Fun with Information Engineering and Security Summer 2024

Day 3 (Aug-02, Fri)







Why does input validation matter?

- Well, there's only so much cryptography can do
- In fact, even cryptographic guarantees often depend upon the correctness of software **implementations**
 - Likewise for network (security) protocols
- Vulnerable software not only breaks the desired security control policies; sometimes allow attackers to completely take over a device
 - This is often how **botnets** are being built

How does software get exploited?

- A lot of the times, a process (a running software) gets a purposely crafted <u>malicious input</u> from an attacker
- And because of an insufficiently thorough (or a complete lack of) input validation, such inputs get through
 - Some can then crash the process (breaks availability)
 - Some can then extract sensitive information (breaks confidentiality)
 - Some can then execute arbitrary code (attackers can do whatever the want)

How does software get exploited?

- Inputs can come in many different forms, e.g.,
 - Inputs from Web forms
 - Inputs from command line
 - Email attachments
 - Configuration files
 - Environment variables
 - Parameters from Inter-Process
 Communication (IPC) communication
 - PDUs (frames/packets/segments) from network

Name			
Mr./Mrs./Ms.	First Name	Last Name	
E-mail			
Phone			
(000) 000-0000			
Address			

□.

Another example

- Web contents can be dynamically generated by server-side scripts (e.g., PHP)
 - "PHP: Hypertext Preprocessor" is a recursive acronym
- In PHP, passthru(string) executes string as command

passthru

(PHP 4, PHP 5, PHP 7, PHP 8) passthru — Execute an external program and display raw output

Description

passthru(string \$command, int &\$result_code = null): ?false

The **passthru()** function is similar to the <u>exec()</u> function in that it executes a **command**. This function should be used in place of <u>exec()</u> or <u>system()</u> when the output from the Unix command is binary data which needs to be passed directly back to the browser. A common use for this is to execute something like the pbmplus utilities that can output an image stream directly. By setting the Content-type to <u>image/gif</u> and then calling a pbmplus program to output a gif, you can create PHP scripts that output images directly.

Another example

 Imagine a simple PHP-based Web page that displays a user's usage log (e.g., a Web portal for checking printing quota)

> echo 'Your usage log:
'; \$username = \$_GET['username']; passthru("cat /logs/usage/\$username");

 Since attacker can choose the username on the Web page, it can put ";" in the input to run additional command with the PHP daemon's user privilege (depending on the system config, can be root), e.g.,

```
username = john; rm -rf /home
```

This type of threat is not hypothetical

• A very common threat to Websites, especially those that uses a relational database



Cross Site Scripting (XSS)

- A common security threat to Web due to problems in input validation
- It is a bit different from SQL injection, in the sense that XSS is more about attacking users of a Website
 - SQL injection, on the other hand, tends to be more about attacking the Website itself

A historic example of Stored XSS

- Back in the days, myspace.com was a popular social network site, and users can post custom HTML code on their personal pages
- To prevent abuse, myspace blocks many things, e.g.
 - Tags: <scripts>, <body>,
 - As well as the onclick event
- However, a clever guy figured out how to workaround these blocks

A historic example of Stored XSS

- Result = the "Samy worm" aka "JS.Spacehero worm"
 - Infects anyone who visits an infected myspace page, and adds Samy as a friend on myspace
 - Samy got millions of friends within 24 hours

 This kind of problem still occasionally haunts online forums/message boards, where users are free to type in long inputs, which will then be stored on the server and served to other users at a later time

- Need to properly encode + validate user inputs
 - Sometimes this is easier said than done; creative attackers (see the myspace example)

 Learn and use features from the underlying programming language to help you



Preventing Cross-Site Scripting

Prevention?

- Never trust user input

• Encoding: "escapes" (preprocess) the user input so that it will be interpreted as data, not code

- Validation: checks that the user input is expected w.r.t your assumptions
 - E.g., not longer than a certain length, not containing malicious commands

- Examples of encoding functions
 - In PHP: htmlspecialchars(string, flags)

Performed translations				
Character	Replacement			
& (ampersand)	Samp;			
" (double quote)	", unless ENT_NOQUOTES is set			
' (single quote)	' (for ENT_HTML401) or ' (for ENT_XML1, ENT_XHTML or ENT_HTML5), but only when ENT_QUOTES is set			
< (less than)	Slt;			
> (greater than)	θgt;			

- htmlspecialchars("Test")
 - Test
- In ASP.NET: Server.HtmlEncode(string)
 - Similar to PHP's htmlspecialchars()

- In some programming languages, for specific scenarios (e.g., Web request), some built-in validation features exist, e.g.,
 - In ASP.NET: validateRequest
 - Looks for a hardcoded list of patterns (blacklist)
 - Crashes the page if it finds un-encoded HTML code (such as the <script> tag) in the request content

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SQL Injection

- Many Websites **assemble user inputs** as part of the SQL query, without thorough input validation
 - SQL = structured query language, is a domain-specific language commonly used to manage data in relational database systems



SELECT * FROM phonebook WHERE username = 'John' AND password = 'open_sesame'

> John's phonebook entries are displayed

SQL Injection

- An attacker can then inject additional logic/command to bypass checks and/or cause harm
- Use "--" to render rest of the original query ineffective (turn it into comment)



SELECT * FROM phonebook WHERE username = 'John' OR 1=1 --' AND password = 'not needed'

All phonebook entries are displayed

SQL Injection

- An attacker can then inject additional logic/command to bypass checks and/or cause harm
- Use "--" to render rest of the original query ineffective (turn it into comment)
 DO NOT TRY THIS ON REAL WEBSITES (they should have defenses, but what if they don't?)



SELECT * FROM phonebook WHERE username = 'J' ; DROP TABLE phonebook; --' AND password = 'not needed'

All phonebook entries are removed

How to defend?

- Be very careful when you assemble user inputs into SQL commands
 - Sanitize/filter inputs, strip special symbols
 - Instead of allowing free text, if possible, perhaps use elements like radio buttons to limit the input space



What is buffer overflow?

- Can think of it as another input validation problem
- In programming languages (e.g., C/C++) where memory management is done by the programmer, inputs related to memory access are not properly validated
- Because of that, various exploits exist
 - Sometimes the program can be induced into reading from unexpected addresses
 - Sometimes can overwrite existing values stored on the memory

Memory layout of a C program

- To better understand (and exploit) buffer overflow, it's useful to first look at the memory layout
- Text segment: program code
 - Begins at low address
 - Normally read-only
- Data segment: global/static variables + constants
- Heap and stack: dynamically variables



Memory layout of a C program

• Heap: dynamically allocated storage space via the likes of malloc() and new()



- Each function call results in an activation record being added to the stack
- This is also why too many recursions can lead to segmentation fault

Memory layout of a C program

- Heap vs stack
 - They share the same space
 - Grow towards each other

- Note: sometimes the diagram will be drawn in reverse (upside down)
 - pay attention to the positionof high and low addresses



Stack

- Stack is "last in, first out" (LIFO)
- Basic operation: push, pop
 - Both on to/from the top of the stack
- Each function call results in an activation record being pushed to the top of the stack
 - Each function return results in an activation record being popped from the top of the stack

(Lack of) Input Validation strikes again

- Now we can look at buffer overflow (BOF) attacks
- Imagine a function has buffers of limited sizes on its stack
- Due to input validation problems, e.g., no boundary checks, one could read/write beyond the boundary of some buffers

<pre>void foo(int a, int b, int c) {</pre>
<pre>char buffer1[13];</pre>
}
<pre>void main() {</pre>
foo(1,2,3);
}

(Lack of) Input Validation strikes again

- In some languages, programmers are expected to manage memory themselves, and perform their own boundary checks
 - In C, many functions DO NOT have built-in length checks
 - strcpy (char *dest, const char *src)
 - strcat (char *dest, const char *src)
 - gets (char *s)
 - scanf (const char *format, ...)
 - sprintf (conts char *format, ...)

No boundary checks ... who's to blame?



(Lack of) Input Validation strikes again

- Increasingly, many new languages take matter into their own hands, and feature boundary checks without bothering the programmer
 - E.g., Python, Java, Rust, ...
 - Perhaps a better fit for programmer's expectation
- But loads of important software still written in C/C++
 - E.g., OSes, IoT firmware, ...

No boundary checks ... who's to blame?



What's the harm?

- Here are some possibilities
 - Overread can lead to exposure of sensitive info
 - E.g., OpenSSL
 heartbleed bug
 - Server's private key can be stolen

Example: TLS heartbeat + heartbleed

🐑 Heartbeat – Normal usad

💭 Heartbeat – Malicious usage

- The lack of a message length check can be used to induce a buffer over-read
- Attack can obtain chunks of server's memory
 - might contain private keys and other sensitive data (e.g. passwords or previous messages sent by clients)
- Led to all kinds of key revocation and new certificates being issued ...

What's the harm?

- Here are some possibilities
 - Overwrite some critical variable and change the program behaviour
 - We will try this in the challenge

- Overwrite return address with invalid address => can crash the program (DoS; breaks availability)
- Overwrite return address with meaningful address => may lead to arbitrary code execution

How to defend?

- First and foremost, do boundary checks
 - But programmers keep forgetting
- What else can we do?
 - StackGuard
 - NX bit
 - ASLR

How to defend? (StackGuard)

- A runtime checking technique
- Compiler adds code to a function call's prologue and epilogue, to add and check a special "canary" value
 - " "canary in a coal mine"
 - detect the presence of carbon monoxide



 While smashing the stack, if the "canary" value doesn't look right, then the program knows something is wrong



Stack guard in action

#include <stdio.h>
#include <string.h>

```
void echo(char *inp) {
    int a = 10;
    char b1[2];
    strcpy(b1, inp);
    printf("echo:\n");
    printf("%s\n", b1);
```

```
int main() {
    char input[10];
    printf("what is your input?\n");
    scanf("%s", input);
```

```
echo(input);
```

}

}

Copy and paste this code to <u>https://www.onlinegdb.com/online_c_compiler</u>

then click "run"

Now try to give a long input

*** stack smashing detected ***: terminated
Aborted

How to defend? (StackGuard)

- The presence of canary makes it **more difficult** to smash the stack, but **not impossible**
 - There are different ways of choosing the canary value
 - Random? How random?
 - Sometimes if the attacker can guess the canary value, then stack smashing can still work
 - In some cases, can target the error handler (called when the canary is dead)
 - If interested, more technical details can be found at <u>https://www.coresecurity.com/sites/default/files/private-</u> <u>files/publications/2016/05/StackguardPaper.pdf</u>

