# Computer Systems

CSE 410 Spring 2012

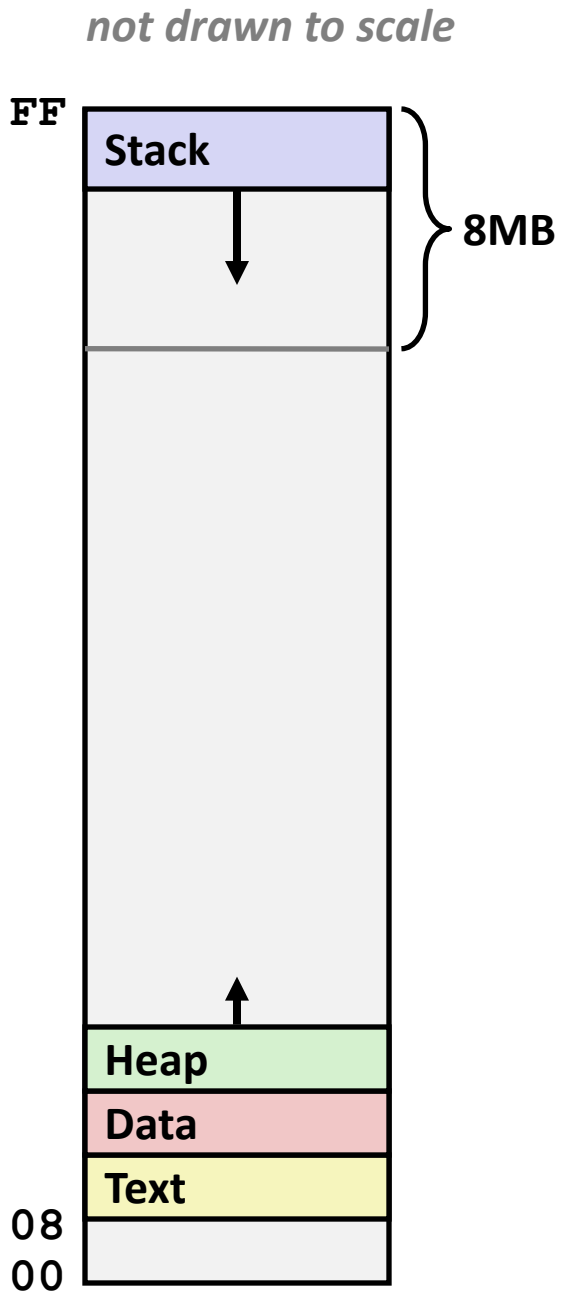
9 – Memory Allocation and Buffer Overflow

# Buffer Overflow

- Basics of memory allocation
- Buffers on stacks
- Overwriting buffers
- Injecting code

# 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

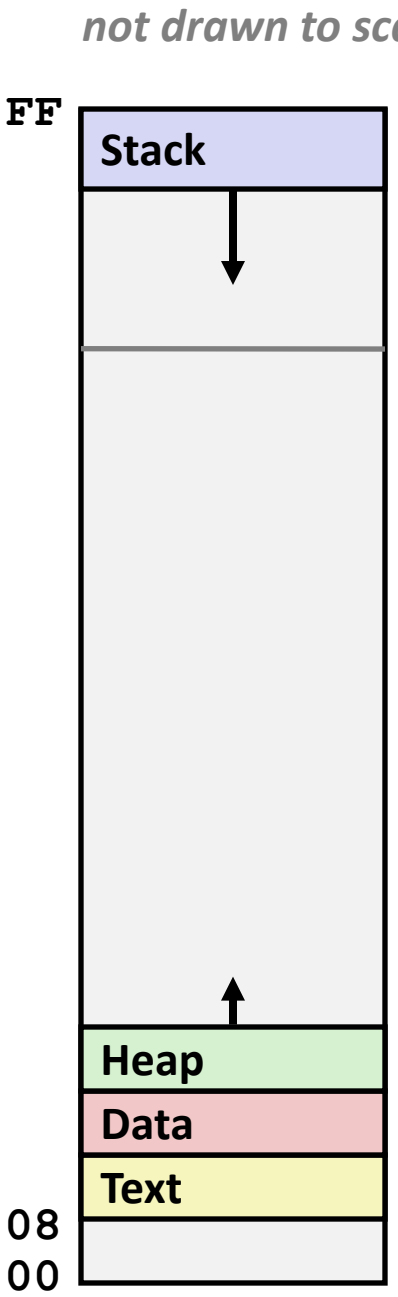
```
char big_array[1<<24];  /*  16 MB */
char huge_array[1<<28]; /* 256 MB */

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?*



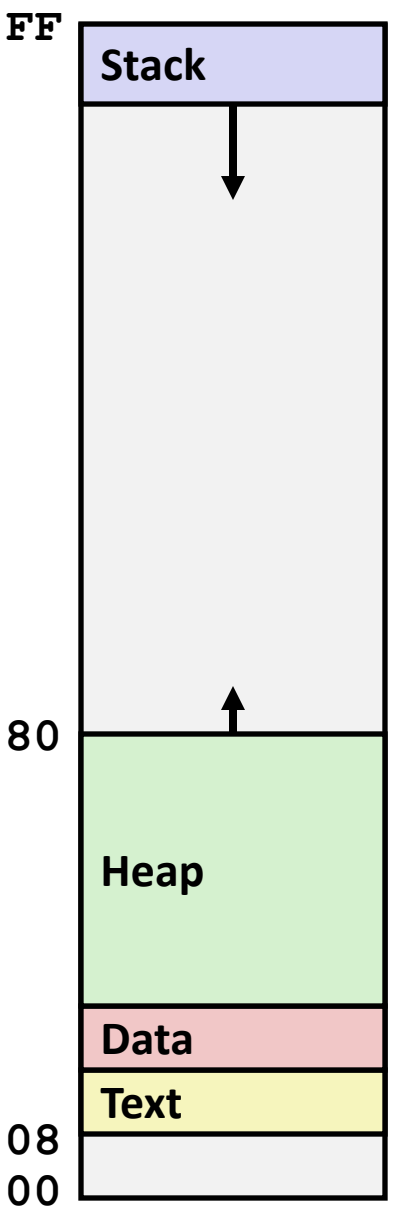
# IA32 Example Addresses

*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*



# Internet Worm

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  - How did it happen?

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- **November, 1988**
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- **The Internet Worm was based on *stack buffer overflow* exploits!**
    - many Unix functions do not check argument sizes
    - allows target buffers to overflow

# 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;
}
```

  - Anything interesting in the above?

# 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
```

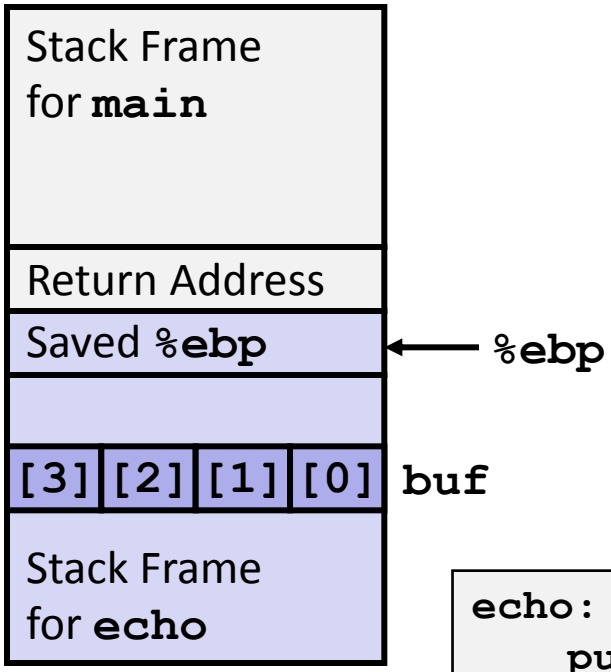
# Buffer Overflow Disassembly

```
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

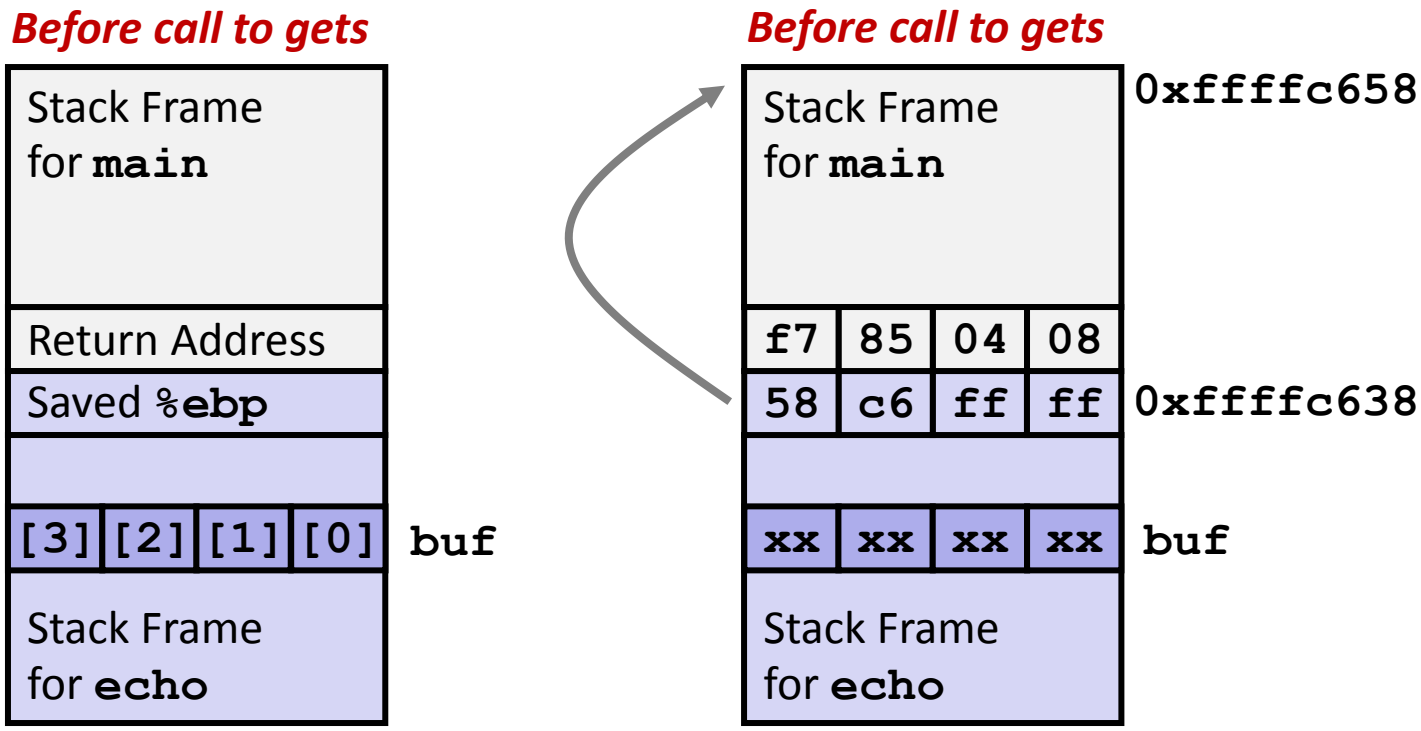
***Before call to gets***




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

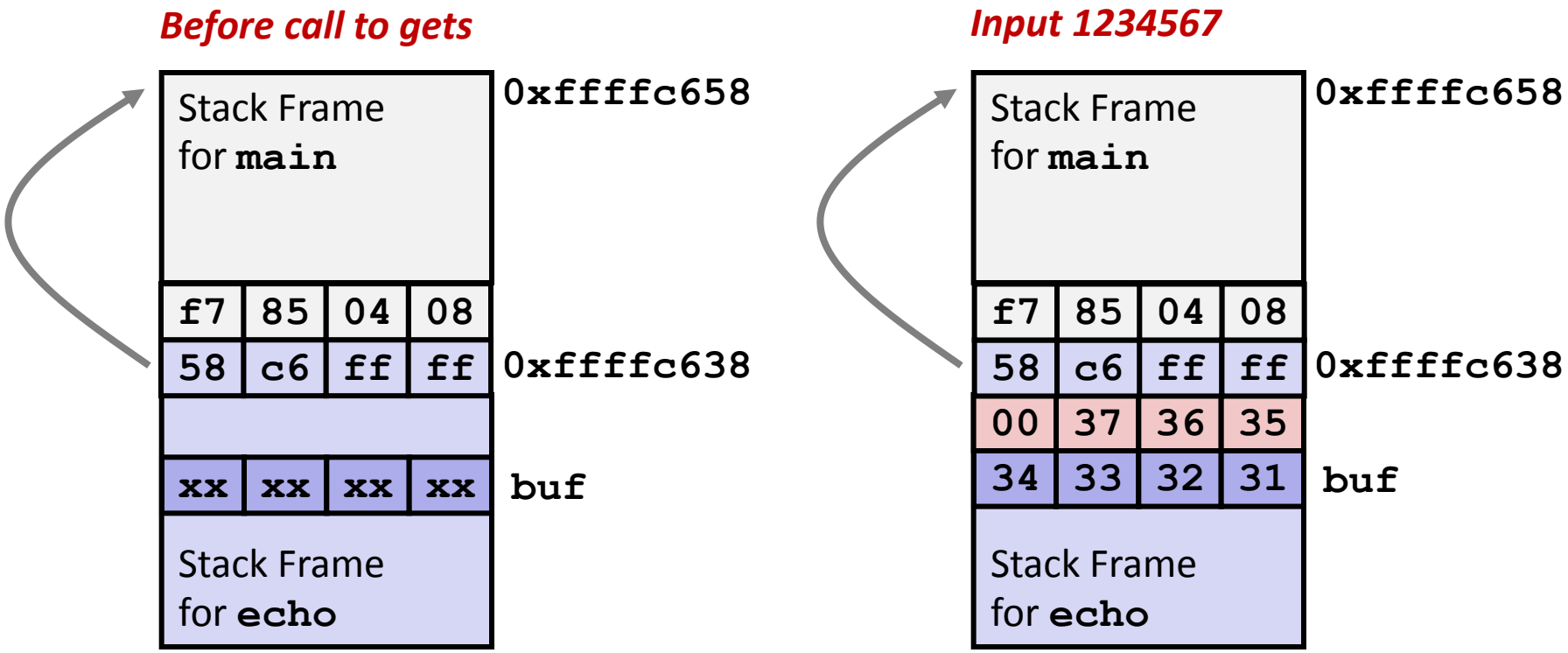
```
echo:
    pushl %ebp              # Save %ebp on stack
    movl  %esp, %ebp
    pushl %ebx              # Save %ebx
    leal  -8(%ebp),%ebx     # Compute buf as %ebp-8
    subl  $20, %esp         # Allocate stack space
    movl  %ebx, (%esp)      # Push buf addr on
stack
    call  gets          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

# Buffer Overflow Stack Example



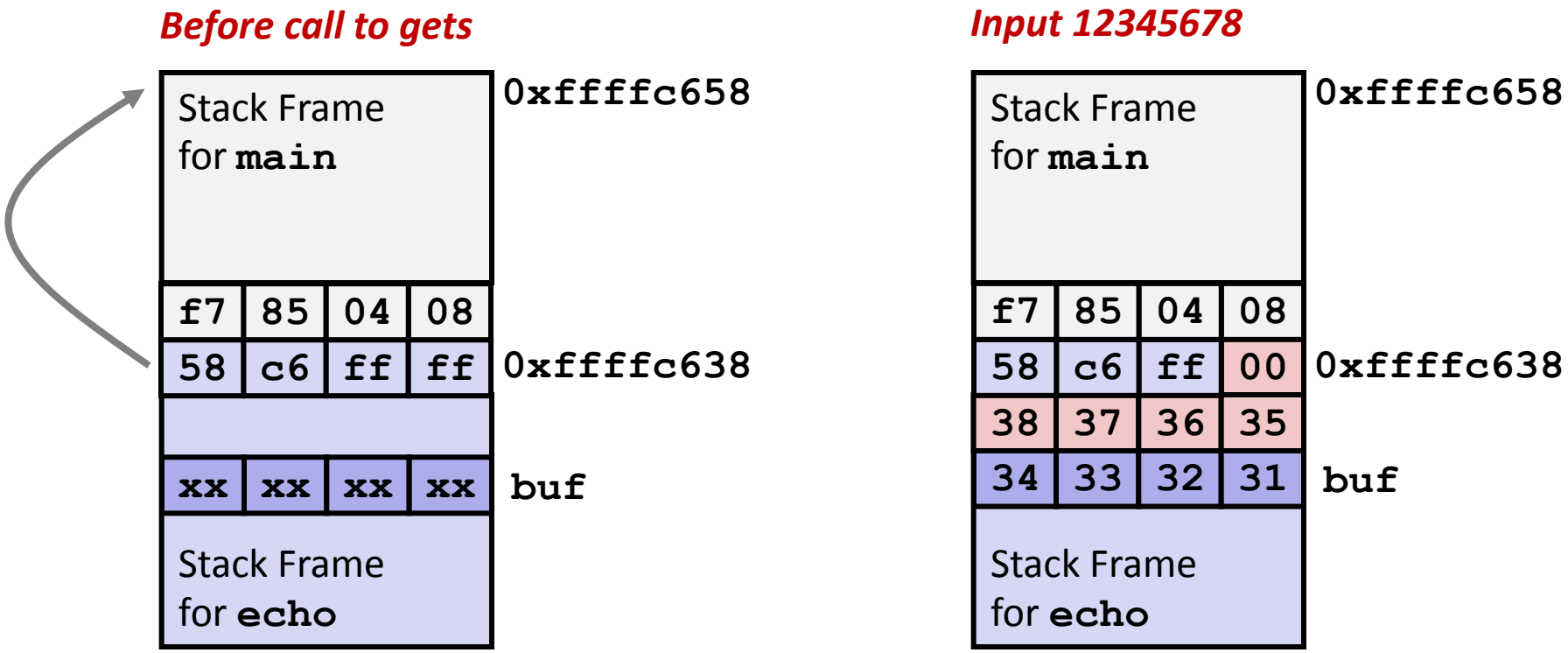

```
80485f2:call 80484f0 <echo>
80485f7:mov  0xffffffc(%ebp),%ebx # Return Point
```

# Buffer Overflow Example #1




**Overflow buf, but no problem**

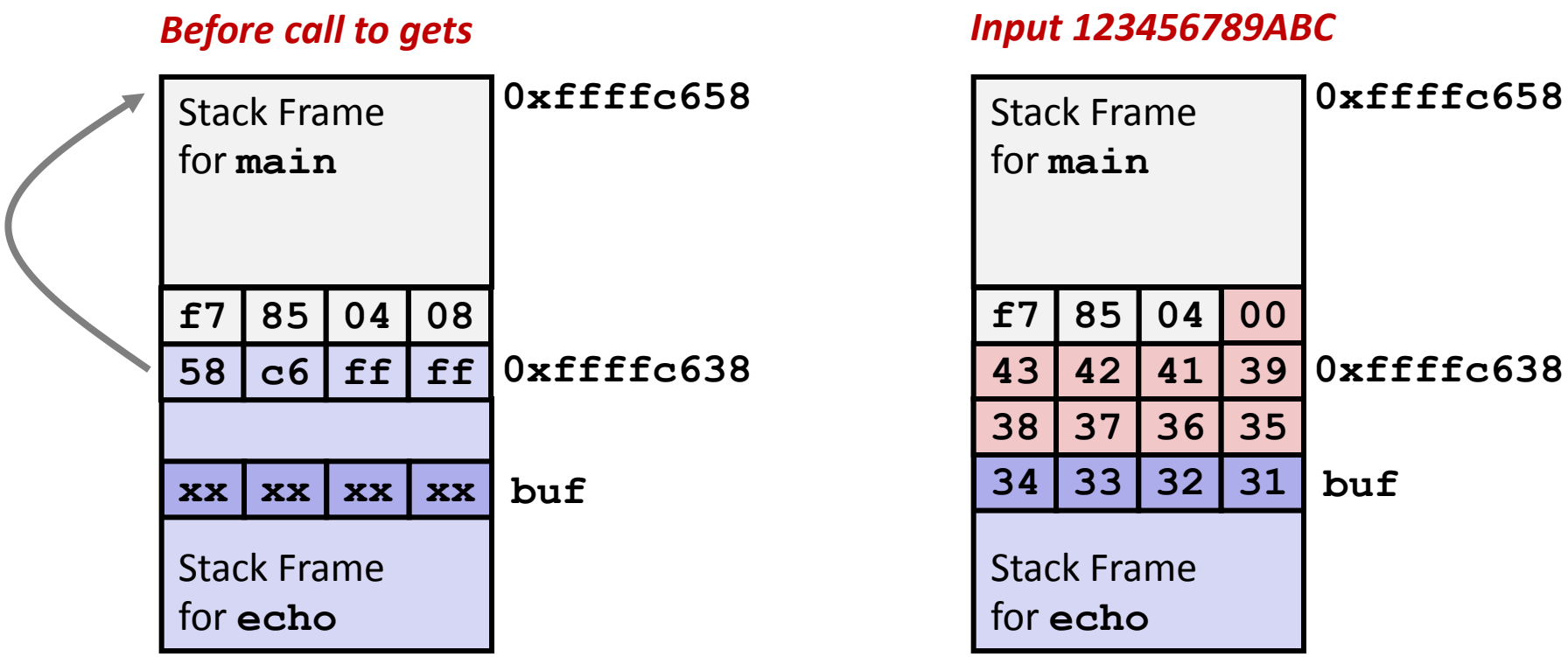
# Buffer Overflow Example #2




**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**

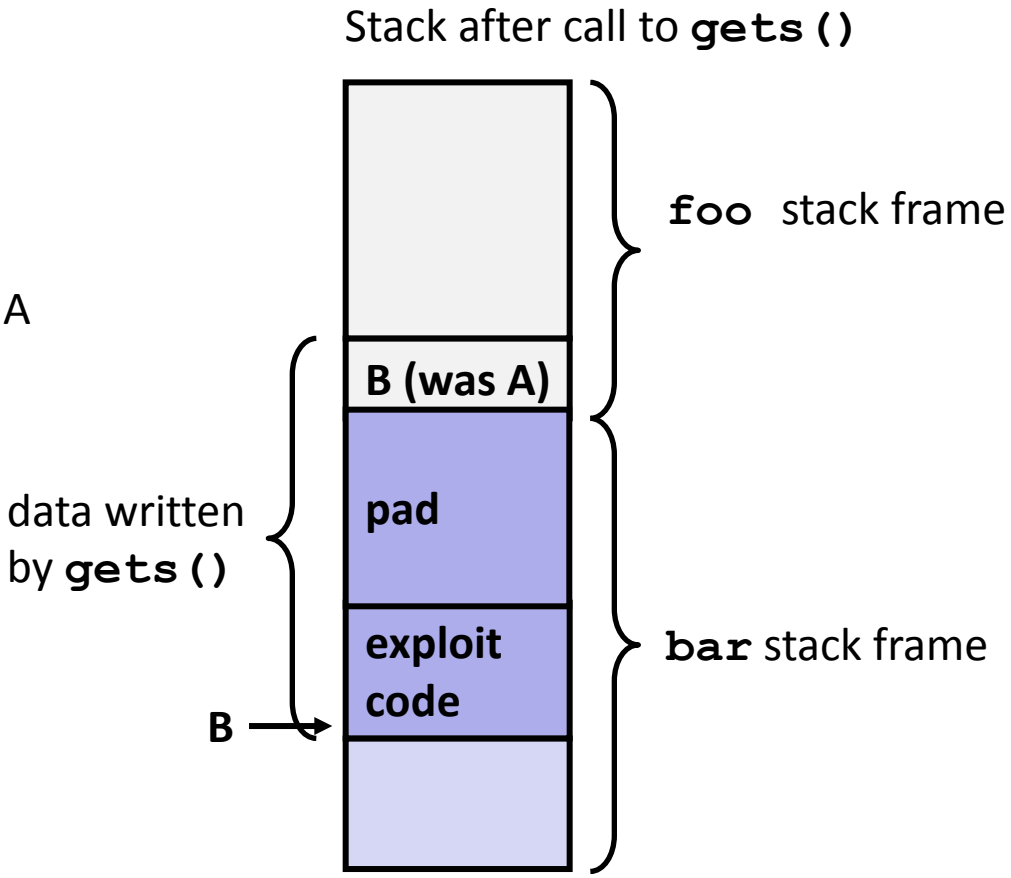
```
80485f2:  call 80484f0 <echo>
80485f7:  mov  0xffffffffc(%ebp),%ebx # Return Point
```

# 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
- Stack frame must be big enough to hold exploit code
- Overwrite return address with address of buffer (need to know B)
- When `bar()` executes `ret`, will jump to exploit code (instead of A)

# 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 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`** (second argument to fgets sets limit)
  - 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**
  - Only allow code to execute from "text" sections of memory
  - Do NOT execute code in stack, data, or heap regions
  - Hardware support