SQL Injection – Attacks and Defenses

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engineering the way

Vision: Security-integrated CS Education

- Integrate (inject) cybersecurity topics into CS courses
  - CS students have no way to escape cybersecurity education
  - CS students understand the correlation and interplay between cybersecurity and other sub-areas of CS
  - Job, career, ...
- Evaluate the teaching and learning effectiveness
- Promote the adoption of this approach

National Science Foundation
WHERE DISCOVERIES BEGIN

Thanks!

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Outline

- SQL Injection
  - Unchecked inputs change SQL execution logic
- Defense in practice - new applications
  - Prepared Statements
  - Stored procedures
  - User input escaping
- Three research papers – detecting vulnerabilities in legacy applications

What is SQL Injection

- A type of injection attack: SQL commands are injected into data-plane input in order to effect the execution of predefined SQL commands.
- It occurs when:
  - Data enter a program from an untrusted source
  - The data used to dynamically construct a SQL query

(https://www.owasp.org/index.php/SQL_Injection)

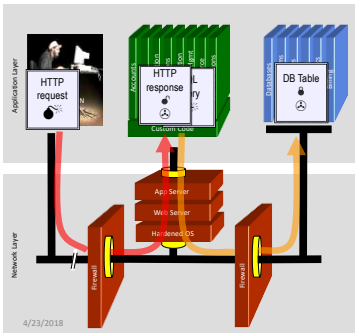
SQL Injection Consequence

- Allow attackers to
  - Drop data from database
  - Alter or insert data
  - Dump sensitive data for attacker to retrieve
  - Take control of the database
- No. 1 at OWASP Top 10 Vulnerabilities – 2013
  - *https://www.owasp.org/index.php/Top_10_2013-A1-Injection*

A typical example of SQL Injection

- A SQL call construction
  - String query = "SELECT * FROM accounts WHERE acct=' " + *request.getParameter("name")* + "' ";
- The value of "name" could be
  - " Bob "
    - SELECT * FROM accounts WHERE acct= 'Bob'
  - " ' or '1'='1 "
    - SELECT * FROM accounts WHERE acct= '' or '1'='1'
  - " ' or 1=1 --" -- comment the rest of the query
    - SELECT * FROM accounts WHERE acct= '' or 1=1--'

SQL Injection – Illustrated



1. Application presents a form to the attacker
2. Attacker sends an attack in the form data
3. Application forwards attack to the database in a SQL query
4. Database runs query containing attack and sends encrypted results back to application
5. Application decrypts data as normal and sends results to the user

Avoiding SQL Injection Flaws

Recommendations

- Avoid the interpreter entirely, or
- Use an interface that supports bind variables (e.g., prepared statements, or stored procedures),
  - Bind variables allow the interpreter to distinguish between code and data
- Encode all user input before passing it to the interpreter
- Always perform 'white list' input validation on all user supplied input
- Always minimize database privileges to reduce the impact of a flaw

References

- For more details, read the https://www.owasp.org/index.php/SQL_Injection_Prevention_Cheat_Sheet

Defenses - New Applications

- Prevent user supplied input (which contains malicious SQL) from affecting the logic of the executed query
  - Prepared statements
  - Stored procedures
  - User input escaping

Defense Option 1

- Prepared Statements (with Parameterized Queries)
  - First define all the SQL code
  - Then pass in each parameter to the query later
- Allows the database to ***distinguish*** between code and data, regardless of what user input is supplied

Defense Option 1

```
String custname = request.getParameter("customerName");

String query = "SELECT account_balance FROM user_data WHERE
user_name = ? ";

PreparedStatement pstmt = connection.prepareStatement(query);

pstmt.setString(1, custname);

ResultSet results = pstmt.executeQuery( );

// look for a customerName which literally matched the entire string
```


Defense Option 2

- Stored Procedures
  - The same effect as the use of prepared statements
  - Stored procedures is that its SQL code is defined and stored in the database itself, and then called from the application

```
String custname = request.getParameter("customerName");

CallableStatement cs = connection.prepareCall("{call
sp_getAccountBalance(?)}");

cs.setString(1, custname);
```

Defense Option 3

- Escaping All User Supplied Input (e.g., OWASP ESAPI library)
  - Cannot guarantee it will prevent all SQL Injection in all situations
  - Should only be used, with caution, to retrofit legacy code in a cost effective way

```
Codec ORACLE_CODEC = new OracleCodec();

String query =
"SELECT user_id FROM user_data WHERE user_name = '" +

ESAPI.encoder().encodeForSQL(ORACLE_CODEC, req.getParameter("userID")) +

"' and user_password = '" +

ESAPI.encoder().encodeForSQL(ORACLE_CODEC, req.getParameter("pwd")) +"'";
```


Interesting Research on SQL Injection (more on vulnerability detection)

- "**AMNESIA: Analysis and Monitoring for NEutralizing SQL Injection Attacks**", *ASE, 2005*
  - William G. J. Halfond, Alessandro Orso
- "**Automatic Generation of XSS and SQL Injection Attacks with Goal-Directed Model Checking**", *USENIX Security Symposium, 2008*
  - Michael Martin, Monica S. Lam
- "**Automated Testing for SQL Injection Vulnerabilities: An Input Mutation Approach**", *ISSTA, 2014*
  - Dennis Appelt, Cu Duy Nguyen, Lionel C. Briand, Nadia Alshahwan

"AMNESIA: Analysis and Monitoring for NEutralizing SQL Injection Attacks", *ASE, 2005*
William G. J. Halfond, Alessandro Orso

- Combined static & dynamic program analysis
  - Static part: automatically build a model of the legitimate queries that could be generated by the application;
  - Dynamic part: monitors the dynamically generated queries at runtime and checks them for compliance with the statically-generated model.
  - Queries that violate the model are classified as illegal, prevented from executing on the database, and reported to the application developers and administrators.

AMNESIA

- Instrumentation: adding calls to the monitor that check the queries at runtime
- Analysis:
  - Query to model mapping

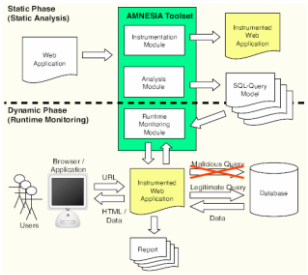


Figure 6: High-level overview of AMNESIA.

"Automatic Generation of XSS and SQL Injection Attacks with Goal-Directed Model Checking", *USENIX Security Symposium, 2008*
Michael Martin, Monica S. Lam

- Proposed QED, a goal-directed model-checking system
  - Automatically generates attacks exploiting taint-based vulnerabilities in large Java web applications.
- Model checking: given a model of a system, exhaustively and automatically check whether queries meet the model specification.

Automatic Generation of XSS and SQL Injection Attacks

- SQL injection and cross-site scripting are both instances of *taint vulnerabilities*:
  - untrusted data from the user is tracked as it flows through the system,
  - if it flows unsafely into a security-critical operation, a vulnerability is flagged.
- We need to analyze more than just individual requests to be sure we have found all vulnerabilities in a web application.

Automatic Generation of XSS and SQL Injection Attacks

- The input application is first instrumented according to the provided PQL query which specifies the vulnerability.
- The instrumented application and a set of seed input values form a harnessed program.
- The harnessed program is then fed to the model checker, along with stub implementations of the application server's environment to systematically explore the space of URL requests.
- The results of that model checker correspond directly to sequences of URLs that demonstrate the attack paths.

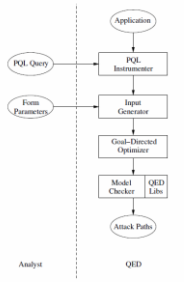


Figure 4: QED architecture. User-supplied information is on the left.

"**Automated Testing for SQL Injection Vulnerabilities: An Input Mutation Approach**", *ISSTA, 2014*
Dennis Appelt, Cu Duy Nguyen, Lionel C. Briand, Nadia Alshahwan

- A black-box automated testing approach
- Applies a set of **mutation operators** that are specifically designed to increase the likelihood of generating successful SQL Injection attacks
  - Some of the mutation operators aims to obfuscate the injected SQL code fragments to bypass security filters

Automated Testing for SQL Injection Vulnerabilities

- Mutation Operations
  - Behavior-changing: alter logic
  - Syntax-repairing
  - Obfuscation

MO name	Description
	Behaviour-Changing Operators
MO_or	Adds an OR-clause to the input
MO_and	Adds an AND-clause to the input
MO_semi	Adds a semicolon followed by an additional SQL statement
	Syntax-Repairing Operators
MO_par	Appends a parenthesis to a valid input
MO_cmt	Adds a comment command (-- or #) to an input
MO_qot	Adds a single or double quote to an input
	Obfuscation Operators
MO_wsp	Changes the encoding of whitespaces
MO_chr	Changes the encoding of a character literal enclosed in quotes
MO_html	Changes the encoding of an input to HTML entity encoding
MO_per	Changes the encoding of an input to percentage encoding
MO_bool	Rewrites a boolean expression while preserving it's truth value
MO_keyw	Obfuscates SQL keywords by randomising the capitalisation and inserting comments

Automated Testing for SQL Injection Vulnerabilities

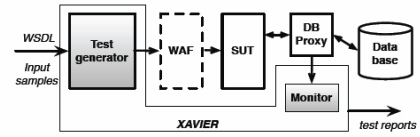


Figure 2: Components of Xavier and how Xavier is used in practice.

- XAVIER: Proposed mutation approach
- WSDL: Web Service Definition Language
- WAF: Web Application Firewall
- SUT: Web Service Under Test

Summary

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  - Prepared Statements
  - Stored procedures
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- Three research papers - vulnerability detection

Thank you!
Q & A