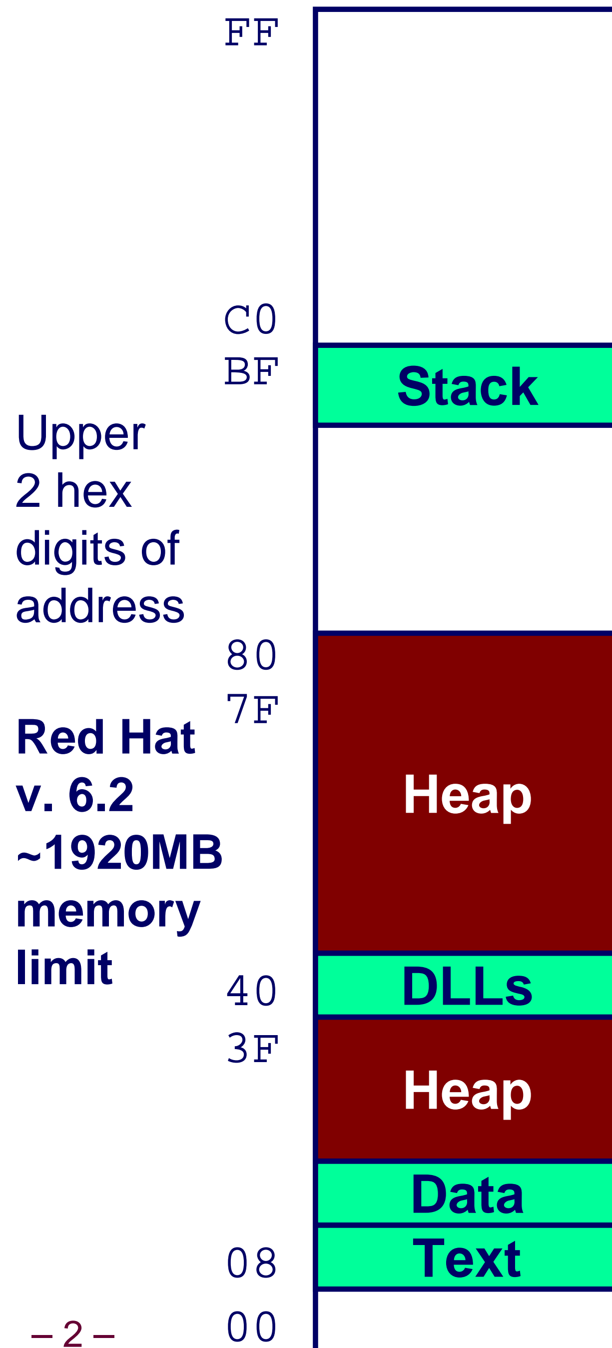
Machine-Level Programming: Miscellaneous Topics From CS:APP by Bryant & O'Hallaron

Topics

- Linux Memory Layout
- Buffer Overflow

Linux Memory Layout



Stack

- Runtime stack (8MB limit)

Heap

- Dynamically allocated storage
- When call `malloc`, `calloc`, `new`

DLLs

- Dynamically Linked Libraries
- Library routines (e.g., `printf`, `malloc`)
- Linked into object code when first executed

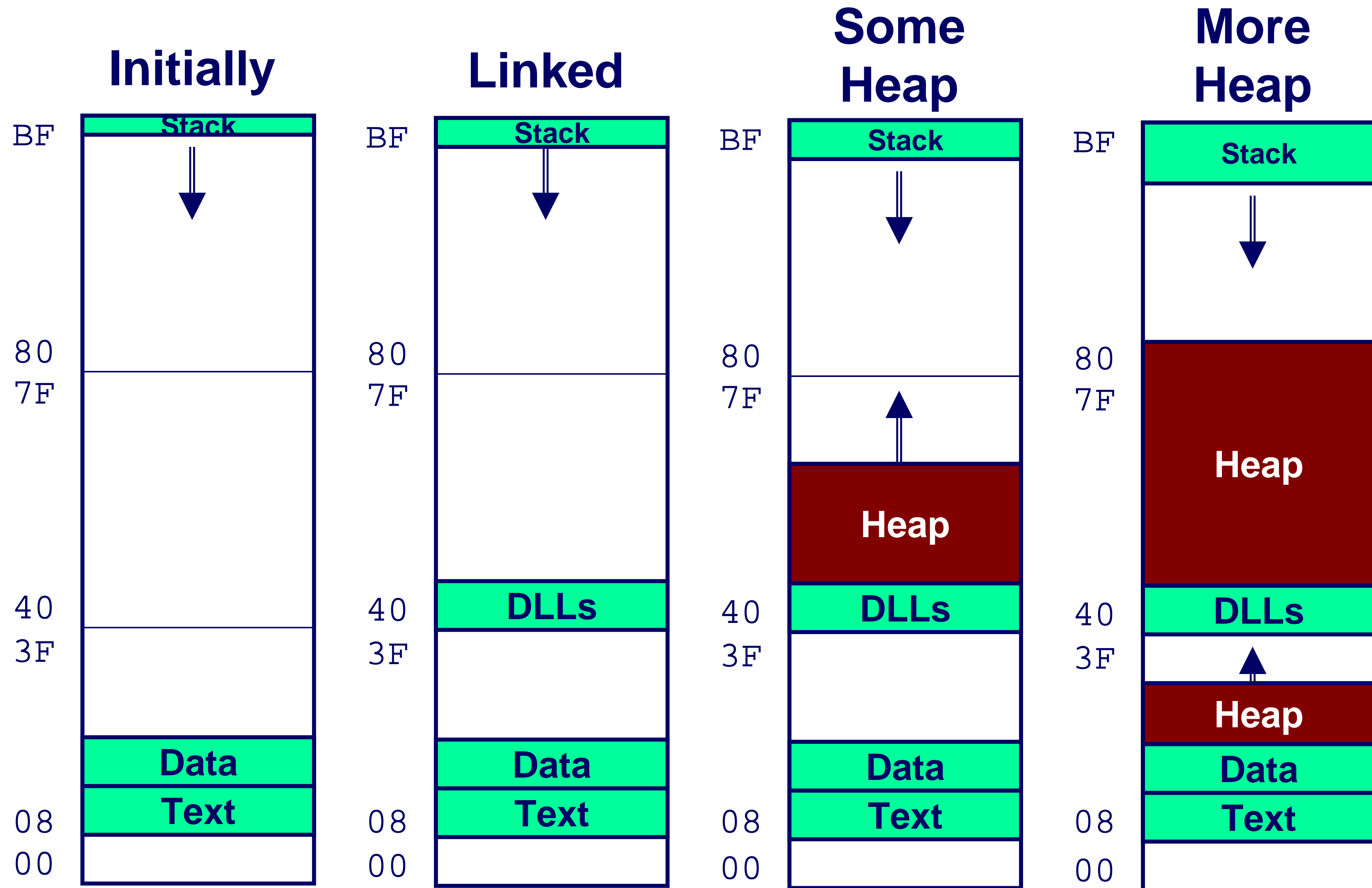
Data

- Statically allocated data
- E.g., arrays & strings declared in code

Text

- Executable machine instructions
- Read-only

Linux Memory Allocation



Text & Stack Example

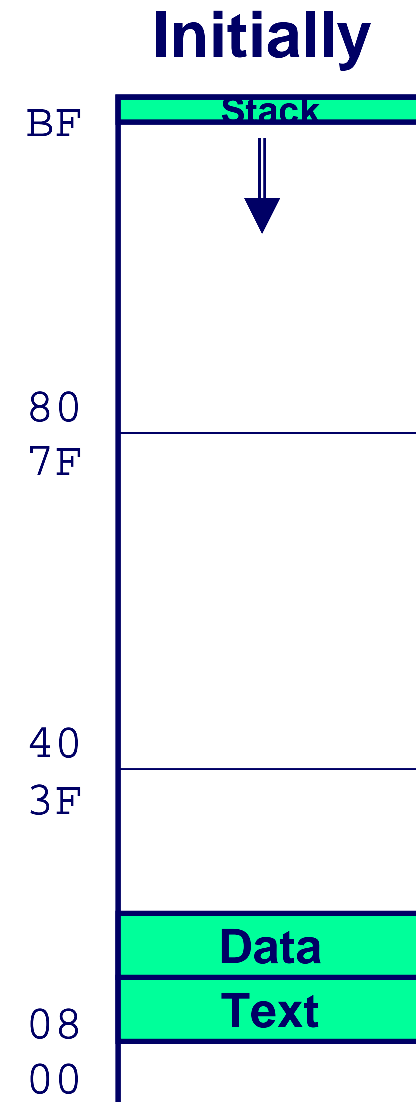
```
(gdb) break main
(gdb) run
  Breakpoint 1, 0x804856f in main ()
(gdb) print $esp
  $3 = (void *) 0xbffffc78
```

Main

- Address `0x804856f` should be read `0x0804856f`

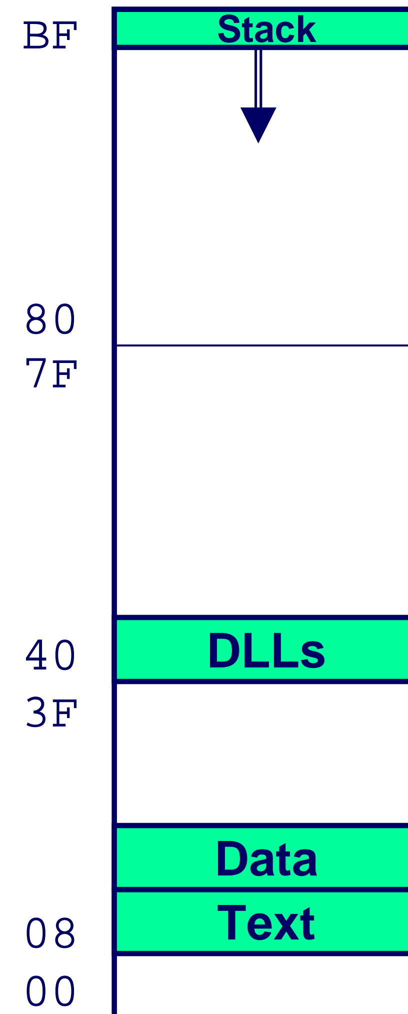
Stack

- Address `0xbffffc78`



Dynamic Linking Example

```
(gdb) print malloc
  $1 = {<text variable, no debug info>}
    0x8048454 <malloc>
(gdb) run
  Program exited normally.
(gdb) print malloc
  $2 = {void *(unsigned int)}
    0x40006240 <malloc>
```



Initially

- Code in text segment that invokes dynamic linker
- Address `0x8048454` should be read `0x08048454`

Final

- Code in DLL region

Memory Allocation Example

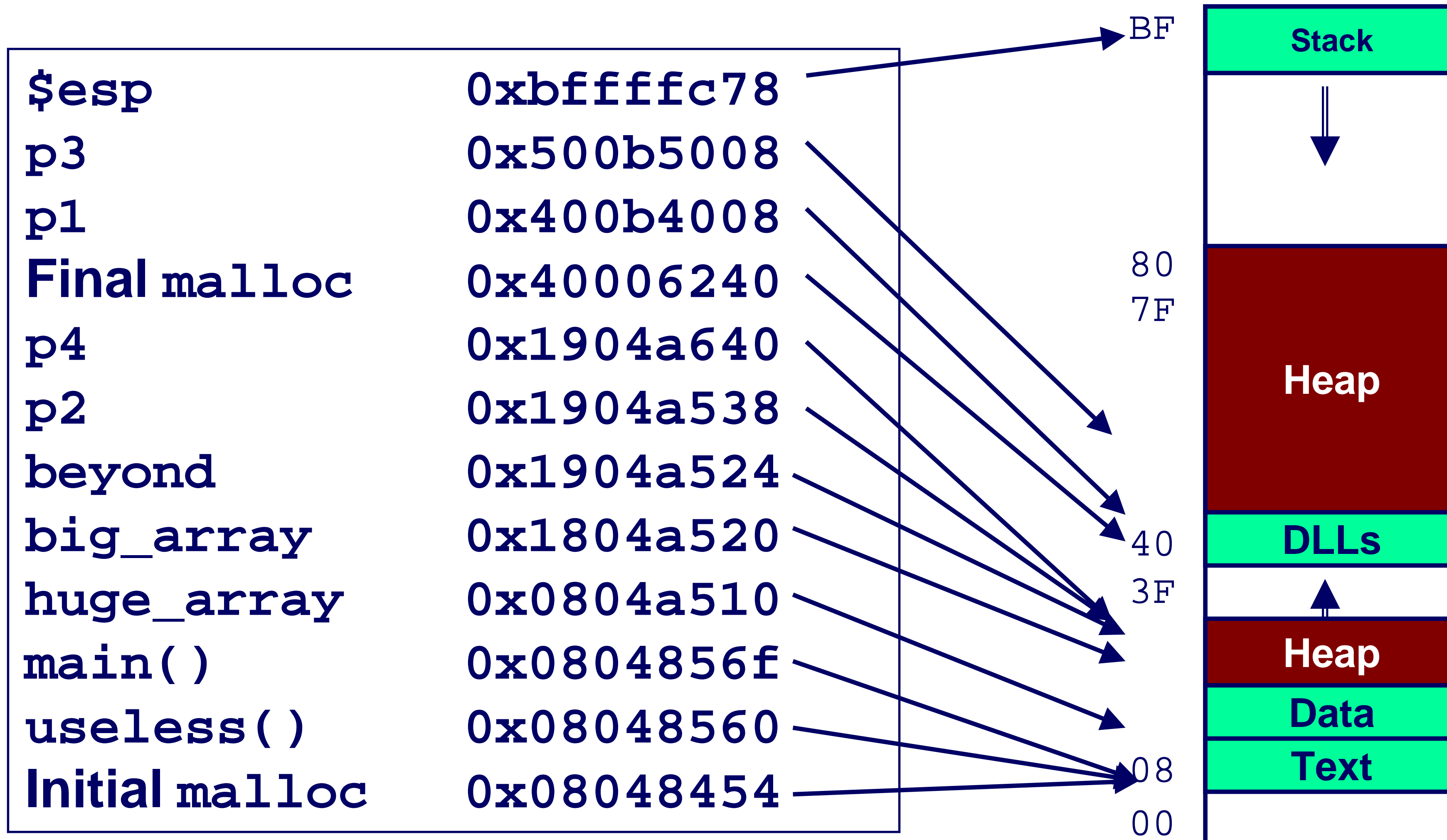
```
char big_array[1<<24];  /*  16 MB */
char huge_array[1<<28]; /* 256 MB */

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 ... */
}
```

Example Addresses



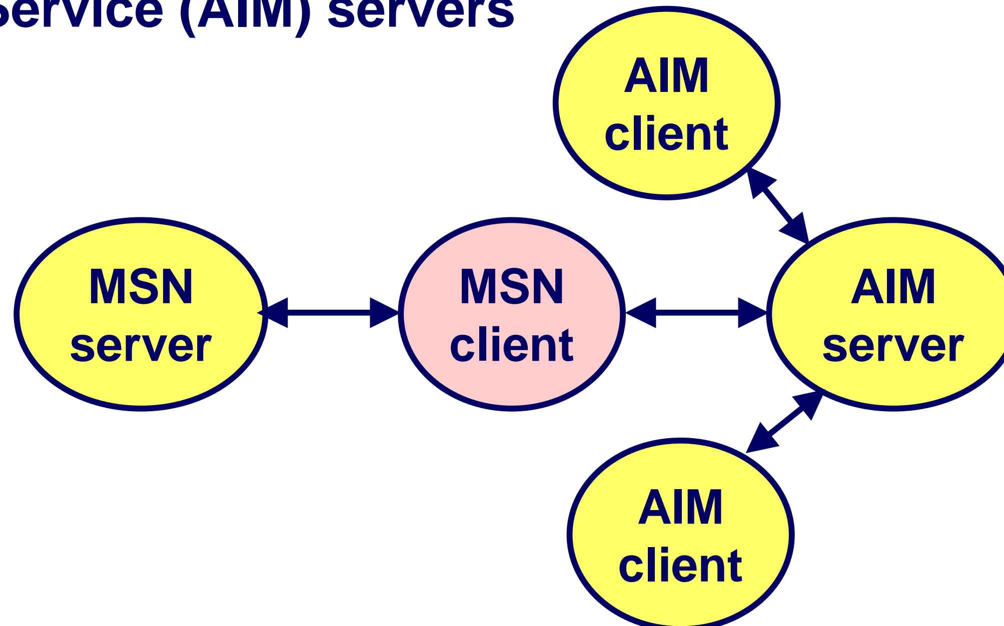
Internet Worm and IM War

November, 1988

- Internet Worm attacks thousands of Internet hosts.
- How did it happen?

July, 1999

- Microsoft launches MSN Messenger (instant messaging system).
- Messenger clients can access popular AOL Instant Messaging Service (AIM) servers



Internet Worm and IM War (cont.)

August 1999

- Mysteriously, Messenger clients can no longer access AIM servers.
- Microsoft and AOL begin the IM war:
  - AOL changes server to disallow Messenger clients
  - Microsoft makes changes to clients to defeat AOL changes.
  - At least 13 such skirmishes.
- How did it happen?

The Internet Worm and AOL/Microsoft War were both 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`
  - No way to specify limit on number of characters to read

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

- 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;
}
```

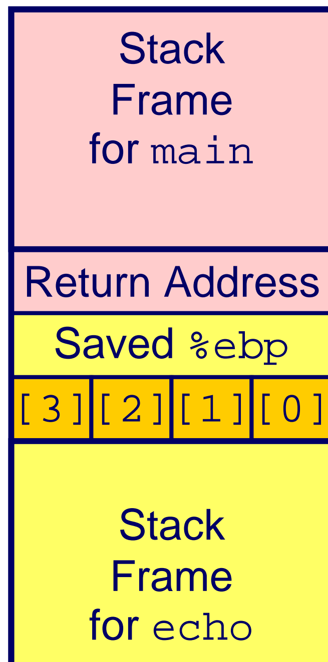
Buffer Overflow Executions

```
unix>./bufdemo
Type a string:123
123
```

```
unix>./bufdemo
Type a string:12345
Segmentation Fault
```

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

Buffer Overflow Stack

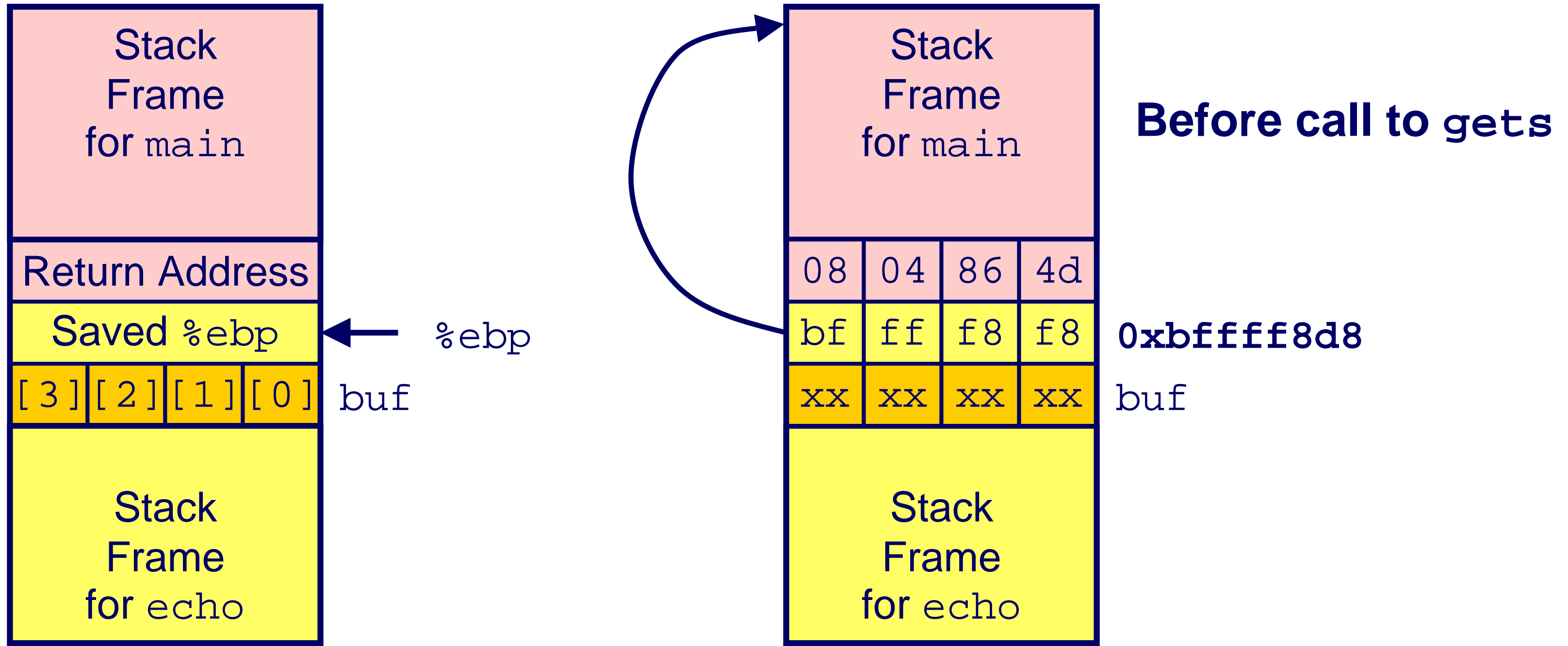



```
/* Echo Line */
void echo()
{
    char buf[4];  /* Way too small! */
    gets(buf);
    puts(buf);
}
```

```
echo:
    pushl %ebp            # Save %ebp on stack
    movl %esp,%ebp
    subl $20,%esp         # Allocate space on stack
    pushl %ebx            # Save %ebx
    addl $-12,%esp        # Allocate space on stack
    leal -4(%ebp),%ebx    # Compute buf as %ebp-4
    pushl %ebx            # Push buf on stack
    call gets             # Call gets
    . . .
```

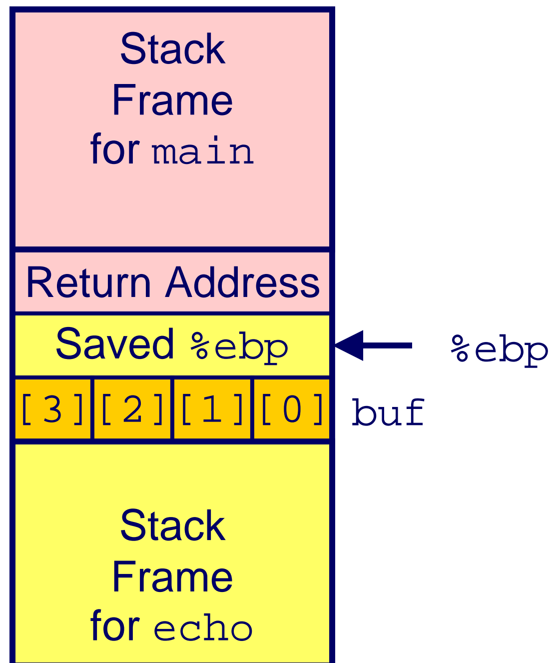
Buffer Overflow Stack Example

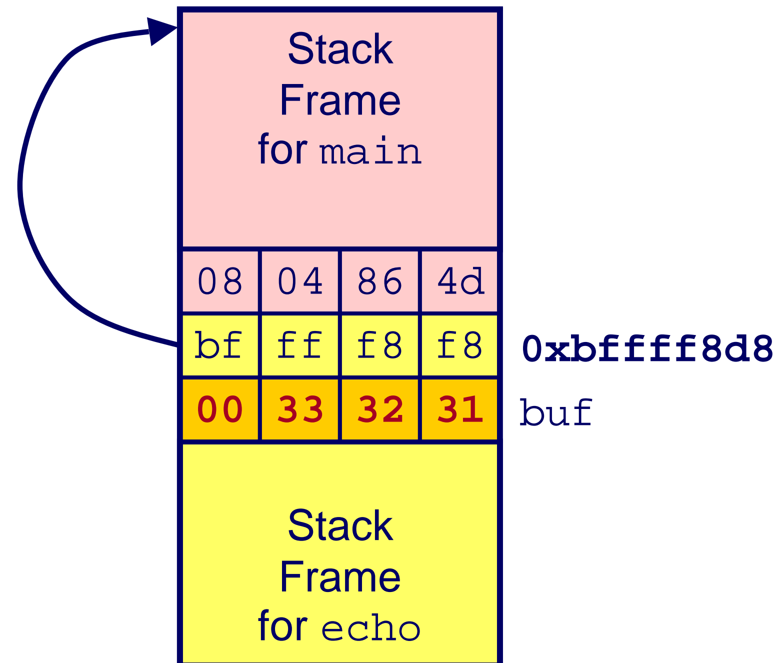
```
unix> gdb bufdemo
(gdb) break echo
Breakpoint 1 at 0x8048583
(gdb) run
Breakpoint 1, 0x8048583 in echo ()
(gdb) print /x *(unsigned *)$ebp
$1 = 0xbffff8f8
(gdb) print /x *((unsigned *)$ebp + 1)
$3 = 0x804864d
```



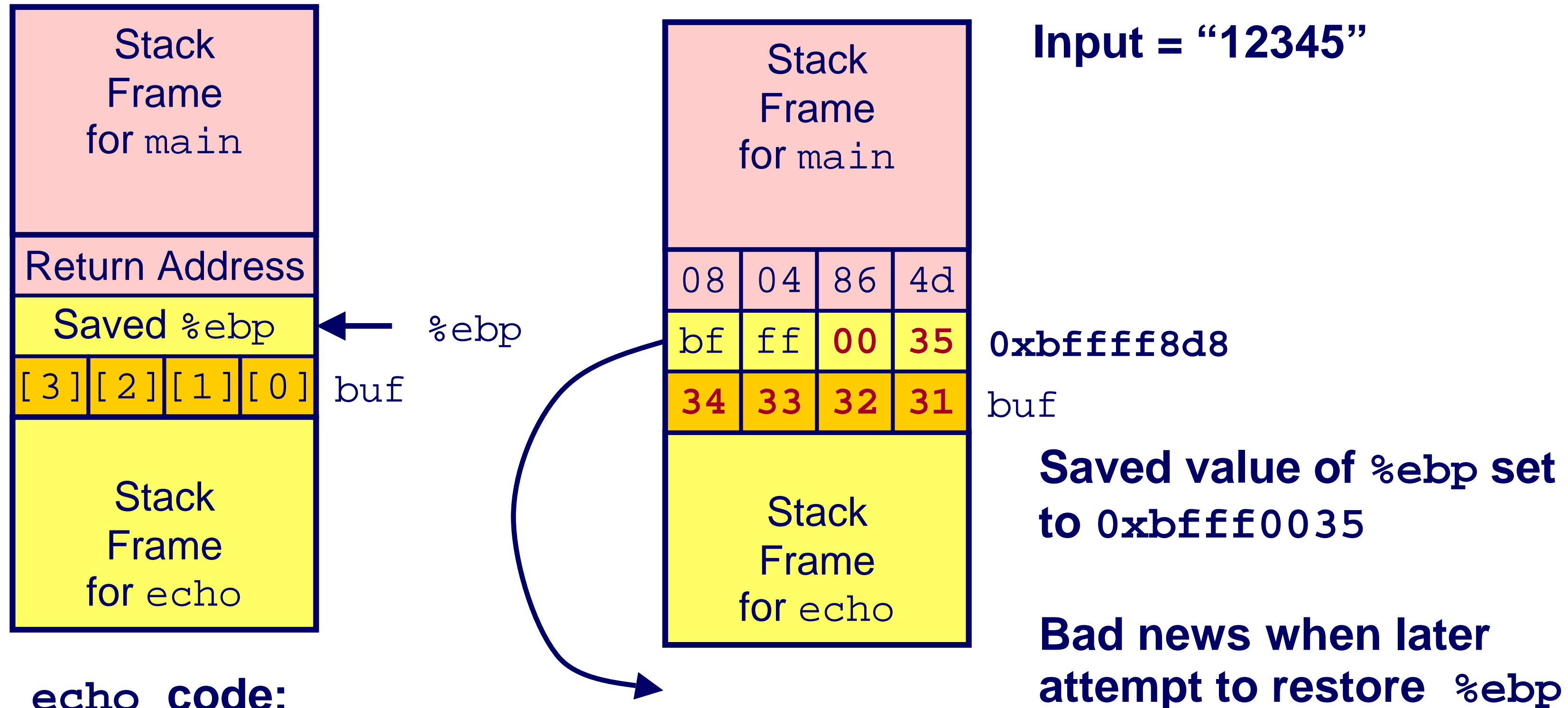

```
8048648: call 804857c <echo>
804864d: mov  0xffffffe8(%ebp),%ebx # Return Point
```

Buffer Overflow Example #1





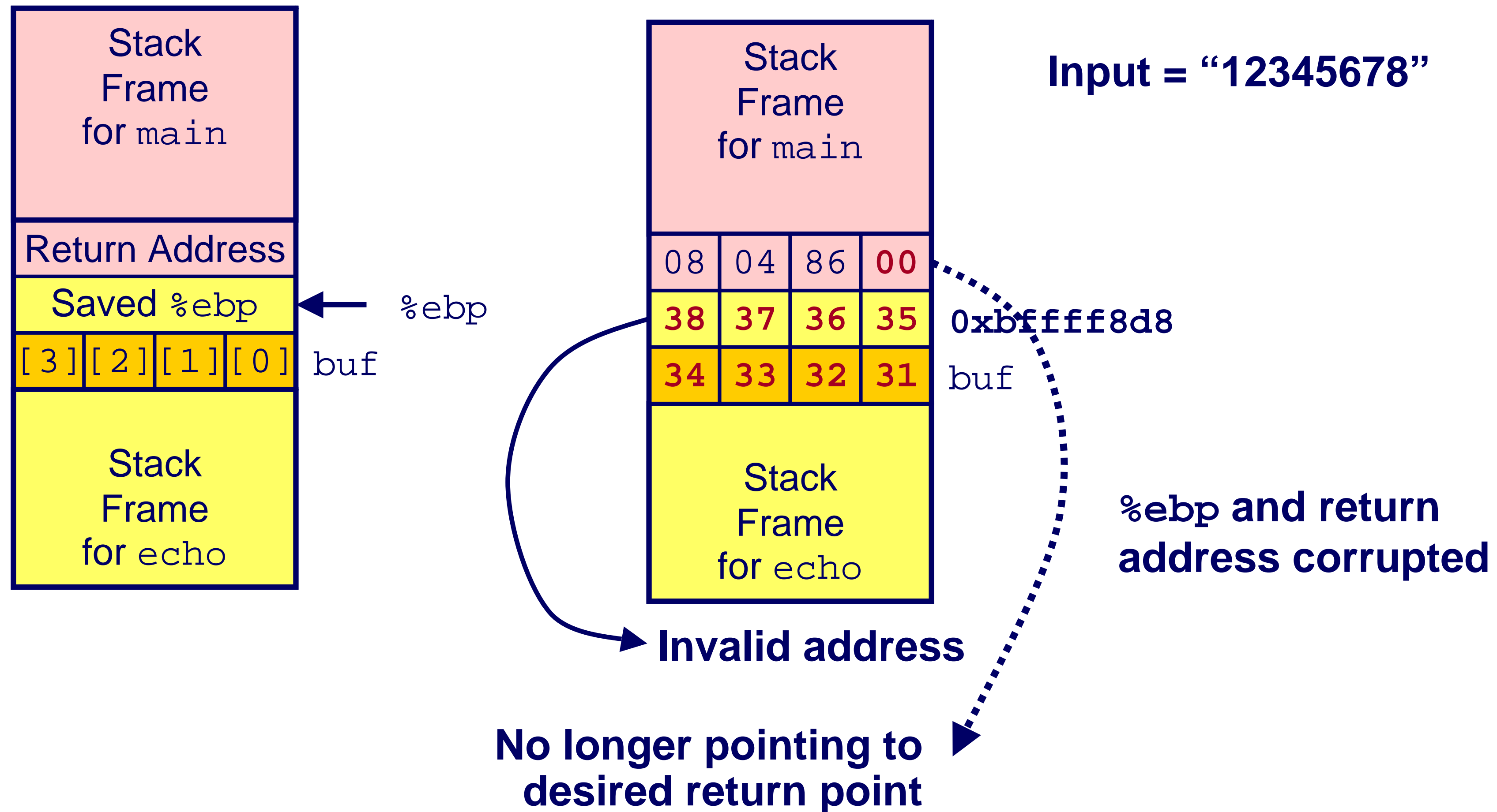
Buffer Overflow Stack Example #2



echo code:

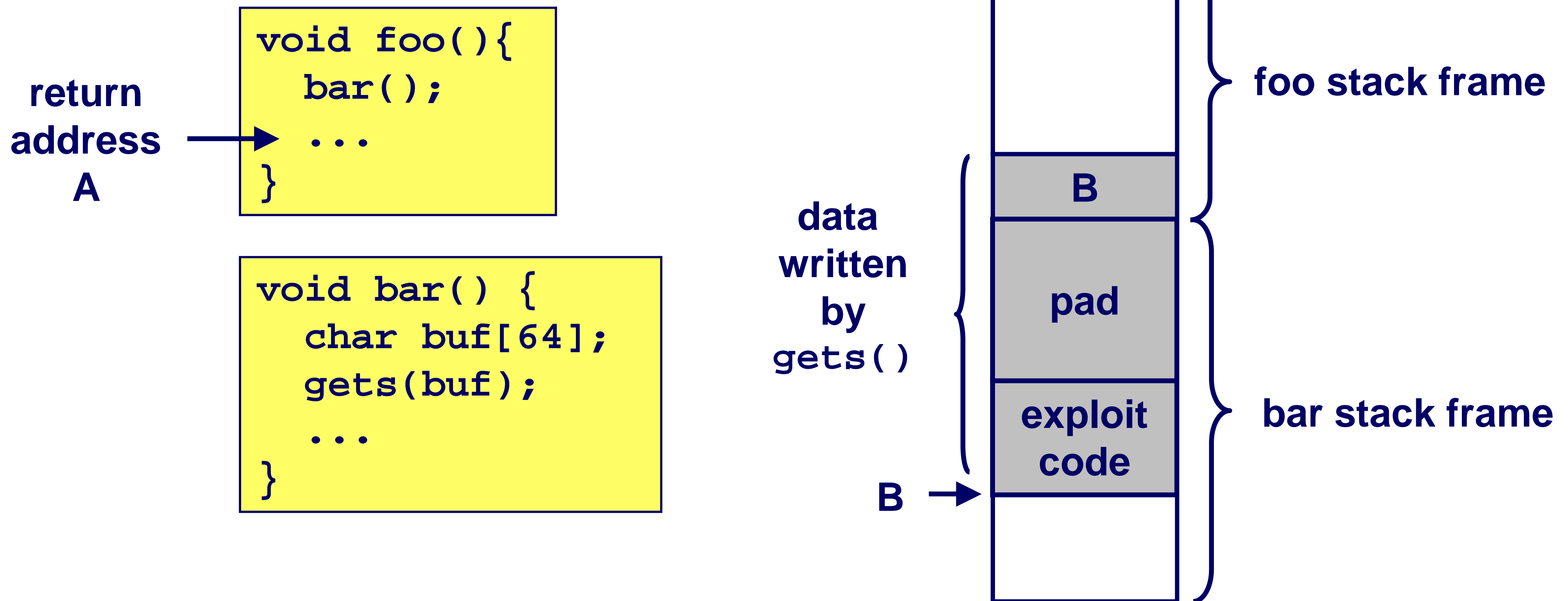
```
8048592:  push   %ebx
8048593:  call   80483e4 <_init+0x50>  # gets
8048598:  mov    0xffffffe8(%ebp),%ebx
804859b:  mov    %ebp,%esp
804859d:  pop    %ebp     # %ebp gets set to invalid value
804859e:  ret
```

Buffer Overflow Stack Example #3




```
8048648:  call  804857c <echo>
804864d:  mov   0xffffffe8(%ebp),%ebx # Return Point
```

Malicious Use of Buffer Overflow



- 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 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.

Exploits Based on Buffer Overflows

Buffer overflow bugs allow remote machines to execute arbitrary code on victim machines.

IM War

- AOL exploited existing buffer overflow bug in AIM clients
- exploit code: returned 4-byte signature (the bytes at some location in the AIM client) to server.
- When Microsoft changed code to match signature, AOL changed signature location.

Date: Wed, 11 Aug 1999 11:30:57 -0700 (PDT)
From: Phil Bucking <philbucking@yahoo.com>
Subject: AOL exploiting buffer overrun bug in their own software!
To: rms@pharlap.com

Mr. Smith,

I am writing you because I have discovered something that I think you might find interesting because you are an Internet security expert with experience in this area. I have also tried to contact AOL but received no response.

I am a developer who has been working on a revolutionary new instant messaging client that should be released later this year.
...
It appears that the AIM client has a buffer overrun bug. By itself this might not be the end of the world, as MS surely has had its share. But AOL is now *exploiting their own buffer overrun bug* to help in its efforts to block MS Instant Messenger.
....
Since you have significant credibility with the press I hope that you can use this information to help inform people that behind AOL's friendly exterior they are nefariously compromising peoples' security.

Sincerely,
Phil Bucking
Founder, Bucking Consulting
philbucking@yahoo.com

It was later determined that this email originated from within Microsoft!

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

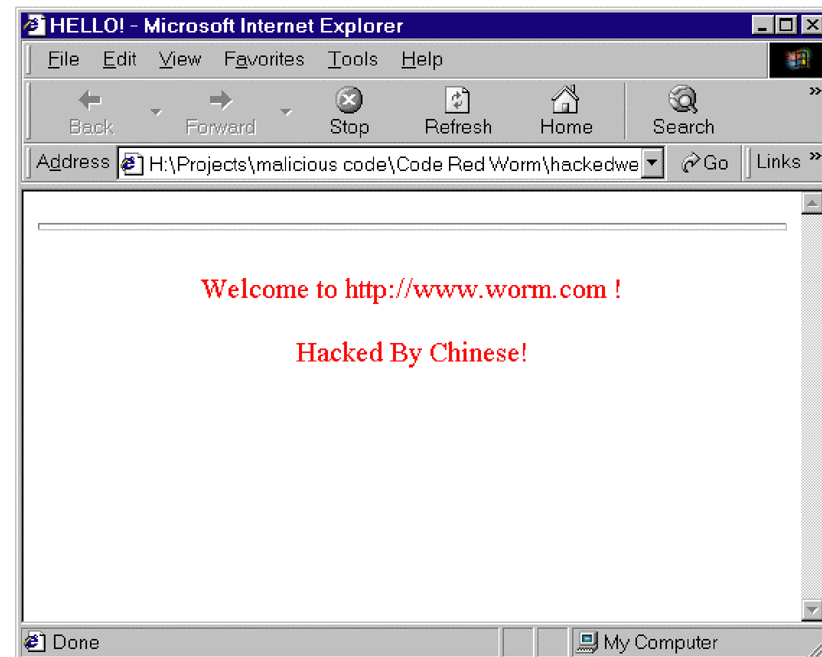
When We Set Up CS:APP Web Site

- Received strings of form

```
GET
  /default.ida?NNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN....NNNN
  NNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN%u9090%u6858%ucbd3%u780
  1%u9090%u6858%ucbd3%u7801%u9090%u6858%ucbd3%u7801%u9090%u909
  0%u8190%u00c3%u0003%u8b00%u531b%u53ff%u0078%u0000%u00=a
HTTP/1.0" 400 325 "-" "-"
```

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



Code Red Effects

Later Version Even More Malicious

- Code Red II
- As of April, 2002, over 18,000 machines infected
- Still spreading

Paved Way for NIMDA

- Variety of propagation methods
- One was to exploit vulnerabilities left behind by Code Red II

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

Final Observations

Memory Layout

- OS/machine dependent (including kernel version)
- Basic partitioning: stack/data/text/heap/DLL found in most machines

Working with Strange Code

- Important to analyze nonstandard cases
  - E.g., what happens when stack corrupted due to buffer overflow
- Helps to step through with GDB