CSE 484 / CSE M 584: Computer Security and Privacy

# Software Security: Buffer Overflow Attacks

## (continued)

Spring 2019

Franziska (Franzi) Roesner
franzi@cs.washington.edu

Thanks to Dan Boneh, Dieter Gollmann, Dan Halperin, Yoshi Kohno, Ada Lerner, John Manferdelli, John Mitchell, Vitaly Shmatikov, Bennet Yee, and many others for sample slides and materials ...

# Admin

- Lab 1:
  - **Group signup instructions will be released today (SSH)**
  - Lab access granted starting by Wednesday
  - Checkpoint (4/19) and Final (4/29) deadlines
- Final Project: Instructions up on website
  - First checkpoint deadline: May 17
- Looking forward
  - Today + Wednesday: More buffer overflows + defenses
  - Friday: Guest lecture (David Aucsmith)
  - Next week: Finish software security, start crypto

# Last Time: Basic Buffer Overflows

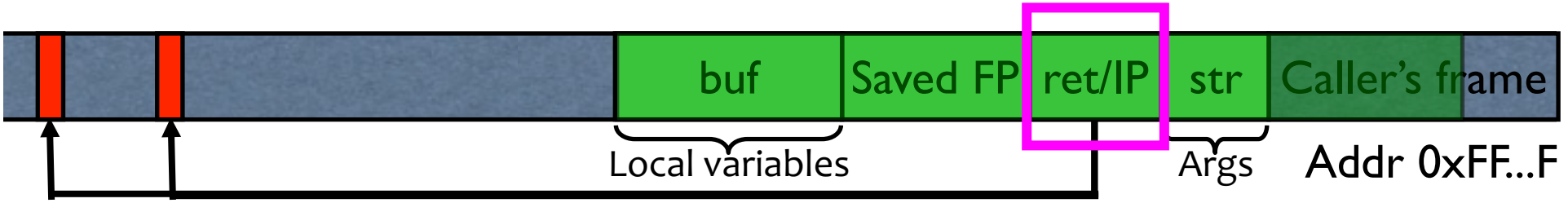
- Memory pointed to by str is copied onto stack…

```
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.

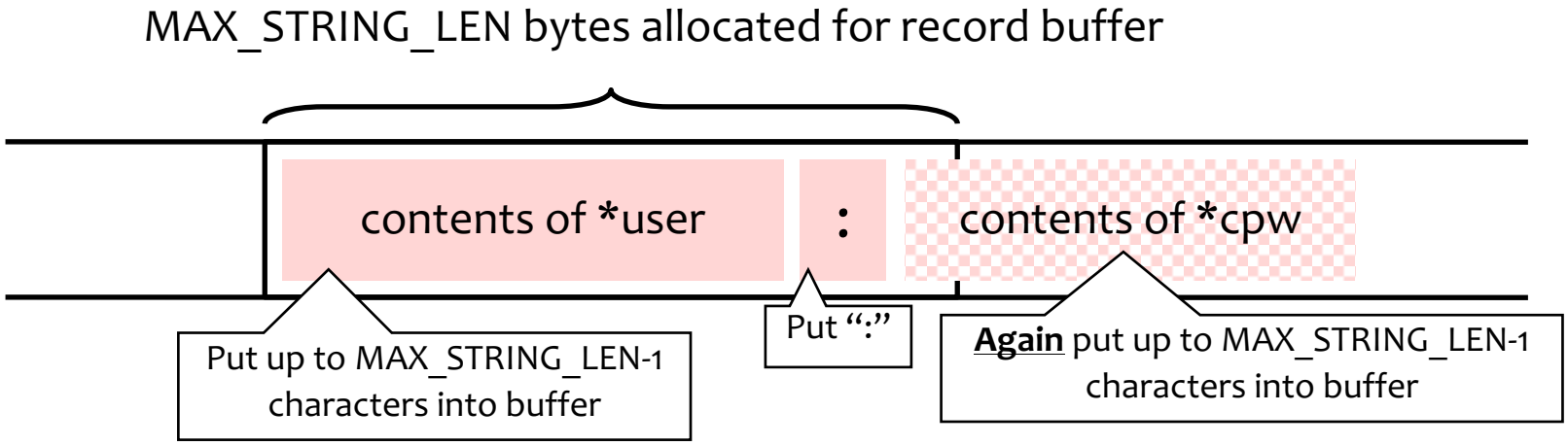
This will be interpreted as return address!



# Misuse of strncpy in htpasswd "Fix"

- Published "fix" for Apache htpasswd overflow:

```
strncpy(record,user,MAX_STRING_LEN-1);
strcat(record,":")
strncat(record,cpw,MAX_STRING_LEN-1);
```



# Off-By-One Overflow

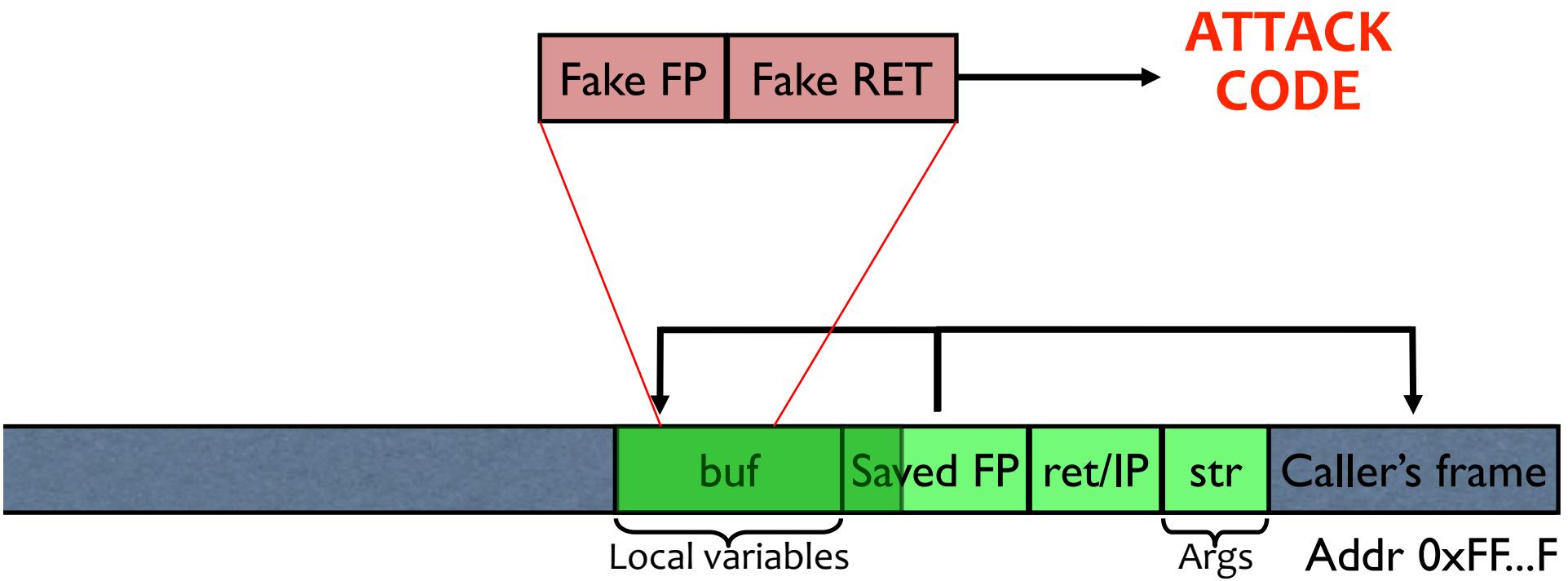
- Home-brewed range-checking string copy

```
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!

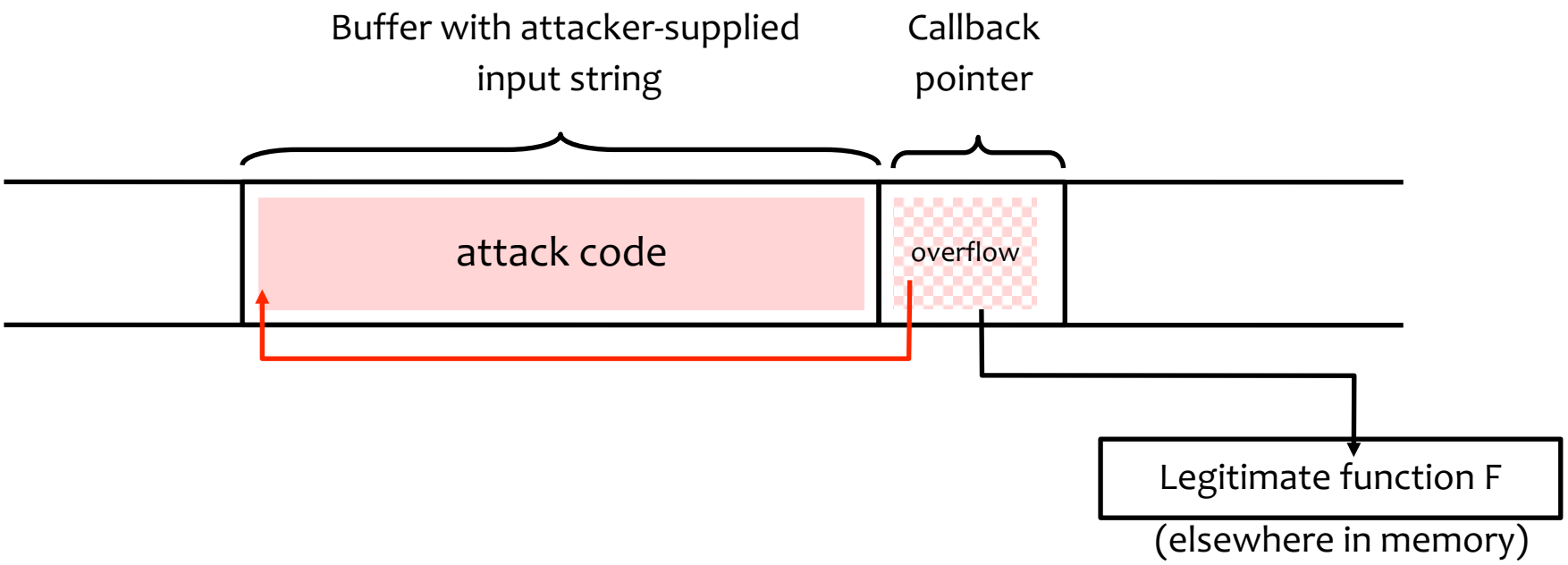
- 1-byte overflow: can't change RET, but can change pointer to previous stack frame…

# Frame Pointer Overflow



# 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:

```
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

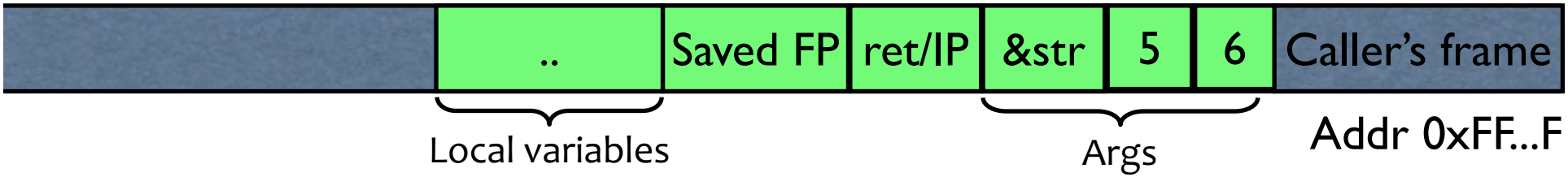
```
void printf(const char* format, ...)
{
     int i; char c; char* s; double d;
     va_list ap; /* declare an "argument pointer" to a variable arg list */
     va_start(ap, format);  /* initialize arg pointer using last known arg */

     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

# Closer Look at the Stack

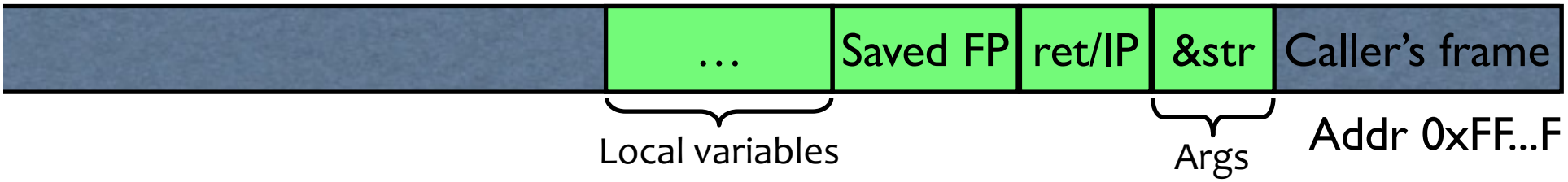
```
printf("Numbers: %d,%d", 5, 6);
```

Internal stack pointer starts here




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

Internal stack pointer starts here



# 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 crypto 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

# Try This At Home

```
#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.

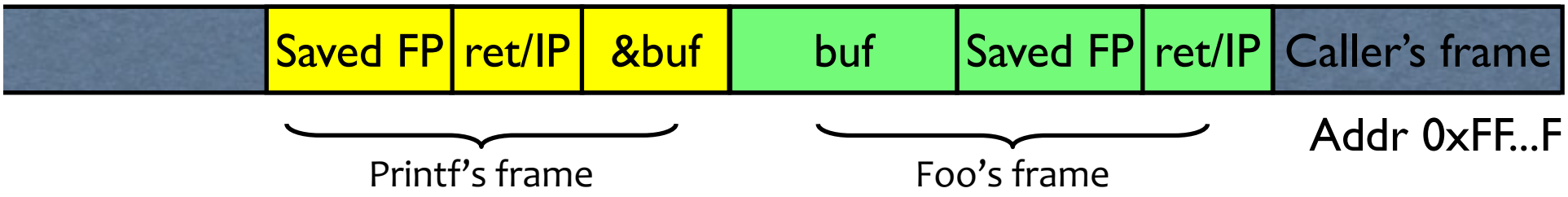
# Summary of Printf Risks

- 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?

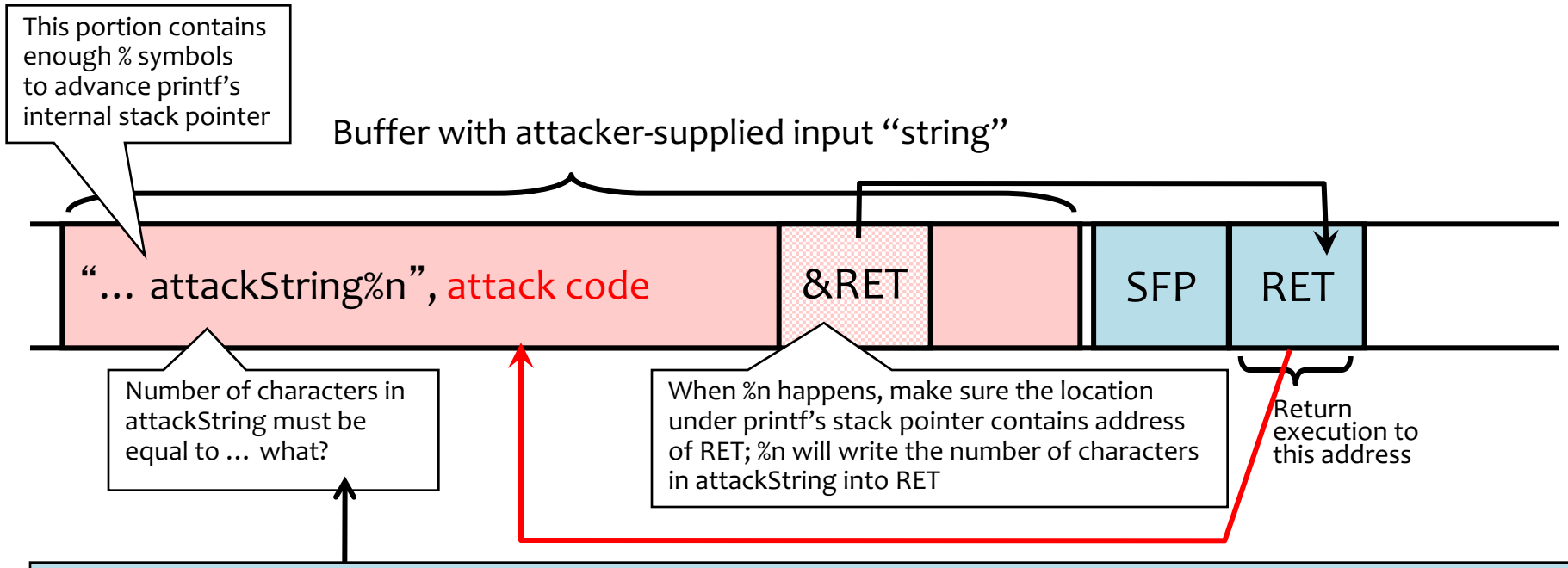
```
foo() {
        char buf[…];
        strncpy(buf, readUntrustedInput(), sizeof(buf));
        printf(buf); //vulnerable
}
```

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




**What should readUntrustedInput() return??**

# Using %n to Overwrite Return 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