs.brown.edu

D. All of the above

E. None of the above

Answer Question #1

If the browser accesses cs.brown.edu, the server can set cookies with which of the following scopes?

A. .brown.edu

B. only math.brown.edu

C. only help.cs.brown.edu

…

The scope is cs.brown.edu by default

The server can optionally set cookies with scope .cs.brown.edu and .brown.edu, but nothing else

Session Management

- Session
  - Keep track of client over a series of requests
  - Server assigns clients a unique, unguessable ID
  - Clients send back ID to verify themselves

- Session
  - Necessary in sites with authentication (e.g., banking)
  - Useful in most other sites (e.g., remembering preferences)
- Various methods to implement them (mainly cookies), but also could be in HTTP variables

Session Management: goal

- Goal
  - Users should not have to authenticate for every single request
- Problem
  - HTTP is stateless
- Solution
  - User logs in once
  - Server generate session ID and gives it to browser
    - Temporary token that identifies and authenticates user
  - Browser returns session ID to server in subsequent requests

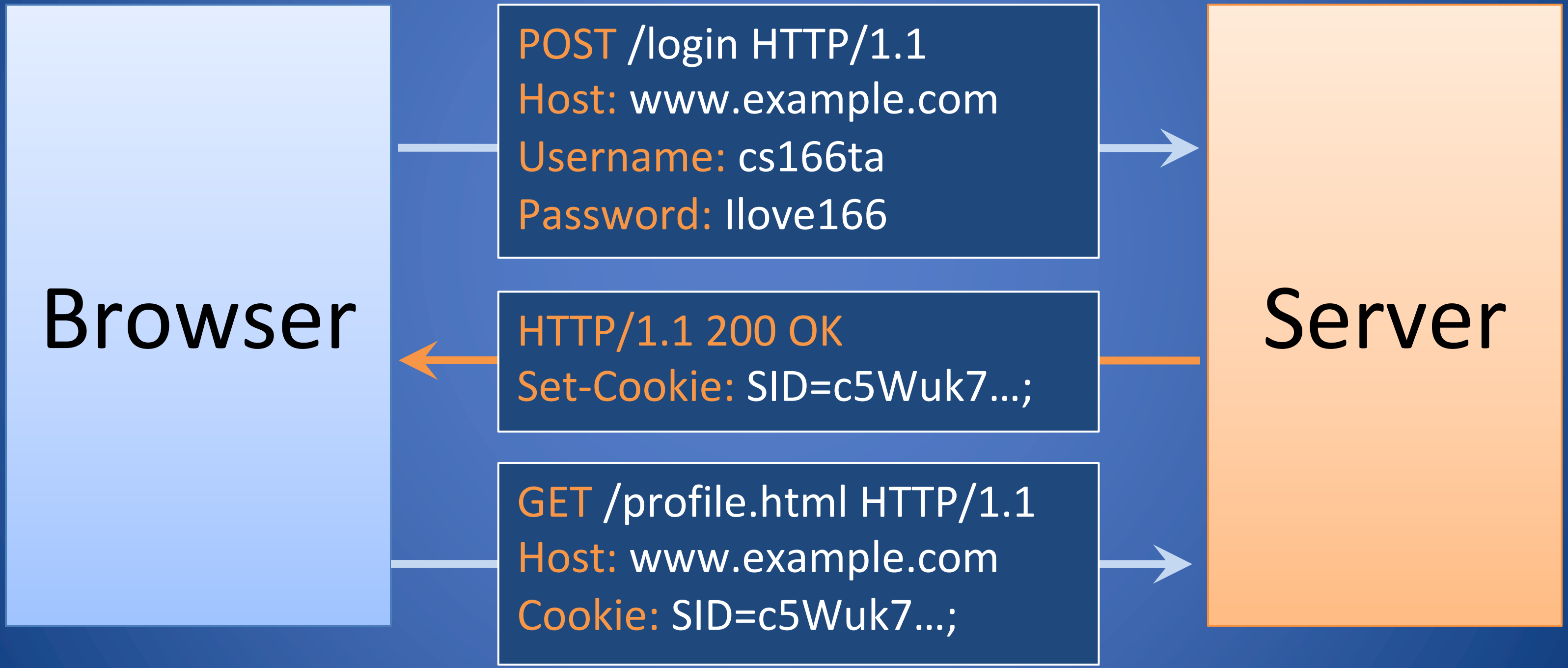
Specifications for a Session ID

- Created by server upon successful user authentication
  - Generated as long random string
  - Associated with scope (set of domains) and expiration
  - Sent to browser
- Kept as secret shared by browser and server
- Transmitted by browser at each subsequent request to server
  - Must use secure channel between browser and server
- Session ID becomes invalid after expiration
  - User asked to authenticate again

Implementation of Session ID

- Cookie
  - Transmitted in HTTP headers
  - `Set-Cookie: SID=c5Wuk7…`
  - `Cookie: SID=c5Wuk7…`
- GET variable
  - Added to URLs in links
  - `https://www.example.com?SID=c5Wuk7…`
- POST variable
  - Navigation via POST requests with hidden variable
  - `<input type="hidden" name="SID" value="c5Wuk7…">`

Session ID in Cookie



```
POST /login HTTP/1.1
Host: www.example.com
Username: cs166ta
Password: Ilove166
```

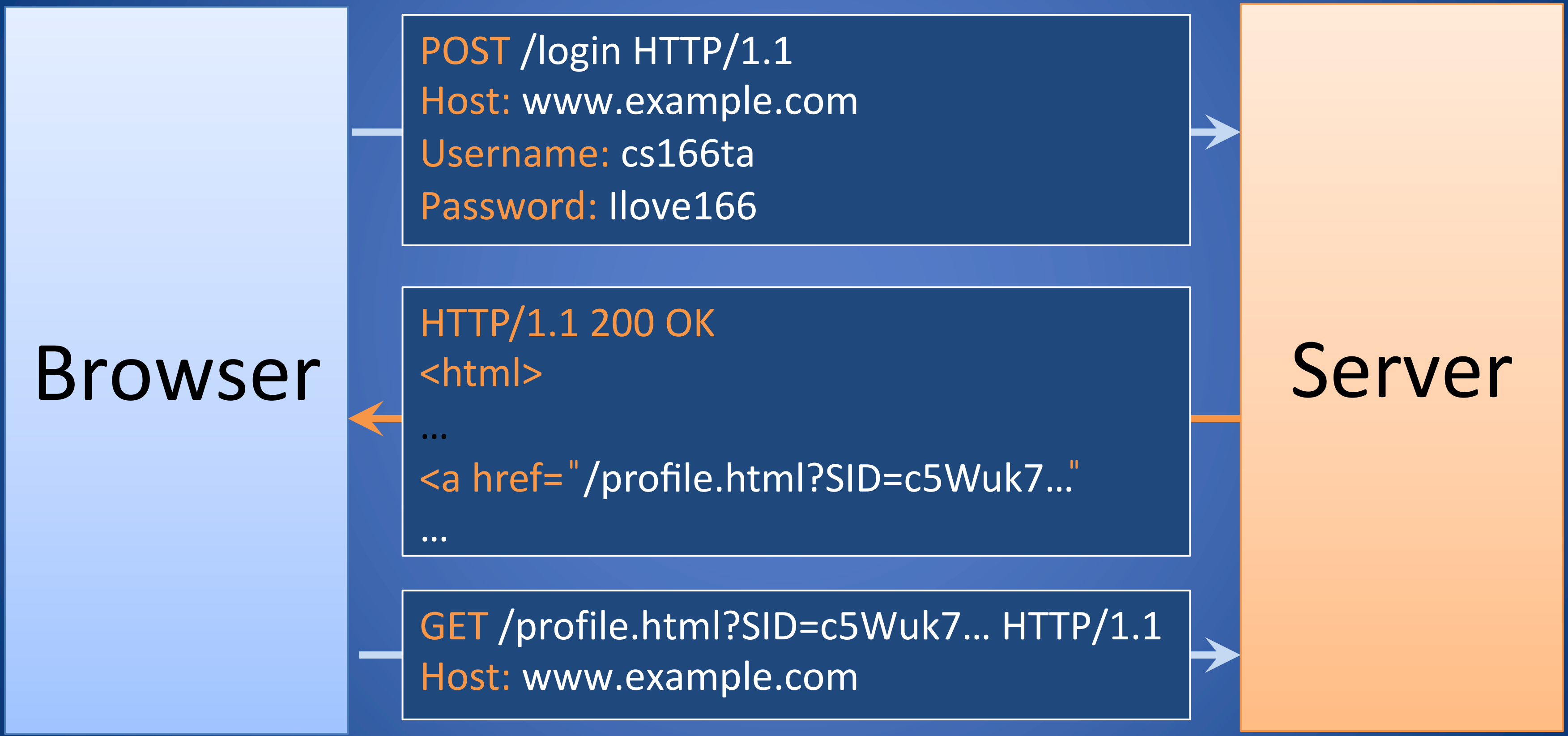
```
HTTP/1.1 200 OK
Set-Cookie: SID=c5Wuk7…;
```

```
GET /profile.html HTTP/1.1
Host: www.example.com
Cookie: SID=c5Wuk7…;
```

Session ID in Cookie

- Advantages
  - Cookies automatically returned by browser
  - Cookie attributes provide support for expiration, restriction to secure transmission (HTTPS), and blocking JavaScript access (httponly)
- Disadvantages
  - Cookies are shared among all browser tabs
    - (**not** other browsers or incognito)
  - Cookies are returned by browser even when request to server is made from element (e.g., image or form) within page from other server
  - This may cause browser to send cookies in context not intended by user

Session ID in GET Variable



```
POST /login HTTP/1.1
Host: www.example.com
Username: cs166ta
Password: Ilove166
```

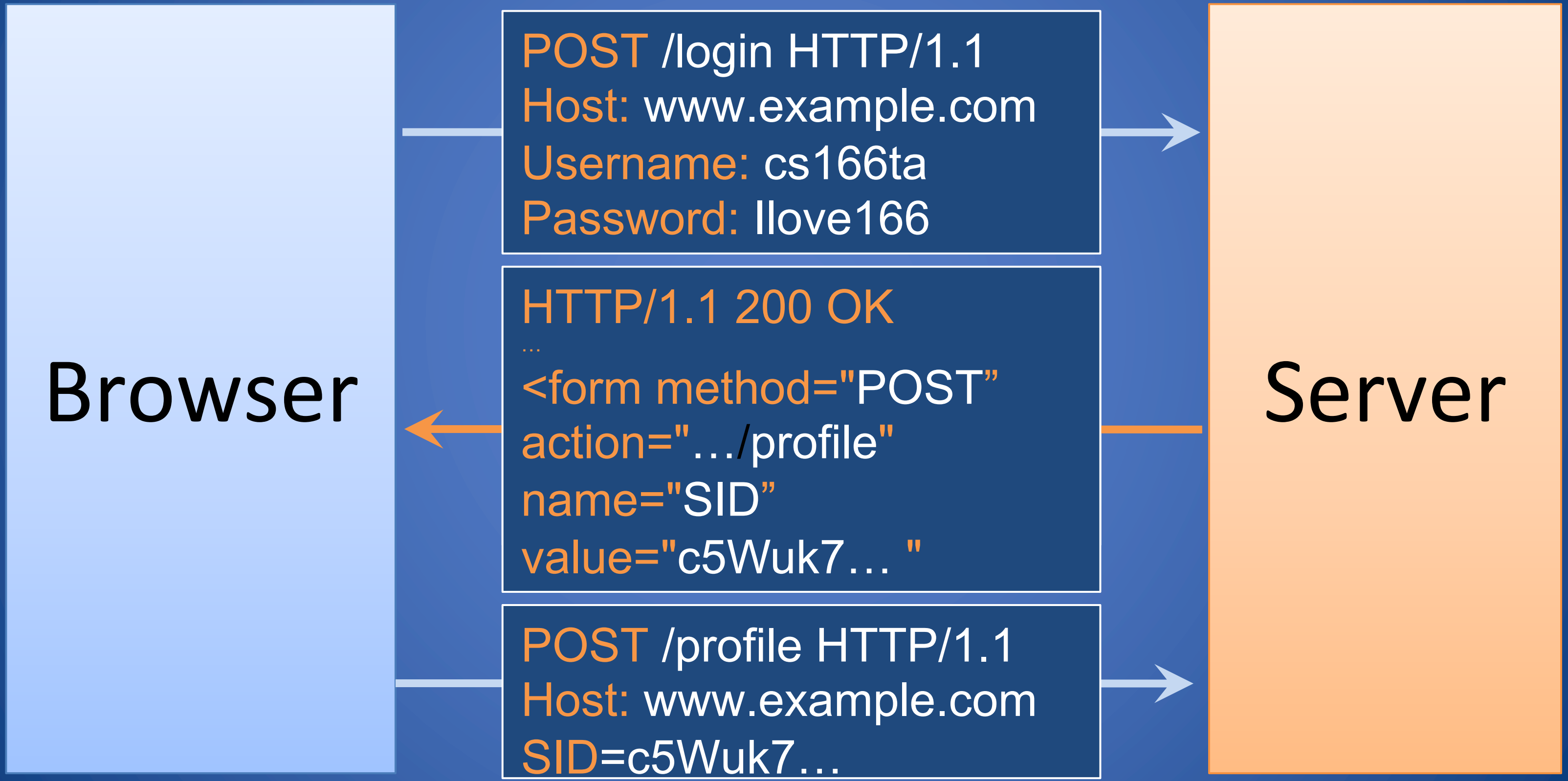
```
HTTP/1.1 200 OK
<html>
…
<a href="/profile.html?SID=c5Wuk7…"
…
```

```
GET /profile.html?SID=c5Wuk7… HTTP/1.1
Host: www.example.com
```

Session ID in GET Variable

- Advantages
  - Session ID transmitted to server only when intended by user
- Disadvantages
  - Session ID inadvertently transmitted when user shares URL
  - Session ID transmitted to third-party site within referrer
  - Session ID exposed by bookmarking and logging
  - Server needs to dynamically generate pages to customize site navigation links and POST actions for each user
  - Transmission of session ID needs to be restricted to HTTPS on every link and POST action

Session ID in POST Variable



Browser

```
POST /login HTTP/1.1
Host: www.example.com
Username: cs166ta
Password: Ilove166
```

```
HTTP/1.1 200 OK
…
<form method="POST”
action="…/profile"
name="SID”
value="c5Wuk7… "
```

```
POST /profile HTTP/1.1
Host: www.example.com
SID=c5Wuk7…
```

Server

Session ID in POST Variable

- Advantages
  - Session ID transmitted to server only when intended by user
  - Session ID not present in URL, hence not logged, bookmarked, or transmitted within referrer
- Disadvantages
  - Navigation must be made via POST requests
  - Server needs to dynamically generate pages to customize forms for each user
  - Transmission of session ID needs to be restricted to HTTPS on every link and POST action

Clicker Question 2

In the cookie implementation of session tokens, how is the token transmitted to/from the server?

A. Included as a parameter in the URL
B. As a hidden variable in the initial POST request
C. As an additional field when the user authenticates
D. In the HTTP header (both request and response)

Answer to Clicker Question 2

In the cookie implementation of session tokens, how is the token transmitted to/from the server?

A. Included as a parameter in the URL

B. As a hidden variable in the initial POST request

C. As an additional field when the user authenticates

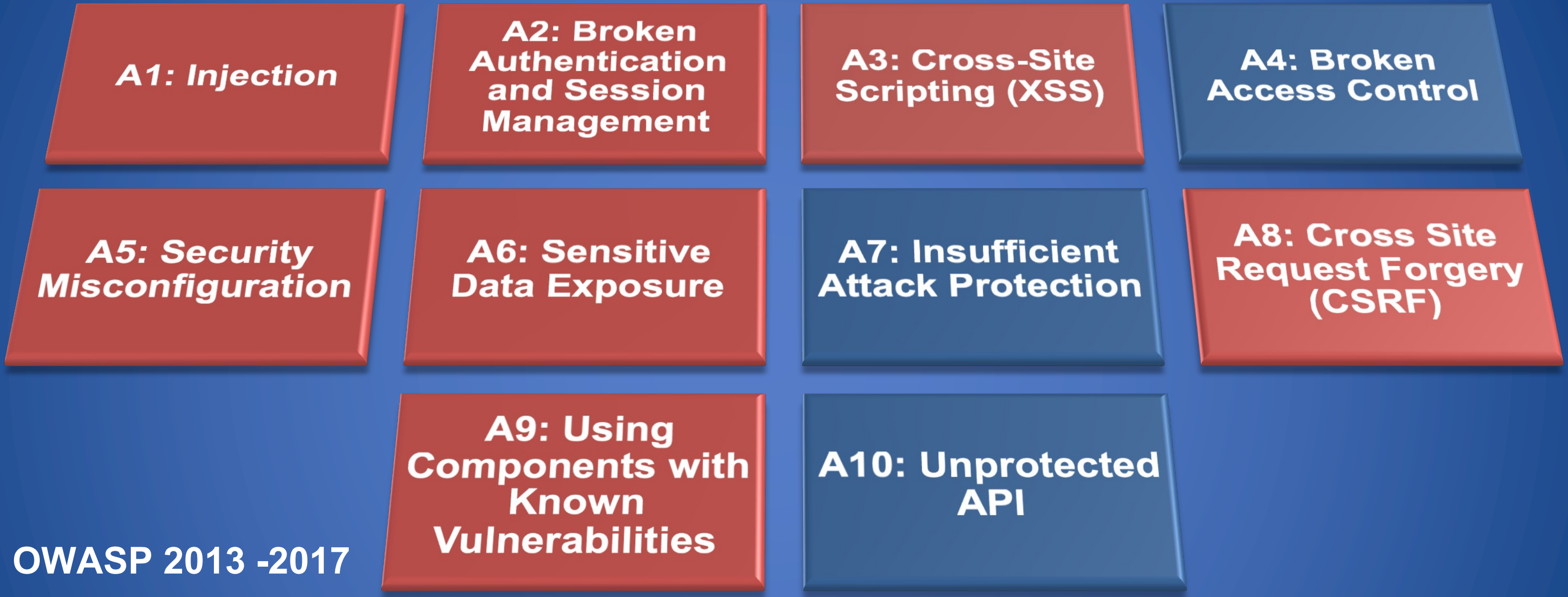
D. In the HTTP header (both request and response)

DEMO

1. Remove cookies or tampering parameters, and it erases authentication
   - Server makes us log in again
2. Close session you do not remove server cookie
3. Logout and session cookie removed on server
4. Cookie stealing for authentication
5. Remember me checkbox on the login
   - Cookie does not expire in the browser but also on the server
6. If we disable cookies, can not sign in to most websites
7. Burp analysis for the entropy of session cookies

Note: In particular for last demos, Browsers can have different policies

OWASP Top Ten (2013-17)



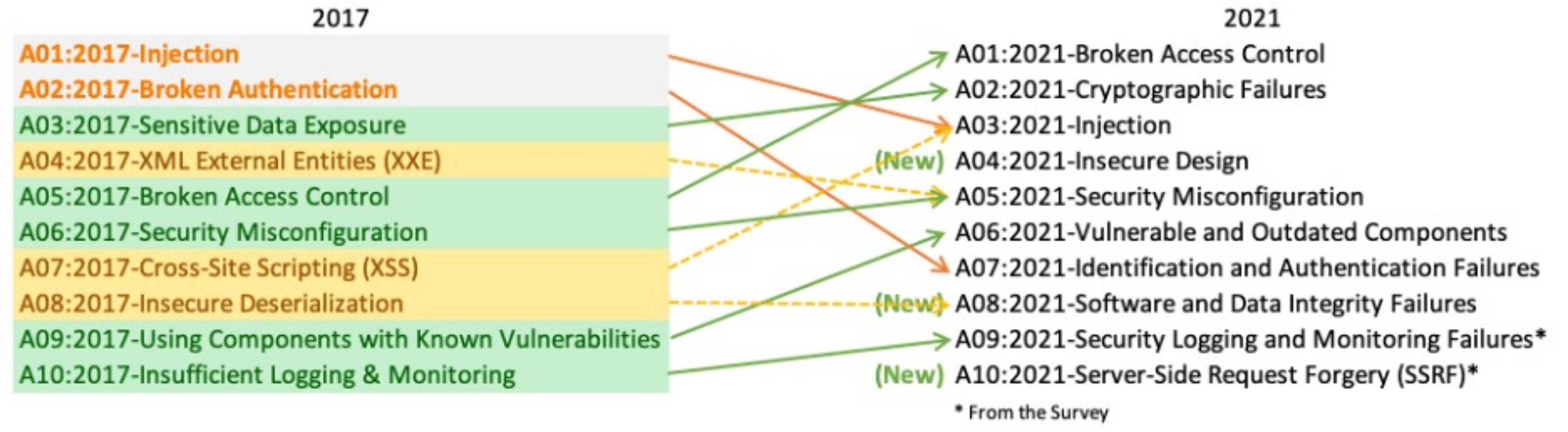
- 🟥 A1: Injection
- 🟥 A2: Broken Authentication and Session Management
- 🟥 A3: Cross-Site Scripting (XSS)
- 🟦 A4: Broken Access Control
- 🟥 A5: Security Misconfiguration
- 🟥 A6: Sensitive Data Exposure
- 🟦 A7: Insufficient Attack Protection
- 🟥 A8: Cross Site Request Forgery (CSRF)
- 🟥 A9: Using Components with Known Vulnerabilities
- 🟦 A10: Unprotected API

🟥 OWASP 2013 -2017

🟦 Just OWASP 2017

OWASP
The Open Web Application Security Project
http://www.owasp.org

Owasp 2017 - 2021



2017

A01:2017-Injection

A02:2017-Broken Authentication

A03:2017-Sensitive Data Exposure

A04:2017-XML External Entities (XXE)

A05:2017-Broken Access Control

A06:2017-Security Misconfiguration

A07:2017-Cross-Site Scripting (XSS)

A08:2017-Insecure Deserialization

A09:2017-Using Components with Known Vulnerabilities

A10:2017-Insufficient Logging & Monitoring

2021

A01:2021-Broken Access Control

A02:2021-Cryptographic Failures

A03:2021-Injection

(New) A04:2021-Insecure Design

A05:2021-Security Misconfiguration

A06:2021-Vulnerable and Outdated Components

A07:2021-Identification and Authentication Failures

(New) A08:2021-Software and Data Integrity Failures

A09:2021-Security Logging and Monitoring Failures*

(New) A10:2021-Server-Side Request Forgery (SSRF)*

* From the Survey

www.owasp.org/index.php/Top_10

OWASP
The Open Web Application Security Project
http://www.owasp.org

What We Have Learned

- Web Security Models
- Same-Origin Policy
- Basics of HTTP protocol
- GET and POST methods for HTTP variables
- Client-Side Controls
- Cookies and session management
- Same origin policy (SOP)