Format String Vulnerability

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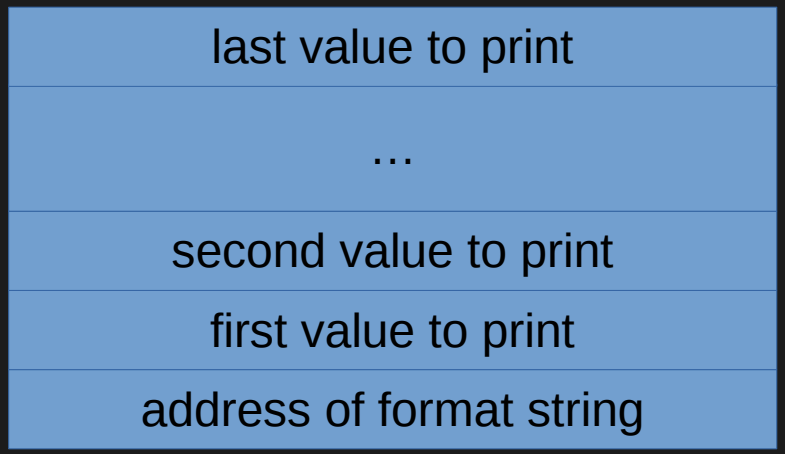
Format String Vulnerability Basics

- The semantic of printf:
  - printf(char *fmt, …)
- The parameters on the stack for printf:



Format String Vulnerability Basics cont'd

- Normally we would do:
  - printf(“%d”, 1234);
  - The number of variables to print should match the number of fields in the format string
- What happens if these two numbers do not match?

Format String Vulnerability Definition

- Consider the following code

```
int main(int argc, char argv[]){
    char buff[256];

    strcpy(buff, argv[1], 200);
    printf(buff);

    return 0;
}
```

- What happens if the argument, argv[1], is just “%d”?
- Format string vulnerability, a.k.a. uncontrolled format string, happens when unchecked user-input is directly used as format string passed to printf, allowing the reading and writing of arbitrary memory

Exploit Format String Vulnerability Case 1: Program Crash

- Format “%s”: prints the string pointed at by an pointer
- The attack:

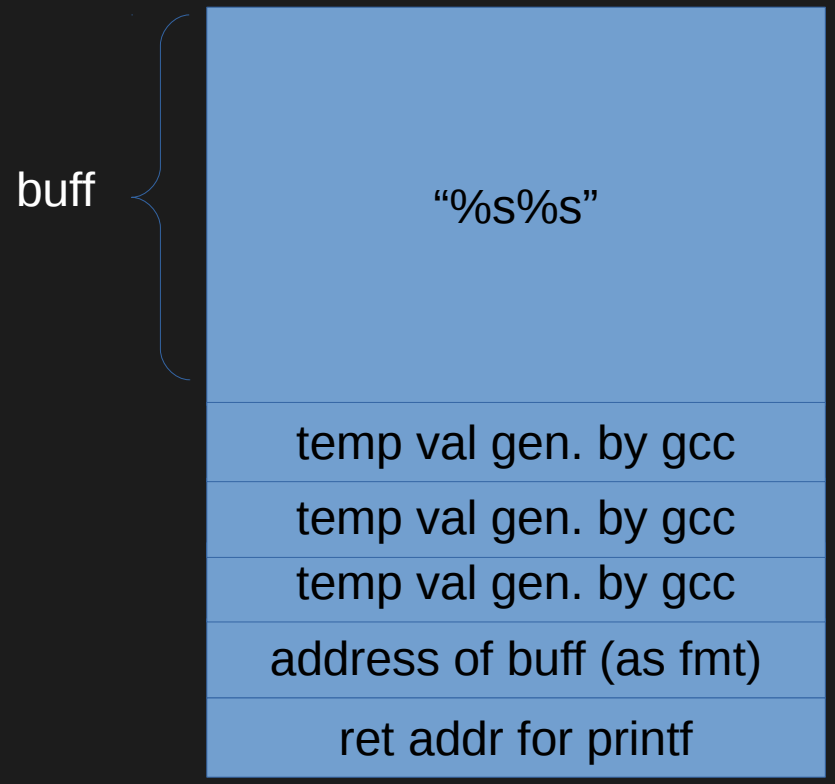
```
buff=“%s%s”;
printf(buff);
```

Exploit Format String Vulnerability Case 1: Program Crash con'td

- The attack:

```
buff="%s%s";
printf(buff);
```

- The stack when printf is called:
- The temporary variables generated by gcc are less likely can be used as valid memory address (string addresses)
- The program will crash if it tries to address some invalid addresses



Exploit Format String Vulnerability Case 2: View Stack

- Format “%x”: prints the hexadecimal values of the memory after format string
- The attack:

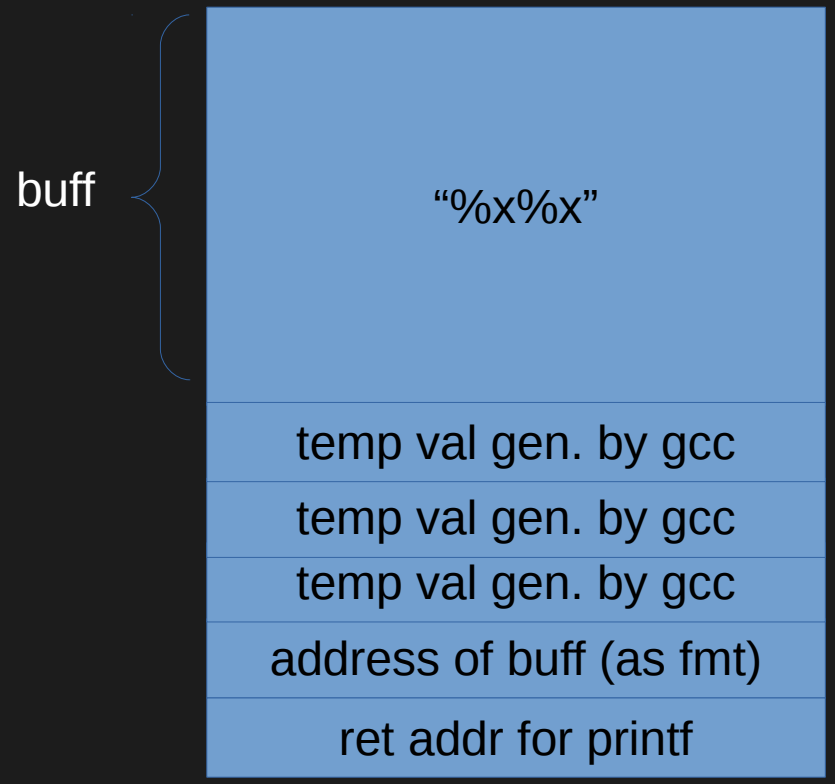
```
buff=“%x%x”;
printf(buff);
```

Exploit Format String Vulnerability Case 2: View Stack con'td

- The attack:

```
buff="%x%x";
printf(buff);
```

- The stack when printf is called:
- Two gcc temporary values will be printed



Exploit Format String Vulnerability Case 2: View Stack cont'd

- If we want to view the 8th element on the stack, we need to use format string
  - “%x%x%x%x%x%x%x%x”
  - It is heavy handed.
  - What happens if we want view the 1024th value?
- We can use the field specifier, e.g.,

```
printf(“%2$x, %1$x”, 1, 2);
```

Exploit Format String Vulnerability Case 2: View Stack cont'd

- We can use the field specifier, e.g.,

```
printf("%2$x, %1$x", 1, 2);
```

  prints 2 first, then 1

- In general "%m$x" tells printf to print the m'th value
  - e.g., for the 1024'th value, we can use "%1024$x"

Exploit Format String Vulnerability Case 2: View Stack cont'd

- This exploit allows the attacker to view the stack.
- This exploit can be used by attacker to determine the important addresses of stack objects, such as return addresses or saved EBP

Exploit Format String Vulnerability Case 3: View Arbitrary Memory

- We will keep using “%s” in this exploit
- The trick is to put an address on to the stack
- For example, if there is a string at address 0x80485e0, the format string can be:

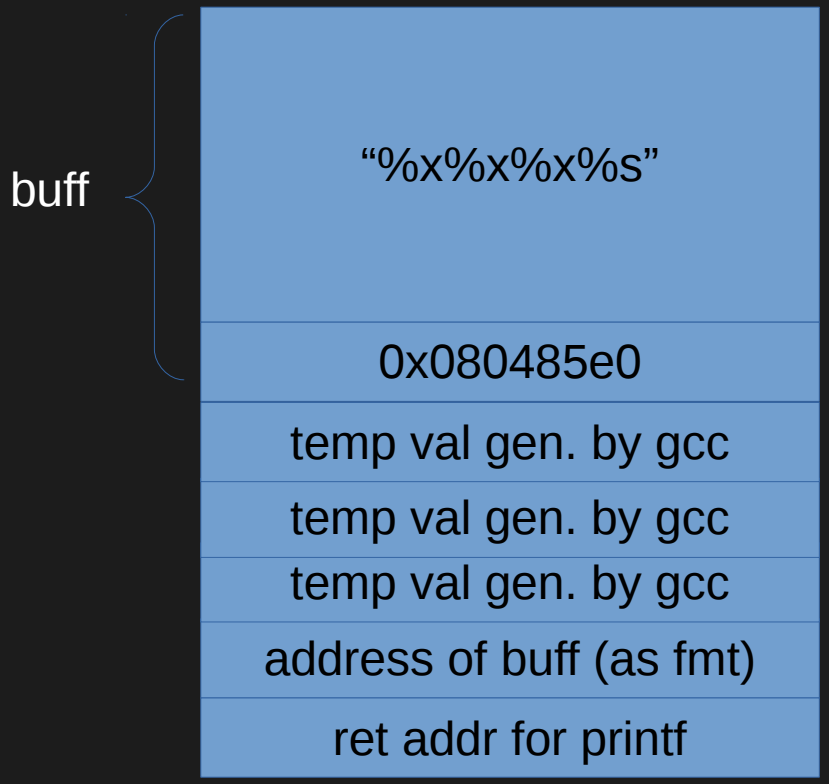
```
buff=“\xe0\x85\x04\x08%x%x%x%s”;
printf(buff);
```

How to Input Non-ASCII Characters?

- How to input a ASCII character “0xe0” ?
- Two methods to generate the attack string
  - Write a C program
    E.g., char a[] = “\xe0\x85”;
  - Use perl
    E.g., perl -e 'print "\xe0\x85";'
- How to pass the attack string to the program?
  - Save the attack string into a file, and use bash stdin redirect (Google bash redirect if you don't know)
  - Command substitution – $(command) or `command` (note it is not single quote)

Exploit Format String Vuln. Case 3: View Arbitrary Memory con'td

- The stack when printf is called:
- Because the format string starts with hex number 0x080485e0, this number is first printed
- Then three %x prints prints the temp vals
- At last %s prints the string at address 0x080485f0



Exploit Format String Vulnerability Case 4: Write Arbitrary Memory

- Format “%n”: writes the number of characters printed to an variable
- E.g., the following code writes 4 to i

```
int i;
printf(“ABCD%n”, &i);
```

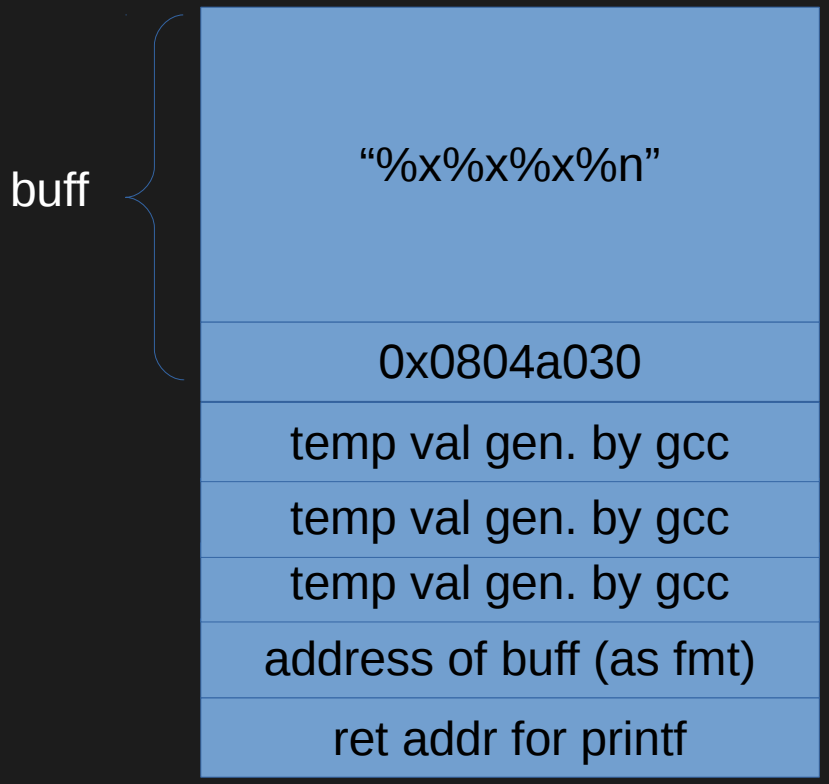
Exploit Format String Vuln. Case 4: Write Arbitrary Memory cont'd

- Similar to the view arbitrary memory exploit, and address has to be push onto stack for writing
- For example, the follow code write to address 0x804a030

```
buff="\x30\xa0\x04\x08%x%x%x%n";
printf(buff);
```

Exploit Format String Vuln. Case 4: Write Arbitrary Memory cont'd

- The stack when printf is called:
- Because the format string starts with hex number 0x0804a030, this number is first printed
- Then three %x prints prints the temp vals
- At last %n prints the string at address 0x0804a028



Exploit Format String Vuln. Case 4: Write Arbitrary Memory cont'd

- Because the value written is the number of characters printed, it is slightly difficult to give a specific value
- Attackers can control the number of characters printed with precision specifier or field with specifier

Summary and Defense

- Format String Vulnerability is a bug that allows user to control the format string passed into printf() family functions

```
printf(user_input);
```

- The correct way to write is (essentially do not let user input be your format string)

```
printf("%s", user_input);
```

- Compiler (e.g., gcc) provides check for unsafe use of format strings

Summary of Format String Vulnerability

- Attackers can exploit this vulnerability to crash a program, view its stack, or view/write arbitrary memory locations
- Format string vulnerability allows attackers to determine the values of important stack objects, which can be used for buffer overflow attacks
- Format string vulnerability sometimes is more dangerous then stack buffer overflow because it allows attackers to write to arbitrary memory location