Secure Programming Lecture 7: SQL Injection

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Outline

Recap

Injection attacks use specially crafted inputs to subvert the intended operation of applications.

- **OS Command Injections** may execute arbitrary commands.
- **SQL Injections** can reveal database contents, affect the results of queries used for authentication; sometimes they can even execute commands.

In this lecture we look at **SQL Injections** in some detail.

Context

SQL Injection (SQLi) has regularly featured high in lists of the most common software vulnerabilities.

- Akami's 2021 State of the Internet report records that SQLi is top of the attack list with 6.2 billion attempts recorded over 18 months.

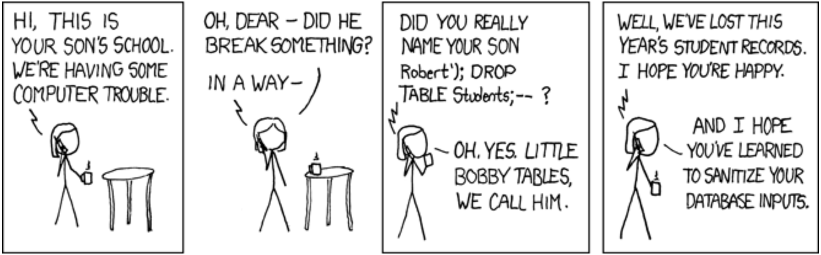
As with overflows, there is a **large body of crafty exploits** made possible by (often small) errors in coding or design.

We will look at:

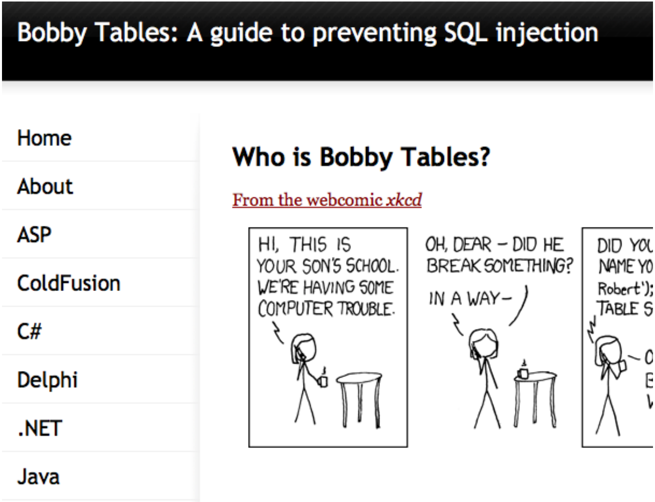
- SQLi attack types and mechanisms
- detecting SQLi
- preventing SQLi

Even if you believe you are safe from SQLi, it is useful to understand the range of problems and solutions. And a "NoSQL" database doesn't mean no NoSQL injections!

xkcd #327 (a classic)



bobby-tables.com: great idea, but incomplete



SQL Queries

SQL: standard language for interacting with databases

- very common with **web applications**
  - authentication: DB of users, passwords
  - main function often data storage
- but also in **desktop and server** apps
  - email clients/servers
  - photo applications, media servers
  - custom database clients
  - application data caches

Question. Why might the second category cause concern for security auditing?

Network versus local injections

Network usually considered the bigger risk

- Access by many, unknown users
- Network is gateway, crossing physical boundaries
- Risk in privileged servers (setguid, etc)

Local inputs: should they be considered too?

- Local users can only deny access to themselves
- desktop apps run as plain user, only risk own data

However, this trust assumption can be wrong:

- *drive-by exploits* attack locally (or use escalation)
- growing concerns over *insider threats*

Outline

How I hacked PacketStorm (1988-2000)

```
-- Advisory RFP2K01 ------------------------------ rfp.labs ----------

                    "How I hacked PacketStorm"

                A look at hacking wwwthreads via SQL

------------------------------- rain forest puppy / rfpwiretrip.net --
```

- One of the first public examples and explanation
- Demonstrated retrieval of 800 passwords
- See Rain Forest Puppy's advisory and his earlier Phrack 54 article

Man steals 130m card records (2009)

US prosecutors have charged a man with stealing data relating to 130 million credit and debit cards.

The card details were allegedly stolen from three firms, including 7-Eleven

Officials say it is the biggest case of identity theft in American history.

They say Albert Gonzalez, 28, and two un-named Russian co-conspirators hacked into the payment systems of retailers, including the 7-Eleven chain.

Prosecutors say they aimed to sell the data on. If convicted, Mr Gonzalez faces up to 20 years in jail for wire fraud and five years for conspiracy.

He would also have to pay a fine of $250,000 (£150,000) for each of the two charges.

'Standard' attack

Mr Gonzalez used a technique known as an "SQL injection attack" to access the databases and steal information, the US Department of Justice (DoJ) said.

The method is believed to involve exploiting errors in programming to access data.

SQL INJECTION ATTACK

- This is a fairly common way that fraudsters try to gain access to consumers' card details.
- They scour the internet for weaknesses in companies' programming which allows them to get behind protection measures.
- Once they find a weakness, they insert a specially designed code into the network

Provocation: Swedish pencil vote (2010)

Did Little Bobby Tables migrate to Sweden?

Posted by Jonas Elfström Thu, 23 Sep 2010 20:36:00 GMT

As you may have heard, we've had a very close election here in Sweden. Today the Swedish Election Authority published the hand written votes. While scanning through them I happened to notice

```
R;13;Hallands län;80;Halmstad;01;Halmstads västra
valkrets;0904;Söndrum 4;pwn DROP TABLE VALJ;1
```

The second to last field[1] is the actual text on the ballot[2]. Could it be that Little Bobby Tables is all grown up and has migrated to Sweden? Well, it's probably just a joke but even so it brings questions since an SQL-injection on election data would be very serious.

Someone even tried to get some JavaScript in there:

```
R;14;Västra Götalands län;80;Göteborg;03;Göteborg,
Centrum;0722;Centrum, Övre Johanneberg;(Script
src=http://hittepa.webs.com/x.txt);1
```

I'm pleased to see that they published the list as text and not HTML. This

Should know better (2011)

FULL DISCLOSURE Full Disclosure mailing list archives

By Date By Thread Search

MySQL.com Vulnerable To Blind SQL Injection Vulnerability

From: Jack haxor <jackh4xor () h4cky0u org>
Date: Sun, 27 Mar 2011 05:46:30 +0000

```
---------------------------------------------------------------------------
[+] MySQL.com Vulnerable To Blind SQL Injection vulnerability
[+] Author: Jackh4xor @ w4ck1ng
[+] Site: http://www.jackh4xor.com
---------------------------------------------------------------------------

About MySQL.com :
----------------------------------------------------------------------------------------------------

The Mysql website offers database software, services and support for your business, including the Enterprise server,
the Network monitoring and advisory services and the production support. The wide range of products include: Mysql
clusters, embedded database, drivers for JDBC, ODBC and Net, visual database tools (query browser, migration toolkit)
and last but not least the MaxDB- the open source database certified for SAP/R3. The Mysql services are also made
available for you. Choose among the Mysql training for database solutions, Mysql certification for the Developers and
DBAs, Mysql consulting and support. It makes no difference if you are new in the database technology or a skilled
developer of DBA, Mysql proposes services of all sorts for their customers.
----------------------------------------------------------------------------------------------------


Vulnerable Target  :   http://mysql.com/customers/view/index.html?id=1170
Host IP                :   213.136.52.29
Web Server           :   Apache/2.2.15 (Fedora)
Powered-by           :   PHP/5.2.13
Injection Type        :   MySQL Blind
Current DB             :   web

Data Bases:

information_schema
bk
certification
```

Should know better (2013)

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SECURITY

Under the microscope: The bug that caught PayPal with its pants down

Payment giant suffers textbook SQL injection flaw

By John Leyden, 15th April 2013

42

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Verizon, Experian and pals bag £25m to inspect Brits' identities for UK gov

The threat landscape

Security researchers have published a more complete rundown of a recently patched SQL injection flaw on PayPal's website.

The Vulnerability Laboratory research team received a $3,000 reward after discovering a remote SQL injection web vulnerability in the official PayPal GP+ Web Application Service. The critical flaw, which could have been remotely exploitable, allowed hackers to inject commands through the vulnerable web app into the backend databases, potentially tricking them into coughing up sensitive data in the process.

Should know better (2015)

TalkTalk hack: MPs to hold inquiry into cyber-attack

26 October 2015 | Business

Analysis: Rory Cellan-Jones, BBC technology editor

The company first indicated that the "sustained" attack was a DDoS, a distributed denial of service attack where a website is bombarded with waves of traffic.

That did not seem to explain the loss of data, and later TalkTalk indicated that there had also been what is known as an SQL injection.

This is a technique where hackers gain access to a database by entering instructions in a web form. It is a well known type of attack and there are relatively simple ways of defending against it.

Many security analysts were stunned by the idea that any major company could still be vulnerable to SQL injection.

Provocation: British company name (2016)

; DROP TABLE "COMPANIES";-- LTD

File for this company

Company number **10542519**

Overview | Filing history | People

Registered office address
1 Moyes Cottages Bentley Hall Road, Capel St. Mary, Ipswich, Suffolk, United Kingdom, IP9 2JL

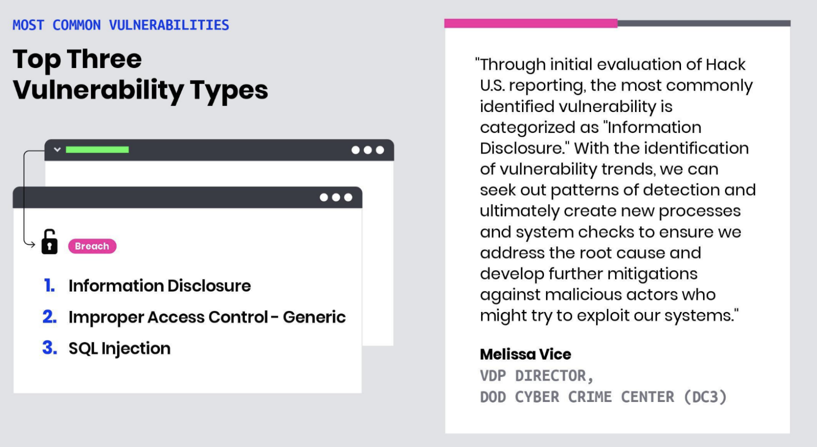
Company status
Active

Company type
Private limited Company

Incorporated on
29 December 2016

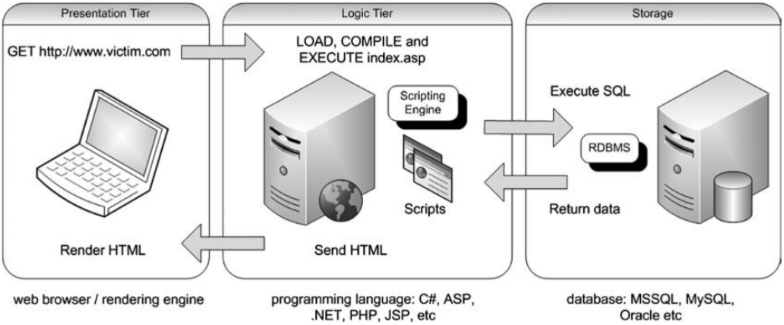
See the reddit thread

Bug bounties in Hack U.S. (4-11 July 2022)



Outline

Typical setting for attacks



Picture from SQL Injection Attacks and Defense, J. Clarke, Syngress, 2012

Typical vulnerability in PHP code

```
$username = $HTTP_POST_VARS['username'];
$password = $HTTP_POST_VARS['passwd'];

$query = "SELECT * FROM logintable WHERE user = '"
   . $username . "' AND pass = '" . $password . "'";
...
$result = mysql_query($query);

if (!$results)
    die_bad_login();
```

Guaranteed login! Try with:

user name: `bob' OR user<>'bob`
password: `foo OR pass<>'foo`

which gives

```
    SELECT * FROM logintable WHERE user=
    'bob' or user<>'bob' AND pass='foo' OR pass<>'foo'
```

Fixes: in-band versus out-of-band

An “in-band” solution is to use *filtering* to escape black-listed characters.

- PHP and MySQL provide functions to help do this, guaranteeing meta-characters are quoted.

An “out-of-band” fix is to use a *prepared query* with parameters carved out for the substituted positions.

- Prepared query has placeholders for parameters which will be safely substituted.

A more general “out-of-band” solution is to use *embedded programming language support*.

- *Object-Relational Mapping* to allow database to be interrogated via objects directly or
- *LINQ*, Language-Integrated Query in .NET.

Question. Why might out-of-band fixes be preferred?

An example in Java servlet code

```java
public class Show extends HttpServlet {
  public ResultSet getuserInfo(String login, String pin) {
    Connection conn = DriverManager.getConnection("MyDB"};
    Statement stmt = conn.createStatement();
    String queryString = "";

    queryString = "SELECT accounts FROM users WHERE ";
    if ((! login.equals("")) && (! pin.equals(""))) {
        queryString += "login='" + login +
        "' AND pin=" + pin;
    } else {
        queryString+="login='guest'";
    }

    ResultSet tempSet = stmt.execute(queryString);
    return tempSet;
    }
}
```

Normal usage

```
    queryString = "SELECT accounts FROM users WHERE ";
    if ((! login.equals("")) && (! pin.equals(""))) {
        queryString += "login='" + login +
        "' AND pin=" + pin;
    } else {
        queryString+="login='guest'";
    }
```

User submits `login="john"` and `pin="1234"`

SQL issued:

```
    SELECT accounts FROM users WHERE login='john' AND pin=1234
```

Malicious usage

```
    queryString = "SELECT info FROM users WHERE ";
    if ((! login.equals("")) && (! pin.equals(""))) {
        queryString += "login='" + login +
        "' AND pin=" + pin;
    } else {
        queryString+="login='guest' ";
    }
```

User submits `login="admin' --"` and `pin="0"`

SQL issued:

```
    SELECT accounts FROM users WHERE login='admin' --' AND pin=0
```

Quotation and meta-characters

Warnings about meta-characters also apply to SQL. They can vary by DB engine, even by configuration.

MySQL 8.0 Reference Manual / ... / String Literals

version 8.0

9.1.1 String Literals

A string is a sequence of bytes or characters, enclosed within either single quote (`'`) or double quote (`"`) characters. Examples:

```
'a string'
"another string"
```

Quoted strings placed next to each other are concatenated to a single string. The following lines are equivalent:

```
'a string'
'a' ' ' 'string'
```

If the `ANSI_QUOTES` SQL mode is enabled, string literals can be quoted only within single quotation marks because a string quoted within double quotation marks is interpreted as an identifier.

Outline

Classifying SQL injections

There are a wide variety of SQL injection techniques. Sometimes several are used to mount a single attack.

It's useful to examine:

- **route** – where injection happens
- **motive** — what it aims to achieve
- **SQL code** — the form of SQL injected

These slides follow *A Classification of SQL Injection Attacks and Countermeasures* by Halfond, Viegas and Orso. ISSE 2006.

Outline

Injection routes

- **User input** e.g., web forms via HTTP GET or POST
- **Cookies** used by web apps to build queries
- **Server variables** logged by web apps (e.g., http headers)
- In so-called **second-order injections** the injection is separated from attack

Primary and auxiliary motives

Primary motives may be:

- Extracting data
- Adding or modifying data
- Mounting a denial of service attack
- Bypassing authentication
- Executing arbitrary commands

Auxiliary motives may be

- Finding injectable parameters
- Database server finger-printing
- Finding database schema
- Escalating privilege at the database level

Outline

Forms of SQL code injected

1. Tautologies
2. Illegal/incorrect queries
3. Union query
4. Piggy-backed queries
5. Inference pairs
6. Stored procedures and other DB engine features

Additionally, the injection may use *alternate encodings* to try to defeat sanitization routines that don't interpret them (e.g., `char(120)` instead of x).

Exercise. For each of these types (described next), consider which primary/secondary motive(s) might apply.

Tautologies

Inject code into condition statement(s) so they always evaluate to `true`.

```
SELECT accounts FROM users WHERE
login='' or 1=1 -- AND pin=
```

Blacklisting tautologies is difficult

- Many ways of writing them: `1>0`, `'x' LIKE 'x'`, `...`
- Quasi tautologies: very often true `RAND()>0.01`, `...`

Question. Instead of a tautology, can you think of how an attacker might use an always-false condition?

Illegal/incorrect

Cause a run-time error, hoping to learn information from error responses.

```
SELECT accounts FROM users WHERE
login='' AND pin=convert(int,(select top 1 name from
                              sysobjects where xtype='u'))
```

- Supposes MS SQL server
  - `sysobjects` is server table of metadata
- Tries to find first user table
- Converts name into integer: runtime error

Example response

```
Microsoft OLE DB Provider for SQL Server (0x80040E07)
Error converting nvarchar value 'CreditCards'
to a column of data type int
```

Tells the attacker:

- MS SQL Server is running
- The first user-defined table is called `CreditCards`

Union query

Inject a second query using UNION:

```
SELECT accounts FROM users WHERE
    login='' UNION SELECT cardNo from CreditCards where
    acctNo=10032 -- AND pin=
```

- Suppose there are no tuples with `login=''`
- Result: may reveal `cardNo` for account 10032

Piggy-backed (sequenced) queries

The Bobby Tables attack is an example of a piggy-backed query.

The attcker injects a second, distinct query:

```
SELECT accounts FROM users WHERE
  login='doe'; drop table users -- ' AND pin=
```

- Database parses second command after ';'
- Executes second query, deleting `users` table
- NB: some servers don't need `;` character

Inference pairs

Suppose error responses are correctly captured and *not* seen by the client.

It might still be possible to extract information from the database, by finding some difference between outputs from pairs of queries.

- A **Blind Injection** tries to reveal information by exploiting some visible difference in outputs.
- A **Timing Attack** tries to reveal information by making a difference in response time dependent on a boolean (e.g., via `WAITFOR`)

If the attacker has unlimited access, these can be used in repeated, automated, differential analysis.

Blind injection example

Idea: discover whether login parameter is vulnerable with two tests.

Step 1. Always true:

```
login='legalUser' and 1=1 -- '
```

Step 2. Always false:

```
login='legalUser' and 1=0 -- '
```

Blind injection example

Step 1

```
SELECT accounts FROM users WHERE login='legalUser' and 1=1 -- '
```

RESPONSE: INVALID PASSWORD

The attacker thinks:

> *Perhaps my invalid input was detected and rejected, or perhaps the username query was executed separately from the password check.*

Blind injection example

Step 2

```
SELECT accounts FROM users WHERE login='legalUser' and 1=0 -- '
```

RESPONSE: INVALID USERNAME AND PASSWORD

The attacker thinks:

> *Aha, the response is different! Now I can infer that the* `login` *parameter is injectable.*

Stored procedures

Stored procedures are custom sub-routines which provide support for additional operations.

- May be written in scripting languages.
- Can open up additional vulnerabilities.

```
CREATE PROCEDURE DBO.isAuthenticated
userName varchar2, pin int
AS
EXEC("SELECT accounts FROM users
WHERE login=’" +userName+ "’ and pass=’" +pass+
    "’ and pin=" +pin);
GO
```

varchar2 is an Oracle datatype for variable length strings

Stored procedures

This is invoked with something like:

```
EXEC DBO.isAuthenticated 'david' 'bananas' 1234
```

Stored procedures

Or something like:

```
EXEC DBO.isAuthenticated ’ ; SHUTDOWN; --' '' ''
```

which results in:

```
SELECT accounts FROM users WHERE
login=’doe’  pass=’ ’; SHUTDOWN; -- AND pin=
```

An especially dangerous stored procedure

Microsoft SQL Server offers: **xp_cmdshell**, which allows operating system commands to be executed!

```
EXEC master..xp_cmdshell 'format c:'
```

- Since SQL Server 2005, this is disabled by default
- ... but might be switched back on by DB admins
- ... maybe from inside the db?!

Lesson: **access control and passwords** may be critical inside the DB, even for restricting attacks outside.

Other database server features

There are other features offered variously depending on the DB engine.

For example, queries in MySQL can write files with the idiom:

```sql
SELECT INTO outfile.txt ...
```

Question. Why might writing files be of use to an attacker?

Outline

How do I repair an SQLi vulnerability?

Mentioned earlier:

- *filtering* to sanitize inputs
- *prepared* (aka *parameterized*) queries

Both methods are server side, so it is better to use database driver gitlibraries to abstract away from the underlying DB engine.

In Java, JDBC provides the `PreparedStatement` class.

We'll look at further relevant secure coding issues later lectures; in particular, ways of managing input and also *output* filtering.

Question. What type of SQL attacks might PreparedStatements not prevent against?

How do I prevent SQLi vulnerabilities?

Choice of stages (as usual):

1. eliminate before deployment:
   - use programming language support; object-relational mapping
   - manual code review or automatic static analysis
2. in testing or deployment:
   - pen testing tools
   - instrumented code
3. after deployment:
   - wait until attacked, manually investigate
   - use dynamic remediation plus alarms (app firewall or specialised technique)

Some examples follow.

Detection externally: pen testing tools

sqlmap®

Automatic SQL injection and database takeover tool

SQLNINJA

...a SQL Server injection & takeover tool

These incorporate the injection methods shown before, to explore a server for known vulnerabilities.

Static prevention: automated analysis

Idea: static code analysis used to warn programmer or prohibit/fix vulnerable code.

Techniques:

- Detect suspicious code patterns, e.g., dynamic query construction
- Use static taint analysis to detect data-flows from input parameters to queries

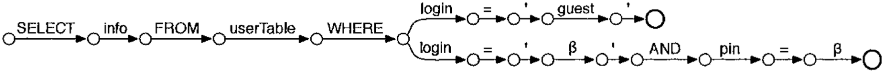
We'll look at static analysis in more detail in later lectures

Dynamic detection tool: AMNESIA

Idea: use static analysis pre-processing to generate a *dynamic* detection tool:

1. Find SQL query-generation points in code
2. Build *SQL-query model* as NDFA which models SQL grammar, transition labels are tokens
3. Instrument application to call runtime monitor
4. If monitor detects violation of state machine, triggers error, preventing SQL query

State machine for SQL production

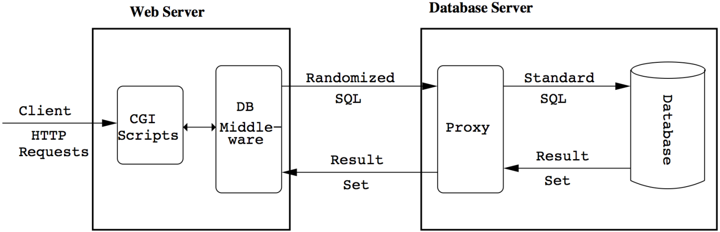


- Variable β: matches any string *in SQL grammar*
- Spots violation in injectable parameters
  - abort query if model not in accepting state

See Halfond and Orso, *AMNESIA: Analysis and Monitoring for NEutralizing SQL-injection Attacks*, Automated Software Engineering, 2005

Dynamic prevention: SQLrand

Idea: use *instruction set randomization* to change language dynamically to use opcodes/keywords that attacker can't easily guess.



See Boyd and Keromytis, *SQLrand: Preventing SQL Injection Attacks*, Applied Cryptography and Network Security, 2004

Outline

Review questions

SQLi classification

- Describe three routes for SQL injection.
- Describe three auxiliary motives that an attacker may have when using SQL injection techniques to learn about a target.

SQLi prevention and detection

- How would you repair the prototypical example SQLi vulnerability?
- Describe automatic ways to *prevent* and *detect* SQLi vulnerabilities.

References and credits

This lecture includes content adapted from:

- *A Classification of SQL Injection Attacks and Countermeasures* by Halfond, Viegas and Orso. ISSE 2006
- *SQL Injection Attacks and Defense*, Edited by Justin Clarke, Syngress. 2nd Edition 2012.