CSE 484 / CSE M 584: Computer Security and Privacy

Software Security: Buffer Overflow Attacks

Spring 2020

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 ...

Announcements

- Where to find what
  - **Course website:**
    - Schedule (with slide decks, assignment links)
    - Assignments (all homeworks, labs, research readings, final project)
  - **Canvas:**
    - Assignment / Lab / Readings / Project turn-in
    - In-class Activities ("Quizzes")
    - Zoom links and cloud recordings
  - **Ed:**
    - Discussion board (questions, discussion)
- Things Due:
  - Ethics form: Due next Wednesday (4/8)
  - Homework #1: Due next Friday (4/10)

TOWARDS DEFENSES

Approaches to Security

- Prevention
  - Stop an attack
- Detection
  - Detect an ongoing or past attack
- Response
  - Respond to attacks

- The threat of a response may be enough to deter some attackers

Whole System is Critical

- Securing a system involves a whole-system view
  - Cryptography
  - Implementation
  - People
  - Physical security
  - Everything in between

- This is because “security is only as strong as the weakest link,” and security can fail in many places
  - No reason to attack the strongest part of a system if you can walk right around it.

Whole System is Critical

- Securing a system involve
  - Cryptography
  - Implementation
  - People
  - Physical security
  - Everything in between

- This is because "security is only as strong as the weakest link," and security can fail in many places
  - No reason to attack the strongest part of a system if you can walk right around it.

Whole System is Critical

Attacker's Asymmetric Advantage

Attacker's Asymmetric Advantage

- Attacker only needs to win in one place
- Defender's response: Defense in depth

From Policy to Implementation

- After you've figured out what security means to your application, there are still challenges:
  - Requirements bugs
    - Incorrect or problematic goals
  - Design bugs
    - Poor use of cryptography
    - Poor sources of randomness
    - ...
  - Implementation bugs
    - Buffer overflow attacks
    - ...
  - Is the system **usable**?

Many Participants

- Many parties involved
  - System developers
  - Companies deploying the system
  - The end users
  - The adversaries (possibly one of the above)
- Different parties have different goals
  - System developers and companies may wish to optimize cost
  - End users may desire security, privacy, and usability
  - But the relationship between these goals is quite complex
    (will customers choose features or security?)

Better News

- There are a lot of defense mechanisms
  - We’ll study some, but by no means all, in this course
- It’s important to understand their limitations
  - “If you think cryptography will solve your problem, then you don’t understand cryptography… and you don’t understand your problem” -- Bruce Schneier

SOFTWARE SECURITY

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
- 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, ...)

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
  - Now an EECS professor at MIT

- 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.)

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 2

Stack Buffers

- Suppose Web server contains this function

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

untrusted

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

Example: Changing Flags

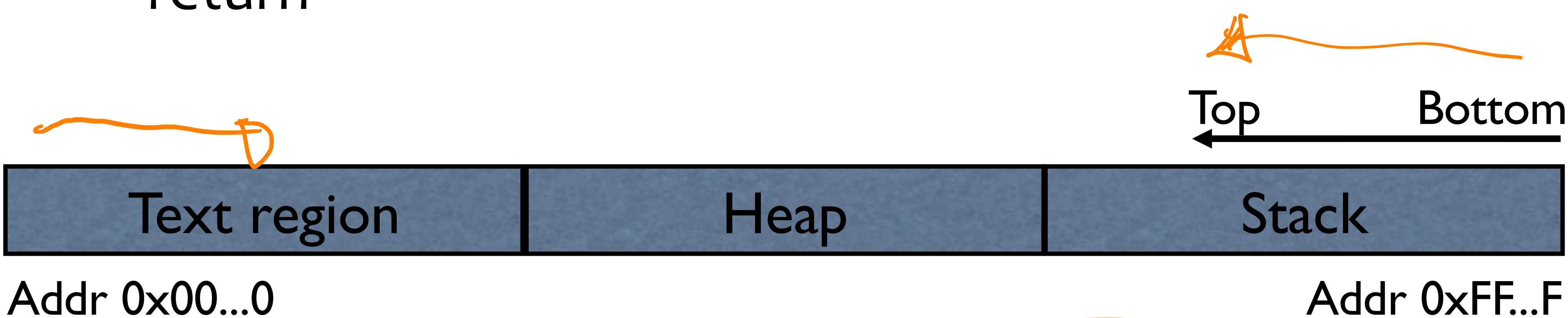
- Suppose Web server contains this function

```
void func(char *str) {
        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

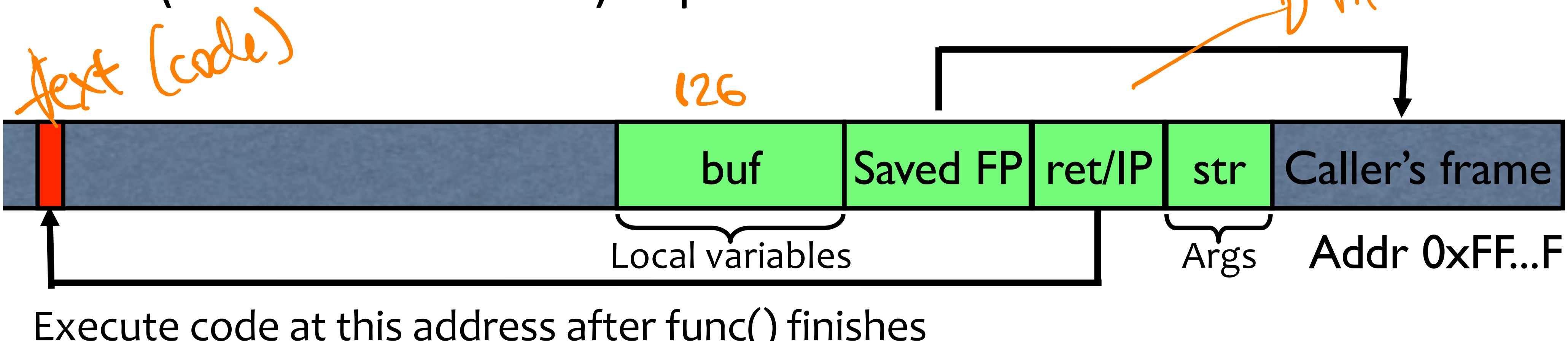
- Suppose Web server contains this function:

```
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?

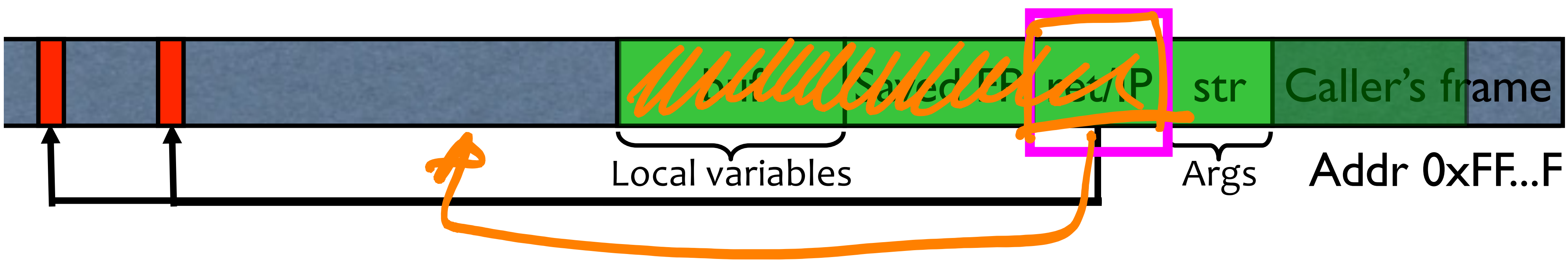
- Memory pointed to by str is copied onto stack…

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

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

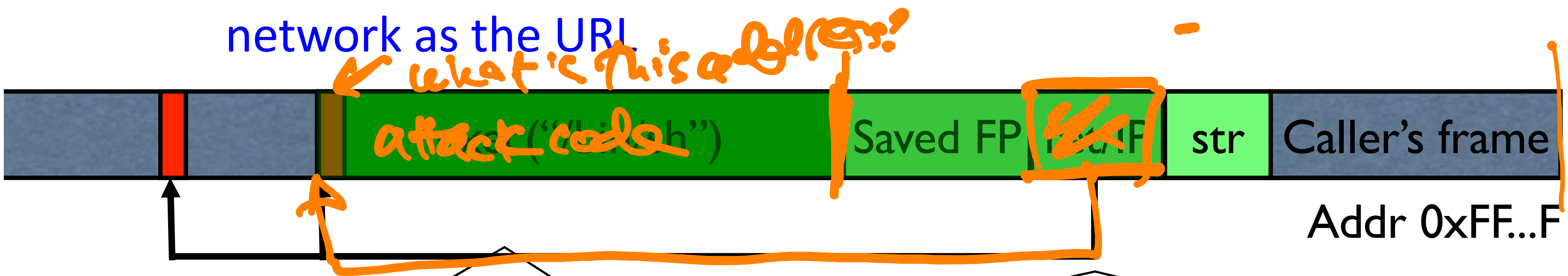
- If a string longer than 126 bytes is copied into buffer, it will overwrite adjacent stack locations.

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



Attacker puts actual assembly instructions into his input string, e.g., binary code of execve("/bin/sh")

In the overflow, a pointer back into the buffer appears in the location where the system expects to find return address

- 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 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?

126 size of buffer

- 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);
```

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 -> April 3

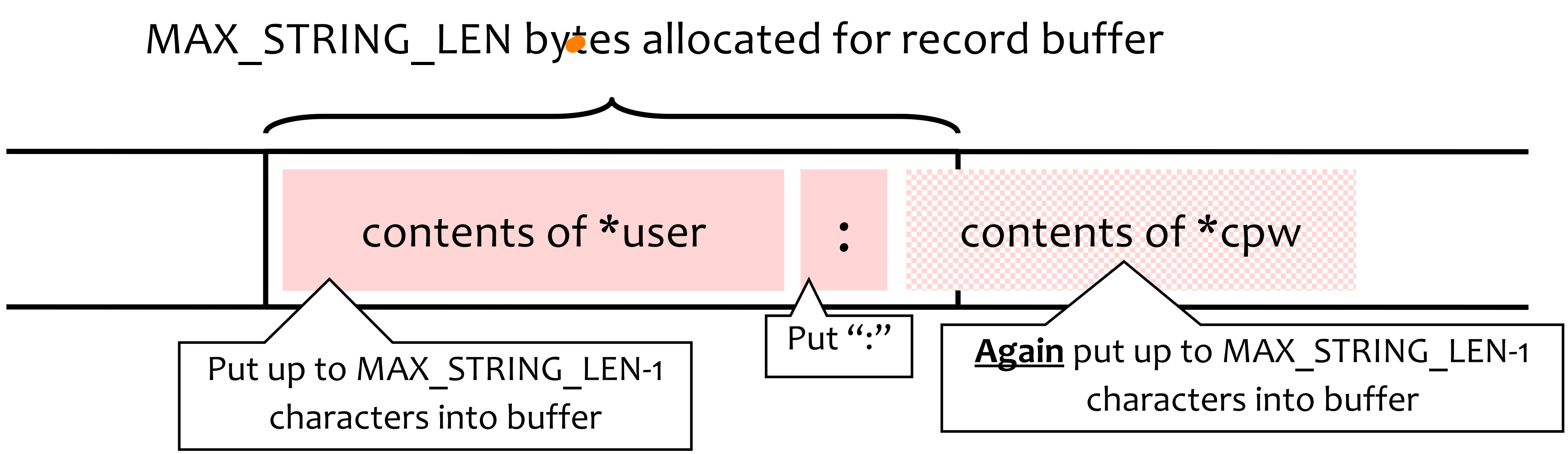
(This one still won't be graded. We will send out an update via email about how we will be counting "in-class" activities before Monday.)

https://canvas.uw.edu/courses/1371936/quizzes/1234443

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]);
}
```

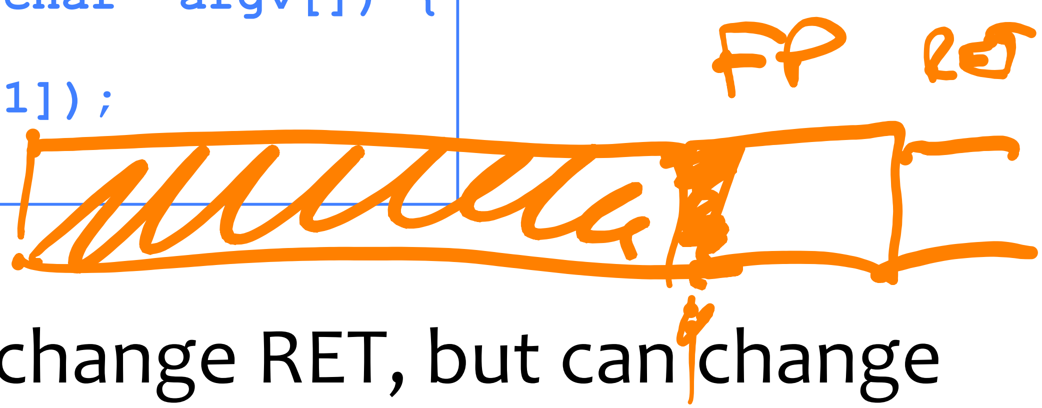
Off-By-One Overflow

- 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...