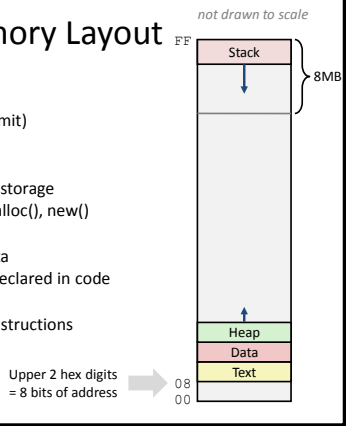
Lecture 18

Buffer Overflow

CPSC 275
Introduction to Computer Systems

IA32 Linux Memory Layout

- Stack
  - Runtime stack (8MB limit)
  - e. g., local variables
- Heap
  - Dynamically allocated storage
  - When call malloc(), calloc(), new()
- Data
  - Statically allocated data
  - e.g., arrays & strings declared in code
- Text
  - Executable machine instructions
  - Read-only



Memory Allocation Example

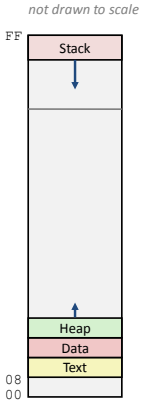
```
char big_array[1<<24];  /*  16 MB */
char huge_array[1<<28]; /* 256 MB */

int beyond;
char *p1, *p2, *p3, *p4;

int useless() {  return 0; }

int main()
{
 p1 = malloc(1 <<28);  /* 256 MB */
 p2 = malloc(1 << 8);  /* 256 B  */
 p3 = malloc(1 <<28);  /* 256 MB */
 p4 = malloc(1 << 8);  /* 256 B  */
 /* Some print statements ... */
}
```

Where does everything go?

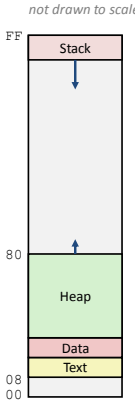


IA32 Example Addresses

address range ~2^{32}

$esp	0xffffbcd0
p3	0x65586008
p1	0x55585008
p4	0x1904a110
p2	0x1904a008
&p2	0x18049760
&beyond	0x08049744
big_array	0x18049780
huge_array	0x08049760
main()	0x080483c6
useless()	0x08049744
malloc()	0x006be166

`malloc()` is dynamically linked
address determined at runtime



Internet Worm

- November, 1988
  - Internet Worm attacks thousands of Internet hosts.
  - How did it happen?
- It was based on *stack buffer overflow* exploits!
  - Many library functions do not check argument sizes.
  - Allows target buffers to overflow.

String Library Code

- Implementation of C Standard Library function **`gets()`**

```
/* Get string from stdin */
char *gets(char *dest)
{
    int c = getchar();
    char *p = dest;
    while (c != EOF && c != '\n') {
        *p++ = c;
        c = getchar();
    }
    *p = '\0';
    return dest;
}
```

- No way to specify limit on number of characters to read

String Library Code (con't)

- Similar problems with other library functions
  - **`strcpy`, `strcat`**: Copy strings of arbitrary length
  - **`scanf`, `fscanf`, `sscanf`,** when given **`%s`** conversion specification

Vulnerable Buffer Code

```
/* Echo Line */
void echo()
{
    char buf[4];  /* Way too small! */
    gets(buf);
    puts(buf);
}
```

```
void call_echo() {
    echo();
}
```

```
$ ./bufdemo
Type a string:123
123
```

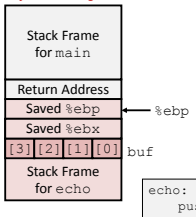
```
$ ./bufdemo
Type a string:1234567
Segmentation Fault
```

```
$ ./bufdemo
Type a string:12345678
Segmentation Fault
```

```
$ ./bufdemo
Type a string:123456789ABC
Segmentation Fault
```

Buffer Overflow Stack

Before call to gets



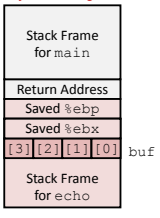

```
/* Echo Line */
void echo()
{
    char buf[4];  /* Way too small! */
    gets(buf);
    puts(buf);
}
```

```
echo:
    pushl %ebp              # Save %ebp on stack
    movl  %esp, %ebp
    pushl %ebx              # Save %ebx
    subl  $20, %esp         # Allocate stack space
    leal  -8(%ebp),%ebx     # Compute buf as %ebp-8
    movl  %ebx, (%esp)      # Push buf on stack
    call  gets              # Call gets
    . . .
```

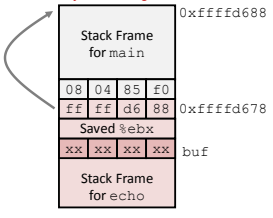
Buffer Overflow Stack Example

```
$ gdb bufdemo
(gdb) break echo
Breakpoint 1 at 0x80485c9
(gdb) run
Breakpoint 1, 0x80485c9 in echo ()
(gdb) print /x $ebp
$1 = 0xffffd678
(gdb) print /x *(unsigned *)$ebp
$2 = 0xffffd688
(gdb) print /x *((unsigned *)$ebp + 1)
$3 = 0x80485f0
```

Before call to gets



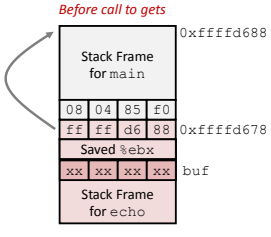
Before call to gets



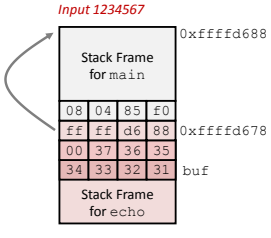

```
80485eb:  e8 d5 ff ff ff    call   80485c5 <echo>
80485f0:  c9                leave
```

Buffer Overflow Example #1

Before call to gets



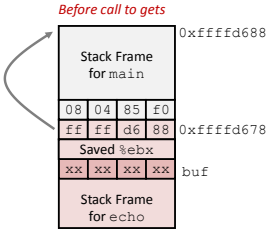
Input 1234567



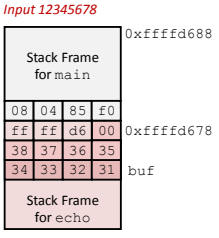
Overflow buf and corrupt %ebx

Buffer Overflow Example #2

Before call to gets



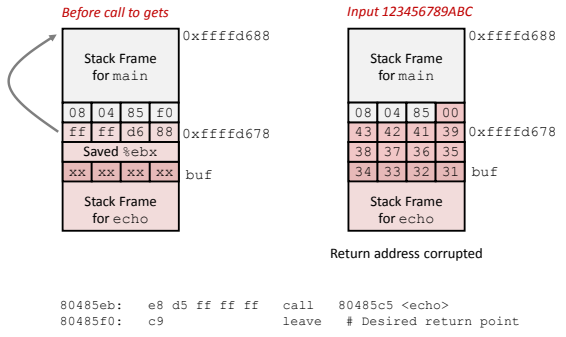
Input 12345678



Base pointer corrupted

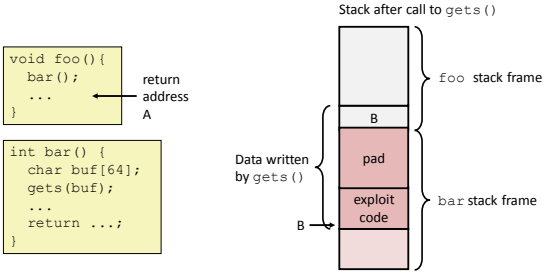
```
. . .
80485eb:   e8 d5 ff ff ff   call   80485c5 <echo>
80485f0:   c9               leave    # Set %ebp to corrupted value
80485f1:   c3               ret
```

Buffer Overflow Example #3




```
80485eb:    e8 d5 ff ff ff    call   80485c5 <echo>
80485f0:    c9                leave  # Desired return point
```

Malicious Use of Buffer Overflow



- Input string contains byte representation of executable code
- Overwrite return address A with address of buffer B
- When `bar()` executes `ret`, will jump to exploit code

Exploits Based on Buffer Overflows

- *Buffer overflow bugs allow remote machines to execute arbitrary code on victim machines*
- Internet worm
  - Early versions of the finger server (**fingerd**) used **`gets()`** to read the argument sent by the client:
    - **`finger pyoon@lab.cs.trincoll.edu`**
  - Worm attacked fingerd server by sending phony argument:
    - **`finger "exploit-code padding new-return-address"`**
    - exploit code: executed a root shell on the victim machine with a direct TCP connection to the attacker.

Avoiding Overflow Vulnerability

```
/* Echo Line */
void echo()
{
    char buf[4];  /* Way too small! */
    fgets(buf, 4, stdin);
    puts(buf);
}
```

- Use library routines that limit string lengths
  - **`fgets`** instead of **`gets`**
  - **`strncpy`** instead of **`strcpy`**
  - Don't use **`scanf`** with **`%s`** conversion specification
    - Use **`fgets`** to read the string
    - Or use **`%ns`** where **`n`** is a suitable integer

System-Level Protections

- Randomized stack offsets
  - At start of program, allocate random amount of space on stack
  - Makes it difficult for hacker to predict beginning of inserted code
- Nonexecutable code segments
  - In traditional x86, can mark region of memory as either "read-only" or "writeable"
    - Can execute anything readable
  - X86-64 added explicit "execute" permission

```
$ gdb bufdemo
(gdb) break echo

(gdb) run
(gdb) print /x $ebp
$1 = 0xffffc638

(gdb) run
(gdb) print /x $ebp
$2 = 0xffffbb08

(gdb) run
(gdb) print /x $ebp
$3 = 0xffffc6a8
```

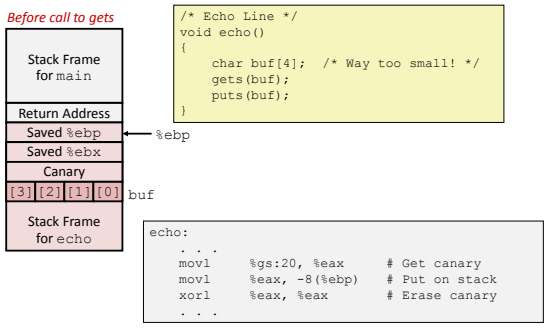
Stack Canaries

- Idea
  - Place special value ("canary") on stack just beyond buffer
  - Check for corruption before exiting function
- gcc Implementation
  - **`-fstack-protector`**
  - **`-fstack-protector-all`**

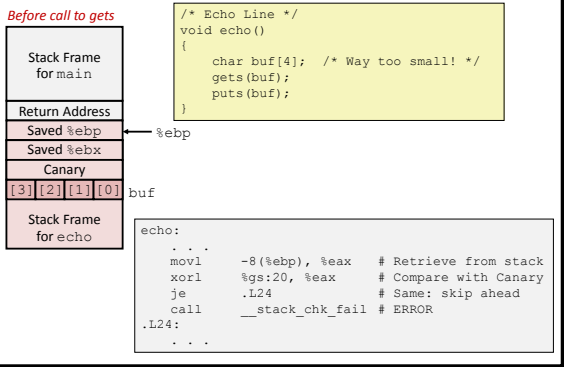
```
$ ./bufdemo-protected
Type a string:123
123
```

```
$ ./bufdemo-protected
Type a string:12345
*** stack smashing detected ***
```

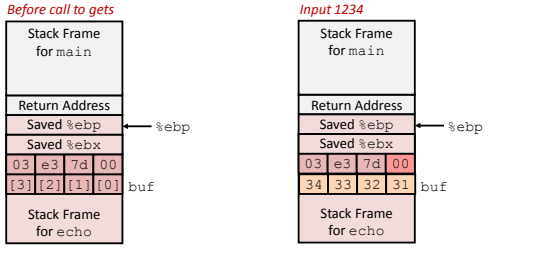
Setting Up Canary



Checking Canary



Canary Example




```
(gdb) break echo
(gdb) run
(gdb) stepi 3
(gdb) print /x *((unsigned *) $ebp - 2)
$1 = 0x3e37d00
```

Benign corruption!
(allows programmers to make silent off-by-one errors)

Worms and Viruses

- Worm: A program that
  - Can run by itself
  - Can propagate a fully working version of itself to other computers
- Virus: Code that
  - Add itself to other programs
  - Cannot run independently
- Both are (usually) designed to spread among computers and to wreak havoc

Practice Problems

- Read CSaPP Sec. 3.12 and try the following problems:

  3.43, 3.44 and 3.45