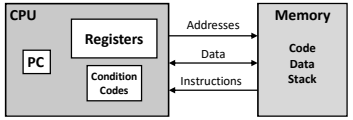
Machine-Level Programming II: Control

15-213: Introduction to Computer Systems
6th Lecture, Sept. 13, 2018

Today

- **Control: Condition codes**
- **Conditional branches**
- **Loops**
- **Switch Statements**

Recall: ISA = Assembly/Machine Code View

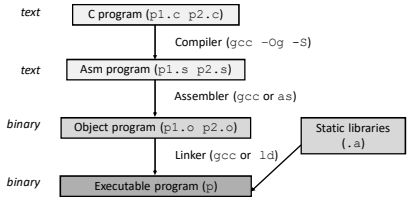


Programmer-Visible State
- **PC: Program counter**
  - Address of next instruction
- **Register file**
  - Heavily used program data
- **Condition codes**
  - Store status information about most recent arithmetic or logical operation
  - Used for conditional branching

- **Memory**
  - Byte addressable array
  - Code and user data
  - Stack to support procedures

Recall: Turning C into Object Code

- Code in files `p1.c p2.c`
- Compile with command: `gcc –Og p1.c p2.c -o p`
  - Use basic optimizations (`–Og`) [New to recent versions of GCC]
  - Put resulting binary in file `p`



Recall: Move & Arithmetic Operations

- **Some Two Operand Instructions:**

Format	*Computation*		
`movq`	*Src,Dest*	Dest = Src (Src can be $const)	
`leaq`	*Src,Dest*	Dest = address computed by expression Src	
`addq`	*Src,Dest*	Dest = Dest + Src	
`subq`	*Src,Dest*	Dest = Dest – Src	
`imulq`	*Src,Dest*	Dest = Dest * Src	
`salq`	*Src,Dest*	Dest = Dest << Src	***Also called shlq***
`sarq`	*Src,Dest*	Dest = Dest >> Src	***Arithmetic***
`shrq`	*Src,Dest*	Dest = Dest >> Src	***Logical***
`xorq`	*Src,Dest*	Dest = Dest ^ Src	
`andq`	*Src,Dest*	Dest = Dest & Src	
`orq`	*Src,Dest*	Dest = Dest | Src	

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**

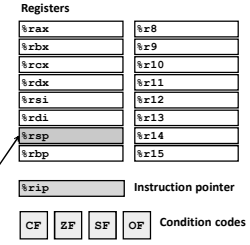
  (Rb,Ri) **Mem[Reg[Rb]+Reg[Ri]]**

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

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

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)
  - **ZF** Zero Flag
  - **SF** Sign Flag (for signed)
  - **OF** Overflow Flag (for signed)

- **Implicitly set (as side effect) of arithmetic operations**

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

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

  ZF set if `t == 0`

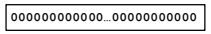
  SF set if `t < 0` (as signed)

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

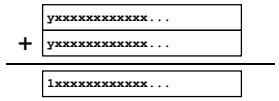
  `(a>0 && b>0 && t<0) || (a<0 && b<0 && t>=0)`

- **Not set by `leaq` instruction**

ZF set when

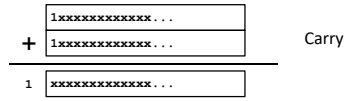


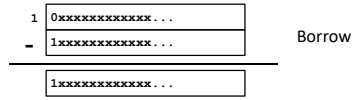
SF set when



For signed arithmetic, this reports when result is a negative number

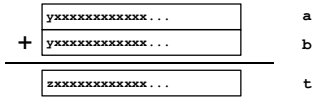
CF set when





For unsigned arithmetic, this reports overflow

OF set when



z = ~y

```
(a>0 && b>0 && t<0) || (a<0 && b<0 && t>=0)
```

For signed arithmetic, this reports overflow

Condition Codes (Explicit Setting: Compare)

- **Explicit Setting by Compare Instruction**
  - **`cmpq`** *Src2, Src1*
  - **`cmpq b,a`** like computing **`a-b`** without setting destination
  - **CF set** if carry/borrow 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)`

Condition Codes (Explicit Setting: Test)

- **Explicit Setting by Test instruction**
  - **`testq`** *Src2, Src1*
    - **`testq b,a`** like computing **`a&b`** without setting destination
  - Sets condition codes based on value of *Src1* & *Src2*
  - Useful to have one of the operands be a mask
  - **ZF set** when **`a&b == 0`**
  - **SF set** when **`a&b < 0`**

Very often:
`testq %rax,%rax`

Condition Codes (Explicit Reading: Set)

- **Explicit Reading by Set Instructions**
  - **`setX`** *Dest*: Set low-order byte of destination *Dest* to 0 or 1 based on combinations of condition codes
  - Does not alter remaining 7 bytes of *Dest*

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

Explicit 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;
}
```

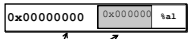
Register	Use(s)
`%rdi`	Argument **`x`**
`%rsi`	Argument **`y`**
`%rax`	Return value

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

Explicit 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
```


Today

- **Control: Condition codes**
- **Conditional branches**
- **Loops**
- **Switch Statements**

Jumping

- **jX Instructions**
  - Jump to different part of code depending on condition codes
  - Implicit reading of 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)

- **Generation**

Get to this shortly

```
shark> gcc –Og –S –fno-if-conversion control.c
```

```
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

When is this bad?

```
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;
```

Unsafe

- **Both values get computed**
- **May have undesirable effects**

Computations with side effects

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

Illegal

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

Exercise

`cmpq b,a` like computing a-b w/o setting dest

- CF set if carry/borrow 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

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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)

```
xorq    %rax, %rax
subq    $1, %rax
cmpq    $2, %rax
setl    %al
movzblq %al, %eax
```

%rax	SF	CF	OF	ZF

Note: `setl` and `movzblq` do not modify condition codes

Exercise

`cmpq b,a` like computing a-b w/o setting dest

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setl	SF^OF	Less (signed)
setle	(SF^OF)|ZF	Less or Equal (signed)
seta	~CF&~ZF	Above (unsigned)
setb	CF	Below (unsigned)

```
xorq    %rax, %rax
subq    $1, %rax
cmpq    $2, %rax
setl    %al
movzblq %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

Note: `setl` and `movzblq` do not modify condition codes

Today

- 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

```
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
```


Quiz Time!

Check out:

https://canvas.cmu.edu/courses/5835

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;
}
```

- Initial conditional guards entrance to loop
- Compare to do-while version of function
  - Removes jump to middle. When is this good or bad?

"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;                          Init
  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

- Control: Condition codes
- Conditional branches
- Loops
- Switch Statements


```
long my_switch
    (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
}
```

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

Setup

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

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

What range of values takes default?

Note that **w** not initialized here

Switch Statement Example

```
long my_switch(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

```
my_switch:
    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 $0 \le x \le 6$

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  # 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                # sign extend
                        # rax to rdx:rax
    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**
%rcx	**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

Summarizing

- **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
- **Standard Techniques**
  - Loops converted to do-while or jump-to-middle form
  - Large switch statements use jump tables
  - Sparse switch statements may use decision trees (if-elseif-elseif-else)

Summary

- **Today**
  - Control: Condition codes
  - Conditional branches & conditional moves
  - Loops
  - Switch statements
- **Next Time**
  - Stack
  - Call / return
  - Procedure call discipline

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
(gdb)
```

```
  . . .
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
```