Homework 0: 2.84

- Given: k-bit exponent, n-bit fraction
- Find:
  - Exponent E,
  - Significand M,
  - Fraction f,
  - Value V,
  - Bit representation

Homework 0: 2.84

- Given: k-bit exponent, n-bit fraction
- 7.0: $0111 = 1.11 \times 2^2$
  - Exponent E = 2
  - Significand M = 1.11
  - Fraction f = 0.11
  - Value V = 7
  - Bit representation
    - $E = 2 = e - \text{Bias} = e - (2^{k-1} - 1)$
    - $e = 2 + 2^{k-1} - 1 = 1 + 2^{k-1} = 0\ldots01 + 10\ldots0 = 10\ldots..01$
    - f = 110….

Homework 0: 2.84

- Given: k-bit exponent, n-bit fraction
- Largest odd int: n+1 1's (to represent exactly)
  - Exponent E = n
  - Significand M = 1.11….1
  - Fraction f = 0.1111….
  - Value V = n+1 1's = 2^{n+1}-1
  - Bit representation
    - E = n = e - Bias = e – (2^{k-1} – 1)
    - e = n + 2^{k-1} - 1
    - f = 1…1

Condition Codes (Explicit Setting: Compare)

- Explicit Setting by Compare Instruction

  `cmpl`/`cmpq` *Src2,Src1*

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

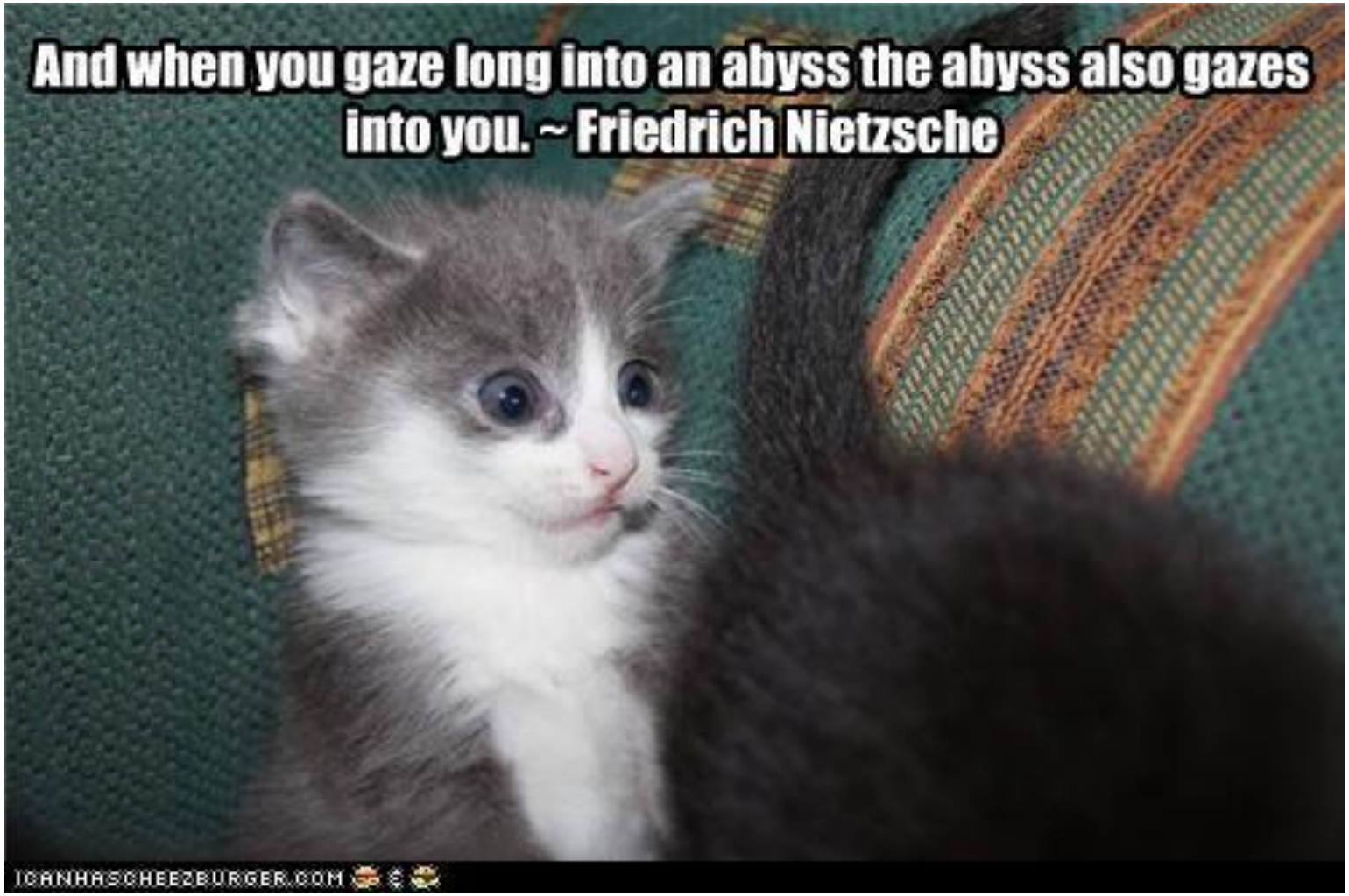
  - **CF set** if carry out from most significant bit (used for unsigned comparisons)
  - **ZF set** if **`a == b`**
  - **SF set** if **`(a-b) < 0`** (as signed)
  - **OF set** if two's complement (signed) overflow
    `(a>0 && b<0 && (a-b)<0) || (a<0 && b>0 && (a-b)>0)`

Reading Condition Codes

- SetX Instructions
  - Set single byte based on combinations of condition codes

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)

Let’s Work Through an Example



Reading Condition Codes (Cont.)

- SetX Instructions:
  Set single byte based on combination of condition codes
- One of 8 addressable byte registers
  - Does not alter remaining 3 bytes
  - Typically use **`movzbl`** to finish job

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

%eax	%ah	%al
%ecx	%ch	%cl
%edx	%dh	%dl
%ebx	%bh	%bl
%esi		
%edi		
%esp		
%ebp		

Body

```
movl 12(%ebp),%eax
cmpl %eax,8(%ebp)
setg %al
movzbl %al,%eax
```

Reading Condition Codes (Cont.)

- SetX Instructions:
  Set single byte based on combination of condition codes
- One of 8 addressable byte registers
  - Does not alter remaining 3 bytes
  - Typically use **`movzbl`** to finish job

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

%eax	%ah	%al
%ecx	%ch	%cl
%edx	%dh	%dl
%ebx	%bh	%bl
%esi		
%edi		
%esp		
%ebp		

Body

```
movl 12(%ebp),%eax      # eax = y
cmpl %eax,8(%ebp)       # Compare x and y
setg %al                # al = x > y
movzbl %al,%eax         # Zero rest of %eax
```

Note inverted ordering!

Conditional Branch Example

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

```
absdiff:
    pushl   %ebp                    } Setup
    movl    %esp, %ebp
    movl    8(%ebp), %edx           } Body1
    movl    12(%ebp), %eax
    cmpl    %eax, %edx
    jle     .L7
    subl    %eax, %edx
    movl    %edx, %eax
.L8:
    leave                           } Finish
    ret
.L7:
    subl    %edx, %eax              } Body2
    jmp     .L8
```

Conditional Branch Example (Cont.)

```
int goto_ad(int x, int y)
{
  int result;
  if (x <= y) goto Else;
  result = x-y;
Exit:
  return result;
Else:
  result = y-x;
  goto Exit;
}
```

```
absdiff:
    pushl   %ebp
    movl    %esp, %ebp
    movl    8(%ebp), %edx
    movl    12(%ebp), %eax
    cmpl    %eax, %edx
    jle     .L7
    subl    %eax, %edx
    movl    %edx, %eax
.L8:
    leave
    ret
.L7:
    subl    %edx, %eax
    jmp     .L8
```

- C allows “goto” as means of transferring control
  - Closer to machine-level programming style
- Generally considered bad coding style

Conditional Branch Example (Cont.)

```
int goto_ad(int x, int y)
{
  int result;
  if (x <= y) goto Else;
  result = x-y;
Exit:
  return result;
Else:
  result = y-x;
  goto Exit;
}
```

```
absdiff:
    pushl   %ebp
    movl    %esp, %ebp
    movl    8(%ebp), %edx
    movl    12(%ebp), %eax
    cmpl    %eax, %edx
    jle     .L7
    subl    %eax, %edx
    movl    %edx, %eax
.L8:
    leave
    ret
.L7:
    subl    %edx, %eax
    jmp     .L8
```

Conditional Branch Example (Cont.)

```
int goto_ad(int x, int y)
{
  int result;
  if (x <= y) goto Else;
  result = x-y;
Exit:
  return result;
Else:
  result = y-x;
  goto Exit;
}
```

```
absdiff:
    pushl   %ebp
    movl    %esp, %ebp
    movl    8(%ebp), %edx
    movl    12(%ebp), %eax
    cmpl    %eax, %edx
    jle     .L7
    subl    %eax, %edx
    movl    %edx, %eax
.L8:
    leave
    ret
.L7:
    subl    %edx, %eax
    jmp     .L8
```

Conditional Branch Example (Cont.)

```
int goto_ad(int x, int y)
{
  int result;
  if (x <= y) goto Else;
  result = x-y;
Exit:
  return result;
Else:
  result = y-x;
  goto Exit;
}
```

```
absdiff:
    pushl   %ebp
    movl    %esp, %ebp
    movl    8(%ebp), %edx
    movl    12(%ebp), %eax
    cmpl    %eax, %edx
    jle     .L7
    subl    %eax, %edx
    movl    %edx, %eax
.L8:
    leave
    ret
.L7:
    subl    %edx, %eax
    jmp     .L8
```

Conditional Branch Example (Cont.)

```
int goto_ad(int x, int y)
{
  int result;
  if (x <= y) goto Else;
  result = x-y;
Exit:
  return result;
Else:
  result = y-x;
  goto Exit;
}
```

```
absdiff:
    pushl   %ebp
    movl    %esp, %ebp
    movl    8(%ebp), %edx
    movl    12(%ebp), %eax
    cmpl    %eax, %edx
    jle     .L7
    subl    %eax, %edx
    movl    %edx, %eax
.L8:
    leave
    ret
.L7:
    subl    %edx, %eax
    jmp     .L8
```

General Conditional Expression Translation

C Code

```
val = Test ? Then-Expr : Else-Expr;
```

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

Goto Version

```
  nt = !Test;
  if (nt) goto Else;
  val = Then-Expr;
Done:
  . . .
Else:
  val = Else-Expr;
  goto Done;
```

- *Test* is expression returning integer
  - = 0 interpreted as false
  - ≠0 interpreted as true
- Create separate code regions for then & else expressions
- Execute appropriate one

General Form with Conditional Move

C Code

```
val = Test ? Then-Expr : Else-Expr;
```

Conditional Move Version

```
val1  = Then-Expr;
val2  = Else-Expr;
val1  = val2 if !Test;
```

- Both values get computed
- Overwrite then-value with else-value if condition doesn't hold
- Don't use when:
  - Then or else expression have side effects
  - Then and else expression are to expensive

“Do-While” Loop Example

C Code

```
int fact_do(int x)
{
  int result = 1;
  do {
    result *= x;
    x = x-1;
  } while (x > 1);

  return result;
}
```

Goto Version

```
int fact_goto(int x)
{
  int result = 1;
loop:
  result *= x;
  x = x-1;
  if (x > 1)
    goto loop;
  return result;
}
```

- Use backward branch to continue looping
- Only take branch when “while” condition holds

“Do-While” Loop Compilation

Goto Version

```
int
fact_goto(int x)
{
  int result = 1;


loop:
  result *= x;
  x = x-1;
  if (x > 1)
    goto loop;

  return result;
}
```

Assembly

```
fact_goto:
  pushl %ebp
  movl %esp,%ebp
  movl $1,%eax
  movl 8(%ebp),%edx

.L11:
  imull %edx,%eax
  decl %edx
  cmpl $1,%edx
  jg .L11

  movl %ebp,%esp
  popl %ebp
  ret
```

Registers:

%edx	**x**
%eax	**result**

“Do-While” Loop Compilation

Registers:

%edx	**x**
%eax	**result**

Goto Version

```
int
fact_goto(int x)
{
  int result = 1;


loop:
  result *= x;
  x = x-1;
  if (x > 1)
    goto loop;

  return result;
}
```

Assembly

```
fact_goto:
  pushl %ebp              # Setup
  movl %esp,%ebp          # Setup
  movl $1,%eax            # eax = 1
  movl 8(%ebp),%edx       # edx = x

.L11:
  imull %edx,%eax         # result *= x
  decl %edx               # x--
  cmpl $1,%edx            # Compare x : 1
  jg .L11                 # if > goto loop

  movl %ebp,%esp          # Finish
  popl %ebp               # Finish
  ret                     # Finish
```

General "Do-While" Translation

C Code

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

Goto Version

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

- ***Body:***

  {
  Statement$_1$;
  Statement$_2$;
  …
  Statement$_n$;
  }

- ***Test*** returns integer

  = 0 interpreted as false

  ≠0 interpreted as true

“While” Loop Example

C Code

```
int fact_while(int x)
{
  int result = 1;
  while (x > 1) {


    result *= x;
    x = x-1;
  };

  return result;
}
```

Goto Version #1

```
int fact_while_goto(int x)
{
  int result = 1;
loop:
  if (!(x > 1))
    goto done;
  result *= x;
  x = x-1;
  goto loop;
done:
  return result;
}
```

- Is this code equivalent to the do-while version?
- Must jump out of loop if test fails

Alternative "While" Loop Translation

C Code

```
int fact_while(int x)
{
  int result = 1;
  while (x > 1) {
    result *= x;
    x = x-1;
  };
  return result;
}
```

Goto Version #2

```
int fact_while_goto2(int x)
{
  int result = 1;
  if (!(x > 1))
    goto done;
loop:
  result *= x;
  x = x-1;
  if (x > 1)
    goto loop;
done:
  return result;
}
```

- Historically used by GCC
- Uses same inner loop as do-while version
- Guards loop entry with extra test

General “While” Translation

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:
```

New Style "While" Loop Translation

C Code

```
int fact_while(int x)
{
  int result = 1;
  while (x > 1) {
    result *= x;
    x = x-1;
  };
  return result;
}
```

Goto Version

```
int fact_while_goto3(int x)
{
  int result = 1;
  goto middle;
loop:
  result *= x;
  x = x-1;
middle:
  if (x > 1)
    goto loop;
  return result;
}
```

- Recent technique for GCC
  - Both IA32 & x86-64
- First iteration jumps over body computation within loop

Jump-to-Middle While Translation

C Code

```
while (Test)
  Body
```

- Avoids duplicating test code
- Unconditional `goto` incurs no performance penalty
- `for` loops compiled in similar fashion

Goto Version

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

Goto (Previous) Version

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

Jump-to-Middle Example

```
int fact_while(int x)
{
  int result = 1;
  while (x > 1) {
    result *= x;
    x--;
  };
  return result;
}
```

```
# x in %edx, result in %eax
  jmp    .L34        #   goto Middle
.L35:                # Loop:
  imull %edx, %eax #   result *= x
  decl   %edx        #   x--
.L34:                # Middle:
  cmpl   $1, %edx    #   x:1
  jg     .L35        #   if >, goto Loop
```

Implementing Loops

- IA32
  - All loops translated into form based on “do-while”
- x86-64
  - Also make use of “jump to middle”
- Why the difference
  - IA32 compiler developed for machine where all operations costly
  - x86-64 compiler developed for machine where unconditional branches incur (almost) no overhead