CSE 484 / CSE M 584: Computer Security and Privacy

Software Security: Buffer Overflow Attacks

(continued)

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Admin

- Lab 1 out, groups being formed
  - Come to quiz section this week!

- Looking forward
  - This week: More buffer overflows + beyond
  - Also this week: Transition to crypto

Buffer Overflow: Causes and Cures

- Typical memory exploit involves code injection
  - Classic approach: 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 pointers
  4. Address space layout randomization
  5. Code analysis
  6. …

Executable Space Protection

- Mark all writeable memory locations as non-executable
  - Example: Microsoft's Data Execution Prevention (DEP)
  - This blocks many code injection exploits
- Hardware support
  - AMD "NX" bit (no-execute), Intel "XD" bit (executed disable) (in post-2004 CPUs)
  - Makes memory page non-executable
- Widely deployed
  - Windows XP SP2+ (2004), Linux since 2004 (check distribution), OS X 10.5+ (10.4 for stack but not heap), Android 2.3+

What Does "Executable Space Protection" Not Prevent?

- Can still corrupt stack …
  - … or function pointers or critical data on the heap
- **As long as "saved EIP" points into existing code, executable space protection will not block control transfer**
- This is the basis of return-to-libc exploits
  - Overwrite saved EIP with address of any library routine, arrange stack to look like arguments
- Does not look like a huge threat
  - Attacker cannot execute arbitrary code
  - But … ?

return-to-libc

- Can still call critical functions, like exec
- See lab 1, sploit 8

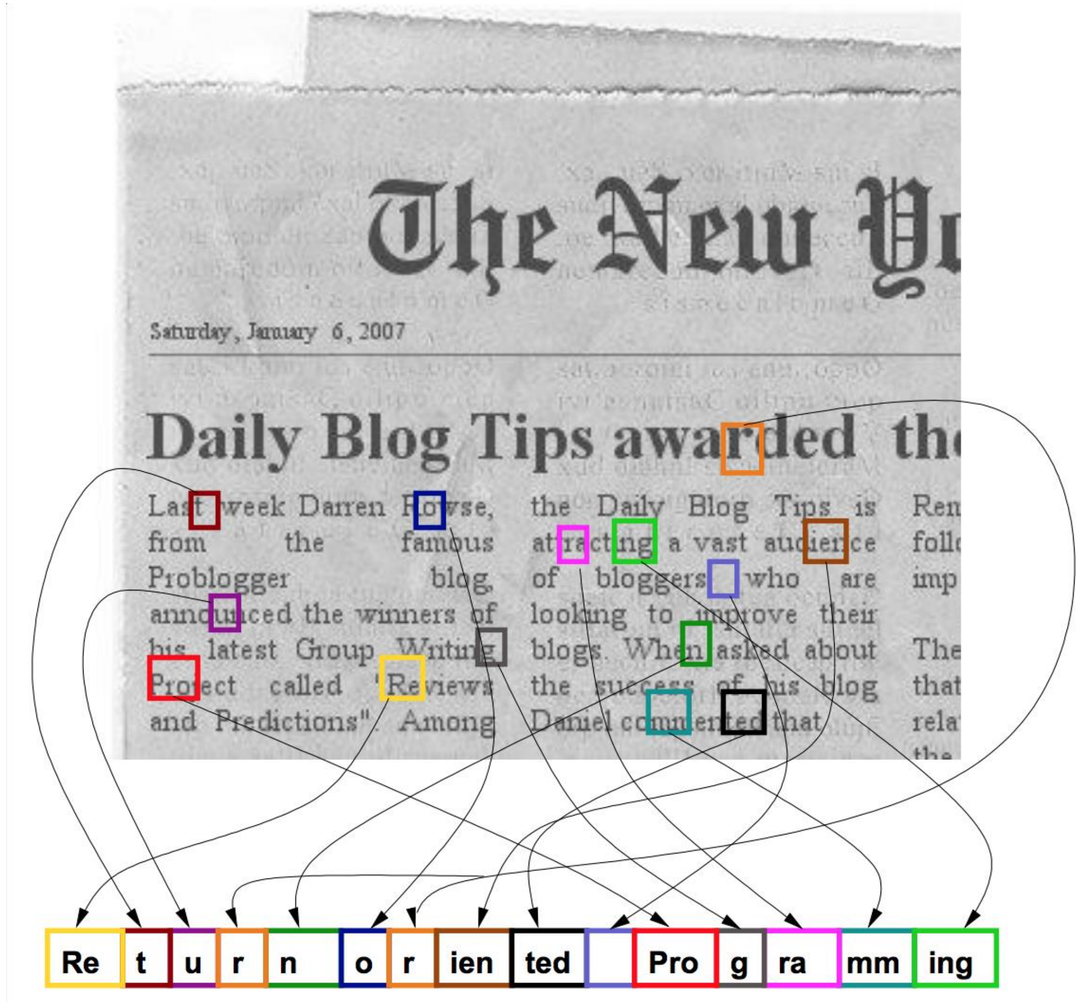
return-to-libc on Steroids

- Overwritten saved EIP need not point to the beginning of a library routine
- **Any** existing instruction in the code image is fine
  - Will execute the sequence starting from this instruction
- What if instruction sequence contains RET?
  - Execution will be transferred… to where?
  - Read the word pointed to by stack pointer (ESP)
    - Guess what? Its value is under attacker's control!
  - Use it as the new value for EIP
    - Now control is transferred to an address of attacker's choice!
  - Increment ESP to point to the next word on the stack

Chaining RETs for Fun and Profit

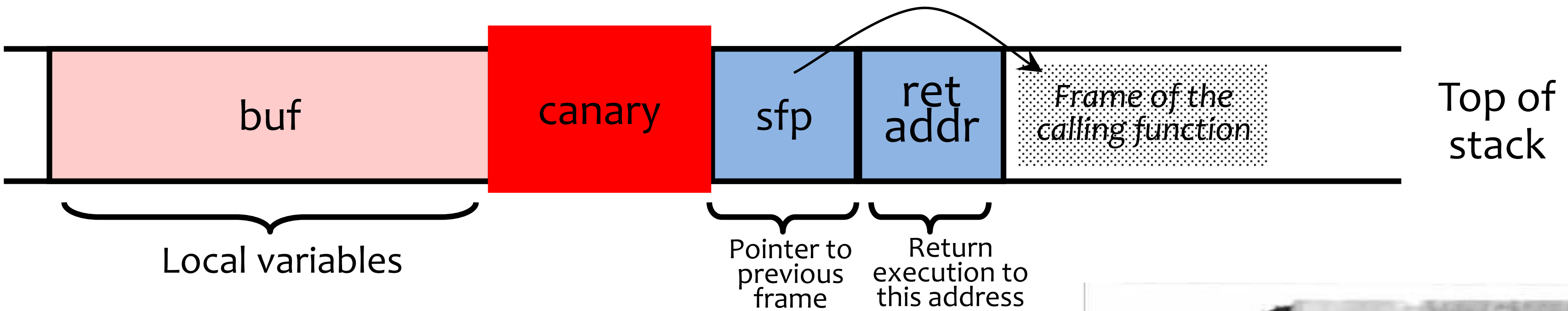
- Can chain together sequences ending in RET
  - Krahmer, “x86-64 buffer overflow exploits and the borrowed code chunks exploitation technique” (2005)
- What is this good for?
- Answer [Shacham et al.]: everything
  - Turing-complete language
  - Build “gadgets” for load-store, arithmetic, logic, control flow, system calls
  - Attack can perform arbitrary computation using no injected code at all – return-oriented programming

Return-Oriented Programming



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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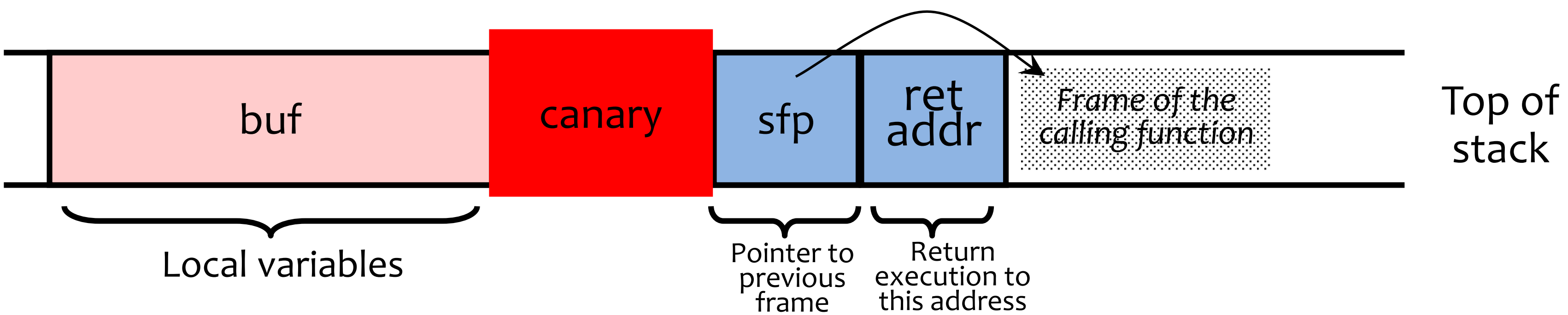


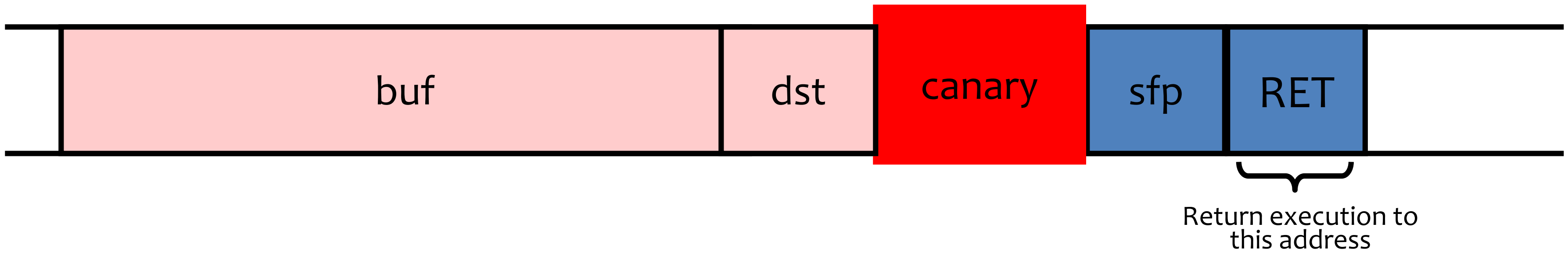
- Choose random canary string on program start
  - Attacker can't guess what the value of canary will be
- Terminator canary: "\0", newline, linefeed, EOF
  - String functions like strcpy won't copy beyond "\0"

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
- StackGuard can be defeated
  - A single memory write where the attacker controls both the value and the destination is sufficient

Defeating StackGuard

- Suppose program contains strcpy(dst,buf) where attacker controls both dst and buf
  - Example: dst is a local pointer variable



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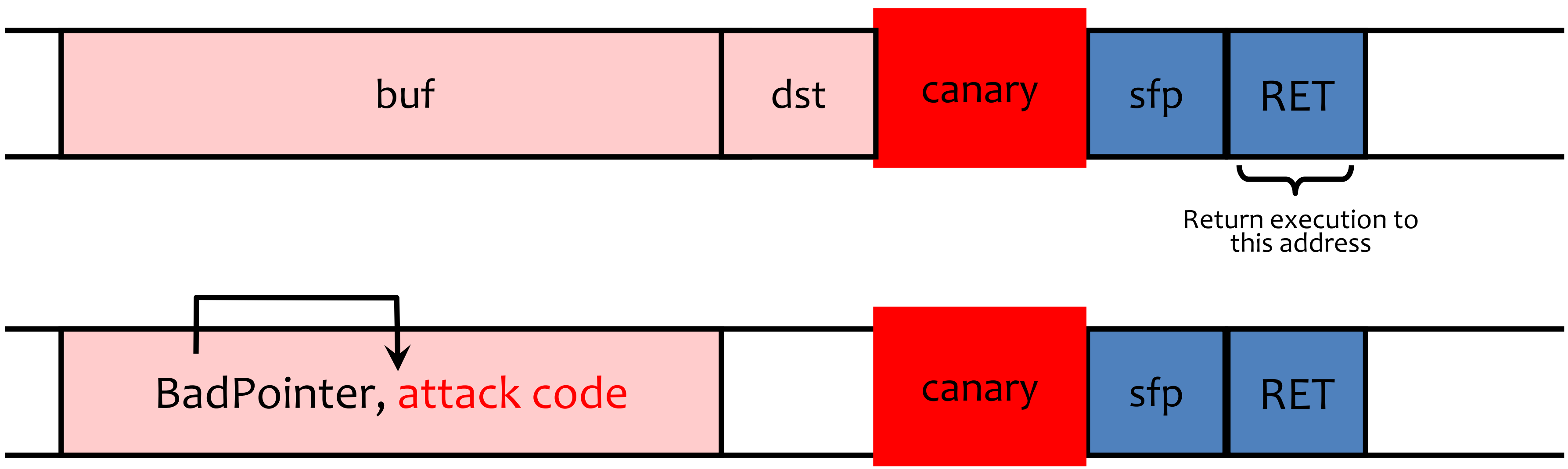

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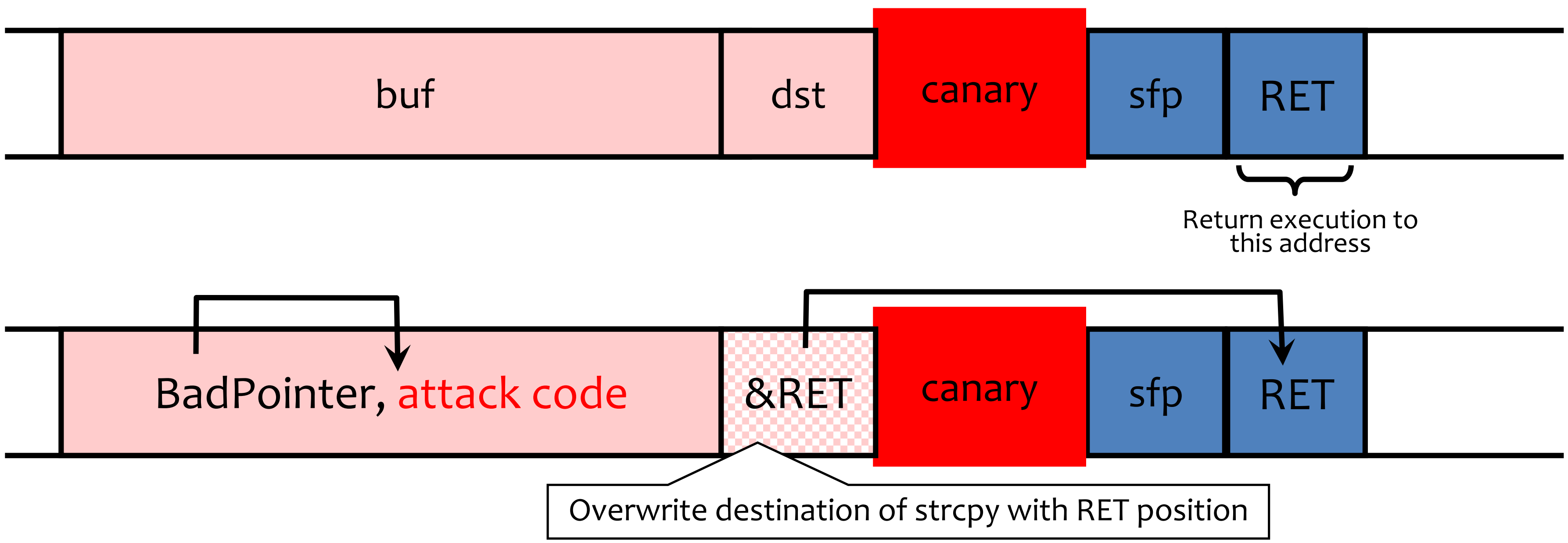

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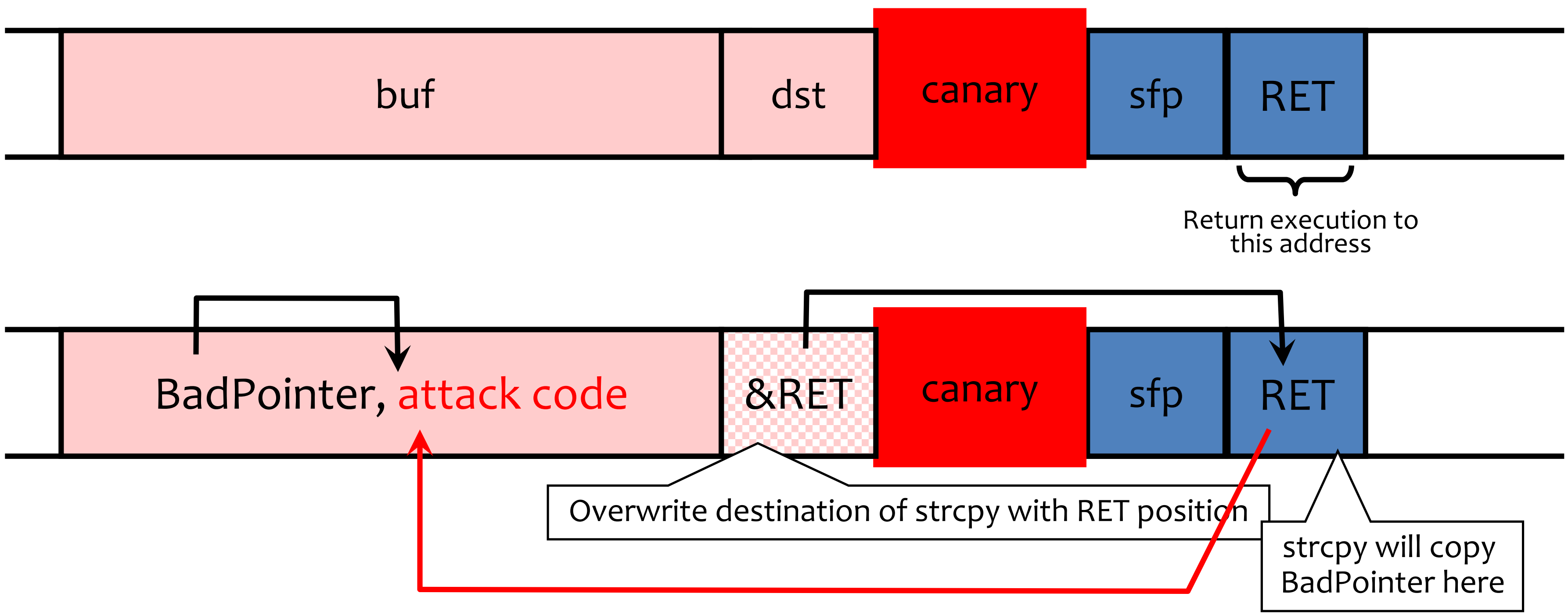

More on Defeating StackGuard

- Attacker sets buf to contain (first) a pointer to another region in buf with the attack code, and then (second) the attack code
- Attacker sets dst, to contain the address where RET is stored (recall the assumption that the attacker can also set dst)
- When the strcpy happens, memory beginning at the address of RET is overwritten with the contents of buf
  - This puts “BadPointer” in the location of RET
  - Recall that “BadPointer” is a value for the address at which the attack code starts (in buf)

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) (not by default)
- Attacker goal: Guess or figure out target address (or addresses)
- ASLR more effective on 64-bit architectures

ASLR Issues

- NOP slides and heap spraying to increase likelihood for custom code (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

Other Possible Solutions

- Use safe programming languages, e.g., Java
  - 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"
- Modern compiler options, e.g., incorporate stack canaries

Beyond Buffer Overflows…

Another Type of Vulnerability

- Consider this code:

```
int openfile(char *path) {
      struct stat s;
      if (stat(path, &s) < 0)
            return -1;
      if (!S_ISRREG(s.st_mode)) {
            error("only allowed to regular files!");
            return -1;
      }
      return open(path, O_RDONLY);
}
```

- **Goal:** Open only regular files (not symlink, etc)
- What can go wrong?

TOCTOU (Race Condition)

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

```
int openfile(char *path) {
    struct stat s;
    if (stat(path, &s) < 0)
        return -1;
    if (!S_ISRREG(s.st_mode)) {
        error("only allowed to regular files!");
        return -1;
    }
    return open(path, O_RDONLY);
}
```

- **Goal:** Open only regular files (not symlink, etc)
- Attacker can change meaning of path between stat and open (and access files he or she shouldn't)

This TOCTOU Example

- In call to open, pass O_NOFOLLOW to not follow symbolic links
- Call fstat on open file descriptor
- …
- Nice reference: https://developer.apple.com/library/archive/documentation/Security/Conceptual/SecureCodingGuide/Articles/RaceConditions.html

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;
```

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;
```

Another Example

```
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)

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)