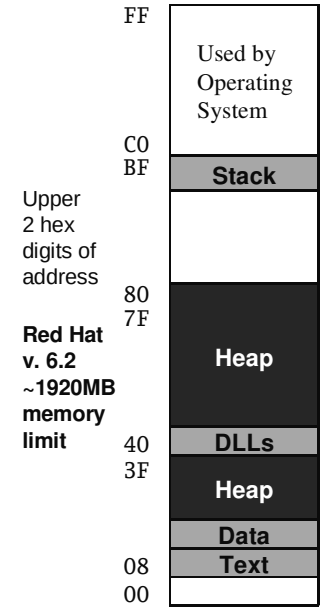
Lecture 6B
Machine-Level Programming V: Miscellaneous Topics

Topics

- Linux Memory Layout
- Understanding Pointers
- Buffer Overflow



Linux Memory Layout

Stack
- Runtime stack (8MB limit)

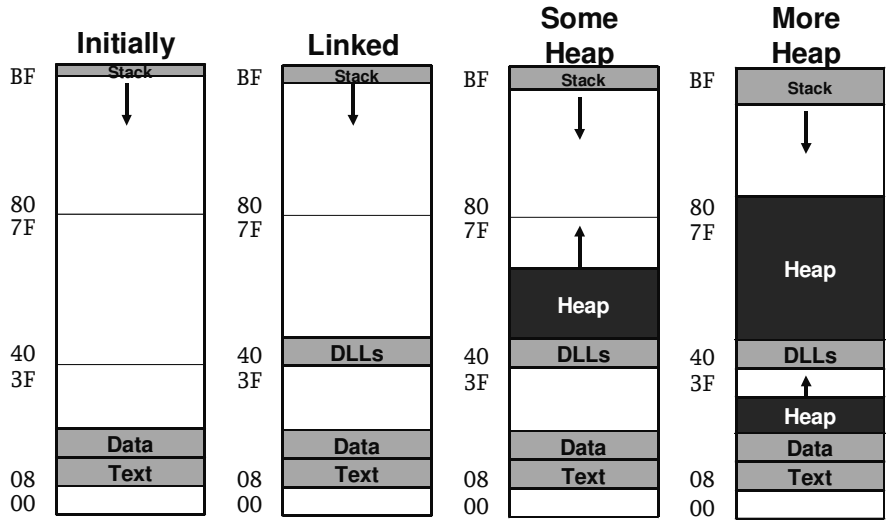
Heap
- Dynamically allocated storage
- When call `malloc`, `calloc`, `new`

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

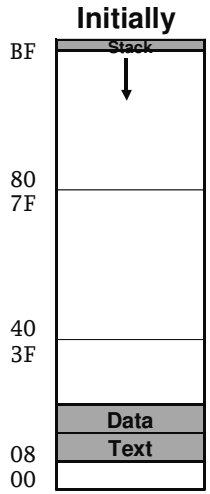


Text & Stack Example

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

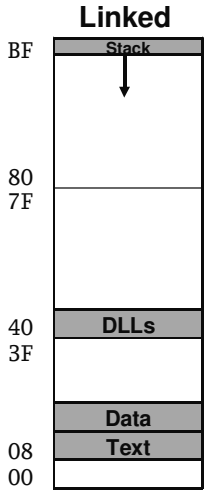
Main
- Address 0x804856f should be read 0x*08*04856f

Stack
- Address 0x*bf*ffffc78



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 0x40006240

Final

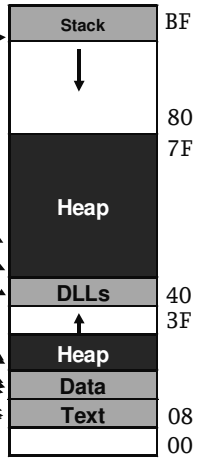
- Code in DLL region

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

$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



C operators

Operators	Associativity
() [] -> .	left to right
! ~ ++ -- + - * & (type) sizeof	right to left
* / %	left to right
+ -	left to right
<< >>	left to right
< <= > >=	left to right
== !=	left to right
&	left to right
^	left to right
|	left to right
&&	left to right
||	left to right
?:	right to left
= += -= *= /= %= &= ^= != <<= >>=	right to left
,	left to right

Note: Unary +, –, and * have higher precedence than binary forms

C pointer declarations

`int *p`	p is a pointer to int
`int *p[13]`	p is an array[13] of pointer to int
`int *(p[13])`	p is an array[13] of pointer to int
`int **p`	p is a pointer to a pointer to an int
`int (*p)[13]`	p is a pointer to an array[13] of int
`int *f()`	f is a function returning a pointer to int
`int (*f)()`	f is a pointer to a function returning int
`int (*(*f())[13])()`	f is a function returning ptr to an array[13] of pointers to functions returning int
`int (*(*x[3])())[5]`	x is an array[3] of pointers to functions returning pointers to array[5] of ints

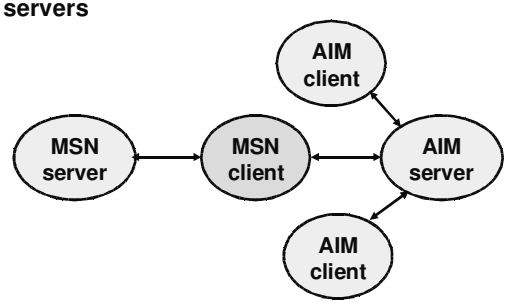
Internet Worm and IM War

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;
}
```

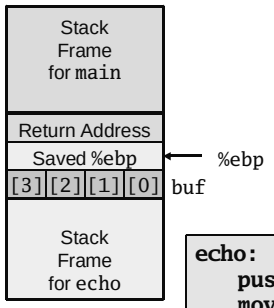

Buffer Overflow Executions

```
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

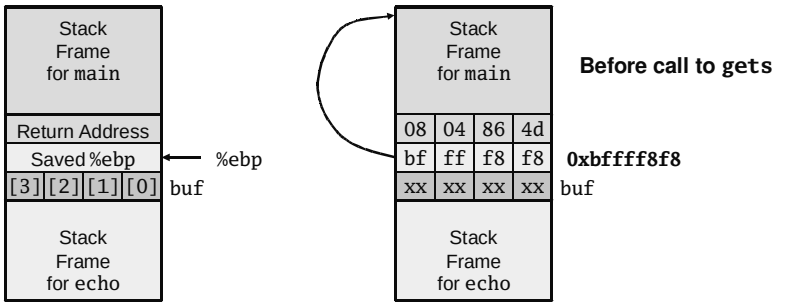



```
/* Echo Line */
void echo()
{
    char buf[4];  /* Way too small! */
    gets(buf);
    puts(buf);
}
```

```
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
    . . .
```

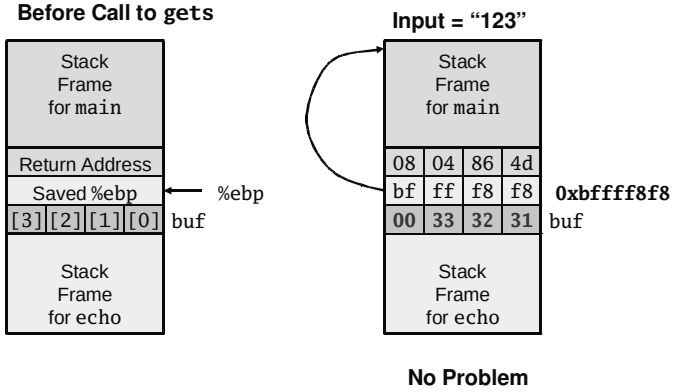

Buffer Overflow Stack Example

```
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
```

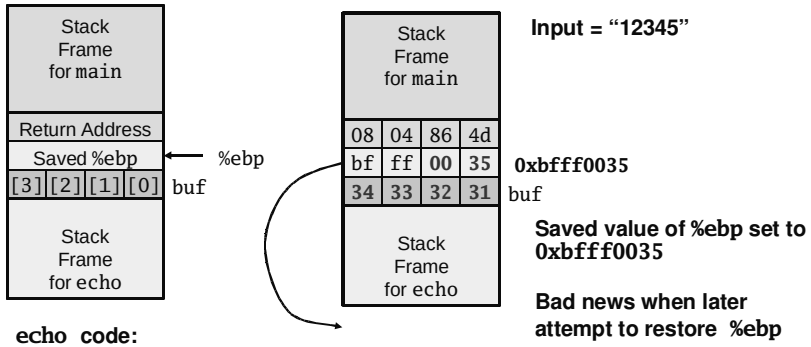



```
8048648: call 804857c <echo>
804864d: mov  0xfffffff8(%ebp),%ebx # Return Point
```

Buffer Overflow Example #1



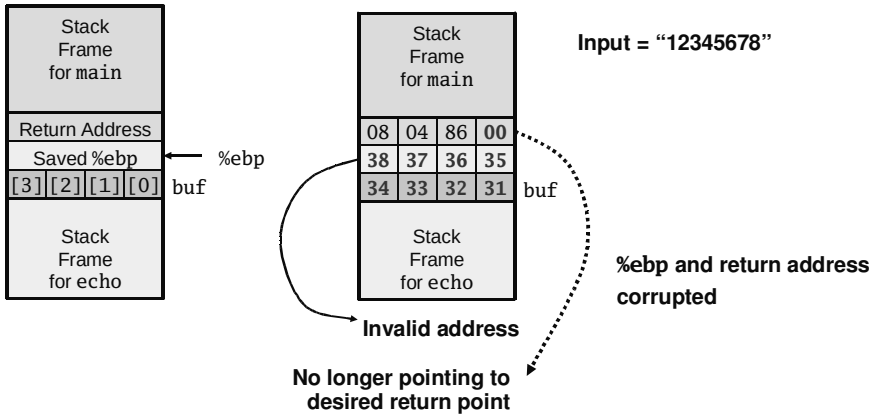
Buffer Overflow Stack Example #2



echo code:

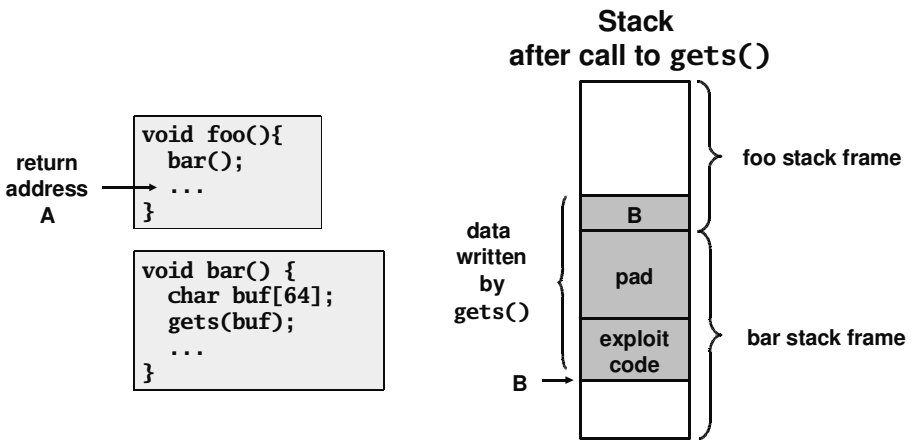
```
8048592: push   %ebx
8048593: call   80483e4 <_init+0x50>  # gets
8048598: mov    0xffffffe8(%ebp),%ebx
804859b: mov    %ebp,%esp
804859d: pop    %ebp     # %ebp gets set to invalid value
804859e: ret
```


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.

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

Type Declarations in C

- Notation obscure, but very systematic

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