CSE 484 / CSE M 584: Buffer Overflows (Continued)

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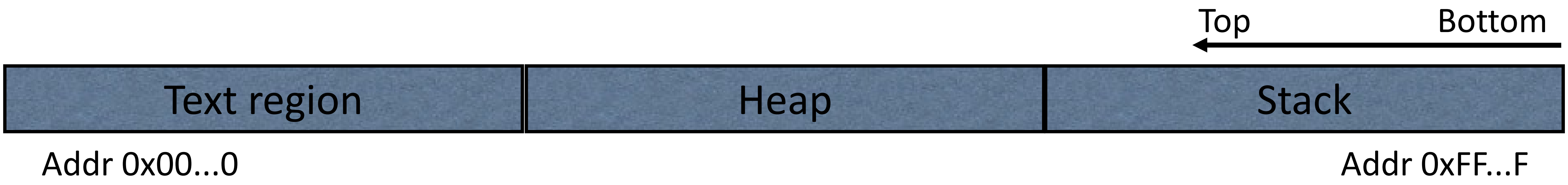
Announcements

- Things Due:
  - Homework #1: Due Thursday
  - Research Readings (CSE M 584): Due Thursday (and every Thursday thereafter)
- **Tentative** TA office hours (in addition to quiz sections and discussion board, best place for discussing homeworks and labs) (may still juggle some, final times will be on course web page)
  - Mon 2-3
  - Tues 5-6
  - Wed 4-5
  - Thurs 5-6
  - Fri 5-6

First, Review slides from Friday

Memory Layout

- Text region: Executable code of the program
- Heap: Dynamically allocated data
- Stack: Local variables, function return addresses; grows and shrinks as functions are called and return



Stack Buffers

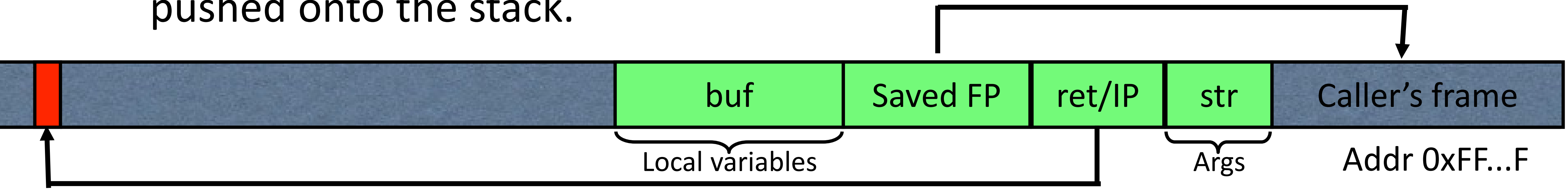
- Suppose Web server contains this function:

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

Allocate local buffer (126 bytes reserved on stack)

Copy argument into local buffer

- When this function is invoked, a new frame (activation record) is pushed onto the stack.



Execute code at this address after func() finishes

What if Buffer is Overstuffed?

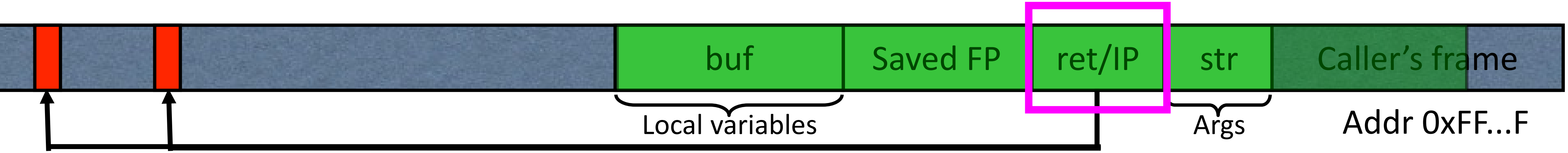
- Memory pointed to by str is copied onto stack…

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

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

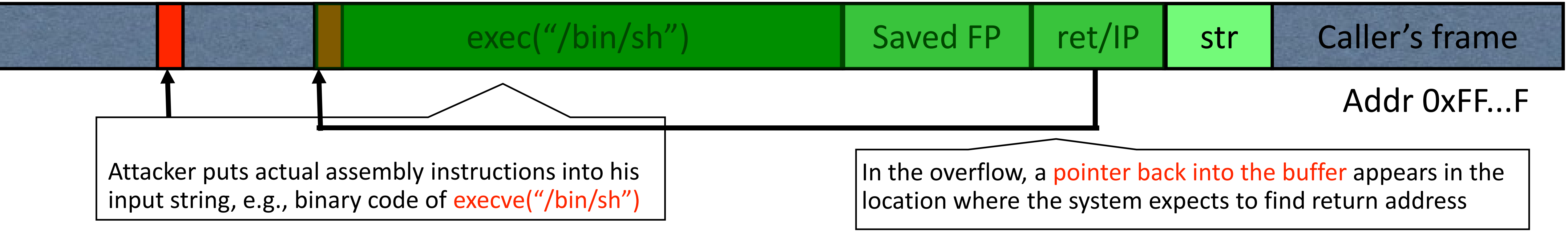
- If a string longer than 126 bytes is copied into buffer, it will overwrite adjacent stack locations.

This will be interpreted as return address!



Executing Attack Code

- Suppose buffer contains attacker-created string
  - For example, str points to a string received from the network as the URL



- When function exits, code in the buffer will be executed, giving attacker a shell **("shellcode")**
  - Root shell if the victim program is setuid root

Review: “End”

- “End” in quotes because although those were past slides, we have not ended the review – we will continue to revisit the contents of the earlier slides, just in slightly different ways

Problem: No Bounds Checking

- strcpy does not check input size
  - strcpy(buf, str) simply copies memory contents into buf starting from *str until “\0” is encountered, ignoring the size of area allocated to buf
- Many C library functions are unsafe
  - strcpy(char *dest, const char *src)
  - strcat(char *dest, const char *src)
  - gets(char *s)
  - scanf(const char *format, …)
  - printf(const char *format, …)

Does Bounds Checking Help?

- strncpy(char *dest, const char *src, size_t n)
  - If strncpy is used instead of strcpy, no more than n characters will be copied from *src to *dest
    - Programmer has to supply the right value of n
- Potential overflow in htpasswd.c (Apache 1.3):

```
strcpy(record,user);
strcat(record,":");
strcat(record,cpw);
```

Copies username ("user") into buffer ("record"), then appends ":" and hashed password ("cpw")

- Published fix:

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

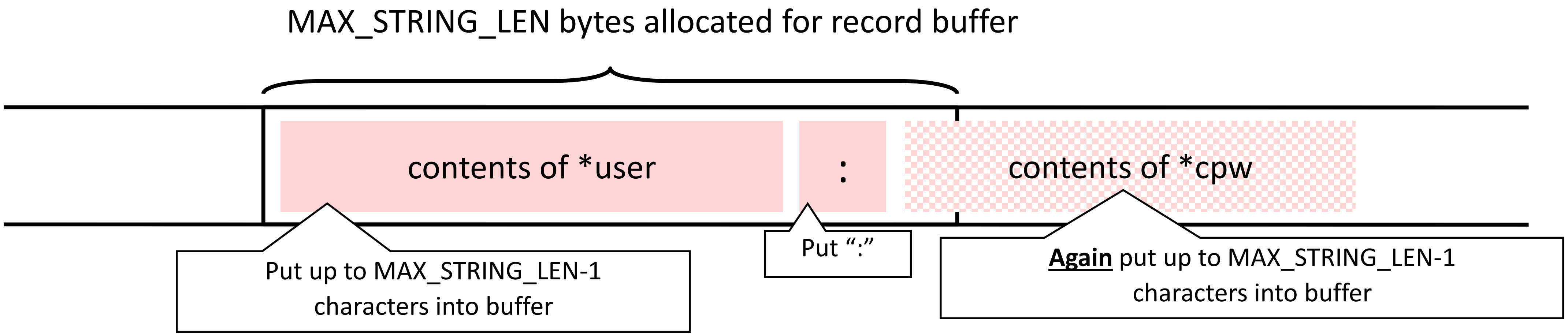
Breakout Activity

Canvas -> Quizzes

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);
```

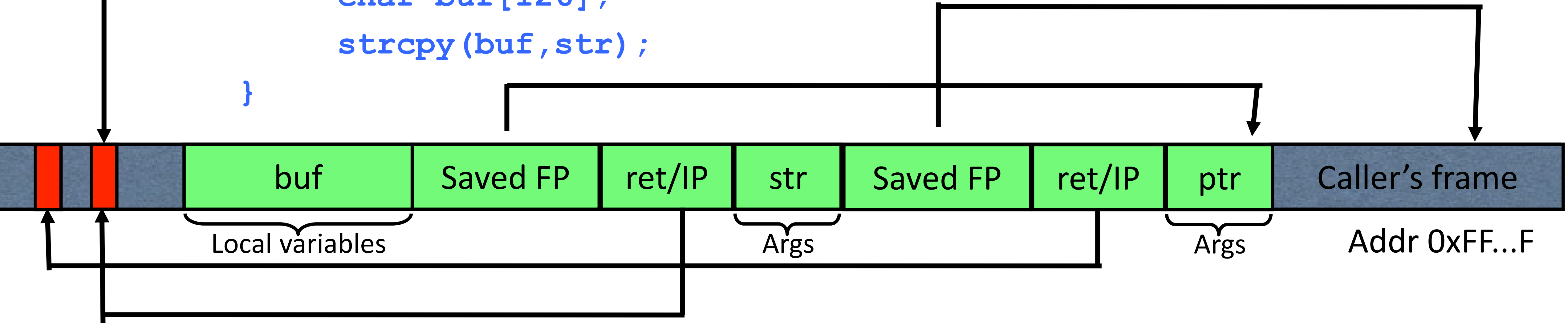


Stack Buffers – Revisit – bar() calls foo()

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

Note: Toy example, functions not useful

Note: Exact pointer locations may vary by architecture; this description focuses on high-level ideas



What About This?

- 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]);
}
```

Breakout Activity

Canvas -> Quizzes

Off-By-One Overflow

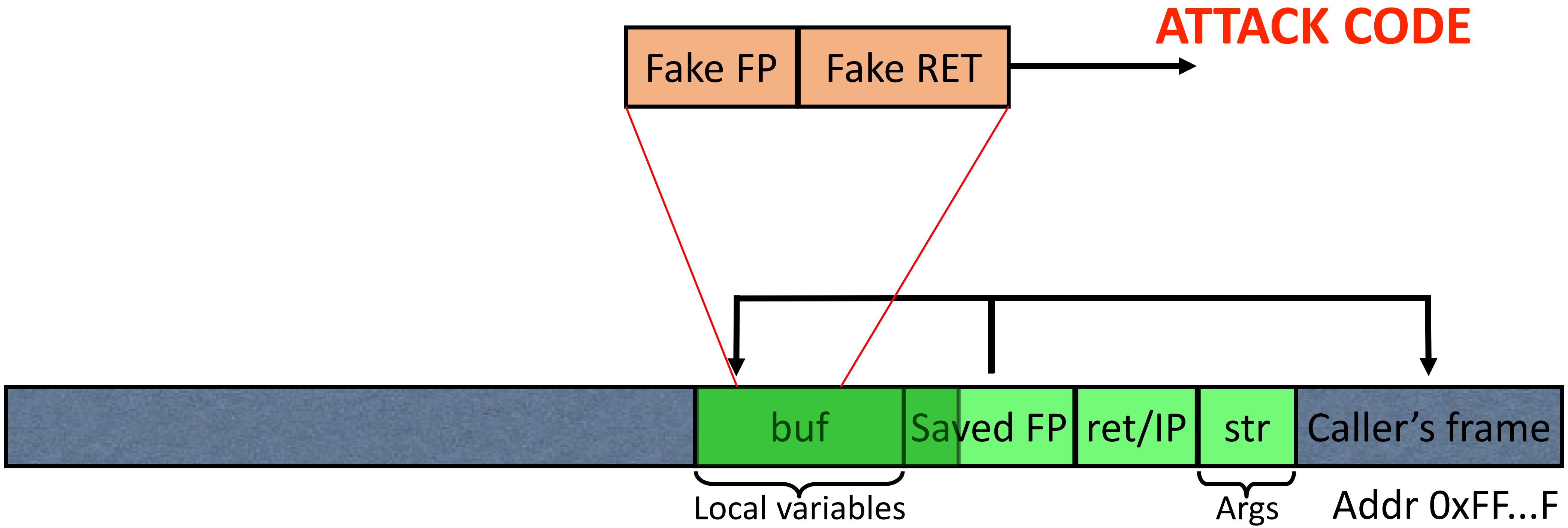
- Home-brewed range-checking string copy

```
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!

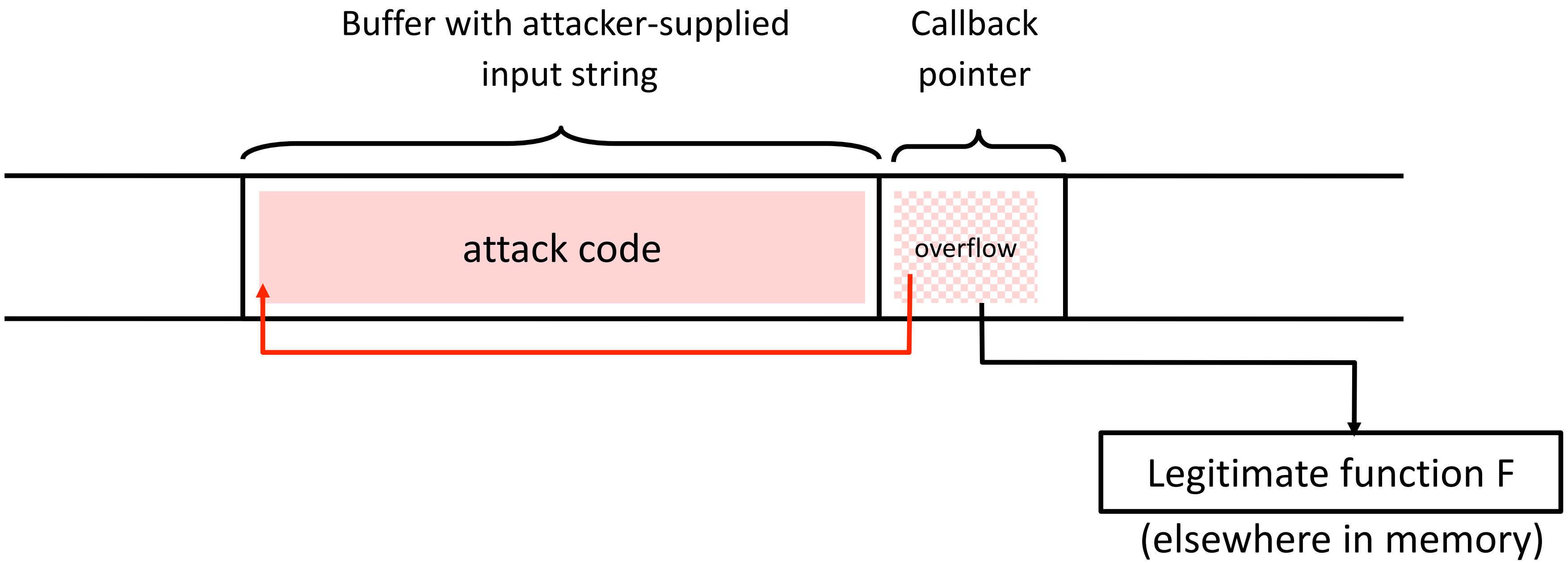
- 1-byte overflow: can't change RET, but can change pointer to previous stack frame…

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
  - We'll walk through this one next
- 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:

```
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
```

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

- Unsafe use of printf format string:

```
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

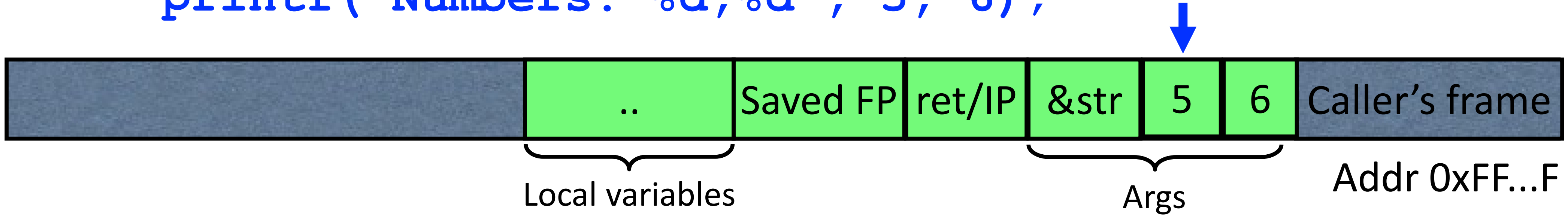
```
void printf(const char* format, ...)
{
     int i; char c; char* s; double d;
     va_list ap;  /* declare an "argument pointer" to a variable arg list */
     va_start(ap, format);  /* initialize arg pointer using last known arg */

     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 */
}
```

This is simplified code, e.g., handles %d but not %10d

Closer Look at the Stack

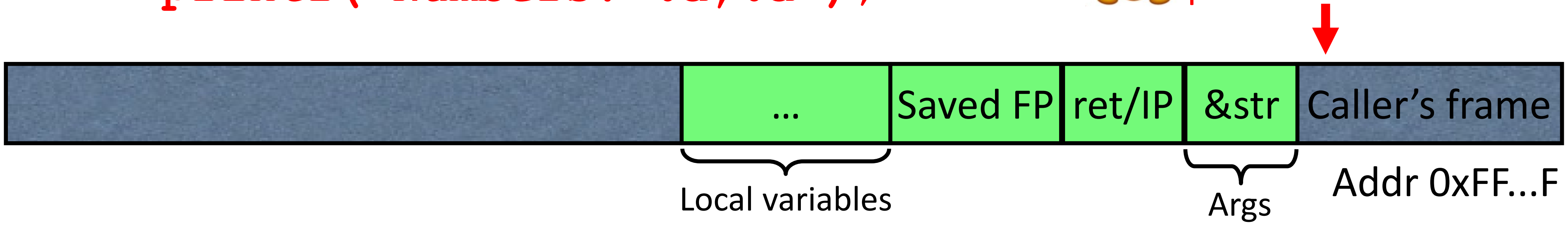
```
printf("Numbers: %d,%d", 5, 6);
```

Printf's internal stack pointer starts here




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

Printf's internal stack pointer starts here



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
```

- Unsafe use of printf format string:

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

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!

```
foo = 1234 in decimal, 4D2 in hex
```

- Unsafe 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

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 interpreted as destination address
  - This writes 14 into myVar ("Overflow this!" has 14 characters)

- What if printf does <u>not</u> 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

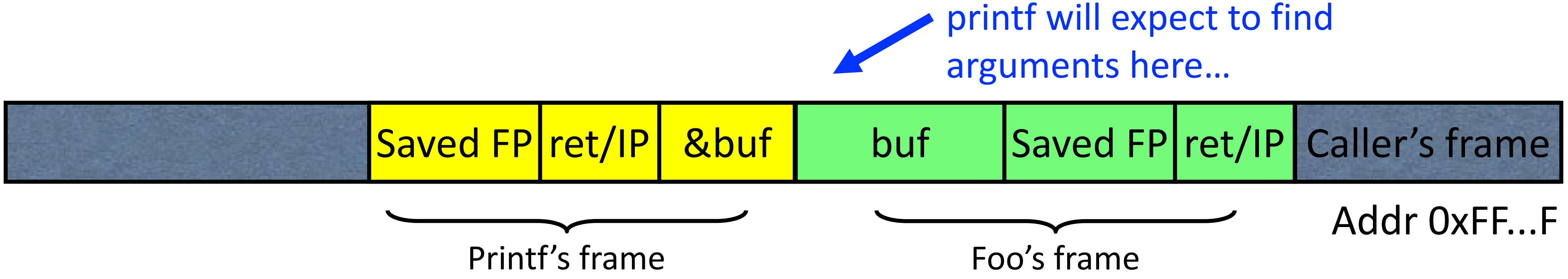
“Weird Machines”

- 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?

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

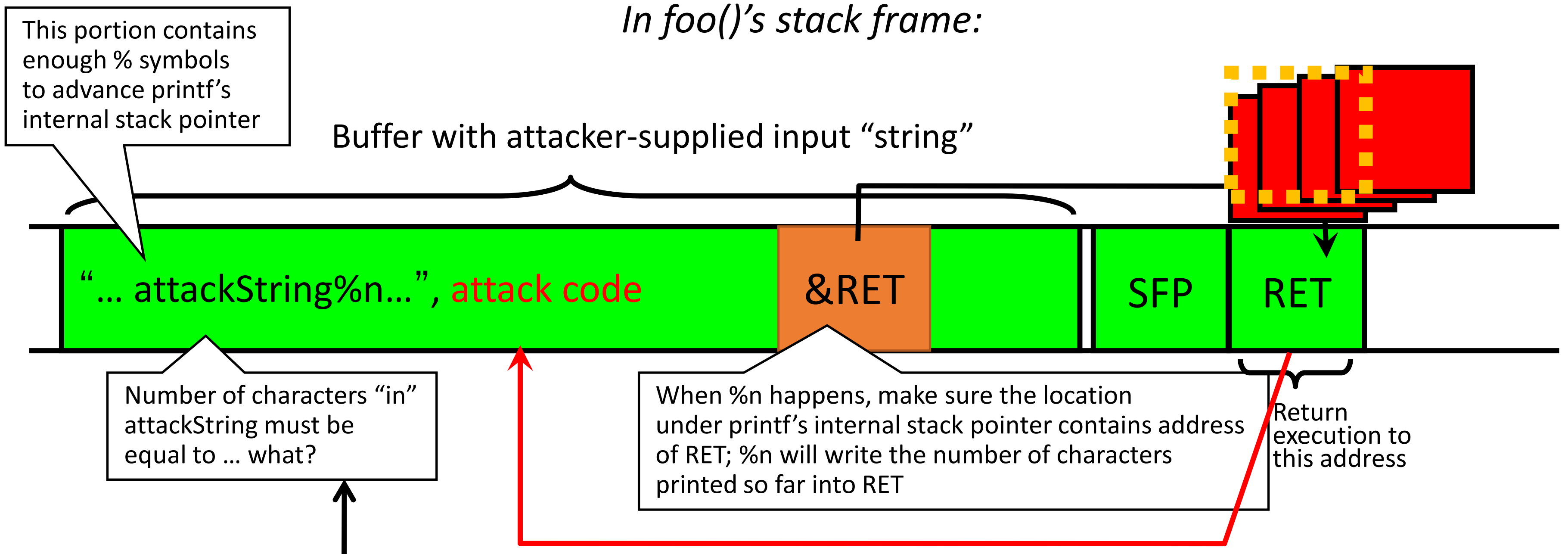
If format string contains % then printf will expect to find arguments here…



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

Different compilers / compiler options / architectures might vary

Using %n to Overwrite Return Address



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