Software Security: Buffer Overflow Attacks (continued)

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Announcements

• Participation and Breakout Groups
  – We’ll be using in-class activities for participation (see email)
  – Sign up via Canvas if you’d like a specific breakout group
  – Also using Canvas groups for assignment groups (new group set per assignment, to support changing groups)

• TA Office Hours
  – See course website; Zoom links on Canvas

• Lab 1
  – Group signup instructions will be released today (SSH)
  – Lab access granted starting mid-week
  – Checkpoint (4/17) and Final (4/29) deadlines

• Feedback re: online course logistics? Survey sent Friday
Last Time: Basic Buffer Overflows

• Memory pointed to by str is copied onto stack...

```c
void func(char *str) {
    char buf[126];
    strcpy(buf,str);
}
```

• If a string longer than 126 bytes is copied into buffer, it will overwrite adjacent stack locations.

This will be interpreted as return address!
What About This?

- Home-brewed range-checking string copy

```c
void mycopy(char *input) {
    char buffer[512]; int i;
    for (i=0; i<=512; i++)
        buffer[i] = input[i];
}
void main(int argc, char *argv[]) {
    if (argc==2)
        mycopy(argv[1]);
}
```

- 1-byte overflow: can’t change RET, but can change pointer to previous stack frame...

This will copy 513 characters into buffer. Oops!
Frame Pointer Overflow

Memory that you control:

Fake FP → Fake RET

buf → saved FP → sp → str

Local variables

Args

Caller’s frame

Addrs 0xFF...F

ATTACK CODE

4/6/20

CSE 484 / CSE M 584 - Spring 2020
Another Variant: Function Pointer Overflow

C uses function pointers for callbacks: if pointer to F is stored in memory location P, then one can call F as (*P)(...)

Buffer with attacker-supplied input string

Callback pointer

attack code

Overflow

Legitimate function F (elsewhere in memory)

1. Overwrite metadata (address)
2. Jump to attack code
Other Overflow Targets

• Format strings in C
  – More details today

• Heap management structures used by malloc()
  – More details in section

• These are all attacks you can look forward to in Lab #1 😊
Variable Arguments in C

• In C, can define a function with a variable number of arguments
  – Example: `void printf(const char* format, ...)`
• Examples of usage:

```c
printf(“hello, world”);
printf(“length of %s = %d\n”, str, str.length());
printf(“unable to open file descriptor %d\n”, fd);
```

Format specification encoded by special % characters

%0,%i,%o,%u %x,%X – integer argument
%s – string argument
%p – pointer argument (void *)
Several others
Format Strings in C

- Proper use of printf format string:
  ```c
  int foo = 1234;
  printf("foo = %d in decimal, %X in hex",foo,foo);
  ```
  This will print:
  ```
  foo = 1234 in decimal, 4D2 in hex
  ```

- Sloppy use of printf format string:
  ```c
  char buf[14] = "Hello, world!";
  printf(buf);
  // should've used printf("%s", buf);
  ```
  What happens if buffer contains format symbols starting with % ????
Implementation of Variable Args

- Special functions `va_start`, `va_arg`, `va_end` compute arguments at run-time

```c
void printf(const char* format, ...) {
    int i; char c; char* s; double d;
    va_list ap; /* declare an "argument pointer" to a variable arg list */
    va_start(ap, format); /* initialize arg pointer using last known arg */

    for (char* p = format; *p != '\0'; p++) {
        if (*p == '%') {
            switch (*++p) {
                case 'd':
                    i = va_arg(ap, int); break;
                case 's':
                    s = va_arg(ap, char*); break;
                case 'c':
                    c = va_arg(ap, char); break;
            }
        }
    /* etc. for each % specification */
    }
    ...
}
va_end(ap); /* restore any special stack manipulations */
```
Closer Look at the Stack

```c
printf("Numbers: %d, %d\n", 5, 6);
printf("Numbers: %d, %d\n");
```

![Diagram of stack frame with annotations]

- Local variables
- Args
- Saved FP
- Caller's frame
- Internal stack pointer starts here
- Addr 0xFF...F

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... Saved FP ret/IP &str [5 6] Caller's frame
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**Format Strings in C**

- Proper use of `printf` format string:
  ```c
  int foo=1234;
  printf("foo = %d in decimal, %X in hex", foo, foo);
  ```
  This will print:
  
  `foo = 1234 in decimal, 4D2 in hex`

- Sloppy use of `printf` format string:
  ```c
  char buf[14] = "Hello, world!";
  printf(buf);
  // should've used printf("%s", buf);
  ```

  What happens if buffer contains format symbols starting with `%`???

If the buffer contains format symbols starting with `%`, the location pointed to by `printf`’s internal stack pointer will be interpreted as an argument of `printf`.

This can be exploited to move `printf`’s internal stack pointer!
Viewing Memory

• %x format symbol tells printf to output data on stack

\[
\text{printf(“Here is an int: %x”, i);}
\]

• What if printf does not have an argument?

\[
\text{char buf[16]=“Here is an int: %x”;}
\text{printf(buf);} \\
\]

• Or what about:

\[
\text{char buf[16]=“Here is a string: %s”;}
\text{printf(buf);} \\
\]
Viewing Memory

• %x format symbol tells printf to output data on stack

```c
printf("Here is an int: %x", i);
```

• What if printf does **not** have an argument?

```c
char buf[16]="Here is an int: %x";
printf(buf);
```

  – Stack location pointed to by printf’s internal stack pointer will be interpreted as an int. *(What if crypto key, password, ...?)*

• Or what about:

```c
char buf[16]="Here is a string: %s";
printf(buf);
```

  – Stack location pointed to by printf’s internal stack pointer will be interpreted as a pointer to a string
Writing Stack with Format Strings

• `%n` format symbol tells `printf` to write the number of characters that have been printed

```c
printf(“Overflow this %n”, &myVar);
```
– Argument of `printf` is interpreted as destination address
– This writes 14 into `myVar` (“Overflow this!” has 14 characters)

• What if `printf` does not have an argument?

```c
char buf[16]=“Overflow this! %n”;
printf(buf);
```
– Stack location pointed to by `printf`’s internal stack pointer will be **interpreted as address** into which the number of characters will be written.
Summary of Printf Risks

• Printf takes a variable number of arguments
  – E.g., printf(“Here’s an int: %d”, 10);

• Assumptions about input can lead to trouble
  – E.g., printf(buf) when buf=“Hello world” versus when buf=“Hello world %d”
  – Can be used to advance printf’s internal stack pointer
  – Can read memory
    • E.g., printf(“%x”) will print in hex format whatever printf’s internal stack pointer is pointing to at the time
  – Can write memory
    • E.g., printf(“Hello%n”); will write “5” to the memory location specified by whatever printf’s internal SP is pointing to at the time
How Can We Attack This?

```c
foo() {
    char buf[...];
    char const* untrusted_input = readUntrustedInput();
    printf(buf, untrusted_input, sizeof(buf));
}
```

What should the string returned by `readUntrustedInput()` contain?

Go to Canvas Quiz for April 6!
Using %n to Overwrite Return Address

In foo()'s stack frame:

Buffer with attacker-supplied input “string”

“... attackString%n”, attack code

&RET

SFP

RET

When %n happens, make sure the location under printf’s stack pointer contains address of RET; %n will write the number of characters in attackString into RET

Return execution to this address

This portion contains enough % symbols to advance printf's internal stack pointer

Number of characters in attackString must be equal to ... what?

C allows you to concisely specify the “width” to print, causing printf to pad by printing additional blank characters without reading anything else off the stack.

Example: printf(“%5d”, 10) will print three spaces followed by the integer: “   10”

That is, %n will print 5, not 2.

Key idea: do this 4 times with the right numbers to overwrite the return address byte-by-byte.

(4x %n to write into &RET, &RET+1, &RET+2, &RET+3)

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Recommended Reading

• It will be hard to do Lab 1 without:
  – Reading (see course schedule):
    • Smashing the Stack for Fun and Profit
    • Exploiting Format String Vulnerabilities
  – Attending section this week