Announcements

• Homework #1 due Friday

• Clarifying Homework 1:
  • Option 1: Part 1 and Part 2 use the same technology. In this case, the technology can be any technology.
  • Option 2: Part 1 and Part 2 use different technologies. In this case, Part 1 must consider a security-related technology. Part 2 can still be any technology.
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.

strcpy does NOT check whether the string at *str contains fewer than 126 characters

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...
Frame Pointer Overflow

```
foo()  \n\nbar()  \n```

Little Endian architecture: overwritten byte is least significant byte
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)(...)

[Diagram showing buffer with attacker-supplied input string, callback pointer, attack code with overflow, and legitimate function F elsewhere in memory.]
Other Overflow Targets

• Format strings in C
  • We’ll walk through this one today

• Heap management structures used by malloc()
  • More details in section
  • Techniques have changed wildly over time

• 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

  `%d,%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", 5, 6);
```

```c
printf("Numbers: %d,%d");
```

Image of stack diagram showing the internal stack pointer and the caller's frame with local variables and arguments.
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);
```
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);
```

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!

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

• Or what about:

```c
char buf[16]="Here is a string: \%s";
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
“Weird Machines”

• Way of thinking about exploits (the best way 😊)

• Treat each discrete side-effect as an ‘instruction’

• Synthesize a ‘program’ from these instructions

• This is now your exploit!
How Can We Attack This?

```c
foo() {
    char buf[...];
    strncpy(buf, readUntrustedInput(), sizeof(buf));
    printf(buf); //vulnerable
}
```

If format string contains % then printf will expect to find arguments here...

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

Go to Canvas Quiz for today!

Different compilers / compiler options / architectures might vary
Using %n to Overwrite Return Address

In foo()'s stack frame:

Buffer with attacker-supplied input “string”

“... attackString%n”, attack code

&RET

SFP

RET

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

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

Why is “in” in quotes? 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%n”, 10) will print three spaces followed by the integer: “ 10”
That is, the %n will write 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)
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 and next