Using `leal` for Arithmetic Expressions

```
int arith
  (int x, int y, int z)
{
  int t1 = x+y;
  int t2 = z+t1;
  int t3 = x+4;
  int t4 = y * 48;
  int t5 = t3 + t4;
  int rval = t2 * t5;
  return rval;
}
```

```
arith:
    pushl %ebp
    movl %esp,%ebp

    movl 8(%ebp),%eax
    movl 12(%ebp),%edx
    leal (%edx,%eax),%ecx
    leal (%edx,%edx,2),%edx
    sall $4,%edx
    addl 16(%ebp),%ecx
    leal 4(%edx,%eax),%eax
    imull %ecx,%eax

    movl %ebp,%esp
    popl %ebp
    ret
```

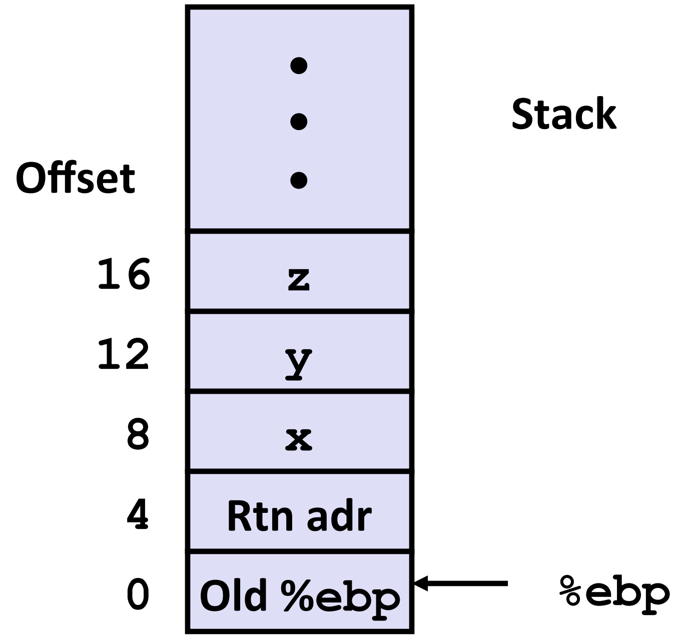
Set Up

Body

Finish

Understanding `arith`

```
int arith
  (int x, int y, int z)
{
  int t1 = x+y;
  int t2 = z+t1;
  int t3 = x+4;
  int t4 = y * 48;
  int t5 = t3 + t4;
  int rval = t2 * t5;
  return rval;
}
```

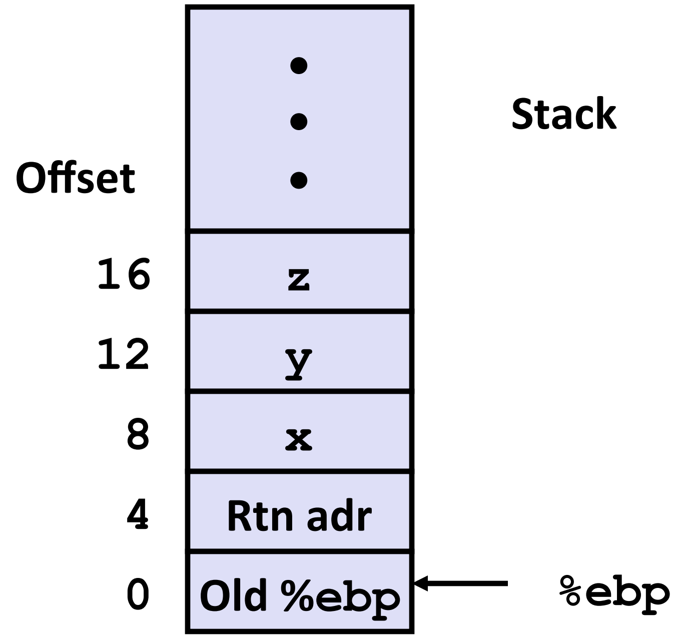



```
movl  8(%ebp),%eax
movl  12(%ebp),%edx
leal  (%edx,%eax),%ecx
leal  (%edx,%edx,2),%edx
sall  $4,%edx
addl  16(%ebp),%ecx
leal  4(%edx,%eax),%eax
imull  %ecx,%eax
```

What does each of these instructions mean?

Understanding `arith`

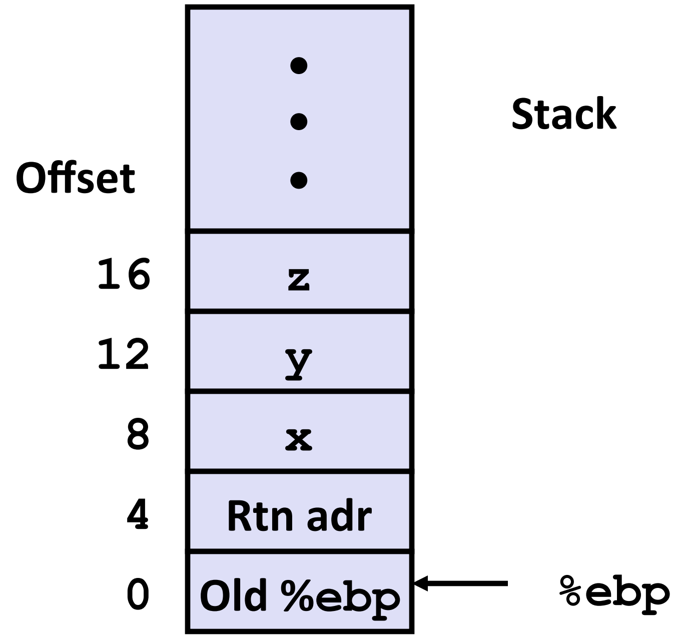
```
int arith
   (int x, int y, int z)
{
  int t1 = x+y;
  int t2 = z+t1;
  int t3 = x+4;
  int t4 = y * 48;
  int t5 = t3 + t4;
  int rval = t2 * t5;
  return rval;
}
```




```
movl  8(%ebp),%eax         # eax = x
movl  12(%ebp),%edx        # edx = y
leal  (%edx,%eax),%ecx     # ecx = x+y  (t1)
leal  (%edx,%edx,2),%edx   # edx = 3*y
sall  $4,%edx              # edx = 48*y (t4)
addl  16(%ebp),%ecx        # ecx = z+t1 (t2)
leal  4(%edx,%eax),%eax    # eax = 4+t4+x (t5)
imull %ecx,%eax            # eax = t5*t2 (rval)
```

Understanding `arith`

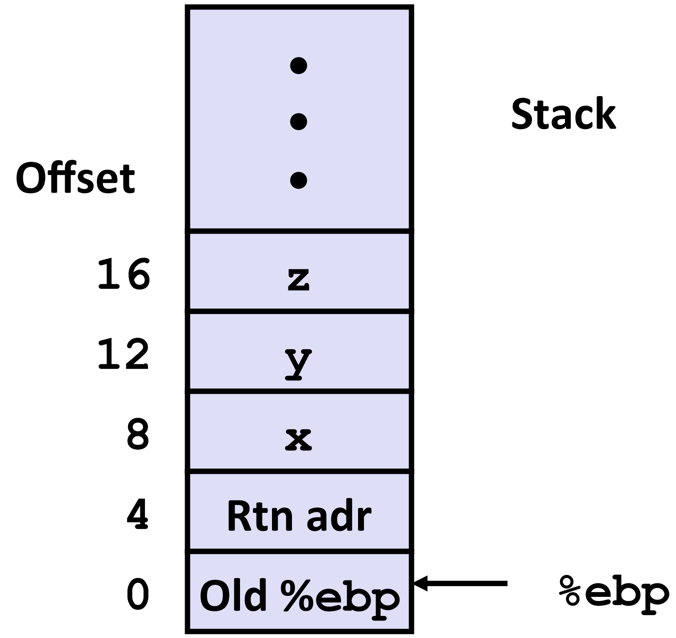
```
int arith
  (int x, int y, int z)
{
  int t1 = x+y;
  int t2 = z+t1;
  int t3 = x+4;
  int t4 = y * 48;
  int t5 = t3 + t4;
  int rval = t2 * t5;
  return rval;
}
```




```
movl  8(%ebp),%eax          # eax = x
movl  12(%ebp),%edx         # edx = y
leal  (%edx,%eax),%ecx      # ecx = x+y   (t1)
leal  (%edx,%edx,2),%edx    # edx = 3*y
sall  $4,%edx               # edx = 48*y (t4)
addl  16(%ebp),%ecx         # ecx = z+t1 (t2)
leal  4(%edx,%eax),%eax     # eax = 4+t4+x (t5)
imull %ecx,%eax             # eax = t5*t2 (rval)
```

Understanding `arith`

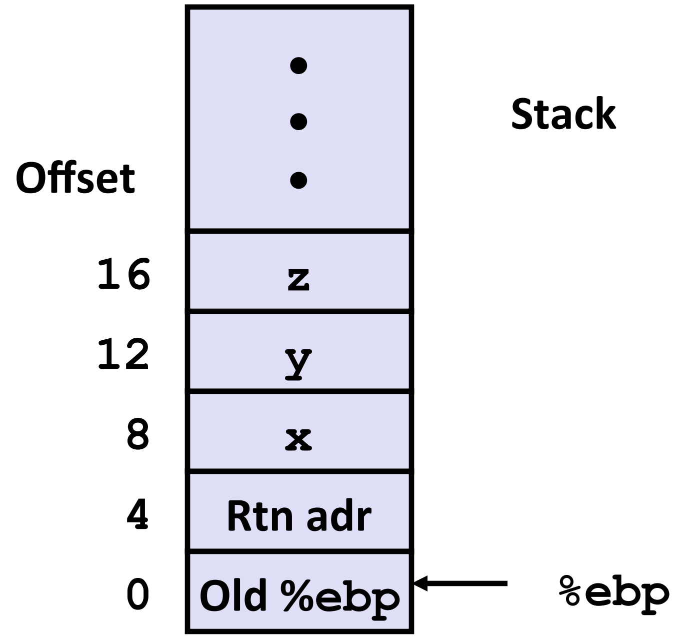
```
int arith
  (int x, int y, int z)
{
  int t1 = x+y;
  int t2 = z+t1;
  int t3 = x+4;
  int t4 = y * 48;
  int t5 = t3 + t4;
  int rval = t2 * t5;
  return rval;
}
```




```
movl  8(%ebp),%eax          # eax = x
movl  12(%ebp),%edx         # edx = y
leal  (%edx,%eax),%ecx      # ecx = x+y   (t1)
leal  (%edx,%edx,2),%edx    # edx = 3*y
sall  $4,%edx               # edx = 48*y (t4)
addl  16(%ebp),%ecx         # ecx = z+t1 (t2)
leal  4(%edx,%eax),%eax     # eax = 4+t4+x (t5)
imull %ecx,%eax             # eax = t5*t2 (rval)
```

Understanding `arith`

```
int arith
   (int x, int y, int z)
{
   int t1 = x+y;
   int t2 = z+t1;
   int t3 = x+4;
   int t4 = y * 48;
   int t5 = t3 + t4;
   int rval = t2 * t5;
   return rval;
}
```



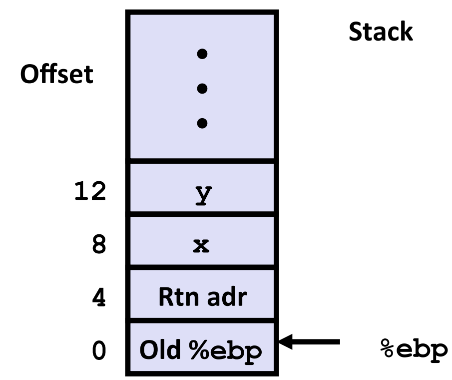

```
movl  8(%ebp),%eax          # eax = x
movl  12(%ebp),%edx         # edx = y
leal  (%edx,%eax),%ecx      # ecx = x+y   (t1)
leal  (%edx,%edx,2),%edx    # edx = 3*y
sall  $4,%edx               # edx = 48*y  (t4)
addl  16(%ebp),%ecx         # ecx = z+t1  (t2)
leal  4(%edx,%eax),%eax     # eax = 4+t4+x  (t5)
imull %ecx,%eax             # eax = t5*t2  (rval)
```

Another Example

```
int logical(int x, int y)
{
  int t1 = x^y;
  int t2 = t1 >> 17;
  int mask = (1<<13) - 7;
  int rval = t2 & mask;
  return rval;
}
```

```
logical:
    pushl %ebp              } Set Up
    movl %esp,%ebp

    movl 8(%ebp),%eax       } Body
    xorl 12(%ebp),%eax
    sarl $17,%eax
    andl $8185,%eax

    movl %ebp,%esp          } Finish
    popl %ebp
    ret
```

```
movl  8(%ebp),%eax     # eax = x
xorl  12(%ebp),%eax    # eax = x^y
sarl  $17,%eax         # eax = t1>>17
andl  $8185,%eax       # eax = t2 & 8185
```



Another Example

```
int logical(int x, int y)
{
  int t1 = x^y;
  int t2 = t1 >> 17;
  int mask = (1<<13) - 7;
  int rval = t2 & mask;
  return rval;
}
```

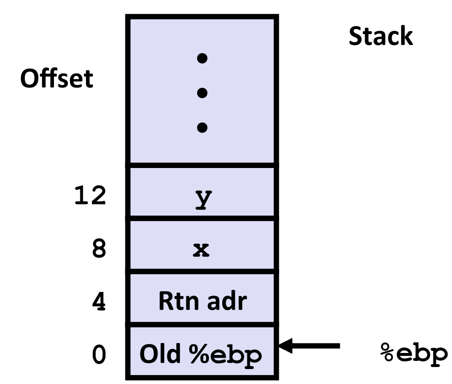
```
logical:
    pushl %ebp
    movl %esp,%ebp

    movl 8(%ebp),%eax
    xorl 12(%ebp),%eax
    sarl $17,%eax
    andl $8185,%eax

    movl %ebp,%esp
    popl %ebp
    ret
```

Set Up

Body

Finish

```
movl 8(%ebp),%eax
xorl 12(%ebp),%eax
sarl $17,%eax
andl $8185,%eax
```

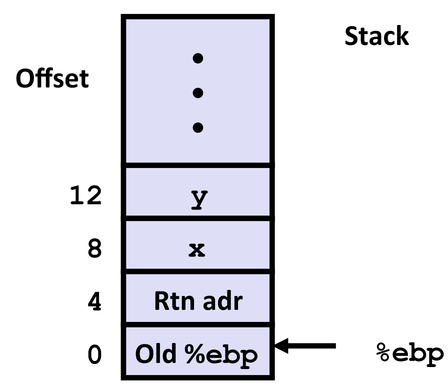


Another Example

```
int logical(int x, int y)
{
  int t1 = x^y;
  int t2 = t1 >> 17;
  int mask = (1<<13) - 7;
  int rval = t2 & mask;
  return rval;
}
```

```
logical:
    pushl %ebp              } Set Up
    movl %esp,%ebp

    movl 8(%ebp),%eax       } Body
    xorl 12(%ebp),%eax
    sarl $17,%eax
    andl $8185,%eax

    movl %ebp,%esp          } Finish
    popl %ebp
    ret
```

```
movl 8(%ebp),%eax       # eax = x
xorl 12(%ebp),%eax      # eax = x^y
sarl $17,%eax           # eax = t1>>17
andl $8185,%eax         # eax = t2 & 8185
```



Another Example

```
int logical(int x, int y)
{
  int t1 = x^y;
  int t2 = t1 >> 17;
  int mask = (1<<13) - 7;
  int rval = t2 & mask;
  return rval;
}
```

```
logical:
    pushl %ebp            } Set Up
    movl %esp,%ebp

    movl 8(%ebp),%eax     } Body
    xorl 12(%ebp),%eax
    sarl $17,%eax
    andl $8185,%eax

    movl %ebp,%esp        } Finish
    popl %ebp
    ret
```

```
movl 8(%ebp),%eax      eax = x
xorl 12(%ebp),%eax     eax = x^y      (t1)
sarl $17,%eax          eax = t1>>17   (t2)
andl $8185,%eax        eax = t2 & 8185
```

Another Example

```
int logical(int x, int y)
{
  int t1 = x^y;
  int t2 = t1 >> 17;
  int mask = (1<<13) - 7;
  int rval = t2 & mask;
  return rval;
}
```

```
logical:
    pushl %ebp              } Set
    movl %esp,%ebp          } Up

    movl 8(%ebp),%eax       }
    xorl 12(%ebp),%eax      }
    sarl $17,%eax           }
    andl $8185,%eax         } Body

    movl %ebp,%esp          }
    popl %ebp               } Finish
    ret                     }
```

```
movl 8(%ebp),%eax       eax = x
xorl 12(%ebp),%eax      eax = x^y      (t1)
sarl $17,%eax           eax = t1>>17   (t2)
andl $8185,%eax         eax = t2 & 8185
```

Another Example

```
int logical(int x, int y)
{
  int t1 = x^y;
  int t2 = t1 >> 17;
  int mask = (1<<13) - 7;
  int rval = t2 & mask;
  return rval;
}
```

```
logical:
    pushl %ebp            Set
    movl %esp,%ebp        Up

    movl 8(%ebp),%eax
    xorl 12(%ebp),%eax
    sarl $17,%eax
    andl $8185,%eax       Body

    movl %ebp,%esp
    popl %ebp             Finish
    ret
```

$2^{13} = 8192$, $2^{13} - 7 = 8185$

```
movl 8(%ebp),%eax      eax = x
xorl 12(%ebp),%eax     eax = x^y      (t1)
sarl $17,%eax          eax = t1>>17   (t2)
andl $8185,%eax        eax = t2 & 8185
```

Reading Condition Codes

- **SetX Instructions**
  - Set a single byte based on combinations of condition codes

SetX	Condition	Description
`sete`	`ZF`	Equal / Zero
`setne`	`~ZF`	Not Equal / Not Zero
`sets`	`SF`	Negative
`setns`	`~SF`	Nonnegative
`setg`	`~(SF^OF)&~ZF`	Greater (Signed)
`setge`	`~(SF^OF)`	Greater or Equal (Signed)
`setl`	`(SF^OF)`	Less (Signed)
`setle`	`(SF^OF)|ZF`	Less or Equal (Signed)
`seta`	`~CF&~ZF`	Above (unsigned)
`setb`	`CF`	Below (unsigned)

Reading Condition Codes (Cont.)

- **SetX Instructions:**
  Set single byte based on combination of condition codes
- **One of 8 addressable byte registers**
  - Does not alter remaining 3 bytes
  - Typically use **`movzbl`** to finish job

%eax	%ah	%al
%ecx	%ch	%cl
%edx	%dh	%dl
%ebx	%bh	%bl
%esi		
%edi		
%esp		
%ebp		

```
int gt (int x, int y)
{
  return x > y;
}
```

Body

```
movl 12(%ebp),%eax
cmpl %eax,8(%ebp)
setg %al
movzbl %al,%eax
```

What does each of these instructions do?

Reading Condition Codes (Cont.)

- **SetX Instructions:**
  Set single byte based on combination of condition codes
- **One of 8 addressable byte registers**
  - Does not alter remaining 3 bytes
  - Typically use **`movzbl`** to finish job

%eax	%ah	%al
%ecx	%ch	%cl
%edx	%dh	%dl
%ebx	%bh	%bl
%esi		
%edi		
%esp		
%ebp		

```
int gt (int x, int y)
{
  return x > y;
}
```

Body

```
movl 12(%ebp),%eax      # eax = y
cmpl %eax,8(%ebp)       # Compare x and y
setg %al                # al = x > y
movzbl %al,%eax         # Zero rest of %eax
```

Note inverted ordering! (refers to the `cmpl` line)

Conditionals: x86-64

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

```
absdiff: # x in %edi, y in %esi
  movl   %edi, %eax  # eax = x
  movl   %esi, %edx  # edx = y
  subl   %esi, %eax  # eax = x-y
  subl   %edi, %edx  # edx = y-x
  cmpl   %esi, %edi  # x:y
  cmovle %edx, %eax  # eax=edx if <=
  ret
```

- **Conditional move instruction**
  - **`cmovC`** src, dest
  - Move value from src to dest if condition *C* holds
  - More efficient than conditional branching (simple control flow)
  - But overhead: both branches are evaluated

Switch Statement Example

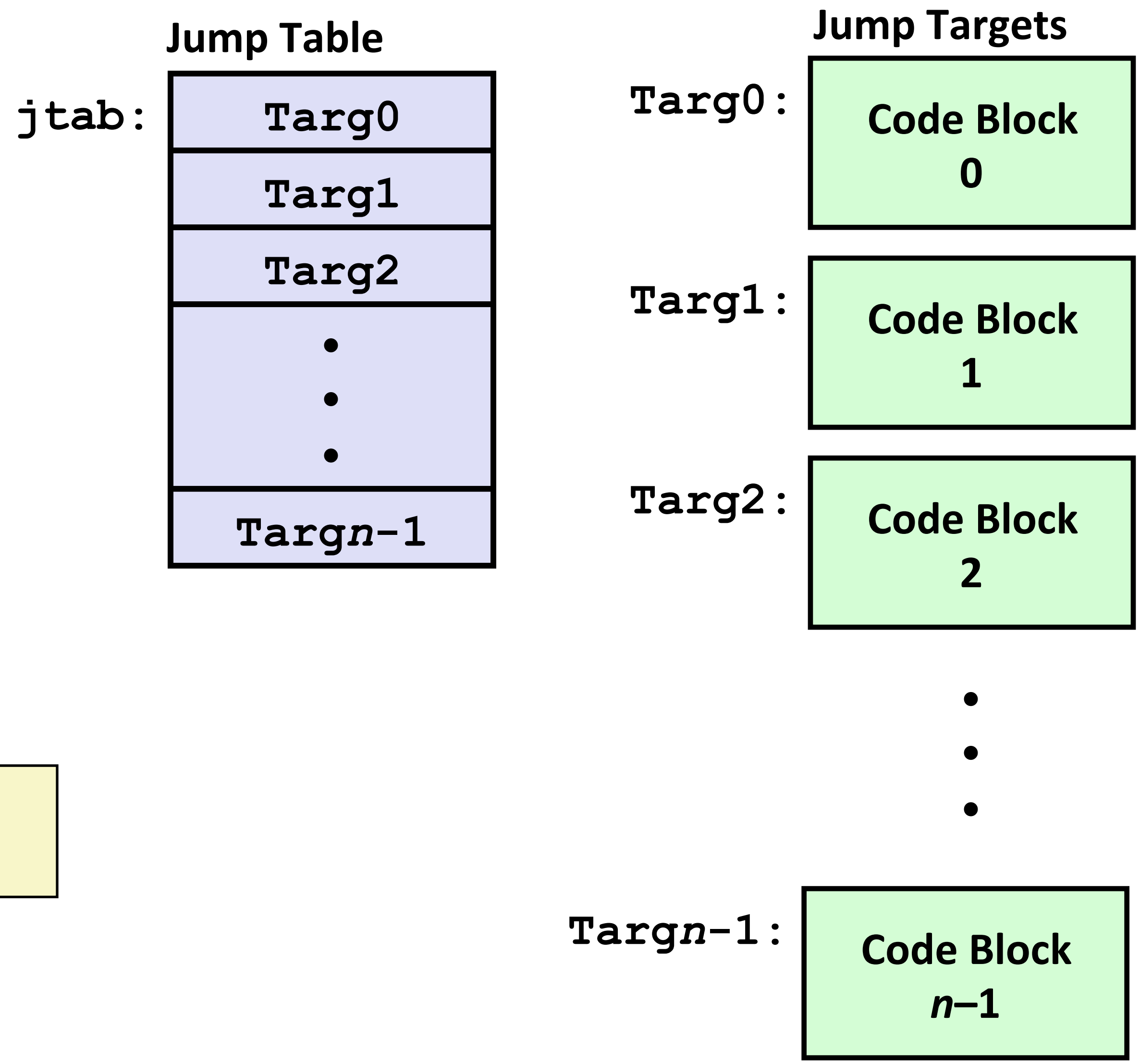
```
long switch_eg
   (long x, long y, long z)
{
    long w = 1;
    switch(x) {
    case 1:
        w = y*z;
        break;
    case 2:
        w = y/z;
        /* Fall Through */
    case 3:
        w += z;
        break;
    case 5:
    case 6:
        w -= z;
        break;
    default:
        w = 2;
    }
    return w;
}
```

- **Multiple case labels**
  - Here: 5, 6
- **Fall through cases**
  - Here: 2
- **Missing cases**
  - Here: 4

Jump Table 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 = JTab[x];
goto *target;
```

Switch Statement Example (IA32)

```
long switch_eg(long x, long y, long z)
{
    long w = 1;
    switch(x) {
      . . .
    }
    return w;
}
```

Setup:

```
switch_eg:
    pushl %ebp              # Setup
    movl  %esp, %ebp        # Setup
    pushl %ebx              # Setup
    movl  $1, %ebx
    movl  8(%ebp), %edx
    movl  16(%ebp), %ecx
    cmpl  $6, %edx
    ja    .L61
    jmp   *.L62(,%edx,4)
```

Translation?

Switch Statement Example (IA32)

```
long switch_eg(long x, long y, long z)
{
    long w = 1;
    switch(x) {
      . . .
    }
    return w;
}
```

Jump table

```
.section .rodata
  .align 4
.L62:
  .long    .L61   # x = 0
  .long    .L56   # x = 1
  .long    .L57   # x = 2
  .long    .L58   # x = 3
  .long    .L61   # x = 4
  .long    .L60   # x = 5
  .long    .L60   # x = 6
```

Setup:

```
switch_eg:
   pushl  %ebp              # Setup
   movl   %esp, %ebp        # Setup
   pushl  %ebx              # Setup
   movl   $1, %ebx          # w = 1
   movl   8(%ebp), %edx     # edx = x
   movl   16(%ebp), %ecx    # ecx = z
   cmpl   $6, %edx          # x:6
   ja     .L61              # if > goto default
   jmp    *.L62(,%edx,4)    # goto JTab[x]
```

Indirect jump →

Assembly Setup Explanation

- **Table Structure**
  - Each target requires 4 bytes
  - Base address at **`.L62`**

- **Jumping**

  Direct: **`jmp .L61`**
  - Jump target is denoted by label **`.L61`**

  Indirect: **`jmp *.L62(,%edx,4)`**
  - Start of jump table: **`.L62`**
  - Must scale by factor of 4 (labels have 32-bit = 4 Bytes on IA32)
  - Fetch target from effective Address **`.L62 + edx*4`**
    - Only for $0 \le \mathbf{x} \le 6$

Jump table

```
.section .rodata
   .align 4
.L62:
  .long    .L61   # x = 0
  .long    .L56   # x = 1
  .long    .L57   # x = 2
  .long    .L58   # x = 3
  .long    .L61   # x = 4
  .long    .L60   # x = 5
  .long    .L60   # x = 6
```

Jump Table

Jump table

```
.section .rodata
   .align 4
.L62:
  .long    .L61  # x = 0
  .long    .L56  # x = 1
  .long    .L57  # x = 2
  .long    .L58  # x = 3
  .long    .L61  # x = 4
  .long    .L60  # x = 5
  .long    .L60  # x = 6
```

```
switch(x) {
case 1:       // .L56
    w = y*z;
    break;
case 2:       // .L57
    w = y/z;
    /* Fall Through */
case 3:       // .L58
    w += z;
    break;
case 5:
case 6:       // .L60
    w -= z;
    break;
default:      // .L61
    w = 2;
}
```

Code Blocks (Partial)

```
switch(x) {
  . . .
case 2:       // .L57
    w = y/z;
    /* Fall Through */
case 3:       // .L58
    w += z;
    break;
  . . .
default:      // .L61
    w = 2;
}
```

```
.L61:  // Default case
   movl  $2, %ebx     # w = 2
   movl  %ebx, %eax   # Return w
   popl  %ebx
   leave
   ret
.L57:  // Case 2:
   movl  12(%ebp), %eax   # y
   cltd                 # Div prep
   idivl %ecx           # y/z
   movl  %eax, %ebx # w = y/z
# Fall through
.L58:  // Case 3:
   addl  %ecx, %ebx # w+= z
   movl  %ebx, %eax # Return w
   popl  %ebx
   leave
   ret
```

Code Blocks (Rest)

```
switch(x) {
case 1:         // .L56
    w = y*z;
    break;
  . . .
case 5:
case 6:         // .L60
    w -= z;
    break;
  . . .
}
```

```
.L60: // Cases 5&6:
  subl   %ecx, %ebx   # w -= z
  movl   %ebx, %eax   # Return w
  popl   %ebx
  leave
  ret
.L56: // Case 1:
  movl   12(%ebp), %ebx # w = y
  imull  %ecx, %ebx      # w*= z
  movl   %ebx, %eax   # Return w
  popl   %ebx
  leave
  ret
```

IA32 Object Code

- **Setup**
  - Label **.L61** becomes address **0x08048630**
  - Label **.L62** becomes address **0x080488dc**

Assembly Code

```
switch_eg:
  . . .
  ja    .L61             # if > goto default
  jmp   *.L62(,%edx,4)  # goto JTab[x]
```

Disassembled Object Code

```
08048610 <switch_eg>:
 . . .
08048622:  77 0c                  ja     8048630
08048624:  ff 24 95 dc 88 04 08   jmp    *0x80488dc(,%edx,4)
```

IA32 Object Code (cont.)

- **Jump Table**
  - Doesn't show up in disassembled code
  - Can inspect using GDB

```
 gdb asm-cntl
(gdb) x/7xw 0x080488dc
```

    - Examine 7 hexadecimal format "words" (4-bytes each)
    - Use command "**help x**" to get format documentation

```
0x080488dc:
   0x08048630
   0x08048650
   0x0804863a
   0x08048642
   0x08048630
   0x08048649
   0x08048649
```

Disassembled Targets

```
8048630:    bb 02 00 00 00        mov    $0x2,%ebx
8048635:    89 d8                 mov    %ebx,%eax
8048637:    5b                    pop    %ebx
8048638:    c9                    leave
8048639:    c3                    ret
804863a:    8b 45 0c              mov    0xc(%ebp),%eax
804863d:    99                    cltd
804863e:    f7 f9                 idiv   %ecx
8048640:    89 c3                 mov    %eax,%ebx
8048642:    01 cb                 add    %ecx,%ebx
8048644:    89 d8                 mov    %ebx,%eax
8048646:    5b                    pop    %ebx
8048647:    c9                    leave
8048648:    c3                    ret
8048649:    29 cb                 sub    %ecx,%ebx
804864b:    89 d8                 mov    %ebx,%eax
804864d:    5b                    pop    %ebx
804864e:    c9                    leave
804864f:    c3                    ret
8048650:    8b 5d 0c              mov    0xc(%ebp),%ebx
8048653:    0f af d9              imul   %ecx,%ebx
8048656:    89 d8                 mov    %ebx,%eax
8048658:    5b                    pop    %ebx
8048659:    c9                    leave
804865a:    c3                    ret
```

Matching Disassembled Targets

```
0x08048630
0x08048650
0x0804863a
0x08048642
0x08048630
0x08048649
0x08048649
```

```
8048630:   bb 02 00 00 00   mov
8048635:   89 d8            mov
8048637:   5b               pop
8048638:   c9               leave
8048639:   c3               ret
804863a:   8b 45 0c         mov
804863d:   99               cltd
804863e:   f7 f9            idiv
8048640:   89 c3            mov
8048642:   01 cb            add
8048644:   89 d8            mov
8048646:   5b               pop
8048647:   c9               leave
8048648:   c3               ret
8048649:   29 cb            sub
804864b:   89 d8            mov
804864d:   5b               pop
804864e:   c9               leave
804864f:   c3               ret
8048650:   8b 5d 0c         mov
8048653:   0f af d9         imul
8048656:   89 d8            mov
8048658:   5b               pop
8048659:   c9               leave
804865a:   c3               ret
```