Software Security: Buffer Overflow Attacks (continued)

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Announcements

• Ethics form due today (11:59pm)!
• First research reading (584M) due tomorrow (Thursday)!
• Lab 1 sign-up is now live!
  – See email to course mailing list
  – See Ed discussion board for groups w/ access
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!

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

- Fake FP
- Fake RET
- ATTACK CODE

- buf
- Saved FP
- ret/IP
- str
- Caller’s frame

Local variables

Args

Addr 0xFF...F
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)
Other Overflow Targets

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

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

• 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 \texttt{va\_start}, \texttt{va\_arg}, \texttt{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”);
```

Internal stack pointer starts here

Local variables

Saved FP

ret/IP

&str

5

6

Caller’s frame

Addr 0xFF...F

Internal stack pointer starts here

Local variables

Saved FP

ret/IP

&str

Caller’s frame

Addr 0xFF...F
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

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

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

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

• Or what about:

```
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
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 Oct 7!
```
Saved FP  ret/IP  &buf  buf  Saved FP  ret/IP  Caller's frame
```

- **Printf's frame**
- **Foo's frame**
Using %n to Overwrite Return Address

In foo()’s stack frame:

Buffer with attacker-supplied input “string”

“... attackString%n”, attack code

&RET

SFP

RET

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

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 attackString into RET

Return execution to this address

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)
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