
WELCOME
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15-213
14-513
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15-513

Machine-Level Programming II: Control

15-213/14-513/15-513: Introduction to Computer Systems
4th Lecture, Sept 5, 2024

While waiting for class to start:

login to a shark machine, then type

```
wget http://www.cs.cmu.edu/~213/activities/machine-control.pdf
wget http://www.cs.cmu.edu/~213/activities/machine-control.tar
tar xf machine-control.tar
cd machine-control
```

Today

- Review of a few tricky bits from last time
- Control: Condition codes — CSAPP 3.6.1 - 3.6.2
- Conditional branches — CSAPP 3.6.3 - 3.6.6
- Loops — CSAPP 3.6.7
- Switch Statements (time permitting) — CSAPP 3.6.8

Recall: Machine Instructions

```
*dest = t;
```

```
movq %rax, (%rbx)
```

```
0x40059e:  48 89 03
```

```
0100 1 0 0 0  10001011  00 000 011
REX  W R X B  MOV r->x  Mod R   M
```

C
- Store value **t** where designated by **dest**

Assembly
- Move 8-byte value to memory
  - Quad words in x86-64 parlance
- Operands:

  t: Register **%rax**

  dest: Register **%rbx**

  ***dest:** Memory **M[%rbx]**

Machine
- 3 bytes at address **0x40059e**
- Compact representation of the assembly instruction
- (Relatively) easy for hardware to interpret

Recall: Addressing Modes

Most General Form

D(Rb,Ri,S) **Mem[Reg[Rb]+S*Reg[Ri]+ D]**

- D: Constant “displacement” 1, 2, or 4 bytes
- Rb: Base register: Any of 16 integer registers
- Ri: Index register: Any, except for `%rsp`
- S: Scale: 1, 2, 4, or 8

Special Cases

(Rb)	**Mem[Reg[Rb]]**
(Rb,Ri)	**Mem[Reg[Rb]+Reg[Ri]]**
D(Rb,Ri)	**Mem[Reg[Rb]+Reg[Ri]+D]**
(Rb,Ri,S)	**Mem[Reg[Rb]+S*Reg[Ri]]**

Memory operands and LEA

- **In most instructions, a memory operand accesses memory**

Assembly	C equivalent
mov 6(%rbx,%rdi,8), %ax	ax = *(rbx + rdi*8 + 6)
add 6(%rbx,%rdi,8), %ax	ax += *(rbx + rdi*8 + 6)
xor %ax, 6(%rbx,%rdi,8)	*(rbx + rdi*8 + 6) ^= ax

- **LEA is special: it *doesn't* access memory**

Assembly	C equivalent
lea 6(%rbx,%rdi,8), %rax	rax = rbx + rdi*8 + 6

Why use LEA?

- **CPU designers' intended use: calculate a pointer to an object**
  - An array element, perhaps
  - For instance, to pass just one array element to another function

Assembly	C equivalent
lea (%rbx,%rdi,8), %rax	rax = &rbx[rdi]

- **Compiler authors like to use it for ordinary arithmetic**
  - It can do complex calculations in one instruction
  - It's one of the only three-operand instructions the x86 has
  - It doesn't touch the condition codes (we'll come back to this)

Assembly	C equivalent
lea (%rbx,%rbx,2), %rax	rax = rbx * 3

Which numbers are pointers?

- They aren't labeled
- You have to figure it out from context

```
(gdb) info registers
rax      0x40057d         4195709
rbx      0x0              0
rcx      0x4005e0         4195808
rdx      0x7fffffffdc28   140737488346152
rsi      0x7fffffffdc18   140737488346136
rdi      0x1              1
rbp      0x0              0x0
rsp      0x7fffffffdb38   0x7fffffffdb38
r8       0x7ffff7dd5e80   140737351868032
r9       0x0              0
r10      0x7fffffffd7c0   140737488345024
r11      0x7ffff7a2f460   140737348039776
r12      0x400490         4195472
r13      0x7fffffffdc10   140737488346128
r14      0x0              0
r15      0x0              0
rip      0x40057d         0x40057d
```

Which numbers are pointers?

- They aren't labeled
- You have to figure it out from context

- %rsp and %rip always hold pointers

```
(gdb) info registers
rax     0x40057d        4195709
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rbp     0x0             0x0
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r8      0x7ffff7dd5e80  140737351868032
r9      0x0             0
r10     0x7fffffffd7c0  140737488345024
r11     0x7ffff7a2f460  140737348039776
r12     0x400490        4195472
r13     0x7fffffffdc10  140737488346128
r14     0x0             0
r15     0x0             0
rip     0x40057d        0x40057d
```

Which numbers are pointers?

- They aren't labeled
- You have to figure it out from context
- %rsp and %rip always hold pointers
  - Register values that are "close" to %rsp or %rip are *probably* also pointers

```
(gdb) info registers
rax       0x40057d        4195709
rbx       0x0             0
rcx       0x4005e0        4195808
rdx       0x7fffffffdc28  140737488346152
rsi       0x7fffffffdc18  140737488346136
rdi       0x1             1
rbp       0x0             0x0
rsp       0x7fffffffdb38  0x7fffffffdb38
r8        0x7ffff7dd5e80  140737351868032
r9        0x0             0
r10       0x7fffffffd7c0  140737488345024
r11       0x7ffff7a2f460  140737348039776
r12       0x400490        4195472
r13       0x7fffffffdc10  140737488346128
r14       0x0             0
r15       0x0             0
rip       0x40057d        0x40057d
```

Which numbers are pointers?

- If a register is being *used* as a pointer…

```
Dump of assembler code for function main:
=> 0x40057d <+0>:  sub   $0x8,%rsp
   0x400581 <+4>:  mov   (%rsi),%rsi
   0x400584 <+7>:  mov   $0x400670,%edi
   0x400589 <+12>: mov   $0x0,%eax
   0x40058e <+17>: call  0x400460
```

Which numbers are pointers?

- **If a register is being *used* as a pointer…**
  - mov (%rsi), %rsi
  - …Then its value is *expected* to be a pointer.
    - There might be a bug that makes its value incorrect.

```
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   0x40058e <+17>:  call   0x400460
```

Which numbers are pointers?

- **If a register is being *used* as a pointer…**
  - mov (%rsi), %rsi
  - …Then its value is *expected* to be a pointer.
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   0x40058e <+17>:  call   0x400460
```

- **Not as obvious with complicated addressing "modes"**
  - (%rsi, %rbx) – *One* of these is a pointer, we don't know which.
  - (%rsi, %rbx, 2) – %rsi is a pointer, %rbx isn't (why?)
  - 0x400570(, %rbx, 2) – 0x400570 is a pointer, %rbx isn't (why?)
  - lea (anything), %rax – (anything) *may or may not* be a pointer

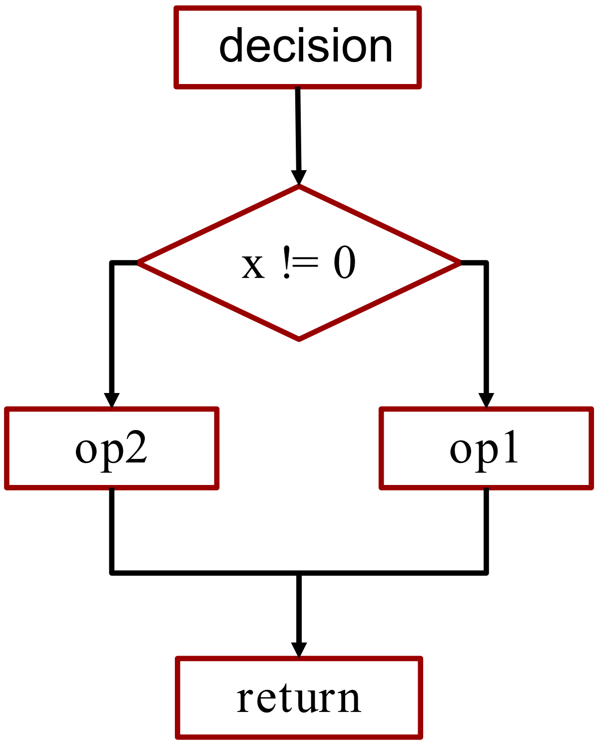
Today

- Review of a few tricky bits from last time
- **Control: Condition codes**
- Conditional branches
- Loops
- Switch Statements

Control flow

```
extern void op1(void);
extern void op2(void);

void decision(int x) {
    if (x) {
        op1();
    } else {
        op2();
    }
}
```



Control flow in assembly language

```
extern void op1(void);
extern void op2(void);

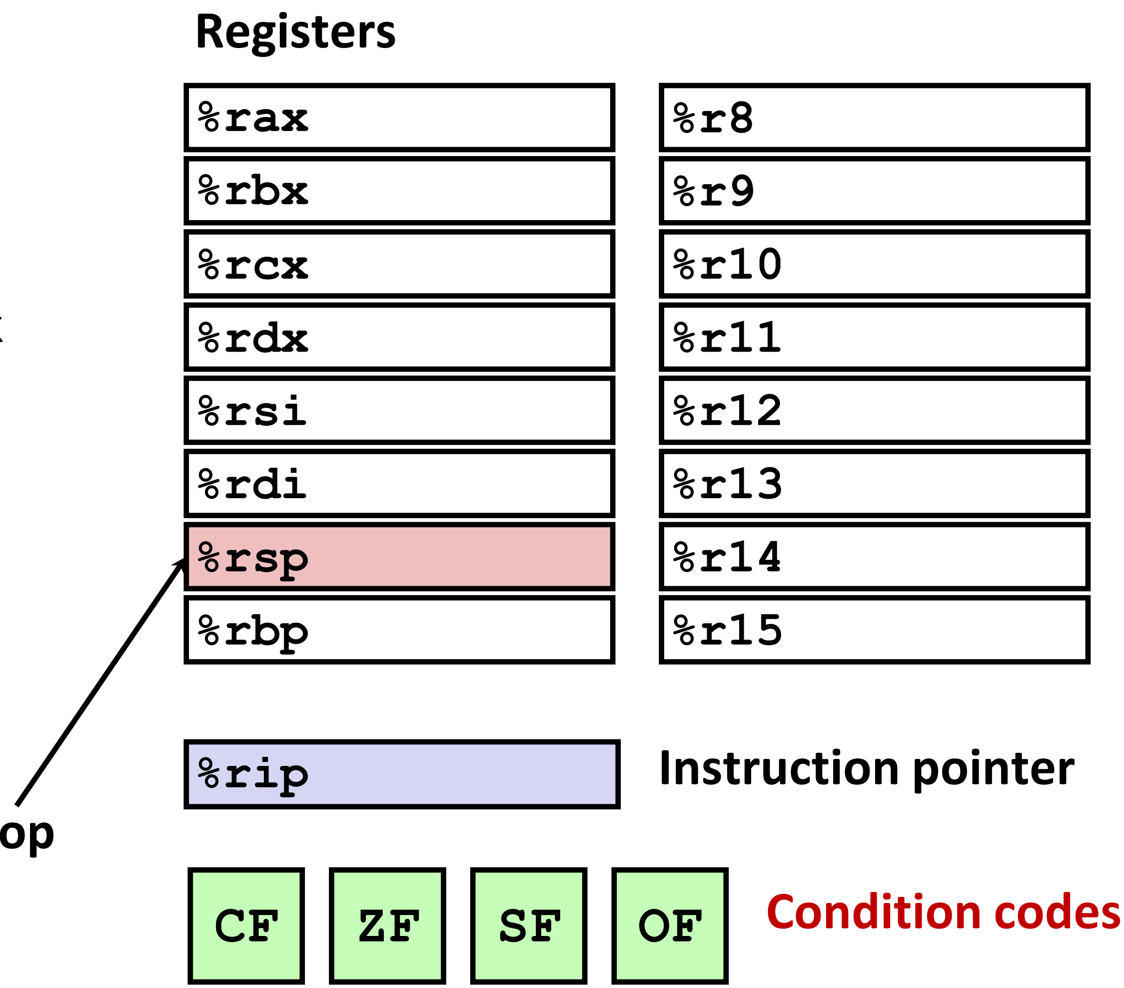
void decision(int x) {
    if (x) {
        op1();
    } else {
        op2();
    }
}
```

```
decision:
        subq    $8, %rsp
        testl   %edi, %edi
        je      .L2
        call    op1
        jmp     .L1
.L2:
        call    op2
.L1:
        addq    $8, %rsp
        ret
```

It's all done with GOTO!

Processor State (x86-64, Partial)

- **Information about currently executing program**
  - Temporary data (**`%rax`**, …)
  - Location of runtime stack (**`%rsp`**)
  - Location of current code control point (**`%rip`**, …)
  - Status of recent tests (**CF, ZF, SF, OF**)



Condition Codes (Implicit Setting)

- **Single bit registers**
  - **CF** Carry Flag (for unsigned) **SF** Sign Flag (for signed)
  - **ZF** Zero Flag **OF** Overflow Flag (for signed)
  - **GDB prints these as one "eflags" register**

    `eflags 0x246 [ PF ZF IF ]` *Z set, CSO clear*
- **Implicitly set (as side effect) of arithmetic operations**

  Example: **`addq`** *Src,Dest* ↔ `t = a+b`

  CF set if carry out from most significant bit (unsigned overflow)

  ZF set if `t == 0`

  SF set if `t < 0` (as signed)

  OF set if two's-complement (signed) overflow

  `(a>0 && b>0 && t<0) || (a<0 && b<0 && t>=0)`
- **Not set by `leaq` instruction**

ZF set when

000000000000…00000000000

SF set when

1xxxxxxxxxxx…xxxxxxxxxxxx

CF set when

```
      1xxxxxxxxxxxxx...
 +    1xxxxxxxxxxxxx...
 ------------------------
   1  xxxxxxxxxxxxxx...
```

Carry

```
   1  0xxxxxxxxxxxxx...
 –    1xxxxxxxxxxxxx...
 ------------------------
      1xxxxxxxxxxxxx...
```

Borrow

For unsigned arithmetic, this reports overflow

OF set when

```
  wxxxxxxxxxxxx...
+ yxxxxxxxxxxxx...
------------------
  zxxxxxxxxxxxx...
```

$$w == y \ \&\& \ w \ != z$$

Compare Instruction

- **`cmp a, b`**
  - Computes $b - a$ (just like **`sub`**)
  - Sets condition codes based on result, but…
  - **Does not change *b***
  - Used for **`if (a < b) { … }`**
    whenever $b - a$ isn't needed for anything else

Test Instruction

- **`test a, b`**
  - Computes $b\&a$ (just like **`and`**)
  - Sets condition codes (only SF and ZF) based on result, but…
  - **Does not change *b***

  - Most common use: `test %rX, %rX`
    to compare `%rX` to zero

  - Second most common use: `test %rX, %rY`
    tests if any of the 1-bits in `%rY` are also 1 in `%rX` (or vice versa)

Today

- Review of a few tricky bits from last time
- Control: Condition codes
- **Conditional branches**
- Loops
- Switch Statements

Jumping

jX Instructions

- Jump to different part of code 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)

Reading Condition Codes

SetX Instructions

- Set low-order byte of destination to 0 or 1 based on *combinations* of condition codes
- Does not alter remaining 7 bytes

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)

x86-64 Integer Registers

`%rax`	`%al`	`%r8`	`%r8b`
`%rbx`	`%bl`	`%r9`	`%r9b`
`%rcx`	`%cl`	`%r10`	`%r10b`
`%rdx`	`%dl`	`%r11`	`%r11b`
`%rsi`	`%sil`	`%r12`	`%r12b`
`%rdi`	`%dil`	`%r13`	`%r13b`
`%rsp`	`%spl`	`%r14`	`%r14b`
`%rbp`	`%bpl`	`%r15`	`%r15b`

- SetX argument is always a low byte (%al, %r8b, etc.)

Reading Condition Codes (Cont.)

SetX Instructions:

- Set single byte based on combination of condition codes

One of addressable byte registers

- Does not alter remaining bytes
- Typically use **`movzbl`** to finish job
  - 32-bit instructions also set upper 32 bits to 0

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

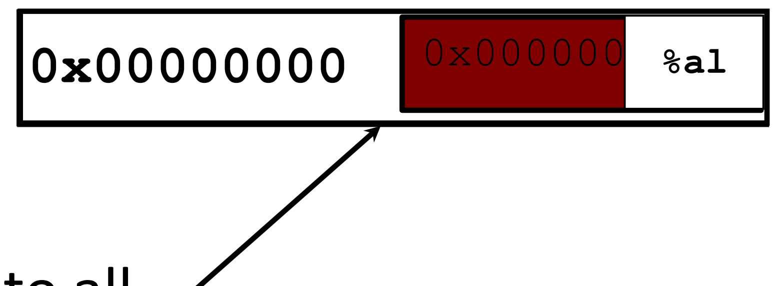
Register	Use(s)
`%rdi`	Argument **`x`**
`%rsi`	Argument **`y`**
`%rax`	Return value

```
    cmpq   %rsi, %rdi   # Compare x:y
    setg   %al          # Set when >
    movzbl %al, %eax    # Zero rest of %rax
    ret
```

Reading Condition Codes (Cont.)

Beware weirdness **movzbl** (and others)

```
movzbl %al, %eax
```



Zapped to all 0's

Use(s)
Argument **x**
Argument **y**
Return value

```
cmpq   %rsi, %rdi   # Compare x:y
setg   %al          # Set when >
movzbl %al, %eax    # Zero rest of %rax
ret
```

Activity Time!

If you didn't do at the start of class:

login to a shark machine, then type

```
wget http://www.cs.cmu.edu/~213/activities/machine-control.pdf
wget http://www.cs.cmu.edu/~213/activities/machine-control.tar
tar xf machine-control.tar
cd machine-control
```

Do parts 1 through 4 (q1-6) now, then stop.

Conditional Branch Example (Old Style)

- **Generation**

```
shark> gcc –Og -S –fno-if-conversion cont
```

I'll get to this shortly.

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

```
absdiff:
   cmpq    %rsi, %rdi   # x:y
   jle     .L4
   movq    %rdi, %rax
   subq    %rsi, %rax
   ret
.L4:               # x <= y
   movq    %rsi, %rax
   subq    %rdi, %rax
   ret
```

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

Expressing with Goto Code

- C allows `goto` statement
- Jump to position designated by label

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

```
long absdiff_j
  (long x, long y)
{
    long result;
    int ntest = x <= y;
    if (ntest) goto Else;
    result = x-y;
    goto Done;
 Else:
    result = y-x;
 Done:
    return result;
}
```

General Conditional Expression Translation (Using Branches)

C Code

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

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

Goto Version

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

- Create separate code regions for then & else expressions
- Execute appropriate one

Using Conditional Moves

Conditional Move Instructions

- Instruction supports:

  if (Test) Dest ← Src
- Supported in post-1995 x86 processors
- GCC tries to use them
  - But, only when known to be safe

Why?

- Branches are very disruptive to instruction flow through pipelines
- Conditional moves do not require control transfer

C Code

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

Goto Version

```
  result = Then_Expr;
  eval = Else_Expr;
  nt = !Test;
  if (nt) result = eval;
  return result;
```

Conditional Move Example

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

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

```
absdiff:
   movq     %rdi, %rax   # x
   subq     %rsi, %rax   # result = x-y
   movq     %rsi, %rdx
   subq     %rdi, %rdx   # eval = y-x
   cmpq     %rsi, %rdi   # x:y
   cmovle   %rdx, %rax   # if <=, result = eval
   ret
```

Bad Cases for Conditional Move

Expensive Computations

```
val = Test(x) ? Hard1(x) : Hard2(x);
```

Bad Performance

- Both values get computed
- Only makes sense when computations are very simple

Risky Computations

```
val = p ? *p : 0;
```

- Both values get computed
- May have undesirable effects

Unsafe

Computations with side effects

```
val = x > 0 ? x*=7 : x+=3;
```

Illegal

- Both values get computed
- Must be side-effect free

Today

- Review of a few tricky bits from last time
- Control: Condition codes
- Conditional branches
- **Loops**
- Switch Statements

"Do-While" Loop Example

C Code

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

Goto Version

```
long pcount_goto
  (unsigned long x) {
  long 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 to either continue looping or to exit loop

"Do-While" Loop Compilation

Goto Version

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

Register	Use(s)
%rdi	Argument **x**
%rax	**result**

```
    movl    $0, %eax          #  result = 0
    .L2:                      # loop:
       movq    %rdi, %rdx
       andl    $1, %edx       #  t = x & 0x1
       addq    %rdx, %rax     #  result += t
       shrq    %rdi           #  x >>= 1
       jne     .L2            #  if (x) goto
    loop
       rep; ret
```

General "Do-While" Translation

C Code

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

Goto Version

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

- **Body:**

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

General "While" Translation #1

- "Jump-to-middle" translation
- Used with `-Og`

While version

```
while (Test)
  Body
```

Goto Version

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

While Loop Example #1

C Code

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

Jump to Middle

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

- Compare to do-while version of function
- Initial goto starts loop at test

General "While" Translation #2

While version

```
while (Test)
  Body
```

Do-While Version

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

- "Do-while" conversion
- Used with –O1

Goto Version

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

While Loop Example #2

C Code

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

Do-While Version

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

- Compare to do-while version of function
- Initial conditional guards entrance to loop

"For" Loop → Do-While Loop

For version

```
for (Init; Test; Update )

    Body
```

- Initial test can often be optimized away – **why?**

Do-While Version

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

Goto Version

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

"For" Loop Do-While Conversion

C Code

```
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;
}
```

- Initial test can be optimized away

Goto Version

```
long pcount_for_goto_dw
  (unsigned long x) {
  size_t i;
  long result = 0;
  i = 0;                          Ini
  if (!(i < WSIZE))               !Test
    goto done;
 loop:
  {
    unsigned bit =
      (x >> i) & 0x1;             Body
    result += bit;
  }
  i++;                            Update
  if (i < WSIZE)                  Test
    goto loop;
 done:
  return result;
}
```

Activity Time!

Do parts 5-6 (q7-11) now, then stop.

Also, take the canvas quiz for Day 4: Machine Control.

Today

- Review of a few tricky bits from last time
- Control: Condition codes
- Conditional branches
- Loops
- **Switch Statements (time permitting)**

```
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;
}
```

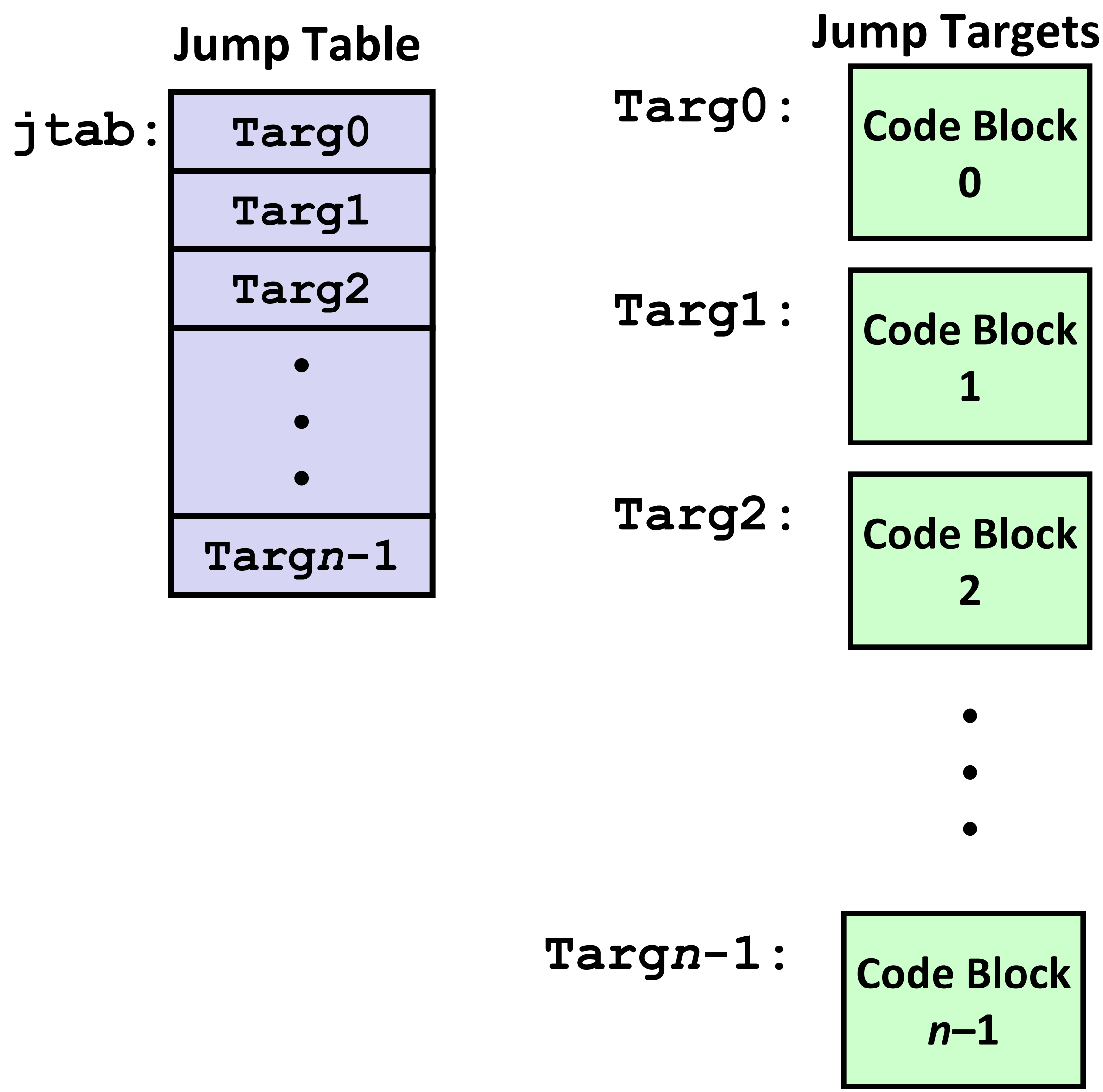
Switch Statement Example

- **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];
```

Switch Statement Example

```
long my_switch
   (long x, long y, long z)
{
    long w = 1;
    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;
    }
    return w;
}
```

```
my_switch:
    cmpq    $6, %rdi    # x:6
    ja      .L8    # if x > 6 jump
                   # to default
    jmp     *.L4(,%rdi,8)
```

```
.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
```

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 $0 \leq x \leq 6$

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
```

Code Blocks (x == 1)

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

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

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

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
   cqto
   idivq   %rcx         #  y/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
   movl   $1, %eax       #  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

Finding Jump Table in Binary

```
 00000000004005e0 <switch_eg>:
4005e0:       48 89 d1                mov    %rdx,%rcx
4005e3:       48 83 ff 06             cmp    $0x6,%rdi
4005e7:       77 2b                   ja     400614 <switch_eg+0x34>
4005e9:       ff 24 fd f0 07 40 00    jmpq   *0x4007f0(,%rdi,8)
4005f0:       48 89 f0                mov    %rsi,%rax
4005f3:       48 0f af c2             imul   %rdx,%rax
4005f7:       c3                      retq
4005f8:       48 89 f0                mov    %rsi,%rax
4005fb:       48 99                   cqto
4005fd:       48 f7 f9                idiv   %rcx
400600:       eb 05                   jmp    400607 <switch_eg+0x27>
400602:       b8 01 00 00 00          mov    $0x1,%eax
400607:       48 01 c8                add    %rcx,%rax
40060a:       c3                      retq
40060b:       b8 01 00 00 00          mov    $0x1,%eax
400610:       48 29 d0                sub    %rdx,%rax
400613:       c3                      retq
400614:       b8 02 00 00 00          mov    $0x2,%eax
400619:       c3                      retq
```

Finding Jump Table in Binary

```
 00000000004005e0 <switch_eg>:
. . .
4005e9:       ff 24 fd f0 07 40 00    jmpq   *0x4007f0(,%rdi,8)
. . .
```

```
 % gdb switch
(gdb) x /8xg 0x4007f0
0x4007f0:       0x0000000000400614      0x00000000004005f0
0x400800:       0x00000000004005f8      0x0000000000400602
0x400810:       0x0000000000400614      0x000000000040060b
0x400820:       0x000000000040060b      0x2c646c25203d2078
(gdb)
```

Activity Time!

Do part 7 (q12) now, then go home ☺