The Hardware/Software Interface

CSE351 Winter 2013

Buffer Overflow

Buffer Overflow

- **Buffer overflows are possible because C doesn't check array boundaries**
- **Buffer overflows are *dangerous* because buffers for user input are often stored on the stack**
  - Probably the most common type of security vulnerability

- **Today we'll go over:**
  - Address space layout
  - Input buffers on the stack
  - Overflowing buffers and injecting code
  - Defenses against buffer overflows

IA32 Linux Memory Layout

- **Stack**
  - Runtime stack (8MB limit)
- **Heap**
  - Dynamically allocated storage
  - Allocated by `malloc(), calloc(), new()`
- **Data**
  - Statically allocated data
    - Read-only: string literals
    - Read/write: global arrays and variables
- **Text**
  - Executable machine instructions
  - Read-only

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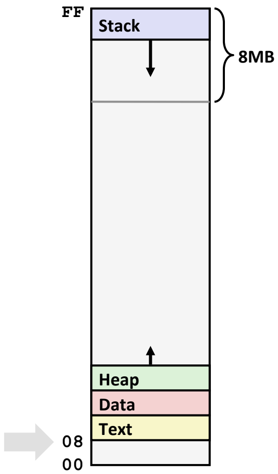

Upper 2 hex digits
= 8 bits of address

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?

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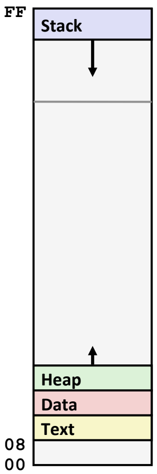

IA32 Example Addresses

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

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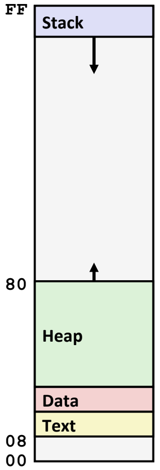


Internet Worm

- **These characteristics of the traditional IA32 Linux memory layout provide opportunities for malicious programs**
  - Stack grows “backwards” in memory
  - Data and instructions both stored in the same memory
- **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;
}
```

  - What could go wrong in this code?

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
```

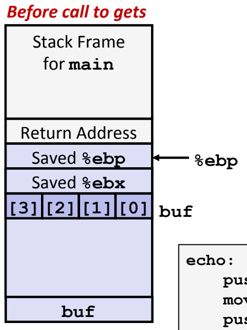
```
unix>./bufdemo
Type a string:123456789ABC
Segmentation Fault
```

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
```

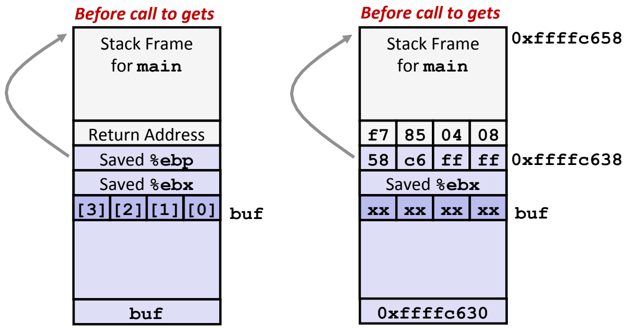
Buffer Overflow Stack



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

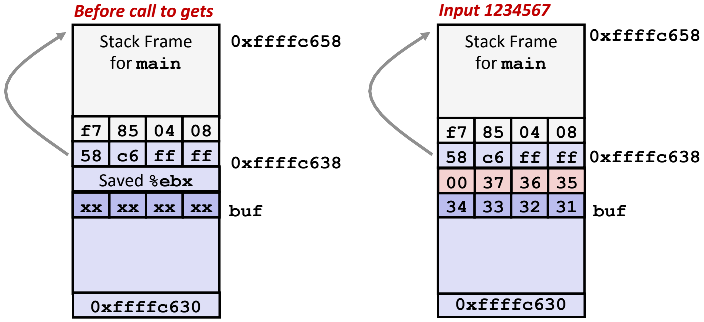
```
echo:
    pushl  %ebp               # Save %ebp on stack
    movl   %esp, %ebp
    pushl  %ebx               # Save %ebx
    leal   -8(%ebp),%ebx      # Compute buf as %ebp-8
    subl   $20, %esp          # Allocate stack space
    movl   %ebx, (%esp)       # Push buf addr on stack
    call   gets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

Buffer Overflow Stack Example



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

Buffer Overflow Example #1



Before call to gets

Stack Frame for `main` 0xffffc658

f7	85	04	08
58	c6	ff	ff

0xffffc638

Saved `%ebx`

xx	xx	xx	xx

buf

0xffffc630

Input 1234567

Stack Frame for `main` 0xffffc658

f7	85	04	08
58	c6	ff	ff
00	37	36	35
34	33	32	31

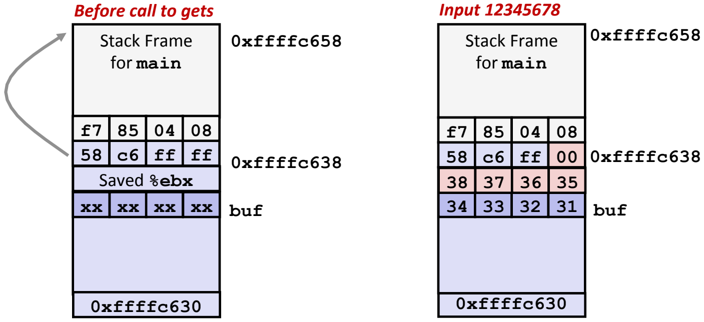
0xffffc638

buf

0xffffc630

Overflow buf, and corrupt saved %ebx, but no problem

Buffer Overflow Example #2



Before call to gets

Stack Frame for `main` 0xffffc658

f7	85	04	08
58	c6	ff	ff

0xffffc638

Saved `%ebx`

xx	xx	xx	xx

buf

0xffffc630

Input 12345678

Stack Frame for `main` 0xffffc658

f7	85	04	08
58	c6	ff	00
38	37	36	35
34	33	32	31

0xffffc638

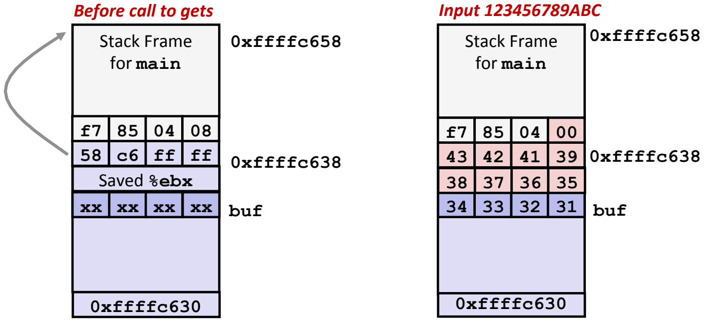
buf

0xffffc630

Frame 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

Stack Frame for `main` 0xffffc658

f7	85	04	08
58	c6	ff	ff

0xffffc638

Saved `%ebx`

xx	xx	xx	xx

buf

0xffffc630

Input 123456789ABC

Stack Frame for `main` 0xffffc658

f7	85	04	00
43	42	41	39
38	37	36	35
34	33	32	31

0xffffc638

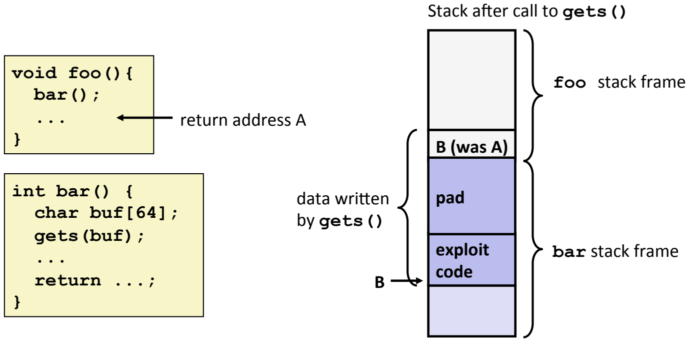
buf

0xffffc630

Return address corrupted

```
080485f2: call  80484f0 <echo>
080485f7: mov   0xfffffffc(%ebp),%ebx # Return Point
```

Malicious Use of Buffer Overflow



Stack after call to `gets()`

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

return address A

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

`foo` stack frame

B (was A)

pad

exploit code

data written by `gets()`

B

`bar` stack frame

- Input string contains byte representation of executable code
- Overwrite return address A 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 exploit to predict beginning of inserted code
- **Use techniques to *detect* stack corruption**
- **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 needed

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