CISC/CMPE 327 Software Quality Assurance

Queen's University, 2020-fall

Software Security – Background

The Black, the White and the Grey

- Black hat hackers:
  - The bad guy!

- White hat hackers:
  - Honest, Ethical, Moral
  - Full responsibility
  - Respect the code of conduct
  - Always hack with permission

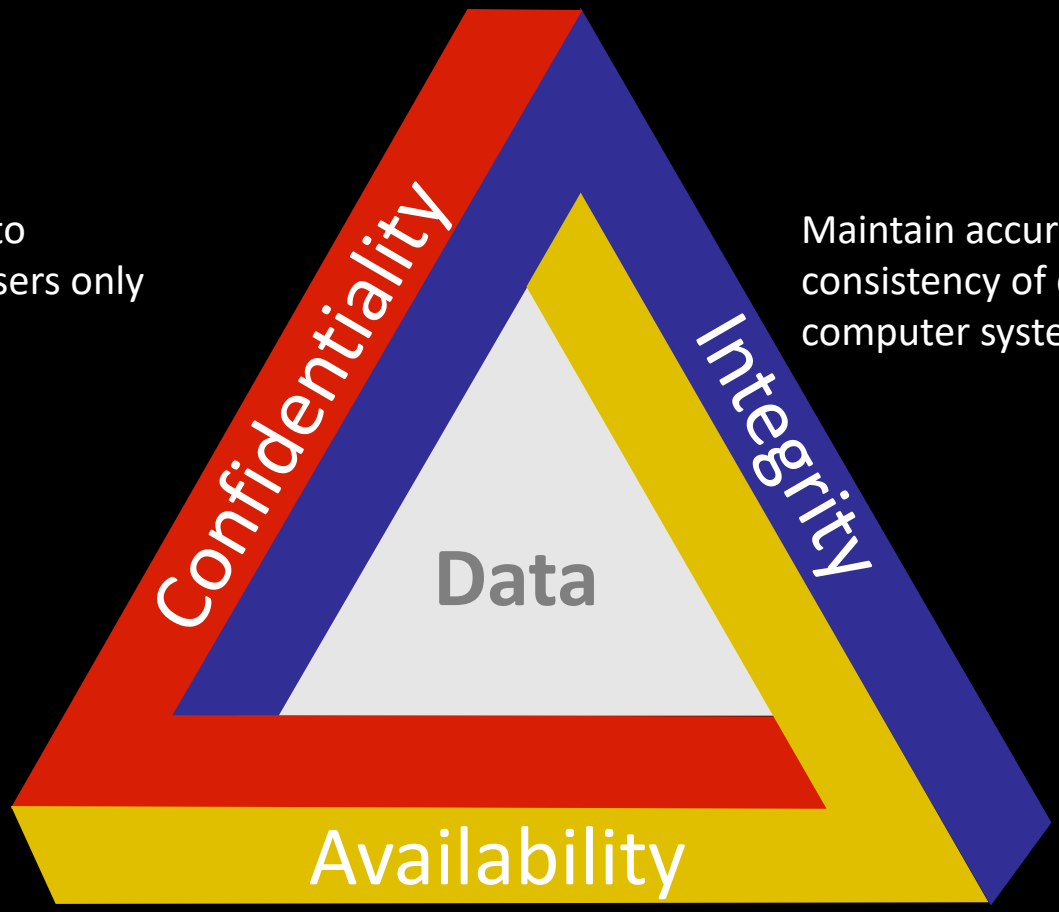
- Grey hackers conduct attacks not for personal or malicious purpose. But they may conduct hacking activities without permission. They may disclose the vulnerability to the public, BUT leaving very short time period for the organization to fix it.

Data vs Information

- Data
  - Raw data stored as its raw physical format
    - e.g. 10101000101010101
    - or raw text data
    - or raw numbers
- Information
  - Putting the data into the context
  - Giving a meaning to the data
  - E.g.
    - Email, messages, etc.
    - Banking account number, social insurance number, etc.

Cybersecurity

Limit access to authorized users only



Maintain accuracy and consistency of data and computer systems

Ensure accessibility to authorized users in a timely fashion

Three aspects of data

Breaking ***Integrity***

- Unauthorized access/transaction
- Corrupted data
- Corrupted software
  - Injected backdoor
  - Skip license virifcation

Breaking ***Availability*** :

- [Distributed]Denial of Service
- Loss of Data/Unavailability of data

Breaking ***Confidentiality***

- [Personal] Sensitive Information
- Internal information
- Military operation

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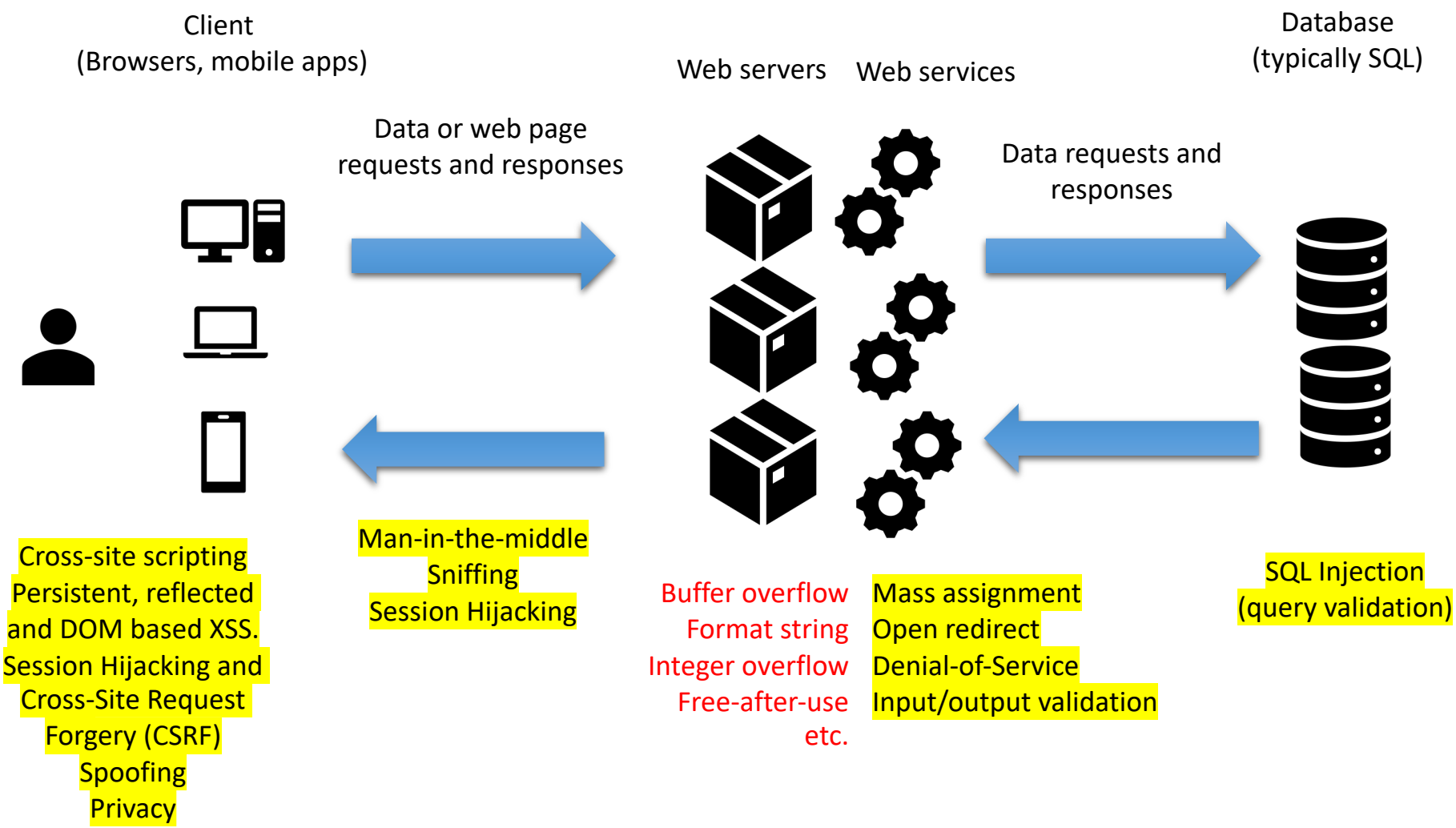
Web Application Security – SQL Injection

Web application - vulnerabilities



Since COVID..

- API attacks
  - The leading attack vectors for retail API attacks in 2020 are cross-site scripting (XSS) (42%) and SQL injection (40%).

- Web attacks
  - The three most common attacks to be remote code execution (RCE) (21%), data leakage (20%) and cross-site scripting (XSS) (16%).

https://www.helpnetsecurity.com/2020/11/24/complex-cyber-attacks-target-online-retailers/

What is SQL?

- SQL (structured query language)
  - Standardized query language for requesting information from database. (ISO/IEC 9075:2016)
  - Supported by many database engines
    - MySQL, SQL Server, IBM DB2, Oracle, PostgreSQL, MS Access
    - Also known as relational databases.

SQL Data Model

- SQL models data as a relational table:

User ID	First_Name	Last_Name	Email	SIN
1	John	Taylor	JS@a.com	123-456-789
2	Adam	Taylor	AT@a.com	987-654-321

- Table contains a list of records. Each record corresponds to an entity.
- All records have the same set of attributes.
- Logically just like an excel table!

SQL - Select

- Retrieve specific attributes of one or more records:

User ID	First_Name	Last_Name	Email	SIN
1	John	Taylor	JS@a.com	123-456-789
2	Adam	Taylor	AT@a.com	987-654-321

SELECT SIN FROM users WHERE User_ID = '1'

123-456-789

SELECT SIN FROM users WHERE Last_Name = 'Talyor'

What is the output?

Database Popularity

Rank			DBMS	Database Model
Sep 2018	Aug 2018	Sep 2017		
1.	1.	1.	Oracle	Relational DBMS
2.	2.	2.	MySQL	Relational DBMS
3.	3.	3.	Microsoft SQL Server	Relational DBMS
4.	4.	4.	PostgreSQL	Relational DBMS
5.	5.	5.	MongoDB	Document store
6.	6.	6.	DB2	Relational DBMS
7.	↑ 8.	↑ 10.	Elasticsearch	Search engine
8.	↓ 7.	↑ 9.	Redis	Key-value store
9.	9.	↓ 7.	Microsoft Access	Relational DBMS
10.	10.	↓ 8.	Cassandra	Wide column store
11.	11.	11.	SQLite	Relational DBMS
12.	12.	12.	Teradata	Relational DBMS
13.	13.	↑ 16.	Splunk	Search engine
14.	14.	↑ 18.	MariaDB	Relational DBMS
15.	15.	↓ 13.	Solr	Search engine

SQL Injection

- The ability to inject SQL commands into the database engine through an existing application
  (by The Open Web Application Security Project)

- SQL injection is a type of security exploit.
  - Attackers manipulate the user input forms.
  - Try to inject crafted SQL statements in to the inputs.
  - The database engine didn't verify the input.
  - Execute the attacker's injected statements.
  - Attacker gain resources or make change to data.

Application

Web interface

Search Email Address

User ID

User input:1

User ID	First_Name	Last_Name	Email	SIN
1	John	Smith	JS@a.com	123-456-789
2	Adam	Taylor	AT@a.com	987-654-321

SELECT Email FROM users WHERE User_ID = '1'

Web interface

Email address is JS@a.com

Attack

Web interface

Search Email Address

User ID

*User input: 1' UNION SELECT * FROM users --*

User ID	First_Name	Last_Name	Email	SIN
1	John	Smith	JS@a.com	123-456-789
2	Adam	Taylor	AT@a.com	987-654-321

*SELECT Email FROM users WHERE User_ID = '1' UNION SELECT * FROM users --'*

Web interface

Email address is JS@a.com *and Everything you have in the database.*

Attack Purposes

- Extract Data

SELECT Email FROM users WHERE User_ID = '1'

SELECT Email FROM users
*WHERE User_ID = '1' UNION SELECT * FROM users --'*

Added a ` to ends the string delimitator

Use -- to comment out the ` added by the application

Attack Purposes

- Bypass Filters

*SELECT *
FROM users WHERE User_Name = 'alex' and Password = `01fac028dfb73'*

*SELECT *
FROM users WHERE User_Name = 'alex' and Password = `' or 1=1 --'*

Added a ` to ends the string delimitator

Use -- to comment out the ` added by the application

Attack Purposes

- Modify Data

SELECT Email FROM users WHERE User_ID = '1'

SELECT Email FROM users
WHERE
User_ID = '' UPDATE Account Set Balance = 100000 WHERE User_ID = `1` --'

Added a ` to ends the string delimitator

Use -- to comment out the ` added by the application

Attack Purposes

- Denial of Service
  - Drop table
  - Drop database
  - Delete backups
  - Lockup database
  - ‘ shutdown—
- Execute System Commands
  - Extended stored procedures in SQL Server enable one to execute shell command
  - *exec xp_regdeletekey*
    - Delete register keys
- Escalating the attack
  - Usually the database also contains the data for other applications

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SQL Injection - Prevention

Types of Attack

- 1st order injection:
  - Inject SQL statement into user input
  - Interpreted by the backend database engine
  - Executed immediately
  - Return the results.
- 2nd order injection:
  - Inject SQL statement into user input
    - (such as user name)
  - Stored it into the database by the application.
  - Will be interpreted and evaluated later.

Tools for Attacker

- SQLmap:
  - Automatic SQL injection and database takeover tool.
  - Automate the process of detecting and exploiting SQL injection flows.
  - Database/Table fingerprinting.
  - Wide range of supported database system.
- SQLsus
  - Another MySQL injection and takeover tool
  - Focus on speed and efficiency.
- SQLdict:
  - A dictionary attack tool for SQL Server
  - Heuristic brute force password guessing

Keyword blacklist filtering?

- Remove or disallow SQL keywords in user input.
  - If user name contains SELECT, tell the user that the name is not valid
  - Using a list of SQL keywords and characters.

- Does it work?

Evasion by String Manipulation

- Cases, space, and encoding
  - SeLeCT
  - %00SELECT
  - %53%45%4c%45%43%54

- Oracle database
  - `serv`||`ices` (|| denotes string concatenation)
- SQL Server
  - `serv`+`ices` (+ denotes string concatenation)
- MySQL
  - `ser` `vices`
- Using exec/execute in SQL
  - exec(`SEL` + `ECT * F` + `ROM U` + `ers`)
- Using variable in SQL
  - set @x=0x12345677234234234; exec(@x)

Evasion by Comments

- Comments are skipped:
  - UNIO/**/N
  - SEL*foo*\ECT
  - SEL/*foo*/ECT username, password FR/*foo*/OM users

Evasion by Char()

- char(..) a function to decode numbers into its corresponding ASCII character

```
select ename, sal from emp where ename='marcus'

SELECT ename, sal FROM emp where ename=CHR(109)||CHR(97)||
CHR(114)||CHR(99)||CHR(117)||CHR(115)

SELECT ename, sal FROM emp WHERE ename=CHAR(109)+CHAR(97)
+CHAR(114)+CHAR(99)+CHAR(117)+CHAR(115)
```

Not even a single quote ` in the query!

Prevention

- Input validation and escaping
- White-list legitimate input, rather than black-list.
- IDS and IPS cannot guarantee a defense
- Least Privilege

Escaping

- Problem: simple string concatenation to construct the SQL query in the program:

```
Connection conn = DriverManager.getConnection(myUrl, "root", "");
// our SQL SELECT query.

 // create the query:
String query = "SELECT * FROM users WHERE user_id =`“ + user_id +
“`”;

// create the java statement
Statement st = conn.createStatement();


// execute the query, and get a java resultset
ResultSet rs = st.executeQuery(query);
```

Need to tell the database that user_id is a string, regardless what the user_id is there.

Escaping

- Don’t trust any input.
- Escape special characters, so the database knows that it is user input instead of a query keyword.

*’ UNION SELECT * FROM users --*

SELECT Email FROM users
*WHERE User_ID = ‘1’ UNION SELECT * FROM users --’*

SELECT Email FROM users
*WHERE User_ID = ‘1\’ UNION SELECT * FROM users \-\-’*

Interpreted as a user input string, rather than SQL keywords

Escaping – Don’t do it yourself!

- Escaping is a complex task:
  - Escaped apostrophe ?
  - But the attacker can use %27 (php)

- OWASP ESAPI
  - The OWASP Enterprise Security API
  - A free, open source, web application security control library that makes it easier for programmers to write lower-risk applications.
  - ESAPI.encoder().encodeForSQL(..)

- Most database engine API comes with:
  - Stock SQL escaping API.
  - Parameterized query, a way to fill in parameters in SQL query.
    - Separate the data definition and the SQL syntax.

Escaping – Don’t do it yourself!

- Parameterized query, a way to fill in parameters in SQL query.
  - Separate the data definition and the SQL syntax.

```
Connection  conn = setupTheDatabaseConnectionSomehow();


PreparedStatement stmt = conn.prepareStatement(
    “SELECT * FROM user where user_id = {}“
);


stmt.setString(1, name_id);


stmt.execute();
```

Escaping – Don’t do it yourself!

- Parameterized query, a way to fill in parameters in SQL query.
  - Should be used for every database query.
  - All user input fields need to be parameterized.
  - Metadata such as database name and table name should not be parametrized.
  - SQL keywords should not be parameterized.
  - Keep your database API library up-to-date.

Escaping – Don’t do it yourself!

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- Most database engine API comes with:
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White-list legitimate input

- Define what is valid, rather that what is invalid.
- Limit length!
- Email
  - Define the required format of an email address.
- User name
  - Define what is allowed to be used as user name.
- Password
  - Allowed characters and required complexity.
- Number
  - Make sure they are actually only numbers.
  - Check range. Age = 65589 ? Suspicious!
  - Alternatively, avoid numbers.
- Verify on server, not just on client!

IDS and IPS

- Intrusion Detection System
- Intrusion Prevention System
- Used on system level to detect or prevent intrusion.
- Detection on SQL injection relies on signatures.
  - Signatures on the SQL query: ` or 1=1 -
  - Can be evaded:
    - `/**/o/**/r/**/ 1 /**/=/**/1/**/-
    - UNI*this is a comment*\ON
- They should be never used alone to protect applications from SQL injection.
- Need to protect it at the application level.

Least Privilege

- Database engine should run using a dedicated user account on the server.
- Minimize the privileges for every database accounts.
  - Different account used for different application.
  - For example, an account used in web application shouldn’t have the write access on the database account table.
  - Generally, except administrator account, no application account can create or modify the metadata (databases, tables..)

Least Privilege

- Most database comes with lots of default functionalities that are not used by your application.
- But they provide the attackers additional attack surface to be leveraged.
- Keep your database service updated.

Prevention

Fundamentally, it is the role of application to work against the SQL injection attacks.

tldr: avoid raw SQL as much as possible