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
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

- 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

![Diagram](image-url)

Return execution to this address:

- Overwrite destination of `strcpy` with RET position
- strcpy will copy BadPointer here

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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:

```c
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

```c
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](www-inst.eecs.berkeley.edu—implflaws.pdf))
Implicit Cast

• Consider this code:

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    }
    memcpy(buf, p, len);
}

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

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

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.

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

(from www-inst.eecs.berkeley.edu—implflaws.pdf)
Another Type of Vulnerability

- Consider this code:

```c
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”

```c
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:

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