CSE 484 / CSE M 584: Computer Security and Privacy

Software Security: Buffer Overflow Attacks

(continued)

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Announcements

- Participation and Breakout Groups
  - We'll be using in-class activities for participation (see email)
  - Sign up via Canvas if you'd like a specific breakout group
  - Also using Canvas groups for assignment groups (new group set per assignment, to support changing groups)
- TA Office Hours
  - See course website; Zoom links on Canvas
- Lab 1
  - **Group signup instructions will be released today (SSH)**
  - Lab access granted starting mid-week
  - Checkpoint (4/17) and Final (4/29) deadlines
- Feedback re: online course logistics? Survey sent Friday

Last Time: Basic Buffer Overflows

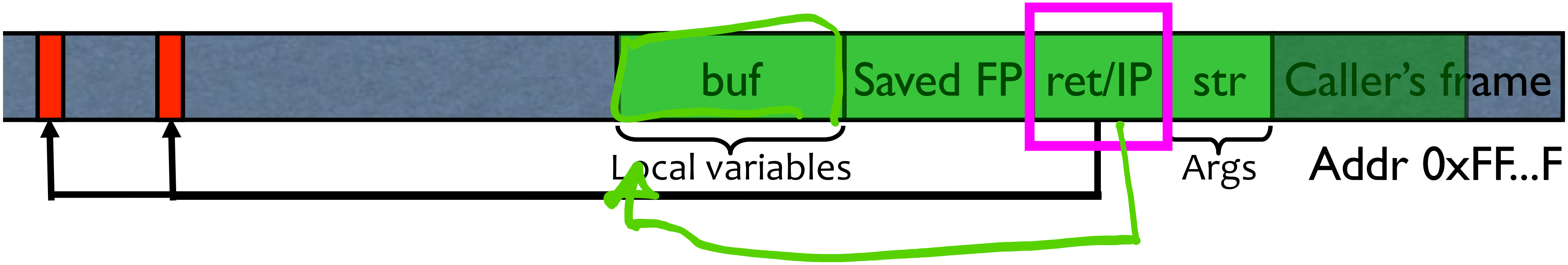
- Memory pointed to by str is copied onto stack…

```
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!



What About This?

- Home-brewed range-checking string copy

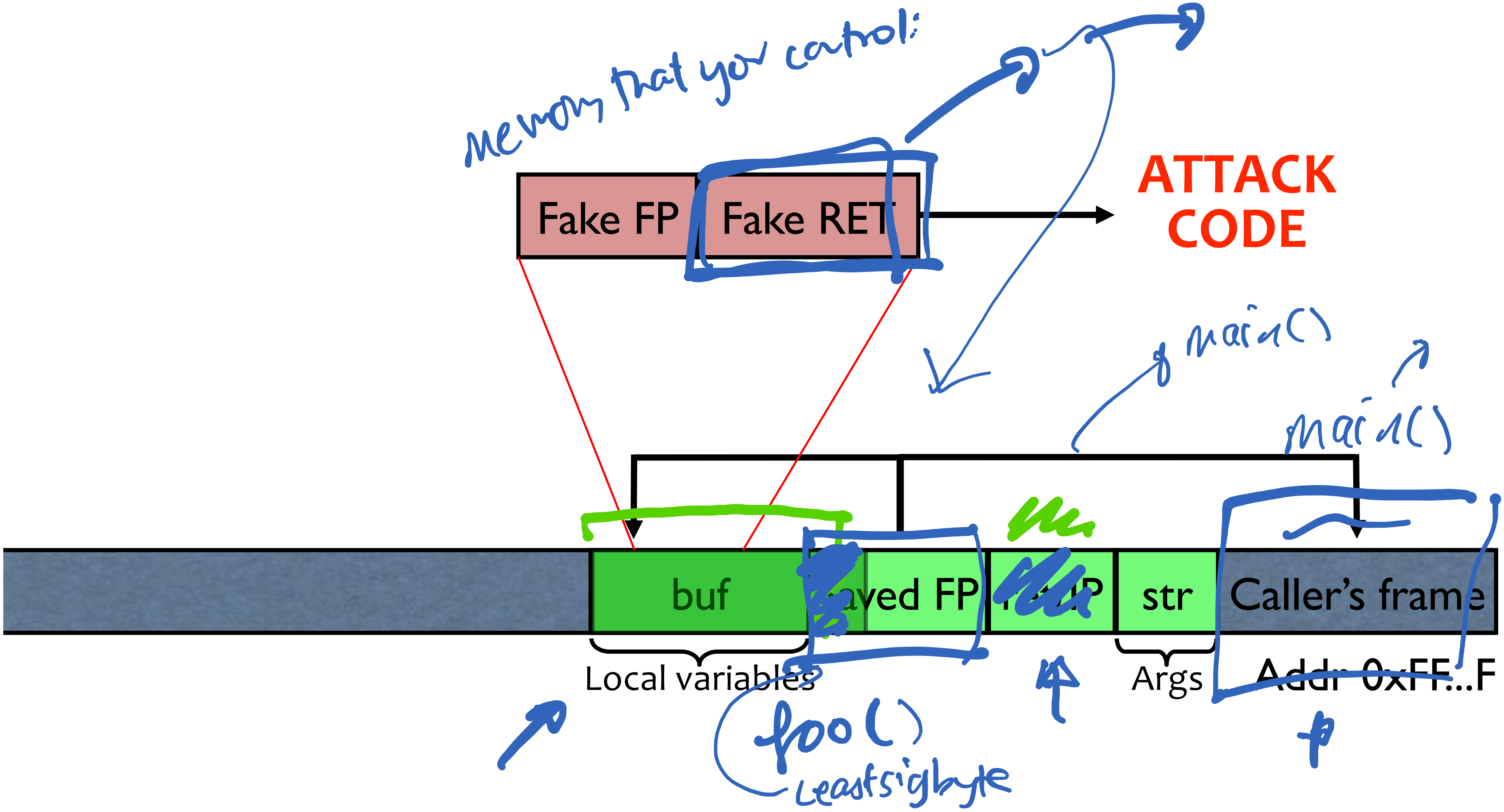
```
void mycopy(char *input) {
     char buffer[512]; int i;

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

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

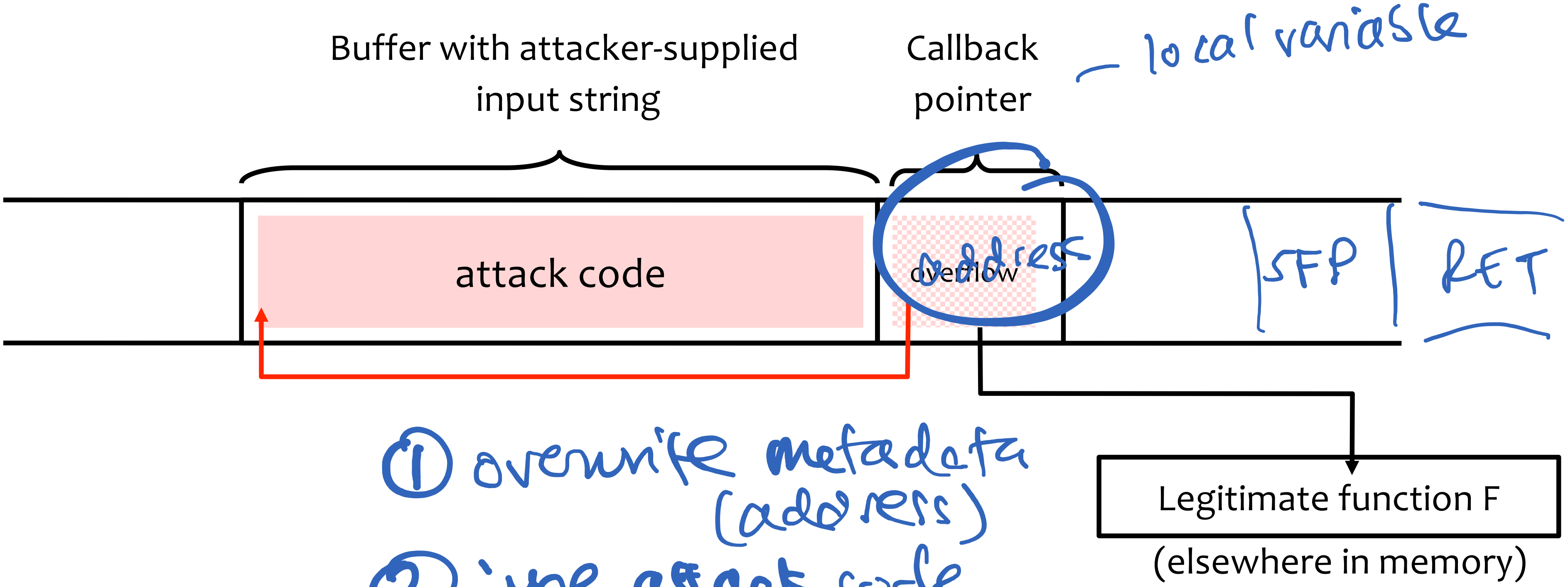
- 1-byte overflow: can't change RET, but can change pointer to previous stack frame…

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)(…)



Buffer with attacker-supplied input string

Callback pointer

attack code

overflow

Legitimate function F

(elsewhere in memory)

① overwrite metadata (address)

② jump attack code

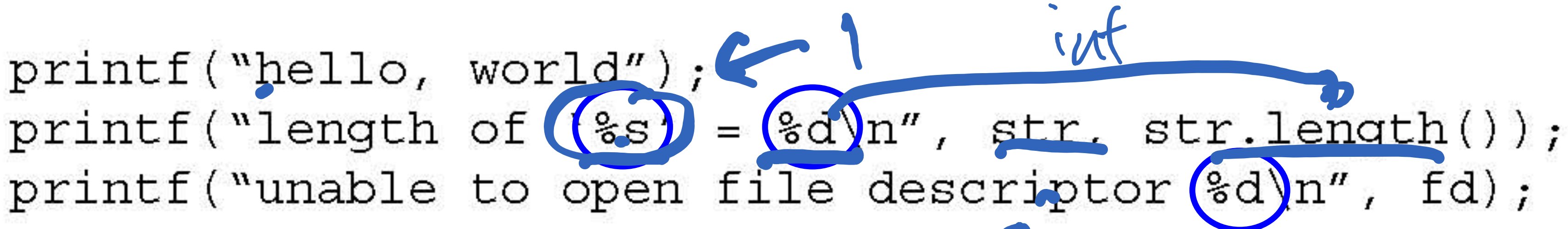
Other Overflow Targets

- 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);
```

1

int

Format specification encoded by special % characters

%d,%i,%o,%u,%x,%X – integer argument
%s – string argument
%p – pointer argument (void *)
Several others

string

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); ← assuming it's just a string
// should’ve used printf(“%s”, buf);
```

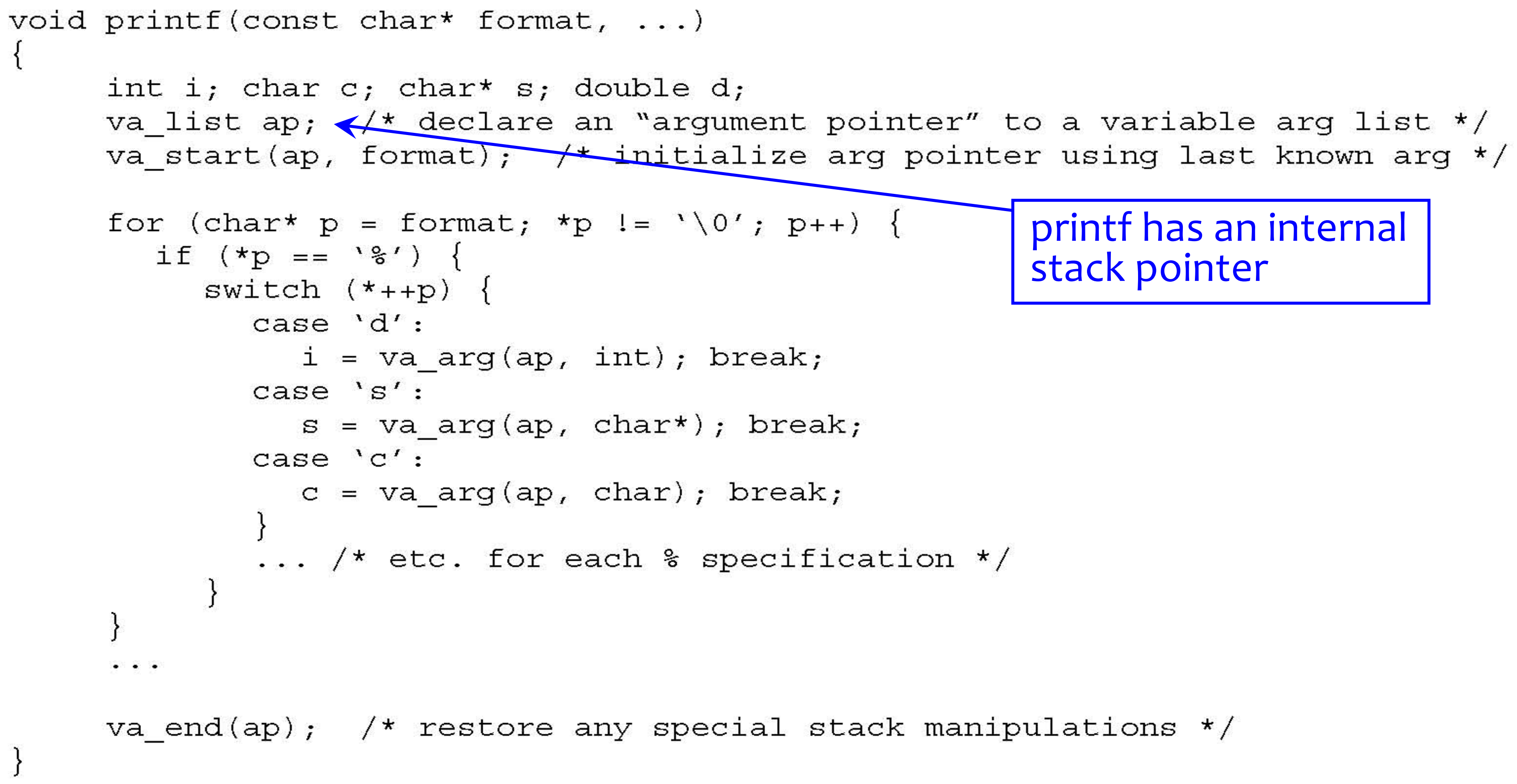
from network

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

“Hello %x”

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 */
}
```

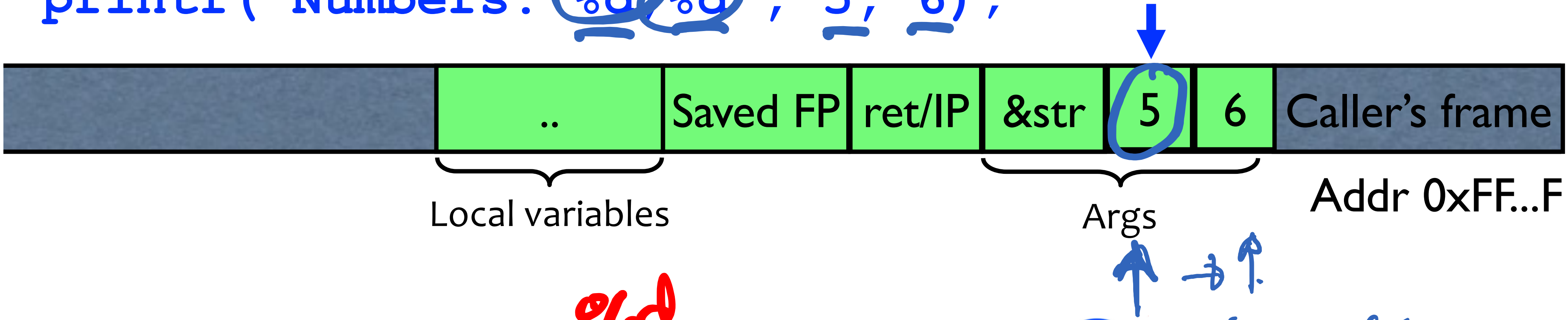
printf has an internal stack pointer

Closer Look at the Stack

null terminated

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

Internal stack pointer starts here

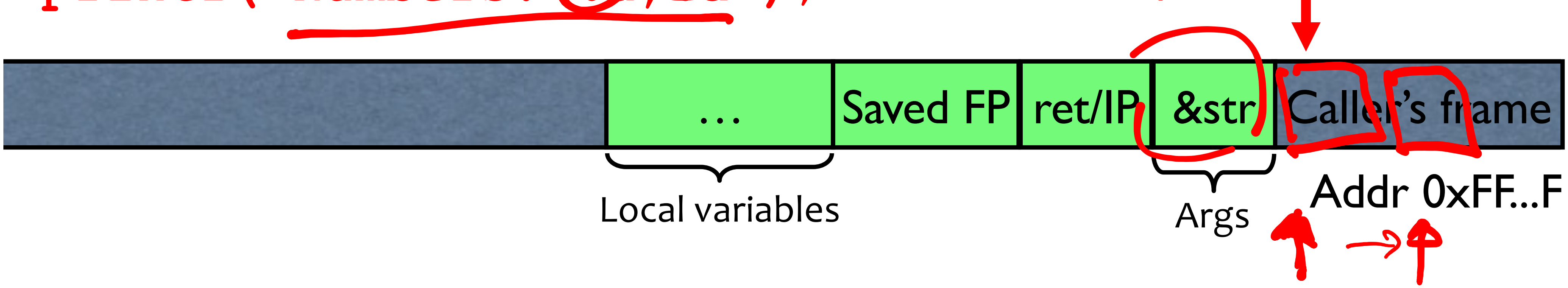


%d

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

Internal stack pointer starts here

internal stack p.



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

Writing Stack with Format Strings

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

interpreted as address

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

14

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? %d 5

```
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.

?

internal sp

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

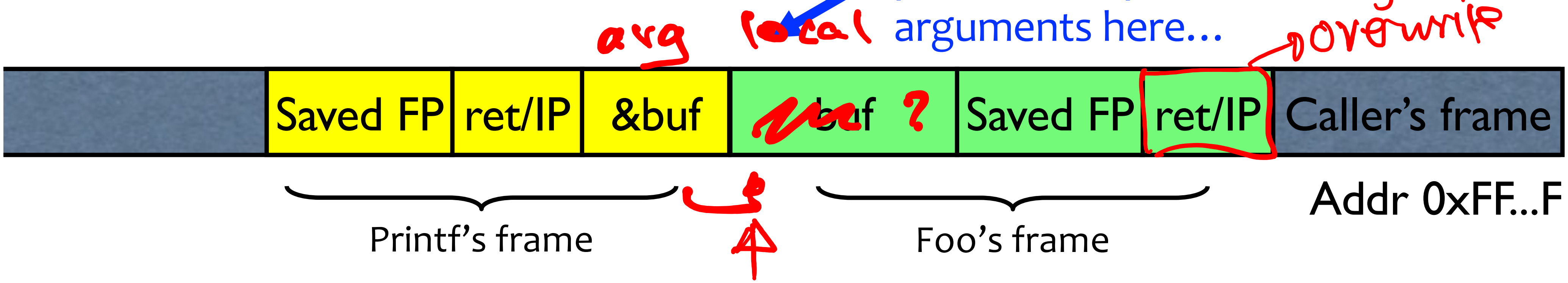
How Can We Attack This?

attacker controls

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

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

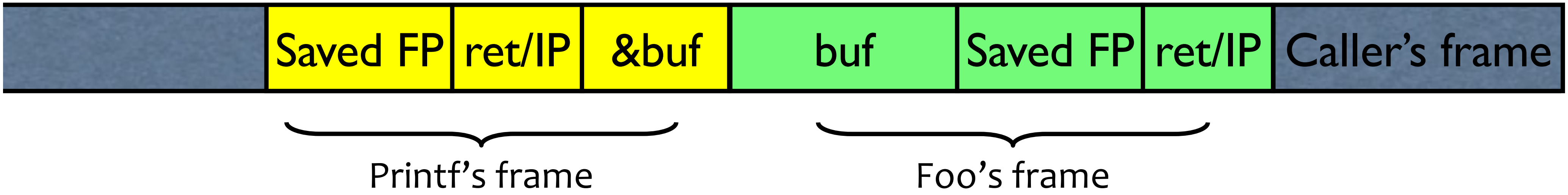
goal: overwrite



start looking here

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

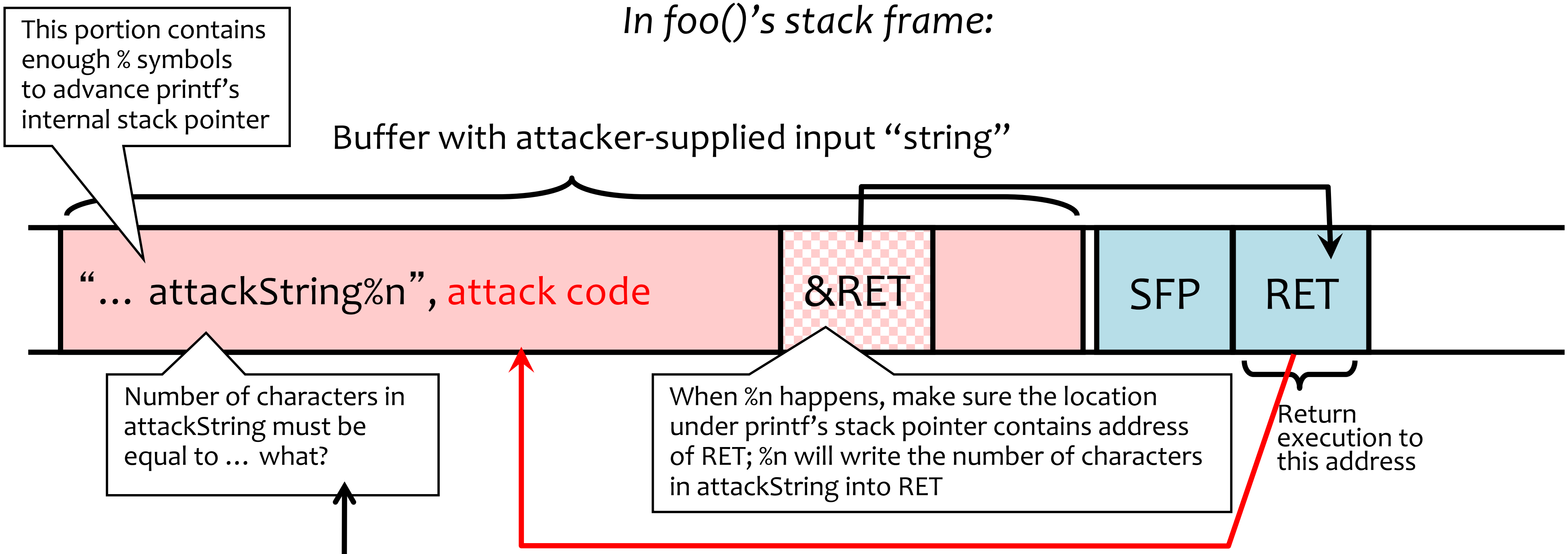
Go to Canvas Quiz for April 6!



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:



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

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 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