CS 33

Machine Programming (4)

Jumping

- **jX instructions**
  - **Jump to different part of program depending on condition codes**

jX	Condition	Description
`jmp`	`1`	Unconditional
`je`	`ZF`	Equal / Zero
`jne`	`~ZF`	Not Equal / Not Zero
`js`	`SF`	Negative
`jns`	`~SF`	Nonnegative
`jg`	`~(SF^OF)&~ZF`	Greater (Signed)
`jge`	`~(SF^OF)`	Greater or Equal (Signed)
`jl`	`(SF^OF)`	Less (Signed)
`jle`	`(SF^OF)|ZF`	Less or Equal (Signed)
`ja`	`~CF&~ZF`	Above (unsigned)
`jb`	`CF`	Below (unsigned)

Conditional-Branch Example

```
int absdiff(int x, int y)
{
    int result;
    if (x > y) {
      result = x-y;
    } else {
      result = y-x;
    }
    return result;
}
```

```
absdiff:
    movl    %esi, %eax
    cmpl    %esi, %edi
    jle     .L6
    subl    %eax, %edi
    movl    %edi, %eax
    jmp     .L7
.L6:
    subl %edi, %eax
.L7:
    ret
```

Body1

Body2a

Body2b

x in %edi

y in %esi

Conditional-Branch Example (Cont.)

```
int goto_ad(int x, int y)
{
  int result;
  if (x <= y) goto Else;
  result = x-y;
  goto Exit;
Else:
  result = y-x;
Exit:
  return result;
}
```

```
absdiff:
    movl    %esi, %eax
    cmpl    %esi, %edi
    jle     .L6
    subl    %eax, %edi
    movl    %edi, %eax
    jmp .L7
.L6:
    subl %edi, %eax
.L7:
    ret
```

Body1

Body2a

Body2b

- C allows “goto” as means of transferring control
  - closer to machine-level programming style
- Generally considered bad coding style

General Conditional-Expression Translation

C Code

```
val = Test ? Then_Expr : Else_Expr;
```

```
val = x>y ? x-y : y-x;
```

Goto Version

```
  nt = !Test;
  if (nt) goto Else;
  val = Then_Expr;
  goto Done;
Else:
  val = Else_Expr;
Done:
  . . .
```

- Test is expression returning integer
  - == 0 interpreted as false
  - ≠ 0 interpreted as true
- Create separate code regions for then and else expressions
- Execute appropriate one

"Do-While" Loop Example

C Code

```
int pcount_do(unsigned x)
{
  int result = 0;
  do {
    result += x & 0x1;
    x >>= 1;
  } while (x);
  return result;
}
```

Goto Version

```
int pcount_do(unsigned x)
{
  int result = 0;
loop:
  result += x & 0x1;
  x >>= 1;
  if (x)
    goto loop;
  return result;
}
```

- Count number of 1's in argument x ("popcount")
- Use conditional branch either to continue looping or to exit loop

"Do-While" Loop Compilation

Goto Version

```
int pcount_do(unsigned x)  {
  int result = 0;
loop:
  result += x & 0x1;
  x >>= 1;
  if (x)
    goto loop;
  return result;
}
```

Registers:

%edi	x
%eax	result

```
  movl   $0, %eax      #   result = 0
.L2:     # loop:
  movl   %edi, %ecx
  andl   $1, %ecx      #   t = x & 1
  addl   %ecx, %eax    #   result += t
  shrl   %edi          #   x >>= 1
  jne    .L2           #   if !0, goto loop
```

General "Do-While" Translation

C Code

```
do
   Body
   while (Test);
```

Goto Version

```
loop:
   Body
   if (Test)
      goto loop
```

- **Body:**

```
{
   Statement1;
   Statement2;
      …
   Statementn;
}
```

- **Test returns integer**
  - **= 0 interpreted as false**
  - **≠ 0 interpreted as true**

"While" Loop Example

C Code

```
int pcount_while(unsigned x) {
  int result = 0;
  while (x) {
    result += x & 0x1;
    x >>= 1;
  }
  return result;
}
```

Goto Version

```
int pcount_do(unsigned x)  {
  int result = 0;
  if (!x) goto done;
loop:
  result += x & 0x1;
  x >>= 1;
  if (x)
    goto loop;
done:
  return result;
}
```

- **Is this code equivalent to the do-while version?**
  - **must jump out of loop if test fails**

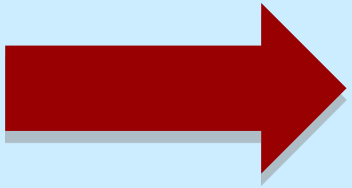
General "While" Translation

While version

```
while (Test)
  Body
```

Do-While Version

```
  if (!Test)
    goto done;
  do
    Body
    while(Test);
done:
```



Goto Version

```
  if (!Test)
    goto done;
loop:
  Body
  if (Test)
    goto loop;
done:
```

“For” Loop Example

C Code

```
#define WSIZE 8*sizeof(int)
int pcount_for(unsigned x) {
  int i;
  int result = 0;
  for (i = 0; i < WSIZE; i++) {
    unsigned mask = 1 << i;
    result += (x & mask) != 0;
  }
  return result;
}
```

- **Is this code equivalent to other versions?**

“For” Loop Form

General Form

```
for (Init; Test; Update)
    Body
```

```
for (i = 0; i < WSIZE; i++) {
    unsigned mask = 1 << i;
    result += (x & mask) != 0;
}
```

Init

```
i = 0
```

Test

```
i < WSIZE
```

Update

```
i++
```

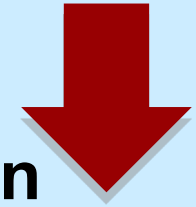
Body

```
{
  unsigned mask = 1 << i;
  result += (x & mask) != 0;
}
```

"For" Loop → While Loop

For Version

```
for (Init; Test; Update)
    Body
```



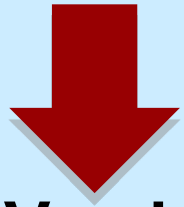
While Version

```
Init;
while (Test) {
    Body
    Update;
}
```

"For" Loop → … → Goto

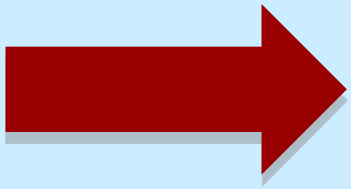
For Version

```
for (Init; Test; Update)
    Body
```

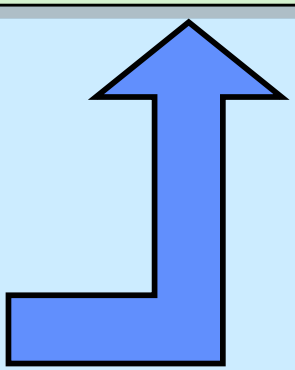


While Version

```
Init;
while (Test) {
    Body
    Update;
}
```



```
  Init;
  if (!Test)
    goto done;
  do
    Body
    Update
  while(Test);
done:
```



```
  Init;
  if (!Test)
    goto done;
loop:
  Body
  Update
  if (Test)
    goto loop;
done:
```

"For" Loop Conversion Example

C Code

```
#define WSIZE 8*sizeof(int)
int pcount_for(unsigned x) {
  int i;
  int result = 0;
  for (i = 0; i < WSIZE; i++) {
    unsigned mask = 1 << i;
    result += (x & mask) != 0;
  }
  return result;
}
```

Initial test can be optimized away

Goto Version

```
int pcount_for_gt(unsigned x) {
  int i;
  int result = 0;
  i = 0;                          Init
  if (!(i < WSIZE))               !Test
    goto done;
 loop:
  {                               Body
    unsigned mask = 1 << i;
    result += (x & mask) != 0;
  }
  i++;                            Update
  if (i < WSIZE)                  Test
    goto loop;
 done:
  return result;
}
```

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;
}
```

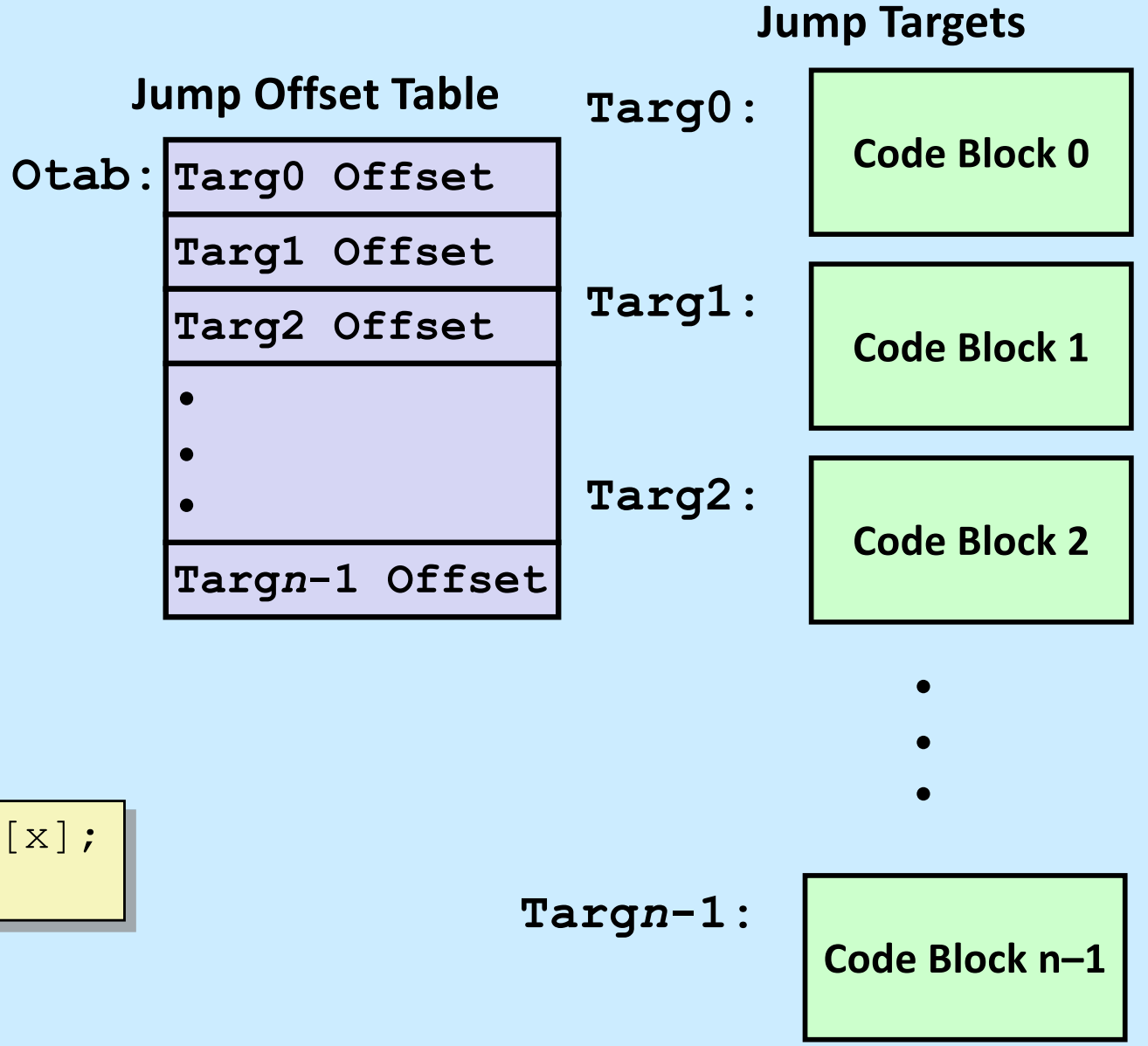
Offset Structure

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 was compiled with the O1 flag
  - no optimization
- O0 often produces easier-to-read (but less efficient) code
  - not so for switch

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
```

Quiz 1

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++;
}
```

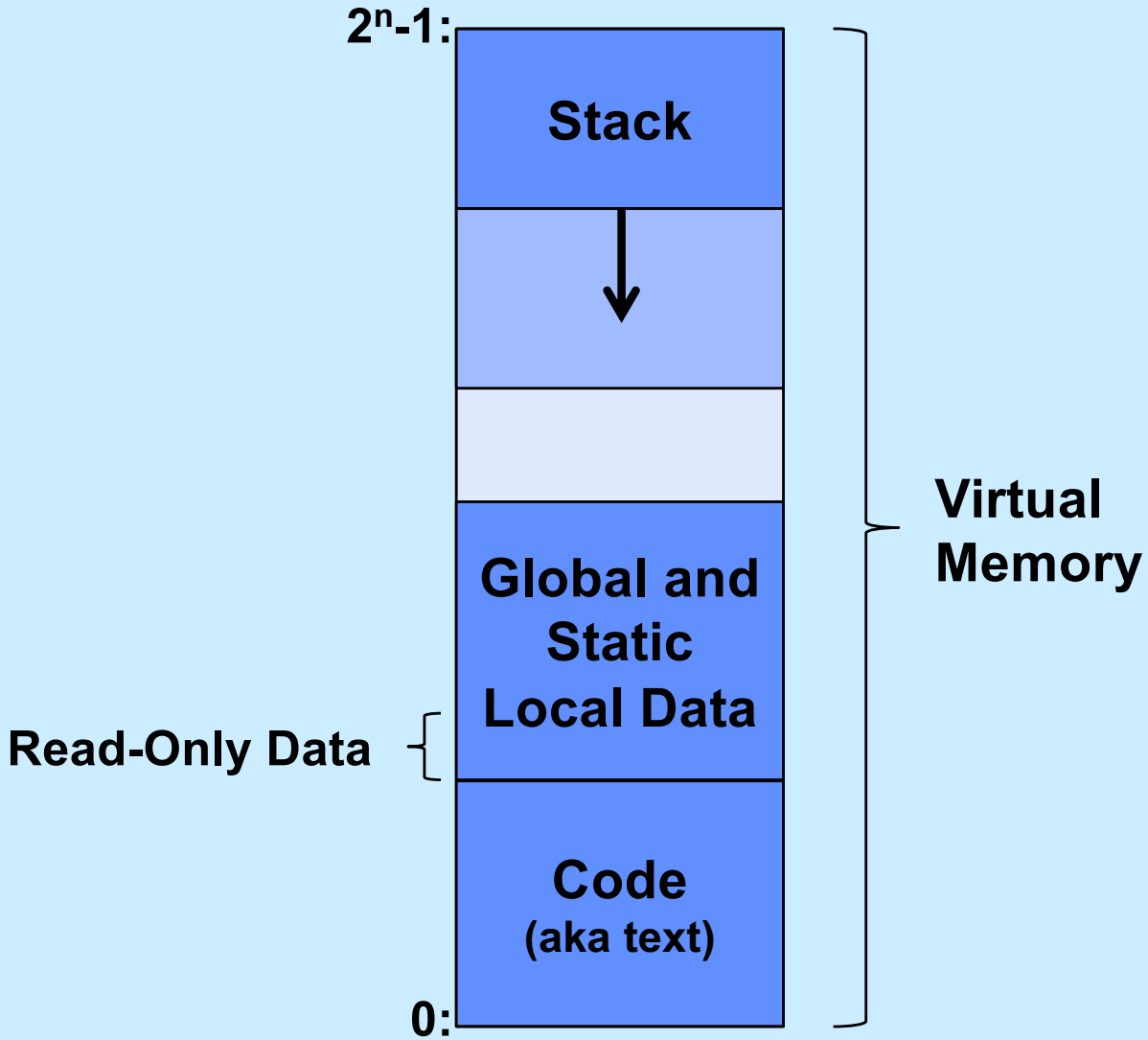
b

```
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)



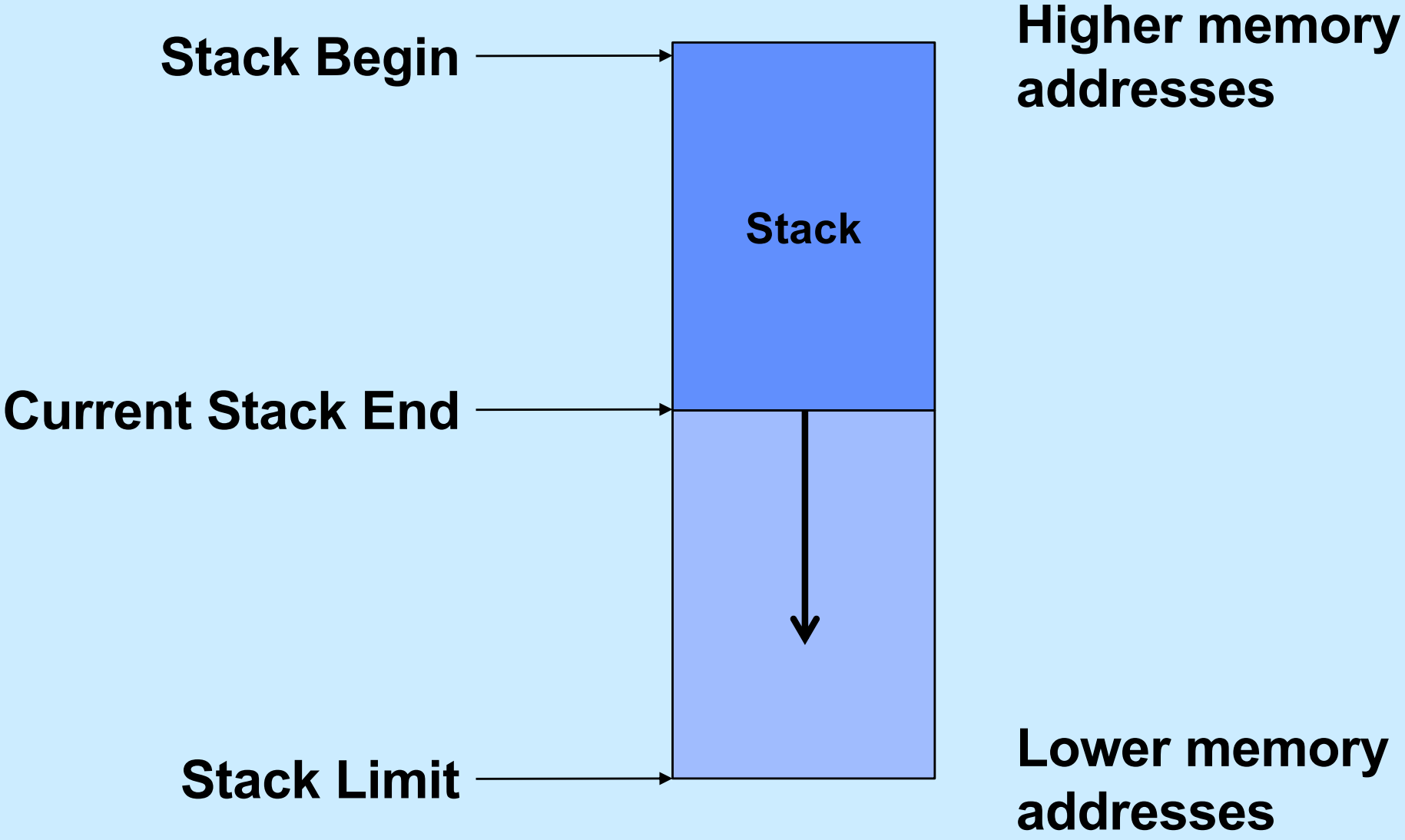
Function Call and Return

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

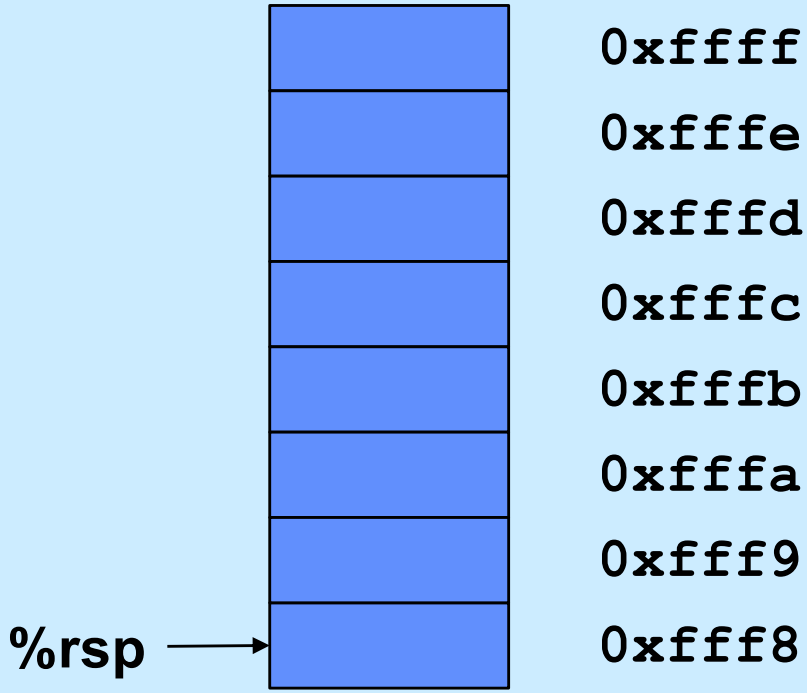
  ... several million instructions later

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

The Runtime Stack

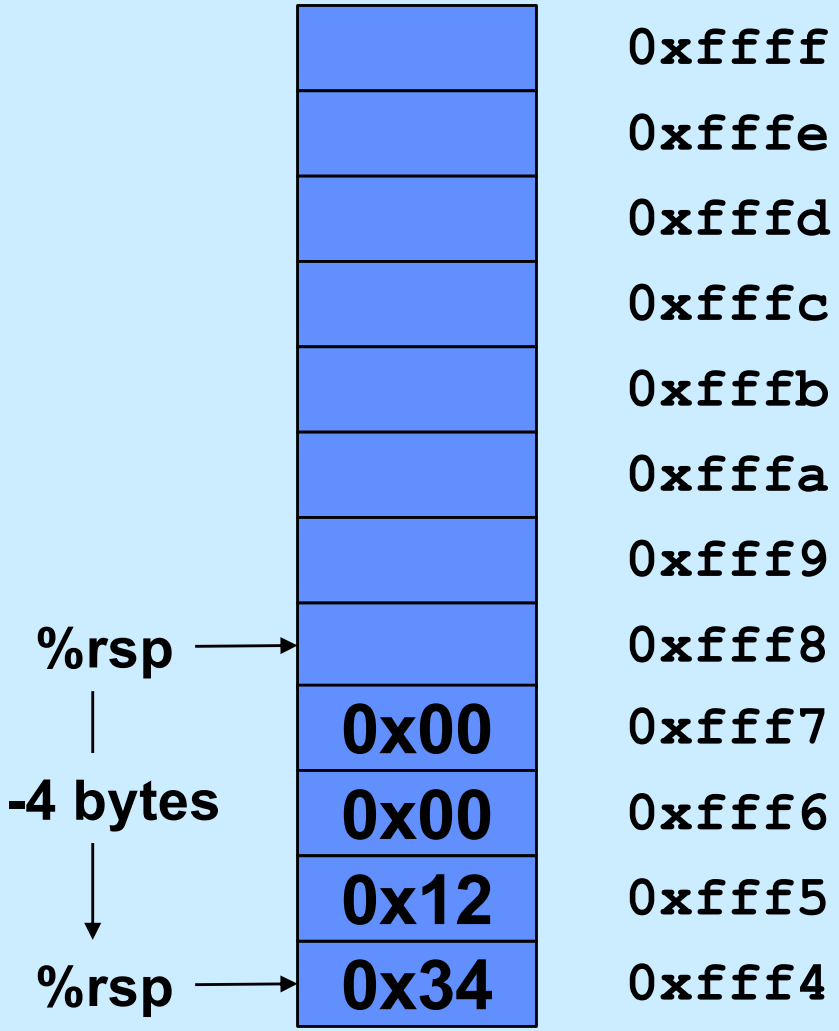


Stack Operations



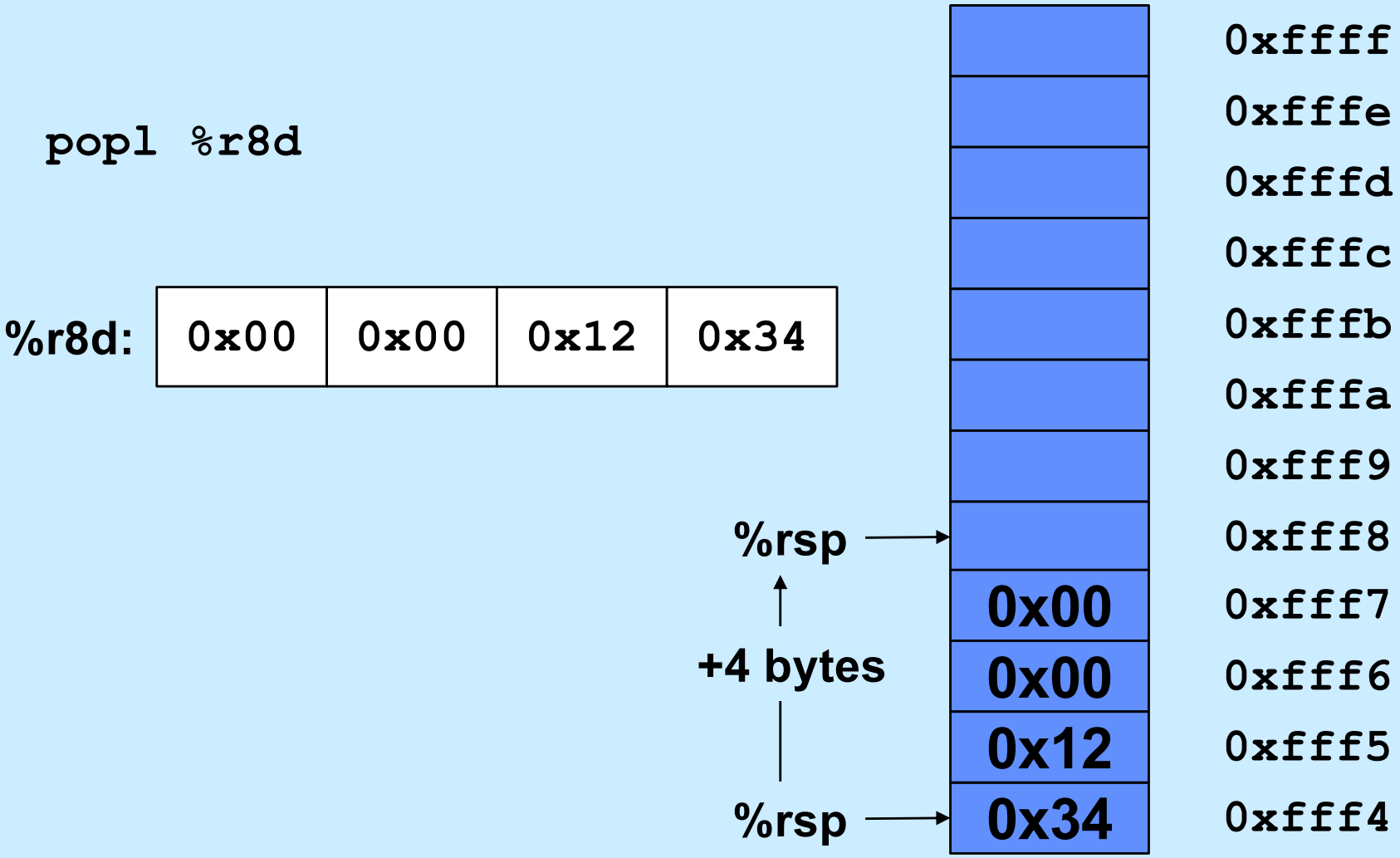
Push

```
pushl $0x1234
```



Pop

```
popl %r8d
```



Call and Return

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

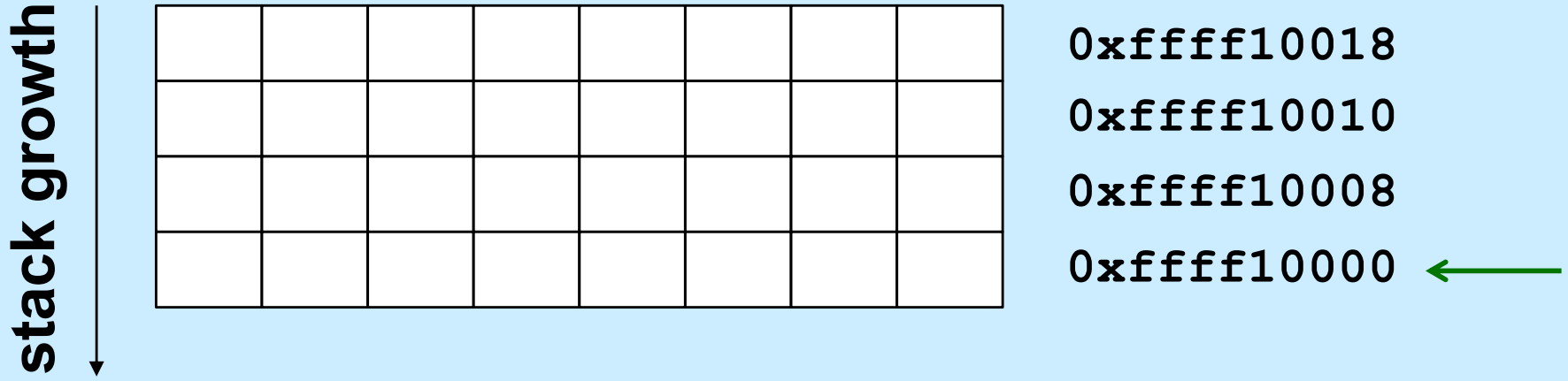
```
0x2000: func:
    ... ...
0x2200: movq $6, %rax
0x2203: ret
```

Call and Return

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



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



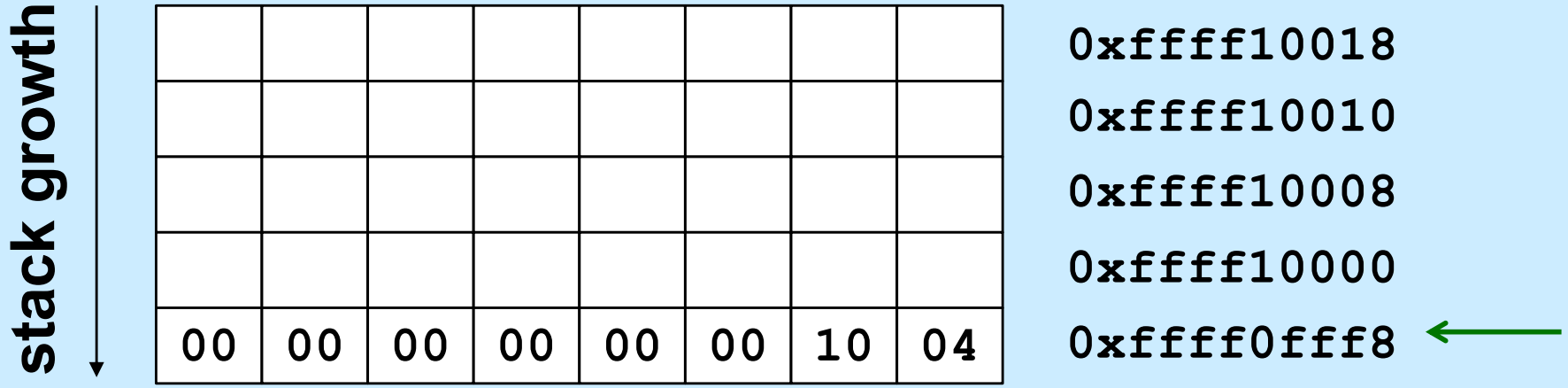
00	00	00	00	00	00	10	00
00	00	00	0f	ff	f1	00	00

%rax
%rip
%rsp

Call and Return

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

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



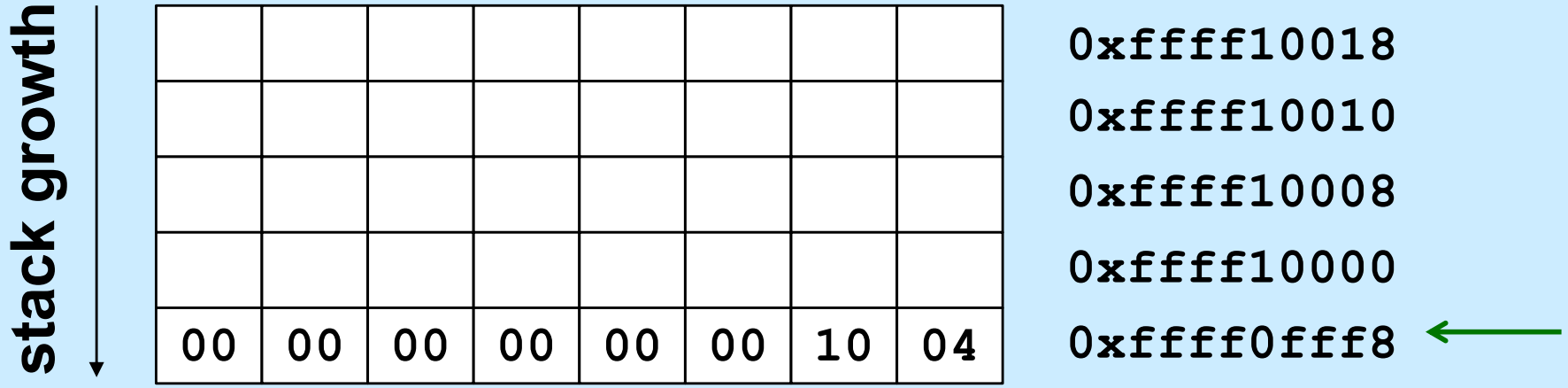
00	00	00	00	00	00	20	00
00	00	00	0f	ff	f0	ff	f8

%rax
%rip
%rsp

Call and Return

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

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



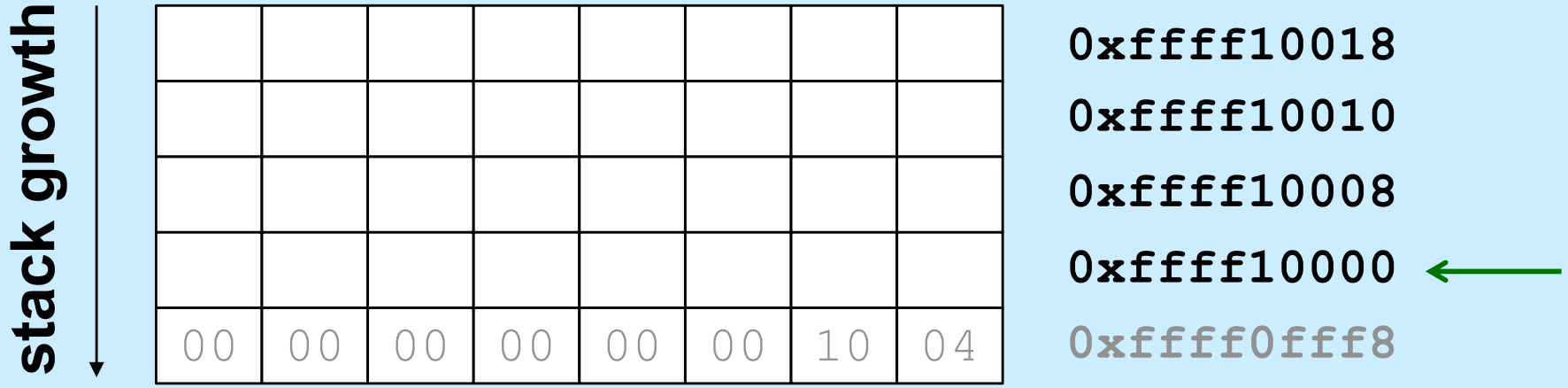
00	00	00	00	00	00	00	06
00	00	00	00	00	00	22	03
00	00	00	0f	ff	f0	ff	f8

%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)**

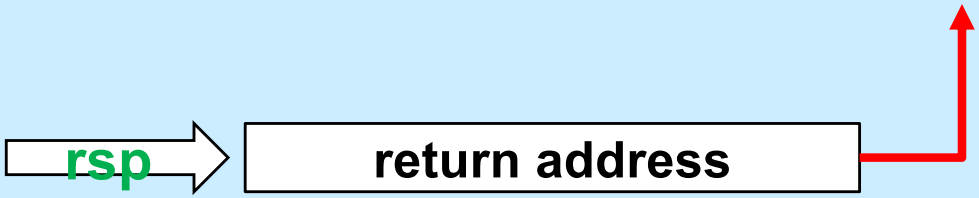
Arguments and Local Variables (1)

```
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)

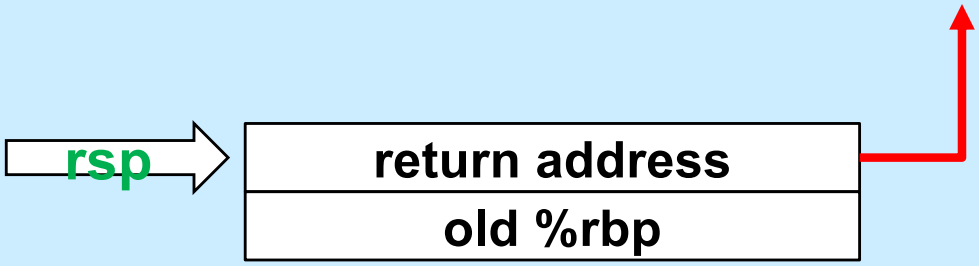
```
ASum:
   pushq %rbp                    # save old %rbp
   movq %rsp, %rbp               # set %rbp to point to stack frame
   movq $0, %rcx                 # i in %rcx
   movq $0, %rax                 # sum in %rax
   movq 16(%rbp), %rdx           # copy arg 1 (array) into %rdx
loop:
   cmpq 24(%rbp), %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



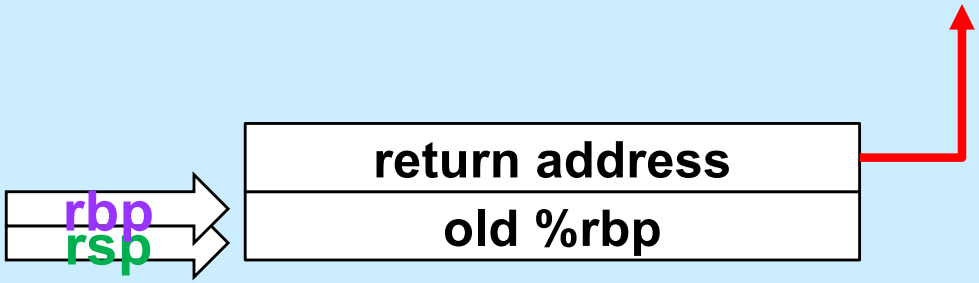

```
mainfunc:
    pushq %rbp
    movq %rsp, %rbp
    subq $32, %rsp
    movq $2, -32(%rbp)
    movq $117, -24(%rbp)
    movq $-6, -16(%rbp)
    pushq $3
    leaq -32(%rbp), %rax
    pushq %rax
    call ASum
    addq $16, %rsp
    movq %rax, -8(%rbp)
    addq $32, %rsp
    popq %rbp
    ret
```

Enter mainfunc



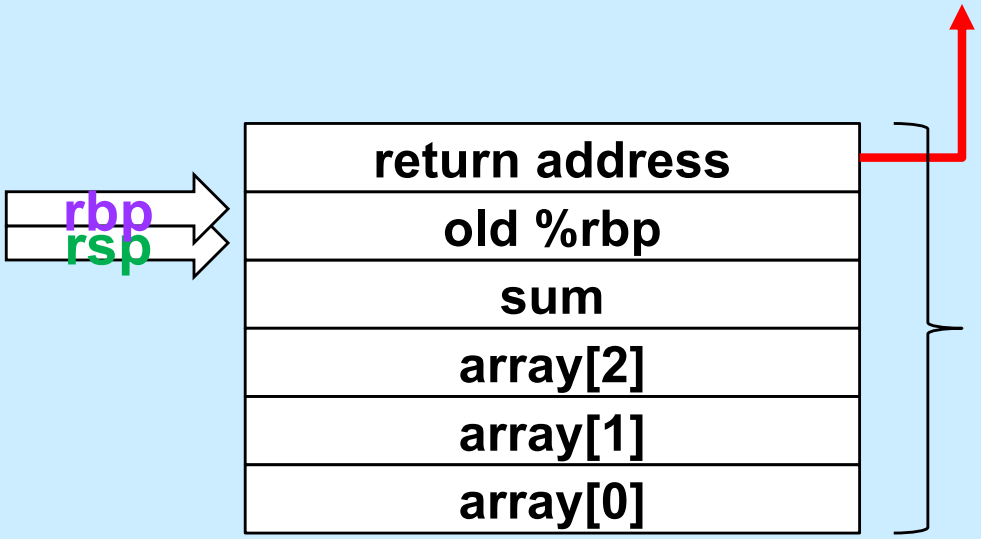

```
mainfunc:
    pushq %rbp
    movq %rsp, %rbp
    subq $32, %rsp
    movq $2, -32(%rbp)
    movq $117, -24(%rbp)
    movq $-6, -16(%rbp)
    pushq $3
    leaq -32(%rbp), %rax
    pushq %rax
    call ASum
    addq $16, %rsp
    movq %rax, -8(%rbp)
    addq $32, %rsp
    popq %rbp
    ret
```

Setup Frame



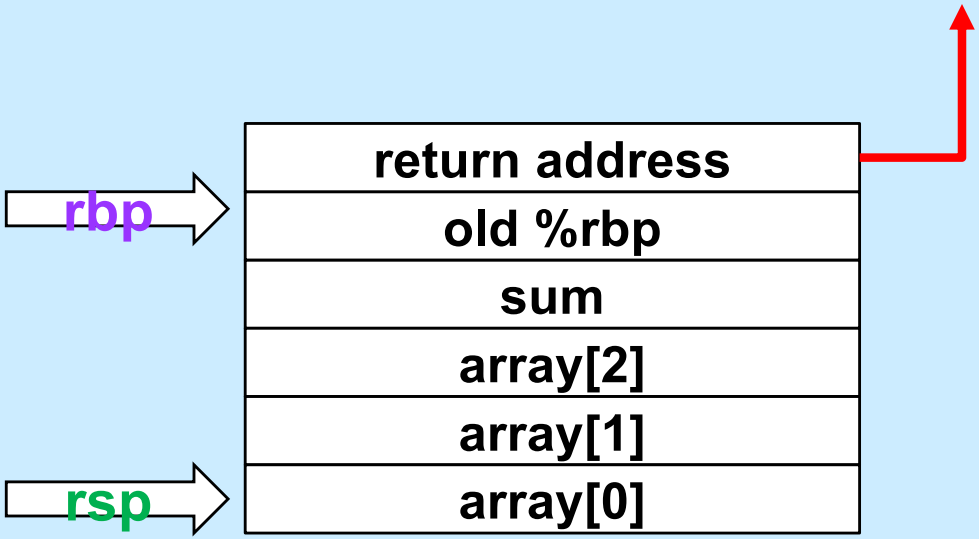

```
mainfunc:
    pushq %rbp
    movq %rsp, %rbp
    subq $32, %rsp
    movq $2, -32(%rbp)
    movq $117, -24(%rbp)
    movq $-6, -16(%rbp)
    pushq $3
    leaq -32(%rbp), %rax
    pushq %rax
    call ASum
    addq $16, %rsp
    movq %rax, -8(%rbp)
    addq $32, %rsp
    popq %rbp
    ret
```

Allocate Local Variables



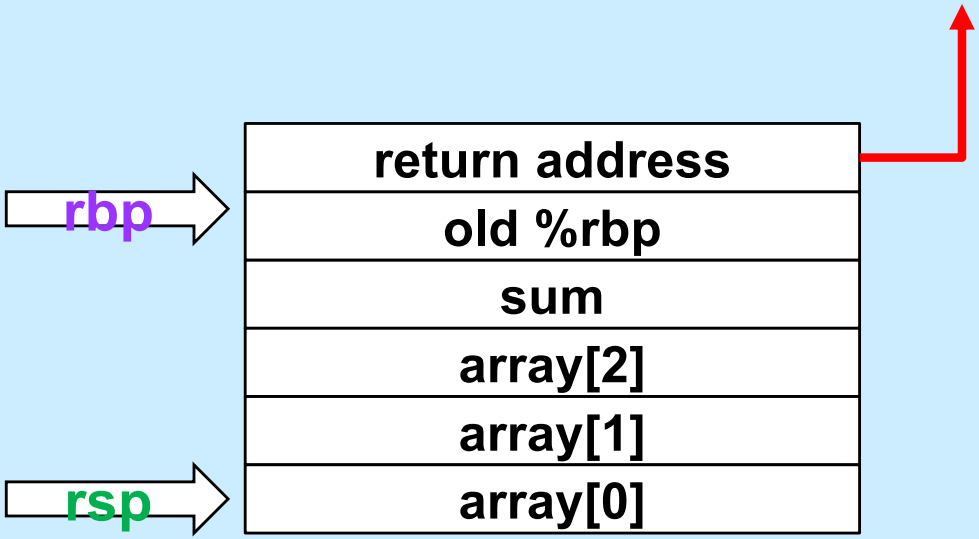

```
mainfunc:
    pushq %rbp
    movq %rsp, %rbp
    subq $32, %rsp
    movq $2, -32(%rbp)
    movq $117, -24(%rbp)
    movq $-6, -16(%rbp)
    pushq $3
    leaq -32(%rbp), %rax
    pushq %rax
    call ASum
    addq $16, %rsp
    movq %rax, -8(%rbp)
    addq $32, %rsp
    popq %rbp
    ret
```

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
```

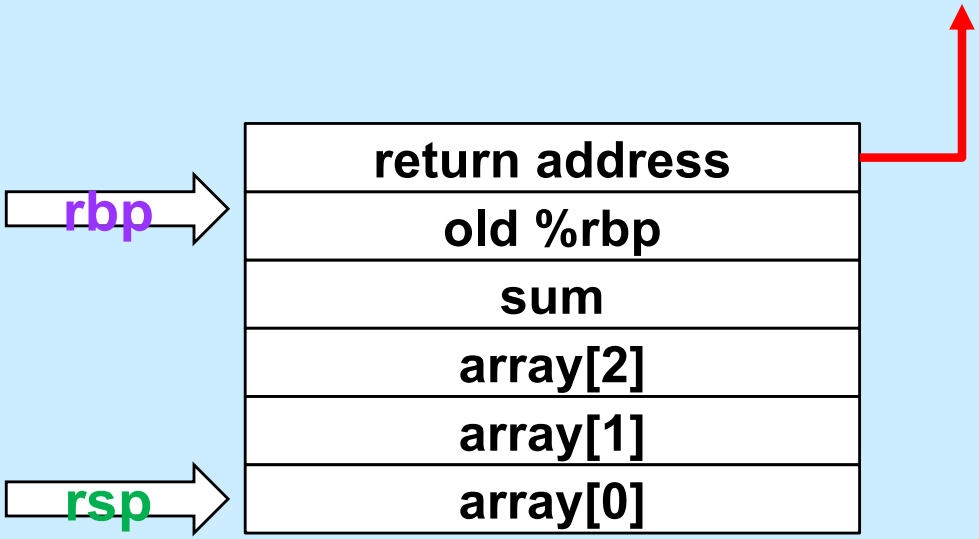
Initialize Local Array




```
mainfunc:
    pushq %rbp
    movq %rsp, %rbp
    subq $32, %rsp
    movq $2, -32(%rbp)
    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
```

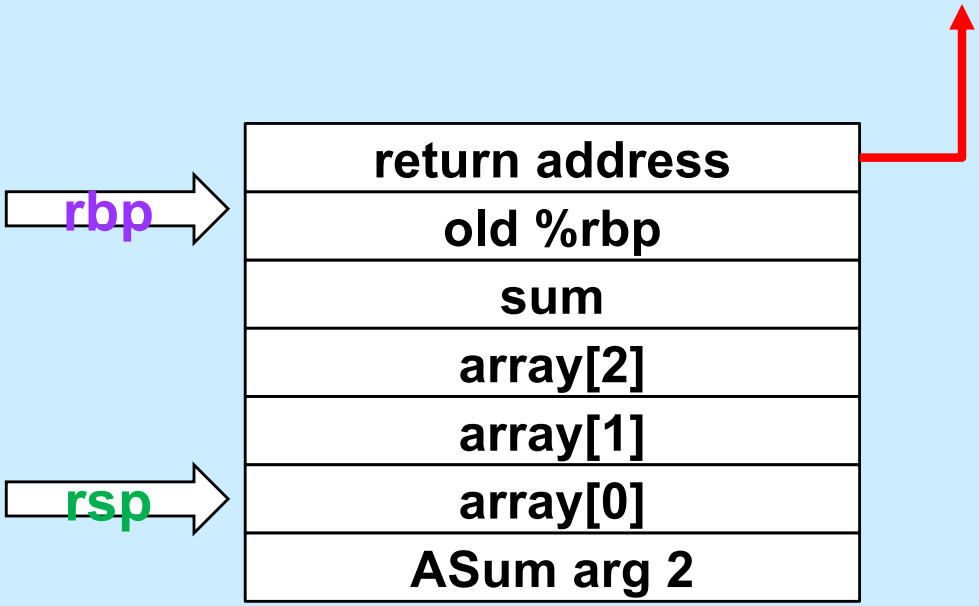
rip

Initialize Local Array



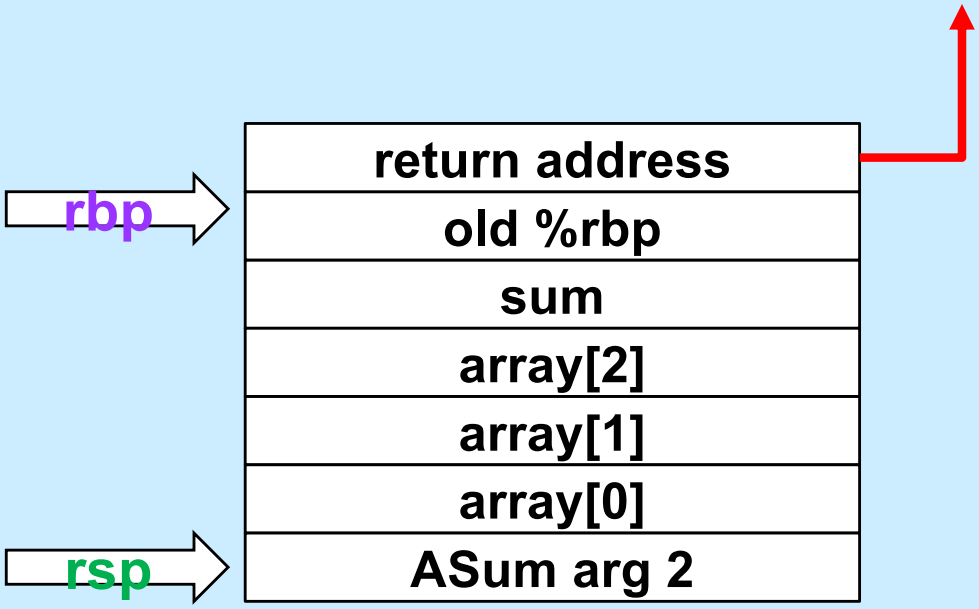

```
mainfunc:
    pushq %rbp
    movq %rsp, %rbp
    subq $32, %rsp
    movq $2, -32(%rbp)
    movq $117, -24(%rbp)
rip movq $-6, -16(%rbp)
    pushq $3
    leaq -32(%rbp), %rax
    pushq %rax
    call ASum
    addq $16, %rsp
    movq %rax, -8(%rbp)
    addq $32, %rsp
    popq %rbp
    ret
```

Push Second Argument



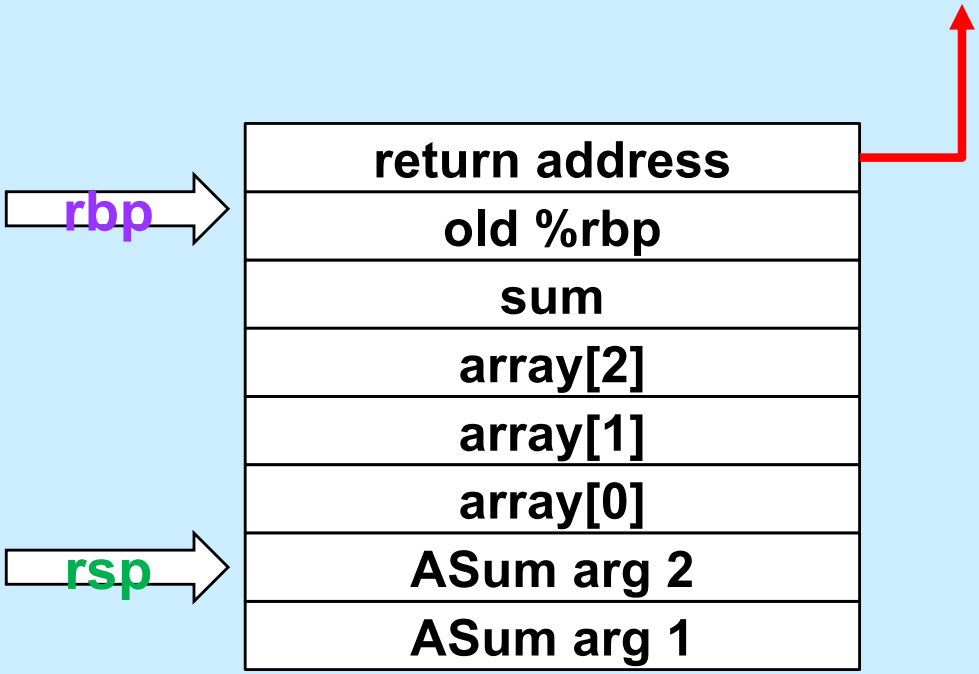

```
mainfunc:
    pushq %rbp
    movq %rsp, %rbp
    subq $32, %rsp
    movq $2, -32(%rbp)
    movq $117, -24(%rbp)
    movq $-6, -16(%rbp)
    pushq $3
    leaq -32(%rbp), %rax
    pushq %rax
    call ASum
    addq $16, %rsp
    movq %rax, -8(%rbp)
    addq $32, %rsp
    popq %rbp
    ret
```

Get Array Address



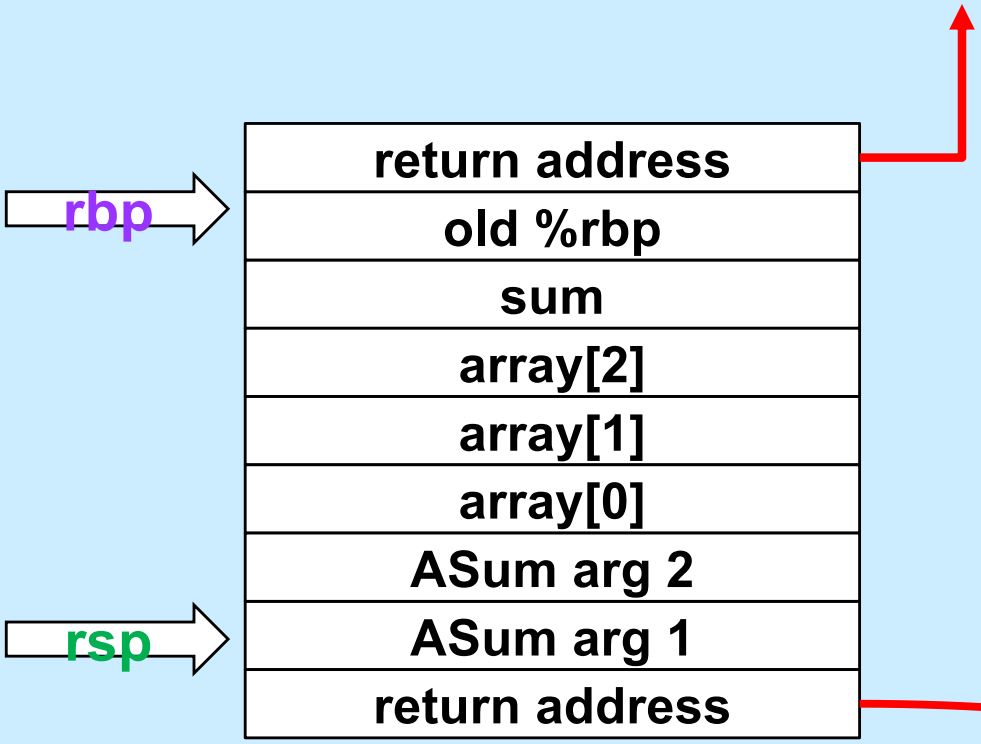

```
mainfunc:
    pushq %rbp
    movq %rsp, %rbp
    subq $32, %rsp
    movq $2, -32(%rbp)
    movq $117, -24(%rbp)
    movq $-6, -16(%rbp)
    pushq $3
    leaq -32(%rbp), %rax
    pushq %rax
    call ASum
    addq $16, %rsp
    movq %rax, -8(%rbp)
    addq $32, %rsp
    popq %rbp
    ret
```

Push First Argument



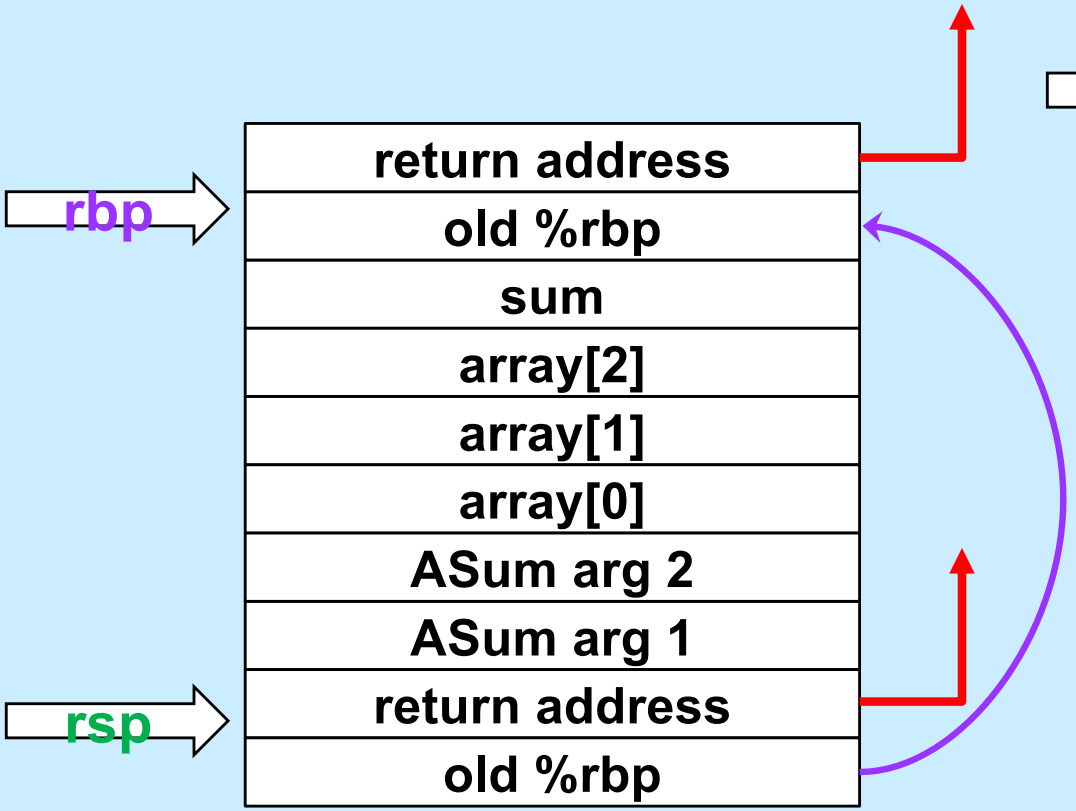

```
mainfunc:
    pushq %rbp
    movq %rsp, %rbp
    subq $32, %rsp
    movq $2, -32(%rbp)
    movq $117, -24(%rbp)
    movq $-6, -16(%rbp)
    pushq $3
    leaq -32(%rbp), %rax
    pushq %rax
    call ASum
    addq $16, %rsp
    movq %rax, -8(%rbp)
    addq $32, %rsp
    popq %rbp
    ret
```

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
```

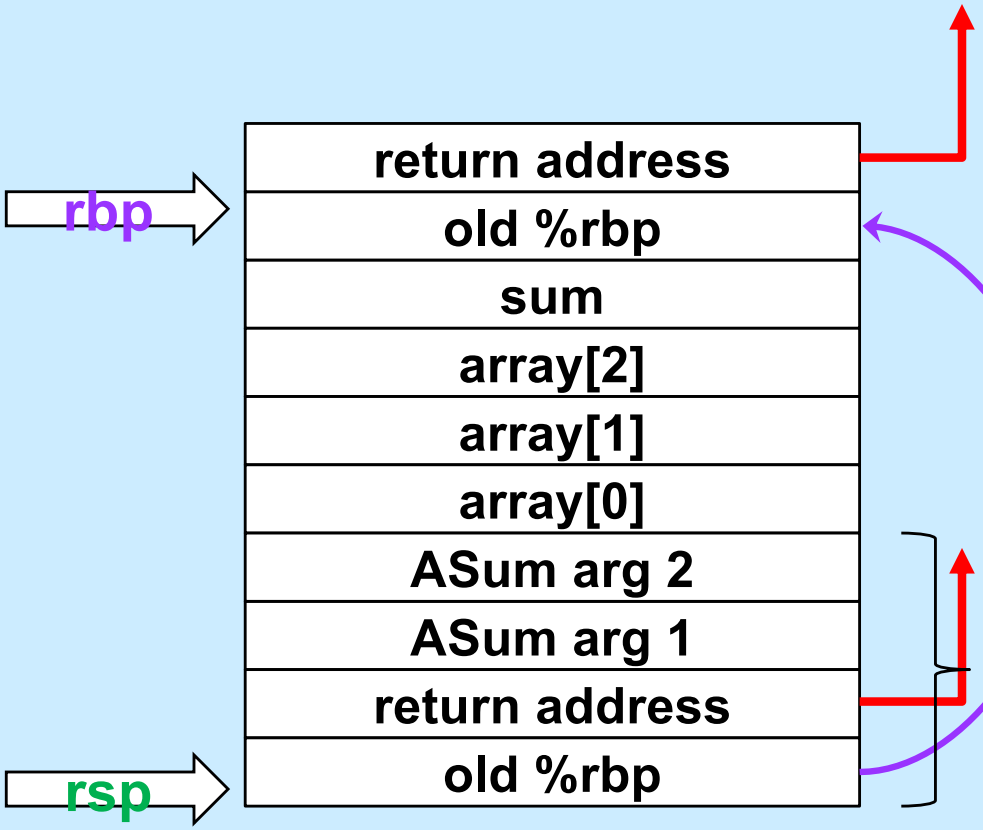
Enter ASum




```
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
```

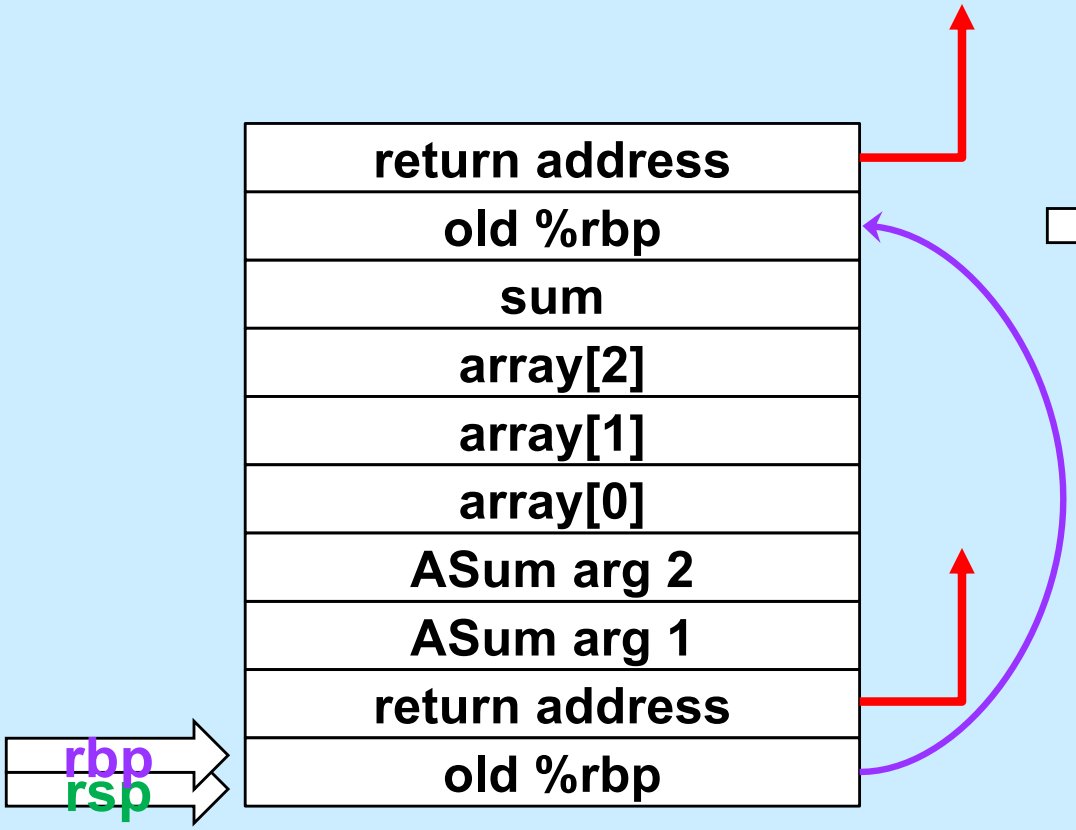
rip

Setup Frame




```
ASum:
    pushq %rbp
rip 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 2

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
```