2550 Intro to cybersecurity

L23: Sql & its vulnerabilities

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Get access to the lecture machine

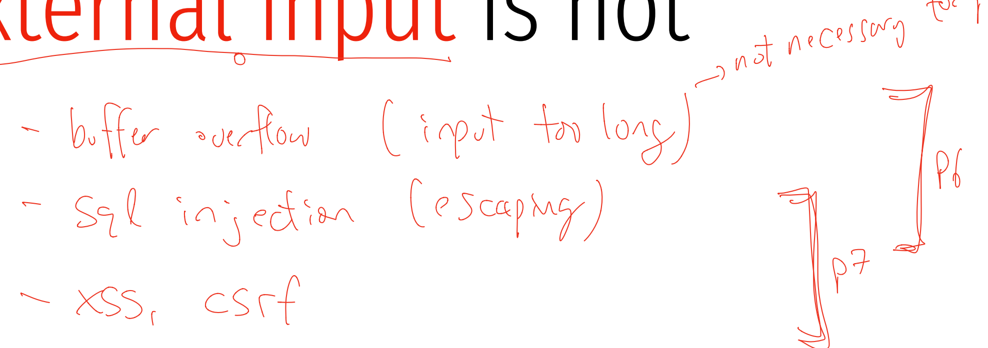
ssh <github username>@l21.neucrypt.org

QUIZ 8 in gradescope

Requires you to have your ssh key uploaded to Github.

We will be flipping between slides and console experiments.

Key insight: security vulnerabilities arise when external input is not verified.



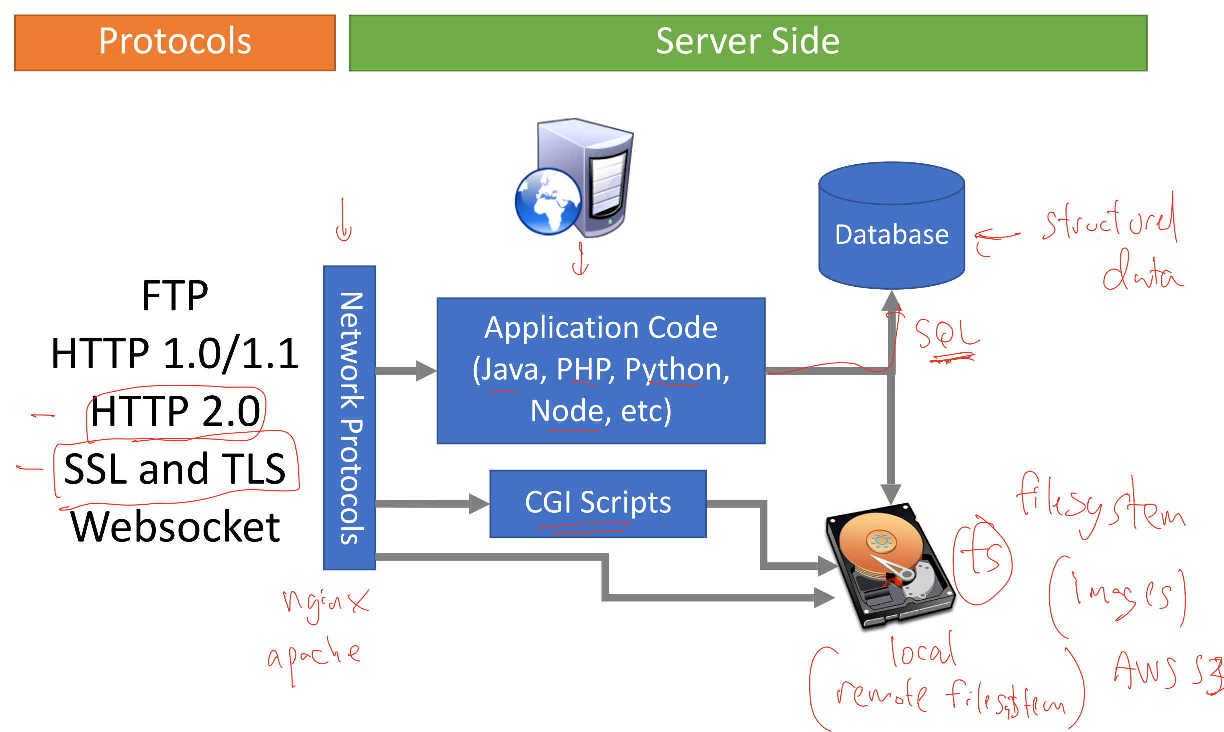
Structured Query Language (SQL)

CREATE, INSERT, UPDATE

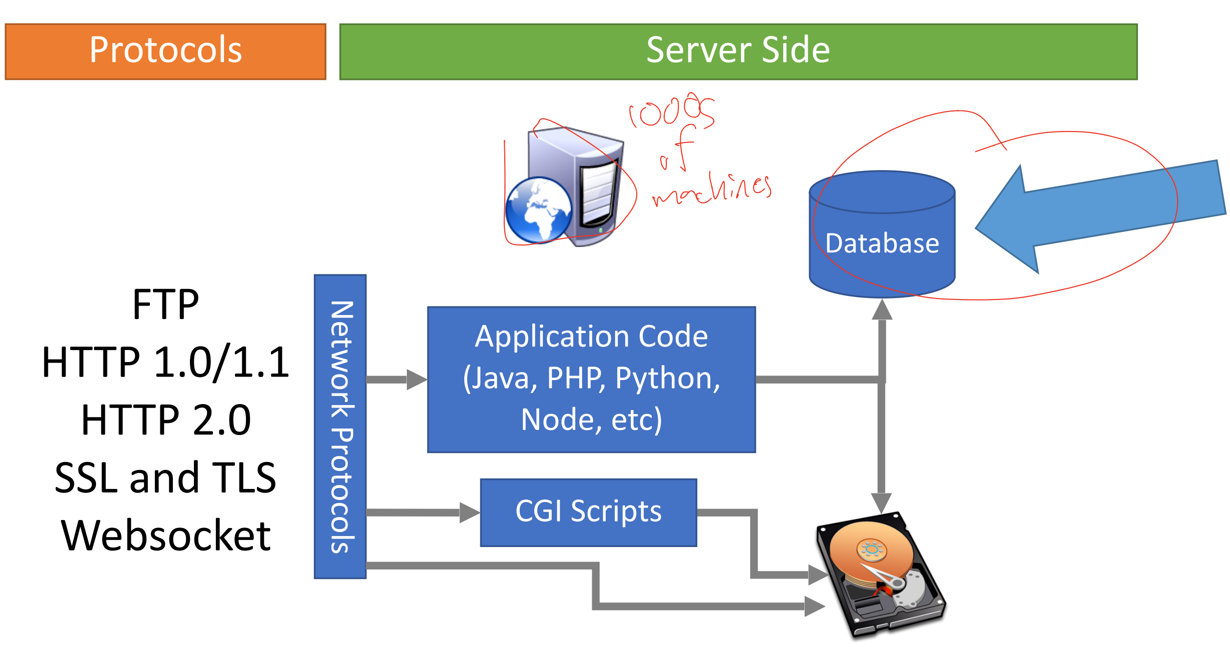
SELECT

Thanks to Christo for sharing slides!

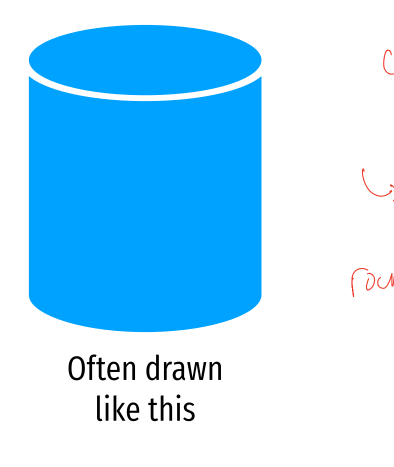
Web Architecture circa-2015



Web Architecture circa-2015



What is a database?



Often drawn like this

consists of "tables"

columns → types of data stored in the table.

rows

name	age	dob	gender
"abbi"	44	...	M

← the actual data

← consistency, especially with concurrent transactions. "ACID"

SQL

language to retrieve (update) data in a database.

- Structured Query Language
  - Relatively simple declarative language
  - Define relational data
  - Operations over that data
- Widely supported: MySQL, Postgres, Oracle, sqlite, etc.
- Why store data in a database?
  - Persistence – DB takes care of storing data to disk
  - Concurrency – DB can handle many requests in parallel
  - Transactions – simplifies error handling during complex updates

SQL Operations

- Common operations:
  - CREATE TABLE makes a new table
  - INSERT adds data to a table
  - UPDATE modifies data in a table
  - DELETE removes data from a table
  - SELECT retrieves data from one or more tables
- Common SELECT modifiers:
  - ORDER BY sorts results of a query
  - UNION combines the results of two queries

CREATE

- Syntax

  CREATE TABLE name (column1_name *type*, column2_name *type*, ...);

- Data types
  - TEXT – arbitrary length strings
  - INTEGER
  - REAL – floating point numbers
  - BOOLEAN

DINOSAURS

name text
weight integer
extinct boolean

CREATE

- Syntax

  CREATE TABLE name (column1_name ***type***, column2_name ***type***, …);

- Data types
  - TEXT – arbitrary length strings
  - INTEGER
  - REAL – floating point numbers
  - BOOLEAN
- Example

  CREATE TABLE people (name TEXT, age INTEGER, employed BOOLEAN);

People:

name (string)	age (integer)	employed (boolean)

INSERT

- Syntax

```
INSERT INTO name (column1, column2, ...) VALUES (val1, val2, ...);
```

- Example

```
INSERT INTO people (name, age, employed) VALUES ("abhi", 78, True);
```

People:

name (string)	age (integer)	employed (boolean)

INSERT

- Syntax

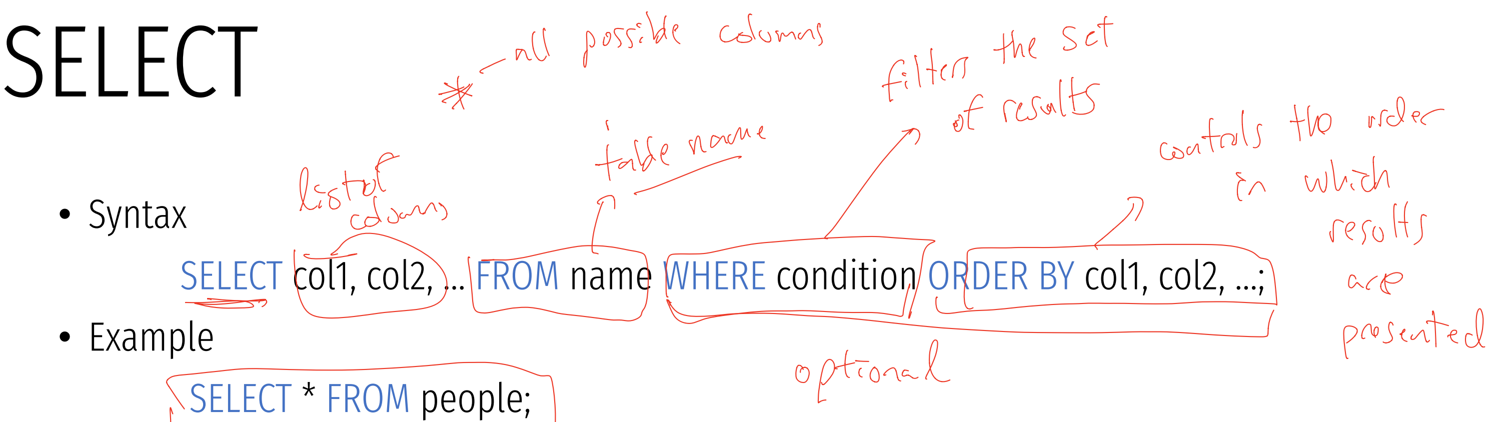
  INSERT INTO name (column1, column2, …) VALUES (val1, val2, …);

- Example

  INSERT INTO people (name, age, employed) VALUES ("abhi", 78, True);

People:

name (string)	age (integer)	employed (boolean)
Abhi	78	True



People:

name (string)	age (integer)	employed (boolean)
Abhi	78	True
Alice	29	True
Bob	41	False

SELECT

- Syntax

  SELECT col1, col2, … FROM name WHERE condition ORDER BY col1, col2, …;

- Example

  SELECT * FROM people;

  SELECT name, age FROM people;

People:

name (string)	age (integer)
Abhi	78
Alice	29
Bob	41

SELECT

- Syntax

```
SELECT col1, col2, … FROM name WHERE condition ORDER BY col1, col2, …;
```

- Example

```
SELECT * FROM people;
SELECT name, age FROM people;
SELECT * FROM people WHERE name="abhi" OR name="Alice";
```

People:

name (string)	age (integer)	employed (boolean)
Abhi	78	True
Alice	29	True

SELECT

- Syntax

  SELECT col1, col2, … FROM name WHERE condition ORDER BY col1, col2, …;

- Example

  SELECT * FROM people;

  SELECT name, age FROM people;

  SELECT * FROM people WHERE name="abhi" OR name="Alice";

  SELECT name FROM people ORDER BY age;

People:

name (string)
Alice
Bob
Abhi

UPDATE

- Syntax

  UPDATE name SET column1=val1, column2=val2, … WHERE condition;

- Example

  UPDATE people SET age=42 WHERE name="Bob";

tablename

specifies the row that you want to update.

be careful.

People:

name (string)	age (integer)	employed (boolean)
Abhi	78	True
Alice	29	True
Bob	41	False

UPDATE

- Syntax

  UPDATE name SET column1=val1, column2=val2, … WHERE condition;

- Example

  UPDATE people SET age=42 WHERE name="Bob";

People:

name (string)	age (integer)	employed (boolean)
Abhi	78	True
Alice	29	True
Bob	42	False

UNION

these columns must be the same type as these columns.

- Syntax

  SELECT col1, col2, … FROM name1 UNION SELECT col1, col2, … FROM name2;

- Example

  SELECT * FROM people UNION SELECT * FROM dinosaurs;

People:

name (string)	age (integer)	employed (boolean)
Abhi	78	True
Alice	29	True

UNION

- Syntax

  SELECT col1, col2, … FROM name1 UNION SELECT col1, col2, … FROM name2;

- Example

  SELECT * FROM people UNION SELECT * FROM dinosaurs;

People:

name (string)	age (integer)	employed (boolean)
Abhi	78	True
Alice	29	True

name (string)	weight (integer)	extinct (boolean)
Tyrannosaurus	14000	True
Brontosaurus	15000	True

UNION

- Syntax

  SELECT col1, col2, … FROM name1 UNION SELECT col1, col2, … FROM name2;

- Example

  SELECT * FROM people UNION SELECT * FROM dinosaurs;

People:

name (string)	age (integer)	employed (boolean)
Abhi	78	True
Alice	29	True

name (string)	weight (integer)	extinct (boolean)
Tyrannosaurus	14000	True
Brontosaurus	15000	True

Note: number of columns must match (and sometimes column types)

Comments

- Syntax

  command; -- comment

- Example

  SELECT * FROM people; -- This is a comment

People:

name (string)	age (integer)	employed (boolean)
Abhi	78	True
Alice	29	True
Bob	41	False

SQL Injection

Blind Injection

Mitigations

SQL Injection

data from a web client etc.

SQL queries often involve untrusted data

- App is responsible for interpolating user data into queries
- Insufficient sanitization could lead to modification of query semantics

Possible attacks

- Confidentiality – modify queries to return unauthorized data
- Integrity – modify queries to perform unauthorized updates
- Authentication – modify query to bypass authentication checks

Server Threat Model

Attacker's goal:

- Steal or modify information on the server

Server's goal: protect sensitive data

- Integrity (e.g. passwords, admin status, etc.)
- Confidentiality (e.g. passwords, private user content, etc.)

Attacker's capability: submit arbitrary data to the website

- POSTed forms, URL parameters, cookie values, HTTP request headers

Threat Model Assumptions

Web server is free from vulnerabilities

- Apache and nginx are pretty reliable

No file inclusion vulnerabilities

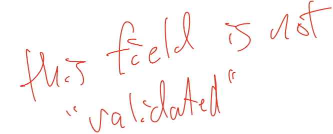
Server OS is free from vulnerabilities

- No remote code exploits

Remote login is secured

- No brute forcing the admin's SSH credentials

Website Login Example



Client-side

Enter the website

Username

Password

Login

Server-side

```
if flask.request.method == 'POST':
    db = get_db()
    cur = db.execute(
        'select * from user_tbl where
         user="%s" and pw="%s";' % (
            flask.request.form['username'],
            flask.request.form['password']))
    user = cur.fetchone()
    if user == None:
        error = 'Invalid username or password'
    else:
        …
```

Login Examples

```
'select * from user_tbl where user="%s" and pw="%s";'
```

form['username']	form['password']	Resulting query

Login Examples

```
'select * from user_tbl where user="%s" and pw="%s";'
```

form['username']	form['password']	Resulting query	
alice	123456	'… where user="alice" and pw="123456";'	OK
bob	qwerty1#	'… where user="bob" and pw="qwery1#";'	OK.

Login Examples

```
'select * from user_tbl where user="%s" and pw="%s";'
```

form['username']	form['password']	Resulting query
alice	123456	'… where user="alice" and pw="123456";'
bob	qwerty1#	'… where user="bob" and pw="qwery1#";'
goofy	a"bc	'… where user="goofy" and pw="a"bc";'

INVALID SQL

Login Examples

`'select * from user_tbl where user="%s" and pw="%s";'`

form['username']	form['password']	Resulting query
alice	123456	'… where user="alice" and
bob	qwerty1#	'… where user="bob" and pw="qw ty1#";'
goofy	a"bc	'… where user="goofy" and pw="a"bc";'

Incorrect syntax, too many double quotes. Server returns 500 error.

Login Examples

```
'select * from user_tbl where user="%s" and pw="%s";'
```

form['username']	form['password']	Resulting query
alice	123456	'… where user="alice" and pw="123456";'
bob	qwerty1#	'… where user="bob" and pw="qwery1#";'
goofy	a"bc	'… where user="goofy" and pw="a"bc";'
weird	abc" or pw="123	'… where user="weird" and pw="abc" or pw="123";'

Login Examples

'select * from user_tbl where user="%s" and pw="%s";'

form['username']	form['password']	Resulting query
alice	123456	'… where user="alice" and pw="123456";'
bob	qwerty1#	'… where user="bob" and pw="qwery1#";'
goofy	a"bc	'… where user="goofy" and pw="a"bc";'
weird	abc" or pw="123	'… where user="weird" and pw="abc" or pw="123";'
eve	" or 1=1; --	'… where user="eve" and pw="" or 1=1; --";'

Login Examples

```
'select * from user_tbl where user="%s" and pw="%s";'
```

form[‘username’]	form[‘password’]	Resulting query
alice	123456	‘… where user="alice" and pw="123456";’
bob	qwerty1#	‘… where user="bob" and p
goofy	a"bc	‘… where user="goofy" and
weird	abc" or pw="123	‘… where user=“weird" and pw="a … r pw="123";’
eve	" or 1=1; --	‘… where user=“eve" and pw="" or 1=1; --";’

1=1 is always true ;)

-- comments out extra quote

Login Examples

```
'select * from user_tbl where user="%s" and pw="%s";'
```

form[‘username’]	form[‘password’]	Resulting query
alice	123456	‘… where user="alice" and pw="123456";’
bob	qwerty1#	‘… where user="bob" and pw="qwery1#";’
goofy	a"bc	‘… where user="goofy" and pw="a"bc";’
weird	abc" or pw="123	‘… where user=“weird" and pw="abc" or pw="123";’
eve	" or 1=1; --	‘… where user=“eve" and pw="" or 1=1; --";’
mallory"; --		‘… where user="mallory"; --" and pw="";’

Login Examples

'select * from user_tbl where user="%s" and pw="%s";'

form[‘username’]	form[‘password’]	Resulting query
alice	123456	‘… where user="alice" and pw="123456";’
bob	qwerty1#	‘… where user="bob" and pw="qwery1#";’
goofy	a"bc	‘… where user="goofy" and [illegible]
weird	abc" or pw="123	‘… where user=“weird" and [illegible]
eve	" or 1=1; --	‘… where user=“eve" and pw=" [illegible] ; --";’
mallory"; --		‘… where user="mallory"; --" and pw="";’

None of this is evaluated. Who needs password checks? ;)

keep-calm.net

Blind SQL Injection

Basic SQL injection requires knowledge of the schema

- e.g., knowing which table contains user data…
- And the structure (column names) of that table

Blind SQL injection leverages information leakage

- Used to recover schemas, execute queries

Requires some observable indicator of query success or failure

- e.g., a blank page (success/true) vs. an error page (failure/false)

Leakage performed bit-by-bit

SQL Injection Examples

Original query:

“SELECT name, description FROM items WHERE id=‘” + req.args.get(‘id’, ‘’) + “’”

SQL Injection Examples

Original query:

“SELECT name, description FROM items WHERE id=‘” + req.args.get(‘id’, ‘’) + “’”

Result after injection:

SELECT name, description FROM items WHERE id='12'
UNION SELECT username, passwd FROM users;--';

or dbl quote ??

guess this name?

SQL Injection Examples

Original query:

```
"SELECT name, description FROM items WHERE id='" + req.args.get('id', '') + "'"
```

Result after injection:

```
SELECT name, description FROM items WHERE id='12'
  UNION SELECT username, passwd FROM users;--';
```

Original query:

```
"UPDATE users SET passwd='" + req.args.get('pw', '') + "' WHERE user='" + req.args.get('user', '')
+ "'"
```

SQL Injection Examples

Original query:

“SELECT name, description FROM items WHERE id=‘” + req.args.get(‘id’, ‘’) + “’”

Result after injection:

SELECT name, description FROM items WHERE id='12'
UNION SELECT username, passwd FROM users;--';

Original query:

“UPDATE users SET passwd=‘” + req.args.get(‘pw’, ‘’) + “’ WHERE user=‘” + req.args.get(‘user’, ‘’)
+ “‘”

Result after injection:

UPDATE users SET passwd='...' WHERE user='dude' OR 1=1;--';

to empty

update the passwd for all users.

SQL Injection Examples

Original query:

```
"SELECT name, description FROM items WHERE id='" + req.args.get('id', '') + "'"
```

Result after injection:

```
SELECT name, description FROM items WHERE id='12'
    UNION SELECT username, passwd FROM users;--';
```

Original query:

```
"UPDATE users SET passwd='" + req.args.get('pw', '') + "' WHERE user='" + req.args.get('user', '')
+ "'"
```

Result after injection:

```
UPDATE users SET passwd='...' WHERE user='dude' OR 1=1;--';
```

SQL Injection Examples

Original query:

“SELECT name, description FROM items WHERE id=‘” + req.args.get(‘id’, “”) + “’”

Result after injection:

SELECT name, description FROM items WHERE id='12' UNION SELECT username, passwd FROM users;--';

quotes are copied verbatim to sql.

Original query:

“UPDATE users SET passwd=‘” + req.args.get(‘pw’, “”) + “’ WHERE user=‘” + req.args.get(‘user’, “”) + “‘”

Result after injection:

UPDATE users SET passwd='...' WHERE user='dude' OR 1=1;--';

- Problem arises when delimiters are unfiltered

SQL Injection Examples

Original query:

```
SELECT * FROM users WHERE id=$user_id;
```

Result after injection:

```
SELECT * FROM users WHERE id=1 UNION SELECT ... --;
```

- Vulnerabilities also arise from improper validation
  - e.g., failing to enforce that numbers are valid

SQL Injection Defenses

```
SELECT * FROM users WHERE user='{{sanitize($id)}}';
```

- Sanitization
- Prepared statements
  - Trust the database to interpolate user data into queries correctly
- Object-relational mappings (ORM)
  - Libraries that abstract away writing SQL statements
  - Java – Hibernate
  - Python – SQLAlchemy, Django, SQLObject
  - Ruby – Rails, Sequel
  - Node.js – Sequelize, ORM2, Bookshelf
- Domain-specific languages
  - LINQ (C#), Slick (Scala), ...

What About NoSQL?

Term for non-SQL databases

- Typically do not support relational (tabular) data
- Use much less expressive and powerful query languages

Are NoSQL databases vulnerable to injection?

What About NoSQL?

Term for non-SQL databases

- Typically do not support relational (tabular) data
- Use much less expressive and powerful query languages

Are NoSQL databases vulnerable to injection?

- YES
- All untrusted input should always be validated and sanitized
  - Even with ORM and NoSQL

Practical demonstrations