CS 33

Machine Programming (4)

Switch-Statement Example

```
long switch_eg (long m, long d) {
    if (d < 1) return 0;
    switch(m) {
    case 1: case 3: case 5:
    case 7: case 8: case 10:
    case 12:
        if (d > 31) return 0;
        else return 1;
    case 2:
        if (d > 28) return 0;
        else return 1;
    case 4: case 6: case 9:
    case 11:
        if (d > 30) return 0;
        else return 1;
    default:
        return 0;
    }
    return 0;
}
```

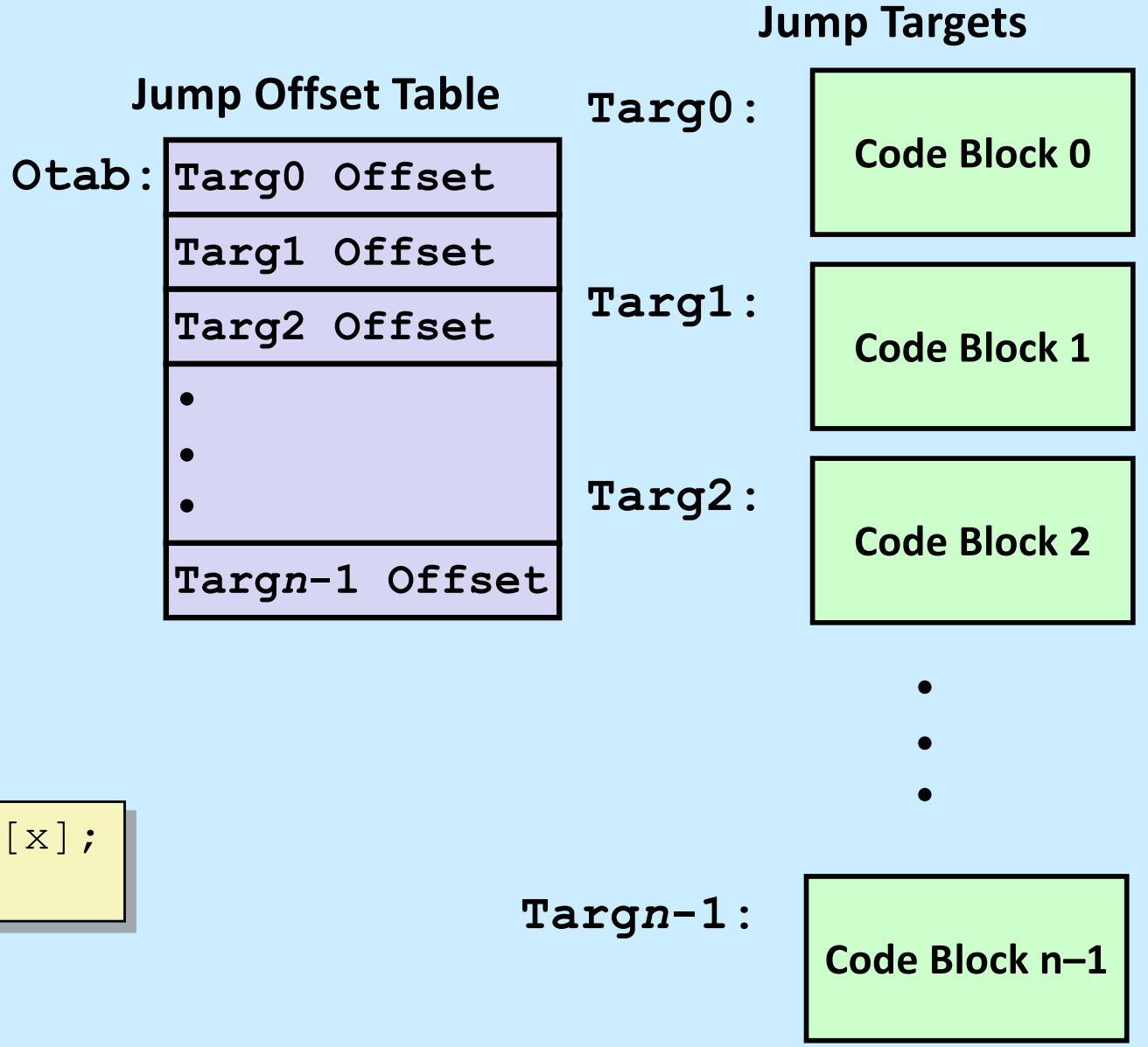
Offset Structure

Switch Form

```
switch(x) {
  case val_0:
    Block 0
  case val_1:
    Block 1
    • • •
  case val_n-1:
    Block n-1
}
```

Approximate Translation

```
target = Otab + OTab[x];
goto *target;
```



Assembler Code (1)

```
switch_eg:
        movl    $0, %eax
        testq   %rsi, %rsi
        jle     .L1
        cmpq    $12, %rdi
        ja      .L8
        leaq    .L4(%rip), %rdx
        movslq  (%rdx,%rdi,4), %rax
        addq    %rdx, %rax
        jmp     *%rax
```

```
        .section    .rodata
        .align 4
.L4:
        .long   .L8-.L4
        .long   .L3-.L4
        .long   .L6-.L4
        .long   .L3-.L4
        .long   .L5-.L4
        .long   .L3-.L4
        .long   .L5-.L4
        .long   .L3-.L4
        .long   .L3-.L4
        .long   .L5-.L4
        .long   .L3-.L4
        .long   .L5-.L4
        .long   .L3-.L4
        .text
```

Assembler Code (2)

```
.L3:
        cmpq    $31, %rsi
        setle   %al
        movzbl  %al, %eax
        ret
.L6:
        cmpq    $28, %rsi
        setle   %al
        movzbl  %al, %eax
        ret
```

```
.L5:
        cmpq    $30, %rsi
        setle   %al
        movzbl  %al, %eax
        ret
.L8:
        movl    $0, %eax
.L1:
        ret
```

Assembler Code Explanation (1)

```
switch_eg:
        movl    $0, %eax        # return value set to 0
        testq   %rsi, %rsi      # sets cc based on %rsi & %rsi
        jle     .L1             # go to L1, where it returns 0
        cmpq    $12, %rdi
        ja      .L8
        leaq    .L4(%rip), %rdx
        movslq  (%rdx,%rdi,4), %rax
        addq    %rdx, %rax
        jmp     *%rax
```

- **testq %rsi, %rsi**
  - **sets cc based on the contents of %rsi (d)**
  - **jle**
    - **jumps if `(SF^OF)|ZF`**
    - **OF is not set**
    - **jumps if SF or ZF is set (i.e., < 1)**

Assembler Code Explanation (2)

```
switch_eg:
        movl    $0, %eax        # return value set to 0
        testq   %rsi, %rsi      # sets cc based on %rsi & %rsi
        jle     .L1             # go to L1, where it returns 0
        cmpq    $12, %rdi       # %rdi : 12
        ja      .L8             # go to L8 if %rdi > 12 or < 0
        leaq    .L4(%rip), %rdx
        movslq  (%rdx,%rdi,4), %rax
        addq    %rdx, %rax
        jmp     *%rax
```

- **ja .L8**
  - **unsigned comparison, though m is signed!**
  - **jumps if %rdi > 12**
  - **also jumps if %rdi is negative**

Assembler Code Explanation (3)

```
switch_eg:
        movl    $0, %eax
        testq   %rsi, %rsi
        jle     .L1
        cmpq     $12, %rdi
        ja      .L8
        leaq     .L4(%rip), %rdx
        movslq   (%rdx,%rdi,4), %rax
        addq     %rdx, %rax
        jmp      *%rax
```

```
        .section     .rodata
        .align 4
.L4:
        .long   .L8-.L4 # m=0
        .long   .L3-.L4 # m=1
        .long   .L6-.L4 # m=2
        .long   .L3-.L4 # m=3
        .long   .L5-.L4 # m=4
        .long   .L3-.L4 # m=5
        .long   .L5-.L4 # m=6
        .long   .L3-.L4 # m=7
        .long   .L3-.L4 # m=8
        .long   .L5-.L4 # m=9
        .long   .L3-.L4 # m=10
        .long   .L5-.L4 # m=11
        .long   .L3-.L4 # m=12
        .text
```

Assembler Code Explanation (4)

```
switch_eg:
        movl    $0, %eax
        testq   %rsi, %rsi
        jle     .L1
        cmpq     $12, %rdi
        ja      .L8
        leaq     .L4(%rip), %rdx
        movslq   (%rdx,%rdi,4), %rax
        addq     %rdx, %rax
        jmp      *%rax
```

indirect jump

```
                .section     .rodata
                .align 4
.L4:
                .long   .L8-.L4 # m=0
                .long   .L3-.L4 # m=1
                .long   .L6-.L4 # m=2
                .long   .L3-.L4 # m=3
                .long   .L5-.L4 # m=4
                .long   .L3-.L4 # m=5
                .long   .L5-.L4 # m=6
                .long   .L3-.L4 # m=7
                .long   .L3-.L4 # m=8
                .long   .L5-.L4 # m=9
                .long   .L3-.L4 # m=10
                .long   .L5-.L4 # m=11
                .long   .L3-.L4 # m=12
                .text
```

Assembler Code Explanation (5)

```
switch_eg:
        movl    $0, %eax
        testq   %rsi, %rsi
        jle     .L1
        cmpq     $12, %rdi
        ja      .L8
        leaq    .L4(%rip), %rdx
        movslq  (%rdx,%rdi,4), %rax
        addq    %rdx, %rax
        jmp     *%rax
```

```
        .section    .rodata
        .align 4
.L4:
        .long   .L8-.L4 # m=0
        .long   .L3-.L4 # m=1
        .long   .L6-.L4 # m=2
        .long   .L3-.L4 # m=3
        .long   .L5-.L4 # m=4
        .long   .L3-.L4 # m=5
        .long   .L5-.L4 # m=6
        .long   .L3-.L4 # m=7
        .long   .L3-.L4 # m=8
        .long   .L5-.L4 # m=9
        .long   .L3-.L4 # m=10
        .long   .L5-.L4 # m=11
        .long   .L3-.L4 # m=12
        .text
```

Assembler Code Explanation (6)

```
switch_eg:
        movl    $0, %eax
        testq   %rsi, %rsi
        jle     .L1
        cmpq     $12, %rdi
        ja      .L8
        leaq     .L4(%rip), %rdx
        movslq   (%rdx,%rdi,4), %rax
        addq     %rdx, %rax
        jmp      *%rax
```

```
        .section     .rodata
        .align 4
.L4:
        .long    .L8-.L4 # m=0
        .long    .L3-.L4 # m=1
        .long    .L6-.L4 # m=2
        .long    .L3-.L4 # m=3
        .long    .L5-.L4 # m=4
        .long    .L3-.L4 # m=5
        .long    .L5-.L4 # m=6
        .long    .L3-.L4 # m=7
        .long    .L3-.L4 # m=8
        .long    .L5-.L4 # m=9
        .long    .L3-.L4 # m=10
        .long    .L5-.L4 # m=11
        .long    .L3-.L4 # m=12
        .text
```

Assembler Code Explanation (7)

```
switch_eg:
        movl    $0, %eax
        testq   %rsi, %rsi
        jle     .L1
        cmpq     $12, %rdi
        ja      .L8
        leaq    .L4(%rip), %rdx
        movslq  (%rdx,%rdi,4), %rax
        addq    %rdx, %rax
        jmp     *%rax
```

```
        .section    .rodata
        .align 4
.L4:
        .long   .L8-.L4 # m=0
        .long   .L3-.L4 # m=1
        .long   .L6-.L4 # m=2
        .long   .L3-.L4 # m=3
        .long   .L5-.L4 # m=4
        .long   .L3-.L4 # m=5
        .long   .L5-.L4 # m=6
        .long   .L3-.L4 # m=7
        .long   .L3-.L4 # m=8
        .long   .L5-.L4 # m=9
        .long   .L3-.L4 # m=10
        .long   .L5-.L4 # m=11
        .long   .L3-.L4 # m=12
        .text
```

Switch Statements and Traps

- The code we just looked at was compiled with gcc's O1 flag
  - a moderate amount of "optimization"
- Traps originally was compiled with the O0 flag
  - no optimization
- O0 often produces easier-to-read (but less efficient) code
  - not so for switch

O1 vs. O0 Code

```
switch_egO1:
    movl    $0, %eax
    testq   %rsi, %rsi
    jle     .L1
    cmpq    $12, %rdi
    ja      .L8
    leaq    .L4(%rip), %rdx
    movslq  (%rdx,%rdi,4), %rax
    addq    %rdx, %rax
    jmp     *%rax
```

```
switch_eg00:
    pushq   %rbp
    movq    %rsp, %rbp
    movq    %rdi, -8(%rbp)
    movq    %rsi, -16(%rbp)
    cmpq    $0, -16(%rbp)
    jg      .L2
    movl    $0, %eax
    jmp     .L3
.L2:
    cmpq    $12, -8(%rbp)
    ja      .L4
    movq    -8(%rbp), %rax
    leaq    0(,%rax,4), %rdx
    leaq    .L6(%rip), %rax
    movl    (%rdx,%rax), %eax
    cltq
    leaq    .L6(%rip), %rdx
    addq    %rdx, %rax
    jmp     *%rax
```

Gdb and Switch (1)

```
B+ 0x555555555165 <switch_eg>      mov    $0x0,%eax                                  
   0x55555555516a <switch_eg+5>    test   %rsi,%rsi                                  
   0x55555555516d <switch_eg+8>    jle    0x5555555551ab <switch_eg+70>              
   0x55555555516f <switch_eg+10>   cmp    $0xc,%rdi                                  
   0x555555555173 <switch_eg+14>   ja     0x5555555551a6 <switch_eg+65>              
   0x555555555175 <switch_eg+16>   lea    0xe88(%rip),%rdx  # 0x555555556004          
   0x55555555517c <switch_eg+23>   movslq (%rdx,%rdi,4),%rax                         
   0x555555555180 <switch_eg+27>   add    %rdx,%rax                                  
  >0x555555555183 <switch_eg+30>   jmp    *%rax                                      
   0x555555555185 <switch_eg+32>   cmp    $0x1f,%rsi                                 
   0x555555555189 <switch_eg+36>   setle  %al                                        
   0x55555555518c <switch_eg+39>   movzbl %al,%eax                                   
   0x55555555518f <switch_eg+42>   ret                                               
```

```
(gdb) x/14dw $rdx
0x555555556004: -3678   -3711   -3700   -3711
0x555555556014: -3689   -3711   -3689   -3711
0x555555556024: -3711   -3689   -3711   -3689
0x555555556034: -3711   1734439765
```

Gdb and Switch (2)

```
>0x555555555183 <switch_eg+30>   jmp    *%rax
 0x555555555185 <switch_eg+32>   cmp    $0x1f,%rsi
 0x555555555189 <switch_eg+36>   setle  %al
 0x55555555518c <switch_eg+39>   movzbl %al,%eax
 0x55555555518f <switch_eg+42>   ret
 0x555555555190 <switch_eg+43>   cmp    $0x1c,%rsi
 0x555555555194 <switch_eg+47>   setle  %al
 0x555555555197 <switch_eg+50>   movzbl %al,%eax
 0x55555555519a <switch_eg+53>   ret
 0x55555555519b <switch_eg+54>   cmp    $0x1e,%rsi
 0x55555555519f <switch_eg+58>   setle  %al
 0x5555555551a2 <switch_eg+61>   movzbl %al,%eax
 0x5555555551a5 <switch_eg+64>   ret
 0x5555555551a6 <switch_eg+65>   mov    $0x0,%eax
 0x5555555551ab <switch_eg+70>   ret
```

Offset -3711

```
(gdb) x/14dw $rdx
0x555555556004: -3678   -3711   -3700   -3711
0x555555556014: -3689   -3711   -3689   -3711
0x555555556024: -3711   -3689   -3711   -3689
0x555555556034: -3711   1734439765
```

Not a Quiz!

What C code would you compile to get the following assembler code?

```
        movq    $0, %rax
.L2:
        movq    %rax, a(,%rax,8)
        addq    $1, %rax
        cmpq    $10, %rax
        jl      .L2
        ret
```

a

```
long a[10];
void func() {
  long i=0;
  while (i<10)
    a[i]= i++;
}
```

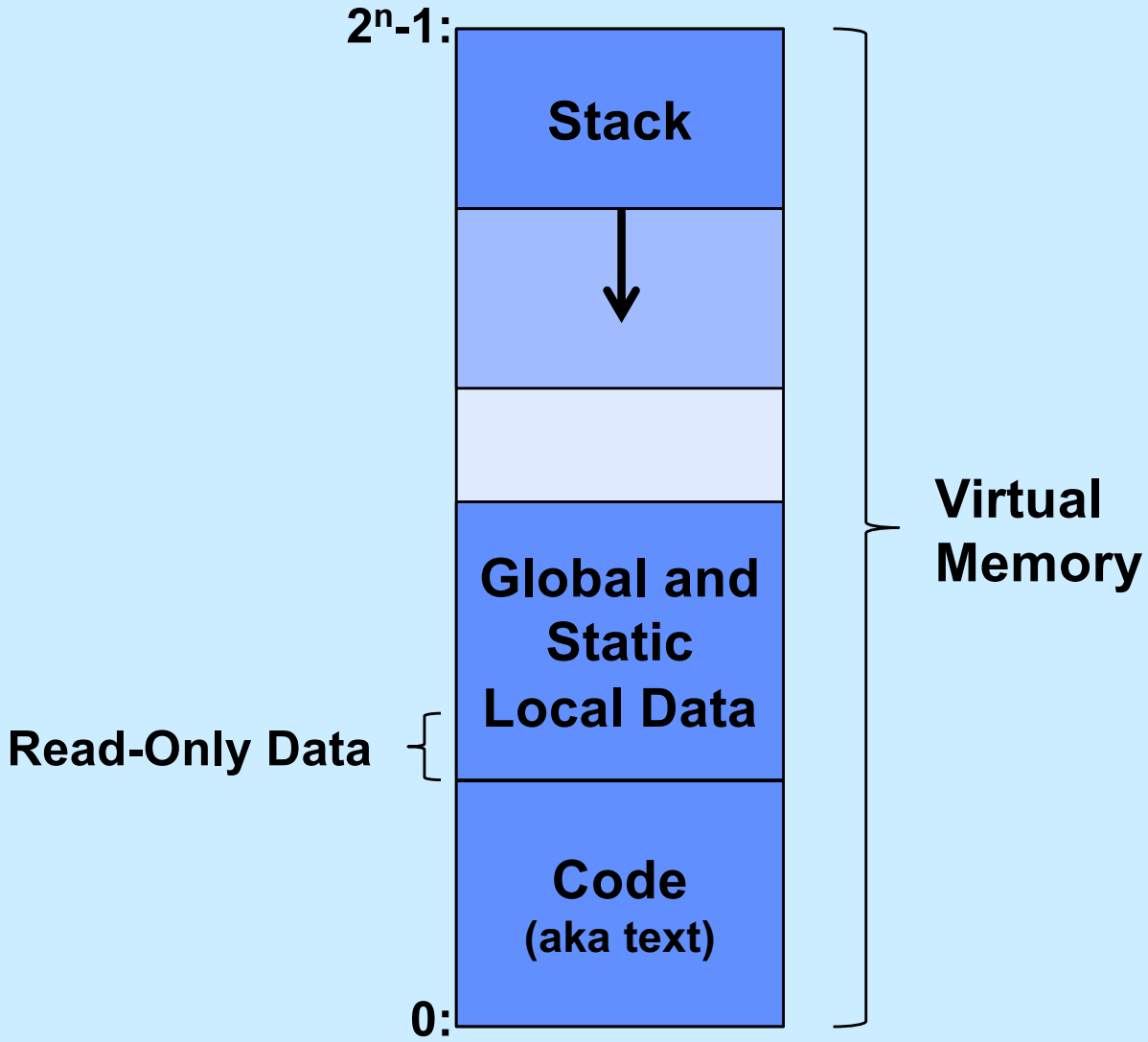
b

```
long a[10];
void func() {
  long i;
  for (i=0; i<10; i++)
    a[i]= 1;
}
```

c

```
long a[10];
void func() {
  long i=0;
  switch (i) {
case 0:
    a[i] = 0;
    break;
default:
    a[i] = 10
  }
}
```

Digression (Again): Where Stuff Is (Roughly)



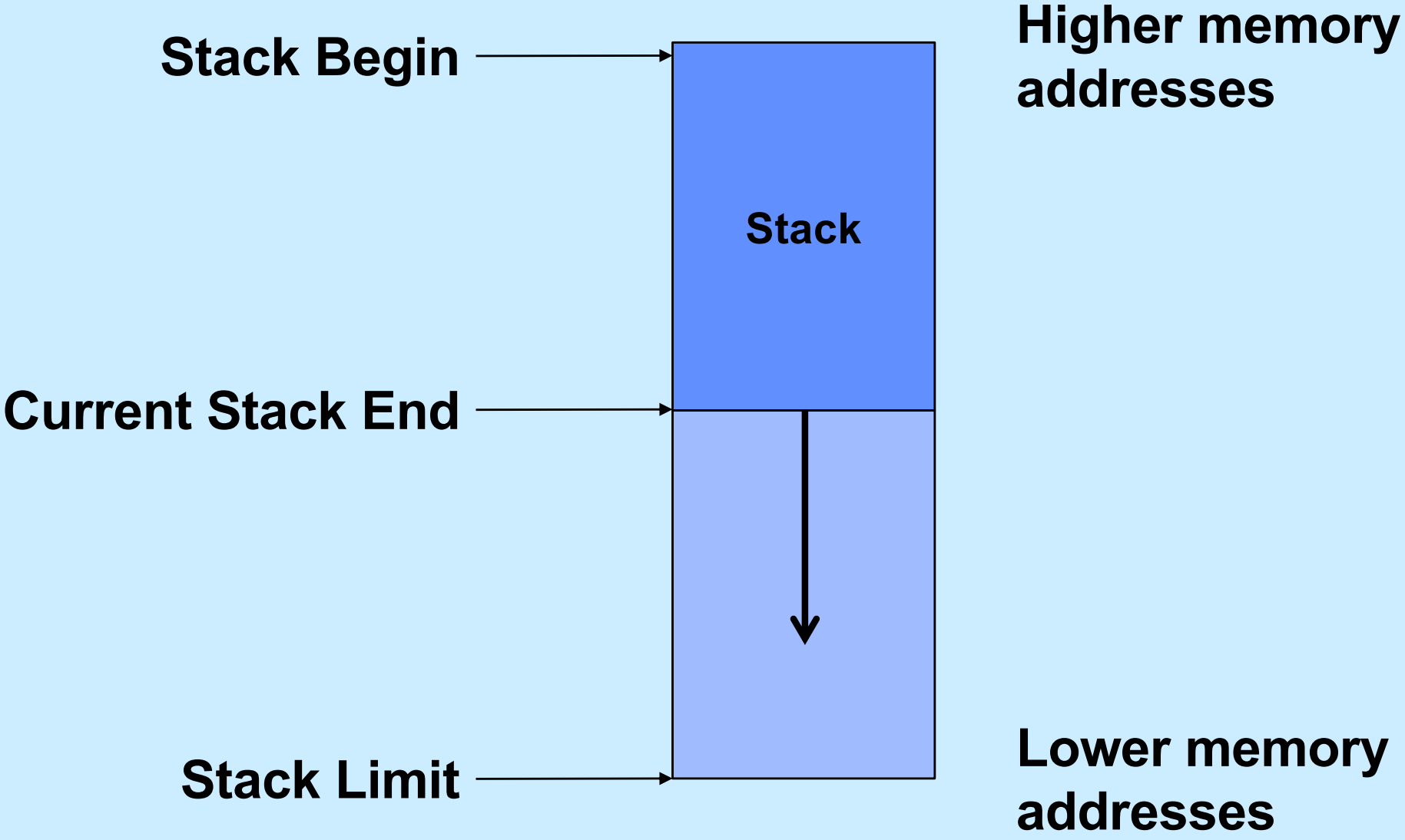
Function Call and Return

- Function A calls function B
- Function B calls function C

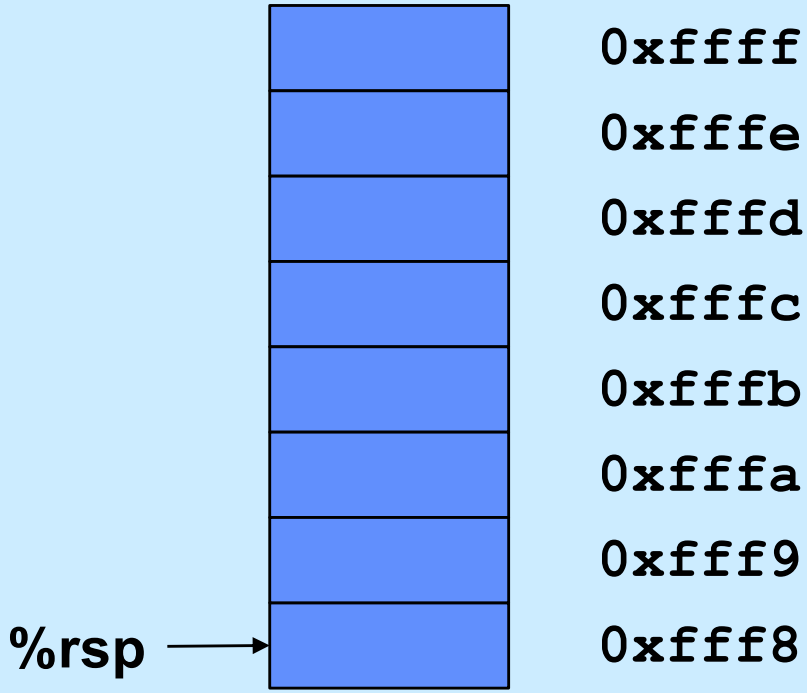
... several million instructions later

- C returns
  - how does it know to return to B?
- B returns
  - how does it know to return to A?

The Runtime Stack

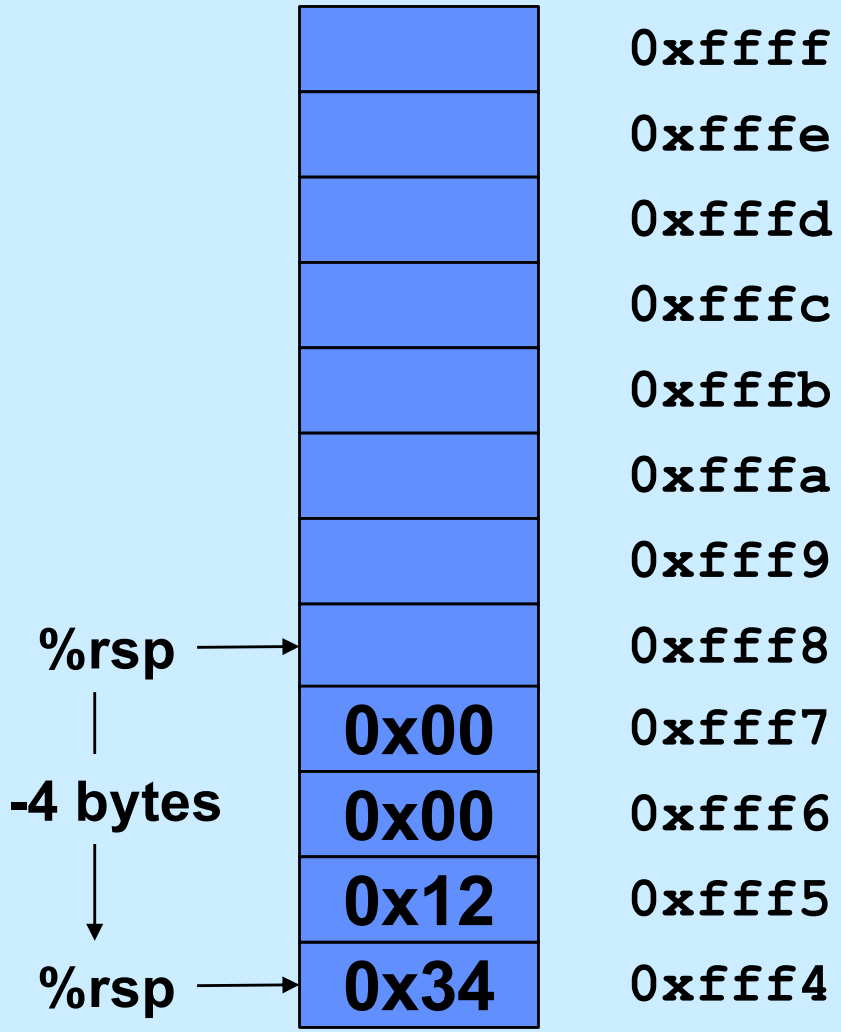


Stack Operations



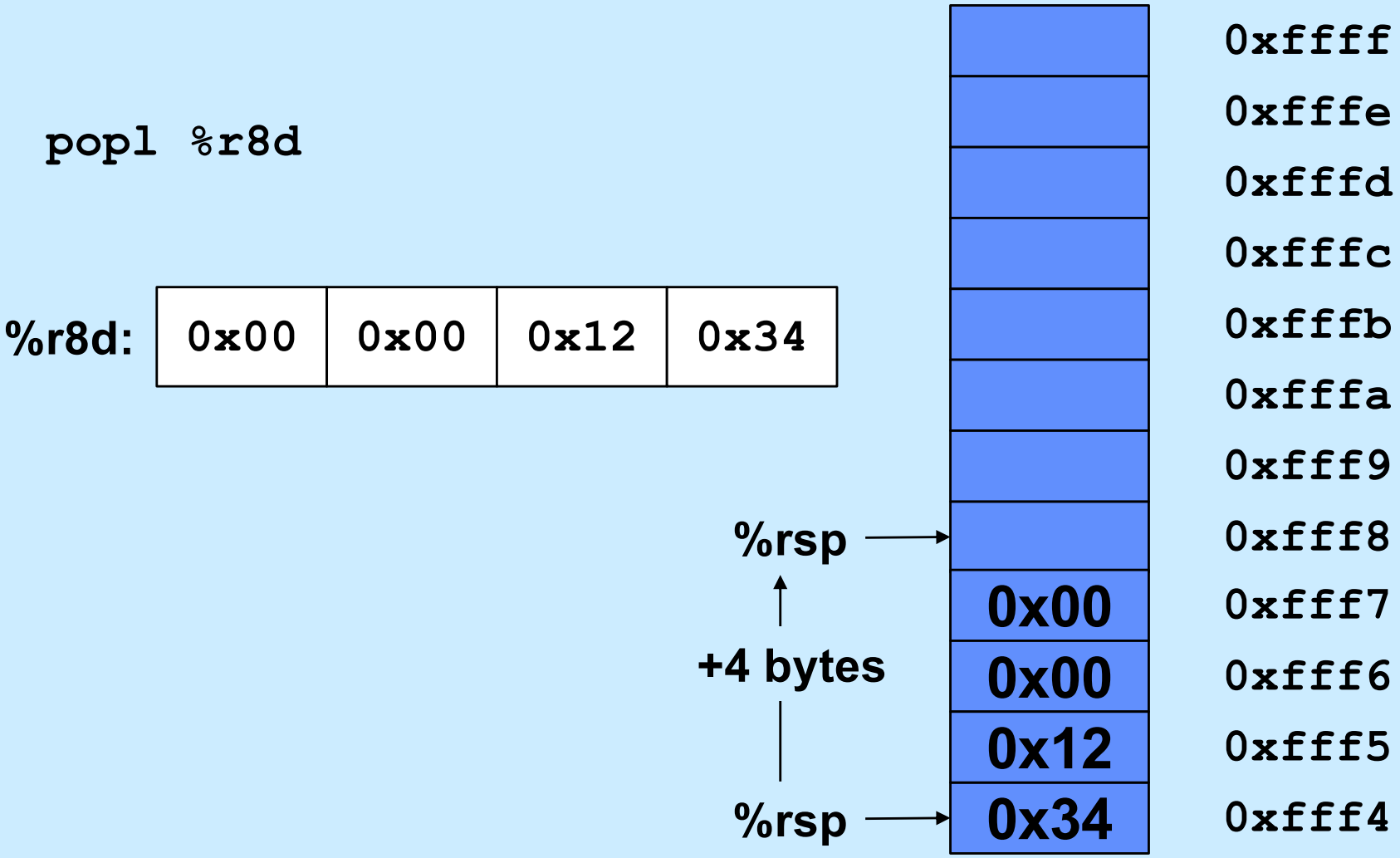
Push

```
pushl $0x1234
```



Pop

```
popl %r8d
```



Call and Return

```
0x1000: call func
0x1004: addq $3, %rax
```

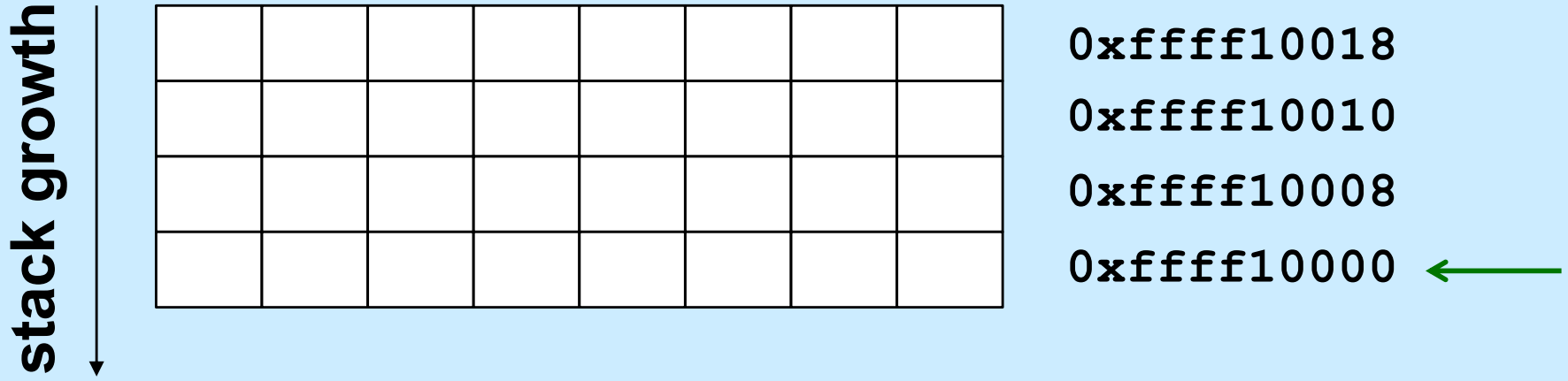
```
0x2000: func:
    ... ...
0x2200: movq $6, %rax
0x2203: ret
```

Call and Return

```
0x2000:  func:
    ...  ...
0x2200:  movq $6, %rax
0x2203:  ret
```



```
0x1000:  call func
0x1004:  addq $3, %rax
```



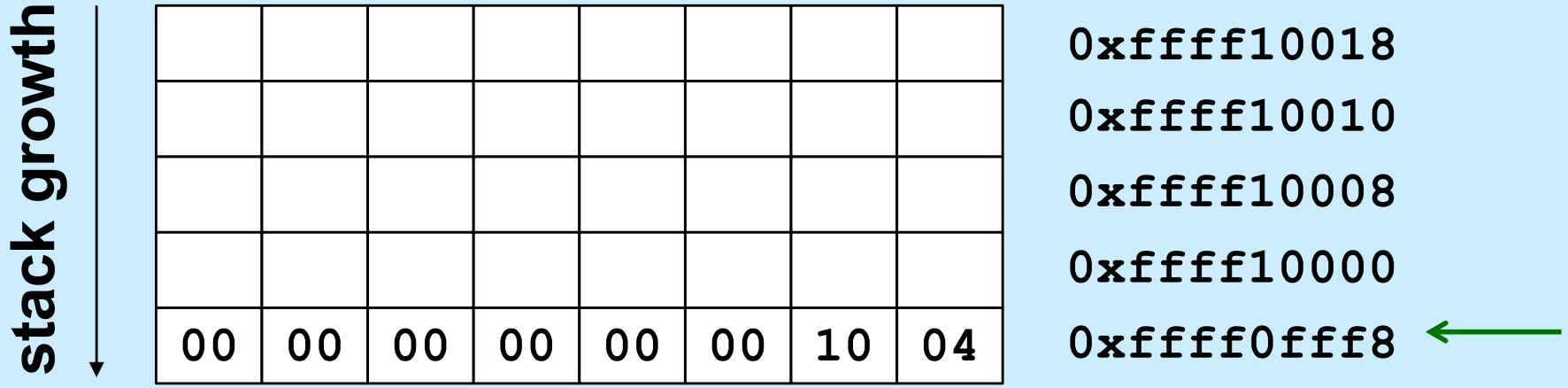
00	00	00	00	00	00	10	00
00	00	00	0f	ff	f1	00	00

%rax
%rip
%rsp

Call and Return

```
0x2000:  func:
    ...  ...
0x2200:  movq $6, %rax
0x2203:  ret
```

```
0x1000:  call func
0x1004:  addq $3, %rax
```



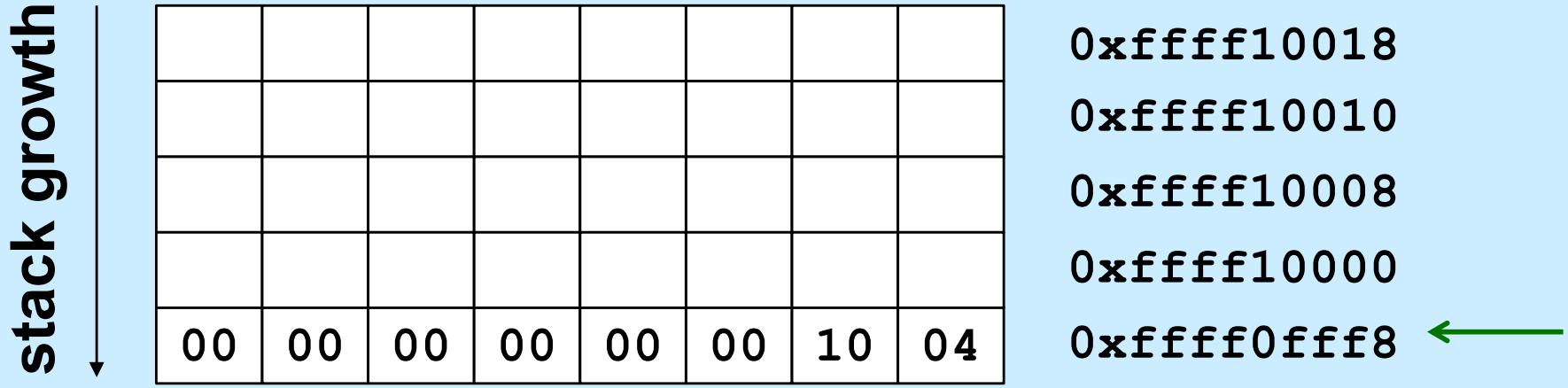
00	00	00	00	00	00	20	00
00	00	00	0f	ff	f0	ff	f8

%rax
%rip
%rsp

Call and Return

```
0x2000:  func:
    ...  ...
0x2200:  movq $6, %rax
0x2203:  ret
```

```
0x1000:  call func
0x1004:  addq $3, %rax
```



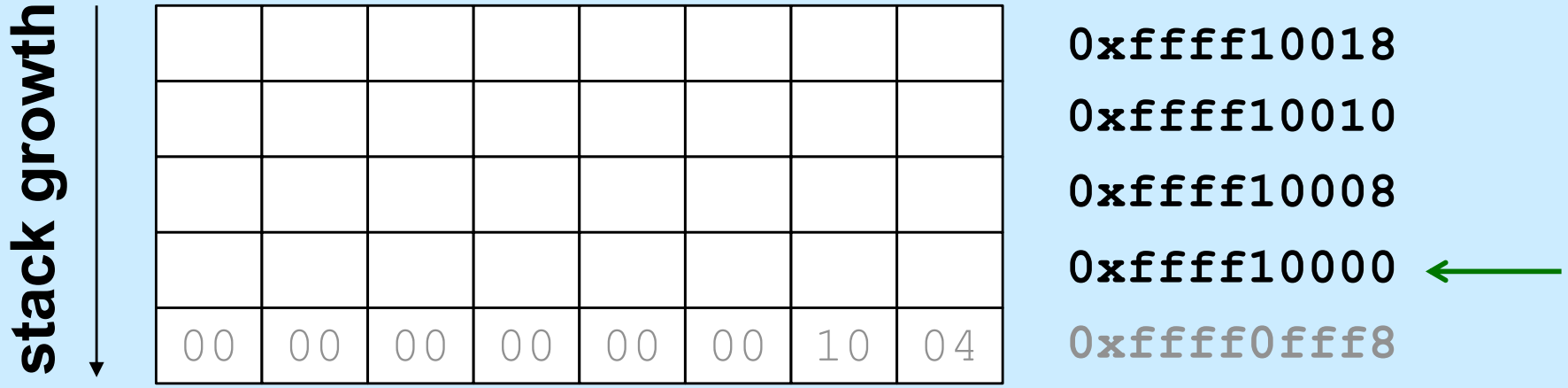
00	00	00	00	00	00	00	06
00	00	00	00	00	00	22	03
00	00	00	0f	ff	f0	ff	f8

%rax
%rip
%rsp

Call and Return

```
0x2000:  func:
    ...  ...
0x2200:  movq $6, %rax
0x2203:  ret
```

```
    0x1000:  call func
→   0x1004:  addq $3, %rax
```



00	00	00	00	00	00	00	06
00	00	00	00	00	00	10	04
00	00	00	0f	ff	f1	00	00

%rax
%rip
%rsp

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)**

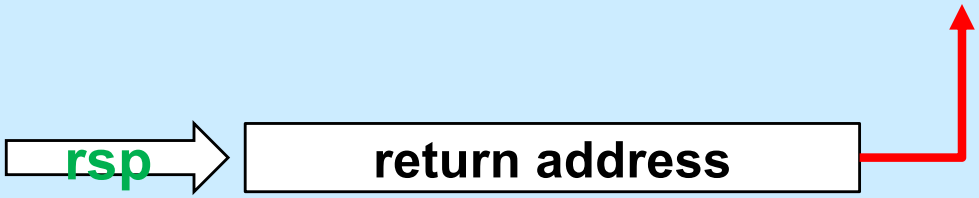
Arguments and Local Variables (1)

```
mainfunc:
   pushq %rbp                  # save old %rbp
   movq %rsp, %rbp             # set %rbp to point to stack frame
   subq $32, %rsp              # alloc. space for locals (array and sum)
   movq $2, -32(%rbp)          # initialize array[0]
   movq $117, -24(%rbp)        # initialize array[1]
   movq $-6, -16(%rbp)         # initialize array[2]
   pushq $3                    # push arg 2
   leaq -32(%rbp), %rax        # array address is put in %rax
   pushq %rax                  # push arg 1
   call ASum
   addq $16, %rsp              # pop args
   movq %rax, -8(%rbp)         # copy return value to sum
   ...
   addq $32, %rsp              # pop locals
   popq %rbp                   # pop and restore old %rbp
   ret
```

Arguments and Local Variables (2)

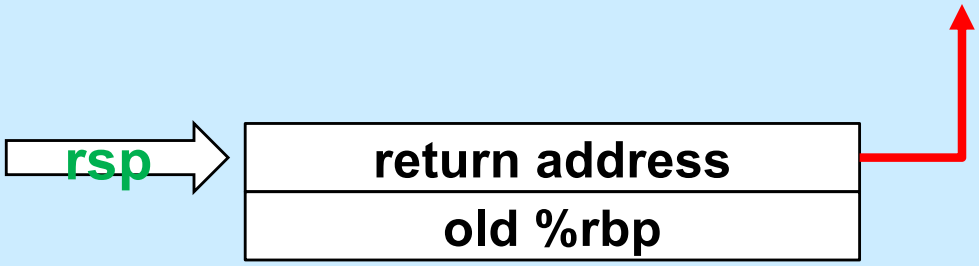
```
ASum:
   pushq %rbp                    # save old %rbp
   movq %rsp, %rbp               # set %rbp to point to stack frame
   movq $0, %rcx                 # i in %rcx
   movq $0, %rax                 # sum in %rax
   movq 16(%rbp), %rdx           # copy arg 1 (array) into %rdx
loop:
   cmpq 24(%rbp), %rcx           # i < size?
   jge done
   addq (%rdx,%rcx,8), %rax      # sum += a[i]
   incq %rcx                     # i++
   ja loop
done:
   popq %rbp                     # pop and restore %rbp
   ret
```

Enter mainfunc



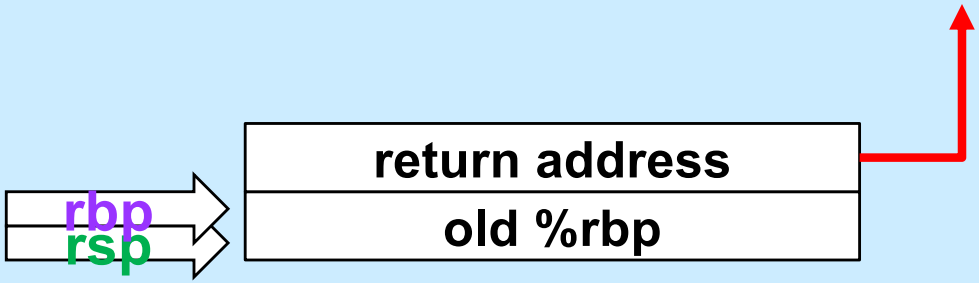

```
mainfunc:
    pushq %rbp
    movq %rsp, %rbp
    subq $32, %rsp
    movq $2, -32(%rbp)
    movq $117, -24(%rbp)
    movq $-6, -16(%rbp)
    pushq $3
    leaq -32(%rbp), %rax
    pushq %rax
    call ASum
    addq $16, %rsp
    movq %rax, -8(%rbp)
    addq $32, %rsp
    popq %rbp
    ret
```

Enter mainfunc



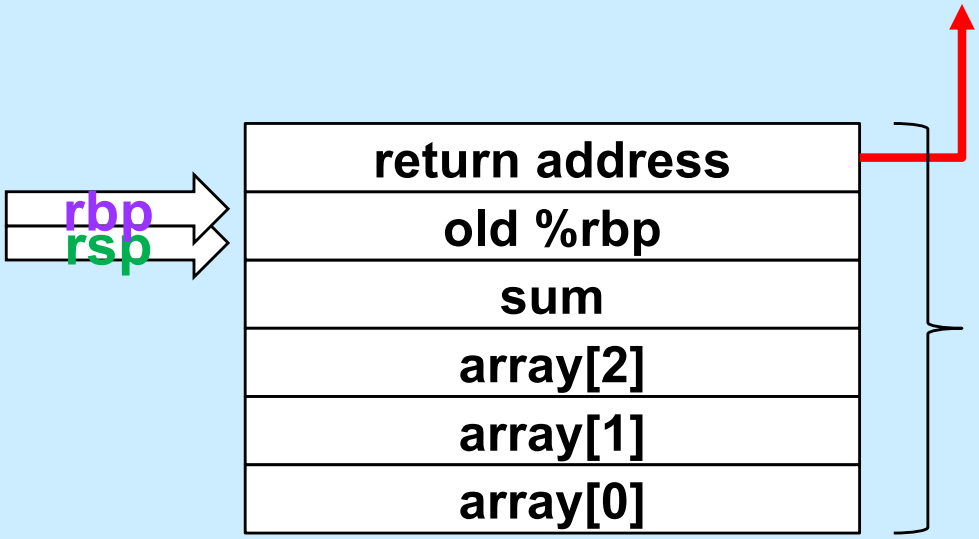

```
mainfunc:
    pushq %rbp
    movq %rsp, %rbp
    subq $32, %rsp
    movq $2, -32(%rbp)
    movq $117, -24(%rbp)
    movq $-6, -16(%rbp)
    pushq $3
    leaq -32(%rbp), %rax
    pushq %rax
    call ASum
    addq $16, %rsp
    movq %rax, -8(%rbp)
    addq $32, %rsp
    popq %rbp
    ret
```

Setup Frame



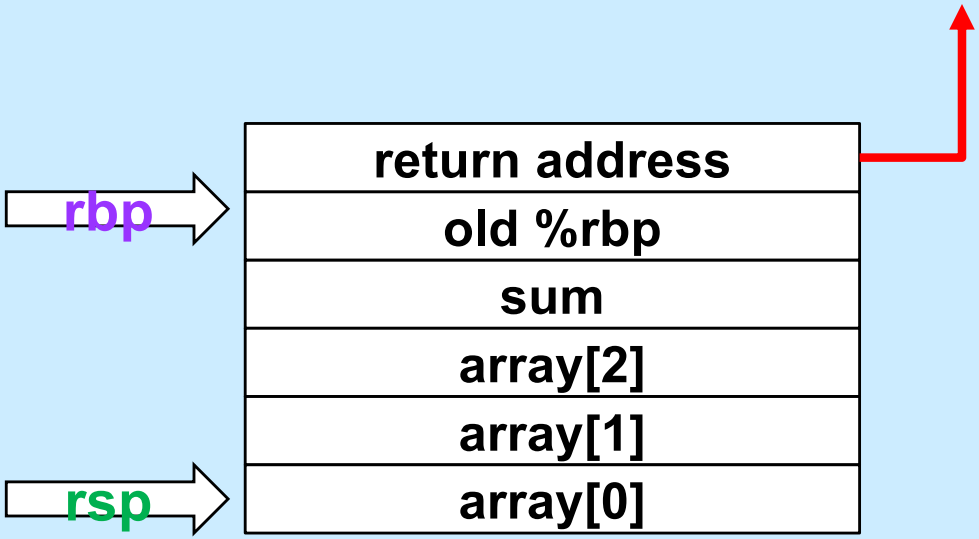

```
mainfunc:
    pushq %rbp
    movq %rsp, %rbp
    subq $32, %rsp
    movq $2, -32(%rbp)
    movq $117, -24(%rbp)
    movq $-6, -16(%rbp)
    pushq $3
    leaq -32(%rbp), %rax
    pushq %rax
    call ASum
    addq $16, %rsp
    movq %rax, -8(%rbp)
    addq $32, %rsp
    popq %rbp
    ret
```

Allocate Local Variables



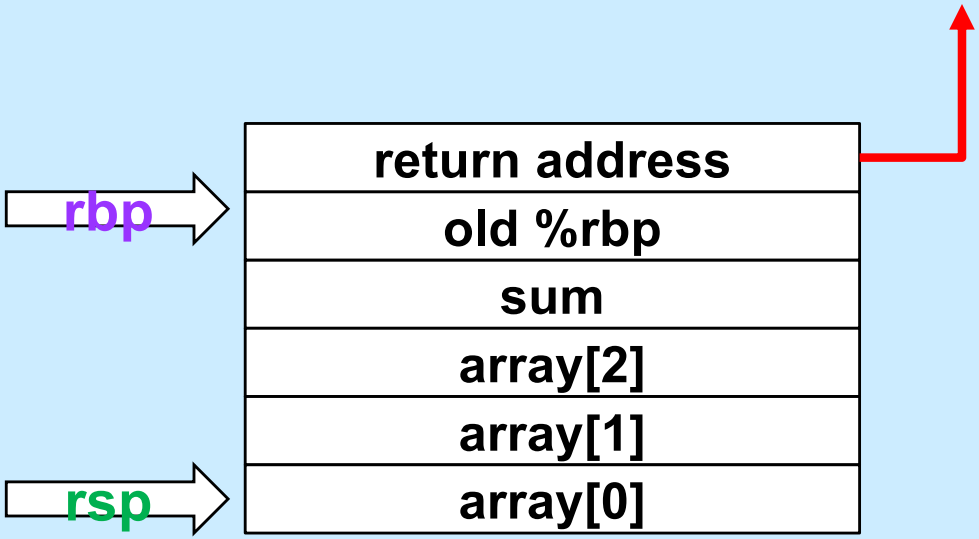

```
mainfunc:
    pushq %rbp
    movq %rsp, %rbp
    subq $32, %rsp
    movq $2, -32(%rbp)
    movq $117, -24(%rbp)
    movq $-6, -16(%rbp)
    pushq $3
    leaq -32(%rbp), %rax
    pushq %rax
    call ASum
    addq $16, %rsp
    movq %rax, -8(%rbp)
    addq $32, %rsp
    popq %rbp
    ret
```

Initialize Local Array



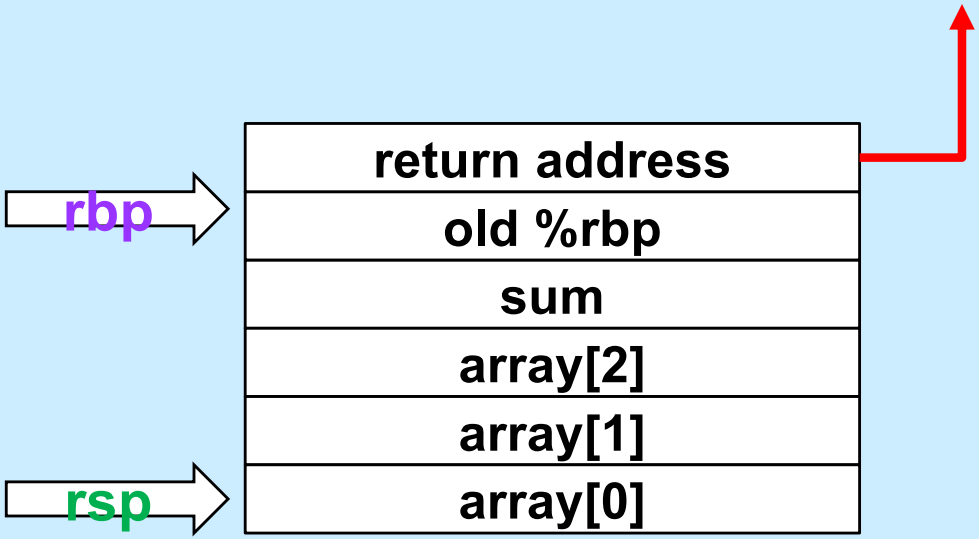

```
mainfunc:
    pushq %rbp
    movq %rsp, %rbp
    subq $32, %rsp
rip movq $2, -32(%rbp)
    movq $117, -24(%rbp)
    movq $-6, -16(%rbp)
    pushq $3
    leaq -32(%rbp), %rax
    pushq %rax
    call ASum
    addq $16, %rsp
    movq %rax, -8(%rbp)
    addq $32, %rsp
    popq %rbp
    ret
```

Initialize Local Array



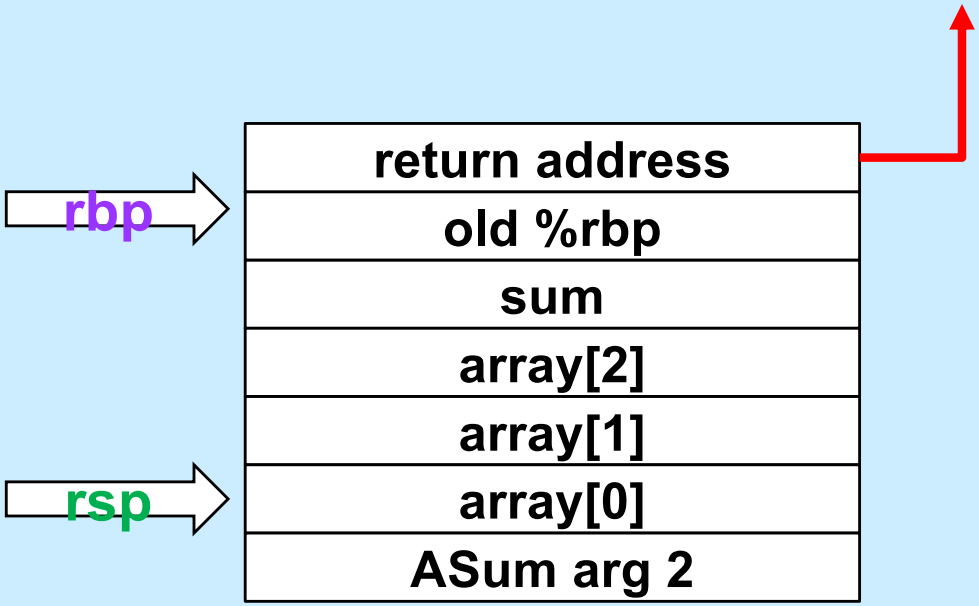

```
mainfunc:
    pushq %rbp
    movq %rsp, %rbp
    subq $32, %rsp
    movq $2, -32(%rbp)
rip movq $117, -24(%rbp)
    movq $-6, -16(%rbp)
    pushq $3
    leaq -32(%rbp), %rax
    pushq %rax
    call ASum
    addq $16, %rsp
    movq %rax, -8(%rbp)
    addq $32, %rsp
    popq %rbp
    ret
```

Initialize Local Array



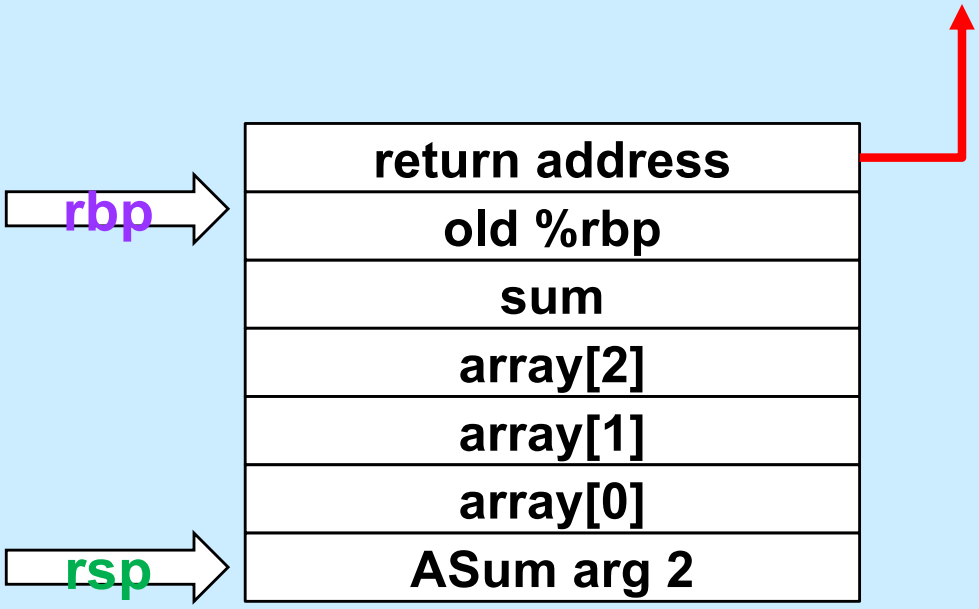

```
mainfunc:
    pushq %rbp
    movq %rsp, %rbp
    subq $32, %rsp
    movq $2, -32(%rbp)
    movq $117, -24(%rbp)
rip movq $-6, -16(%rbp)
    pushq $3
    leaq -32(%rbp), %rax
    pushq %rax
    call ASum
    addq $16, %rsp
    movq %rax, -8(%rbp)
    addq $32, %rsp
    popq %rbp
    ret
```

Push Second Argument



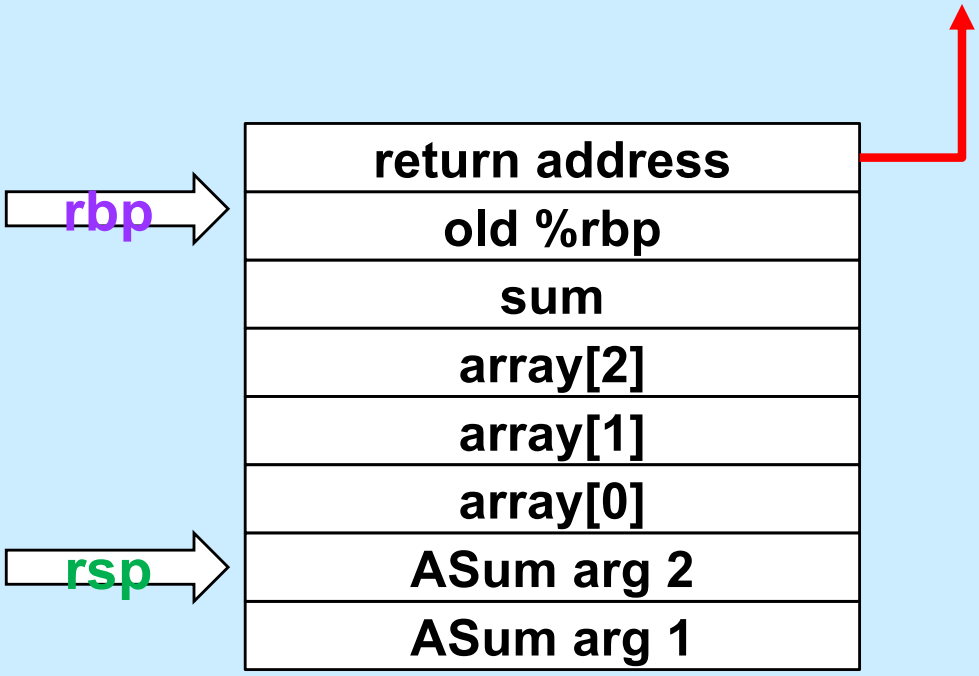

```
mainfunc:
    pushq %rbp
    movq %rsp, %rbp
    subq $32, %rsp
    movq $2, -32(%rbp)
    movq $117, -24(%rbp)
    movq $-6, -16(%rbp)
rip pushq $3
    leaq -32(%rbp), %rax
    pushq %rax
    call ASum
    addq $16, %rsp
    movq %rax, -8(%rbp)
    addq $32, %rsp
    popq %rbp
    ret
```

Get Array Address



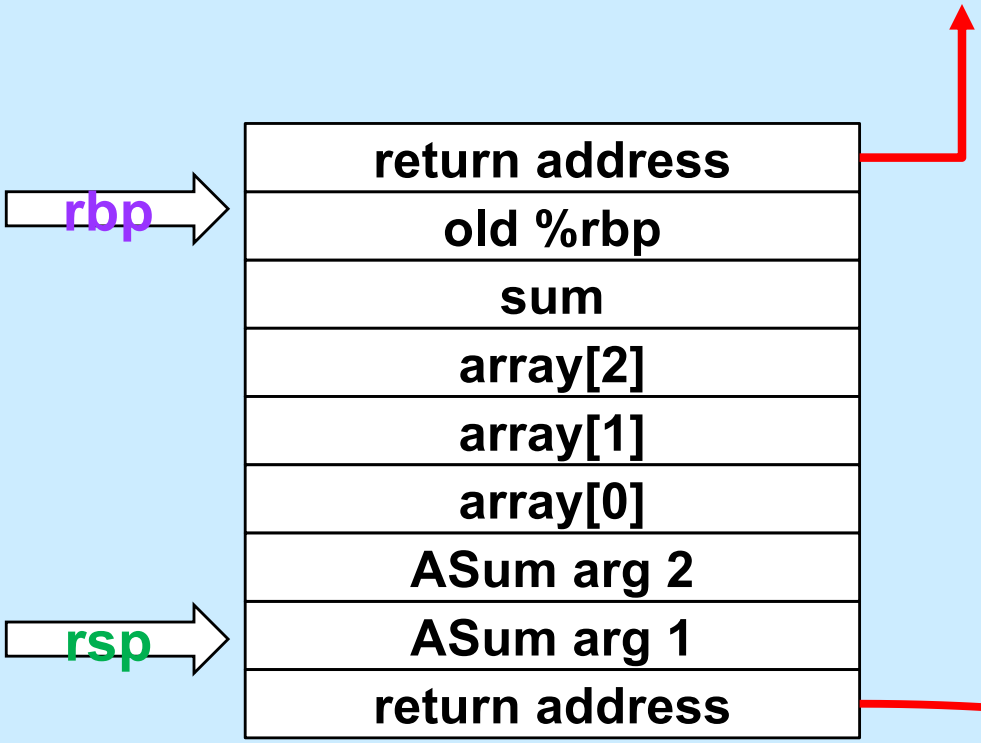

```
mainfunc:
    pushq %rbp
    movq %rsp, %rbp
    subq $32, %rsp
    movq $2, -32(%rbp)
    movq $117, -24(%rbp)
    movq $-6, -16(%rbp)
    pushq $3
rip leaq -32(%rbp), %rax
    pushq %rax
    call ASum
    addq $16, %rsp
    movq %rax, -8(%rbp)
    addq $32, %rsp
    popq %rbp
    ret
```

Push First Argument



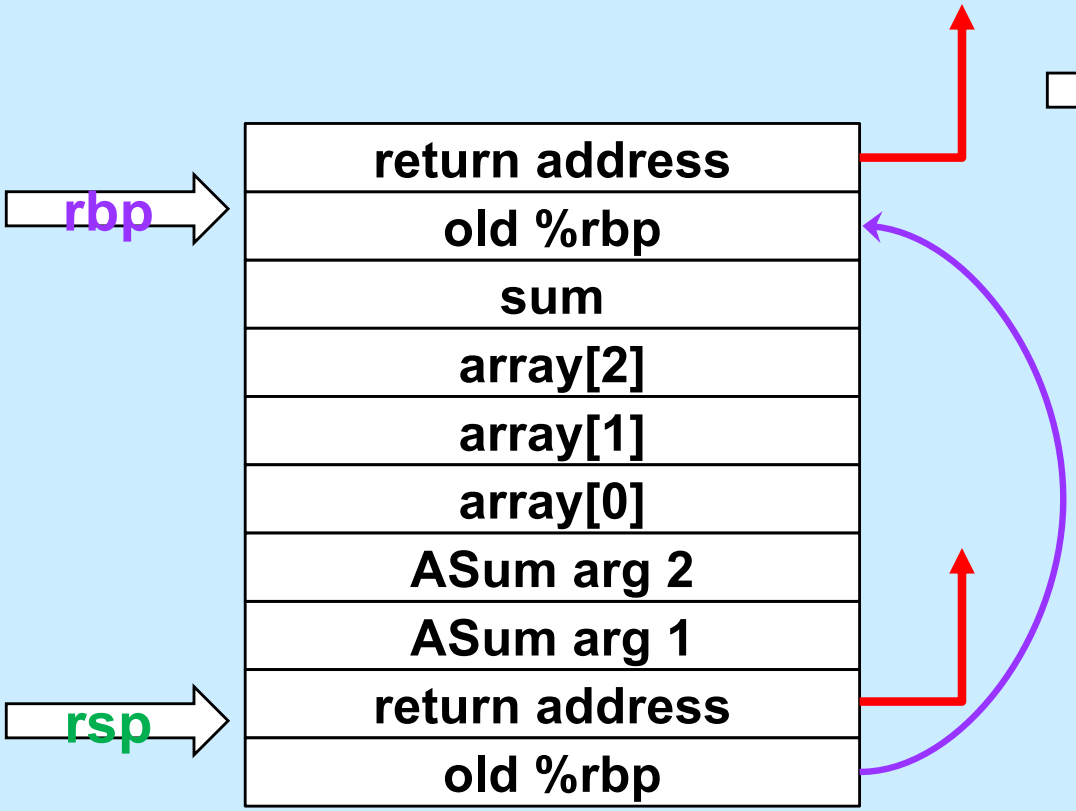

```
mainfunc:
    pushq %rbp
    movq %rsp, %rbp
    subq $32, %rsp
    movq $2, -32(%rbp)
    movq $117, -24(%rbp)
    movq $-6, -16(%rbp)
    pushq $3
    leaq -32(%rbp), %rax
    pushq %rax
    call ASum
    addq $16, %rsp
    movq %rax, -8(%rbp)
    addq $32, %rsp
    popq %rbp
    ret
```

Call ASum




```
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
```

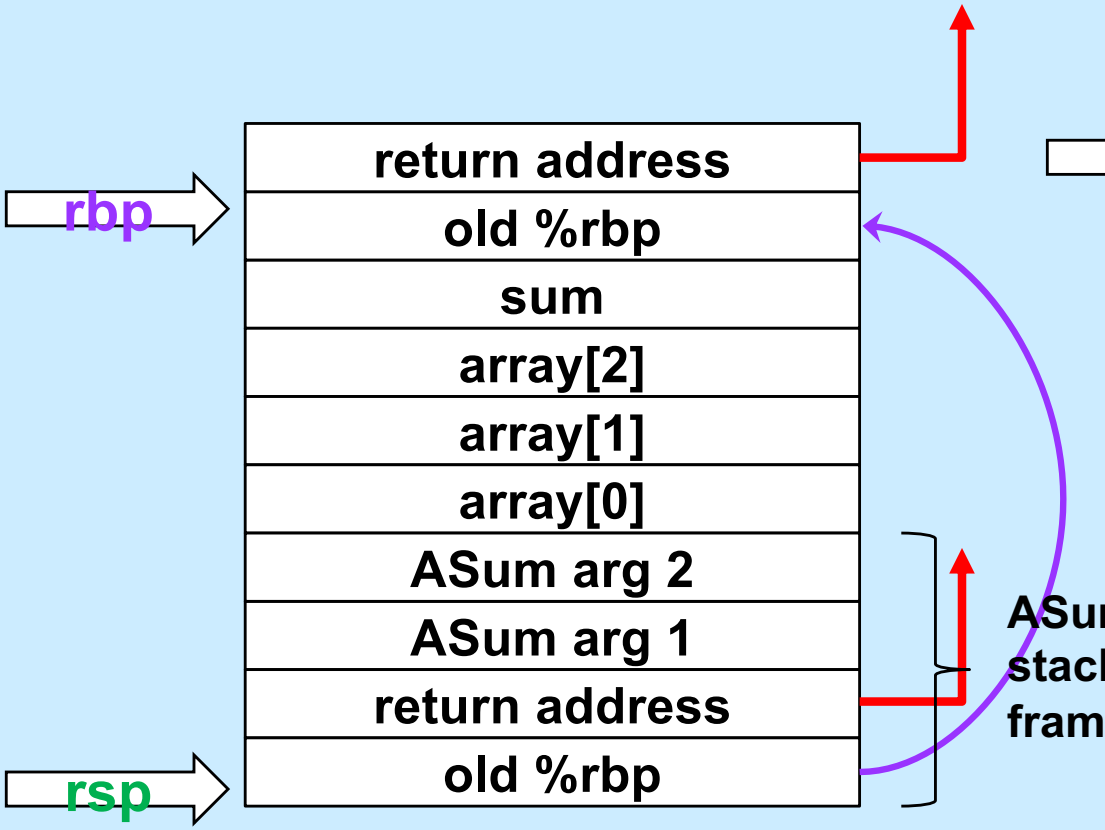
Enter ASum




```
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
```

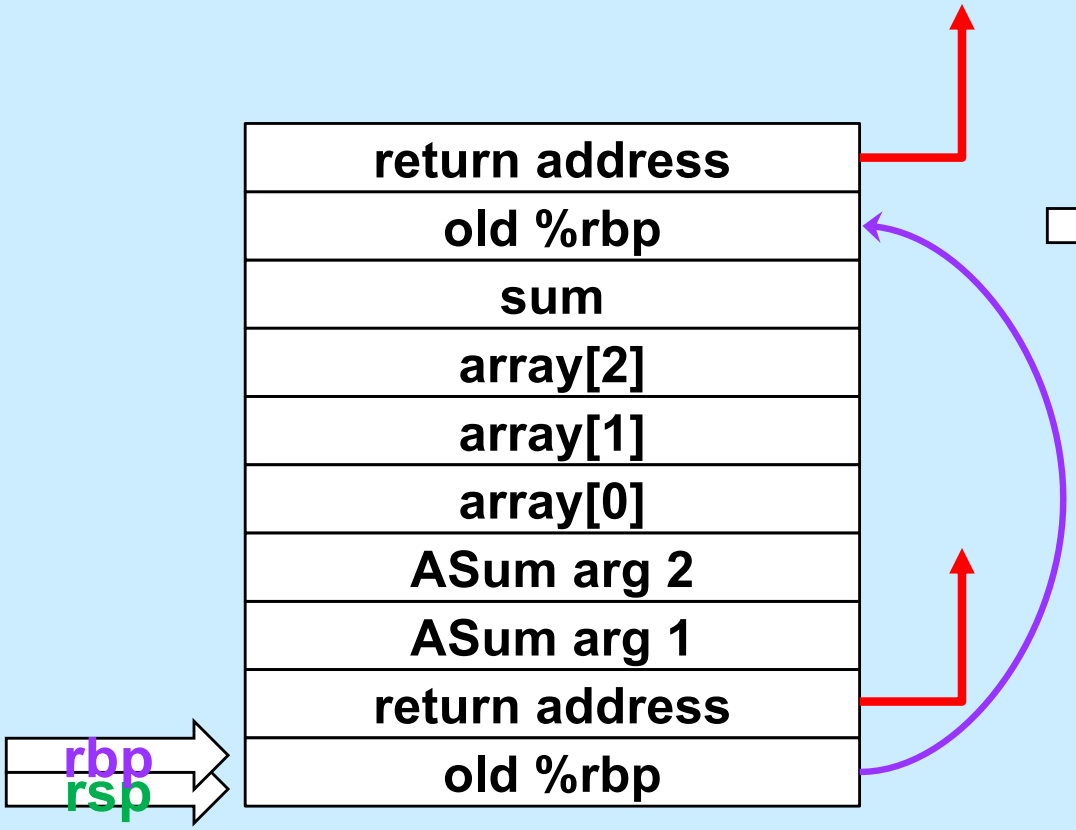
rip

Setup Frame




```
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
```

Execute the Function




```
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
```

Quiz 1

What's at 16(%rbp) (after the second instruction is executed)?

a) a local variable

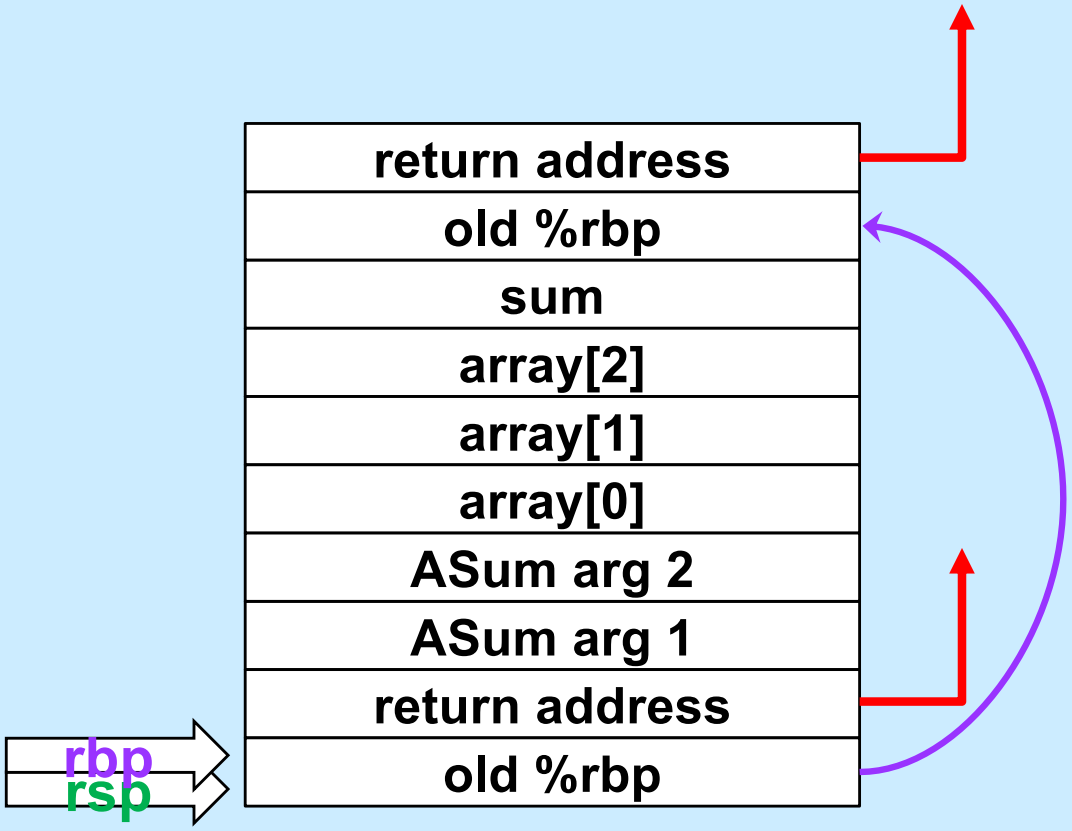
b) the first argument to ASum

c) the second argument to ASum

d) something else

```
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
```

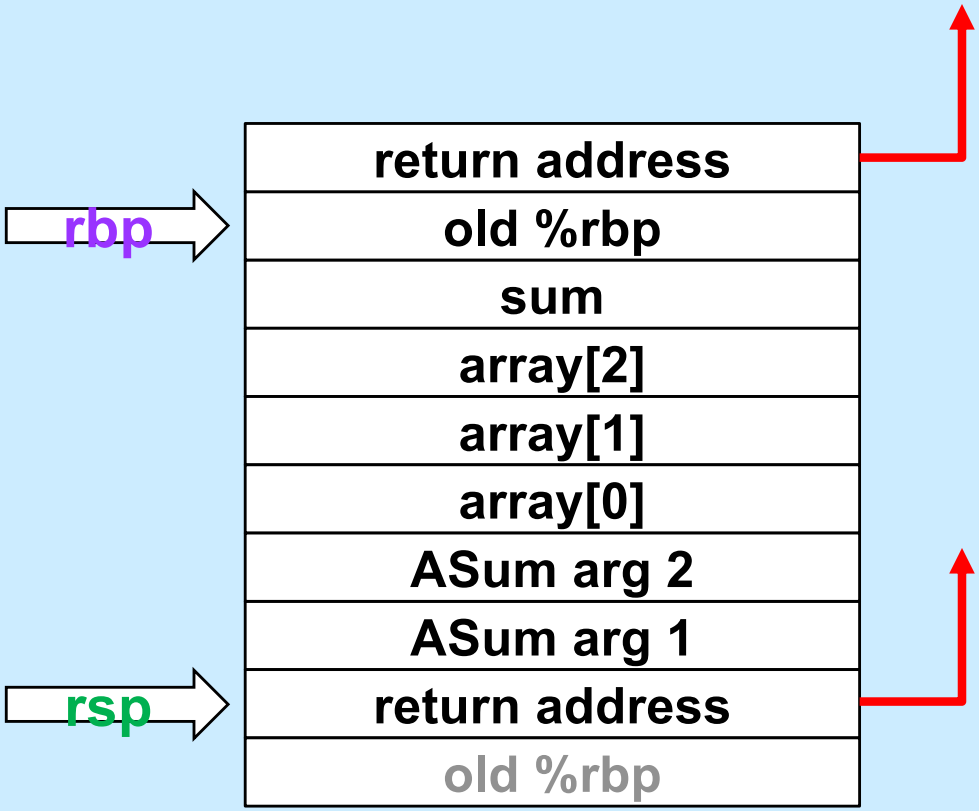
Prepare to Return




```
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
```

rip

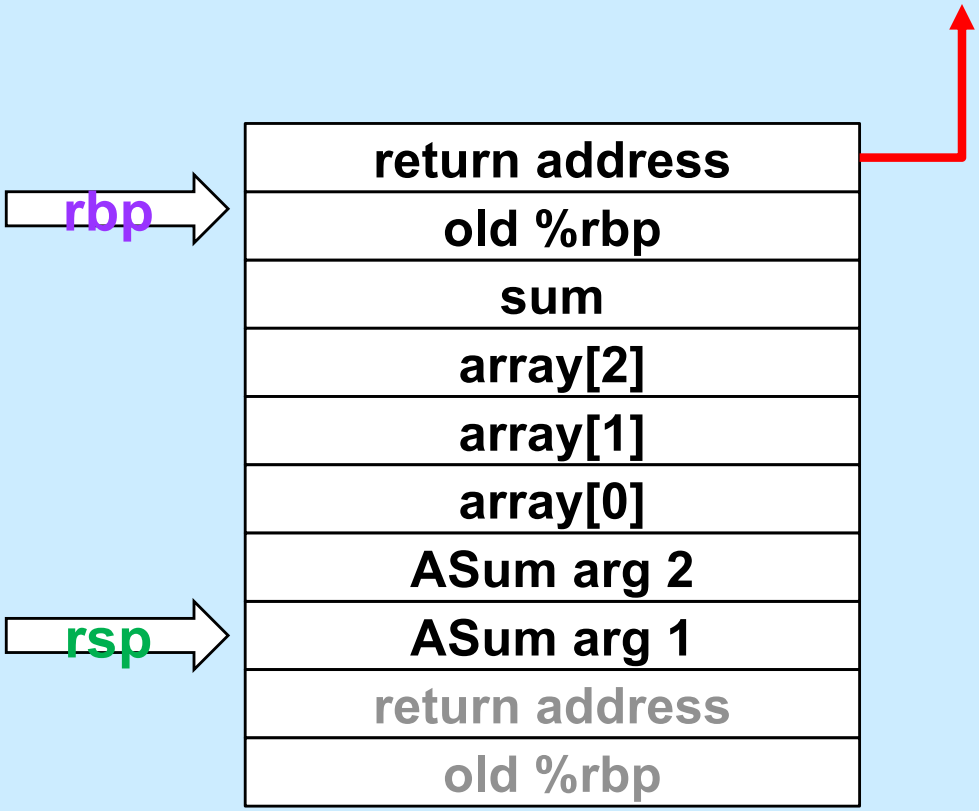
Return




```
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
```

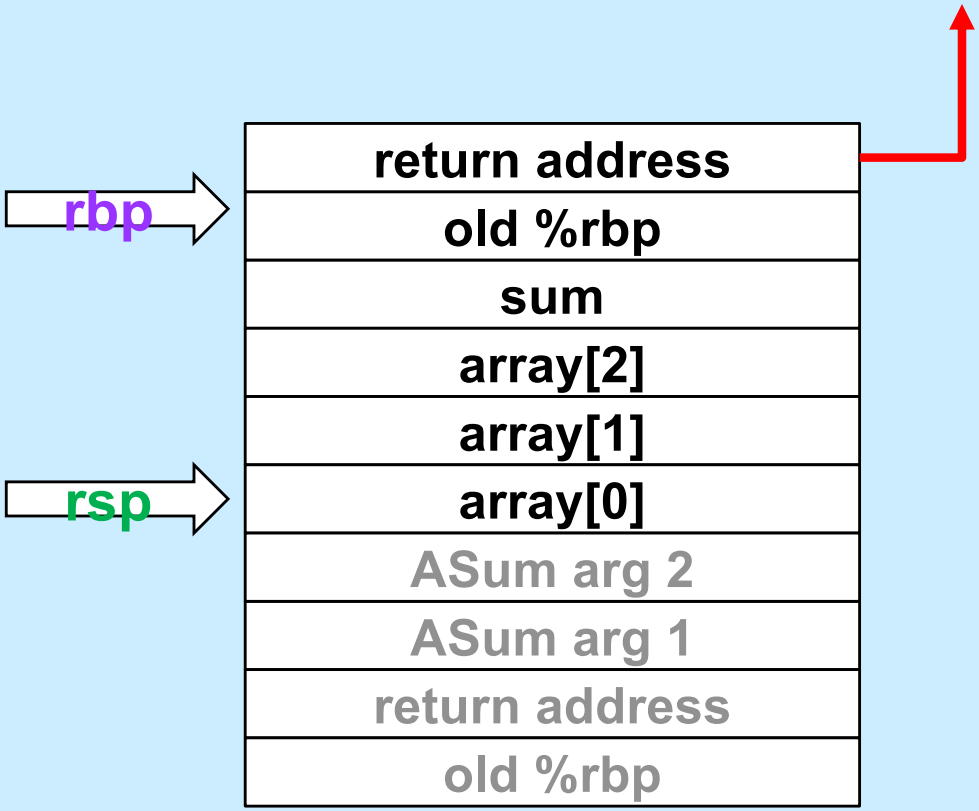
rip

Pop Arguments



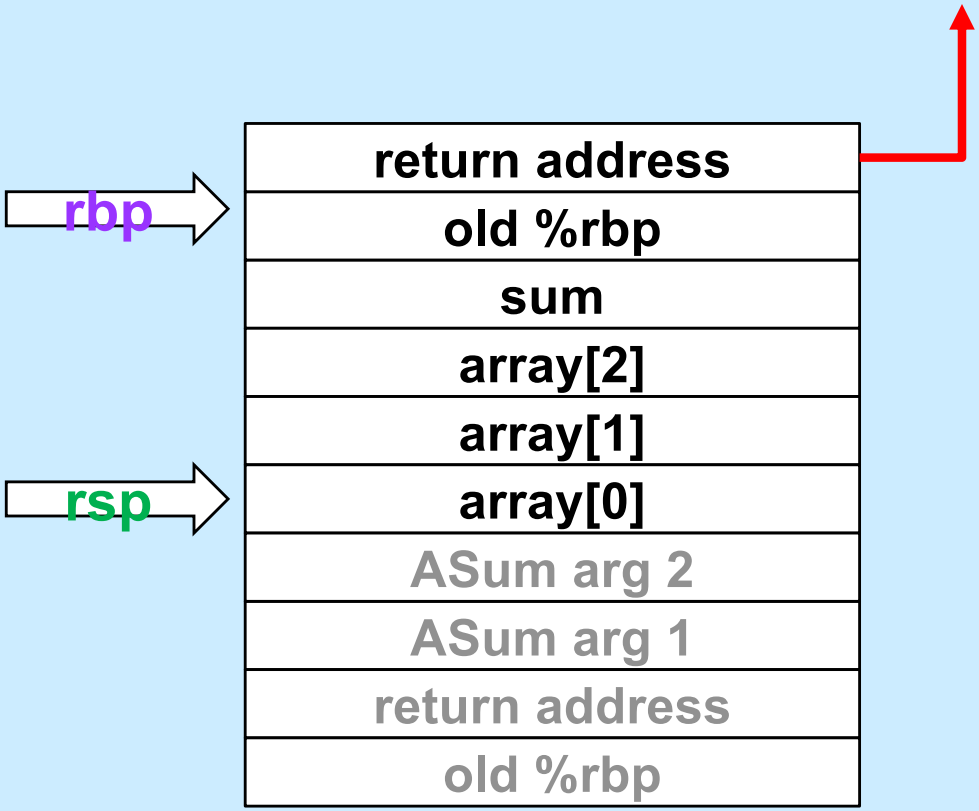

```
mainfunc:
    pushq %rbp
    movq %rsp, %rbp
    subq $32, %rsp
    movq $2, -32(%rbp)
    movq $117, -24(%rbp)
    movq $-6, -16(%rbp)
    pushq $3
    leaq -32(%rbp), %rax
    pushq %rax
    call ASum
    addq $16, %rsp
    movq %rax, -8(%rbp)
    addq $32, %rsp
    popq %rbp
    ret
```

Save Return Value



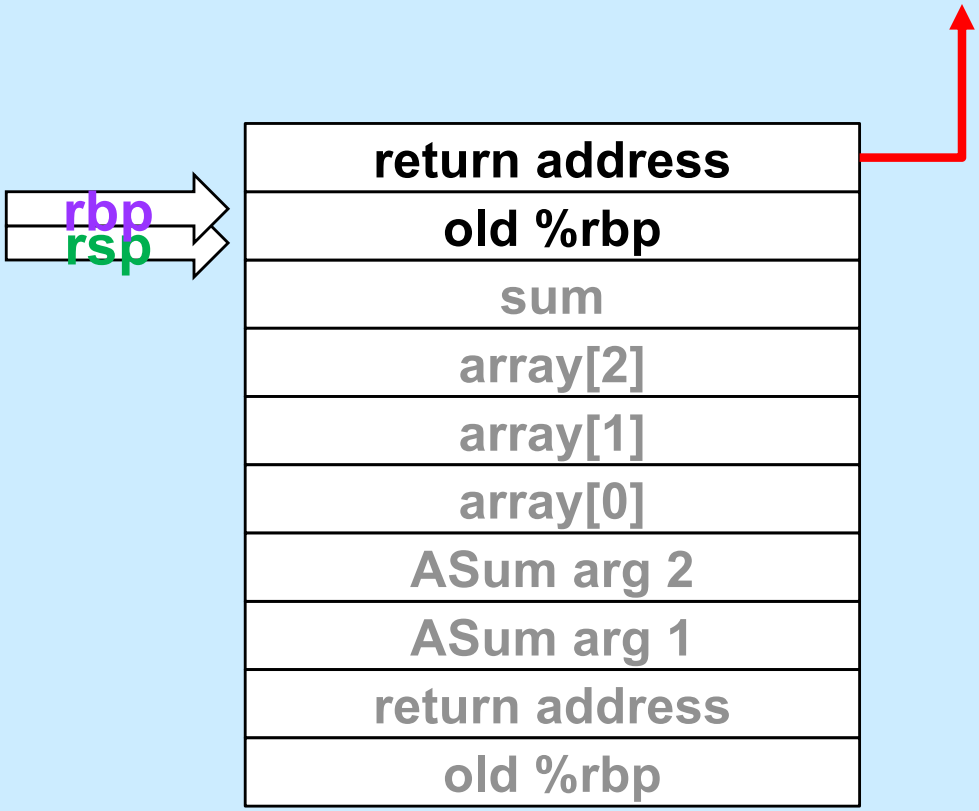

```
mainfunc:
    pushq %rbp
    movq %rsp, %rbp
    subq $32, %rsp
    movq $2, -32(%rbp)
    movq $117, -24(%rbp)
    movq $-6, -16(%rbp)
    pushq $3
    leaq -32(%rbp), %rax
    pushq %rax
    call ASum
    addq $16, %rsp
rip movq %rax, -8(%rbp)
    addq $32, %rsp
    popq %rbp
    ret
```

Pop Local Variables



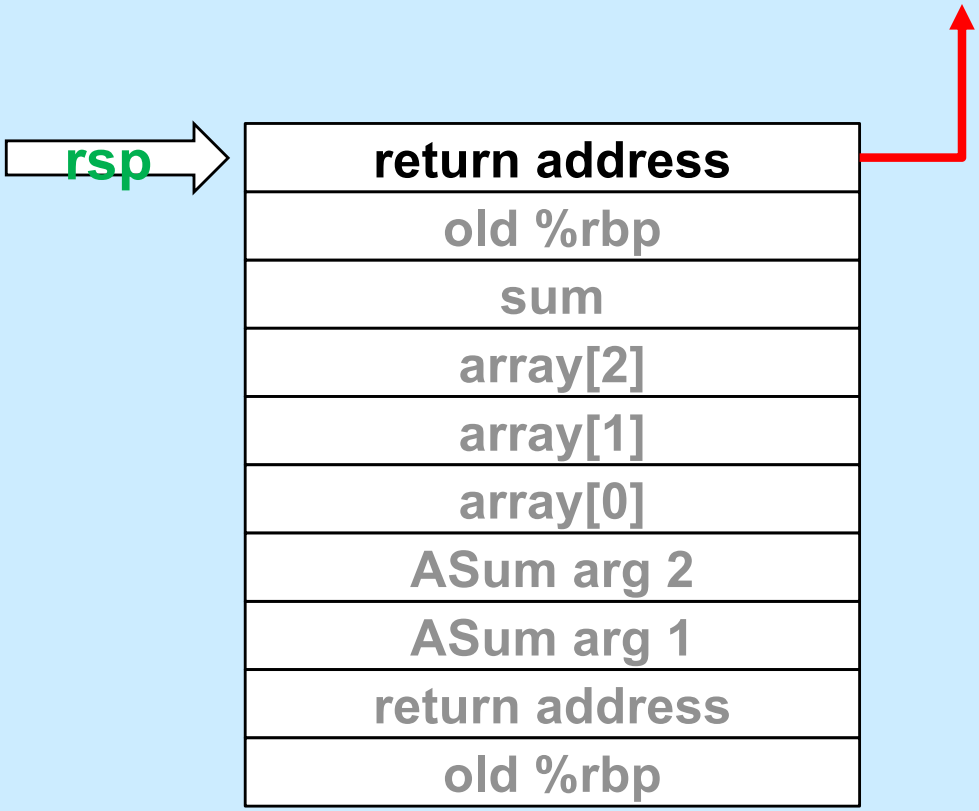

```
mainfunc:
    pushq %rbp
    movq %rsp, %rbp
    subq $32, %rsp
    movq $2, -32(%rbp)
    movq $117, -24(%rbp)
    movq $-6, -16(%rbp)
    pushq $3
    leaq -32(%rbp), %rax
    pushq %rax
    call ASum
    addq $16, %rsp
    movq %rax, -8(%rbp)
rip addq $32, %rsp
    popq %rbp
    ret
```

Prepare to 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
rip 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
```

rip

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

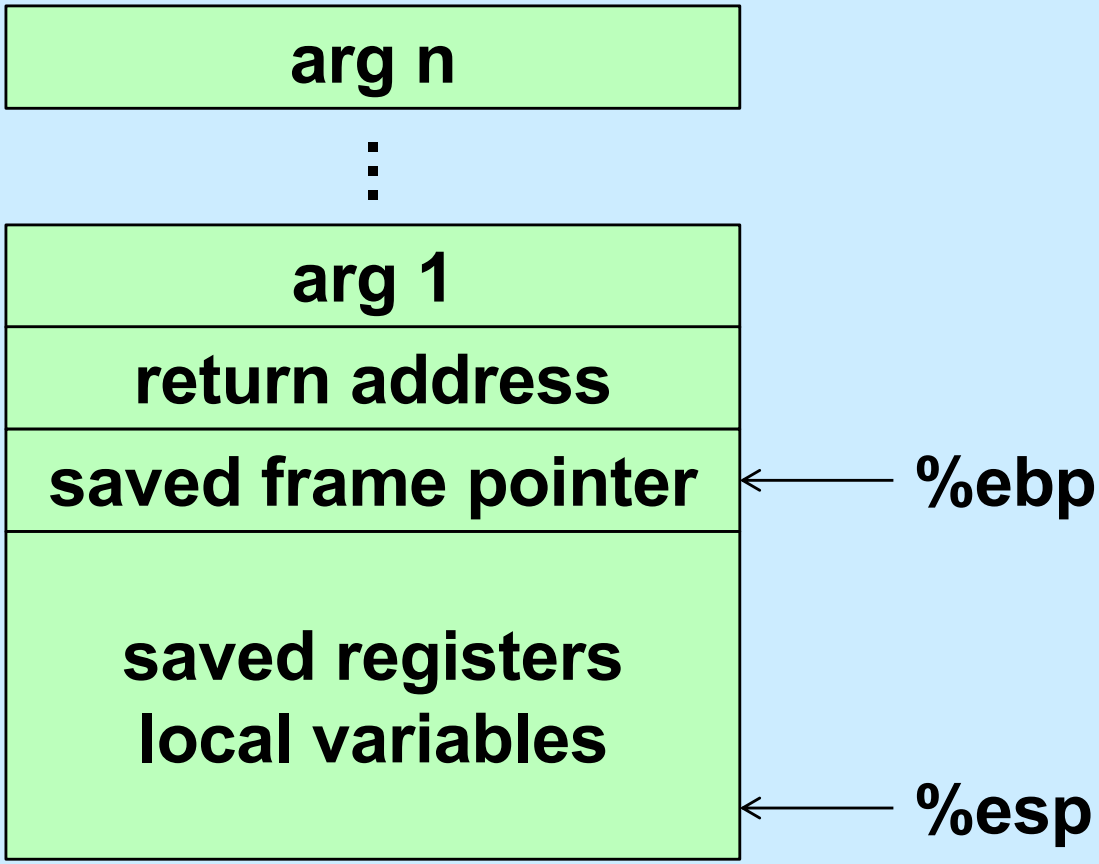
Why Bother with a Base Pointer?

- 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

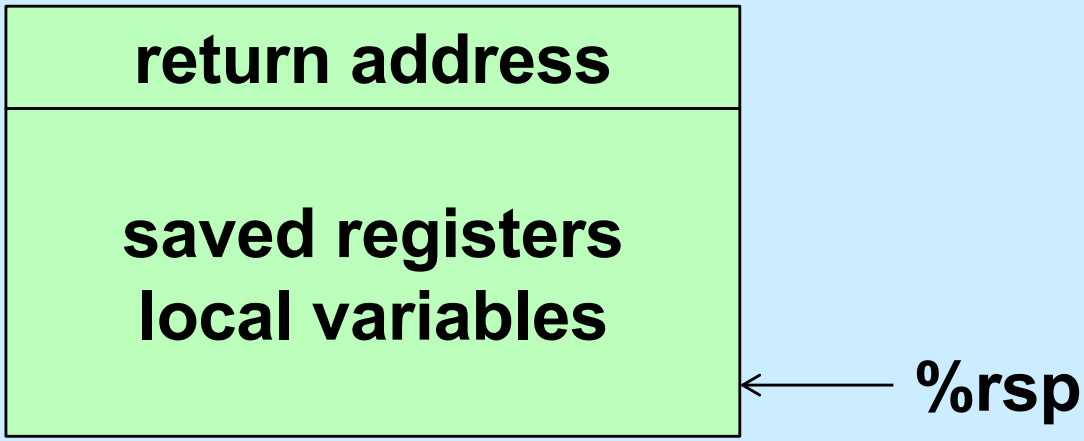
x86-64 General-Purpose Registers: Updated Usage Conventions

%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

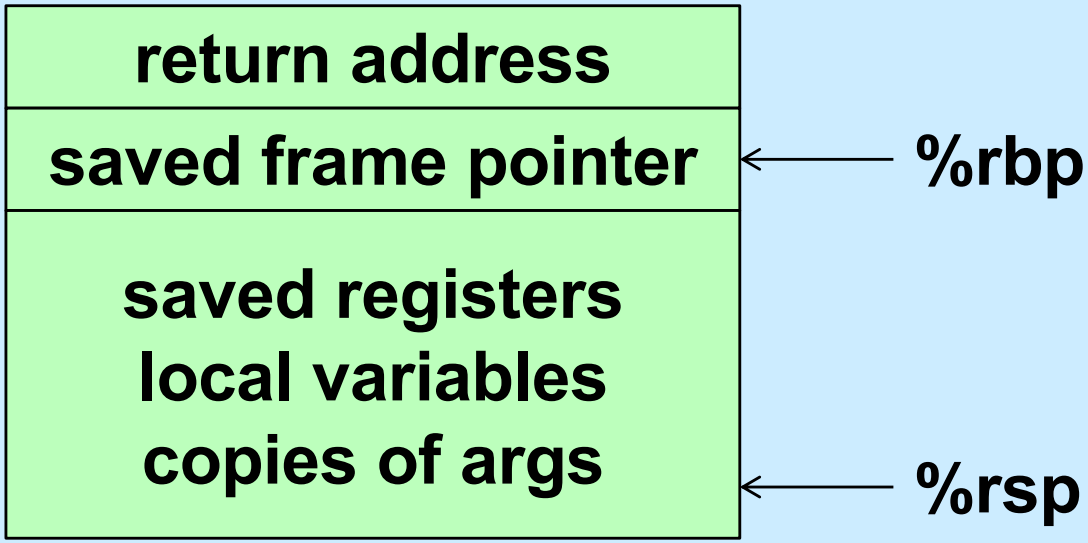
The IA32 Stack Frame



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 2

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