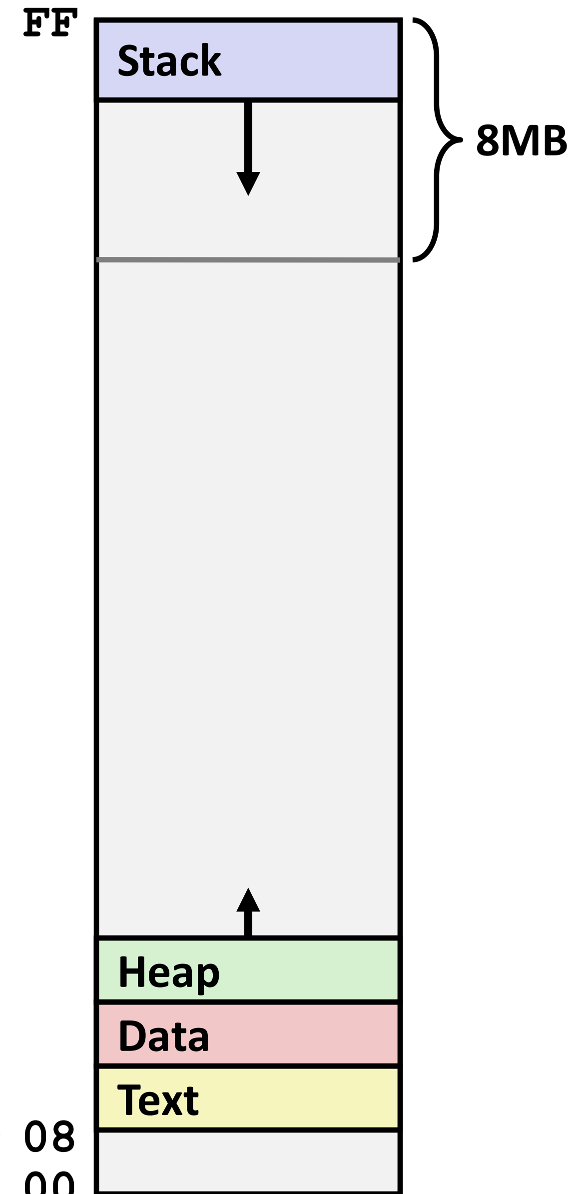
Today

- Memory layout
- Buffer overflow, worms, and viruses

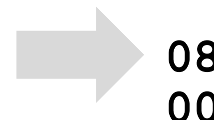
IA32 Linux Memory Layout

- **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

not drawn to scale



Upper 2 hex digits
= 8 bits of address



Memory Allocation Example

not drawn to scale

```
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?

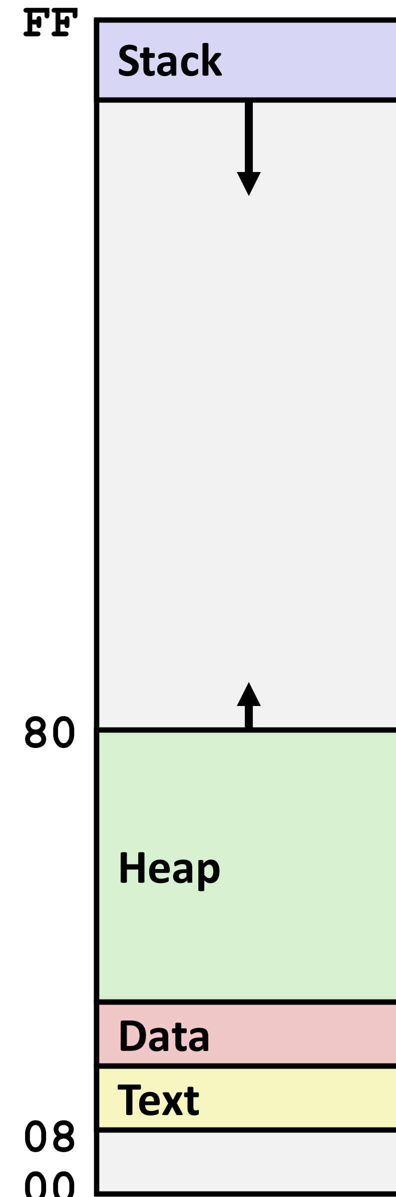
IA32 Example Addresses

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

- **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?

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
```

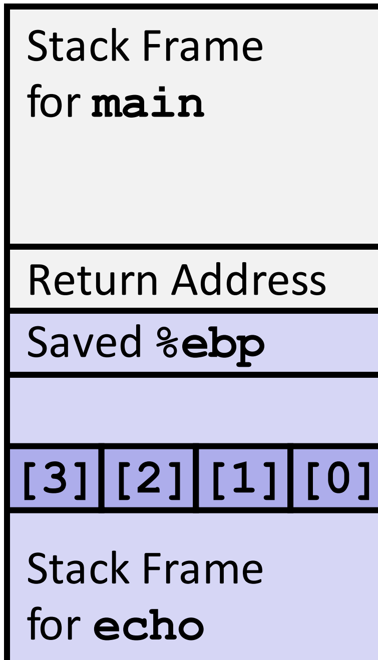
Buffer Overflow Disassembly

```
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

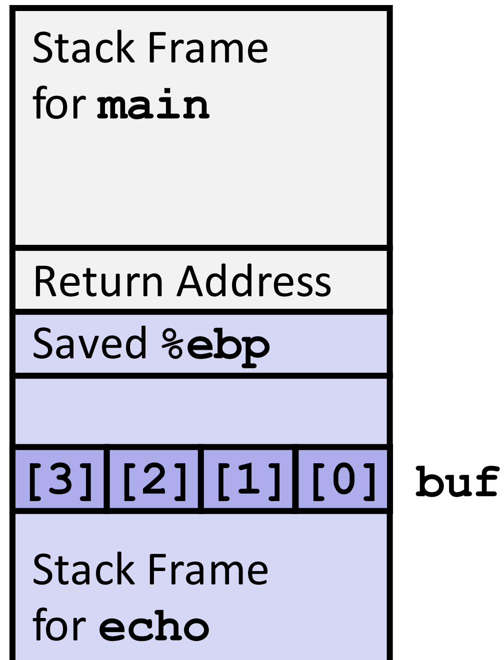
Before call to gets

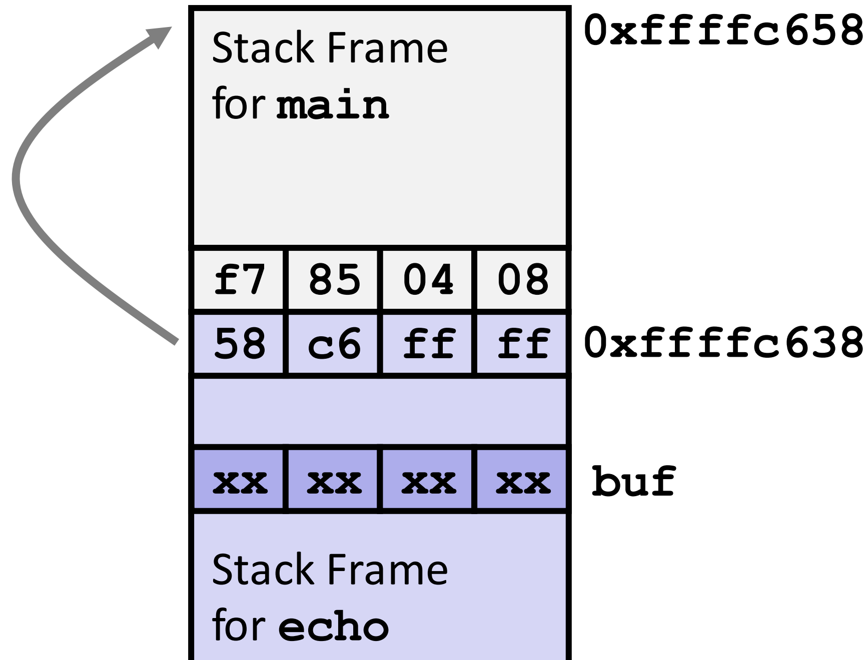



```
/* Echo Line */
void echo()
{
    char buf[4];  /* Way too small! */
    gets(buf);
    puts(buf);
}
```

```
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
    . . .
```

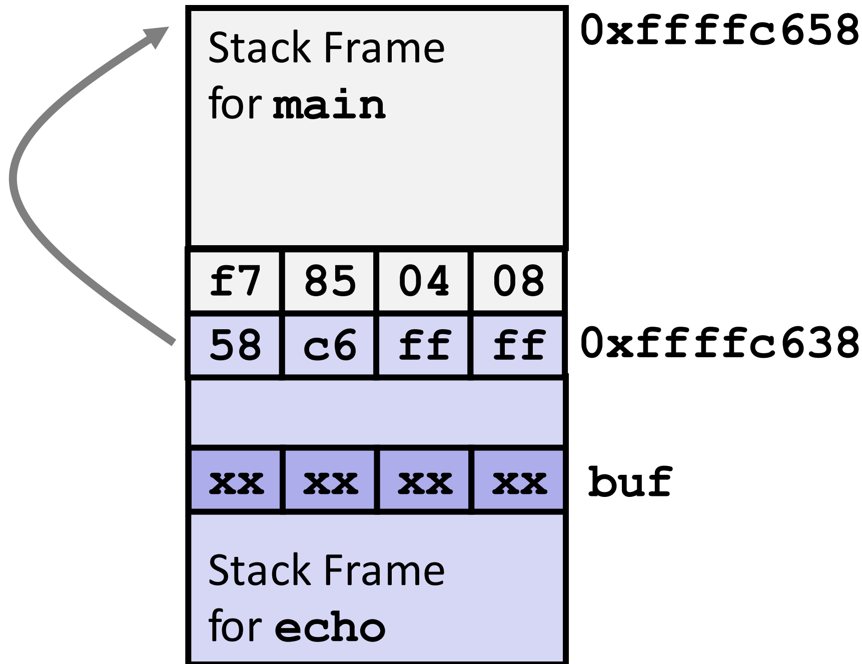
Buffer Overflow Stack Example

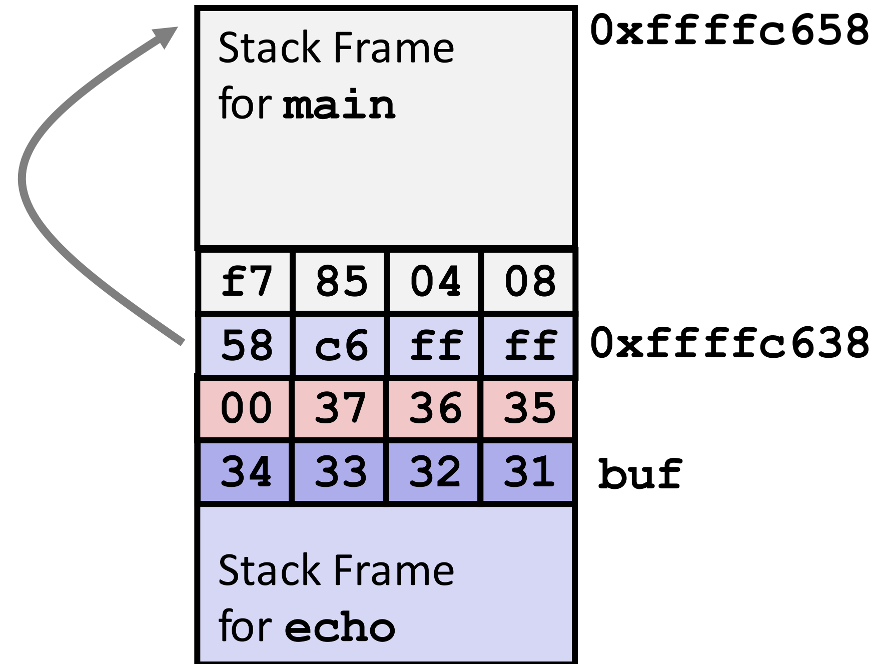





```
80485f2: call  80484f0 <echo>
80485f7: mov   0xfffffffc(%ebp),%ebx # Return Point
```

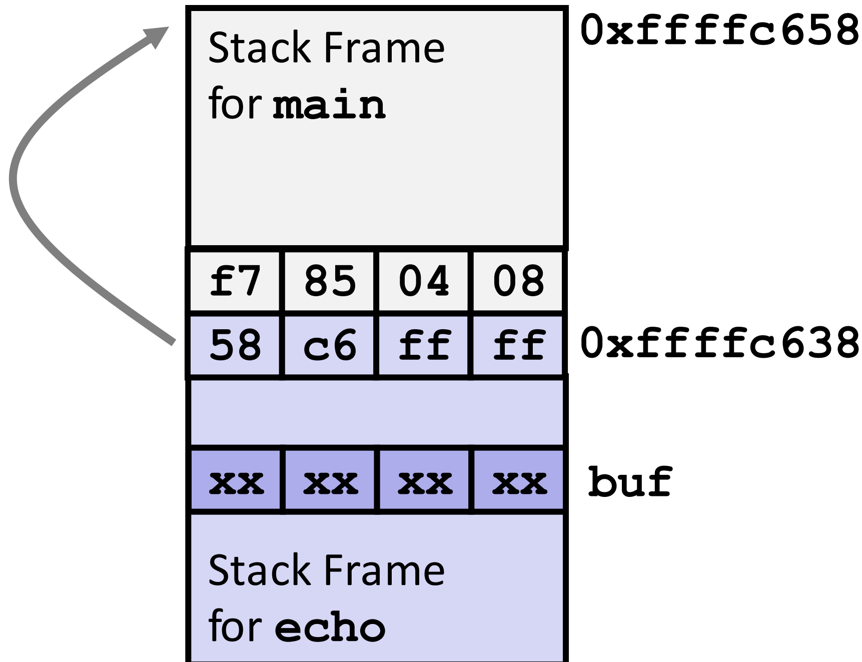
Buffer Overflow Example #1

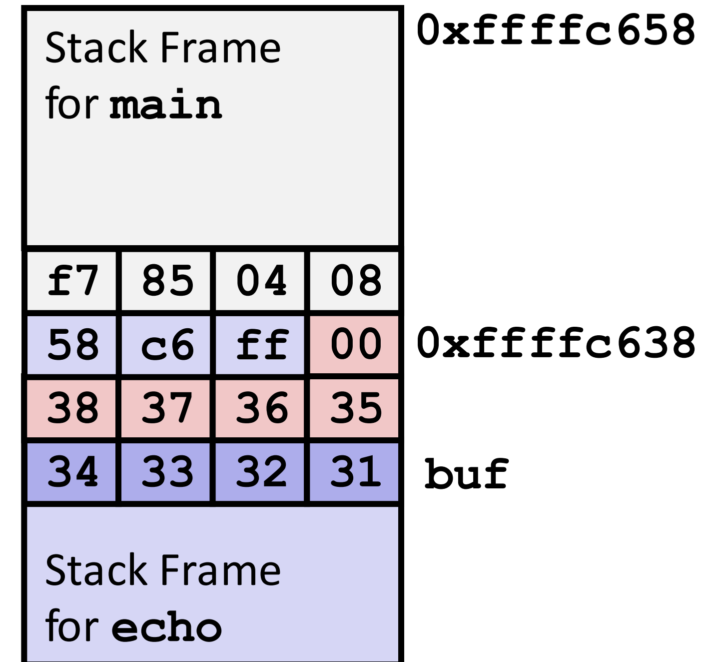




Overflow buf, but no problem

Buffer Overflow Example #2



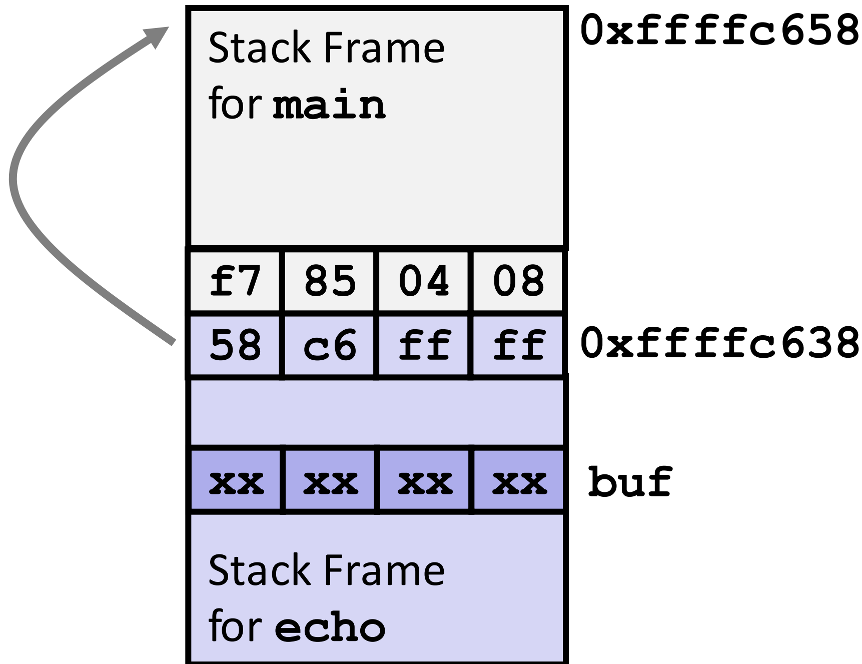


Base pointer corrupted

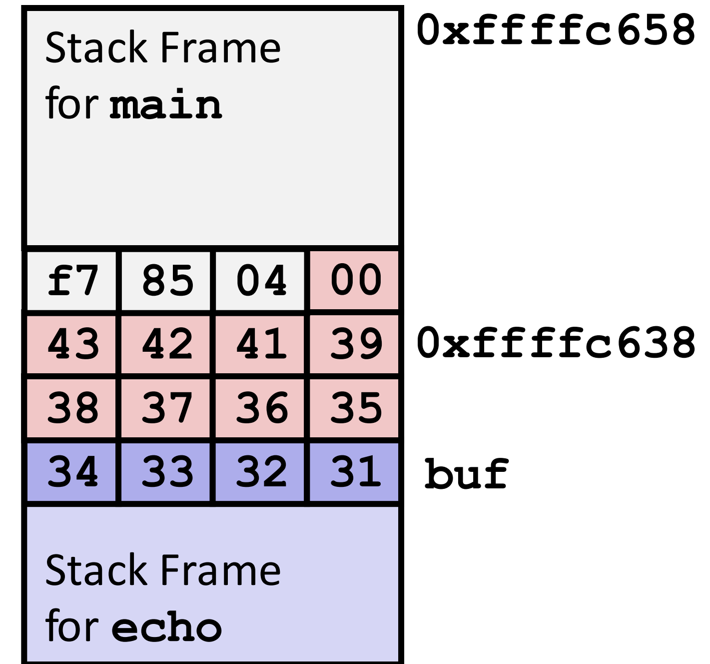
```
. . .
804850a: 83 c4 14    add    $0x14,%esp    # deallocate space
804850d: 5b          pop    %ebx          # restore %ebx
804850e: c9          leave                # movl %ebp, %esp; popl %ebp
804850f: c3          ret                  # Return
```

Buffer Overflow Example #3

Before call to gets



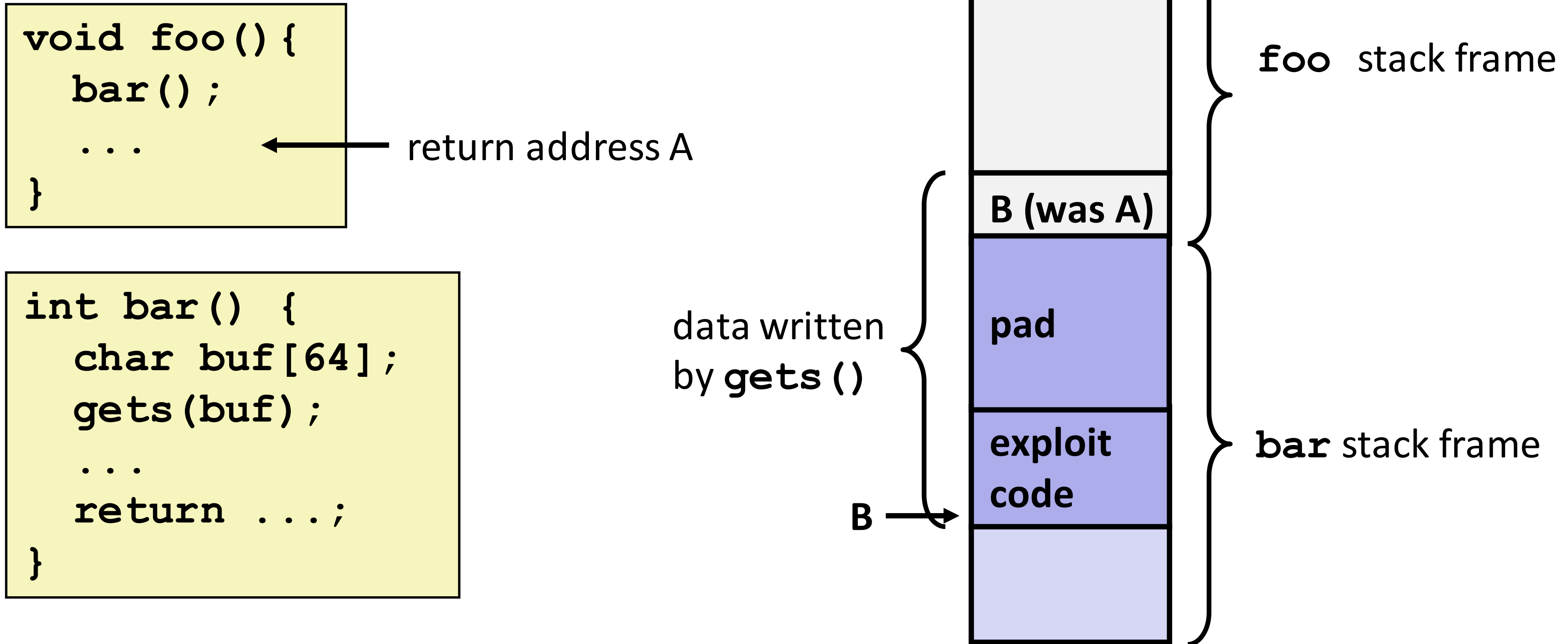
Input 123456789ABC



Return address corrupted

```
80485f2:  call 80484f0 <echo>
80485f7:  mov  0xfffffffc(%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

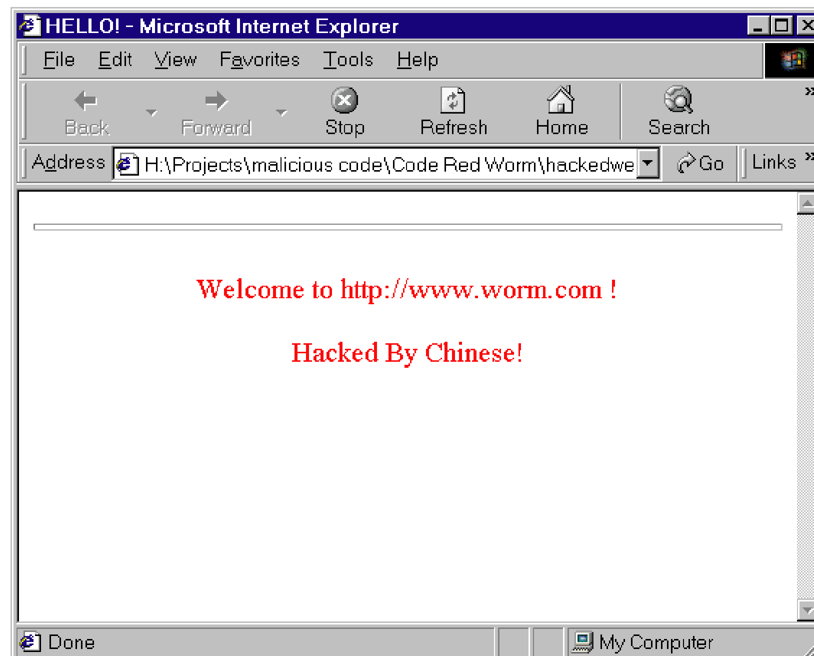
- ***Buffer overflow bugs allow remote machines to execute arbitrary code on victim machines***
- **Internet worm**
  - Early versions of the finger server (fingerd) used **`gets()`** to read the argument sent by the client:
    - **`finger droh@cs.cmu.edu`**
  - Worm attacked fingerd server by sending 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.

Code Red Worm

- **History**
  - June 18, 2001. Microsoft announces buffer overflow vulnerability in IIS Internet server
  - July 19, 2001. over 250,000 machines infected by new virus in 9 hours
  - White house must change its IP address. Pentagon shut down public WWW servers for day

Code Red Exploit Code

- **Starts 100 threads running**
- **Spread self**
  - Generate random IP addresses & send attack string
  - Between 1st & 19th of month
- **Attack www.whitehouse.gov**
  - Send 98,304 packets; sleep for 4-1/2 hours; repeat
    - Denial of service attack
  - Between 21st & 27th of month
- **Deface server's home page**
  - After waiting 2 hours
- **Later versions even more aggressive**
- **And it goes on still...**



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

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**
  - Adds itself to other programs
  - Cannot run independently

- **Both are (usually) designed to spread among computers and to wreak havoc (and, these days, profit$$$)**