

CS915/435 Advanced Computer Security

- Web security (II)

SQL Injection

Outline

- Cross Site Request Forgery
- Cross-Site Scripting Attack
- **SQL Injection Attack**
 - Brief tutorial of SQL
 - How to launch SQL injection attacks
 - The fundamental cause of the vulnerability
 - Countermeasures against SQL Injection attacks

OWASP Top 10

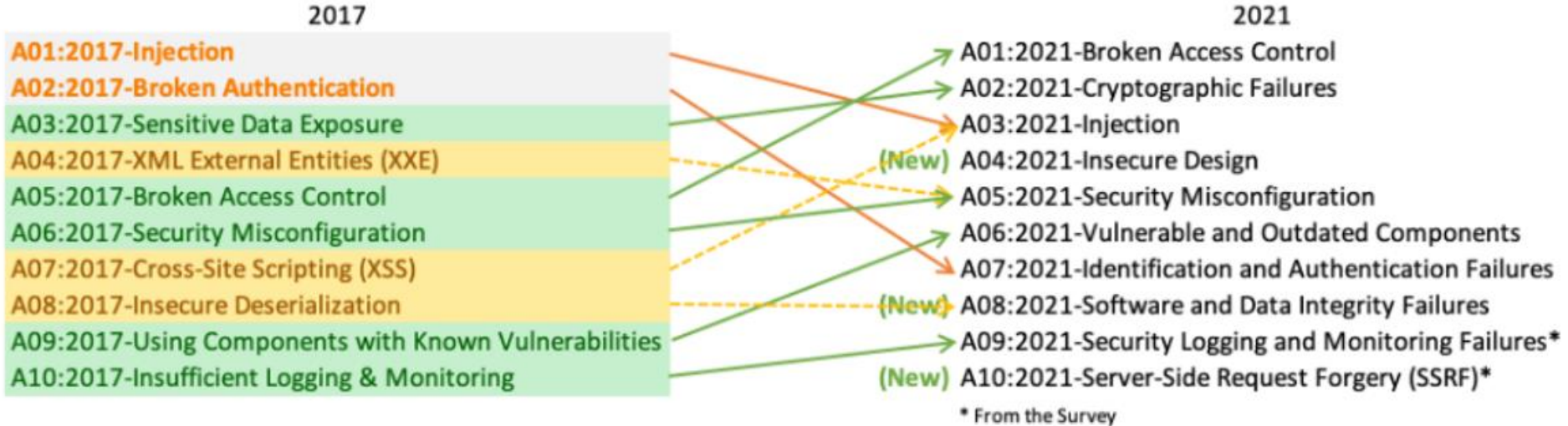
2017

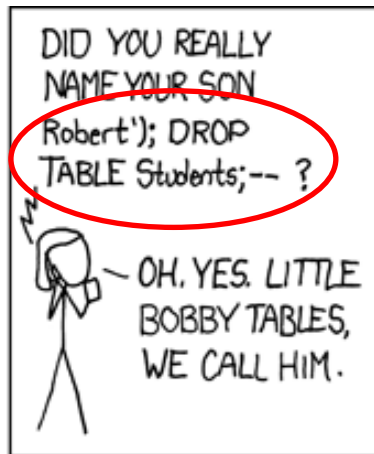
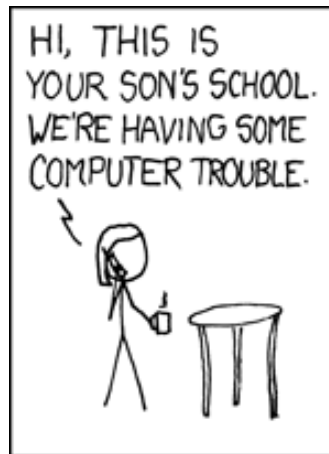
A01:2017-Injection
A02:2017-Broken Authentication
A03:2017-Sensitive Data Exposure
A04:2017-XML External Entities (XXE)
A05:2017-Broken Access Control
A06:2017-Security Misconfiguration
A07:2017-Cross-Site Scripting (XSS)
A08:2017-Insecure Deserialization
A09:2017-Using Components with Known Vulnerabilities
A10:2017-Insufficient Logging & Monitoring

2021

A01:2021-Broken Access Control
A02:2021-Cryptographic Failures
A03:2021-Injection
(New) A04:2021-Insecure Design
A05:2021-Security Misconfiguration
A06:2021-Vulnerable and Outdated Components
A07:2021-Identification and Authentication Failures
(New) A08:2021-Software and Data Integrity Failures
A09:2021-Security Logging and Monitoring Failures*
(New) A10:2021-Server-Side Request Forgery (SSRF)*

* From the Survey





Brief Tutorial of SQL

- **Log in to MySQL:** We will use MySQL database, which is an open-source relational database management system. We can log in using the following command:

```
$ mysql -uroot -pseedubuntu
Welcome to the MySQL monitor.
...
mysql>
```

- **Create a Database:** Inside MySQL, we can create multiple databases. “SHOW DATABASES” command can be used to list existing databases. We will create a new database called dbtest:

```
mysql> SHOW DATABASES;
.....
mysql> CREATE DATABASE dbtest;
```

SQL Tutorial: Create a Table

- A relational database organises its data using tables. Let us create a table called employee with seven attributes (i.e. columns) for the database “dbtest”

- We need to let the system know which database to use as there may be multiple databases
- After a table is created, we can use describe to display the structure of the table

```
mysql> USE dbtest
mysql> CREATE TABLE employee (
  ID      INT (6) NOT NULL AUTO INCREMENT,
  Name    VARCHAR (30) NOT NULL,
  EID     VARCHAR (7) NOT NULL,
  Password VARCHAR (60),
  Salary  INT (10),
  SSN     VARCHAR (11),
  PRIMARY KEY (ID)
);
mysql> DESCRIBE employee;
```

Field	Type	Null	Key	Default	Extra
ID	int(6)	NO	PRI	NULL	auto_increment
Name	varchar(30)	NO		NULL	
EID	varchar(30)	NO		NULL	
Password	varchar(60)	YES		NULL	
Salary	int(10)	YES		NULL	
SSN	varchar(11)	YES		NULL	

SQL Tutorial: Insert a Row

- We can use the INSERT INTO statement to insert a new record into a table :

```
mysql> INSERT INTO employee (Name, EID, Password, Salary, SSN)
VALUES ('Ryan Smith', 'EID5000', 'paswd123', 80000,
       '555-55-5555');
```

- Here, we insert a record into the “employee” table.
- We do not specify a value of the ID column, as it will be automatically set by the database.

SQL Tutorial: SELECT Statement

- The SELECT statement is the most common operation on databases
- It retrieves information from a database

```
mysql> SELECT * FROM employee;
```

ID	Name	EID	Password	Salary	SSN
1	Alice	EID5000	paswd123	80000	555-55-5555
2	Bob	EID5001	paswd123	80000	555-66-5555
3	Charlie	EID5002	paswd123	80000	555-77-5555
4	David	EID5003	paswd123	80000	555-88-5555

Asks the database for all its records, including all the columns

```
mysql> SELECT Name, EID, Salary FROM employee;
```

Name	EID	Salary
Alice	EID5000	80000
Bob	EID5001	80000
Charlie	EID5002	80000
David	EID5003	80000

Asks the database only for Name, EID and Salary columns

SQL Tutorial: WHERE Clause

- It is uncommon for a SQL query to retrieve all records in a database.
- WHERE clause is used to set conditions for several types of SQL statements including SELECT, UPDATE, DELETE etc.

```
mysql> SQL Statement  
      WHERE predicate;
```

- The above SQL statement only reflects the rows for which the predicate in the WHERE clause is TRUE.
- The predicate is a logical expression; multiple predicates can be combined using keywords AND and OR.
- Let's look at an example in the next slide.

SQL Tutorial: WHERE Clause

- The first query returns a record that has EID5001 in EID field
- The second query returns the records that satisfy either EID='EID5001' or Name='David'

```
mysql> SELECT * FROM employee WHERE EID='EID5001';
```

ID	Name	EID	Password	Salary	SSN
2	Bob	EID5001	paswd123	80000	555-66-5555

```
mysql> SELECT * FROM employee WHERE EID='EID5001' OR Name='David';
```

ID	Name	EID	Password	Salary	SSN
2	Bob	EID5001	paswd123	80000	555-66-5555
4	David	EID5003	paswd123	80000	555-88-5555

SQL Tutorial: WHERE Clause

- If the condition is always True, then all the rows are affected by the SQL statement

```
mysql> SELECT * FROM employee WHERE 1=1;
```

ID	Name	EID	Password	Salary	SSN
1	Alice	EID5000	paswd123	80000	555-55-5555
2	Bob	EID5001	paswd123	80000	555-66-5555
3	Charlie	EID5002	paswd123	80000	555-77-5555
4	David	EID5003	paswd123	80000	555-88-5555

- This 1=1 predicate looks quite useless in real queries, but it will become useful in SQL Injection attacks

SQL Tutorial: UPDATE Statement

- We can use the UPDATE Statement to modify an existing record

```
mysql> UPDATE employee SET Salary=82000 WHERE Name='Bob';
mysql> SELECT * FROM employee WHERE Name='Bob';
```

ID	Name	EID	Password	Salary	SSN
2	Bob	EID5001	paswd123	82000	555-66-5555

SQL Tutorial: Comments

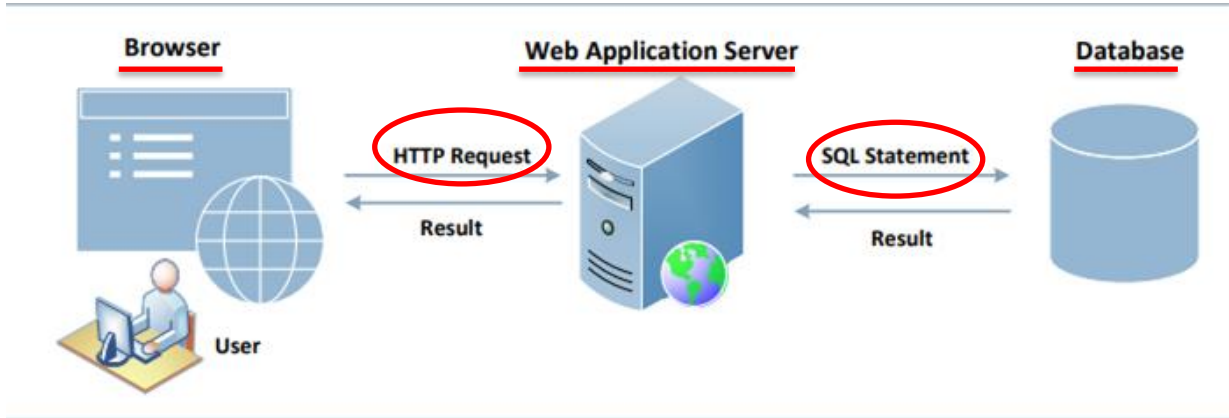
MySQL supports three comment styles

- Text from the # character to the end of line is treated as a comment
- Text from the "-- " (space required) to the end of line is treated as a comment
- Similar to C language, text between /* and */ is treated as a comment

```
mysql> SELECT * FROM employee; # Comment to the end of line
mysql> SELECT * FROM employee; -- Comment to the end of line
mysql> SELECT * FROM /* In-line comment */ employee;
```

Interacting with Database in Web Application

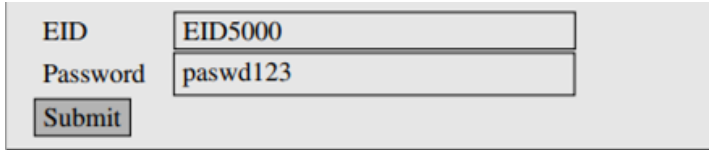
- A typical web application consists of three major components:



- SQL Injection attacks can cause damage to the database. As we notice in the figure, the users do not directly interact with the database but through a web server. If this channel is not implemented properly, malicious users can attack the database.

Getting Data from User

- This example shows a form where users can type their data. Once the submit button is clicked, an HTTP request will be sent out with the data attached



The image shows a simple web form. It has two text input fields. The first field is labeled 'EID' and contains the text 'EID5000'. The second field is labeled 'Password' and contains the text 'paswd123'. Below these fields is a button labeled 'Submit'.

- The HTML source of the above form is given below:

```
<form action="getdata.php" method="get">  
  EID:      <input type="text" name="EID"><br>  
  Password: <input type="text" name="Password"><br>  
           <input type="submit" value="Submit">  
</form>
```

- Request generated is:

```
http://www.example.com/getdata.php?EID=EID5000&Password=paswd123
```

Getting Data from User

- The request shown is an HTTP GET request, because the method field in the HTML code specified the get type
- In GET requests, parameters are attached after the question mark in the URL
- Each parameter has a name=value pair and are separated by “&”
- In the case of HTTPS, the format would be similar but the data will be encrypted
- Once this request reached the target PHP script the parameters inside the HTTP request will be saved to an array \$_GET or \$_POST. The following example shows a PHP script getting data from a GET request

```
<?php
    $eid = $_GET['EID'];
    $pwd = $_GET['Password'];
    echo "EID: $eid --- Password: $pwd\n";
?>
```


How Web Applications Interact with Database

Connecting to MySQL Database

- PHP program connects to the database server before conducting query on database.
- The code shown below uses new mysqli(...) along with its 4 arguments to create the database connection.

```
function getDB() {  
    $dbhost="localhost";  
    $dbuser="root";  
    $dbpass="seedubuntu";  
    $dbname="dbtest";  
  
    // Create a DB connection  
    $conn = new mysqli($dbhost, $dbuser, $dbpass, $dbname);  
    if ($conn->connect_error) {  
        die("Connection failed: " . $conn->connect_error . "\n");  
    }  
    return $conn;  
}
```

How Web Applications Interact with Database

- Construct the query string and then send it to the database for execution.
- The channel between user and database creates a new attack surface for the database.

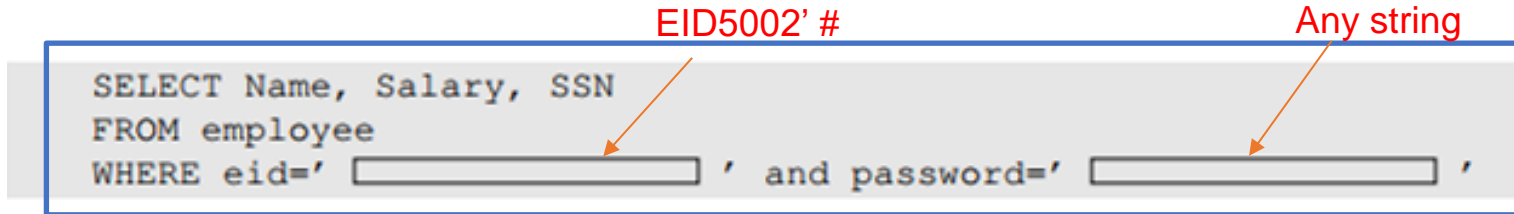
```
/* getdata.php */
<?php
    $eid = $_GET['EID'];
    $pwd = $_GET['Password'];

    $conn = new mysqli("localhost", "root", "seedubuntu", "dbtest");
    $sql = "SELECT Name, Salary, SSN
            FROM employee
            WHERE eid= '$eid' and password='$pwd'";
    $result = $conn->query($sql);
    if ($result) {
        // Print out the result
        while ($row = $result->fetch_assoc()) {
            printf ("Name: %s -- Salary: %s -- SSN: %s\n",
                    $row["Name"], $row["Salary"], $row['SSN']);
        }
        $result->free();
    }
    $conn->close();
?>
```

Constructing SQL statement

Launching SQL Injection Attacks

- Everything provided by user will become part of the SQL statement. Is it possible for a user to change the meaning of the SQL statement?
- The intention of the web app developer by the following is for the user to provide some data for the blank areas.



The diagram shows a SQL query template within a light gray box. The query is: `SELECT Name, Salary, SSN FROM employee WHERE eid=' [input field] ' and password=' [input field] '`. Two red arrows point to the input fields. The first arrow, labeled "EID5002' #" in red, points to the first input field. The second arrow, labeled "Any string" in red, points to the second input field.

- Assume that a user inputs a random string in the password entry and types “EID5002’#” in the eid entry. The SQL statement will become the following

```
SELECT Name, Salary, SSN
FROM employee
WHERE eid= 'EID5002' #' and password='xyz'
```

Launching SQL Injection Attacks

- Everything from the # sign to the end of line is considered as comment. The SQL statement will be equivalent to the following:

```
SELECT Name, Salary, SSN  
FROM employee  
WHERE eid= 'EID5002'
```

- The above statement will return the name, salary and SSN of the employee whose EID is EID5002 even though the user doesn't know the employee's password. This is security breach.
- Let's see if a user can get all the records from the database assuming that we don't know all the EID's in the database.
- We need to create a predicate for WHERE clause so that it is true for all records.

```
SELECT Name, Salary, SSN  
FROM employee  
WHERE eid= 'a' OR 1=1
```

Launching SQL Injection Attacks using cURL

- More convenient to use a command-line tool to launch attacks.
- Easier to automate attacks without a graphic user interface.
- Using cURL, we can send out a form from a command-line, instead of from a web page.

```
% curl 'www.example.com/getdata.php?EID=a' OR 1=1 #&Password='
```

Will not work

- The above command will not work. In an HTTP request, special characters attached to data need to be encoded or they may be mis-interpreted.
- In the above URL we need to encode the apostrophe, whitespace and the # sign and the resulting cURL command is as shown below:

```
% curl 'www.example.com/getdata.php?EID=a%27%20
OR%201=1%20%23&Password='
Name: Alice -- Salary: 80000 -- SSN: 555-55-5555<br>
Name: Bob -- Salary: 82000 -- SSN: 555-66-5555<br>
Name: Charlie -- Salary: 80000 -- SSN: 555-77-5555<br>
Name: David -- Salary: 80000 -- SSN: 555-88-5555<br>
```

Encoded special characters

Modify Database

- If the statement is UPDATE or INSERT INTO, we will have chance to change the database.
- Consider the form created for changing passwords. It asks users to fill in three pieces of information, EID, old password and new password.
- When Submit button is clicked, an HTTP POST request will be sent to the server-side script `changepasswd.php`, which uses an UPDATE statement to change the user's password.

Web Form

EID	<input type="text" value="EID5000"/>
Old Password	<input type="text" value="paswd123"/>
New Password	<input type="text" value="paswd456"/>
<input type="submit" value="Submit"/>	

```
/* changepasswd.php */
<?php
    $eid = $_POST['EID'];
    $oldpwd = $_POST['OldPassword'];
    $newpwd = $_POST['NewPassword'];

    $conn = new mysqli("localhost", "root", "seedubuntu", "dbtest");
    $sql = "UPDATE employee
            SET password=' $newpwd'
            WHERE eid= '$eid' and password=' $oldpwd'";

    $result = $conn->query($sql);
    $conn->close();
?>
```

Modify Database

- Let us assume that Alice (EID5000) is not satisfied with the salary she gets. She would like to increase her own salary using the SQL injection vulnerability. She would type her own EID and old password. The following will be typed into the “New Password” box :

New Password	<input type="text" value="paswd456', salary=100000 #"/>
--------------	---

- By typing the above string in “New Password” box, we get the UPDATE statement to set one more attribute for us, the salary attribute. The SQL statement will now look as follows.

```
UPDATE employee
SET password='paswd456', salary=100000 #
WHERE eid= 'EID5000' and password='paswd123'";
```

apostrophe

- What if Alice doesn't like Bob and would like to reduce Bob's salary to 0, but she only knows Bob's EID (eid5001), not his password. How can she execute the attack?

EID	<input type="text" value="EID5001' #"/>	hash
Old Password	<input type="text" value="anything"/>	
New Password	<input type="text" value="paswd456', salary=0 #"/>	

Multiple SQL Statements

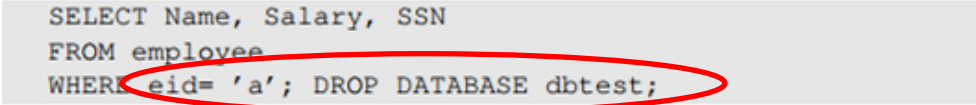
- Damages that can be caused are bounded because we cannot change everything in the existing SQL statement.
- It will be more dangerous if we can cause the database to execute an arbitrary SQL statement.
- To append a new SQL statement “DROP DATABASE dbtest” to the existing SQL statement to delete the entire dbtest database, we can type the following in the EID box



EID `a'; DROP DATABASE dbtest; #`

A screenshot of a web application's EID (Error ID) input box. The box is a light gray rectangle with a thin border. Inside, the text 'a'; DROP DATABASE dbtest; #' is displayed in a monospaced font. A red oval is drawn around the entire content of the box.

- The resulting SQL statement is equivalent to the following, where we have successfully appended a new SQL statement to the existing SQL statement string.



```
SELECT Name, Salary, SSN
FROM employee
WHERE id= 'a'; DROP DATABASE dbtest;
```

A screenshot of a SQL query string. The query is displayed in a monospaced font on a light gray background. The query is: SELECT Name, Salary, SSN FROM employee WHERE id= 'a'; DROP DATABASE dbtest;. A red oval is drawn around the malicious part of the query: id= 'a'; DROP DATABASE dbtest;.

- The above attack doesn't work against MySQL, because in PHP's mysqli extension, the mysqli::query() API doesn't allow multiple queries to run in the database server.

Multiple SQL Statements

- The code below tries to execute two SQL statements using the `$mysqli->query()` API

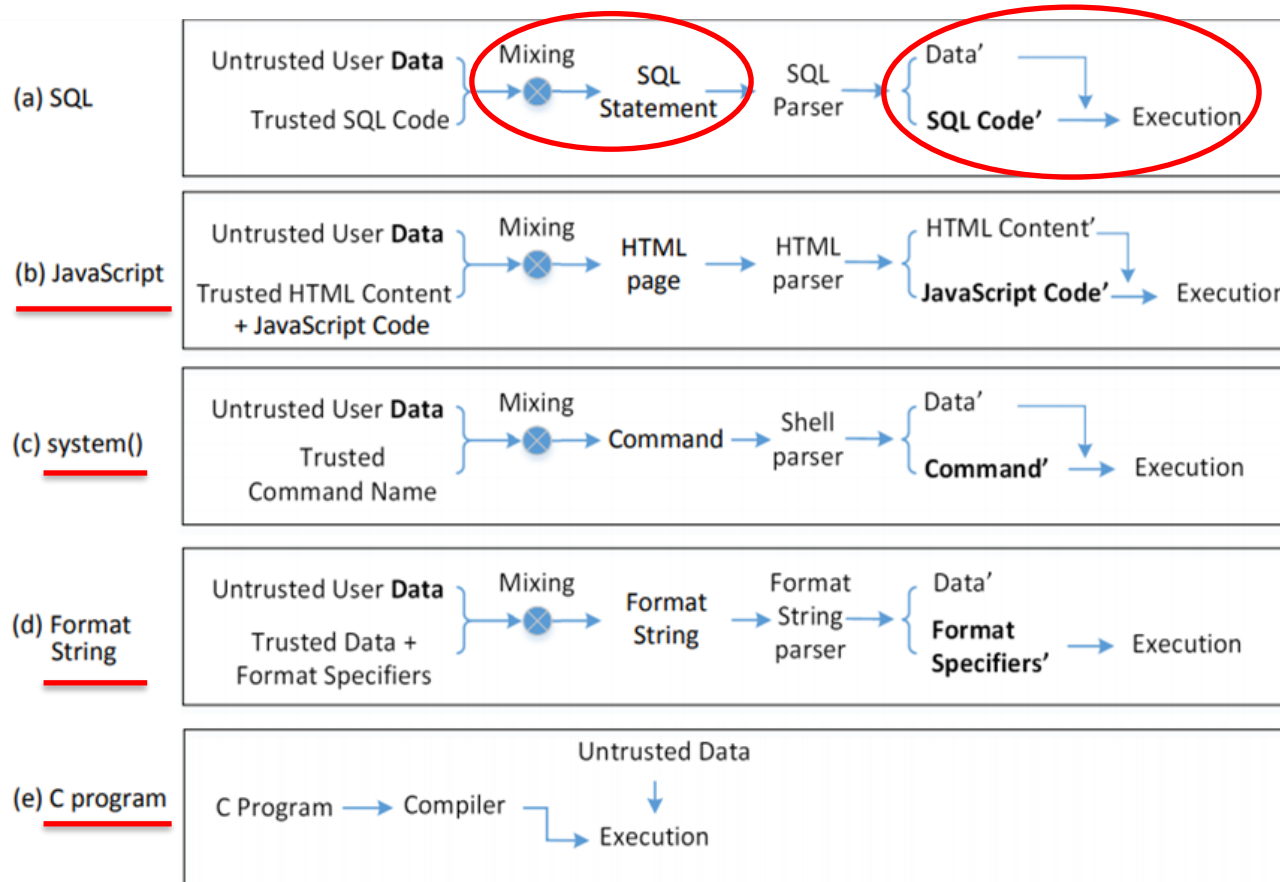
```
/* testmulti_sql.php */
<?php
$mysqli = new mysqli("localhost", "root", "seedubuntu", "dbtest");
$res     = $mysqli->query("SELECT 1; DROP DATABASE dbtest");
if (!$res) {
    echo "Error executing query: (" .
        $mysqli->errno . ") " . $mysqli->error;
}
?>
```

- When we run the code, we get the following error message:

```
$ php testmulti_sql.php
Error executing query: (1064) You have an error in your SQL syntax;
check the manual that corresponds to your MySQL server version
for the right syntax to use near 'DROP DATABASE dbtest' at line 1
```

- If we do want to run multiple SQL statements, we can use `$mysqli->multi_query()`. [not recommended]

The Fundamental Cause



Mixing data and code together is the cause of several types of vulnerabilities and attacks including SQL Injection attack, XSS attack, attacks on the system() function and format string attacks.

Countermeasures: Filtering/Encoding (not recommended)

- Before mixing user-provided data with code, inspect the data. Filter out any character that may be interpreted as code.
- Special characters are commonly used in SQL Injection attacks. To get rid of them, encode them.
- Encoding a special character tells parser to treat the encoded character as data and not as code. This can be seen in the following example

```
Before encoding:   aaa' OR 1=1 #
After encoding:    aaa\' OR 1=1 #
```

- PHP's mysqli extension has a built-in method called `mysqli::real_escape_string()`. It can be used to encode the characters that have special meanings in SQL. The following code snippet shows how to use this API.

```
/* getdata_encoding.php */
<?php
    $conn = new mysqli("localhost", "root", "seedubuntu", "dbtest");
    $eid = $mysqli->real_escape_string($_GET['EID']);           ①
    $pwd = $mysqli->real_escape_string($_GET['Password']);      ②
    $sql = "SELECT Name, Salary, SSN
            FROM employee
            WHERE eid= '$eid' and password='$pwd'";
?>
```

Countermeasures: Prepared Statement (recommended)

- **Fundamental cause** of SQL injection: mixing data and code
- **Fundamental solution**: separate data and code.
- **Main Idea**: Sending code and data in separate channels to the database server. This way the database server knows not to retrieve any code from the data channel.
- **How**: using **prepared statement**
- **Prepared Statement**: It is an optimised feature that provides improved performance if the same or similar SQL statement needs to be executed repeatedly. Using prepared statements, we send an SQL statement template to the database, with certain values called parameters left unspecified. The database parses, compiles and performs query optimisation on the SQL statement template and stores the result without executing it. We later bind data to the prepared statement

Countermeasures: Prepared Statement

```
$conn = new mysqli("localhost", "root", "seedubuntu", "dbtest");  
$sql = "SELECT Name, Salary, SSN  
      FROM employee  
      WHERE eid= '$eid' and password='$pwd'";  
$result = $conn->query($sql);
```

- The vulnerable version: code and data are mixed together.

Using prepared statements, we separate code and data.

```
$conn = new mysqli("localhost", "root", "seedubuntu", "dbtest");  
$sql = "SELECT Name, Salary, SSN  
      FROM employee  
      WHERE eid=? and password=?";  
  
if ($stmt = $conn->prepare($sql)) {  
    $stmt->bind_param("ss", $eid, $pwd);  
    $stmt->execute();  
  
    $stmt->bind_result($name, $salary, $ssn);  
    while ($stmt->fetch()) {  
        printf ("%s %s %s\n", $name, $salary, $ssn);  
    }  
}
```

①

②

③

④

⑤

⑥

Send code

Send data

Start execution

Why Are Prepared Statements Secure?

- Trusted code is sent via a code channel.
- Untrusted user-provided data is sent via data channel.
- Database clearly knows the boundary between code and data.
- Data received from the data channel is not parsed.
- Attacker can hide code in data, but the code will never be treated as code, so it will never be attacked.

Summary

- Brief tutorial of SQL
- SQL Injection attack and how to launch this type of attacks
- The fundamental cause of the vulnerability?
- How to defend against SQL Injection attacks?
- Prepared Statement