CI-1220 Ensamblador y Microprocesadores

Memory Layout and
Buffer Overflows

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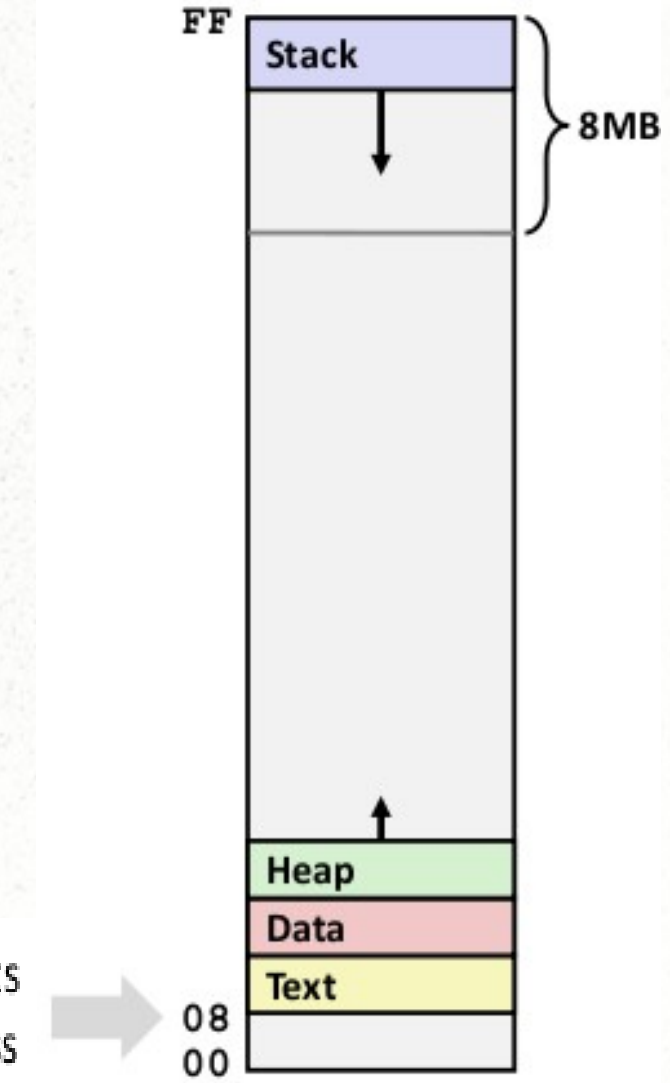
IA32/Linux Memory Layout

- **Stack**
  - Runtime stack (8MB limit)
- **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

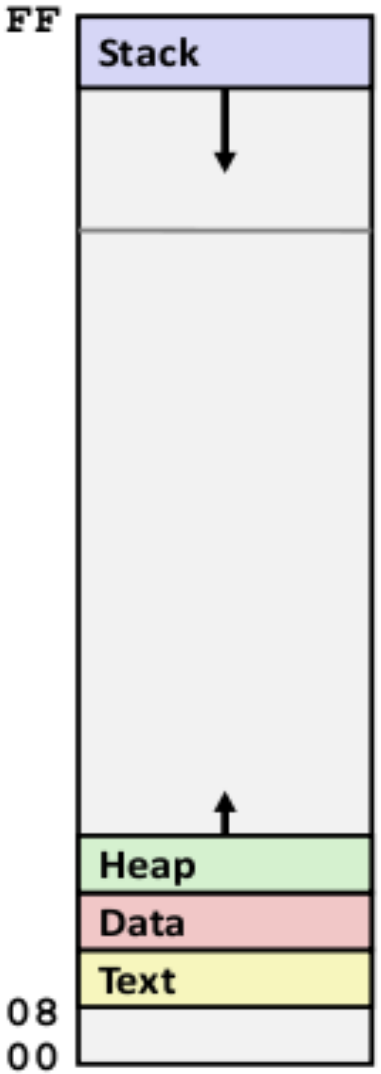


Memory Allocation Example

```
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?

not drawn to scale



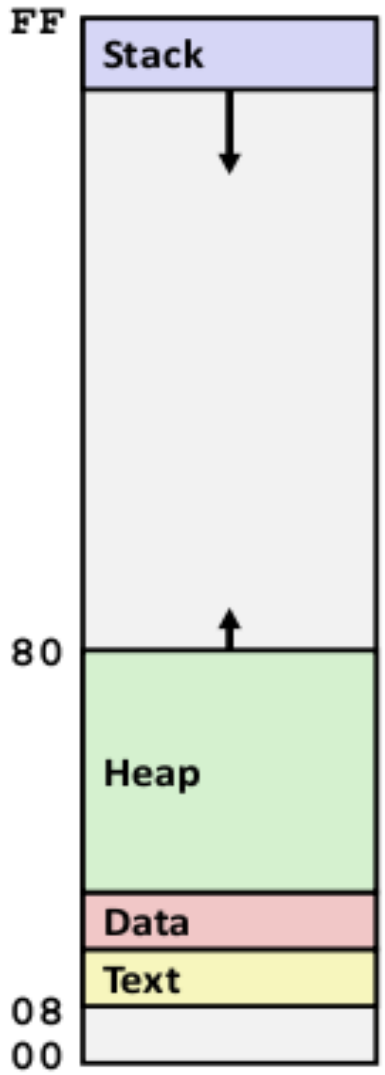
IA32 Example Addresses

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
final malloc()	0x006be166

malloc() is dynamically linked
address determined at runtime

not drawn to scale



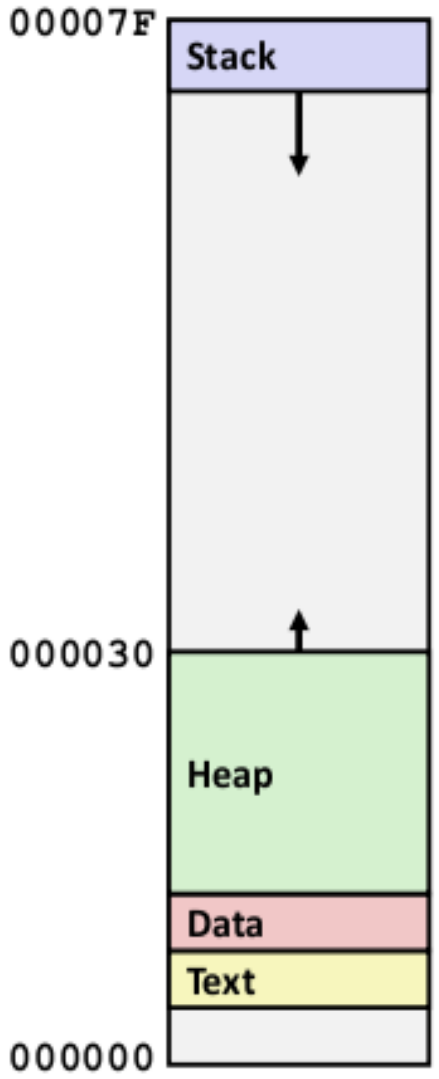
X86-64 Example Addresses

address range ~2^{47}

`$rsp`	`0x7fffffff8d1f8`
`p3`	`0x2aaabaadd010`
`p1`	`0x2aaaaaadc010`
`p4`	`0x000011501120`
`p2`	`0x000011501010`
`&p2`	`0x000010500a60`
`beyond`	`0x000000500a44`
`big_array`	`0x000010500a80`
`huge_array`	`0x000000500a50`
`main()`	`0x000000400510`
`useless()`	`0x000000400500`
`final malloc()`	`0x00386ae6a170`

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

not drawn to scale



Security Problems with Memory Management

Problems with String Library Code

- **Implementation of Unix 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
- **Similar problems with other Unix functions**
  - **`strcpy`**: Copies string 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);
}
```

```
int main()
{
  printf("Type a string:");
  echo();
  return 0;
}
```

```
unix>./bufdemo
Type a string:1234567
1234567
```

```
unix>./bufdemo
Type a string:12345678
Segmentation Fault
```

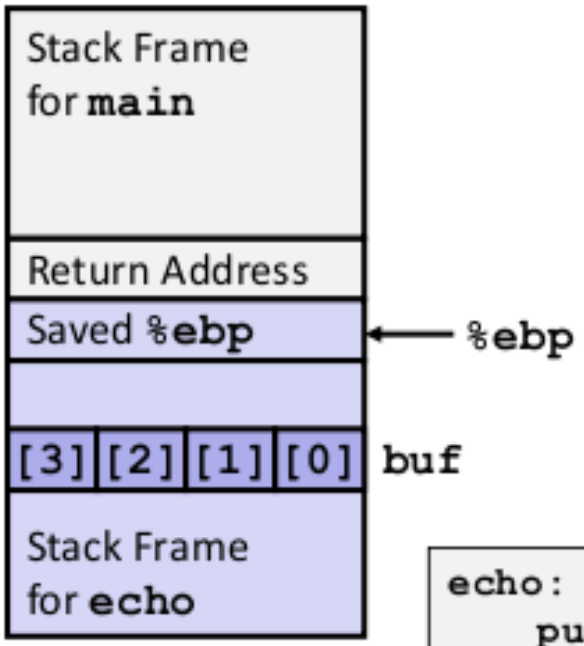
```
unix>./bufdemo
Type a string:123456789ABC
Segmentation Fault
```

Buffer Overflow Disassembly

```
080484f0 <echo>:
 80484f0:   55                      push   %ebp
 80484f1:   89 e5                   mov    %esp,%ebp
 80484f3:   53                      push   %ebx
 80484f4:   8d 5d f8                lea    0xfffffff8(%ebp),%ebx
 80484f7:   83 ec 14                sub    $0x14,%esp
 80484fa:   89 1c 24                mov    %ebx,(%esp)
 80484fd:   e8 ae ff ff ff          call   80484b0 <gets>
 8048502:   89 1c 24                mov    %ebx,(%esp)
 8048505:   e8 8a fe ff ff          call   8048394 <puts@plt>
 804850a:   83 c4 14                add    $0x14,%esp
 804850d:   5b                      pop    %ebx
 804850e:   c9                      leave
 804850f:   c3                      ret

 80485f2:   e8 f9 fe ff ff          call   80484f0 <echo>
 80485f7:   8b 5d fc                mov 0xfffffffc(%ebp),%ebx
 80485fa:   c9                      leave
 80485fb:   31 c0                   xor    %eax,%eax
 80485fd:   c3                      ret
```

Buffer Overflow Stack

Before call to gets

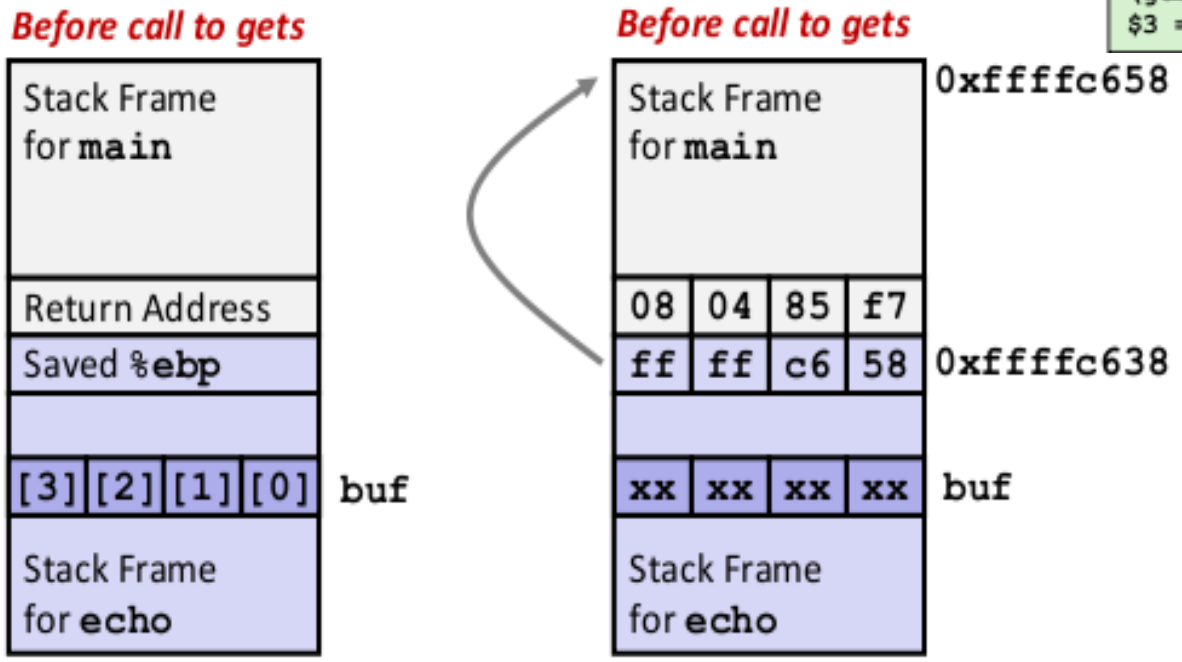



```
/* Echo Line */
void echo()
{
    char buf[4];  /* Way too small! */
    gets(buf);
    puts(buf);
}
```

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

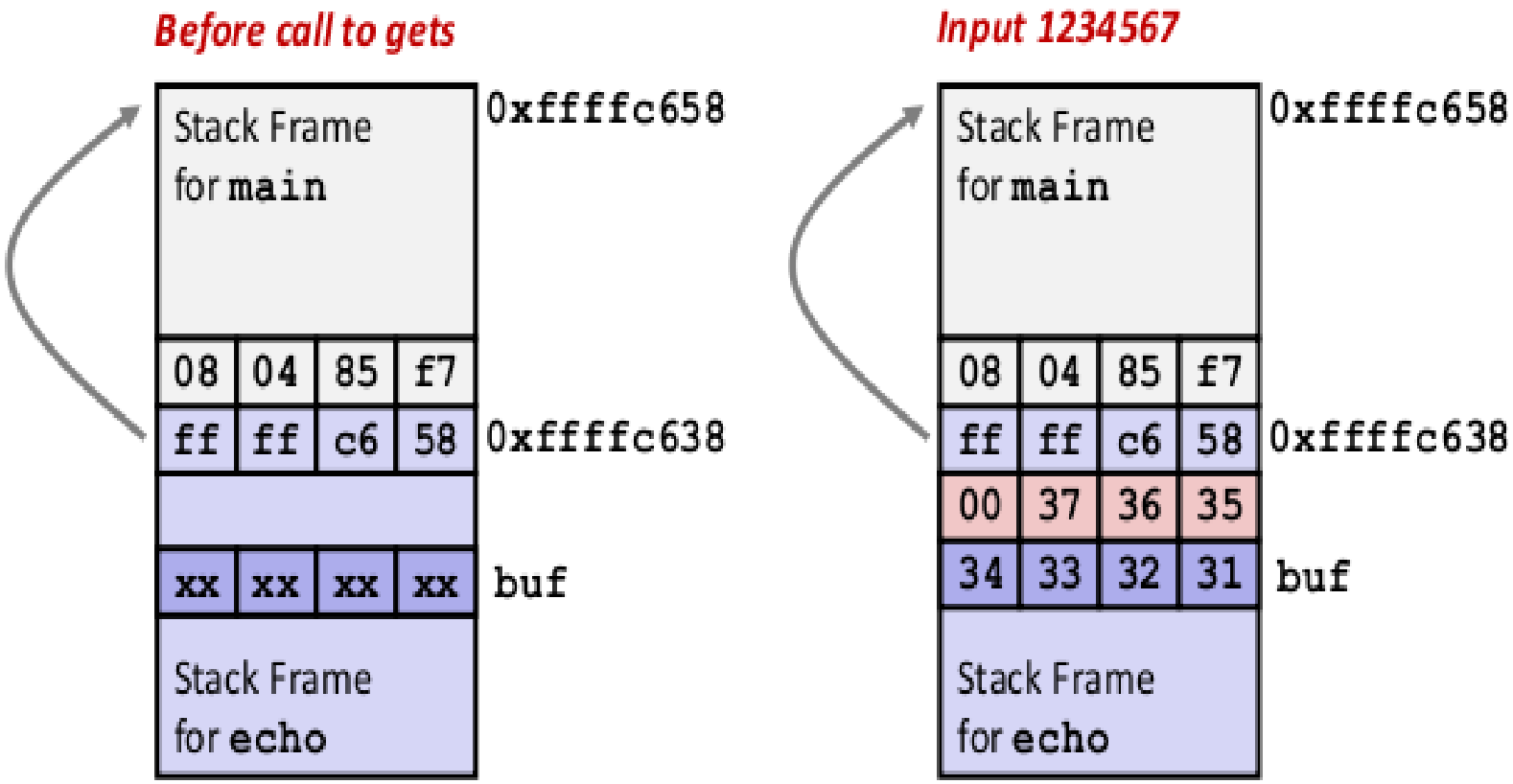
Buffer Overflow Stack Example

```
unix> gdb bufdemo
(gdb) break echo
Breakpoint 1 at 0x8048583
(gdb) run
Breakpoint 1, 0x8048583 in echo ()
(gdb) print /x $ebp
$1 = 0xffffc638
(gdb) print /x *(unsigned *)$ebp
$2 = 0xffffc658
(gdb) print /x *((unsigned *)$ebp + 1)
$3 = 0x80485f7
```



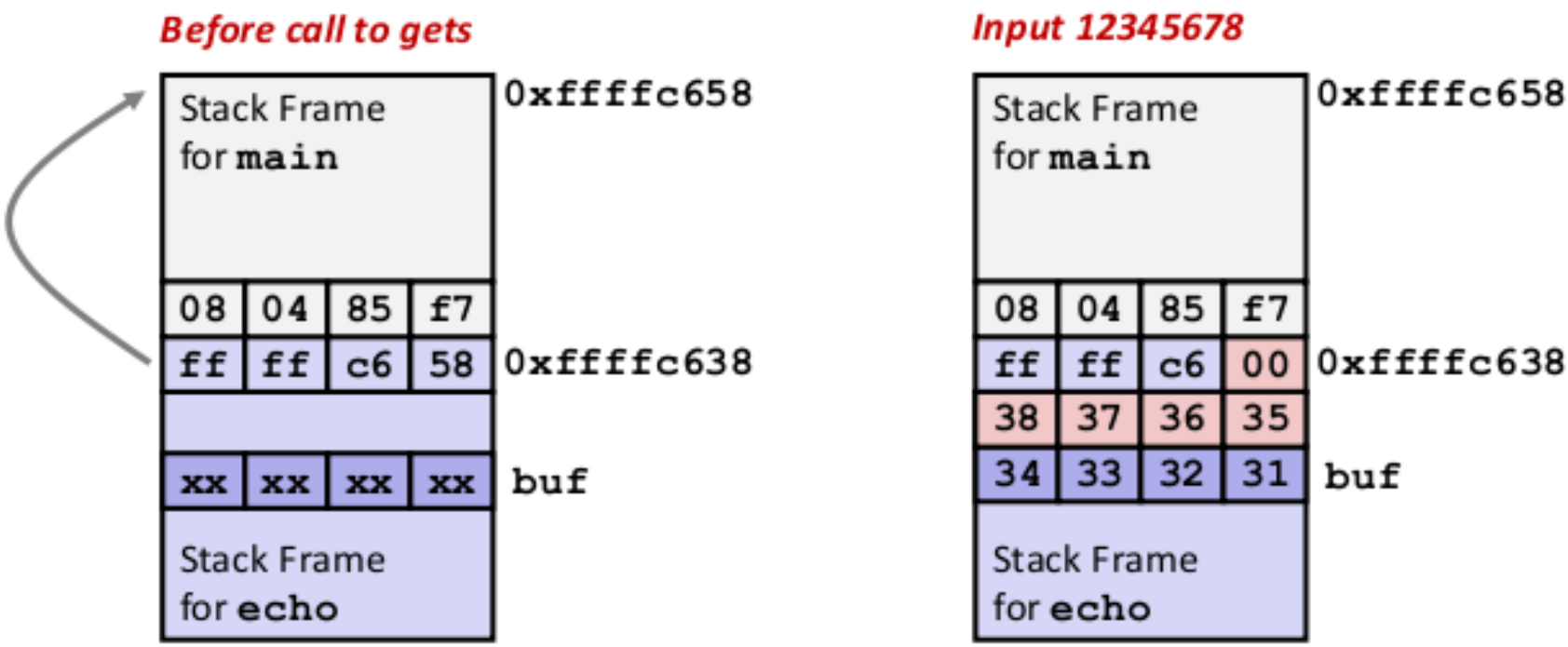

```
80485f2:call 80484f0 <echo>
80485f7:mov  0xffffffffc(%ebp),%ebx # Return Point
```

Buffer Overflow Example #1



Overflow buf, but no problem

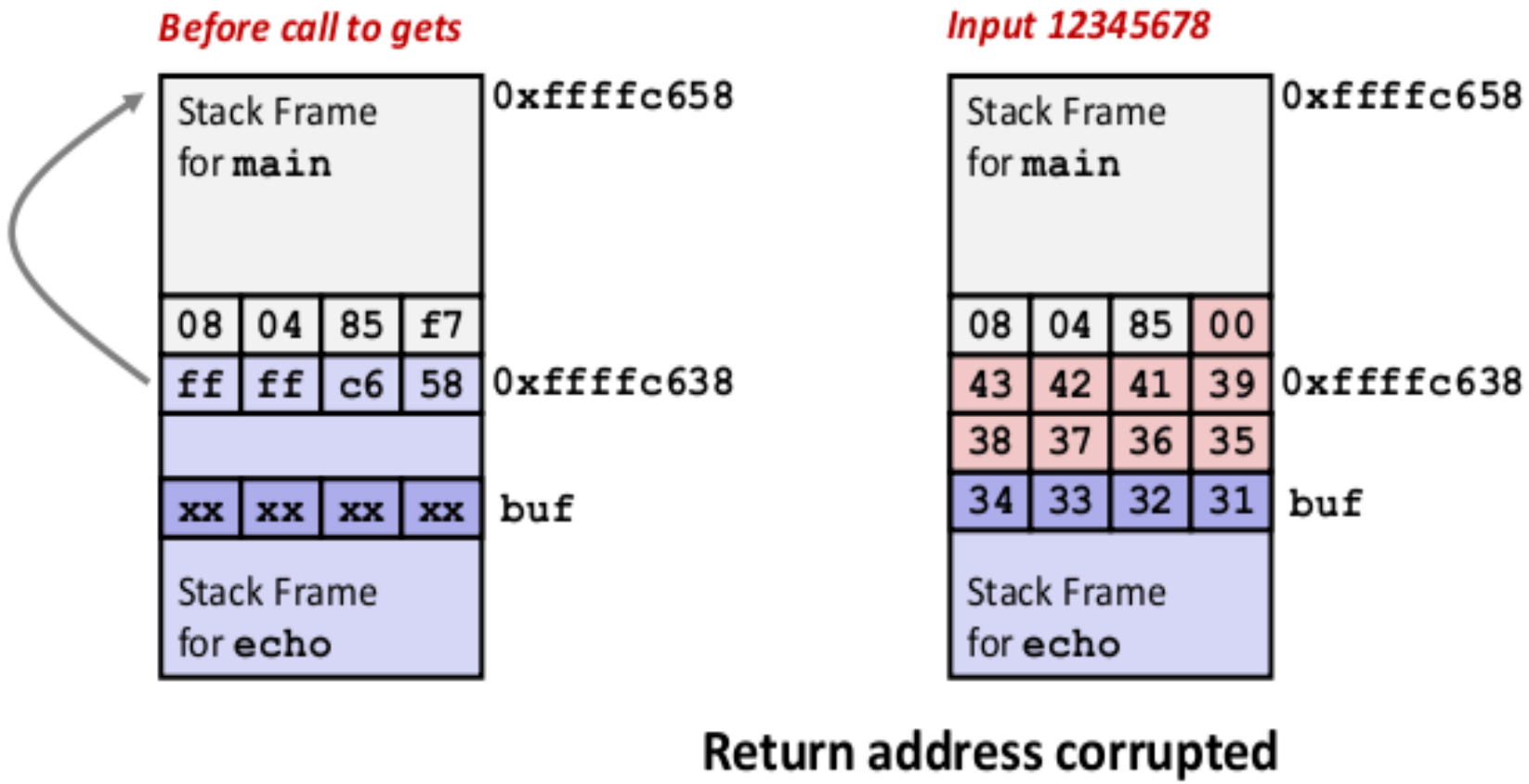
Buffer Overflow Example #2



Base pointer corrupted

```
. . .
804850a:  83 c4 14   add    $0x14,%esp   # deallocate space
804850d:  5b         pop    %ebx         # restore %ebx
804850e:  c9         leave               # movl %ebp, %esp; popl %ebp
804850f:  c3         ret                 # Return
```

Buffer Overflow Example #3



Return address corrupted

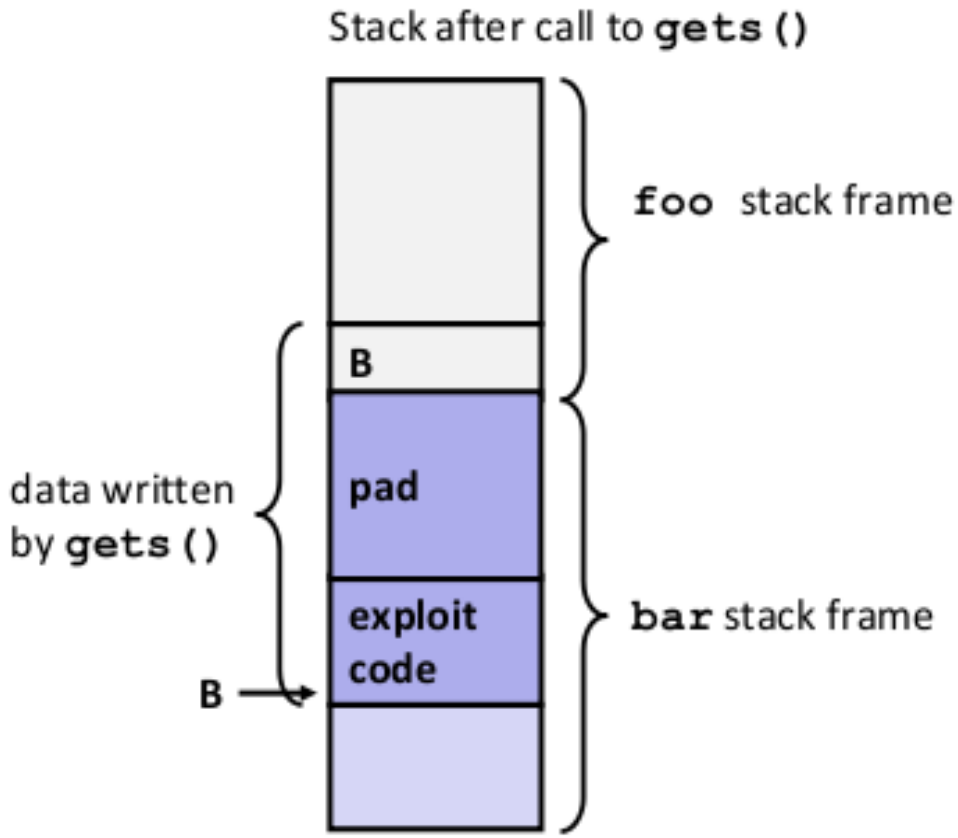
```
80485f2:  call 80484f0 <echo>
80485f7:  mov  0xfffffffc(%ebp),%ebx # Return Point
```

Malicious Use of Buffer Overflow

```
void foo(){
  bar();
  ...
}
```

return address A

```
int bar() {
  char buf[64];
  gets(buf);
  ...
  return ...;
}
```



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

Exploits Based on Buffer Overflow

- ***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 droh@cs.cmu.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
  - Add explicit "execute" permission

```
unix> 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
```

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**