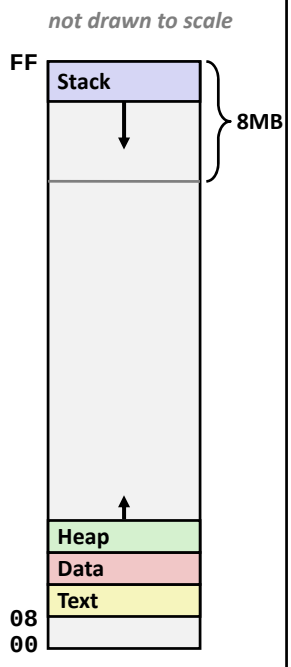
Buffer Overflow

- 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 */

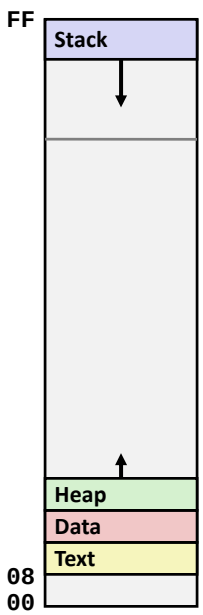
int beyond;
char *p1, *p2, *p3, *p4;

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?

not drawn to scale



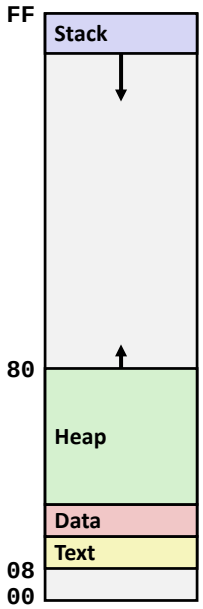
IA32 Example Addresses

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



Internet Worm

- **November, 1988**
  - Internet Worm attacks thousands of Internet hosts.
  - How did it happen?

Internet Worm

- **November, 1988**
  - Internet Worm attacks thousands of Internet hosts.
  - How did it happen?
- **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()`

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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
```

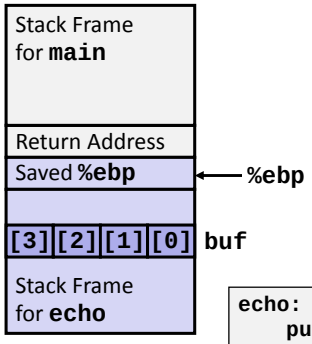

Buffer Overflow Disassembly

```
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

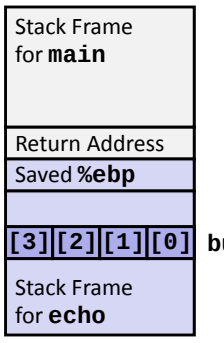



```
/* Echo Line */
void echo()
{
    char buf[4];  /* Way too small! */
    gets(buf);
    puts(buf);
}
```

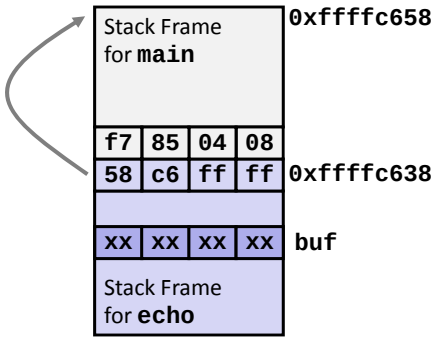
```
echo:
    pushl %ebp              # Save %ebp on stack
    movl  %esp, %ebp
    pushl %ebx              # Save %ebx
    leal  -8(%ebp),%ebx     # Compute buf as %ebp-8
    subl  $20, %esp         # Allocate stack space
    movl  %ebx, (%esp)      # Push buf addr on
stack
    call  gets          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


Buffer Overflow Stack Example

Before call to gets

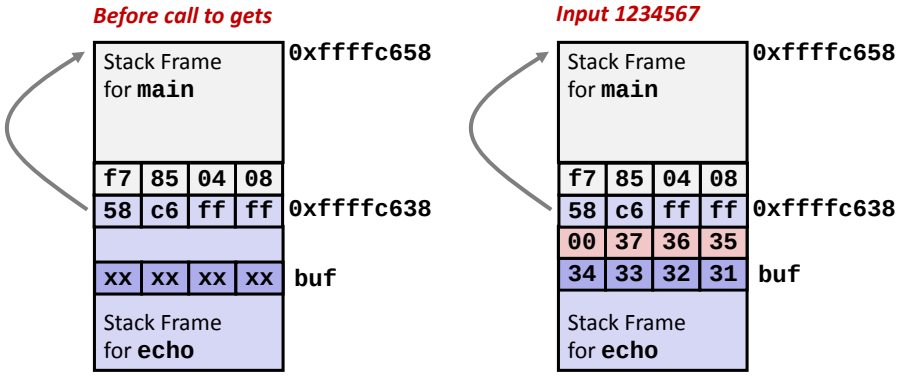


Before call to gets



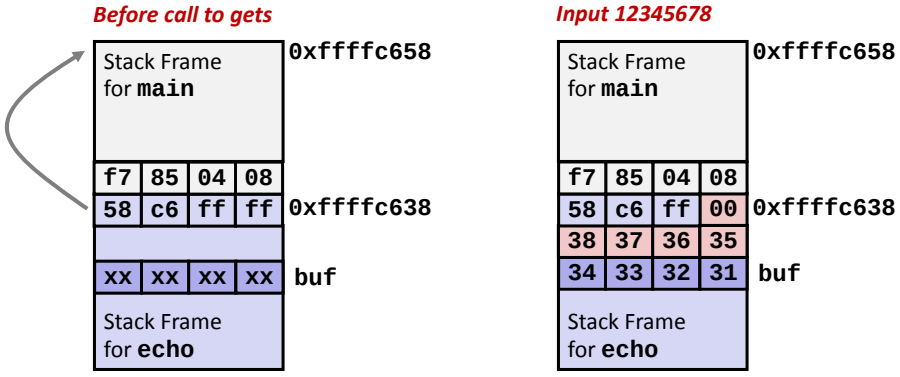

```
80485f2:call 80484f0 <echo>
80485f7:mov  0xffffffc(%ebp),%ebx # Return Point
```

Buffer Overflow Example #1



Overflow buf, but no problem

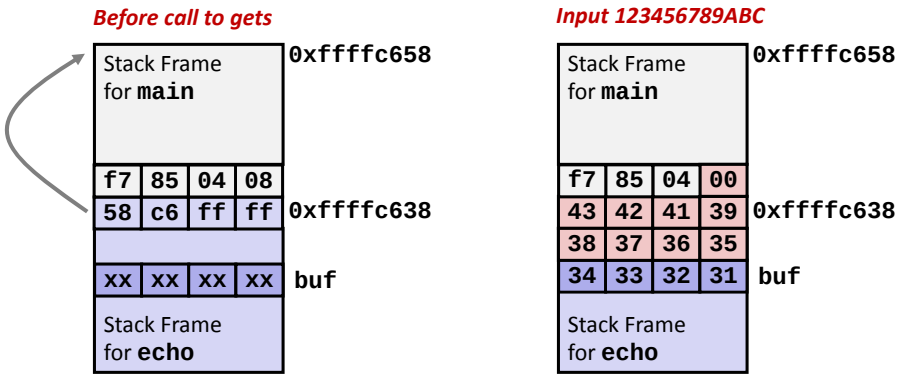
Buffer Overflow Example #2



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
```

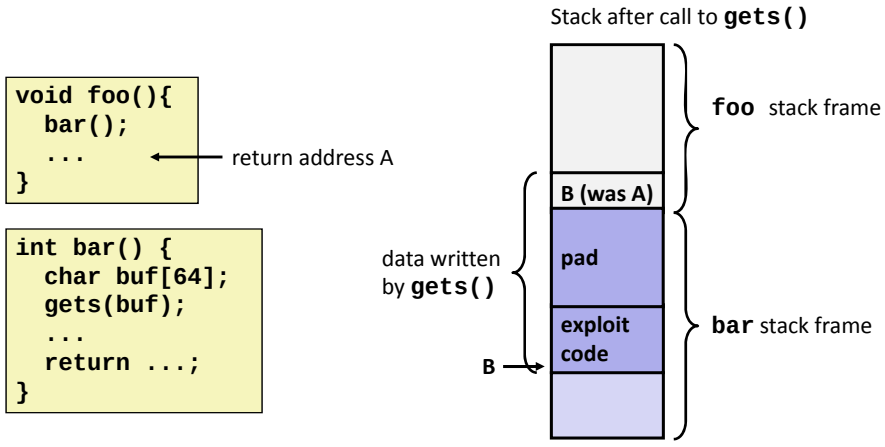
Buffer Overflow Example #3



Return address corrupted

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


Malicious Use of Buffer Overflow



- 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