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CS526: Information security

Web security

Readings for This Lecture

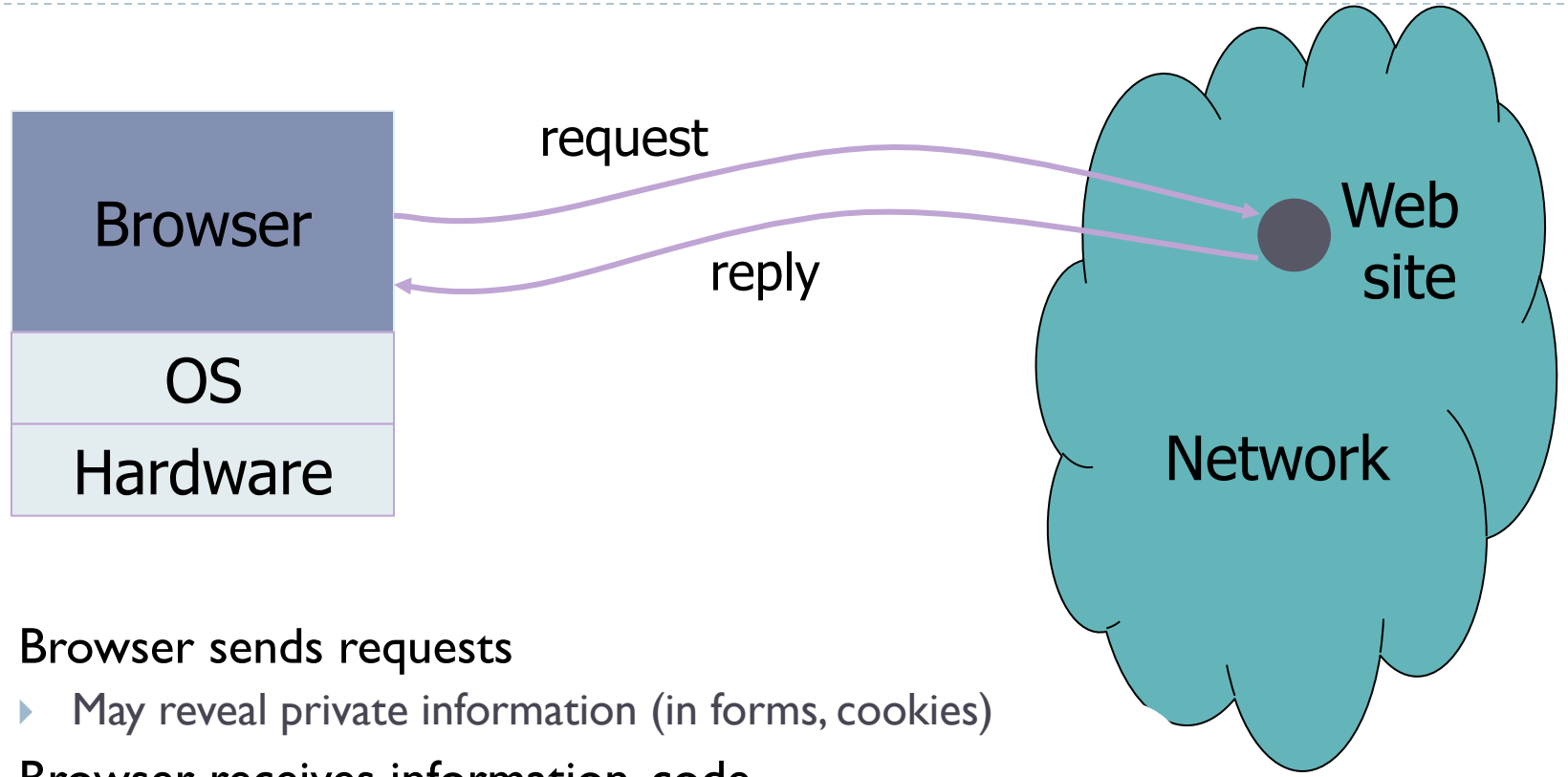
- Wikipedia
  - HTTP Cookie
  - Same Origin Policy
  - Cross Site Scripting
  - Cross Site Request Forgery

1: Background

Background

- Many sensitive tasks are done through web
  - Online banking, online shopping
  - Database access
  - System administration
- Web applications and web users are targets of many attacks
  - Cross site scripting
  - SQL injection
  - Cross site request forgery
  - Information leakage
  - Session hijacking

Browser and Network



- Browser sends requests
  - May reveal private information (in forms, cookies)
- Browser receives information, code
  - May corrupt state by running unsafe code
- Interaction susceptible to network attacks
  - Use HTTPS, which uses SSL/TLS

Web Security Issues

- Secure communications between client & server
  - HTTPS (HTTP over Secure Socket Layer)
- User authentication & session management
  - Cookies & other methods
- Active contents from different websites
  - Protecting resources maintained by browsers
- Web application security
- Web site authentication (e.g., anti-phishing)
- Privacy concerns

HTTP: HyperText Transfer Protocol

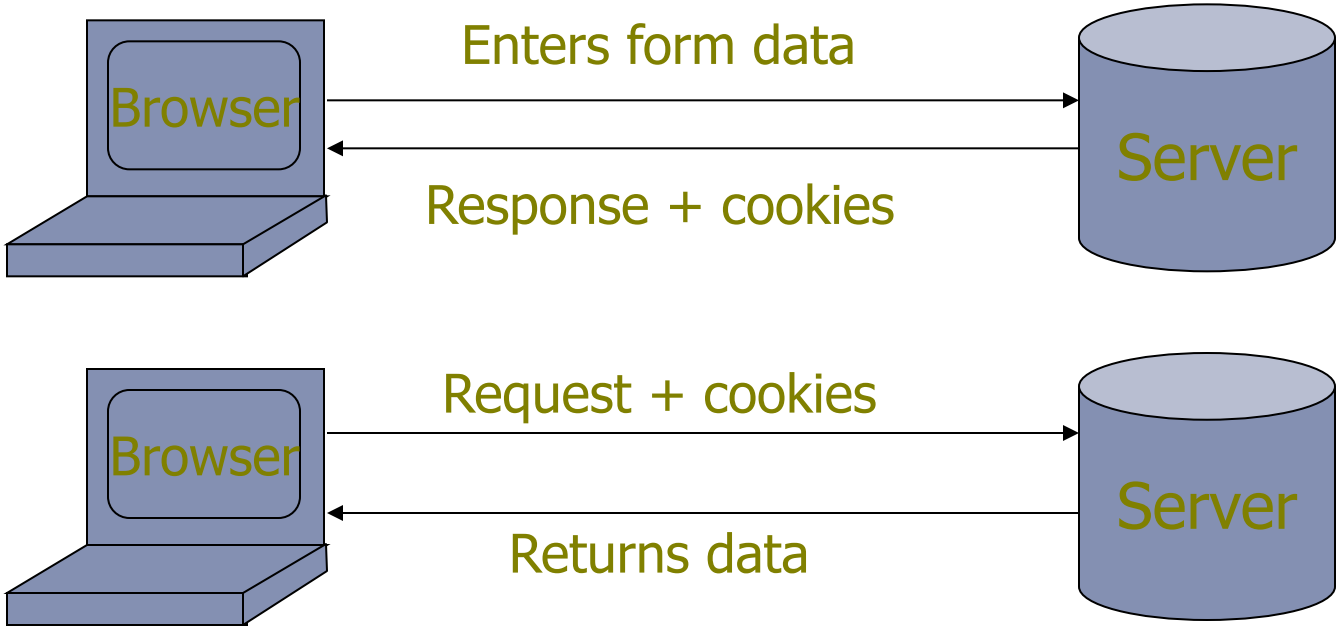
- Browser sends HTTP requests to the server
  - Methods: GET, POST, HEAD, …
  - GET: to retrieve a resource (html, image, script, css,…)
  - POST: to submit a form (login, register, …)
  - HEAD
- Server replies with a HTTP response
- Stateless request/response protocol
  - Each request is independent of previous requests
  - Statelessness has a significant impact on design and implementation of applications

HTTP

- HTTP is a stateless protocol.
- Hosts do not need to retain information about users between requests
- Web applications must use alternative methods to track the user's progress from page to page
  - sending and receiving cookies
  - server side sessions, hidden variables and URL encoded parameters (such as /index.php?session_id=some_unique_session_code).

Use Cookies to Store State Info

- Cookies
  - A cookie is a name/value pair created by a website to store information on your computer



Http is stateless protocol; cookies add state

Cookies Fields

- An example cookie from my browser
  - Name session-token
  - Content "s7yZiOvFm4YymG….”
  - Domain .amazon.com
  - Path /
  - Send For Any type of connection
  - Expires Monday, September 08, 2031 7:19:41 PM

More about Cookies

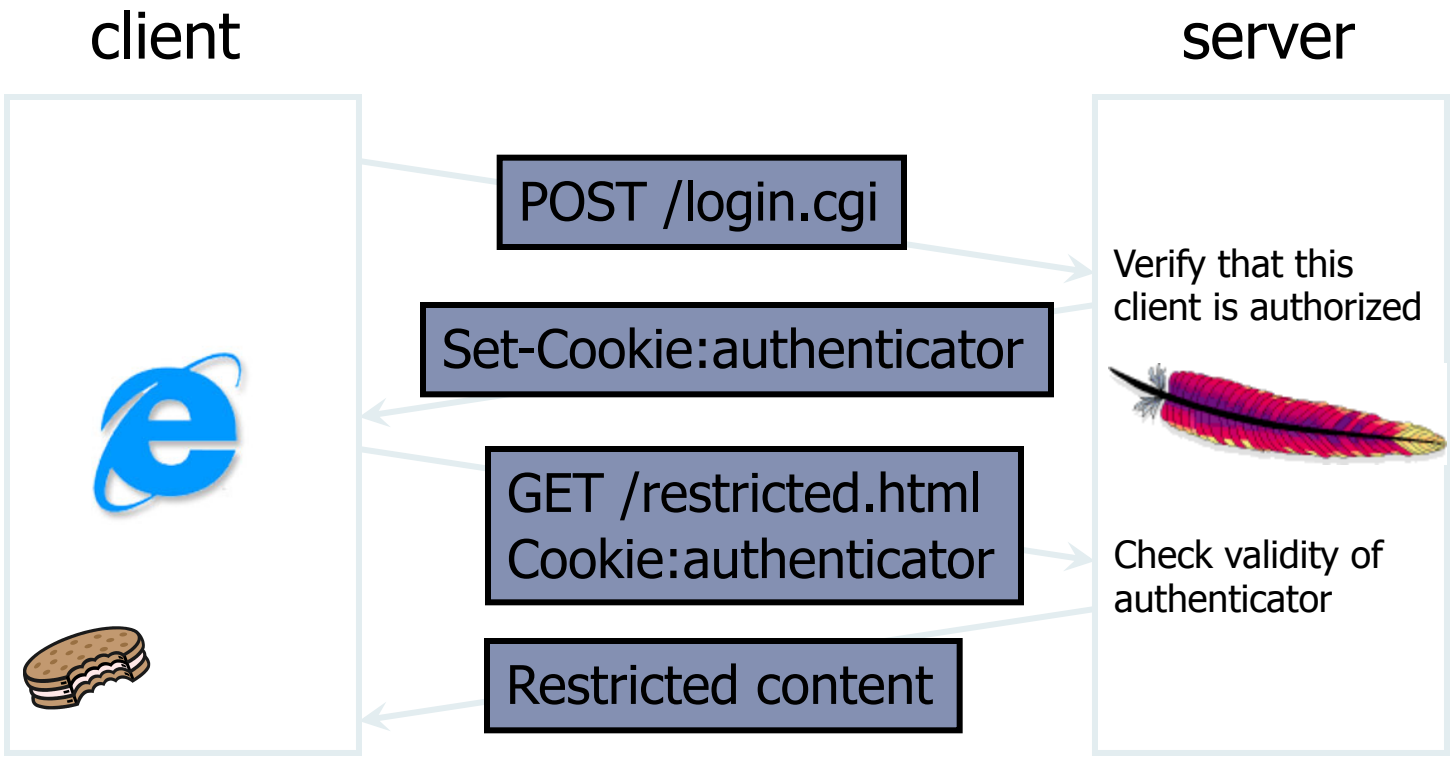
- Stored by the browser
- Used by the web applications
  - used for authenticating, tracking, and maintaining specific information about users
    - e.g., site preferences, contents of shopping carts
- Cookie ownership
  - Once a cookie is saved on your computer, only the website that created the cookie can read it
- Security aspects
  - Data may be sensitive
  - May be used to gather information about specific users

Web Authentication via Cookies

- HTTP is stateless
  - How does the server recognize a user who has signed in?

- Servers can use cookies to store state on client
  - After client successfully authenticates, server computes an authenticator and gives it to browser in a cookie
    - Client cannot forge authenticator on his own (session id)
  - With each request, browser presents the cookie
  - Server verifies the authenticator

A Typical Session with Cookies



Authenticators must be unforgeable and tamper-proof

(malicious clients shouldn't be able to modify an existing authenticator)

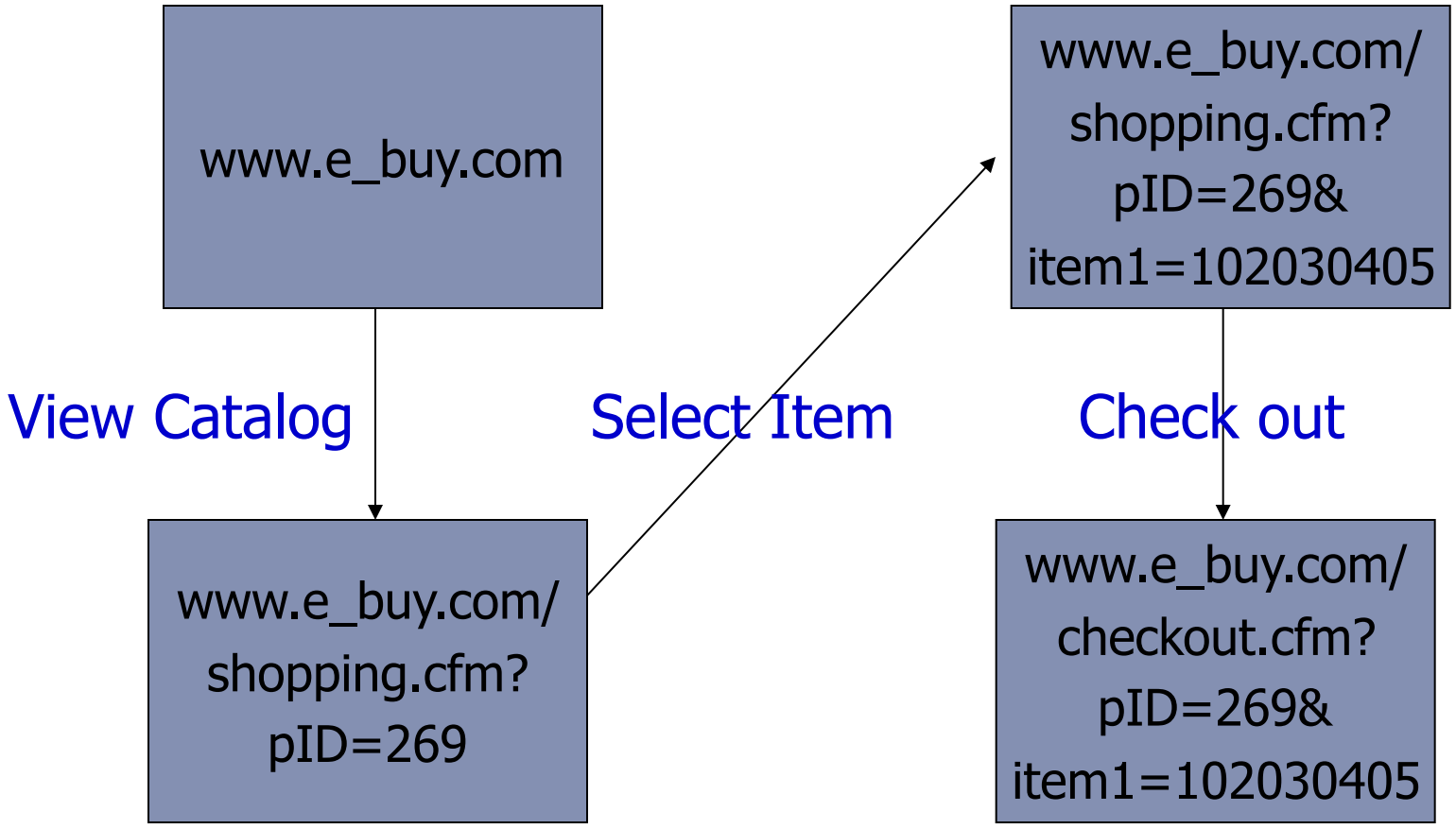
Browser Cookie Management

- Cookie Same-origin ownership
  - Once a cookie is saved on your computer, only the Web site that created the cookie can read it
- Variations
  - Temporary cookies
    - Stored until you quit your browser
  - Persistent cookies
    - Remain until deleted or expire
  - Third-party cookies
    - Originates on or sent to a web site other than the one that provided the current page

Example: Third-Party Cookies

- Get a page from merchant.com
  - Contains <img src=http://doubleclick.com/advt.gif>
  - Image fetched from DoubleClick.com
    - DoubleClick knows IP address and page you were looking at
- DoubleClick sends back a suitable advertisement
  - Stores a cookie that identifies "you" at DoubleClick
- Next time you get page with a doubleclick.com image
  - Your DoubleClick cookie is sent back to DoubleClick
  - DoubleClick could maintain the set of sites you viewed
  - Send back targeted advertising (and a new cookie)
- Cooperating sites
  - Can pass information to DoubleClick in URL, …

Example: Session State in URL



Store session information in URL; Easily read on network

2: Cross Site Scripting

Client Side Scripting

- Web pages (HTML) can embed dynamic contents (code) that can be executed on the browser
- JavaScript
  - embedded in web pages and executed inside browser
- Java applets
  - small pieces of Java bytecodes that execute in browsers

HTML and Scripting

```
<html>
    …
  <P>
<script>
        var num1, num2, sum
        num1 = prompt("Enter first number")
        num2 = prompt("Enter second number")
        sum = parseInt(num1) + parseInt(num2)
        alert("Sum = " + sum)
</script>
        …
</html>
```

Browser receives content, displays HTML and executes scripts

Scripts are Powerful

- Client-side scripting is powerful and flexible, and can access the following resources
  - Local files on the client-side host
    - read / write local files
  - Webpage resources maintained by the browser
    - Cookies
    - Domain Object Model (DOM) objects
      - steal private information
      - control what users see
      - impersonate the user

Browser as an Operating System

- Web users visit multiple websites simultaneously
- A browser serves web pages (which may contain programs) from different web domains
  - a browser runs programs provided by mutually untrusted entities
  - running code one does not know/trust is dangerous
  - a browser also maintains resources created/updated by web domains
- Browser must confine (sandbox) these scripts so that they cannot access arbitrary local resources
- Browser must have a security policy to manage/protect browser-maintained resources and to provide separation among mutually untrusted scripts

Same Origin Policy

- The basic security model enforced in the browser
- SoP isolates the scripts and resources downloaded from different origins
  - E.g., evil.org scripts cannot access bank.com resources
- Use origin as the security principal
- Origin = domain name + protocol + port
  - all three must be equal for origin to be considered the same

Same Original Policy: What it Controls

- Same-origin policy applies to the following accesses:
  - manipulating browser windows
  - URLs requested via the XmlHttpRequest
    - XmlHttpRequest is an API that can be used by web browser scripting languages to transfer XML and other text data to and from a web server using HTTP, by establishing an independent and asynchronous communication channel.
      - used by AJAX
  - manipulating frames (including inline frames)
  - manipulating documents (included using the object tag)
  - manipulating cookies

Problems with S-O Policy

- Poorly enforced on some browsers
  - Particularly older browsers
- Limitations if site hosts unrelated pages
  - Example: Web server often hosts sites for unrelated parties
    - http://www.example.com/account/
    - http://www.example.com/otheraccount/
  - Same-origin policy allows script on one page to access properties of document from another
- Can be bypassed in Cross-Site-Scripting attacks
- Usability: Sometimes prevents desirable cross-origin resource sharing

Cross Site Scripting (XSS)

- Recall the basics
  - scripts embedded in web pages run in browsers
  - scripts can access cookies
    - get private information
  - and manipulate DOM objects
    - controls what users see
  - scripts controlled by the same-origin policy
- Why would XSS occur
  - Web applications often take user inputs and use them as part of webpage (these inputs can have scripts)

How XSS Works on Online Blog

- Everyone can post comments, which will be displayed to everyone who views the post
- Attacker posts a malicious comment that includes script (which reads local authentication credentials and sends them of to the attacker)
- Anyone who viewed the post can have local authentication cookies stolen
- Web apps will check that posts do not include scripts, but the check sometimes fail.
- Bug in the web application. Attack happens in browser.

Effect of the Attack

- Attacker can execute arbitrary scripts in browser
- Can manipulate any DOM component on victim.com
  - Control links on page
  - Control form fields (e.g. password field) on this page and linked pages.
- Can infect other users: MySpace.com worm.

MySpace.com (Samy worm)

- Users can post HTML on their pages
  - MySpace.com ensures HTML contains no

    `<script>, <body>, onclick, <a href=javascript://>`
  - However, attacker find out that a way to include Javascript within CSS tags:

```
<div style="background:url('javascript:alert(1)')">
```

  And can hide `"javascript"` as `"java\nscript"`
- With careful javascript hacking:
  - Samy's worm: infects anyone who visits an infected MySpace page … and adds Samy as a friend.
  - Samy had millions of friends within 24 hours.
- More info: http://namb.la/popular/tech.html

Avoiding XSS bugs (PHP)

- Main problem:
  - Input checking is difficult --- many ways to inject scripts into HTML.
- Preprocess input from user before echoing it
- PHP: **htmlspecialchars**(string)

  & → & " → " ' → '
  < → < > → >

  - **htmlspecialchars**(
    "Test", ENT_QUOTES);

    Outputs:

    Test

Avoiding XSS bugs (ASP.NET)

- ASP.NET 1.1:
  - **Server.HtmlEncode(string)**
    - Similar to PHP htmlspecialchars
  - validateRequest: (on by default)
    - Crashes page if finds <script> in POST data.
    - Looks for hardcoded list of patterns.
    - Can be disabled:

      <%@ Page validateRequest="false" %>

3: Cross site request forgery

Cross site request forgery (abbrev. CSRF or XSRF)

- Also known as one click attack or session riding
- Effect: Transmits unauthorized commands from a user who has logged in to a website to the website.
- Recall that a browser attaches cookies set by domain X to a request sent to domain X; the request may be from another domain
  - Site Y redirects you to facebook; if you already logged in, the cookie is attached by the browser

CSRF Explained

- Example:
  - User logs in to bank.com. Forgets to sign off.
  - Session cookie remains in browser state
  - Then user visits another site containing:

```
<form name=F action=http://bank.com/BillPay.php>
<input name=recipient value=badguy> …
<script> document.F.submit(); </script>
```

  - Browser sends user auth cookie with request
    - Transaction will be fulfilled

- Problem:
  - The browser is a confused deputy; it is serving both the websites and the user and gets confused who initiated a request

GMail Incidence: Jan 2007

- Allows the attacker to steal a user's contact
- Google docs has a script that run a callback function, passing it your contact list as an object. The script presumably checks a cookie to ensure you are logged into a Google account before handing over the list.
- Unfortunately, it doesn't check what page is making the request. So, if you are logged in on window 1, window 2 (an evil site) can make the function call and get the contact list as an object. Since you are logged in somewhere, your cookie is valid and the request goes through.

Real World CSRF Vulnerabilities

- Gmail
- NY Times
- ING Direct (4th largest saving bank in US)
- YouTube
- Various DSL Routers
- Purdue WebMail
- PEFCU
- Purdue CS Portal
- …

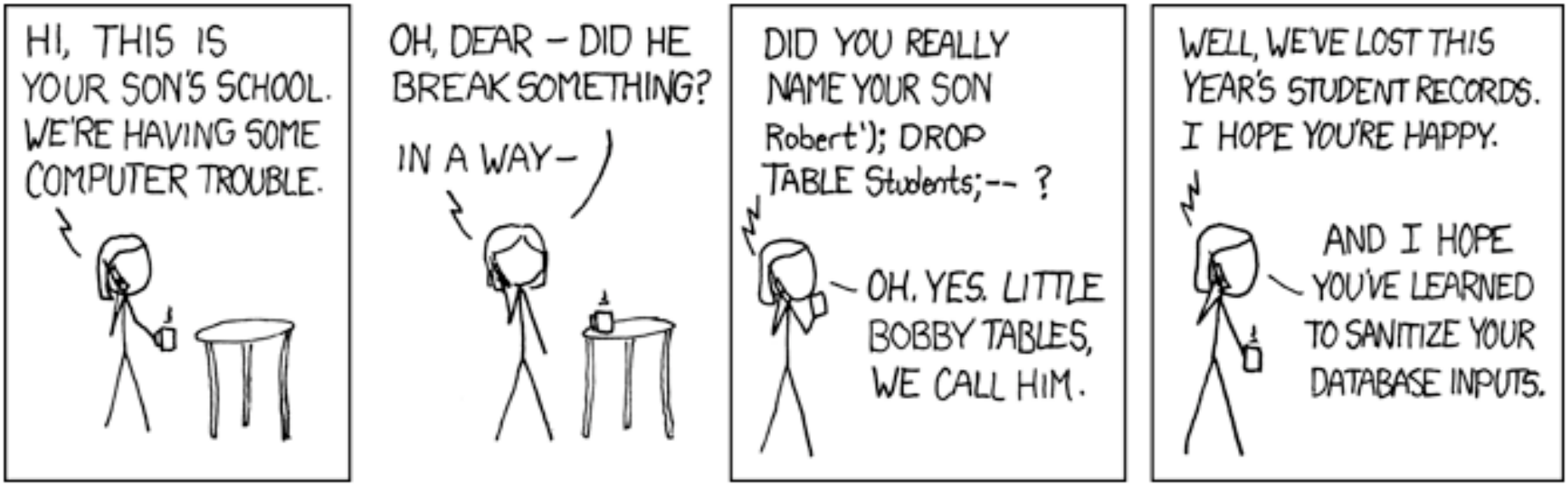
Prevention

- Server side:
  - use cookie + hidden fields to authenticate a web form
    - hidden fields values need to be unpredictable and user-specific; thus someone forging the request need to guess the hidden field values
  - requires the body of the POST request to contain cookies
    - Since browser does not add the cookies automatically, malicious script needs to add the cookies, but they do not have access because of Same Origin Policy
- User side:
  - logging off one site before using others
  - selective sending of authentication tokens with requests (may cause some disruption in using websites)

Other Web Threats

- SQL Injection
- Side channel leakages
- Web browsing privacy: third-party cookies

3: SQL-injection



Acknowledgments: xkcd.com

What is a SQL Injection Attack?

- Many web applications take user input from a form
- Often this user input is used literally in the construction of a SQL query submitted to a database.
  - SELECT productdata FROM table WHERE productname = 'user input product name' ;
- A SQL injection attack involves placing SQL statements in the user input

An Example SQL Injection Attack

- Product Search:

blah ‘ OR ‘x’ = ‘x

- This input is put directly into the SQL statement within the Web application:
  - $query = “SELECT prodinfo FROM prodtable WHERE prodname = ‘” . $_POST[‘prod_search’] . “’ ”;
- Creates the following SQL:
  - SELECT prodinfo FROM prodtable WHERE prodname = ‘blah ‘ OR ‘x’ = ‘x’
  - Attacker has now successfully caused the entire database to be returned.

SQL Injection Attacks Results

- Add new data to the database
- Modify data currently in the database
  - Could be very costly to have an expensive item suddenly be deeply ‘discounted’
- Often can gain access to other user’s system capabilities by obtaining their password

Defenses

- Use provided functions for escaping strings
  - Many attacks can be thwarted by simply using the SQL string escaping mechanism ‘ → \’ and “ → \”
- Check syntax of input for validity
  - Many classes of input have fixed languages
- Have length limits on input
  - Many SQL injection attacks depend on entering long strings
- Scan query string for undesirable word combinations that indicate SQL statements
- Limit database permissions and segregate users
  - Connect with read-only permission if read is the goal
  - Don’t connect as a database administrator from web app

Defenses: PREPARE statement

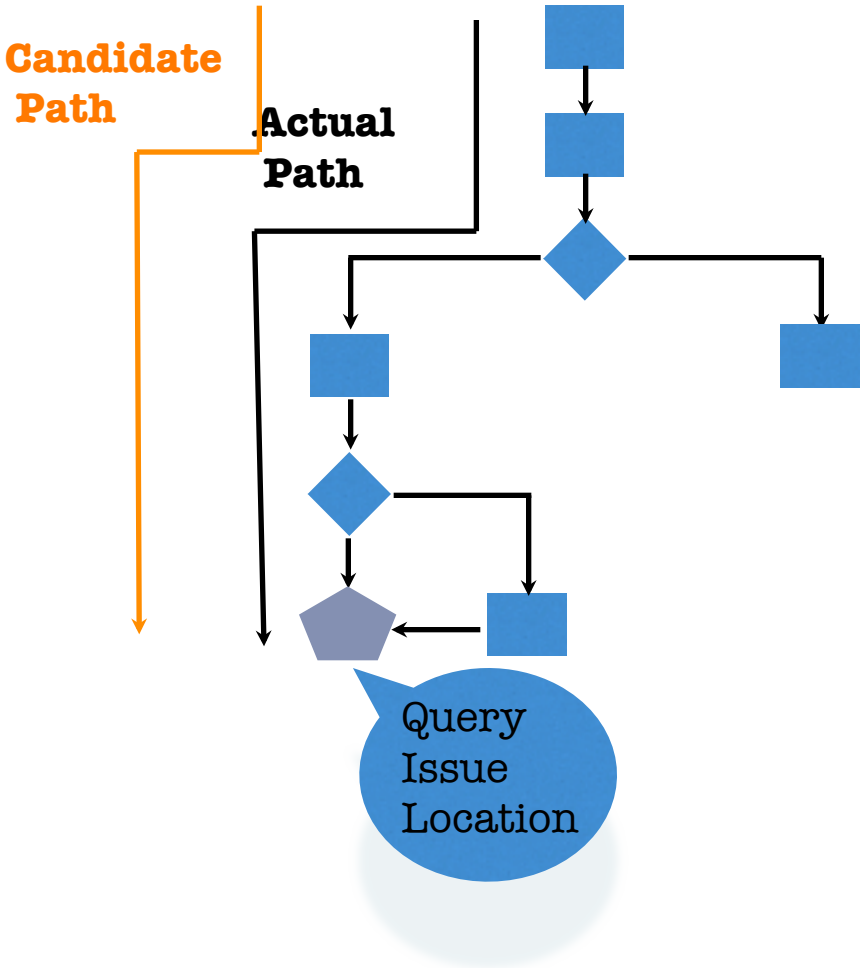
- For existing applications adding PREPARE statements will prevent SQL injection attacks
- Hard to do automatically with static techniques
  - Need to guess the structure of query at each query issue location
  - Query issued at a location depends on path taken in program
- Human assisted efforts can add PREPARE statements
  - Costly effort
- Is it possible to dynamically infer the benign query structure?

Dynamic Candidate Evaluations

- Create benign sample inputs (Candidate Inputs) for every user input
- Execute the program simultaneously over actual inputs and candidate inputs
- Generate a candidate query along with the actual query
  - The candidate query is always non-attacking
  - Actual query is possibly malicious
- Issue the actual query only if parse structures match

Finding Benign Candidate Inputs

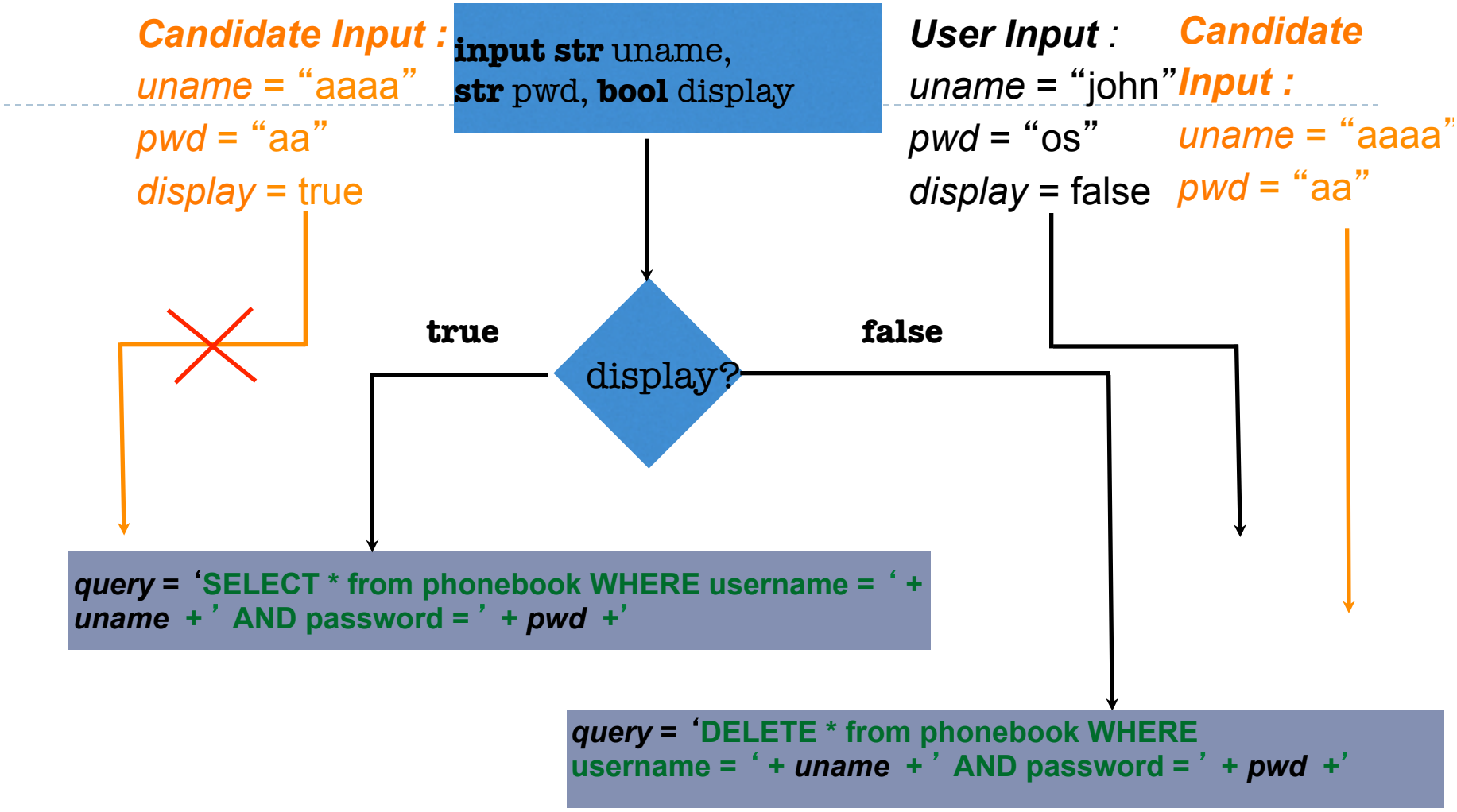
- Have to create a set of candidate inputs which
  - Are Benign
  - Issue a query at the same query issue location
  - By following the same path in the program



- Problem in the most general case it is undecidable

Use Manifestly Benign Inputs

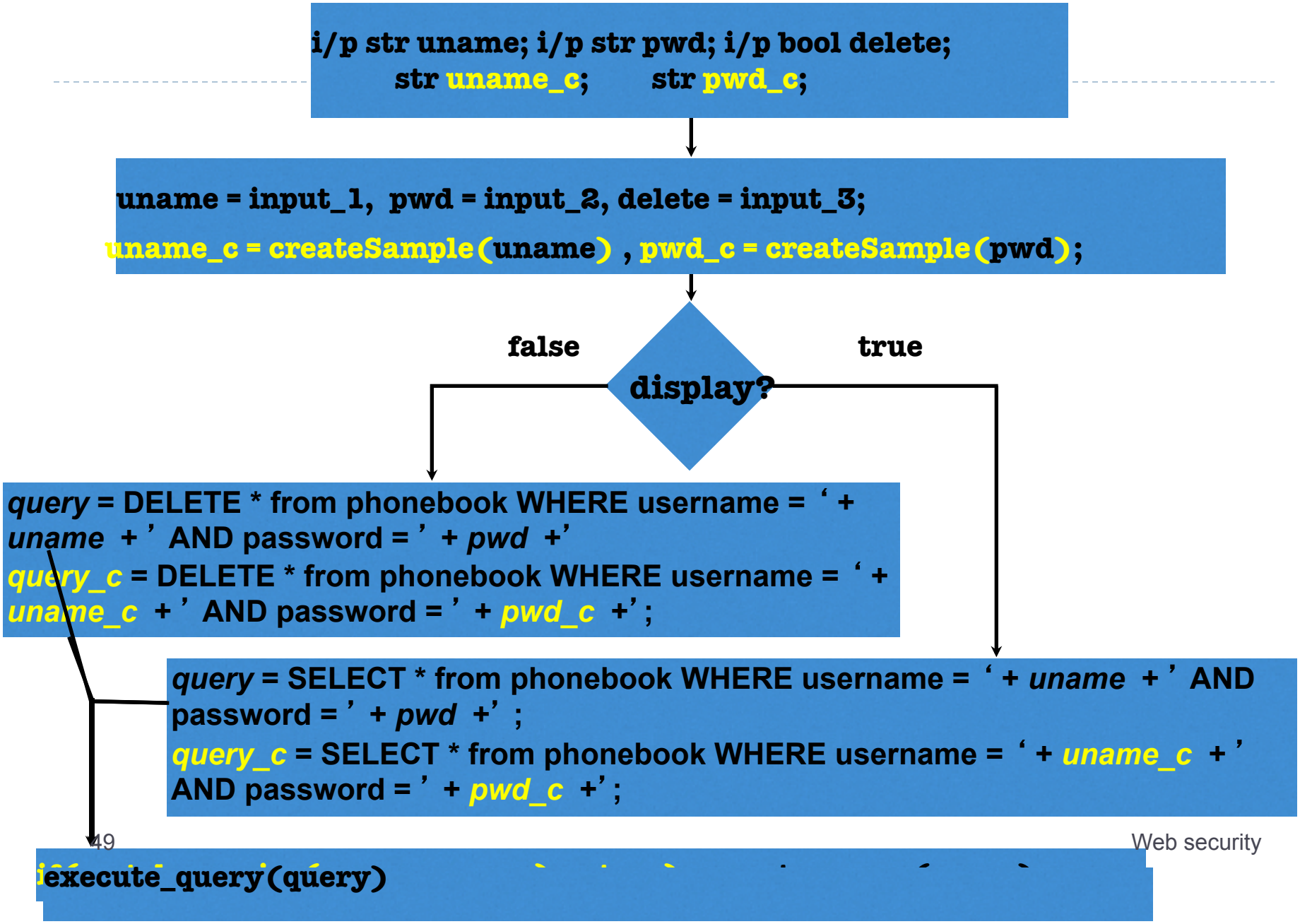
- For every string create a sample string of ‘a’ s having the same length
- Candidate Input:
  uname = ‘aaaa’
  pwd = ‘aa’
- Shadow every intermediate string variable that depends on input
- For integer or boolean variable, use the originals
- Follow the original control flow



tual Query: DELETE * from phonebook WHERE username = 'john' AND password = ' os'

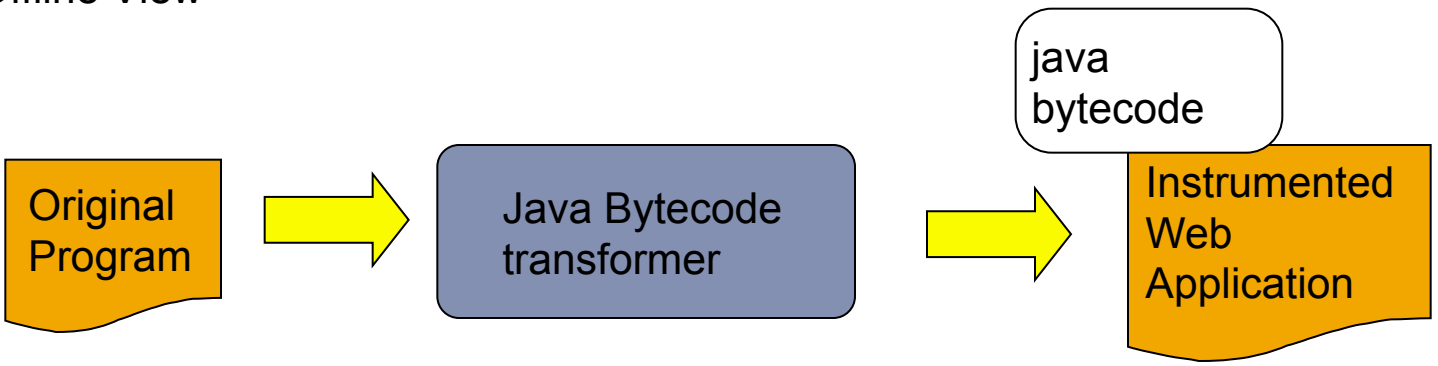
andidate Query: DELETE * from phonebook WHERE username = 'aaaa' AND password = ' aa'

Program Transformation Example

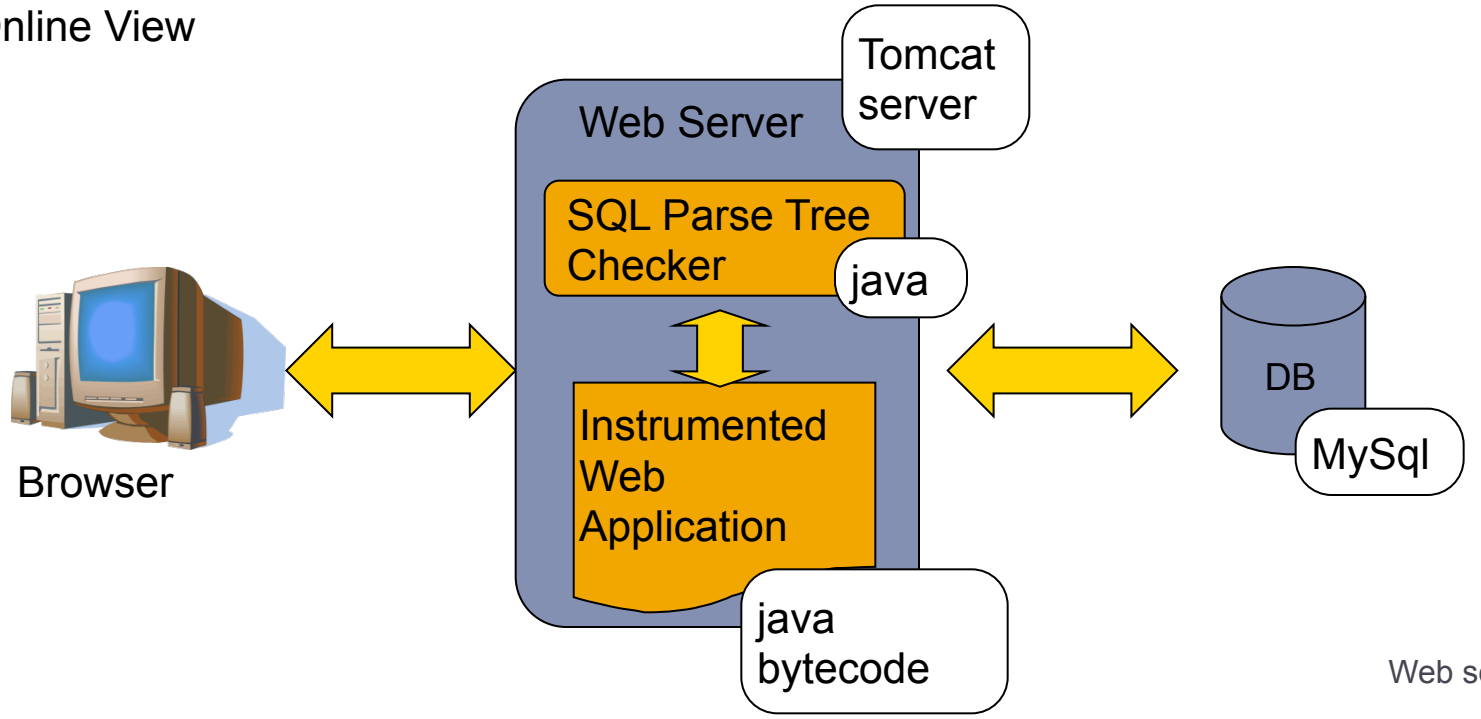


CANDID Implementation Architecture

- Offline View



- Online View



Readings for This Lecture

- **Optional Reading**
  - Bandhakavi et al.:
    CANDID : Preventing SQL Injection Attacks Using Dynamic Candidate Evaluations
  - Chen et al.:
    Side-Channel Leaks in Web Applications: a Reality Today, a Challenge Tomorrow

Browser Cookie Management

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Cookie issues

- Cookies maintain record of your browsing habits
  - Cookie stores information as set of name/value pairs
  - May include any information a web site knows about you
  - Sites track your activity from multiple visits to site
- Sites can share this information (e.g., DoubleClick)
- Browser attacks could invade your "privacy"