SQL INJECTION: ATTACKS AND DEFENSES

RUI ZHAO, CHUAN YUE, AND BERNARDO TRINDADE

Presentation made using reveal.js

ABOUT US

VISION: SECURITY-INTEGRATED CS EDUCATION

- Integrate 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, etc.
- Evaluate the teaching and learning effectiveness
- Promote the adoption of this approach

This activity is supported by the National Science Foundation under Grant no. 1619841

ABOUT ME

- Graduated from Mines May 2016 with B.S. Computer Science and ASI in Mechanical Engineering
- Did security research here at Mines with Dr. Chuan Yue
- Went to DEFCON 24 this year
- I take and help set up courses for Software Freedom School

Handle: fudog931

SQL INJECTION

WHAT IS SQL INJECTION

- A type of injection attack
  - SQL commands are injected as user input in order to affect the execution of predefined SQL commands
- Occurs when:
  - data comes from an untrusted source
  - data is used to dynamically construct a SQL query
- https://www.owasp.org/index.php/SQL_Injection

CONSEQUENCES

If an attacker exploits this vulnerability they can:

- Drop data from the database
- Change or insert data
- Dump potentially sensitive data
- Own the database

In special cases an attacker can use the database to take over the entire computer

Rated #1 of OWASP top 10 Vulnerabilities in 2013

HOW DOES IT WORK?

A webserver will handle a form with code like this:

```
// $conn will be the variable the holds our connection to our database

$string = $_POST['product_string'];
$query = "SELECT id FROM products WHERE name='$string'";

$result = odbc_exec($conn, $query);
```

If I submit `[My Cool Product]` on the form, this is how it gets processed:

```
$string = "My Cool Product";
$query = "SELECT id FROM products WHERE name='My Cool Product'";
```

But what if I submit `['My Cool Product]`? Then we get interesting effects

```
$string = "'My Cool Product";
$query = "SELECT id FROM products WHERE name=''My Cool Product'";

//Syntax or Command not found error depending on the server config
```

Because the user input gets interpolated to make a query string, instead of this:

```
SELECT id
FROM products
WHERE
        name = 'My Cool Product';
```

the server receives this:

```
SELECT id
FROM products
WHERE
        name = ''
My Cool Product';
```

This weird behavior is used to inject extra SQL commands into the query

LET'S HACK SOMETHING!

REFERENCES

- Attacker VM: Kali 2.0 LXDE
- Target VM: Vulnhub Image: De-ICE: S1.120

DEFENSE

GENERAL RECOMMENDATIONS

- Avoid the interpreter entirely
- Use an interface that supports bind variables (we'll go over some options)
- Encode all user input before passing it to an interpreter
  - scrub your input
- Maintain a "white list" of allowed SQL statements
- Minimize privileges

Check out resources like the OWASP SQL Injection Cheat Sheet

BIND VARIABLES

The goal is to design your web server so that if you get malicious input, it doesn't affect the rest of your logic. A few strategies you can use:

- Prepared Statements
- Stored Procedures
- User Input Escaping

PREPARED STATEMENTS

Instead of dynamically creating a statement based on the user's input, we can use objects that maintain a strict separation between *code* and *data*

```
String query = "SELECT account_balance FROM user_data WHERE user_name =

PreparedStatement pstmt = connection.prepareStatement(query);

String custname = request.getParameter("customerName")

pstmt.setString(1, custname);

ResultSet results = pstmt.executeQuery();
```

STORED PROCEDURES

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_getAccountBalanc

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

ESCAPING USER INPUT

The goal is you escape or remove characters from the user that could be used for SQL Injection.

This is **NOT** guaranteed to prevent SQLI. This is a mitigation technique that will force attackers to be more creative.

An example using OWASP ESAPI (Escaping All User Supplied Input) library:

```
Codec ORACLE_CODEC = new OracleCodec();

String uid = ESAPI.encoder().encodeForSQL(ORACLE_CODEC, req.getParameter
String pass = ESAPI.encoder().encodeForSQL(ORACLE_CODEC, req.getParamete
String query = "SELECT user_id FROM user_data WHERE user_name = '" + uid
```

INTERESTING RESEARCH

- "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

- Static analysis to automatically build a model of legitimate queries the application could generate
- Dynamic analysis to monitor generated queries at runtime and checks them for compliance with the model
- Any queries that violate the model are classified as illegal and blocked before being executed

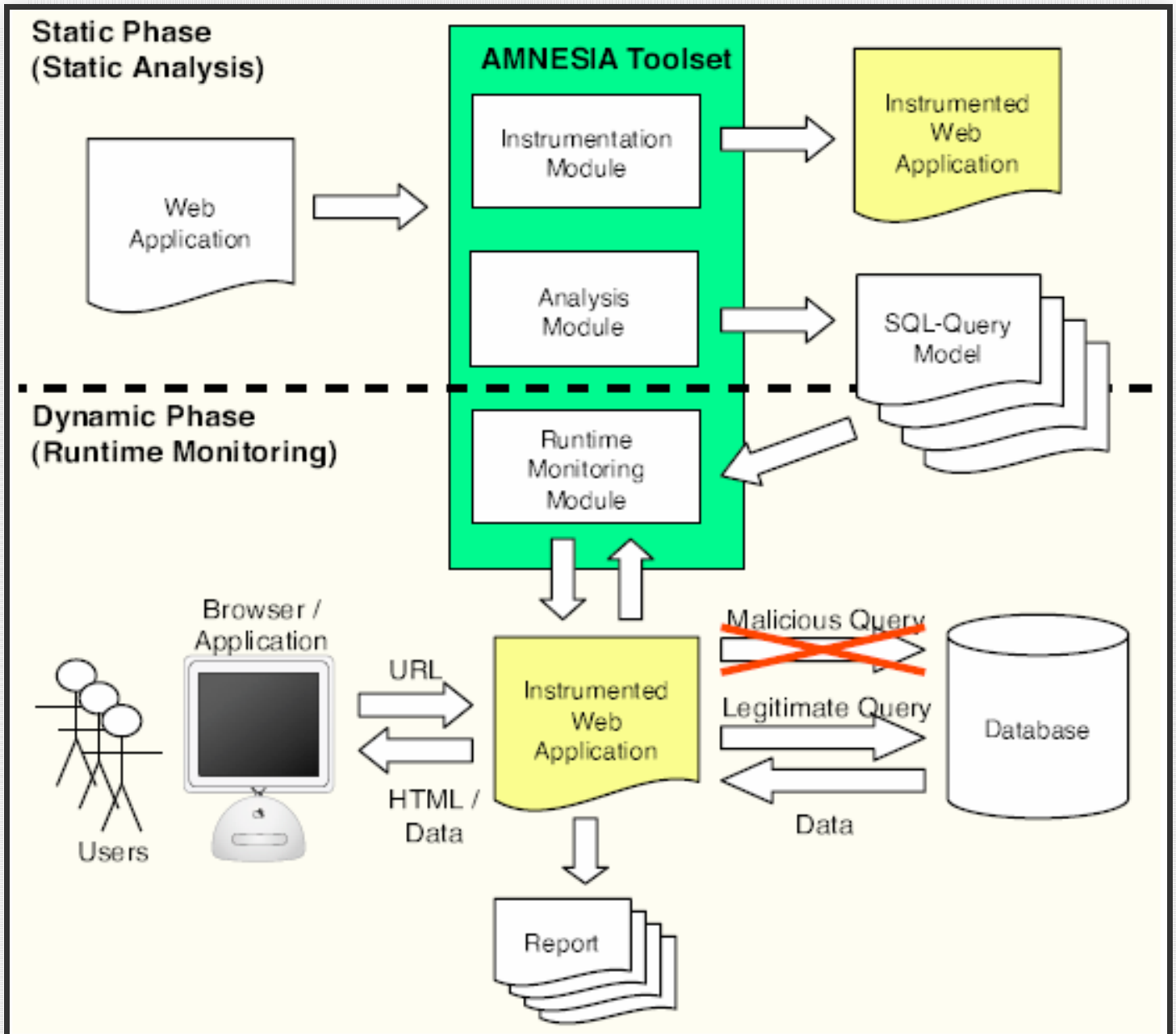


Figure 6: High-level overview of AMNESIA.

AUTOMATIC GENERATION OF SQL INJECTION ATTACKS USING MODEL CHECKING

This uses a goal-directed model-checking system to automatically generate attacks exploiting taint-based vulnerabilities in large Java web applications

Model checking: given a model of a system, exhaustively and automatically check whether this model meets a given specification.

SQL Injection and XSS are both *taint vulnerabilites*

- untrusted data from the user is tracked as it flows through the system
- if it flows into a secure "zone" of the model where it could exploit something the vulnerability gets flagged

We need to analyze more than just individual requests.

We can instead analyze the information flow of our application to find all the vulnerabilities in our application.

- Write a PQL query specifying the vulnerability
- PQL is used to instrument the application along with trace tainted input
- Application is fed to model checker along with simulation of production environment
- Results of model checking and taint tracking returns a list of attack paths

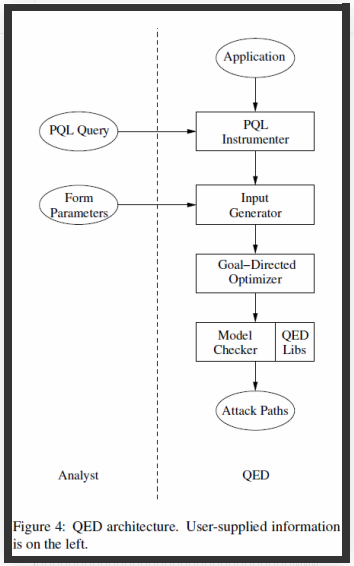


Figure 4: QED architecture. User-supplied information is on the left.

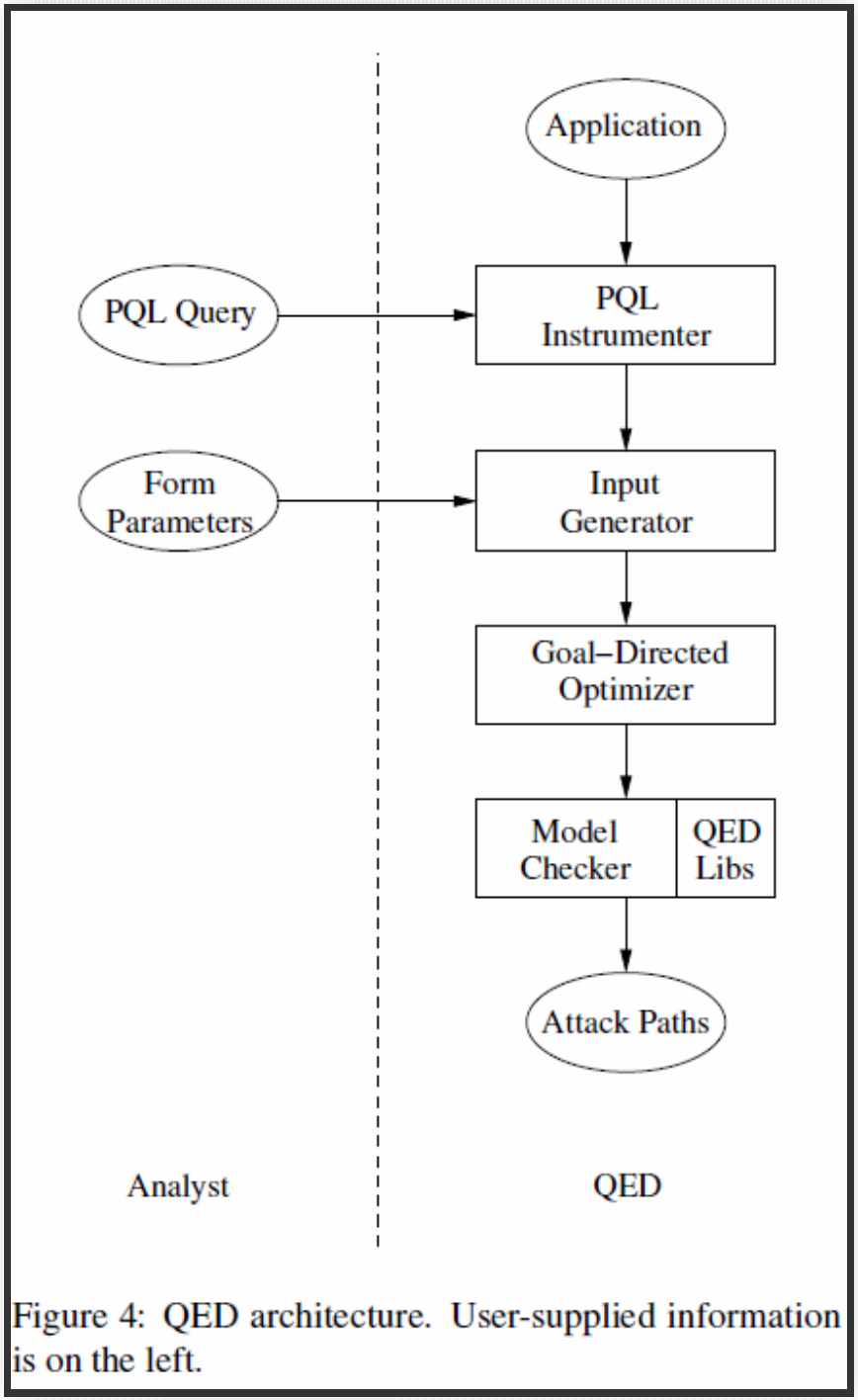


Figure 4: QED architecture. User-supplied information is on the left.

GENERATING ATTACKS USING MUTATION

A black box approach to testing an application for SQLI.

Start with a string for SQL Injection and begin changing, or mutating, it to generate a new string that will get through security filters.

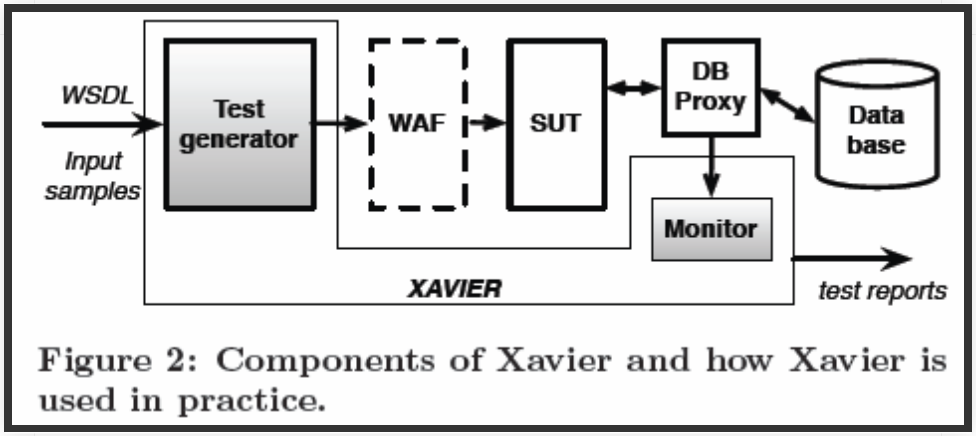


Figure 2: Components of Xavier and how Xavier is used in practice.

- Start with malicious input and mutate it to generate new test strings
- Monitor code listens at the proxy level before the query is executed to see which queries got through

MUTATION OPERATIONS

- Behavior Changing Operations
  - Add an OR to the input. Ex: `"OR 1=1"`
  - Add an AND clause. Ex: `"AND 1=2"`
  - Add a semicolon and an additional SQL statement. Ex: `"; SELECT wait-for(5) FROM dual"`

MUTATION OPERATIONS

- Syntax Repairing Operations
  - Add a closing parenthesis Ex: `"WHERE char=CHR(67) OR 1=1 )"`
  - Add a comment. Ex: `"WHERE char=CHR(67) OR 1=1 #)"`
  - Add a quotation character. Ex: `"id='' OR 1=1"`

MUTATION OPERATIONS

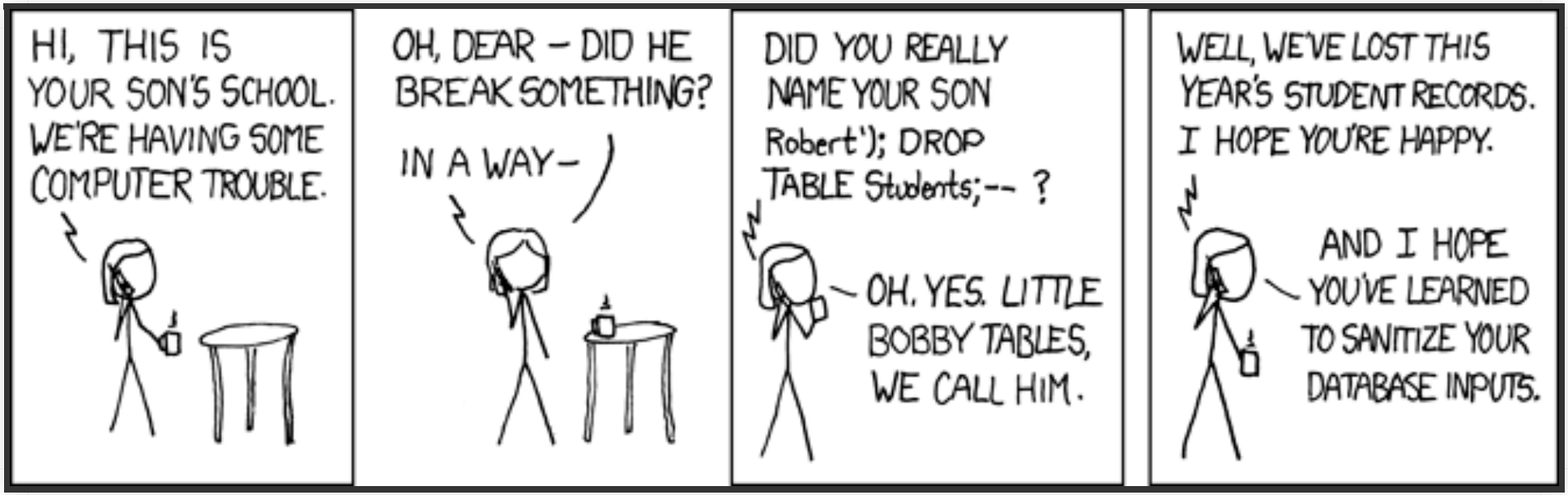
- Obfuscation Operations
  - Replaces whitespace with an equivalent character. Ex: T `"id=3+OR+1=1"`
  - Replaces a character value with an ASCII representation. Ex: `"'a'=x'61'"`
  - Replace characters with their HTML encoded values. Ex: `"OR &quot;a&quot;=&quot;a&quot;"`
  - Replaces a character with their percent encoding. Ex: `"id=3 OR%201=1"`
  - Replaces a boolean with an equivalient expression. Ex: `"1=1"` becomes `"NOT false=!!1"`

- Obfuscate SQL keywords
  - Randomly change the case of letters in keyword. Ex: `"1' oR 1=1"`
  - Adding comments in the middle of keywords. Ex: `"1' 0/* random comment */R 1=1"`
  - Replacing a keyword with an alternative representation Ex: `"1' || 1=1"`

FUZZY COMPUTING

This is a great example of fuzzy computing. These mutation operators have rules for when they are applied, but the programmer has no idea what statements will be generated. This method allows for testing with crazy strings a human would have a hard time finding to ensure your website can defend against these techniques.

THE END



http://xkcd.com/327/