CSE 484 / CSE M 584: Computer Security and Privacy

Software Security: Buffer Overflow Attacks

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Logistics

- Things Due:
  - Homework #1: Due Wednesday
- Things Releasing:
  - Lab 1 TODAY

Last time…

- Threat models
  - Assets
  - Adversaries
  - Vulnerabilities
  - Threats
  - Risks

SOFTWARE SECURITY

Bugs, Vulnerabilities, and Exploits

- Bug
  - Not working quite right
- Vulnerability
  - A malfunction that can be used for an adversary's goals
- Exploit
  - The mechanical set of operations to make use of a vulnerability

Aside: The Weird Machine

- An exploit can also be considered a *program* for a *weird machine*
- If you are more formally-inclined, check out:
  - https://www.cs.dartmouth.edu/~sergey/wm/
- We'll come back to this later in the course

Adversarial Failures

- Software bugs are bad
  - Consequences can be serious
- Even worse when an intelligent adversary wishes to exploit them!
  - Intelligent adversaries: Force bugs into "worst possible" conditions/states
  - Intelligent adversaries: Pick their targets

Many types of vulnerability

Memory Corruption Bugs

- Buffer overflows bugs: Big class of bugs
  - Normal conditions: Can sometimes cause systems to fail
  - Adversarial conditions: Attacker able to violate security of your system (control, obtain private information, ...)
- Stack, Heap both possibilities

BUFFER OVERFLOWS

A Bit of History: Morris Worm

- Worm was released in 1988 by Robert Morris
  - Graduate student at Cornell, son of NSA chief scientist
  - Convicted under Computer Fraud and Abuse Act,
    - 3 years probation and 400 hours of community service

- Worm was intended to propagate slowly and harmlessly measure the size of the Internet
- Due to a coding error, it created new copies as fast as it could and overloaded infected machines
- $10-100M worth of damage

Morris Worm and Buffer Overflow

- One of the worm's propagation techniques was a buffer overflow attack against a vulnerable version of `fingerd` on VAX systems
  - By sending special string to finger daemon, worm caused it to execute code creating a new worm copy

Buffer overflows remain a common source of vulnerabilities and exploits today!

(Especially in embedded systems.)

Aside: Famous Internet Worms

- Morris worm (1988): overflow in `fingerd`
  - 6,000 machines infected
- CodeRed (2001): overflow in MS-IIS server
  - 300,000 machines infected in 14 hours
- SQL Slammer (2003): overflow in MS-SQL server
  - 75,000 machines infected in **10 minutes** (!!)
- Sasser (2005): overflow in Windows LSASS
  - Around 500,000 machines infected

… And More

- Conficker (2008-09): overflow in Windows RPC
  - Around 10 million machines infected (estimates vary)
- Stuxnet (2009-10): several zero-day overflows + same Windows RPC overflow as Conficker
  - Windows print spooler service
  - Windows LNK shortcut display
  - Windows task scheduler
- Flame (2010-12): same print spooler and LNK overflows as Stuxnet
  - Targeted cyperespionage virus
- These days, worms are uncommon

… And More

- Embedded systems
  - E.g., our automotive work
- Formative and foundational for software security

Attacks on Memory Buffers

- Buffer is a pre-defined data storage area inside computer memory (stack or heap)
- Typical situation:
  - A function takes some input that it writes into a pre-allocated buffer.
  - The developer forgets to check that the size of the input isn't larger than the size of the buffer.
  - Uh oh.
    - "Normal" bad input: crash
    - "Adversarial" bad input : take control of execution

Stack Buffers

- Suppose Web server contains this function

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

- No bounds checking on strcpy()
- If str is longer than 126 bytes
  - Program may crash
  - Attacker may change program behavior

Example: Changing Flags

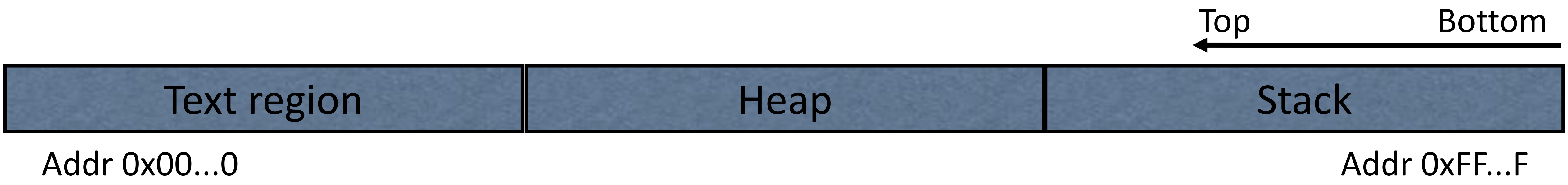
- Suppose Web server contains this function

```
void func(char *str) {
        byte auth = 0;
        char buf[126];
        ...
        strcpy(buf,str);
        ...
    }
```

- Authenticated variable non-zero when user has extra privileges
- Morris worm also overflowed a buffer to overwrite an authenticated flag in fingerd

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

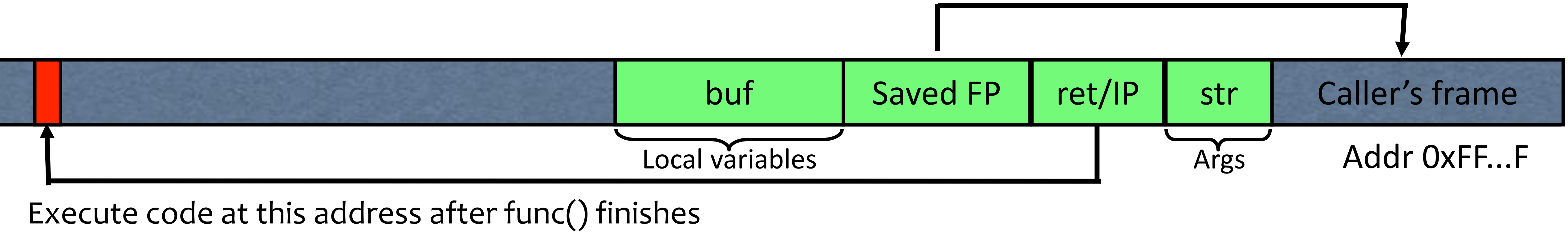
- Suppose Web server contains this function:

```
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.



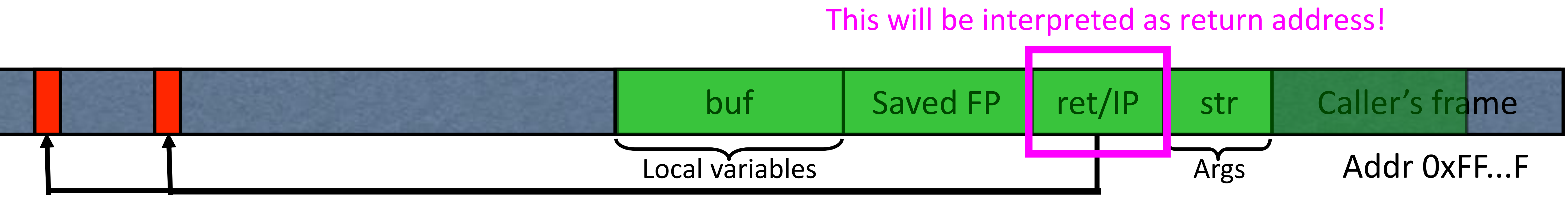
What if Buffer is Overstuffed?

- Memory pointed to by str is copied onto stack…

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

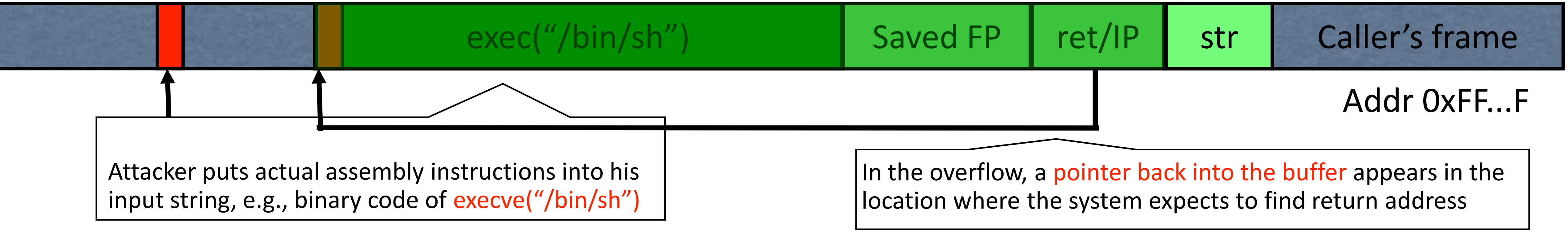
strcpy does NOT check whether the string at *str contains fewer than 126 characters

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



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

Buffer Overflows Can Be Tricky…

- Overflow portion of the buffer must contain correct address of attack code in the RET position
  - The value in the RET position must point to the beginning of attack assembly code in the buffer
    - Otherwise application will (probably) crash with segfault
  - **Attacker must correctly guess in which stack position his/her buffer will be when the function is called**

Problem: No Bounds Checking

- strcpy does <u>not</u> 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);
```

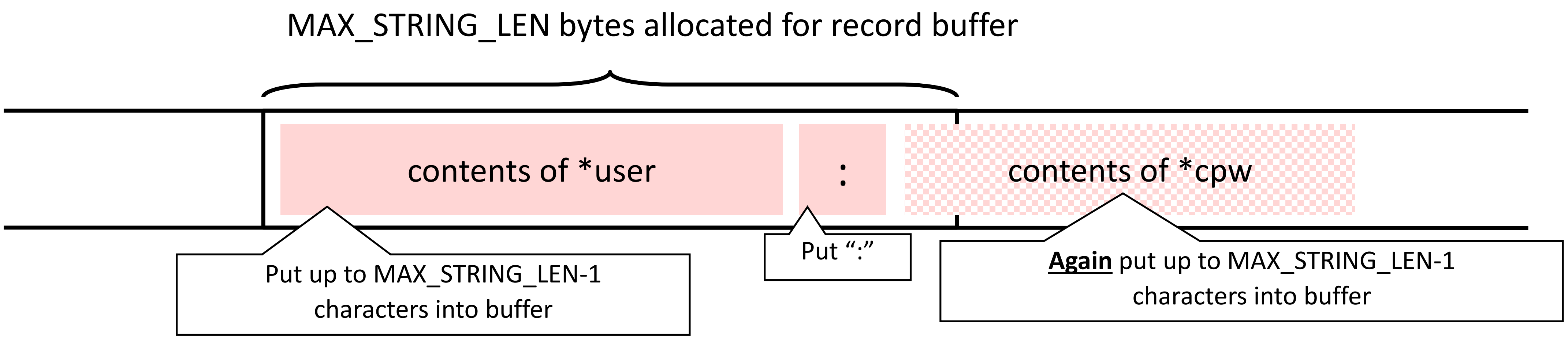
Breakout Activity

Gradescope!

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);
```



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

Gradescope again!

Off-By-One Overflow

- Home-brewed range-checking string copy

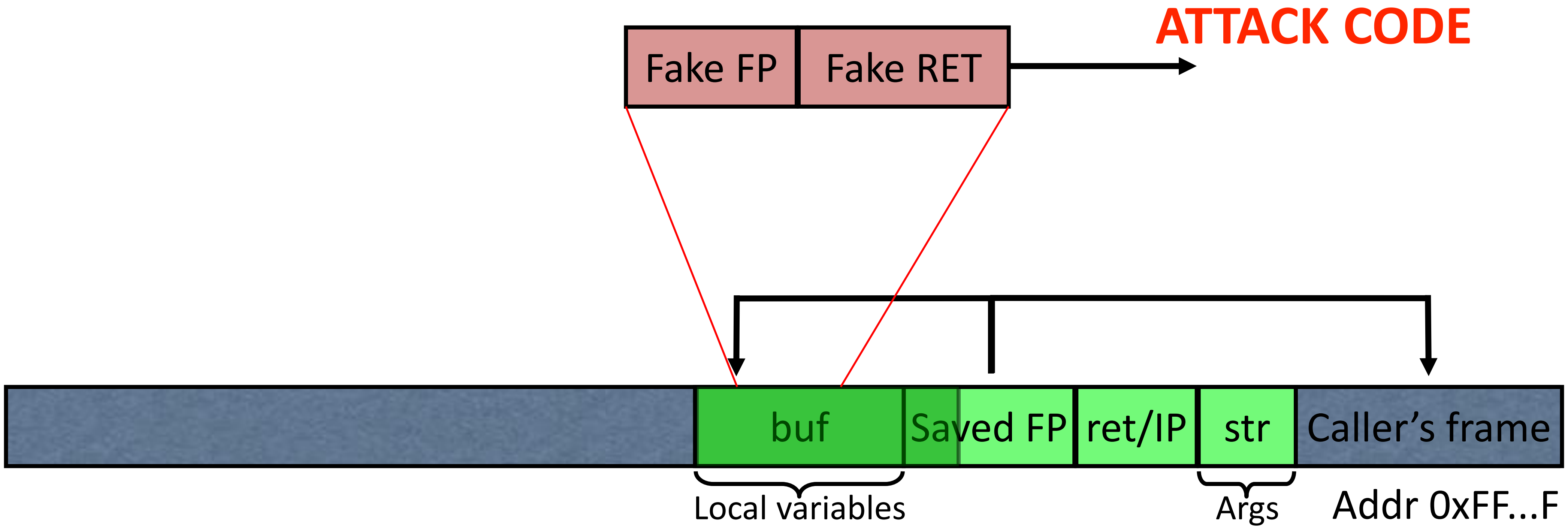
```
void mycopy(char *input) {
  char buffer[512]; int i;

  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!

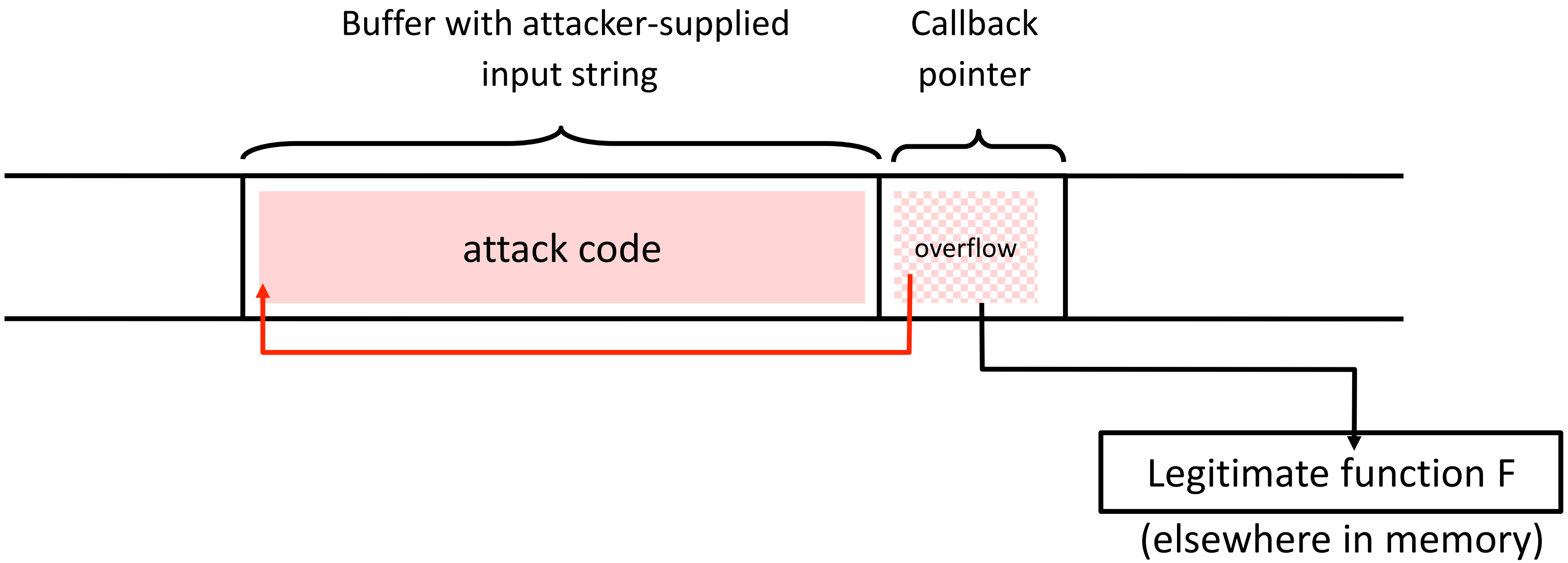
- 1-byte overflow: can't change RET, but can change pointer to previous stack frame…

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 time
- 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 ☺