CSE 484 / CSE M 584: Buffer Overflow Defenses + Misc Software Security

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Announcements

- Lab 1
  - Part 1a due ~~Friday~~ Saturday
    - Outage with unknown cause last night
  - If you haven't created a group and gotten access, please do so **ASAP**
  - Turning things in: **handin.sh, then submit to Canvas**
    - See lab1.pdf description again

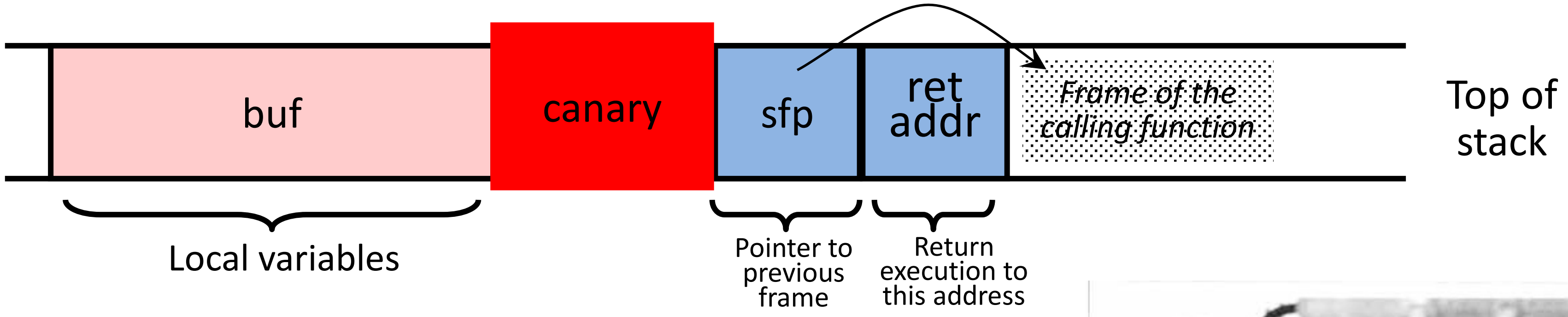
Buffer Overflow: Causes and Cures

- Classical memory exploit involves code injection
  - Put malicious code at a predictable location in memory, usually masquerading as data
  - Trick vulnerable program into passing control to it

- Possible defenses:
  1. Prevent execution of untrusted code
  2. Stack “canaries”
  3. Encrypt or check integrity of pointers
  4. Address space layout randomization
  5. Code analysis
  6. …

Defense: Run-Time Checking: StackGuard

- Embed "canaries" (stack cookies) in stack frames and verify their integrity prior to function return
  - Any overflow of local variables will damage the canary



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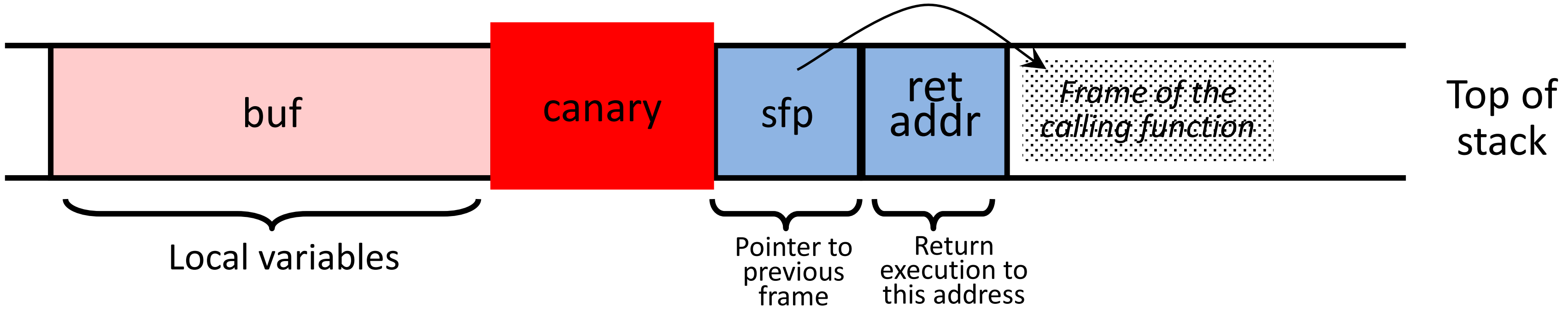


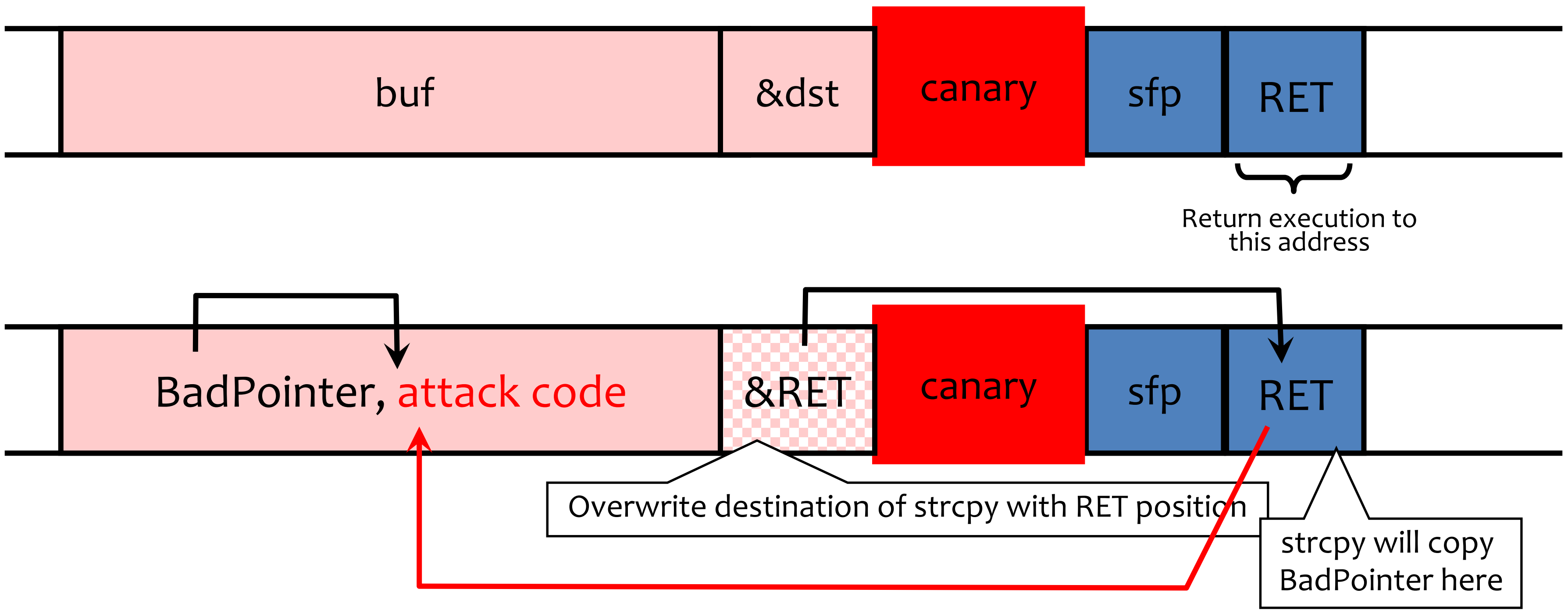
- Choose random canary string on program start
  - Attacker can't guess what the value of canary will be
- Canary contains: "\0", newline, linefeed, EOF
  - String functions like strcpy won't copy beyond "\0"

StackGuard Implementation

- StackGuard requires code recompilation
- Checking canary integrity prior to every function return causes a performance penalty
  - For example, 8% for Apache Web server at one point in time

Defeating StackGuard

- StackGuard can be defeated
  - A single memory write where the attacker controls both the value and the destination is sufficient
- Suppose program contains copy(buf,attacker-input) and copy(dst,buf)
  - Example: dst is a local pointer variable
  - Attacker controls both buf and dst



ASLR: Address Space Randomization

- Randomly arrange address space of key data areas for a process
  - Base of executable region
  - Position of stack
  - Position of heap
  - Position of libraries
- Introduced by Linux PaX project in 2001
- Adopted by OpenBSD in 2003
- Adopted by Linux in 2005

ASLR: Address Space Randomization

- Deployment (examples)
  - Linux kernel since 2.6.12 (2005+)
  - Android 4.0+
  - iOS 4.3+ ; OS X 10.5+
  - Microsoft since Windows Vista (2007)
- Attacker goal: Guess or figure out target address (or addresses)
- ASLR more effective on 64-bit architectures

Attacking ASLR

- **NOP sleds** and **heap spraying** to increase likelihood for adversary's code to be reached (e.g., on heap)
- Brute force attacks or memory disclosures to map out memory on the fly
  - Disclosing a single address can reveal the location of all code within a library, depending on the ASLR implementation

Defense: Shadow Stacks

- Idea: don't store return addresses on the stack!
- Store them on… a different stack!
  - A *hidden* stack
- On function call/return
  - Store/retrieve the return address from shadow stack
- Or store on both main stack and shadow stack, and compare for equality at function return
- 2020/2021 Hardware Support emerged (e.g., Intel Tiger Lake, AMD Ryzen PRO 5000)

Challenges With Shadow Stacks

- Where do we put the shadow stack?
  - Can the attacker figure out where it is? Can they access it?
- How fast is it to store/retrieve from the shadow stack?
- How *big* is the shadow stack?
- Is this compatible with all software?
- (Still need to consider data corruption attacks, even if attacker can't influence control flow.)

Other Big Classes of Defenses

- Use safe programming languages, e.g., Java, Rust
  - What about legacy C code?
  - (Though Java doesn't magically fix all security issues ☺)
- Static analysis of source code to find overflows
- Dynamic testing: "fuzzing"

Fuzz Testing

- Generate "random" inputs to program
  - Sometimes conforming to input structures (file formats, etc.)
- See if program crashes
  - If crashes, found a bug
  - Bug may be exploitable
- Surprisingly effective

- Now standard part of development lifecycle

Other Common Software Security Issues…

Another Type of Vulnerability

- Consider this code:

```
char buf[80];
void vulnerable() {
     int len = read_int_from_network();
     char *p = read_string_from_network();
     if (len > sizeof buf) {
          error("length too large, nice try!");
          return;
     }
     memcpy(buf, p, len);
}
```

```
void *memcpy(void *dst, const void * src, size_t n);
```

```
typedef unsigned int size_t;
```

Another Example

```
size_t len = read_int_from_network();
char *buf;
buf = malloc(len+5);
read(fd, buf, len);
```

Canvas -> Quizzes -> Oct 10

(from www-inst.eecs.berkeley.edu—implflaws.pdf)

Implicit Cast

- Consider this code:

```
char buf[80];
void vulnerable() {
     int len = read_int_from_network();
     char *p = read_string_from_network();
     if (len > sizeof buf) {
          error("length too large, nice try!");
          return;
     }
     memcpy(buf, p, len);
}
```

If len is negative, may copy huge amounts of input into buf.

```
void *memcpy(void *dst, const void * src, size_t n);
```

```
typedef unsigned int size_t;
```

Integer Overflow

```
size_t len = read_int_from_network();
char *buf;
buf = malloc(len+5);
read(fd, buf, len);
```

- What if len is large (e.g., len = 0xFFFFFFFF)?
- Then len + 5 = 4 (on many platforms)
- Result: Allocate a 4-byte buffer, then read a lot of data into that buffer.

(from [www-inst.eecs.berkeley.edu—implflaws.pdf]())

Another Type of Vulnerability

- Consider this code:

```
if (access("file", W_OK) != 0) {
  exit(1); // user not allowed to write to file
}

fd = open("file", O_WRONLY);
write(fd, buffer, sizeof(buffer));
```

- **Goal:** Write to file only with permission
- What can go wrong?

TOCTOU (Race Condition)

- TOCTOU = "Time of Check to Time of Use"

```
if (access("file", W_OK) != 0) {
   exit(1); // user not allowed to write to file
}

fd = open("file", O_WRONLY);
write(fd, buffer, sizeof(buffer));
```

- **Goal:** Write to file only with permission
- Attacker (in another program) can change meaning of "file" between access and open:

```
symlink("/etc/passwd", "file");
```