CSE 523S: Systems Security

Computer & Network Systems Security

Spring 2018
Jon Shidal

Plan for Today

- Announcements
  - HW3 due 1pm 3/21
  - Get started early. It is harder than 1 & 2.

- Security news
- Assignment
- Stack buffer overflows

Security News

Memcrashed: amplification attack using Memcached

Memcached servers speedup loading of dynamic web pages by caching objects.

Recently found vulnerable to amplification attacks:

1, src_ip = target ~51,000X

attacker ----> Memcached Server ----> target

Used on Wednesday for largest DDoS attack ever, target was github(~1.3 Tbps)

Assignment

- For Wednesday, 3/7
  - Readings
    - HTAOE: Ch 5 295-302

Today: Lecture and Exercises

- Many of today's slides come from CSE361
  - from an old offering
  - they use 32-bit architecture
  - Based on Computer Systems, by Bryant and O'Hallaron

Stack Reminders

- Stack grows down from high address
- Each procedure has its own stack frame
- Stack frame contents:
  - return address
  - frame pointer
  - local storage
  - arguments to callee (if needed)
  - temporary space (if needed)
- Set-up code at beginning of procedure
- Clean-up code before return
- For ‘C’ code, managed by the compiler

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
  - `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;
}
```

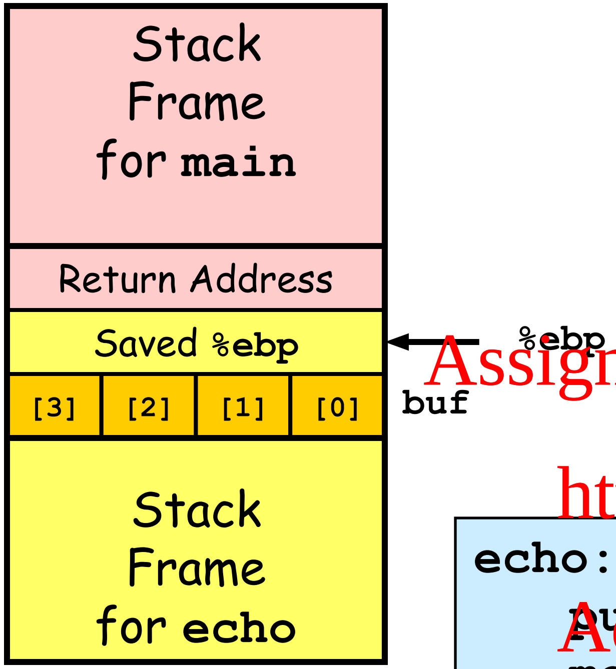
Buffer Overflow Executions

```
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

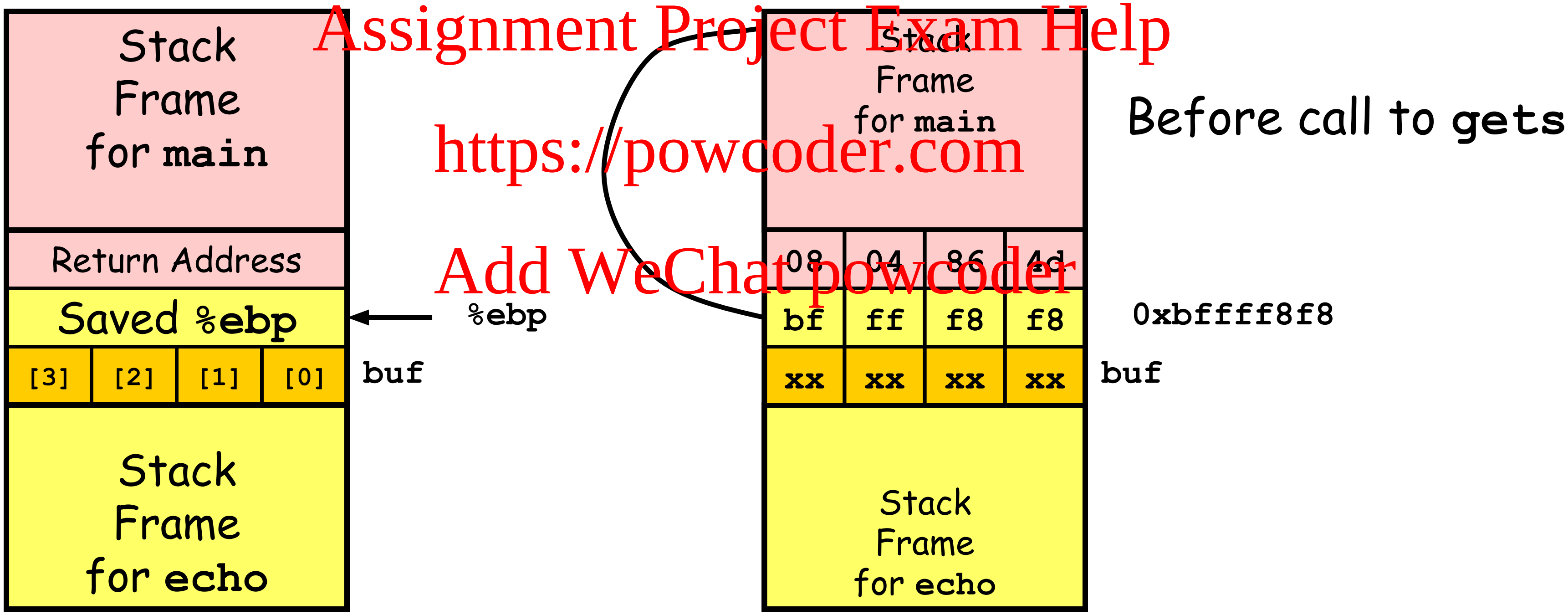


```
/* Echo Line */
void echo()
{
    char buf[4];  /* Way too small! */
    gets(buf);
    puts(buf);
}
```

```
echo:
   pushl %ebp     # Save %ebp on stack
   movl %esp,%ebp
   subl $20,%esp # Allocate stack space
   pushl %ebx     # Save %ebx
   addl $-12,%esp    # Allocate stack space
   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
```



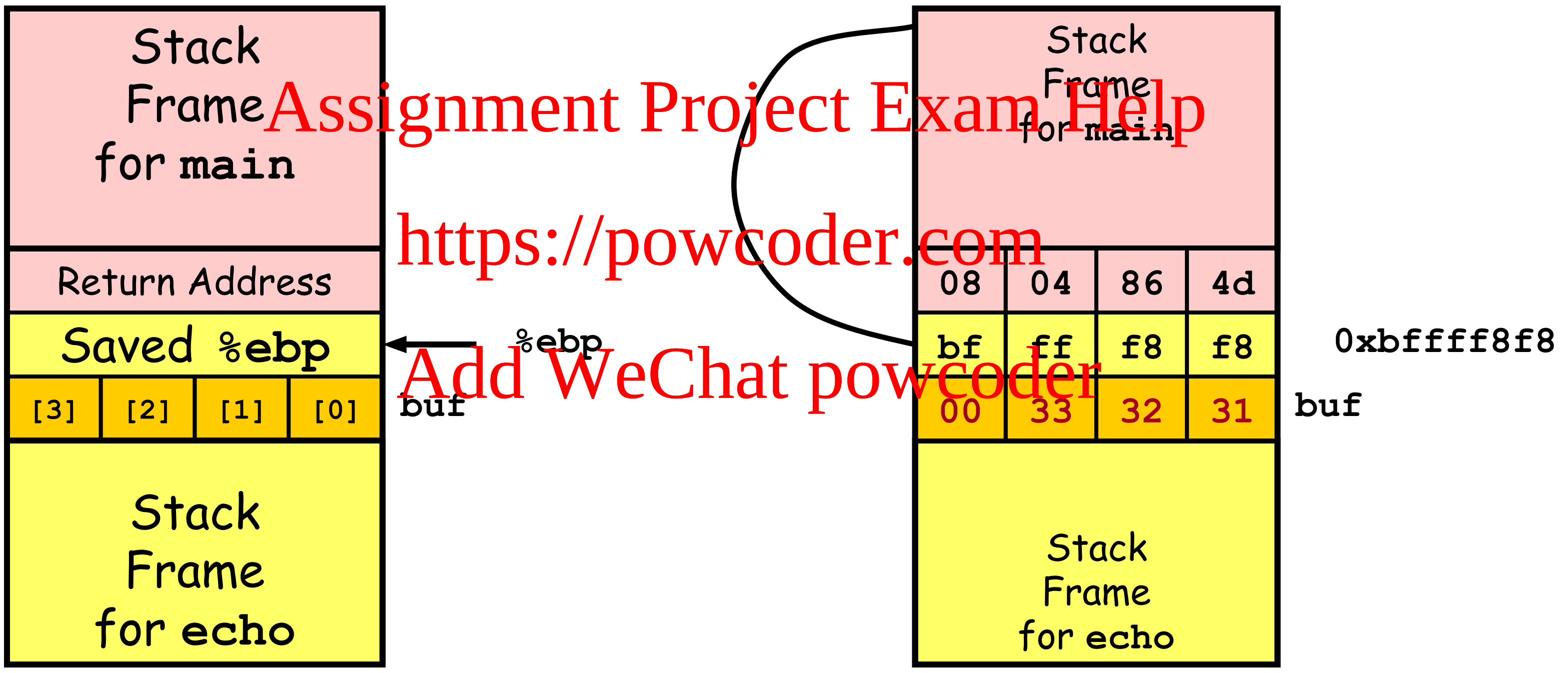
Before call to gets

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

Buffer Overflow Example #1

Before Call to gets

Input = “123”



Stack Frame for main

Return Address

Saved %ebp

[3] [2] [1] [0]

%ebp

buf

Stack Frame for echo

Stack Frame for main

08 04 86 4d

bf ff f8 f8

00 33 32 31

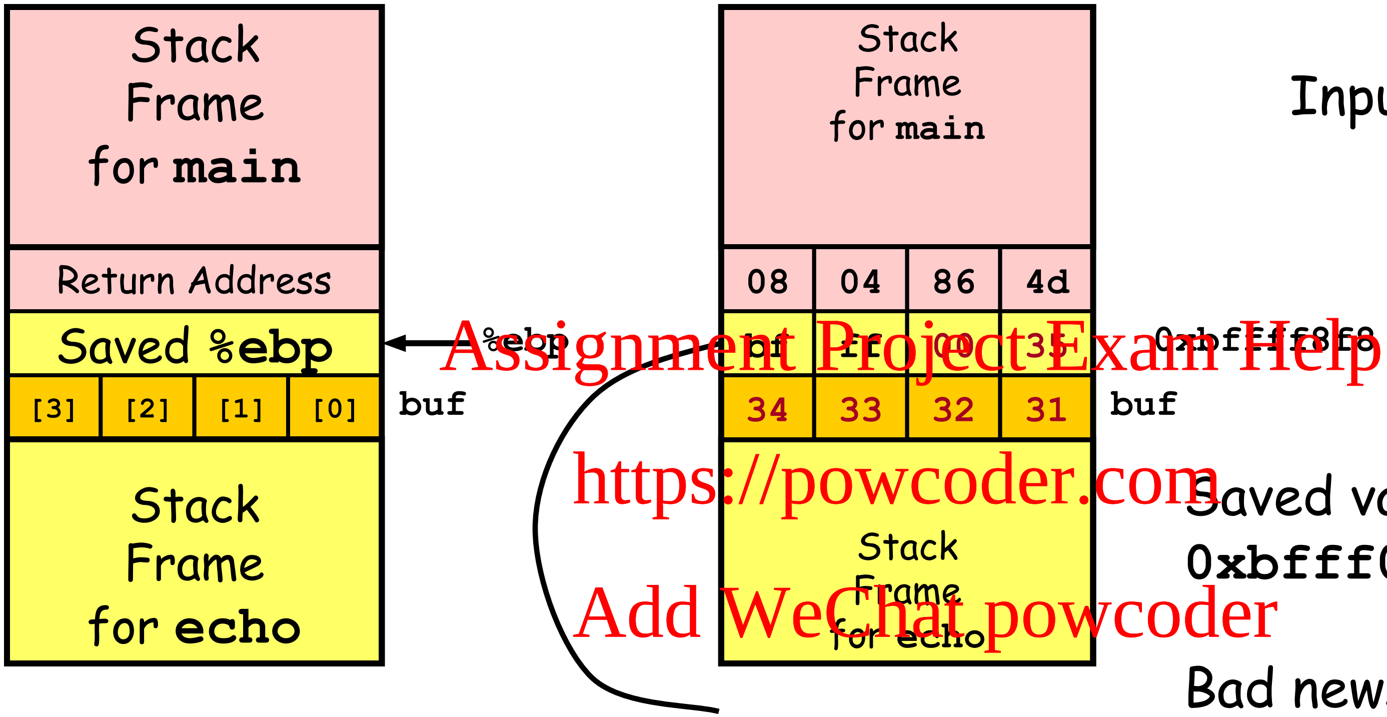
0xbffff8f8

buf

Stack Frame for echo

No Problem

Buffer Overflow Stack Example #2



Input = “12345”

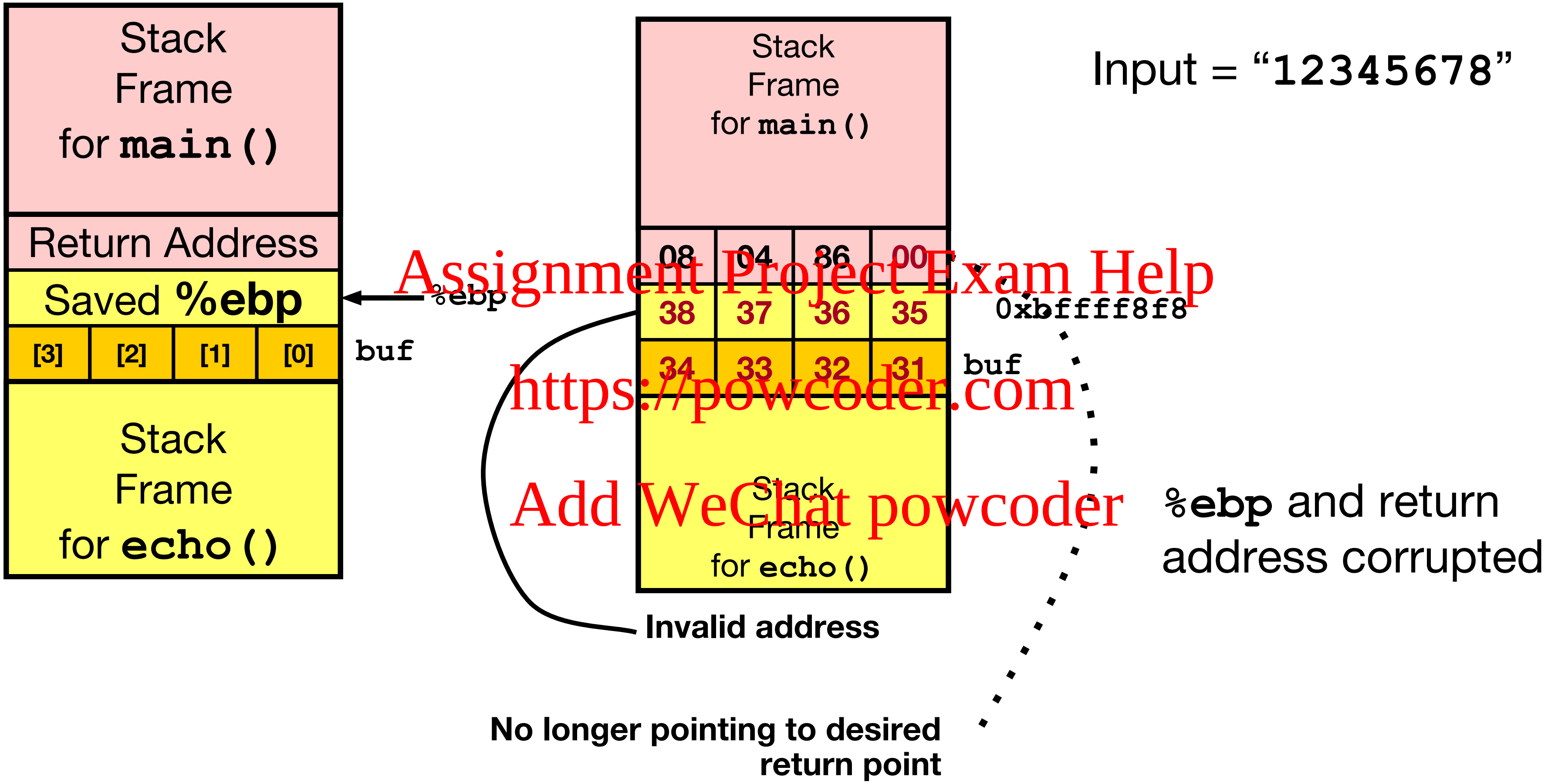
Saved value of %ebp set to 0xbfff0035

Bad news when later attempt to restore %ebp

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



Stack Frame for **main()**

Return Address

Saved **%ebp**

[3] [2] [1] [0]

buf

Stack Frame for **echo()**

%ebp

Stack Frame for **main()**

08 04 86 00

38 37 36 35

34 33 32 31

buf

0xbffff8f8

Stack Frame for **echo()**

Invalid address

No longer pointing to desired return point

Input = “**12345678**”

%ebp and return address corrupted

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

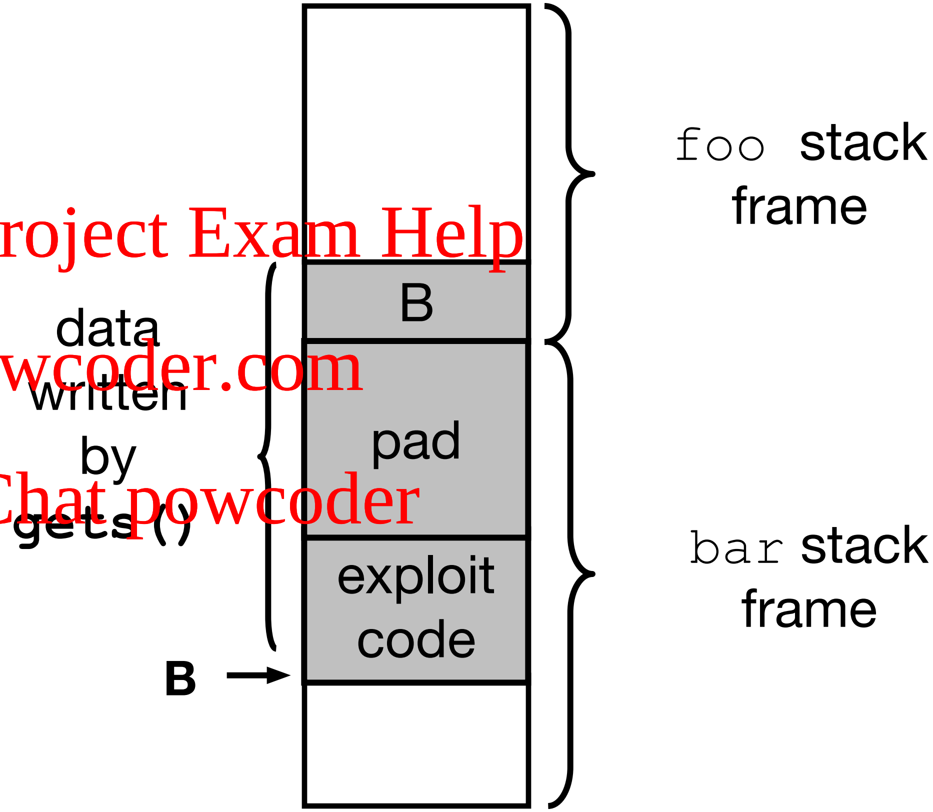
Malicious Use of Buffer Overflow

return address A

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

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

Stack
after call to **gets()**



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

Let’s get to work!

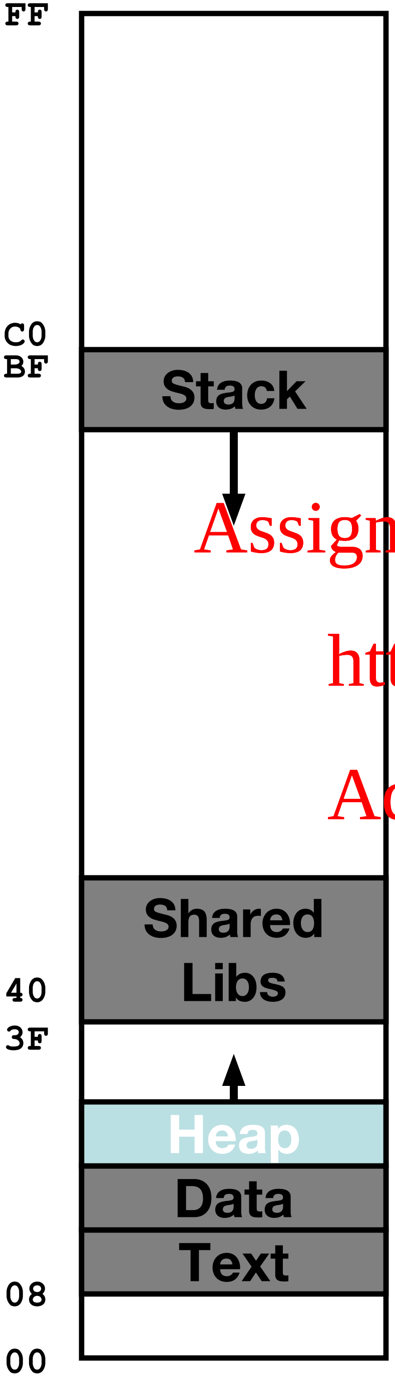
- See exploring-stack-overflow-notes in Google Docs
  - Important: use your host OS browser, do not use the browser in your VM

- Also use “Tracking Progress 3/5/2018” to indicate when you have reached a gate

- Additional background slides follow!

Linux Memory Layout

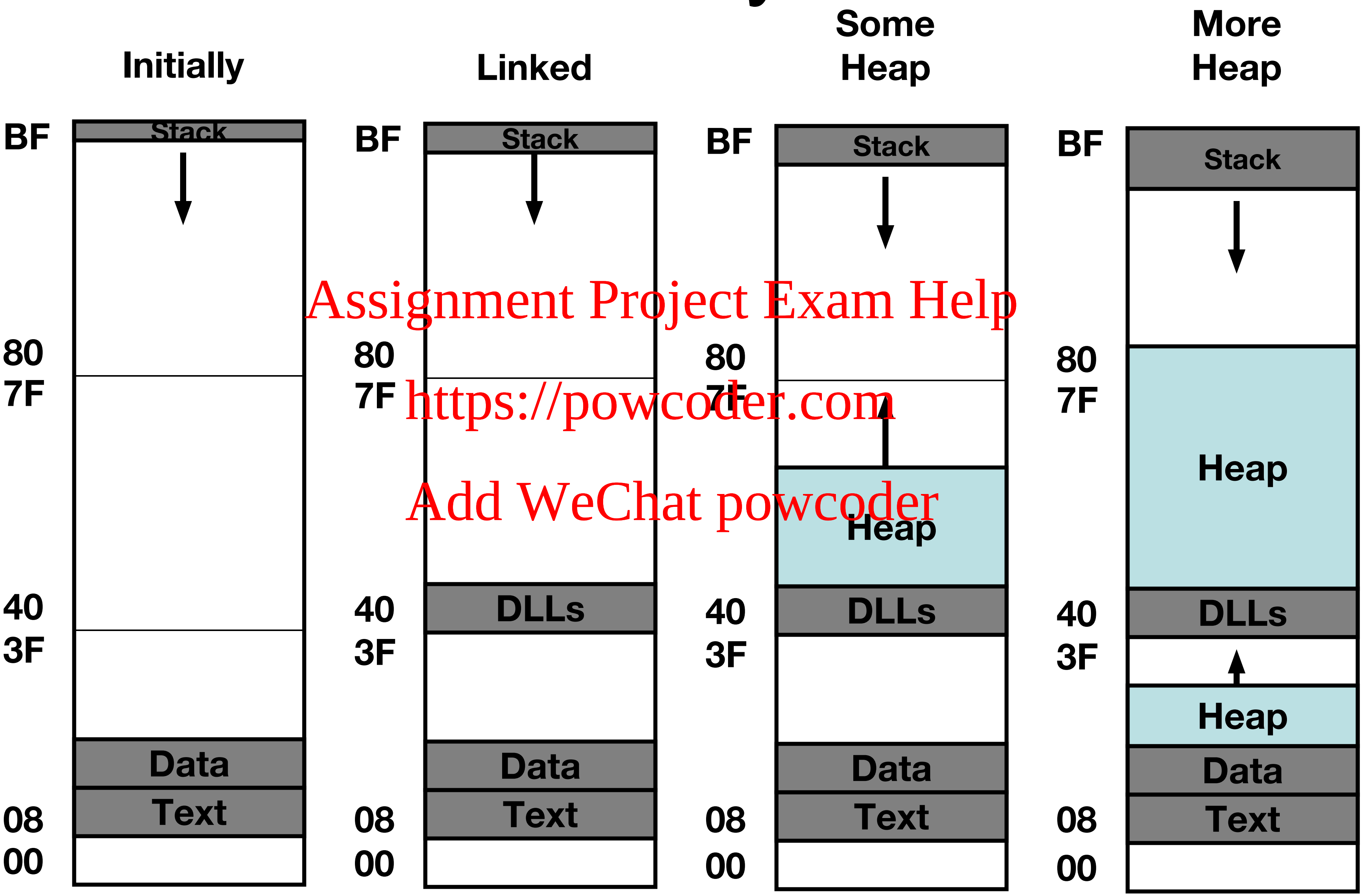
Red Hat
v. 6.2
~1920MB
memory
limit



Upper
2 hex
digits of
address

- Stack
  - Runtime stack (8MB limit)
- Heap
  - Dynamically allocated storage
  - When call `malloc()`, `calloc()`, `new()`
- Shared Libraries
  - Dynamically Linked Libraries
  - Library routines (e.g., `printf()`, `malloc()`)
  - Linked into object code when loaded
- Data
  - Statically allocated data
  - E.g., arrays & strings declared in code
- Text
  - Executable machine instructions
  - Read-only

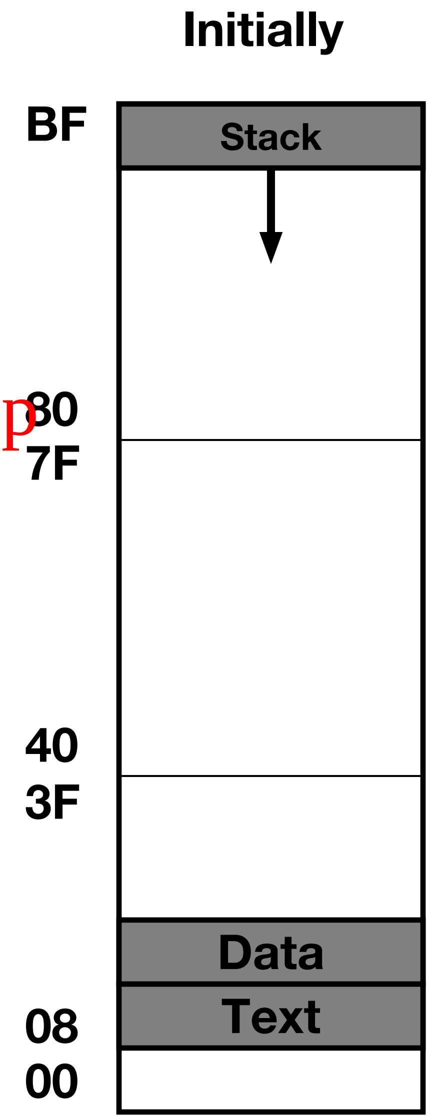
Linux Memory Allocation



Text & Stack Example

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

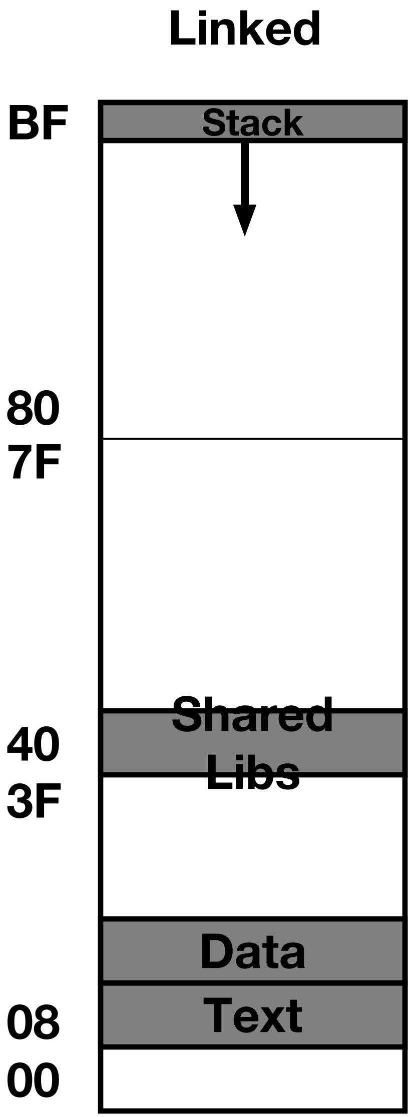
- Main
  - Address 0x804856f (0x0804856f)
- Stack
  - Address 0xbffffc78



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 shared library region

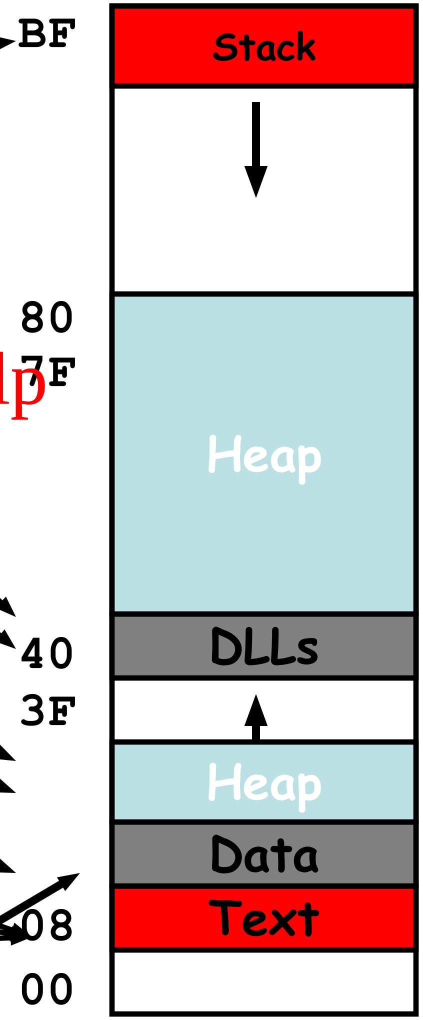


Memory Allocation Example

```
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

`$esp`	`0xbffffc78`
`p3`	`0x500b5008`
`p1`	`0x400b4008`
Final `malloc`	`0x40006240`
`p4`	`0x1904a640`
`p2`	`0x1904a538`
`beyond`	`0x1904a524`
`big_array`	`0x1804a520`
`huge_array`	`0x0804a510`
`main()`	`0x0804856f`
`useless()`	`0x08048560`
Initial `malloc`	`0x08048454`

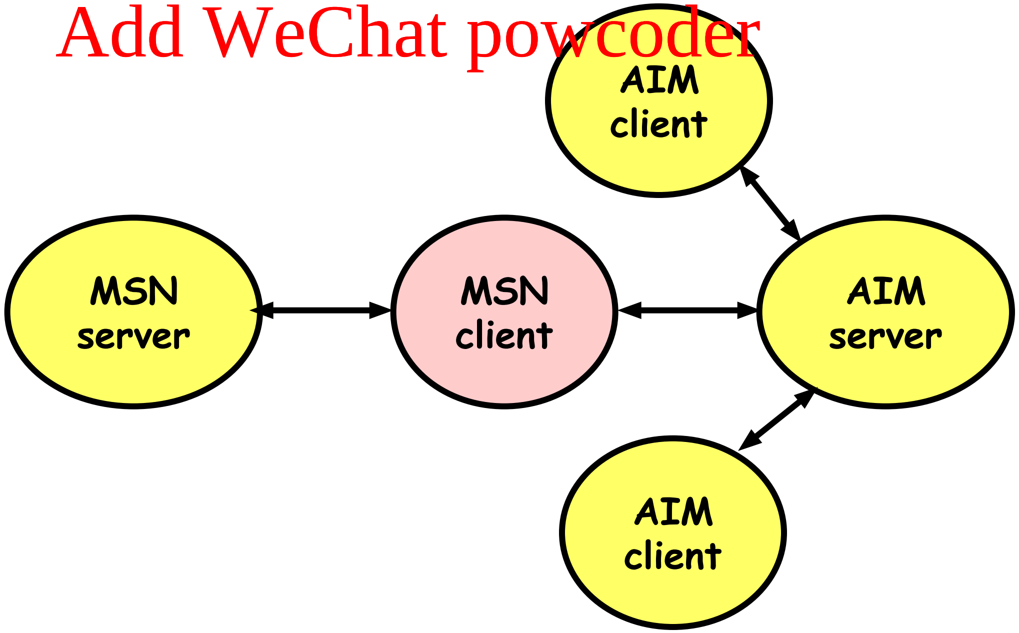


`&p2?` `0x1904a42c`

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.

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 joe@cse.wustl.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.

The Internet Worm

11/2 18:24 first west coast computer infected

19:04 ucb gateway infected

20:00 mit attacked

20:49 cs.utah.edu infected

21:21 load avg reaches 5 on cs.utah.edu

21:41 load avg reaches 7

22:01 load avg reaches 16

22:20 worm killed on cs.utah.edu

22:41 cs.utah.edu reinfected, load avg 27

22:49 cs.utah.edu shut down

23:31 reinfected, load reaches 37

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.
- Server would only respond to clients that sent the right signature
- 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

Still in the wild, today

- Web servers receive strings of form (contains the virus ‘boot sequence’)

```
GET
  /default.ida?NNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN....NNNNNNNNNNN
  NNNNNNNNNNNNNNNNNNNNNNNNNNNNNN%u9090%u6858%ucbd3%u7801%u9090%u6858%
  ucbd3%u7801%u9090%u6858%ucbd3%u7801%u9090%u9090%u8190%u00c3%u0003%u
  8b00%u531b%u53ff%u0078%u0000%u00=a
HTTP/1.0" 400 325 "-" "-"
```

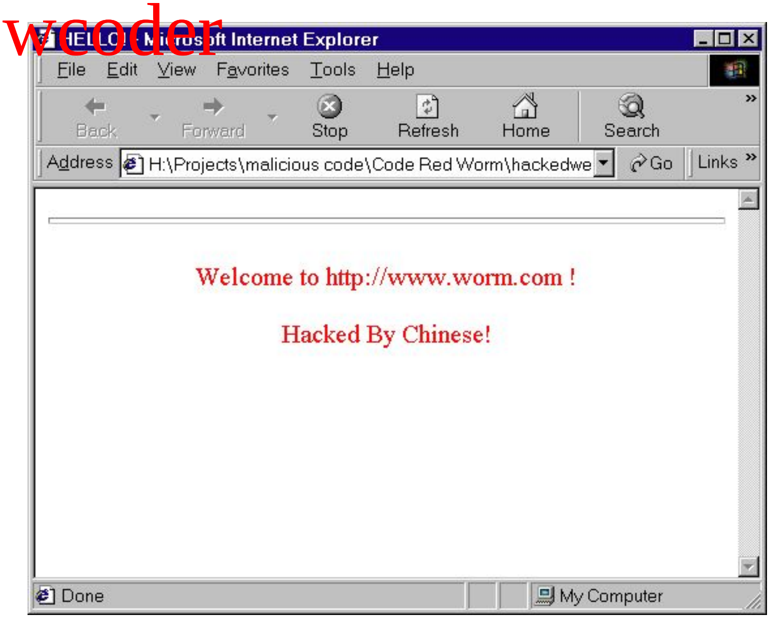
Code Red Exploit Code

- 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



Welcome to http://www.worm.com !

Hacked By Chinese!

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 `%`*`n`*`s` 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