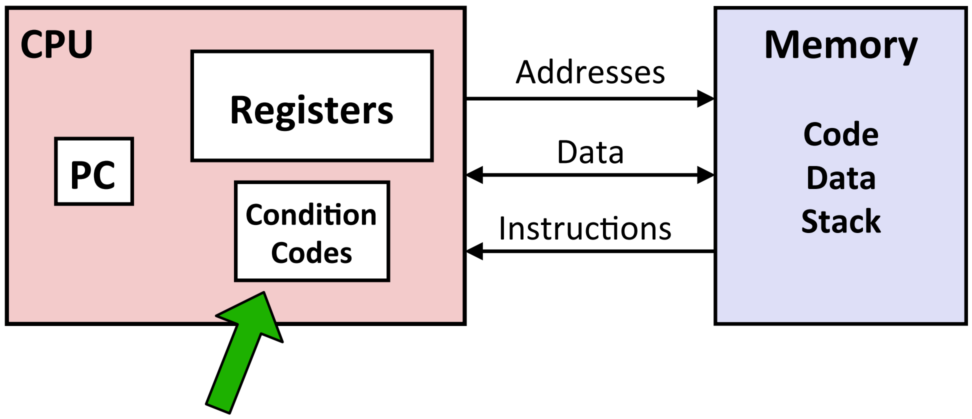
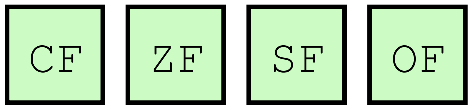
Machine Code: Control Flow



Condition Codes



Condition codes

CF:	**Carry flag**	(set if carry-out bit = 1)
ZF:	**Zero flag**	(set if result = 0)
SF:	**Sign flag**	(set if result top bit = 1)
OF:	**Overflow flag**	(set if signed overflow)

Setting CCs

(1) **`cmpq a,b`** (set based on **`b - a`**)

(2) **`testq a,b`** (set based on **`a & b`**)

(3) arithmetic insts (implicit, all except **`leaq`**)

Reading Condition Codes

SetX	Condition	Description
sete/setz	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)

Example: Greater Than

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

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

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

Goto in C

label

```
#include <stdio.h>

int main() {

    int a = 0;

    FOO:
    while (a < 20) {

        if (a == 15) {
          a++;
          goto FOO;
        }

        printf("%d\n", a);
        a++;

    }

    return 0;
}
```

Jumping

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)

Example: absdiff

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

```
                   y      x
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

absdiff with Goto

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

```
                   y      x
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

Conditional to Goto

Conditional Version

```
if (test)
    then-cmd
else
    else-cmd
...
```

Goto Version

```
    t = test;
    if (!t) goto false;
    then-cmd
    goto done;
false:
    else-cmd
done:
    ...
```

Do-While Loops

C Code

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

Goto Version

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

Do-While Loop Compilation

Goto Version

```
long loop_goto
    (unsigned long x) {
  long result = 0;
 loop:
  result += x & 0x1;
  x = 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 = x >> 1
        jnz     .L2          #  if (x) goto loop
        ret
```

While Loops: Jump to Middle

While Version

```
while (test)
  Body
...
```

Goto Version

```
  goto middle;
loop:
  Body
middle:
  t = test;
  if (t) goto loop;
done:
  ...
```

While Loops: Guarded Do

While Version

```
while (test)
  Body
...
```

Do-While Version

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

Goto Version

```
  t = test;
  if (!t) goto done;
loop:
  Body
  t = test;
  if (t) goto loop;
done:
```

While Loop Example

C Code

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

Jump to Middle

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

Guarded Do

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

Guarded Do Optimization

C Code

```
int x = 0;
while (x < 5) {
    print(x);
    x++;
}
```

Guarded Do

```
  int x = 0;
  if (x >= 5) goto done;
loop:
  print(x);
  x++;
  if (x < 5) goto loop;
done:
  ...
```

For Loops

```
for (init; test; update) {
    body
}
```

```
init
while (test) {
    body
    update
}
```

BitBombs!

Parsing Input in C

```
int things_read; // numbers of "objects" read by scanf

int i;     // declared but uninitialized
char c;

// read an int from user, store it at address &i
things_read = scanf(“%d”, &i);

// read an int and a char, store at addresses &i and &c
things_read = scanf(“%d %c”, &i, &c);

// sscanf variant: read from string instead of user input
things_read = sscanf(some_str, "%d %c", &i, &c);
```

Switch Statements

```c
void print_digit(int digit) {
  switch (digit) {
    case 0:
      printf(“zero\n”);
      break;
    case 1:
      printf(“one\n”);
      break;
    case 2:
      printf(“two\n”);
      break;
    case 3:
      printf(“three\n”);
      break;
    ...
    case 9:
      printf(“nine\n”);
      break;
    default:
      printf(“not a digit\n”);
      break;
  }
}
```

Switch Fall Through

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

No break (fall through)

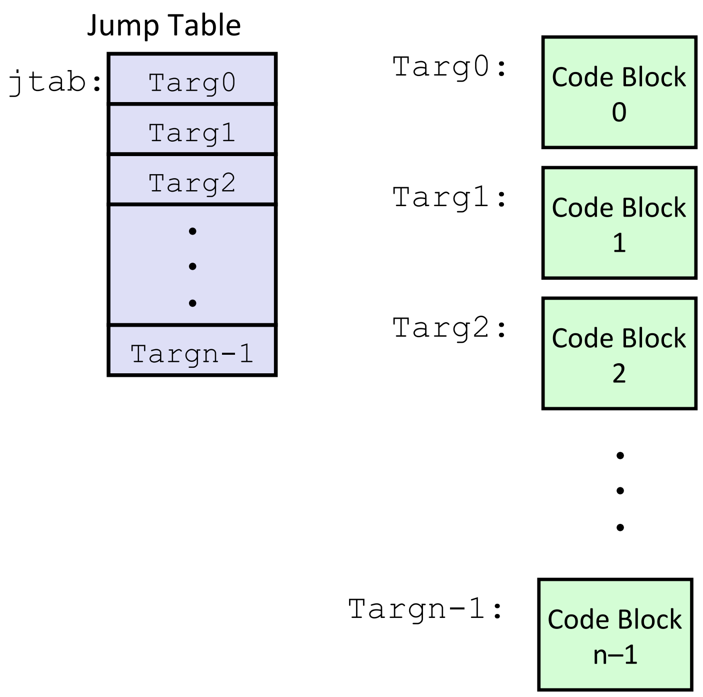
No case 4 (default)

Fall through (case 5 same as 6)

Jump Tables

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 Example

```
long switch_example
    (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;
}
```

Jump Table

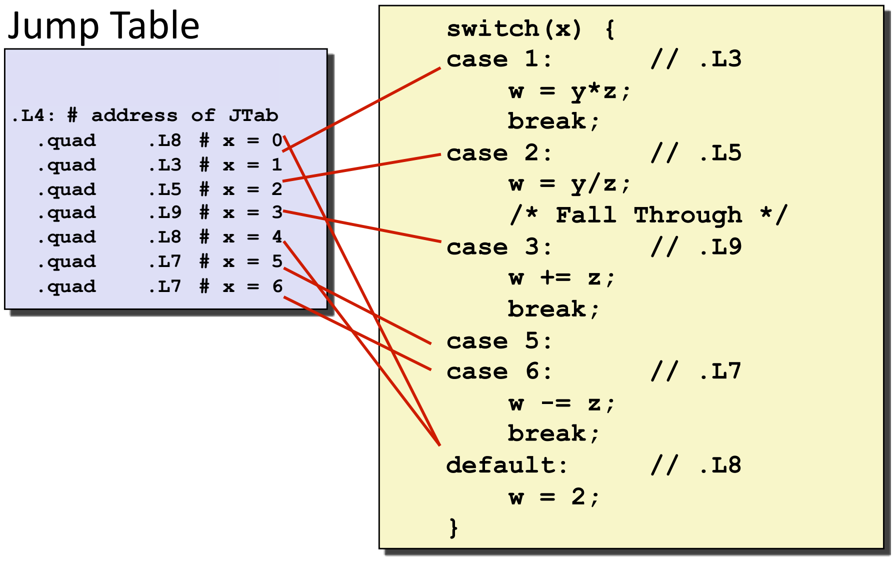
```
.L4: # address of JTab
   .quad   .L8   # x = 0
   .quad   .L3   # x = 1
   .quad   .L5   # x = 2
   .quad   .L9   # x = 3
   .quad   .L8   # x = 4
   .quad   .L7   # x = 5
   .quad   .L7   # x = 6
```

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

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

Indirect jump

Example Jump Table



Jump Table

```
.L4: # address of JTab
   .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

```
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;
```

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

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

```
.L3:                         # Case 1
   movq     %rsi, %rax       # y
   imulq    %rdx, %rax       # y*z
   ret
.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
.L7:                         # Case 5,6
  movl   $1, %eax            #  w = 1
  subq   %rdx, %rax          #  w -= z
  ret
.L8:                         # Default:
  movl   $2, %eax            #  2
  ret
```