Machine-Level Programming II: Control

15-213: Introduction to Computer Systems
6th Lecture, May 26, 2022

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Today

- **Review of a few tricky bits from yesterday**
- Basics of control flow
- Condition codes
- Conditional operations
- Loops
- Activity: understanding disassembled control flow
- If we have time: switch statements

Reminder: Machine Instructions

```
*dest = t;
```

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

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

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

Reminder: Machine Instructions

```
*dest = t;
```

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

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

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

    `t:` Register **`%rax`**

    `dest:` Register **`%rbx`**

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

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

```
0100 1 0 0 0  10001011  00 000 011
REX  W R X B    Move    Mod  R   M
```

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

Reminder: Address 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 (*why these numbers?*)

Special Cases

(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

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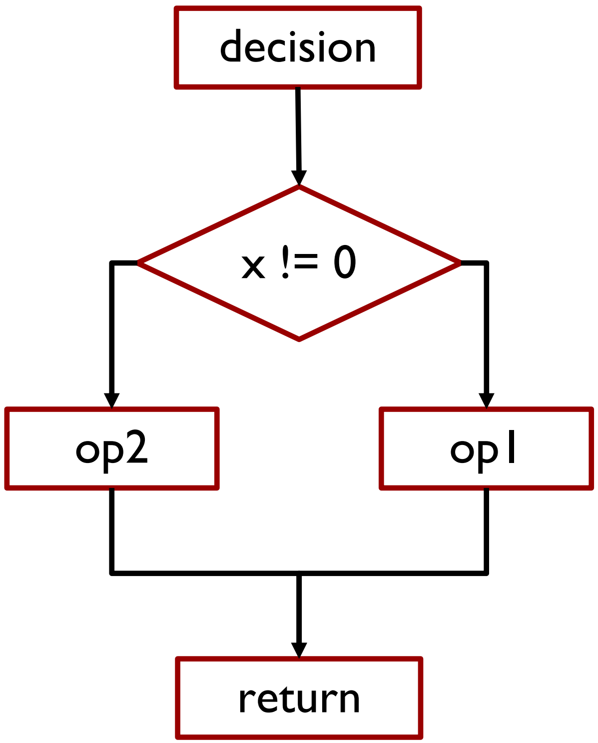
Control flow

```
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);

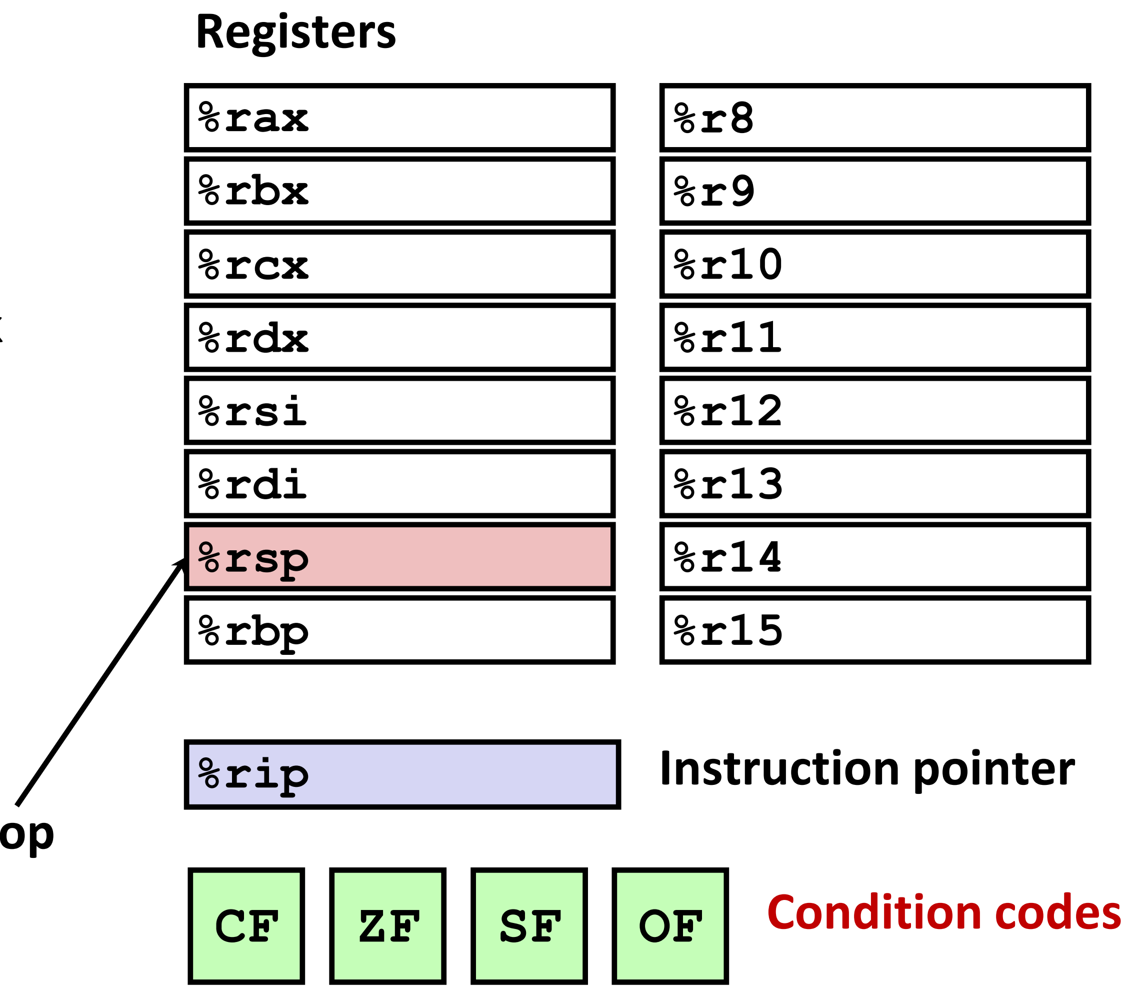
void decision(int x) {
    if (x) {
        op1();
    } else {
        op2();
    }
}
```

```
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)

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...xxxxxxxxxxx
```

CF set when

```
   yxxxxxxxxxxxx...
+  yxxxxxxxxxxxx...
-------------------
1  zxxxxxxxxxxxx...
```

OF set when

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

z != y

Compare Instruction

- **`cmp b, a`**
  - 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 $b \wedge a$ (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)

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- Condition codes
- **Conditional operations**
- Loops
- Activity: understanding disassembled control flow
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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`

- Can reference low-order byte

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;
}
```

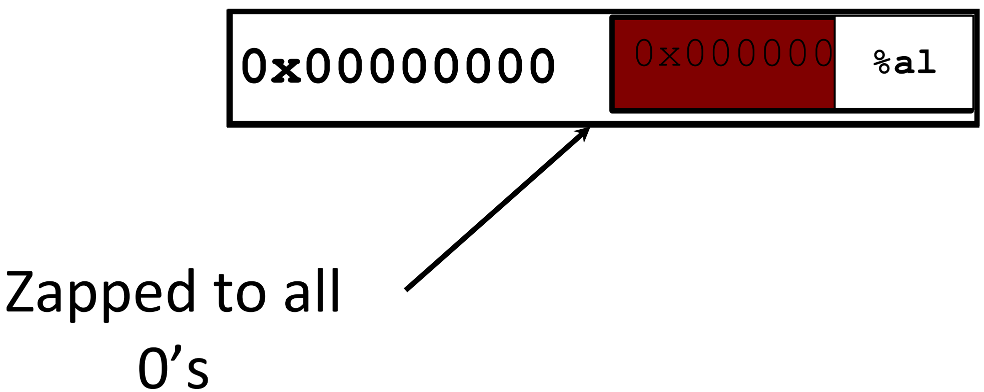
Register	Use(s)
`%rdi`	Argument **`x`**
`%rsi`	Argument **`y`**
`%rax`	Return value

```
        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
```



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
```

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)

Conditional Branch Example (Old Style)

I'll get to this shortly.

- **Generation**

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

```
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);
```

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

Bad Performance

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;
```

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

Illegal

Exercise

SetX	Condition	Description
`sete`	`ZF`	Equal / Zero
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`setle`	`(SF^OF)|ZF`	Less or Equal (Signed)
`seta`	`~CF&~ZF`	Above (unsigned)
`setb`	`CF`	Below (unsigned)

- **`cmpq b,a`** like computing **`a-b`** without setting destination

- **CF set** if carry out from most significant bit (used for unsigned comparisons)
- **ZF set** if **`a == b`**
- **SF set** if **`(a-b) < 0`** (as signed)
- **OF set** if two's-complement (signed) overflow

`(a>0 && b<0 && (a-b)<0) || (a<0 && b>0 && (a-b)>0)`

```
xor    %rax, %rax
sub    $1, %rax
cmp    $2, %rax
setl   %al
movzbl %al, %eax
```

%rax	SF	CF	OF	ZF

Exercise

SetX	Condition	Description
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`sets`	`SF`	Negative
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`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)

- `cmpq b,a` like computing `a-b` without setting destination

- **CF set** if carry out from most significant bit (used for unsigned comparisons)
- **ZF set** if `a == b`
- **SF set** if `(a-b) < 0` (as signed)
- **OF set** if two's-complement (signed) overflow

`(a>0 && b<0 && (a-b)<0) || (a<0 && b>0 && (a-b)>0)`

```
xor    %rax, %rax
sub    $1, %rax
cmp    $2, %rax
setl   %al
movzbl %al, %eax
```

`%rax`	SF	CF	OF	ZF
0x0000 0000 0000 0000	0	0	0	1
0xFFFF FFFF FFFF FFFF	1	1	0	0
0xFFFF FFFF FFFF FFFF	1	0	0	0
0xFFFF FFFF FFFF FF01	1	0	0	0
0x0000 0000 0000 0001	1	0	0	0

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- Review of a few tricky bits from yesterday
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- **Loops**
- Activity: understanding disassembled control flow
- If we have time: 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
```

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" conversion
- Used with –O1

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:
```

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 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;
}
```

"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;
}
```

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;
}
```

- Initial test can be optimized away

Today

- Review of a few tricky bits from yesterday
- Basics of control flow
- Condition codes
- Conditional operations
- Loops
- **Activity: understanding disassembled control flow**
- If we have time: switch statements

https://www.cs.cmu.edu/~213/activities/213_lecture6.pdf

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- Review of a few tricky bits from yesterday
- Basics of control flow
- Condition codes
- Conditional operations
- Loops
- Activity: understanding disassembled control flow
- **If we have time: switch statements**

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
}
```

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
```

Translation (Extended C)

```
goto *JTab[x];
```

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
    ja      .L8
    jmp     *.L4(,%rdi,8)
```

What range of values takes default?

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

Note that **`w`** 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
    ja      .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 $0 \leq x \leq 6$

Jump table

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.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   # 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 (cont.)

```
 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)
```

Finding Jump Table in Binary (cont.)

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

```
  . . .
  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
```