CSE 484 / CSE M 584: Computer Security and Privacy

Software Security: Buffer Overflow Attacks

(continued)

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Admin

- Lab 1 out, discussed in quiz section
- Thanksgiving: no class Wednesday
  - Alternate video assignment

- Looking forward
  - Today + Next week: More buffer overflows + defenses
  - Next week: Transition to crypto

Wednesday: Peter Ney

- Glimpse at some aspects of computer security research
  - Measurement
  - Analysis / attack exploration
- Other types of research
  - Building secure systems
- Also connected to threat modeling, and to buffer overflows

Last Time: Basic Buffer Overflows

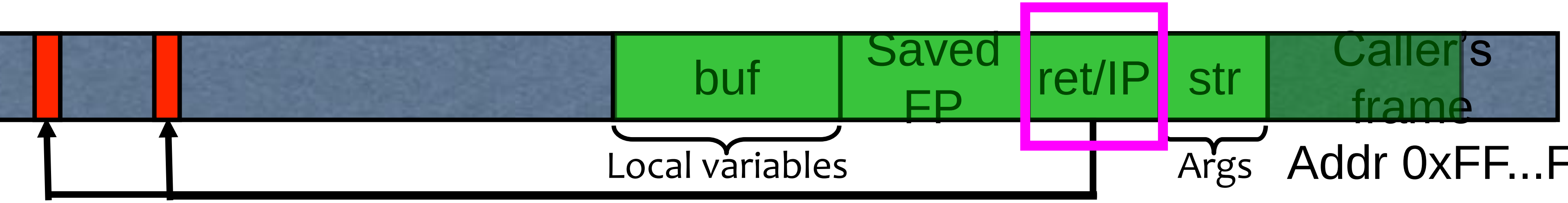
- Memory pointed to by str is copied onto stack…

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

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

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

This will be interpreted as return address!



Off-By-One Overflow

- Home-brewed range-checking string copy

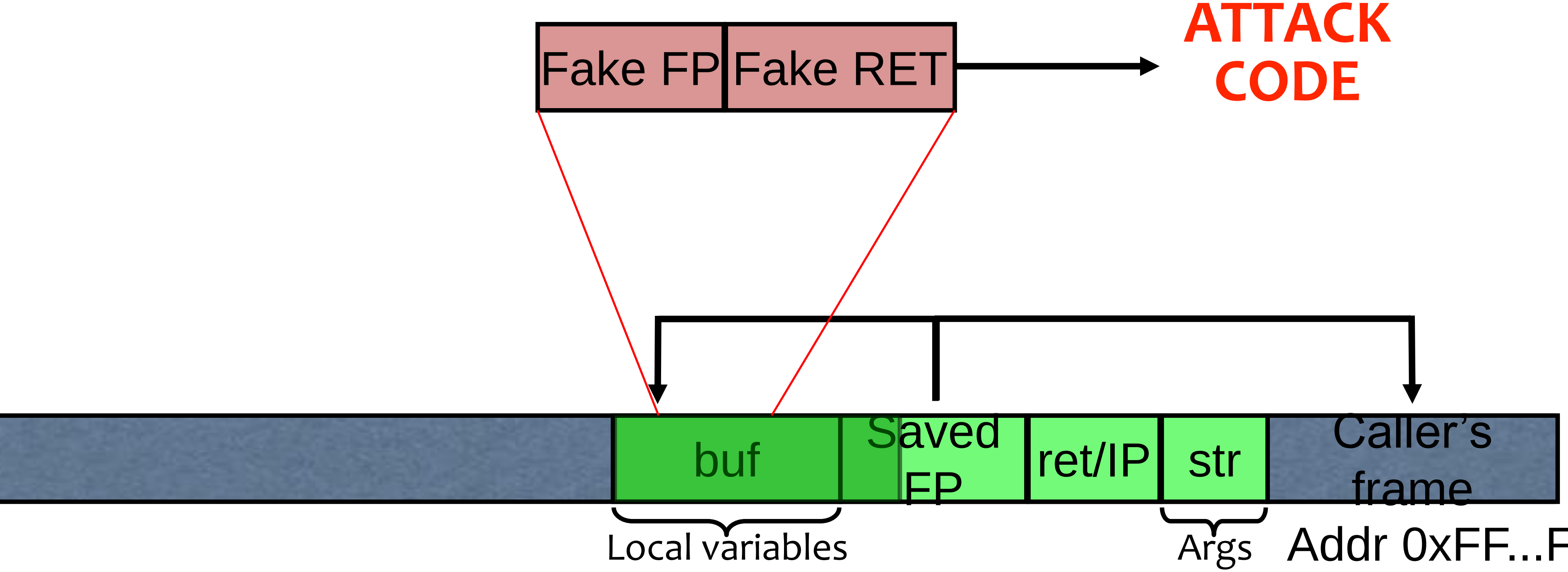
```
 void mycopy(char *input) {
       char buffer[512]; int i;

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

This will copy **513** characters into buffer. Oops!

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

Frame Pointer Overflow



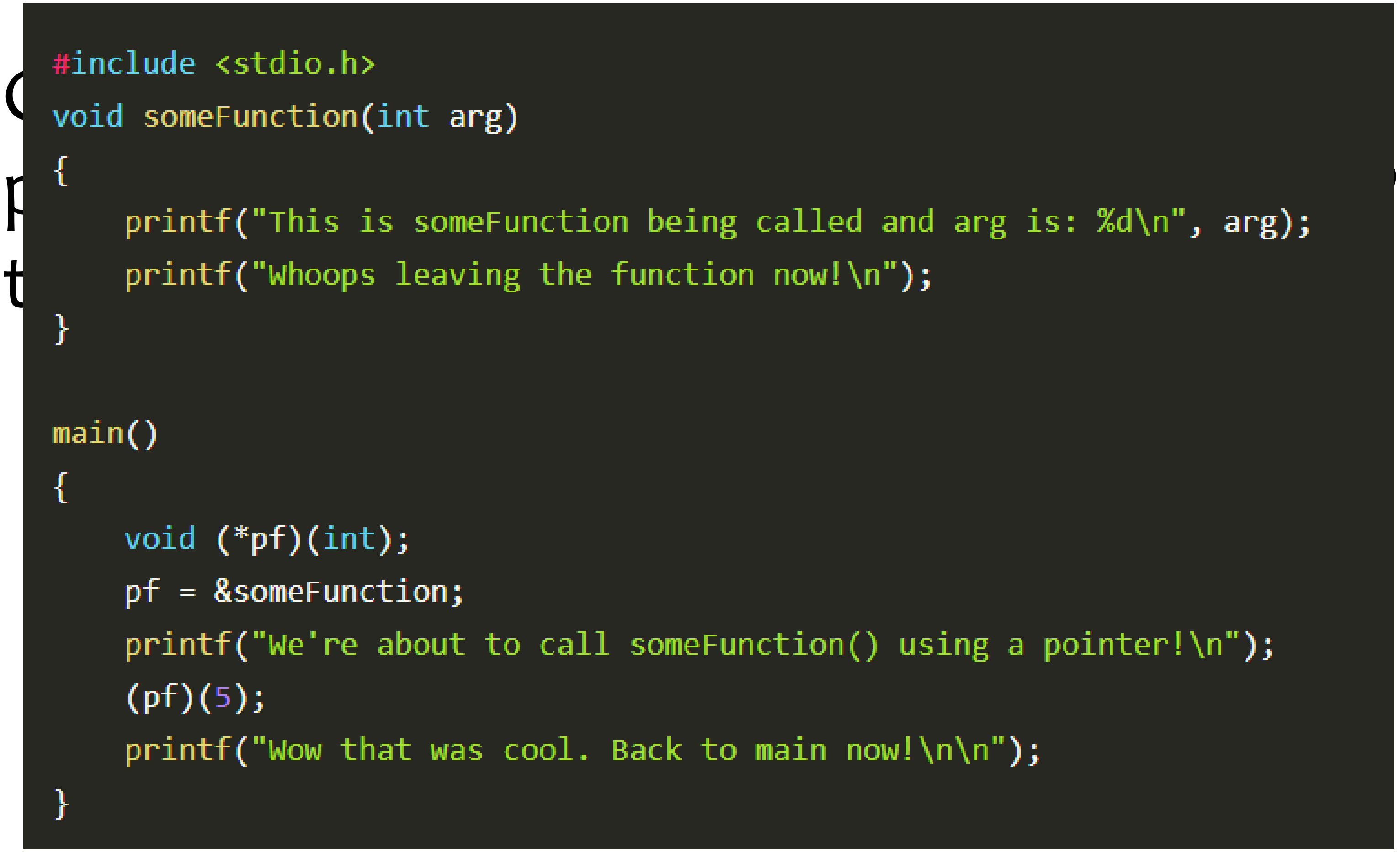
Stepping Back

- This class: Broad tour of key concepts in security
  - Key principles
  - Foundations / historical perspective
  - Lab 1 doesn't have all modern defenses / compiler options enabled
- But you'll still experiment with other variants
  - E.g., one target in lab 1 doesn't save frame pointer on stack

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)(…)

Another Variant: Function Pointer Overflow



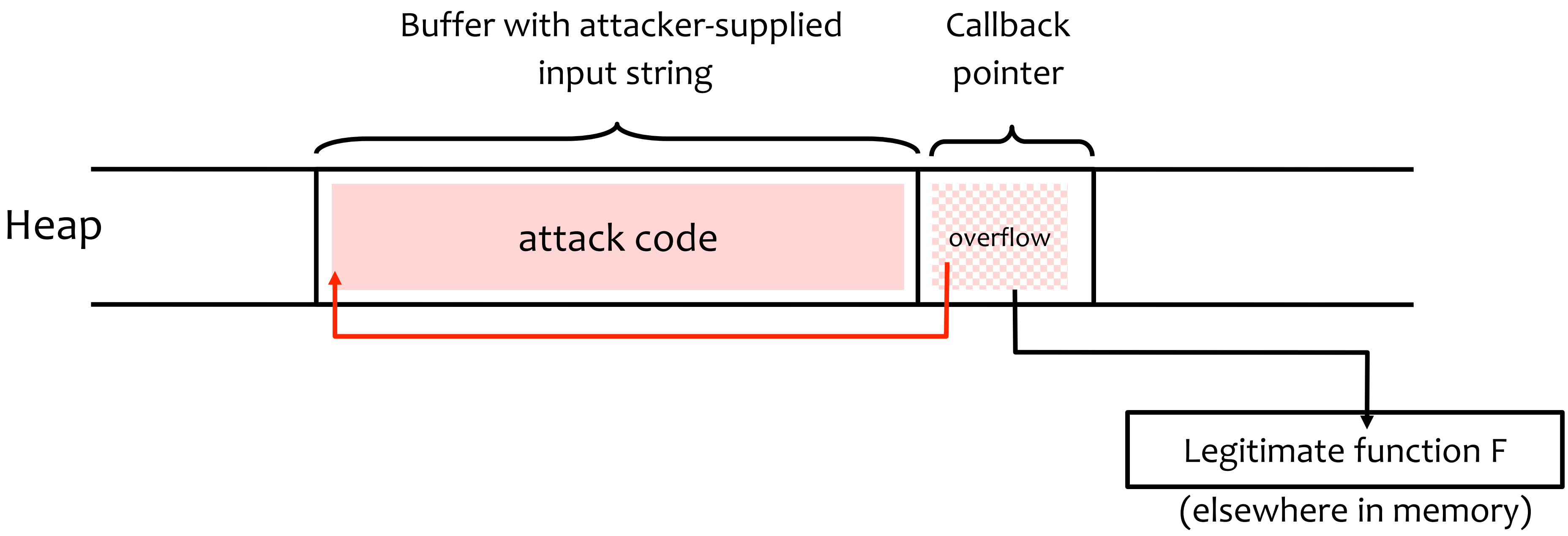
```
#include <stdio.h>
void someFunction(int arg)
{
    printf("This is someFunction being called and arg is: %d\n", arg);
    printf("Whoops leaving the function now!\n");
}

main()
{
    void (*pf)(int);
    pf = &someFunction;
    printf("We're about to call someFunction() using a pointer!\n");
    (pf)(5);
    printf("Wow that was cool. Back to main now!\n\n");
}
```

https://www.learn-c.org/en/Function_Pointers

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)(…)



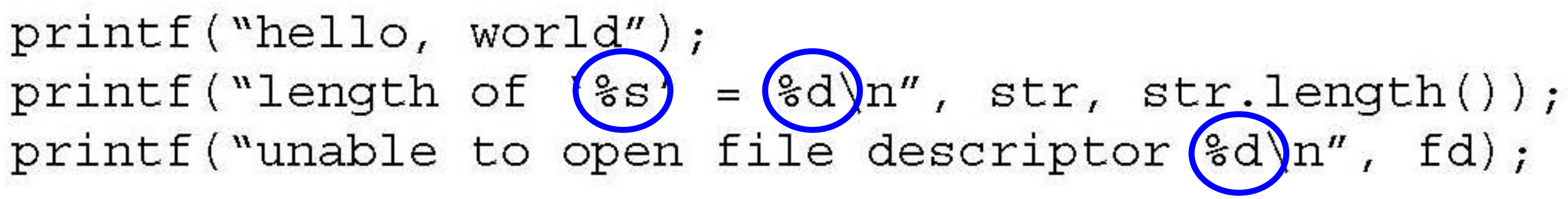
Other Overflow Targets

- 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:



```
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:

```
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:

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

```
char buf[14] = "Hello, world!";
printf(buf);
// should've used printf("%s", buf);
```

Implementation of Variable Args

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

```
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 */
}
```

printf has an internal stack pointer

Format Strings in C

- Proper use of printf format string:

```
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:

```
char buf[14] = “Hello, world!”;
printf(buf);
// should’ve used printf(“%s”, buf);
```

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

Format Strings in C

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!

- Sloppy use of printf format string:

```
char buf[14] = “Hello, world!”;
printf(buf);
// should’ve used printf(“%s”, buf);
```

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

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

```
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);
```

  - Stack location pointed to by printf's internal stack pointer will be interpreted as an int. (What if cryptographic key, password, ...?)

- Or what about:

```
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

Tested on Wednesday, on barb.cs

```
#include <stdio.h>

int main()
{
    char *buf = "%08x\t%08x\t%08x\t%08x\n";
    printf(buf);
}
```

`Compiled with gcc`

Writing Stack with Format Strings

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

```
printf("Overflow this!%n",&myVar);
```

  - Argument of printf is interpeted as destination address
  - This writes 14 into myVar ("Overflow this!" has 14 characters)

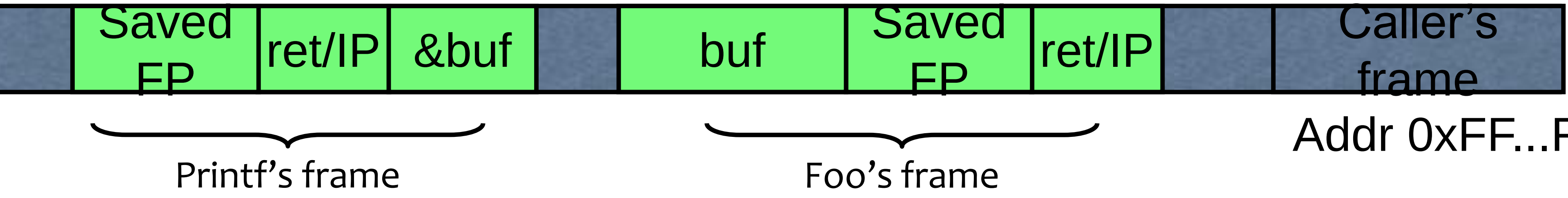
- What if printf does not have an argument?

```
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.

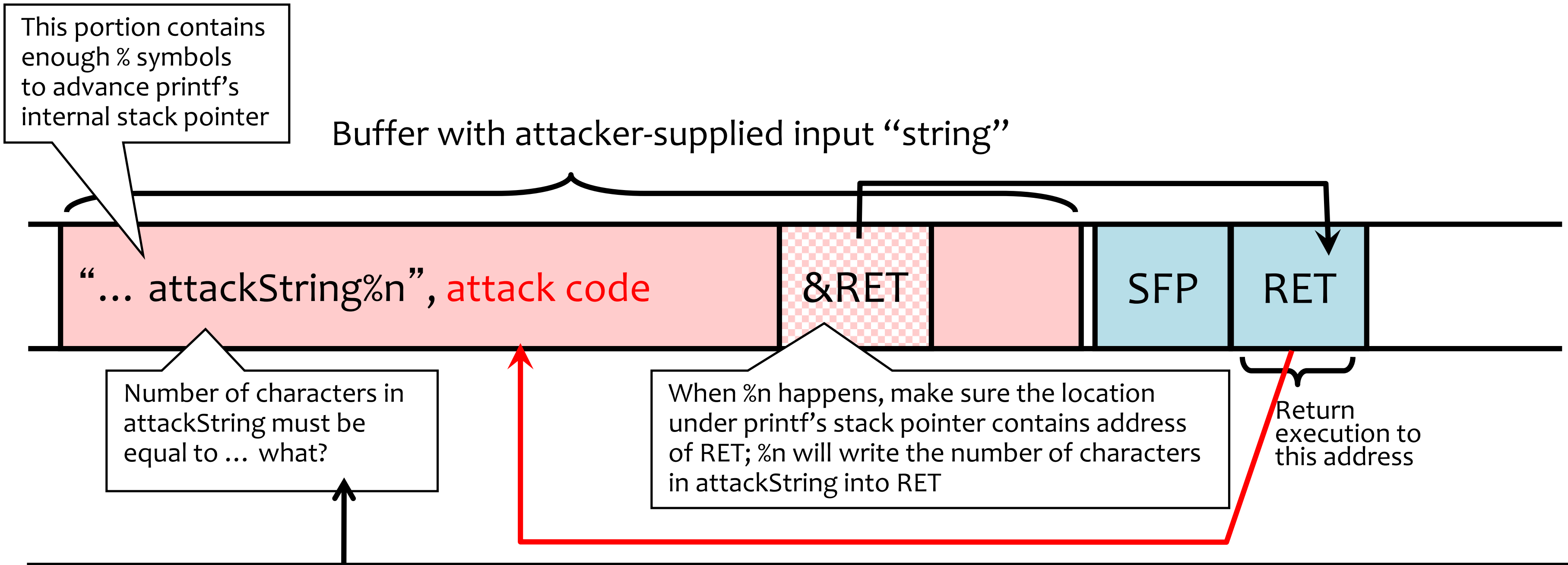
How Can We Attack This?

```
foo() {
      char buf[…] = "attackString";
      printf(buf); //vulnerable
}
```



What should "attackString" be??

Using %n to Overwrite Return Address



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

Buffer with attacker-supplied input “string”

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:
  - Smashing the Stack for Fun and Profit
  - Exploiting Format String Vulnerabilities
- Links to these readings are posted on the course schedule