CSCI-UA.0201

Computer Systems Organization

Machine Level – Control

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Control

“For” Loop Form

General Form

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

```
#define WSIZE 8*sizeof(int)
long pcount_for
  (unsigned long x) {
  size_t i;
  long result = 0;
  for (i = 0; i < WSIZE; i++)
  {
    unsigned bit =
      (x >> i) & 0x1;
    result += bit;
  }
  return result;
}
```

Init

```
i = 0
```

Test

```
i < WSIZE
```

Update

```
i++
```

Body

```
{
  unsigned bit =
      (x >> i) & 0x1;
  result += bit;
}
```

“For” Loop → While Loop

For Version

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

While Version

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

For-While Conversion

Init

```
i = 0
```

Test

```
i < WSIZE
```

Update

```
i++
```

Body

```
{
  unsigned bit =
     (x >> i) & 0x1;
  result += bit;
}
```

```
long pcount_for_while
  (unsigned long x)
{
  size_t i;
  long result = 0;
  i = 0;
  while (i < WSIZE)
  {
    unsigned bit =
      (x >> i) & 0x1;
    result += bit;
    i++;
  }
  return result;
}
```

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

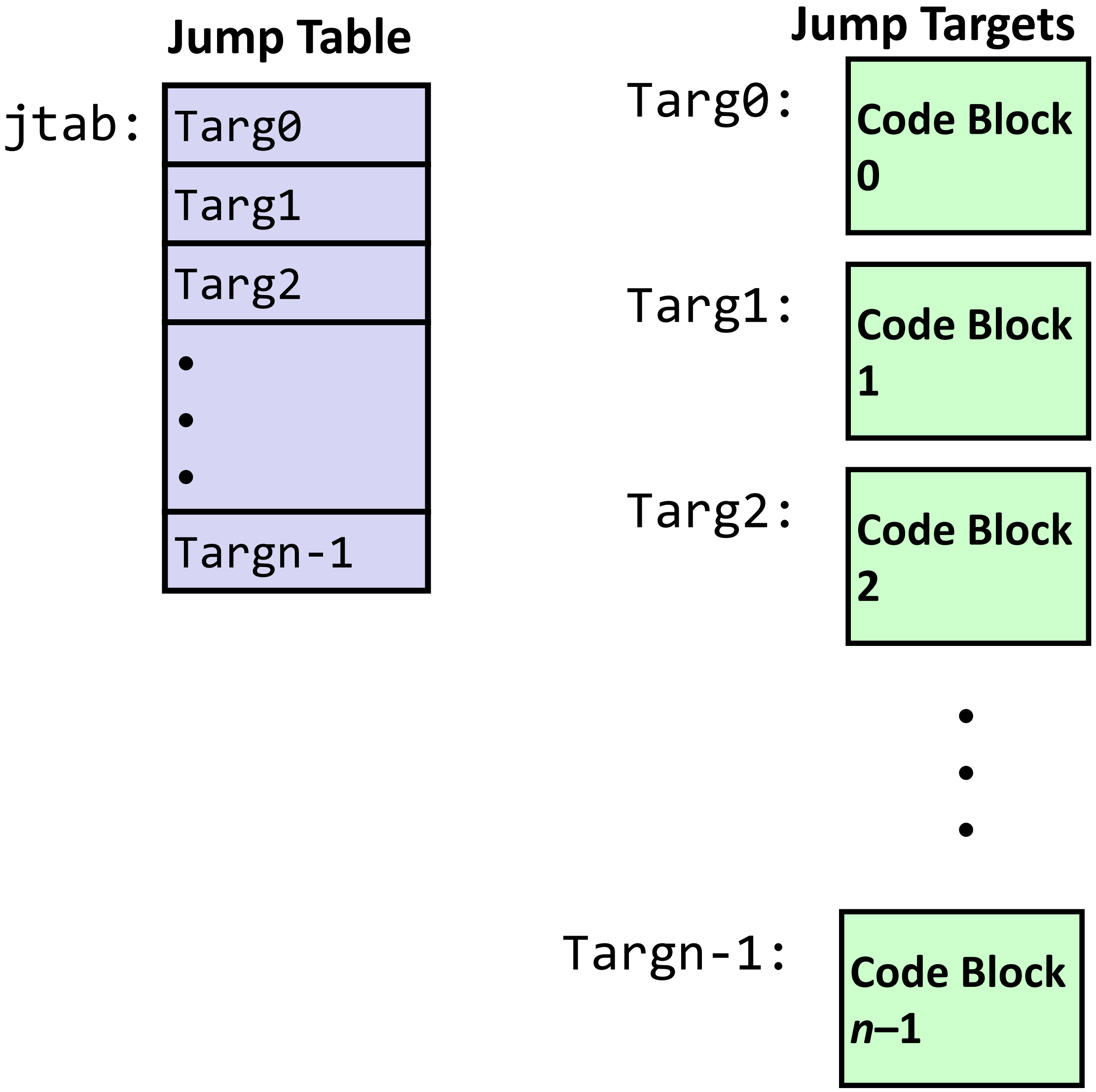
Jump Table Structure

Switch Form

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

Translation (Extended C)

```
goto *jtab[x];
```



Jump Table

jtab:

Targ0

Targ1

Targ2

•
•
•

Targn-1

Jump Targets

Targ0: **Code Block 0**

Targ1: **Code Block 1**

Targ2: **Code Block 2**

•
•
•

Targn-1: **Code Block *n*–1**

Switch Statement Example

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

Setup:

```
switch_eg:
    movq    %rdx, %rcx
    cmpq    $6, %rdi    # x:6
    jg      .L8
    jmp     *.L4(,%rdi,8)
```

Register	Use(s)
%rdi	Argument **x**
%rsi	Argument **y**
%rdx	Argument **z**
%rax	Return value

Note that **w** is not initialized here

Switch Statement Example

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

Jump table

```
.section  .rodata
  .align 8
.L4:
  .quad    .L8  # x = 0
  .quad    .L3  # x = 1
  .quad    .L5  # x = 2
  .quad    .L9  # x = 3
  .quad    .L8  # x = 4
  .quad    .L7  # x = 5
  .quad    .L7  # x = 6
```

Setup:

```
switch_eg:
    movq    %rdx, %rcx
    cmpq    $6, %rdi          # x:6
    jg      .L8               # Use default
    jmp     *.L4(,%rdi,8)     # goto *JTab[x]
```

Indirect jump

Assembly Setup Explanation

- Table Structure
  - Each target requires 8 bytes
  - Base address at .L4

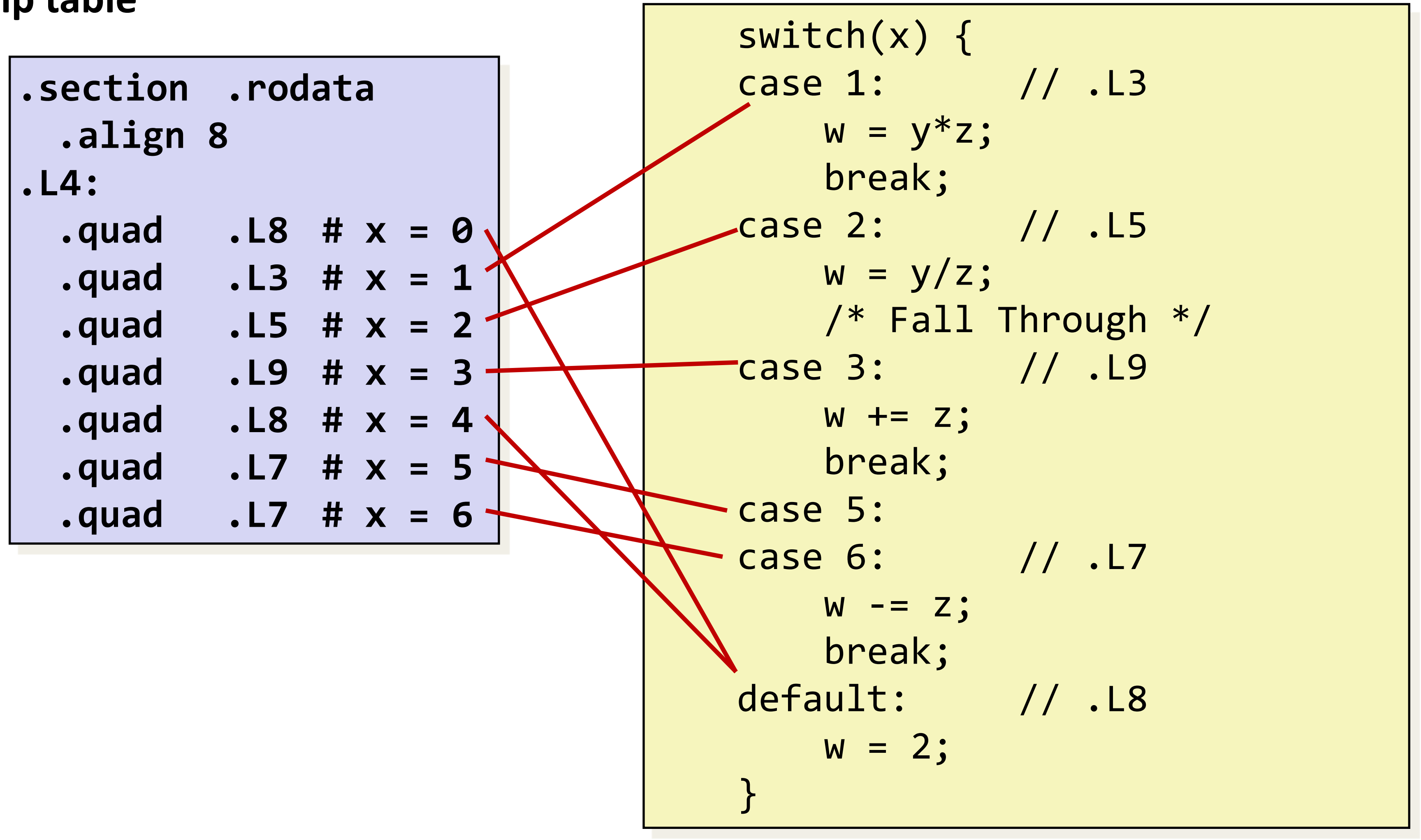
- Jumping
  - **Direct:** **`jmp .L8`**
  - Jump target is denoted by label .L8
  - **Indirect:** **`jmp *.L4(,%rdi,8)`**
  - Start of jump table: **`.L4`**
  - Must scale by factor of 8 (addresses are 8 bytes)
  - Fetch target from effective Address **`.L4 + x*8`**
    - Only for 0 ≤ x ≤ 6

Jump table

```
.section  .rodata
  .align 8
.L4:
  .quad   .L8  # x = 0
  .quad   .L3  # x = 1
  .quad   .L5  # x = 2
  .quad   .L9  # x = 3
  .quad   .L8  # x = 4
  .quad   .L7  # x = 5
  .quad   .L7  # x = 6
```

Jump Table

Jump table



```
.section  .rodata
  .align 8
.L4:
  .quad   .L8  # x = 0
  .quad   .L3  # x = 1
  .quad   .L5  # x = 2
  .quad   .L9  # x = 3
  .quad   .L8  # x = 4
  .quad   .L7  # x = 5
  .quad   .L7  # x = 6
```

```
switch(x) {
case 1:       // .L3
    w = y*z;
    break;
case 2:       // .L5
    w = y/z;
    /* Fall Through */
case 3:       // .L9
    w += z;
    break;
case 5:
case 6:       // .L7
    w -= z;
    break;
default:      // .L8
    w = 2;
}
```

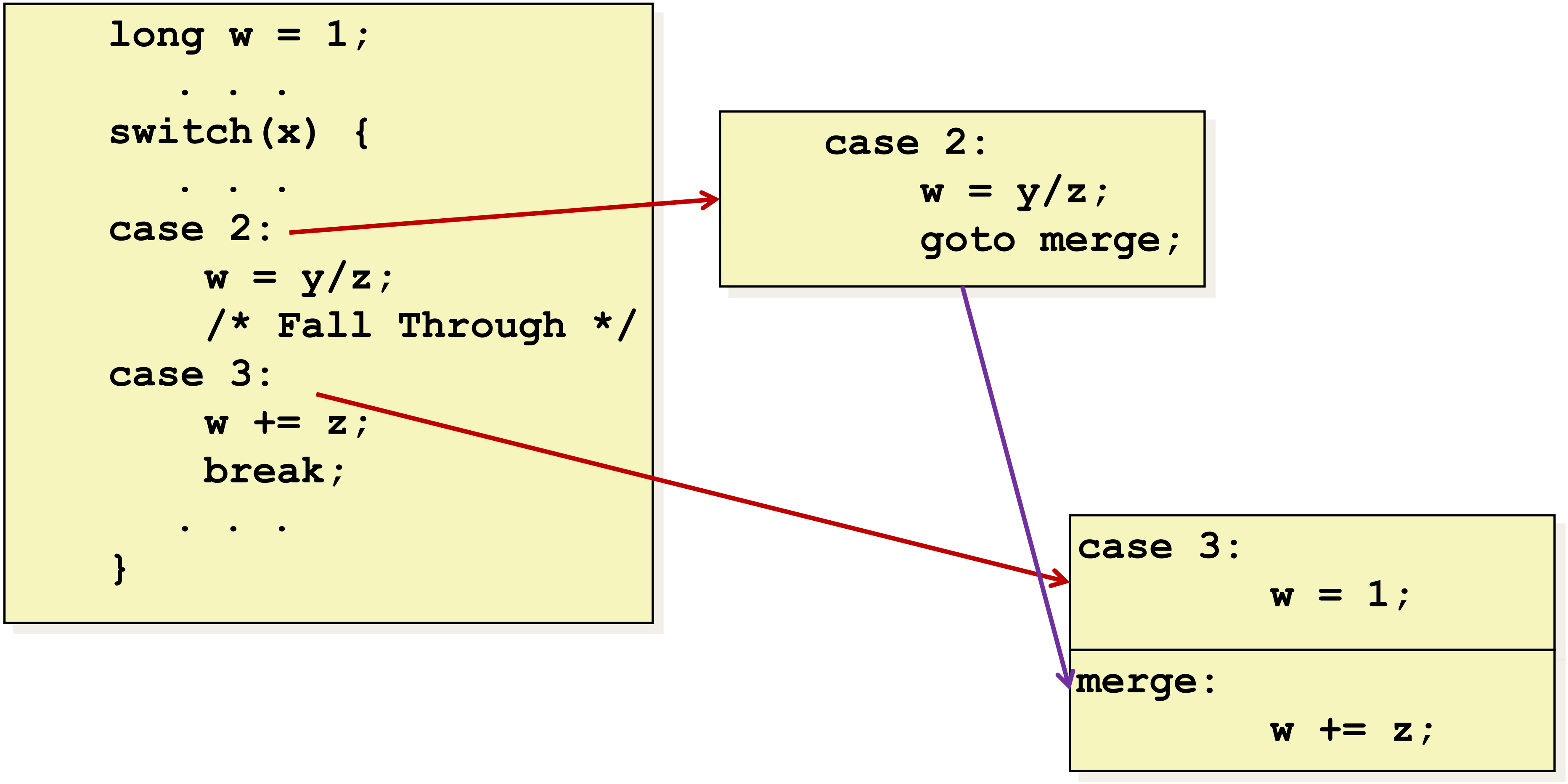
Code Blocks (x == 1)

```
switch(x) {
case 1:      // .L3
      w = y*z;
      break;
 . . .
}
```

```
.L3:
   movq    %rsi, %rax  # w = y
   imulq   %rdx, %rax  # w = w*z
   ret
```

Register	Use(s)
%rdi	Argument **x**
%rsi	Argument **y**
%rdx	Argument **z**
%rax	Return value w

Handling Fall-Through



```
    long w = 1;
       . . .
    switch(x) {
       . . .
    case 2:
        w = y/z;
        /* Fall Through */
    case 3:
        w += z;
        break;
       . . .
    }
```

```
    case 2:
        w = y/z;
        goto merge;
```

```
case 3:
        w = 1;
```

```
merge:
        w += z;
```

Code Blocks (x == 2, x == 3)

```
long w = 1;
    . . .
switch(x) {
    . . .
case 2:
    w = y/z;
    /* Fall Through */
case 3:
    w += z;
    break;
    . . .
}
```

```
.L5:                   # Case 2
   movq    %rsi, %rax  #  w = y
   cqto
   idivq   %rcx        #  w = w/z
   jmp     .L6         #  goto merge
.L9:                   # Case 3
   movl    $1, %eax    #  w = 1
.L6:                   # merge:
   addq    %rcx, %rax  #  w += z
   ret
```

Register	Use(s)
%rdi	Argument **x**
%rsi	Argument **y**
%rdx	Argument **z**
%rax	Return value

Code Blocks (x == 5, x == 6, default)

```
  switch(x) {
    . . .
    case 5:  // .L7
    case 6:  // .L7
        w -= z;
        break;
    default: // .L8
        w = 2;
  }
```

```
.L7:                    # Case 5,6
  movq   $1, %rax       #  w = 1
  subq   %rdx, %rax #   w -= z
  ret
.L8:                    # Default:
  movl   $2, %eax       #  2
  ret
```

Register	Use(s)
%rdi	Argument **x**
%rsi	Argument **y**
%rdx	Argument **z**
%rax	Return value

Conclusions

- C Control
  - if-then-else
  - do-while
  - while, for
  - switch
- Assembler Control
  - Conditional jump
  - Conditional move
  - Indirect jump (via jump tables)
  - Compiler generates code sequence to implement more complex control