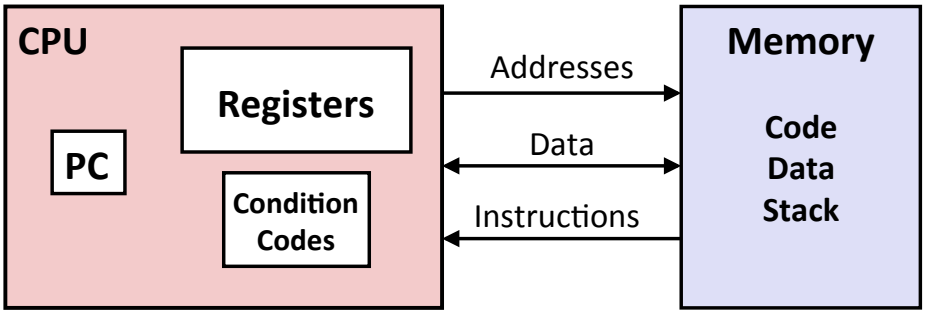
Recap: Assembly View of the Machine



Condition Codes

CF	ZF	SF	OF

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)

Reading Condition Codes

SetX	Condition	Description
`sete`	`ZF`	Equal / Zero (also `setz`)
`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

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

Goto in C

```
#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;
}
```

```
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

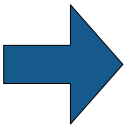
absdiff with Goto

```
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
```

```
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;
}
```

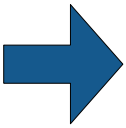
Conditional to Goto

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



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

```
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
```


Bitbombs!

Input in C with scanf

```
int things_read; // numbers of things 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);
```

```
int i;     // declared but uninitialized

...

scanf("%d", i); // DANGER!!!
```


Do-While Loops

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;
}
```

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
```


While Loops: Jump-to-Middle

While version

```
while (Test)
  Body
```

Goto Version

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

Jump-to-Middle Example

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;
}
```


While Loops: Guarded Do

While version

```
while (Test)
  Body
```

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:
```

Guarded Do Example

C Code

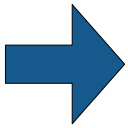
```
long pcount_while
  (unsigned long x) {
  long result = 0;
  while (x) {
    result += x & 0x1;
    x >>= 1;
  }
  return result;
}
```

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;
}
```


Guarded Do Optimization

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



```
  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
}
```


Switch Statements

```
void print_grade_range(char letter_grade) {
  switch (letter_grade) {
    case 'A':
      printf("90-100\n");
      break;
    case 'B':
      printf("80-89\n");
      break;
    case 'C':
      printf("70-79\n");
      break;
    case 'D':
      printf("60-79\n");
      break;
    case 'F':
      printf("0-59\n");
      break;
    default:
      printf("Invalid grade\n");
      break;
  }
}
```

Switch Fall Through

```
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;
}
```


Jump Tables

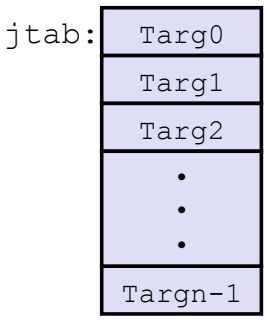
Switch Form

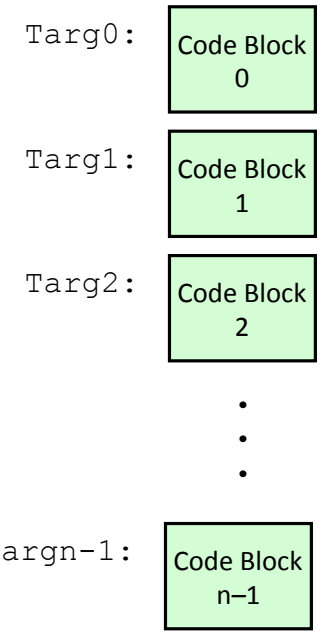
```
switch(x) {
  case val_0:
    Block 0
  case val_1:
    Block 1
    • • •
  case val_n-1:
    Block n–1
}
```

Translation (Extended C)

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

Jump Table





Switch 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;
}
```

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
```

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

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


Example 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

```
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_eg:
    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
```


Procedure Call Registers

Return	%rax	%eax	%r8	%r8d	Arg 5
	%rbx	%ebx	%r9	%r9d	Arg 6
Arg 4	%rcx	%ecx	%r10	%r10d	
Arg 3	%rdx	%edx	%r11	%r11d	
Arg 2	%rsi	%esi	%r12	%r12d	
Arg 1	%rdi	%edi	%r13	%r13d	
Stack ptr	%rsp	%esp	%r14	%r14d	
	%rbp	%ebp	%r15	%r15d	