Building Security In

CMSC 330 Summer 2020

Security breaches

Just a few:

- **TJX** (2007) - 94 million 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, credit card nums, other private info*

https://www.oneid.com/7-biggest-security-breaches-of-the-past-decade-2/

The 2017 Equifax Data Breach

- 148 million consumers' personal information stolen
- They collect every details of your personal life
  - Your SSN, Credit Card Numbers, Late Payments…
- You did not sign up for it
- You cannot ask them to stop collecting your data
- You have to pay to credit freeze/unfreeze

Defects and Vulnerabilities

- Many (if not all of) 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

- The **use of software is growing**
  - So: more bugs and flaws
  - Especially in places that are new to using software

Google
2B LOC

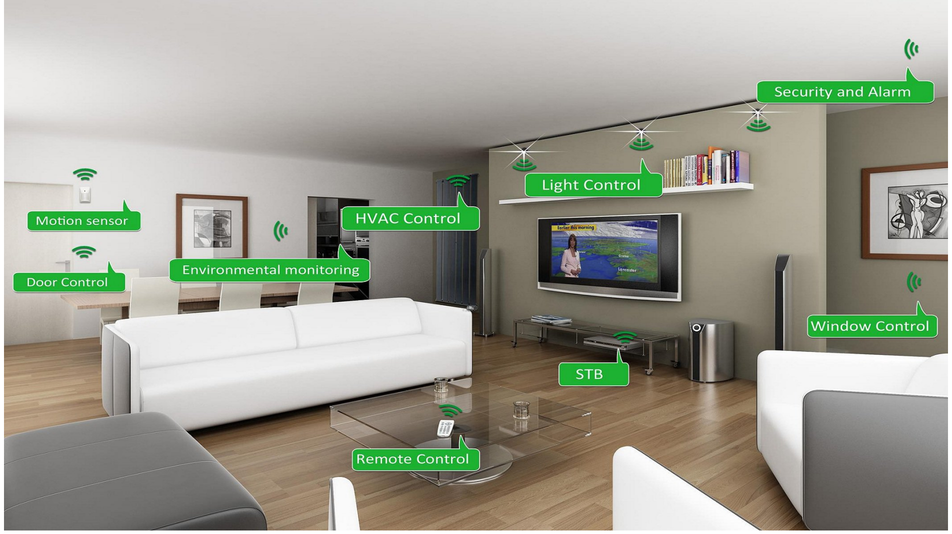
Windows
50M LOC

…

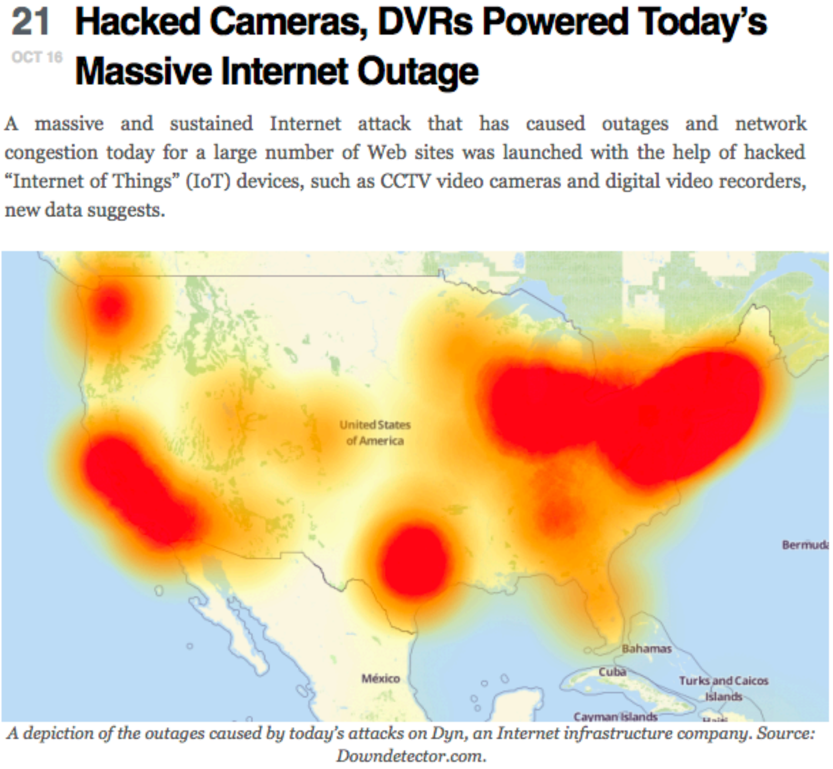
…

“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

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
  - …

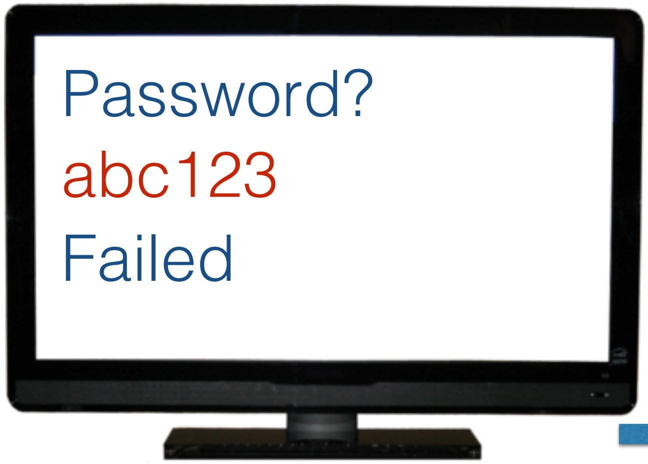
What is a buffer overflow?

- 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!



Password?
abc123
Failed

Normal interaction

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

Data

X = abc123

Exploitation

Password?

Overflow!!!!! 3.log in

Access granted

Instructions

1. print “Password?” to the screen

2. read input into variable X

Data

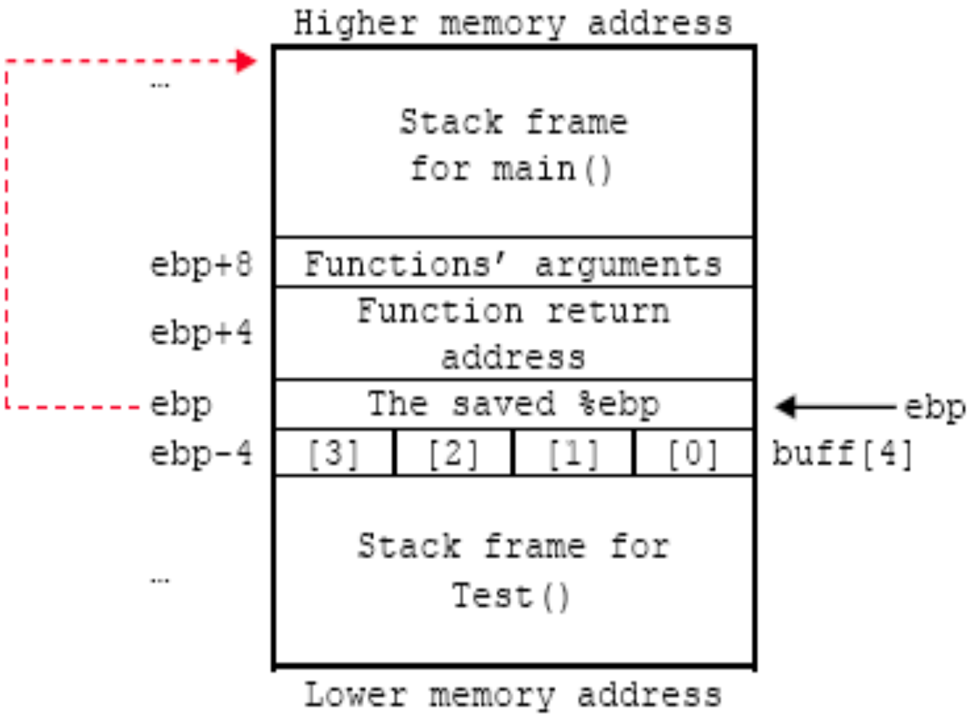
X = Overflow!!!!! 3.log in

4. else print “Failed” to the screen

What happened?

- For C/C++ programs
  - A buffer with the password could be a local variable
- Therefore
  - The input is too long, and overruns the buffer
  - The attacker's 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

```
strcpy(buff, "abc");
```



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

Password?

Overflow!!!!! 3.log in

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
```

Data

X = `Overflow!`

Program halted

Key idea

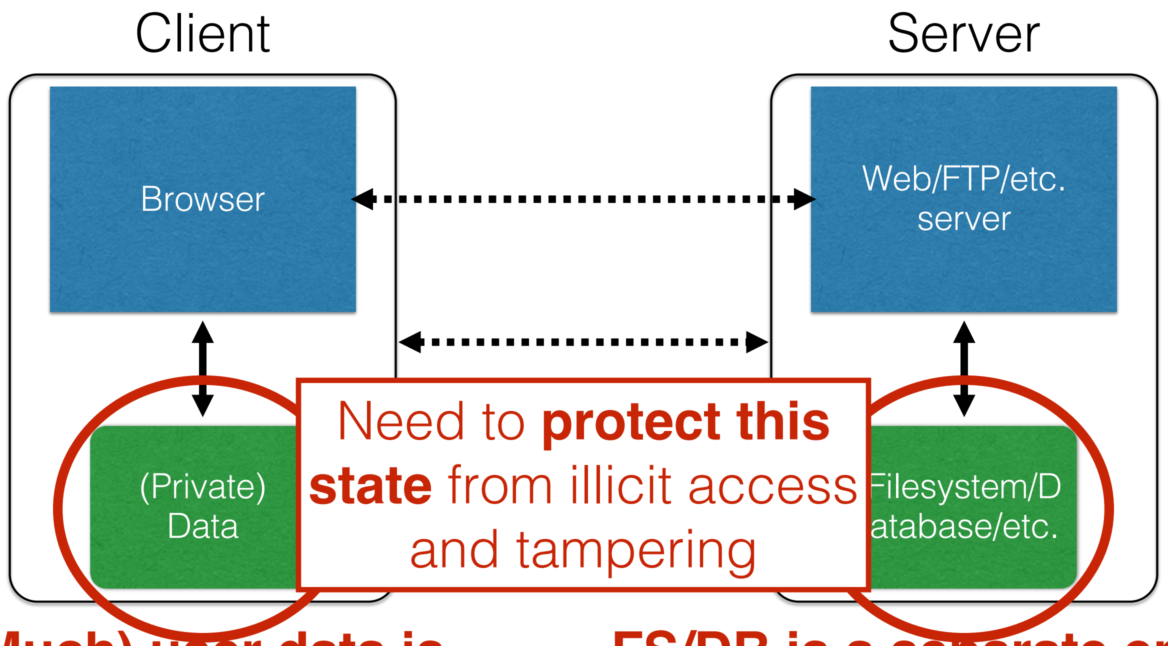
- The key feature of the buffer overflow attack is the attacker getting the application to **treat attacker-provided data as instructions (code) or code parameters**

- 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

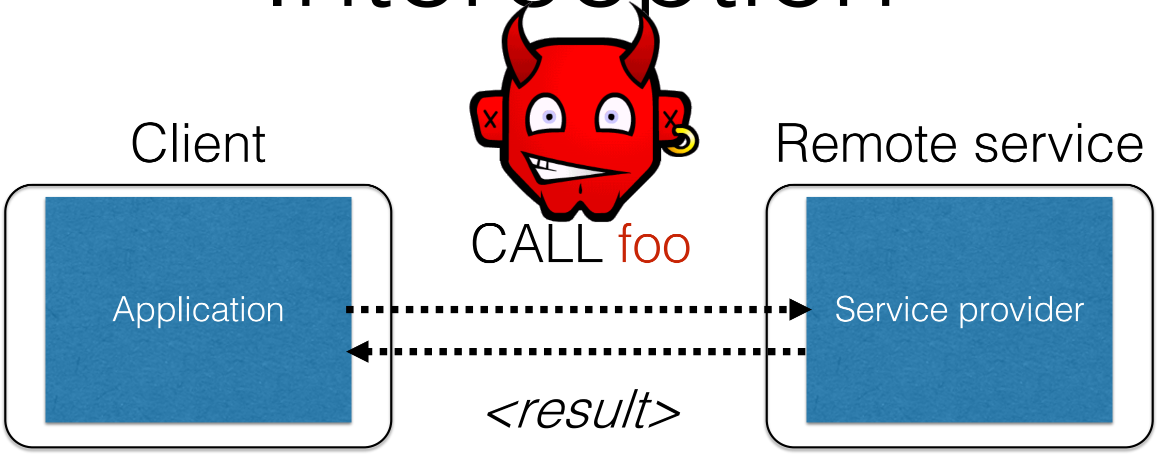


Need to **protect this state** from illicit access and tampering

(Much) user data is part of the browser

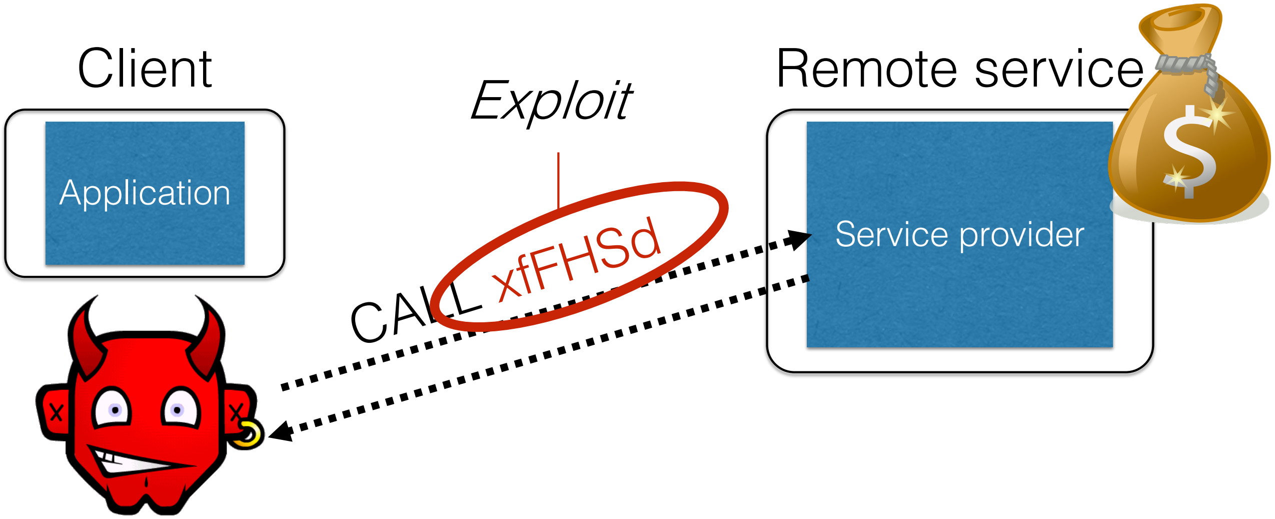
FS/DB is a separate entity, logically (and often physically)

Interception



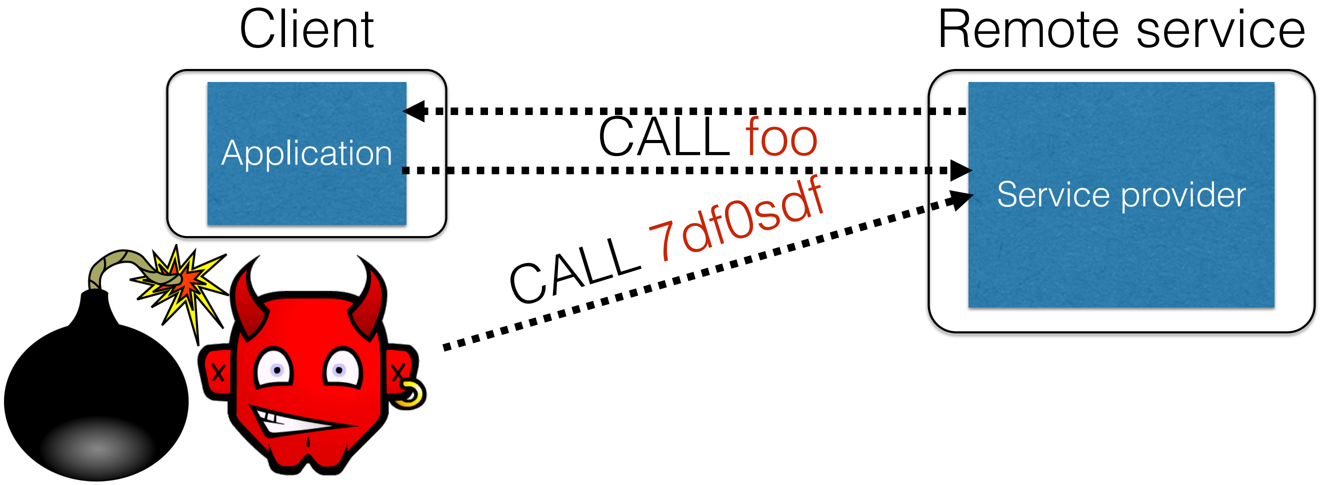
- **Calls** to remote services could be **intercepted** by an adversary
  - **Snoop** on inputs/outputs
  - **Corrupt** inputs/outputs
- Avoid this possibility using **cryptography** (CMSC 414, CMSC 456)

Malicious clients



- Server needs to **protect itself against malicious clients**
  - Won’t run the software the server expects
  - Will probe the limits of the interface

Passing the buck



- **Server needs to protect good clients** from malicious clients that will try to launch attacks via the server
  - 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

catwrapper.rb:

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catwrapper.rb
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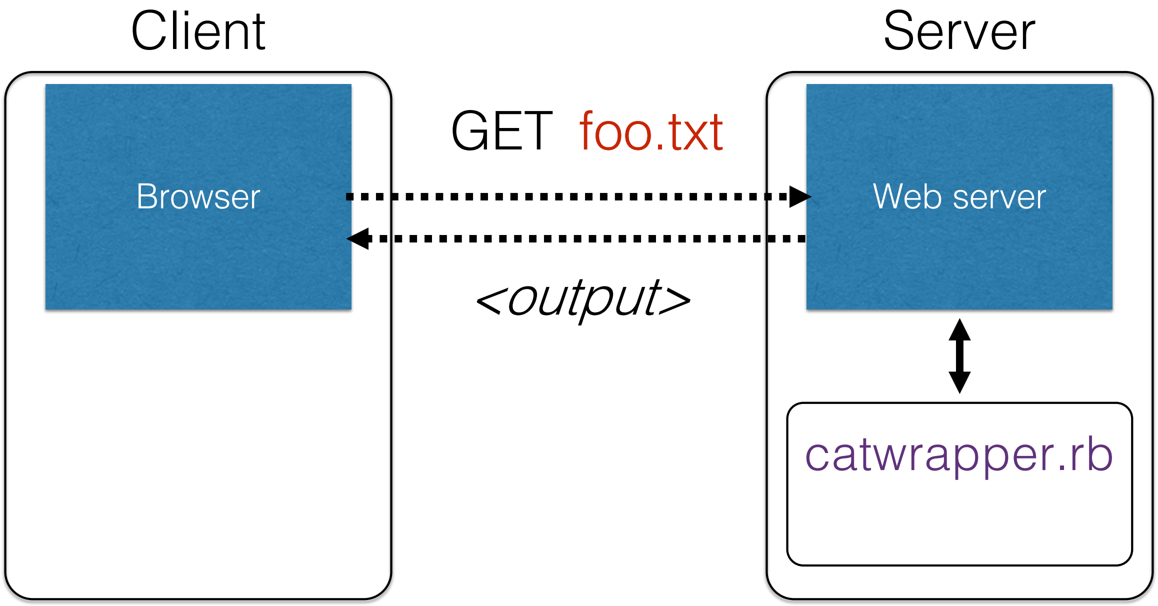
catwrapper.rb
```

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

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: Blacklisting

- **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

```
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)

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 **Hostname/server** **Path to a resource**

```
ftp
https
tor
```

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

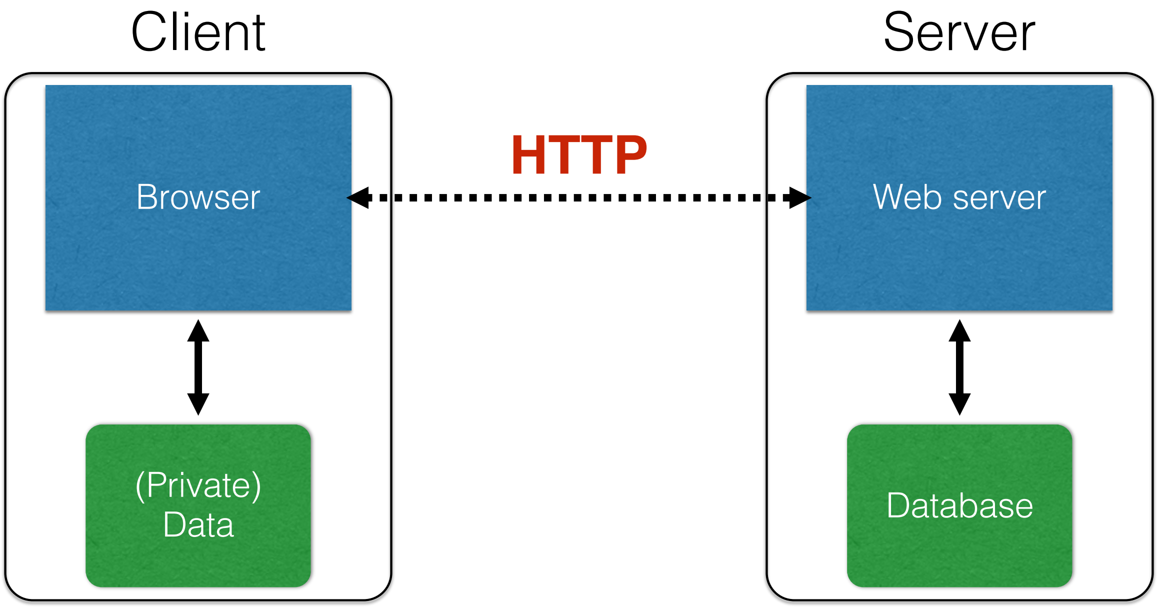
Here, the file `index.html` is static content
i.e., a fixed file returned by the server

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

Path to a resource **Arguments**

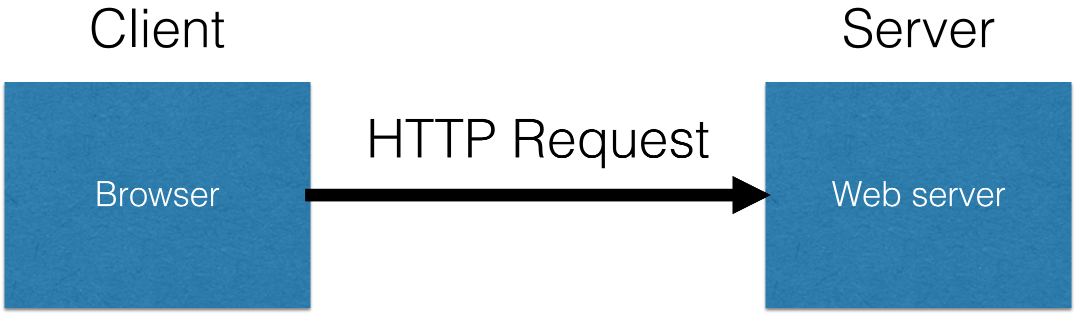
Here, the file `delete.php` is dynamic content
i.e., the server generates the content on the fly

Basic structure of web traffic



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

Basic structure of web traffic

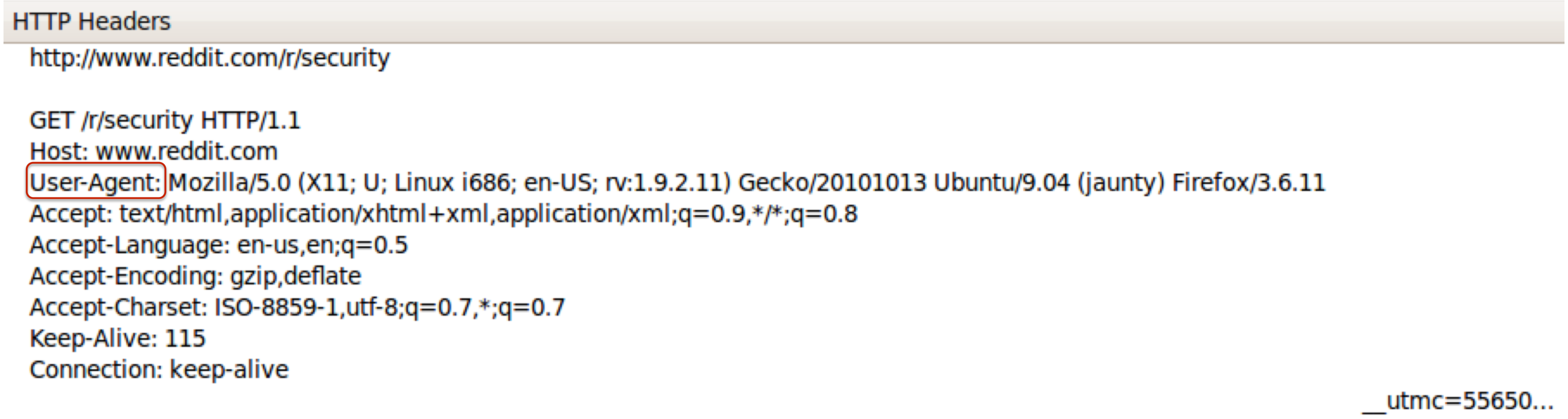


User clicks

- **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

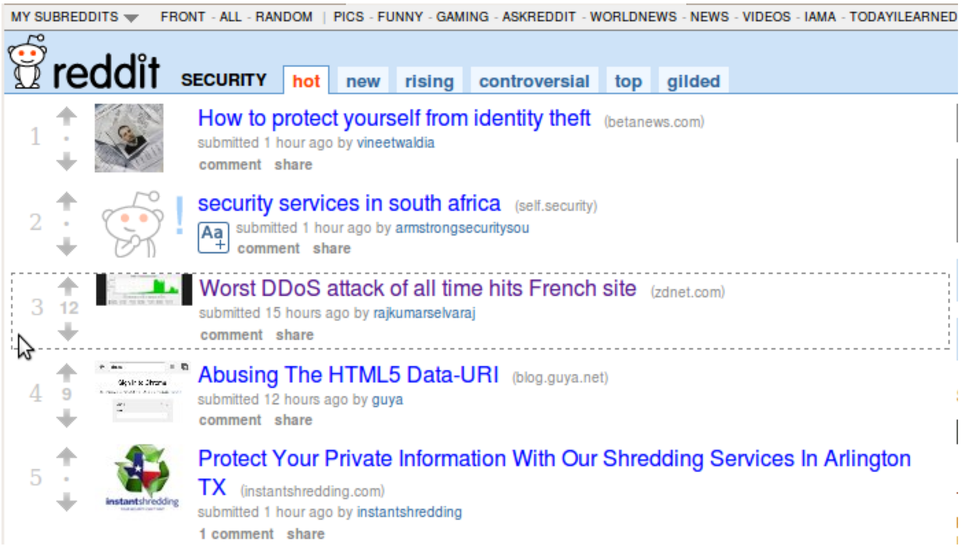
http://www.reddit.com/r/security



```
http://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.


MY SUBREDDITS
FRONT - ALL - RANDOM | PICS - FUNNY - GAMING - ASKREDDIT - WORLDNEWS - NEWS - VIDEOS - IAMA - TODAYILEARNED
reddit
SECURITY
hot
new
rising
controversial
top
gilded

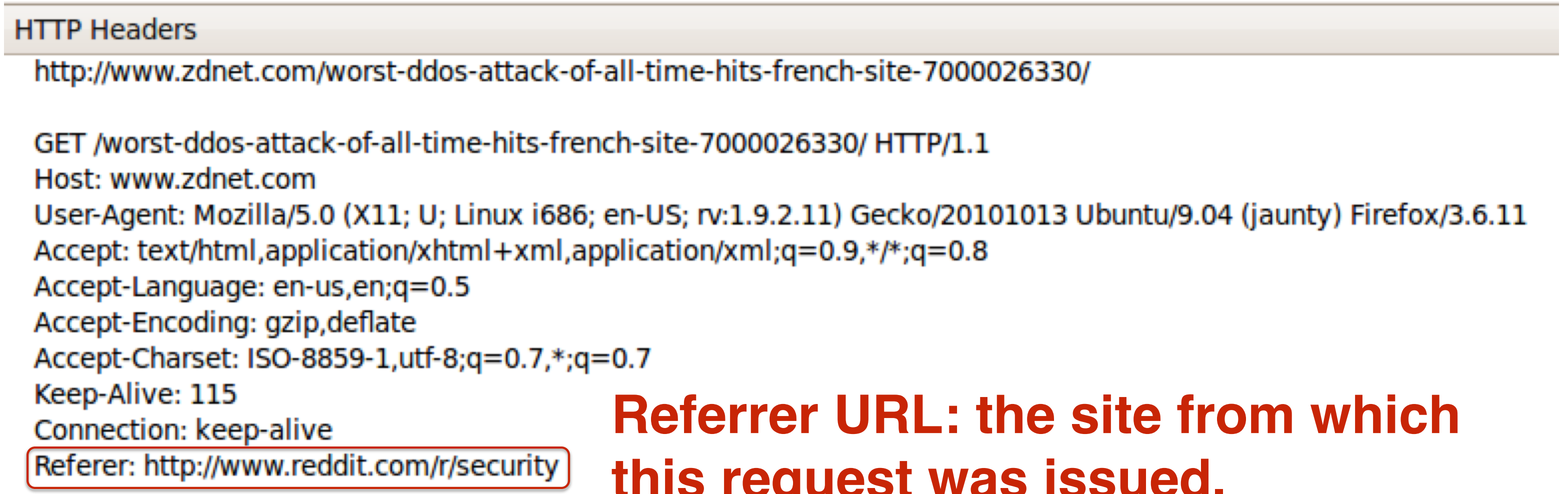
1 How to protect yourself from identity theft (betanews.com)
submitted 1 hour ago by vineetwaldia
comment share

2 security services in south africa (self.security)
submitted 1 hour ago by armstrongsecuritysou
comment share

3 12 Worst DDoS attack of all time hits French site (zdnet.com)
submitted 15 hours ago by rajkumarselvaraj
comment share

4 9 Abusing The HTML5 Data-URI (blog.guya.net)
submitted 12 hours ago by guya
comment share

5 Protect Your Private Information With Our Shredding Services In Arlington TX (instantshredding.com)
submitted 1 hour ago by instantshredding
1 comment share



HTTP Headers

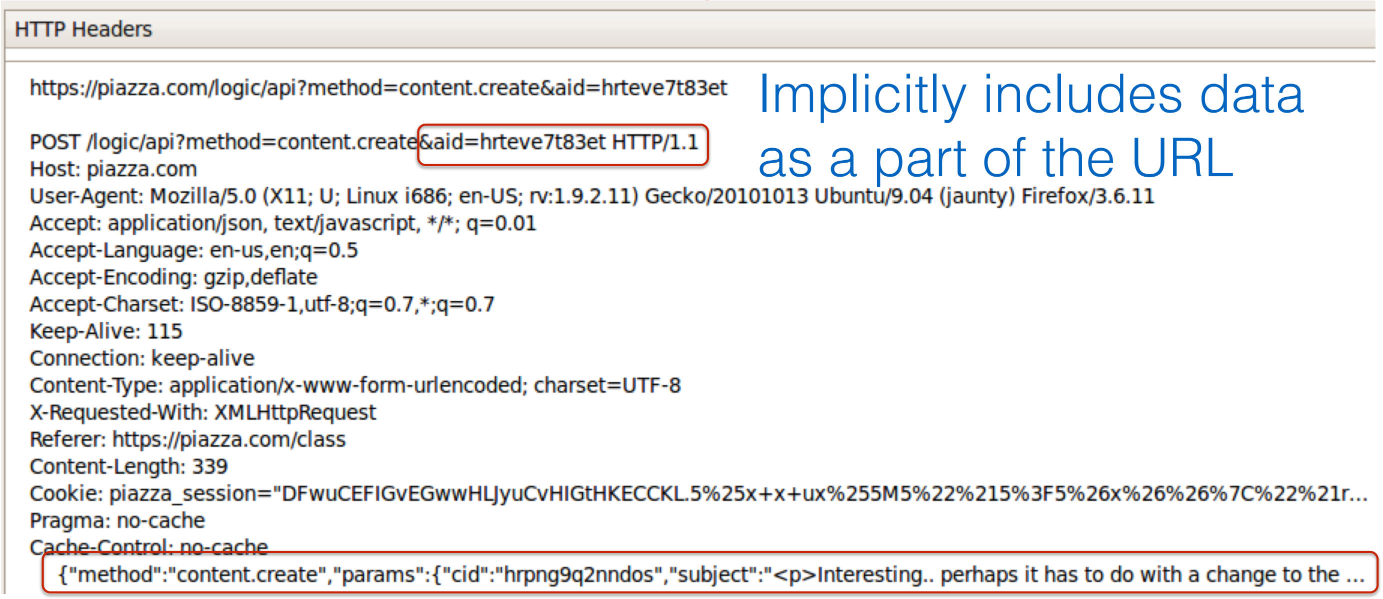
```
http://www.zdnet.com/worst-ddos-attack-of-all-time-hits-french-site-7000026330/

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



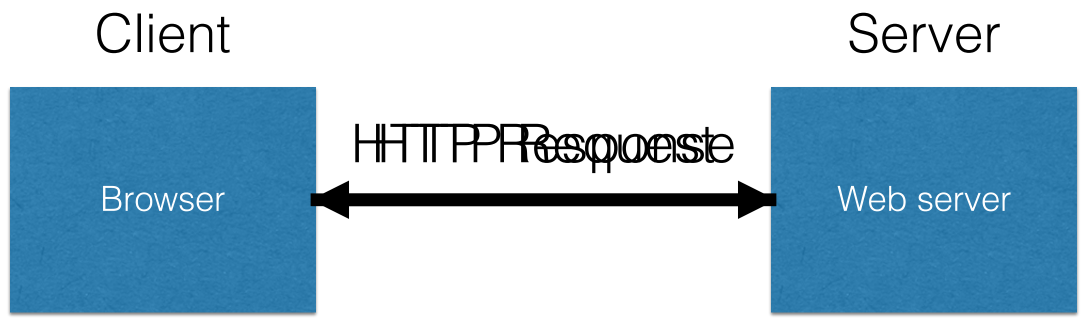
```
https://piazza.com/logic/api?method=content.create&aid=hrteve7t83et

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



Client

Server

Browser

HTTP Request

HTTP Response

Web server

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

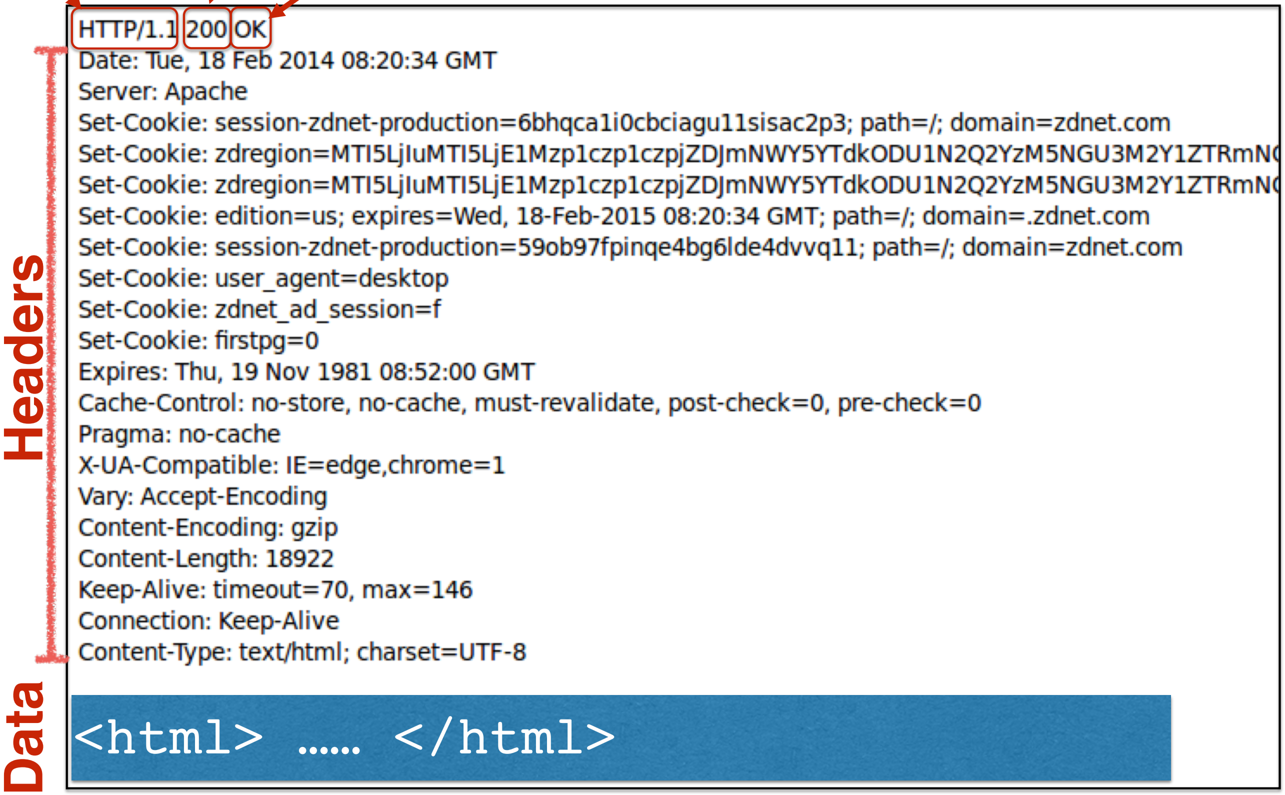
HTTP version

Status code

Reason phrase

Headers

Data



```
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

<html> ...... </html>
```

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

Quiz 1

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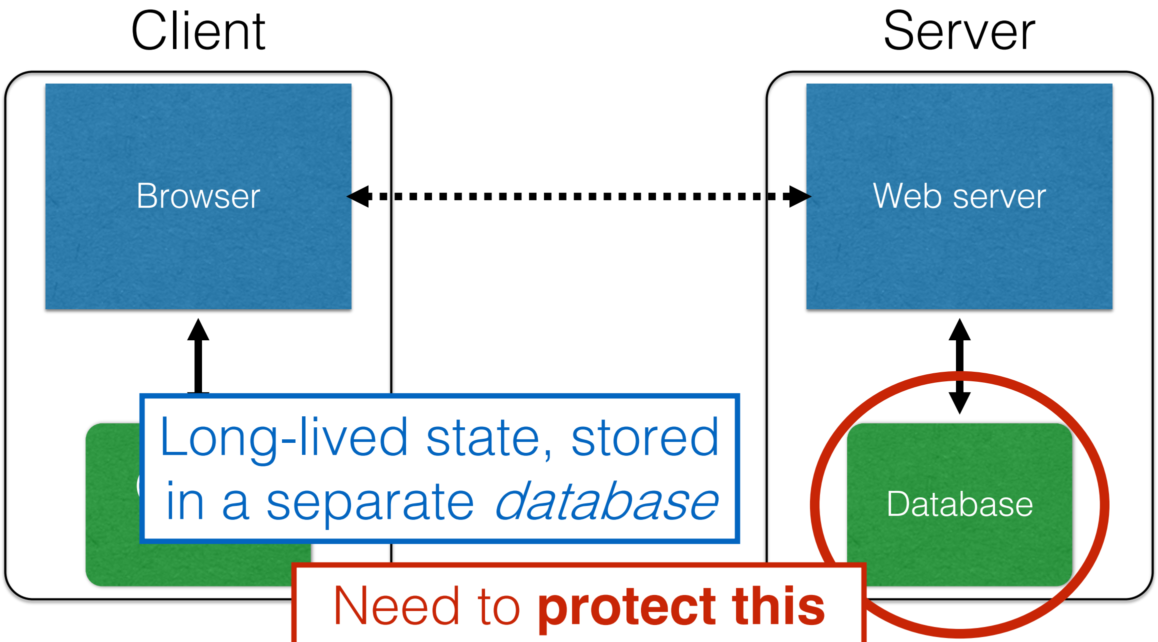
SQL injection

Defending the WWW



Long-lived state, stored in a separate *database*

Need to **protect this state** from illicit access and tampering

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

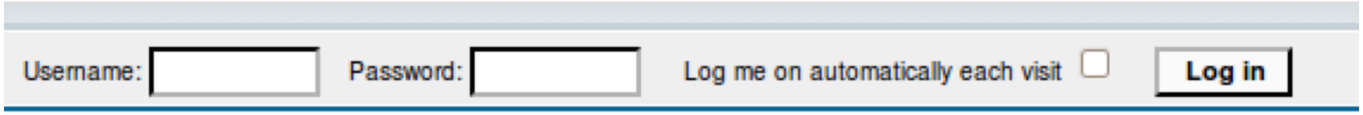
```
SELECT Age FROM Users WHERE Name=‘Dee’;     28

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



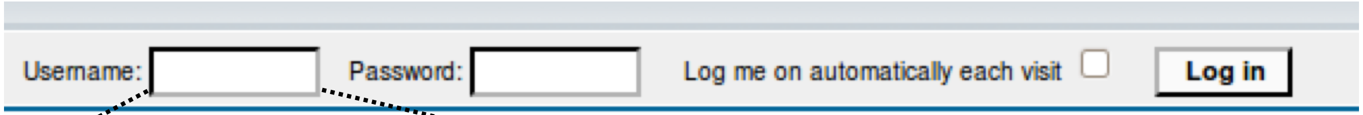
“Login code” (Ruby)

```
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; --
```

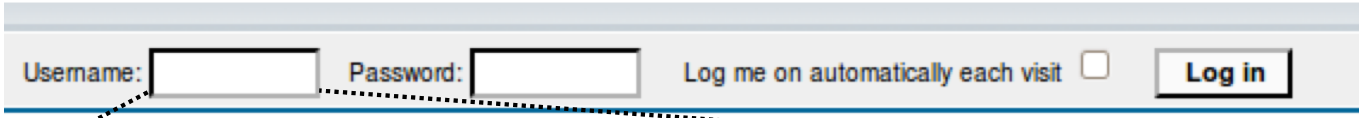
```
result = db.execute “SELECT * FROM Users
        WHERE Name=‘#{user}’ AND Password=‘#{pass}’;”
```

```
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

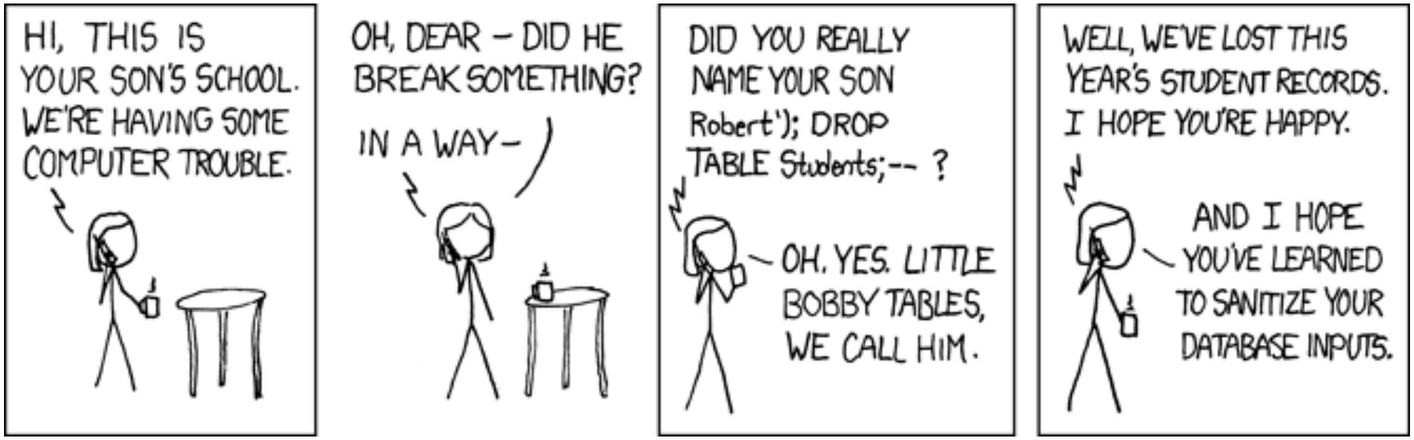


```
frank’ OR 1=1); DROP TABLE Users; --
```

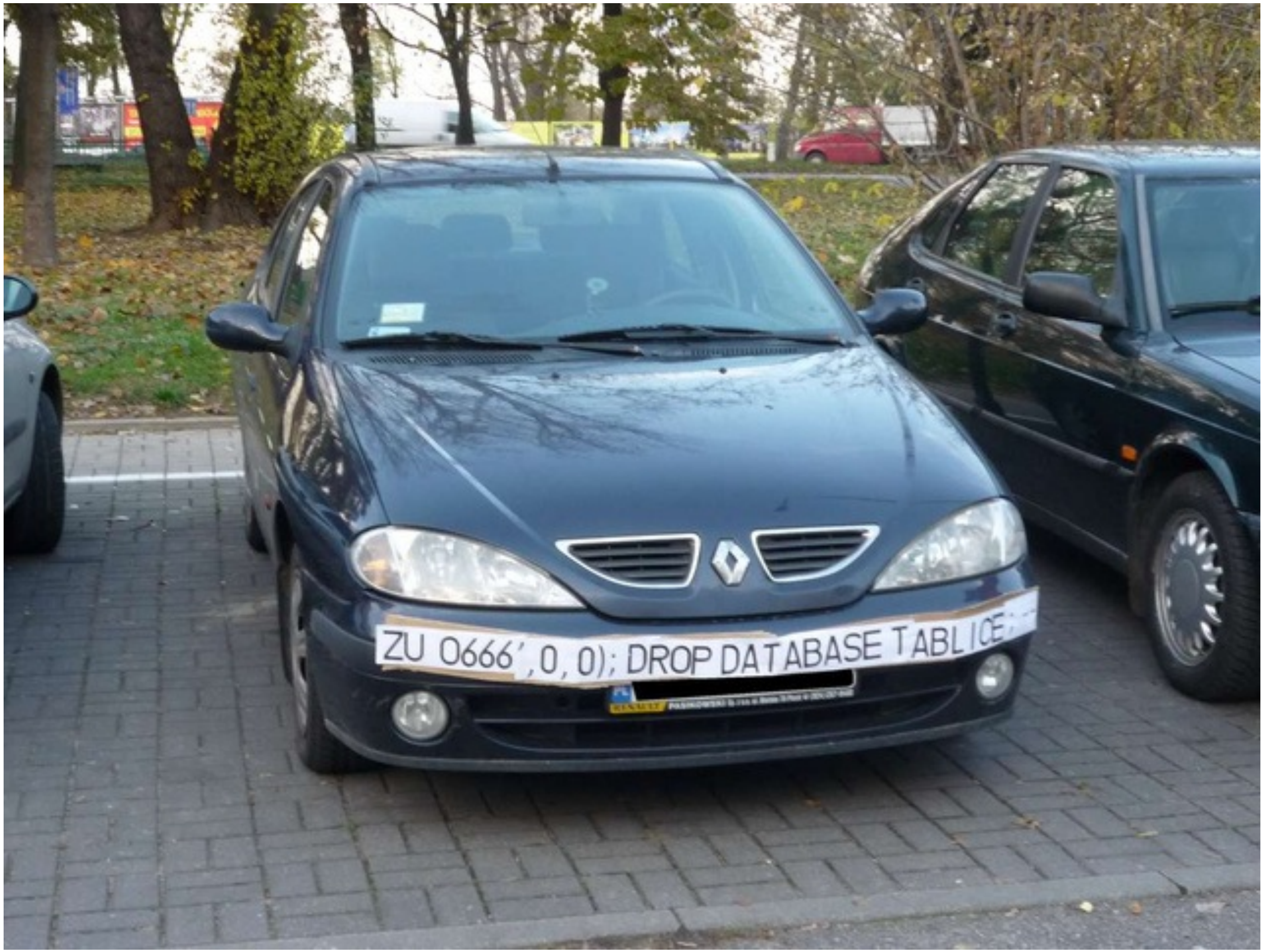
```
result = db.execute “SELECT * FROM Users
         WHERE Name=‘#{user}’ AND Password=‘#{pass}’;”
```

```
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


HI, THIS IS YOUR SON'S SCHOOL. WE'RE HAVING SOME COMPUTER TROUBLE.
OH, DEAR – DID HE BREAK SOMETHING?
IN A WAY–
DID YOU REALLY NAME YOUR SON Robert'); DROP TABLE Students;-- ?
OH. YES. LITTLE BOBBY TABLES, WE CALL HIM.
WELL, WE'VE LOST THIS YEAR'S STUDENT RECORDS. I HOPE YOU'RE HAPPY.
AND I HOPE YOU'VE LEARNED TO SANITIZE YOUR DATABASE INPUTS.

http://xkcd.com/327/


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

SQL injection countermeasures

The underlying issue

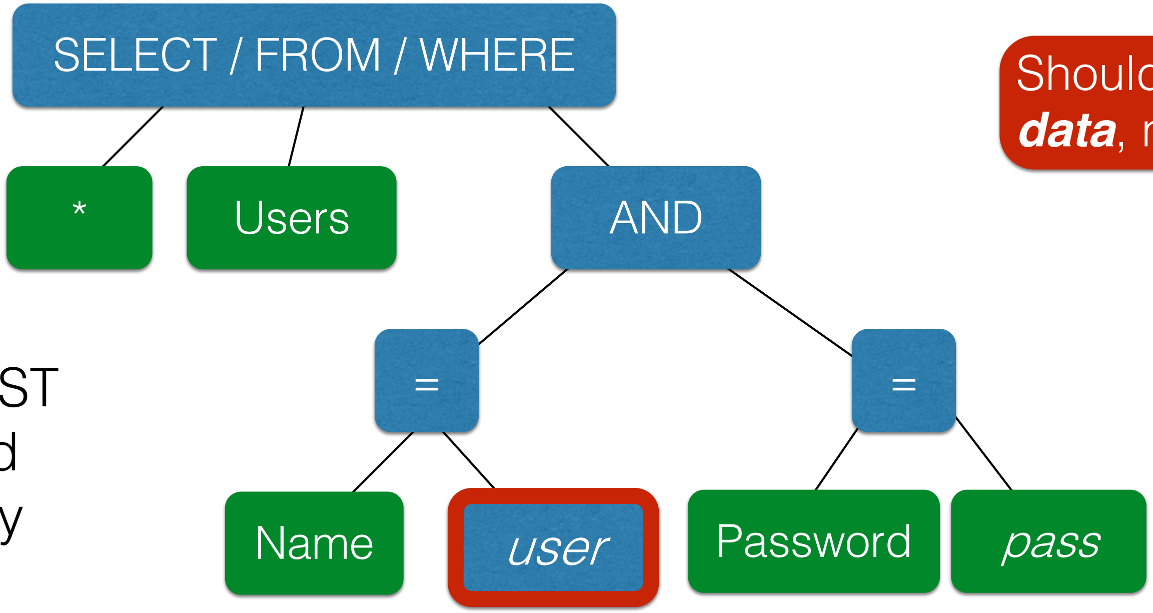
```
result = db.execute “SELECT * FROM Users
         WHERE Name=‘#{user}’ AND Password=‘#{pass}’;”
```

- 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}’;”
```



SELECT / FROM / WHERE

*

Users

AND

=

=

Name

user

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.,

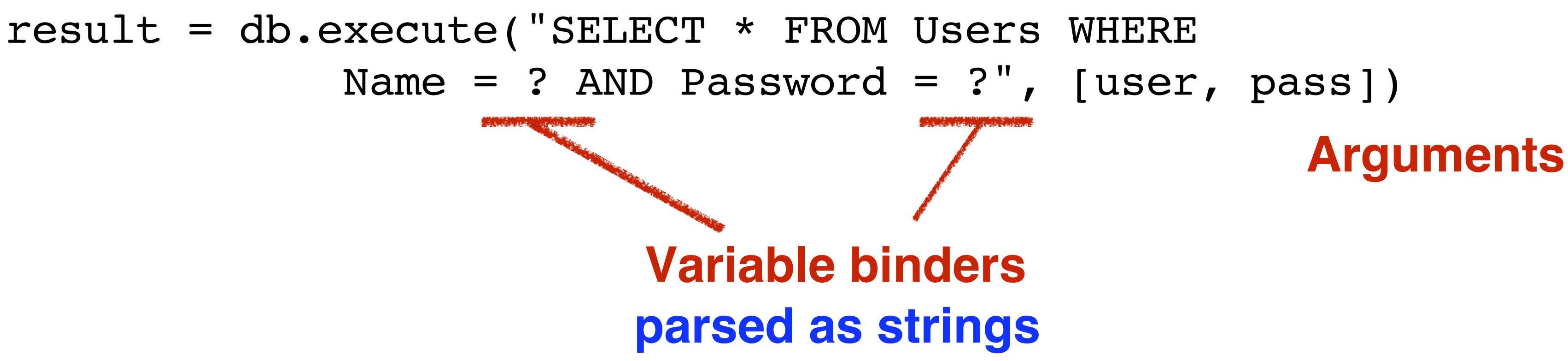
- **Reject** inputs with bad characters (e.g., `;` or `--`)
- **Remove** those characters from input
- **Escape** those characters (in an SQL-specific manner)

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

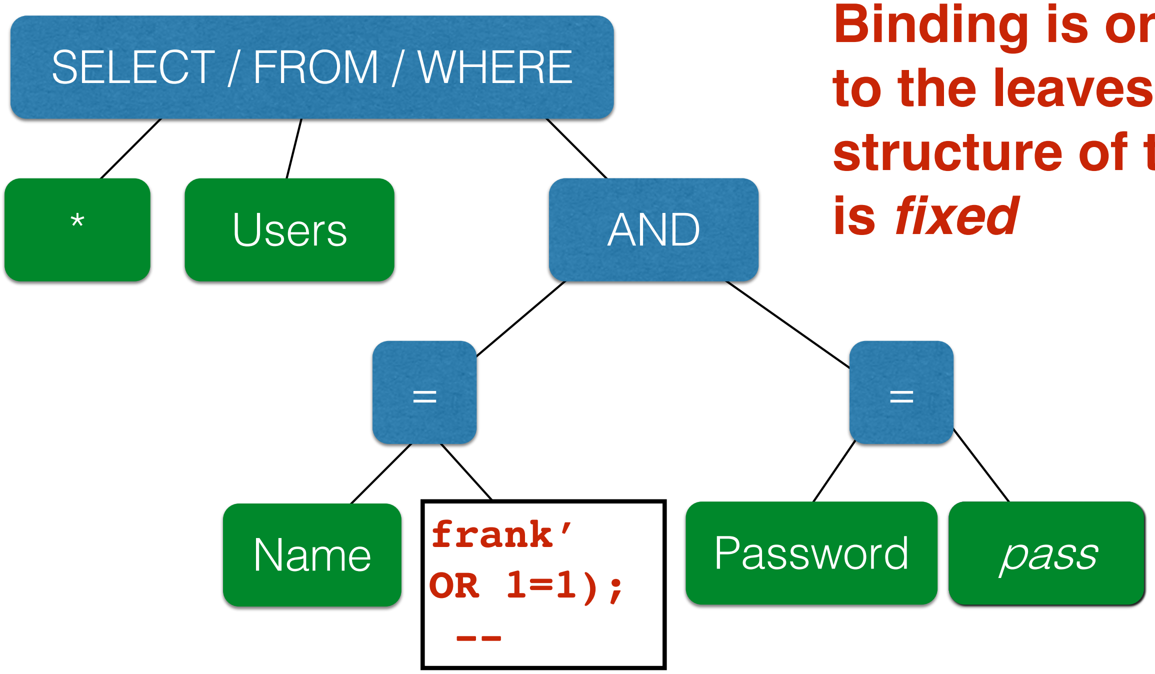
```
result = db.execute “SELECT * FROM Users
       WHERE Name=‘#{user}’ AND Password=‘#{pass}’;”
```



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

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

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What is the benefit of using “prepared statements” ?

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