EL 3010 Computer Architecture
Chapter 3 Control Flow

Sekolah Teknik Elektro dan Informatika

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Condition Codes

- Single Bit Registers

CF	Carry Flag	SF	Sign Flag
ZF	Zero Flag	OF	Overflow Flag

- Implicitly Set By Arithmetic Operations

  `addl` *Src,Dest*

  C analog: `t = a + b`

  - CF set if carry out from most significant bit
    - Used to detect unsigned overflow
  - ZF set if `t == 0`
  - SF set if `t < 0`
  - OF set if two's complement overflow

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

- *Not* Set by `leal` instruction

Setting Condition Codes (cont.)

- Explicit Setting by Compare Instruction

  `cmpl` *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`
  - OF set if two's complement overflow

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

Setting Condition Codes (cont.)

- Explicit Setting by Test instruction

  `testl` *Src2,Src1*

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

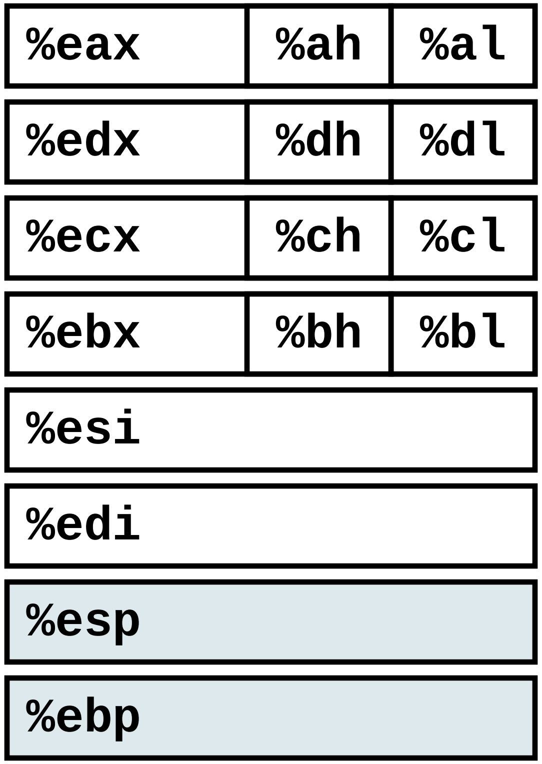
Reading Condition Codes

- 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)

Reading Condition Codes (Cont.)

- SetX Instructions
  - Set single byte based on combinations of condition codes
  - One of 8 addressable byte registers
    - Embedded within first 4 integer registers
    - Does not alter remaining 3 bytes
    - Typically use `movzbl` to finish job



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

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

Body

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

Note inverted ordering!

Condition Code

- We are trying to reverse engineer an assembly code

```
char ctest(int a,int b,int c)
{
        char t1= a …… b;
        char t2= b …… ( …… )a;
        char t3= ( …… )c …… ( …… )a;
        char t4= ( …… )a …… ( …… )c;
        char t5= c …… b;
        char t6= a …… 0;
        return t1+t2+t3+t4+t5+t6;
}
```

```
movl 8(%ebp),%ecx
movl 12(%ebp),%esi
cmpl %esi,%ecx
setl %al
cmpl %ecx,%esi
setb -1(%ebp)
cmpw %cx,16(%ebp)
setge -2(%ebp)
movb %cl,%dl
cmpb 16(%ebp),%dl
setne %bl
cmpl %esi,16(%ebp)
setg -3(%ebp)
testl %ecx,%ecx
setg %dl
addb -1(%ebp),%al
addb -2(%ebp),%al
addb %bl,%al
addb -3(%ebp),%al
addb %dl,%al
movsbl %al,%eax
```

Condition Code

```
char ctest(int a,int b,int c)
{
        char t1= a …… b;
        char t2= b …… ( …… )a;
        char t3= ( …… )c …… ( …… )a;
        char t4= ( …… )a …… ( …… )c;
        char t5= c …… b;
        char t6= a …… 0;
        return t1+t2+t3+t4+t5+t6;
}
```

	Offset		Address
			0x1002c
	16	c	0x10028
	12	b	0x10024
	8	a	0x10020
	4	Rtn Address	0x1001c
%ebp →	0		0x10018
	-1		0x10017
	-2		0x10016
	-3		0x10015
	-4		0x10014

%eax	
%edx	
%ecx	
%esi	
%ebp	0x10018

```
movl 8(%ebp),%ecx           #get a
movl 12(%ebp),%esi          #get b
cmpl %esi,%ecx              #compare a:b
setl %al                    #compute t1
cmpl %ecx,%esi              #compare b:a
setb -1(%ebp)               #compute t2
```

Condition Code

```
char ctest(int a,int b,int c)
{
        char t1= a …… b;
        char t2= b …… ( …… )a;
        char t3= ( …… )c …… ( …… )a;
        char t4= ( …… )a …… ( …… )c;
        char t5= c …… b;
        char t6= a …… 0;
        return t1+t2+t3+t4+t5+t6;
}
```

	Offset		Address
			0x1002c
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%ebp →	0		0x10018
	-1		0x10017
	-2		0x10016
	-3		0x10015
	-4		0x10014

%eax	
%edx	
%ecx	a
%esi	
%ebp	0x10018

```
movl 8(%ebp),%ecx          #get a
movl 12(%ebp),%esi         #get b
cmpl %esi,%ecx             #compare a:b
setl %al                   #compute t1
cmpl %ecx,%esi             #compare b:a
setb -1(%ebp)              #compute t2
```

Condition Code

```
char ctest(int a,int b,int c)
{
        char t1= a …… b;
        char t2= b …… ( …… )a;
        char t3= ( …… )c …… ( …… )a;
        char t4= ( …… )a …… ( …… )c;
        char t5= c …… b;
        char t6= a …… 0;
        return t1+t2+t3+t4+t5+t6;
}
```

	Offset		Address
			0x1002c
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%ebp →	0		0x10018
	-1		0x10017
	-2		0x10016
	-3		0x10015
	-4		0x10014

%eax	
%edx	
%ecx	a
%esi	b
%ebp	0x10018

```
movl 8(%ebp),%ecx               #get a
movl 12(%ebp),%esi              #get b
cmpl %esi,%ecx                  #compare a:b
setl %al                        #compute t1
cmpl %ecx,%esi                  #compare b:a
setb -1(%ebp)                   #compute t2
```

Condition Code

```
char ctest(int a,int b,int c)
{
        char t1= a ...... b;
        char t2= b ...... ( ...... )a;
        char t3= ( ...... )c ...... ( ...... )a;
        char t4= ( ...... )a ...... ( ...... )c;
        char t5= c ...... b;
        char t6= a ...... 0;
        return t1+t2+t3+t4+t5+t6;
}
```

	Offset		Address
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	-4		0x10014

%eax	t1
%edx	
%ecx	a
%esi	b
%ebp	0x10018

```
movl 8(%ebp),%ecx           #get a
movl 12(%ebp),%esi          #get b
cmpl %esi,%ecx              #compare a:b
setl %al                    #compute t1
cmpl %ecx,%esi              #compare b:a
setb -1(%ebp)               #compute t2
```

Condition Code

```
char ctest(int a,int b,int c)
{
        char t1= a < b;
        char t2= b …… ( …… )a;
        char t3= ( …… )c …… ( …… )a;
        char t4= ( …… )a …… ( …… )c;
        char t5= c …… b;
        char t6= a …… 0;
        return t1+t2+t3+t4+t5+t6;
}
```

	Offset		Address
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%ebp →	0		0x10018
	-1		0x10017
	-2		0x10016
	-3		0x10015
	-4		0x10014

%eax	t1
%edx	
%ecx	a
%esi	b
%ebp	0x10018

cmpl %esi,%ecx #compare a:b

compare double words : (a–b) = (%ecx-%esi)

setl %al #compute t1

set condition : less (signed <)

Condition Code

```
char ctest(int a,int b,int c)
{
        char t1= a < b;
        char t2= b …… ( …… )a;
        char t3= ( …… )c …… ( …… )a;
        char t4= ( …… )a …… ( …… )c;
        char t5= c …… b;
        char t6= a …… 0;
        return t1+t2+t3+t4+t5+t6;
}
```

	Offset		Address
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%ebp →	0		0x10018
	-1	t2	0x10017
	-2		0x10016
	-3		0x10015
	-4		0x10014

%eax	t1
%edx	
%ecx	a
%esi	b
%ebp	0x10018

```
movl 8(%ebp),%ecx          #get a
movl 12(%ebp),%esi         #get b
cmpl %esi,%ecx             #compare a:b
setl %al                   #compute t1
cmpl %ecx,%esi             #compare b:a
setb -1(%ebp)              #compute t2
```

Condition Code

```
char ctest(int a,int b,int c)
{
        char t1= a < b;
        char t2= b < (unsigned)a;
        char t3= ( …… )c …… ( …… )a;
        char t4= ( …… )a …… ( …… )c;
        char t5= c …… b;
        char t6= a …… 0;
        return t1+t2+t3+t4+t5+t6;
}
```

	Offset		Address
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%ebp →	0		0x10018
	-1	t2	0x10017
	-2		0x10016
	-3		0x10015
	-4		0x10014

%eax	t1
%edx	
%ecx	a
%esi	b
%ebp	0x10018

cmpl %ecx,%esi #compare b:a

compare double words : (b–a) = (%esi-%ecx)

setb -1(%ebp) #compute t2

set condition : below (unsigned <)

Condition Code

```
char ctest(int a,int b,int c)
{
        char t1= a < b;
        char t2= b < (unsigned)a;
        char t3= ( …… )c …… ( …… )a;
        char t4= ( …… )a …… ( …… )c;
        char t5= c …… b;
        char t6= a …… 0;
        return t1+t2+t3+t4+t5+t6;
}
```

	Offset		Address
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%ebp →	0		0x10018
	-1	t2	0x10017
	-2	t3	0x10016
	-3		0x10015
	-4		0x10014

%eax	t1
%edx	
%ecx	a
%esi	b
%ebp	0x10018

```
cmpw %ecx,16(%ebp)          #compare c:a
setge -2(%ebp)              #hitung t3
movb %cl,%dl
cmpb 16(%ebp),%dl           #compare a:c
setne %bl                   #hitung t4
cmpl %esi,16(%ebp)          #compare c:b
setg -3(%ebp)               #hitung t5
```

Condition Code

```
char ctest(int a,int b,int c)
{
        char t1= a < b;
        char t2= b < (unsigned)a;
        char t3= (short)c >= (short)a;
        char t4= ( …… )a …… ( …… )c;
        char t5= c …… b;
        char t6= a …… 0;
        return t1+t2+t3+t4+t5+t6;
}
```

	Offset		Address
			0x1002c
	16	c	0x10028
	12	b	0x10024
	8	a	0x10020
	4	Rtn Address	0x1001c
%ebp →	0		0x10018
	-1	t2	0x10017
	-2	t3	0x10016
	-3		0x10015
	-4		0x10014

%eax	t1
%edx	
%ecx	a
%esi	b
%ebp	0x10018

cmpw %ecx,16(%ebp) #compare c:a

compare word : (c–a) = (16(%ebp)-%cx)

setge -2(%ebp) #hitung t3

set condition : greater or equal(signed >=)

Condition Code

- Program

```
char ctest(int a,int b,int c)
{
        char t1= a < b;
        char t2= b < (unsigned)a;
        char t3= (short)c >= (short)a;
        char t4= ( char)a != (char)c;
        char t5= c > b;
        char t6= a > 0;
        return t1+t2+t3+t4+t5+t6;
}
```

```
movl 8(%ebp),%ecx
movl 12(%ebp),%esi
cmpl %esi,%ecx
setl %al
cmpl %ecx,%esi
setb -1(%ebp)
cmpw %cx,16(%ebp)
setge -2(%ebp)
movb %cl,%dl
cmpb 16(%ebp),%dl
setne %bl
cmpl %esi,16(%ebp)
setg -3(%ebp)
testl %ecx,%ecx
setg %dl
addb -1(%ebp),%al
addb -2(%ebp),%al
addb %bl,%al
addb -3(%ebp),%al
addb %dl,%al
movsbl %al,%eax
```

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

```
int max(int x, int y)
{
  if (x > y)
    return x;
  else
    return y;
}
```

```
_max:
       pushl %ebp
       movl %esp,%ebp
```

Set Up

```
       movl 8(%ebp),%edx
       movl 12(%ebp),%eax
       cmpl %eax,%edx
       jle L9
       movl %edx,%eax
```

Body

```
L9:

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

Finish

Conditional Branch Example (Cont.)

```
int goto_max(int x, int y)
{
  int rval = y;
  int ok = (x <= y);
  if (ok)
    goto done;
  rval = x;
done:
  return rval;
}
```

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

```
    movl 8(%ebp),%edx   # edx = x
    movl 12(%ebp),%eax  # eax = y
    cmpl %eax,%edx      # x : y
    jle L9              # if <= goto L9
    movl %edx,%eax      # eax = x }   Skipped when x ≤ y
L9:                   # Done:
```

“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          # 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
```

- Registers

%edx	x
%eax	result

General “Do-While” Translation

C Code

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

Goto Version

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

- *Body* can be any C statement
  - Typically compound statement:

```
{
   Statement_1;
   Statement_2;
     …
   Statement_n;
}
```

- *Test* is expression returning integer

  = 0 interpreted as false ≠0 interpreted as true

“While” Loop Example #1

C Code

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

First Goto Version

```
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

Actual “While” Loop Translation

C Code

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

- Uses same inner loop as do-while version
- Guards loop entry with extra test

Second Goto Version

```
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;
}
```

General “While” Translation

C Code

```
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:
```

“For” Loop Example

```
/* Compute x raised to nonnegative power p */
int ipwr_for(int x, unsigned p) {
int result;
  for (result = 1; p != 0; p = p>>1) {
    if (p & 0x1)
      result *= x;
    x = x*x;
  }
  return result;
}
```

- Algorithm
  - Exploit property that $p = p_0 + 2p_1 + 4p_2 + \ldots\ 2^{n-1}p_{n-1}$
  - Gives: $x^p = z_0 \cdot z_1^{\ 2} \cdot (z_2^{\ 2})^{\,2} \cdot \ \ldots \ \cdot \underbrace{(\ldots((z_{n-1}^{\ \ 2})^{\,2})\ldots)^{\,2}}_{n\text{–}1\ \text{times}}$

    $z_i = 1$ when $p_i = 0$

    $z_i = x$ when $p_i = 1$
  - Complexity $\mathrm{O}(\log p)$

Example

$3^{10} = 3^2 * 3^8$

$= 3^2 * ((3^2)^2)^2$

ipwr Computation

```
/* Compute x raised to nonnegative power p */
int ipwr_for(int x, unsigned p) {
int result;
  for (result = 1; p != 0; p = p>>1) {
    if (p & 0x1)
      result *= x;
    x = x*x;
  }
  return result;
}
```

result	x	p
1	3	10
1	9	5
9	81	2
9	6561	1
531441	43046721	0

“For” Loop Example

```
   int result;
   for (result = 1;
        p != 0;
        p = p>>1) {
     if (p & 0x1)
       result *= x;
     x = x*x;
   }
```

General Form

```
for (Init; Test; Update )

    Body
```

Init

```
result = 1
```

Test

```
p != 0
```

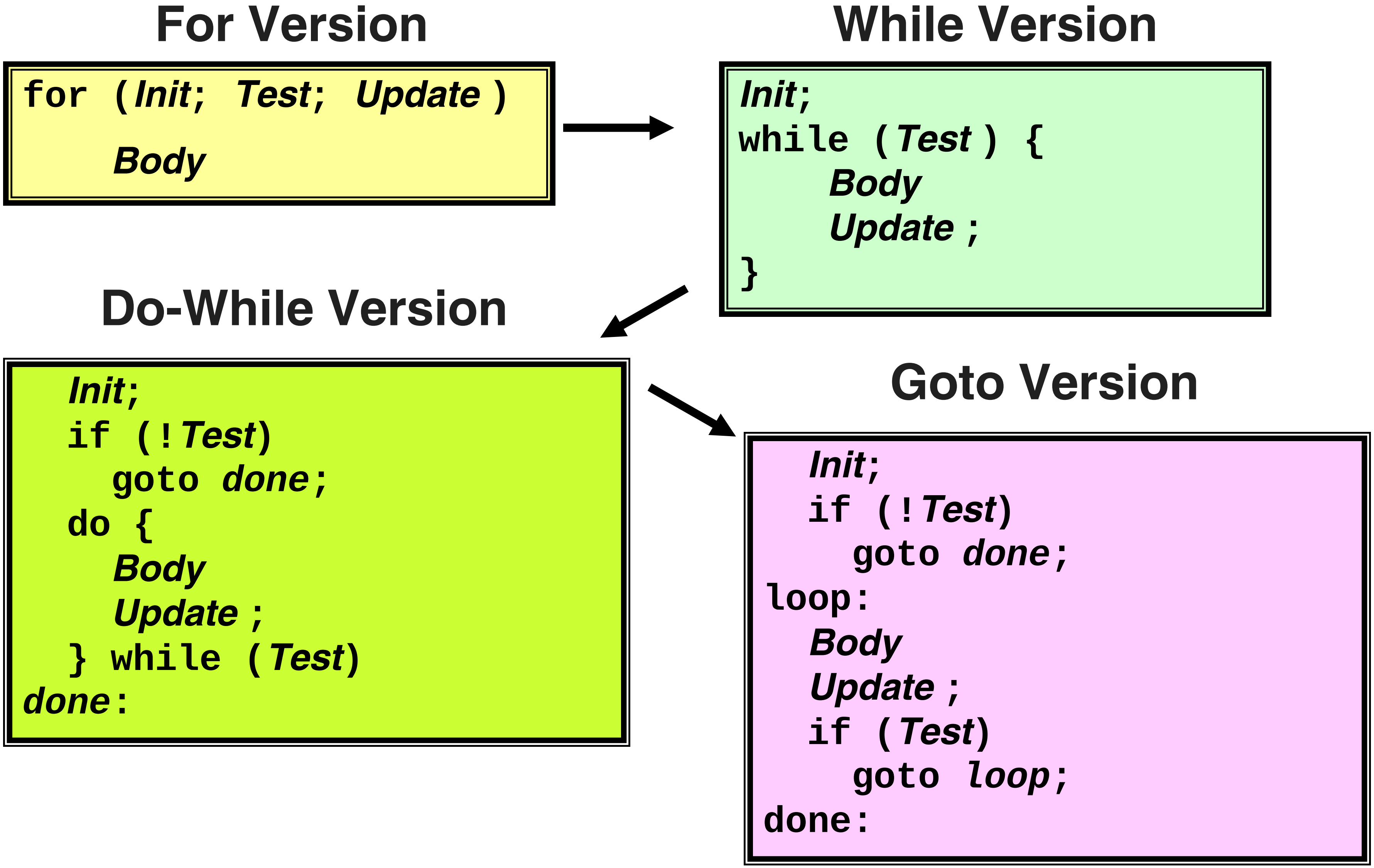
Update

```
p = p >> 1
```

Body

```
   {
     if (p & 0x1)
       result *= x;
     x = x*x;
   }
```

“For”→ “While”



For Version

```
for (Init; Test; Update )

     Body
```

While Version

```
Init;
while (Test ) {
      Body
      Update ;
}
```

Do-While Version

```
   Init;
   if (!Test)
     goto done;
   do {
     Body
     Update ;
   } while (Test)
done:
```

Goto Version

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

“For” Loop Compilation

Goto Version

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

→

```
   result = 1;
   if (p == 0)
      goto done;
loop:
   if (p & 0x1)
      result *= x;
   x = x*x;
   p = p >> 1;
   if (p != 0)
      goto loop;
done:
```

Init

```
result = 1
```

Test

```
p != 0
```

Update

```
p = p >> 1
```

Body

```
   {
      if (p & 0x1)
         result *= x;
      x = x*x;
   }
```

Switch Statements

```
typedef enum
 {ADD, MULT, MINUS, DIV, MOD, BAD}
    op_type;

char unparse_symbol(op_type op)
{
  switch (op) {
  case ADD :
    return '+';
  case MULT:
    return '*';
  case MINUS:
    return '-';
  case DIV:
    return '/';
  case MOD:
    return '%';
  case BAD:
    return '?';
  }
}
```

- Implementation Options
  - Series of conditionals
    - Good if few cases
    - Slow if many
  - Jump Table
    - Lookup branch target
    - Avoids conditionals
    - Possible when cases are small integer constants
  - GCC
    - Picks one based on case structure
  - Bug in example code
    - No default given

Jump Table Structure

Switch Form

```
switch(op) {
  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
```

Approx. Translation

```
target = JTab[op];
goto *target;
```

Switch Statement Example

- Branching Possibilities

```
typedef enum
  {ADD, MULT, MINUS, DIV, MOD, BAD}
    op_type;

char unparse_symbol(op_type op)
{
  switch (op) {
    • • •
  }
}
```

Enumerated Values

ADD	0
MULT	1
MINUS	2
DIV	3
MOD	4
BAD	5

Setup:

```
unparse_symbol:
   pushl %ebp              # Setup
   movl %esp,%ebp          # Setup
   movl 8(%ebp),%eax       # eax = op
   cmpl $5,%eax            # Compare op : 5
   ja .L49                 # If > goto done
   jmp *.L57(,%eax,4)      # goto Table[op]
```

Assembly Setup Explanation

- Symbolic Labels
  - Labels of form `.L`*XX* translated into addresses by assembler
- Table Structure
  - Each target requires 4 bytes
  - Base address at `.L57`
- Jumping

```
jmp .L49
```

  - Jump target is denoted by label `.L49`

```
jmp *.L57(,%eax,4)
```

  - Start of jump table denoted by label `.L57`
  - Register `%eax` holds `op`
  - Must scale by factor of 4 to get offset into table
  - Fetch target from effective Address `.L57 + op*4`

Jump Table

Table Contents

```
.section .rodata
   .align 4
.L57:
  .long .L51 #Op = 0
  .long .L52 #Op = 1
  .long .L53 #Op = 2
  .long .L54 #Op = 3
  .long .L55 #Op = 4
  .long .L56 #Op = 5
```

Enumerated Values

ADD	0
MULT	1
MINUS	2
DIV	3
MOD	4
BAD	5

Targets & Completion

```
.L51:
    movl $43,%eax # ’+’
    jmp .L49
.L52:
    movl $42,%eax # ’*’
    jmp .L49
.L53:
    movl $45,%eax # ’-’
    jmp .L49
.L54:
    movl $47,%eax # ’/’
    jmp .L49
.L55:
    movl $37,%eax # ’%’
    jmp .L49
.L56:
    movl $63,%eax # ’?’
    # Fall Through to .L49
```

Switch Statement Completion

```
.L49:                  # Done:
    movl %ebp,%esp     # Finish
    popl %ebp          # Finish
    ret                # Finish
```

- Puzzle
  - What value returned when op is invalid?
- Answer
  - Register %eax set to op at beginning of procedure
  - This becomes the returned value
- Advantage of Jump Table
  - Can do *k*-way branch in *O*(1) operations

Object Code

- Setup
  - Label `.L49` becomes address `0x804875c`
  - Label `.L57` becomes address `0x8048bc0`

```
08048718 <unparse_symbol>:
8048718:55                pushl  %ebp
8048719:89 e5             movl   %esp,%ebp
804871b:8b 45 08          movl   0x8(%ebp),%eax
804871e:83 f8 05          cmpl   $0x5,%eax
8048721:77 39             ja     804875c <unparse_symbol+0x44>
8048723:ff 24 85 c0 8b jmp    *0x8048bc0(,%eax,4)
```

Object Code (cont.)

- Jump Table
  - Doesn’t show up in disassembled code
  - Can inspect using GDB

```
gdb code-examples
(gdb) x/6xw 0x8048bc0
```

- Examine 6 hexadecimal format “words” (4-bytes each)
- Use command “`help x`” to get format documentation

```
0x8048bc0 <_fini+32>:
   0x08048730
   0x08048737
   0x08048740
   0x08048747
   0x08048750
   0x08048757
```

Extracting Jump Table from Binary

- Jump Table Stored in Read Only Data Segment (.rodata)
  - Various fixed values needed by your code
- Can examine with objdump

  `objdump code-examples –s --section=.rodata`
  - Show everything in indicated segment.
- Hard to read
  - Jump table entries shown with reversed byte ordering

```
Contents of section .rodata:
 8048bc0 30870408 37870408 40870408 47870408  0...7...@...G...
 8048bd0 50870408 57870408 46616374 28256429  P...W...Fact(%d)
 8048be0 203d2025 6c640a00 43686172 203d2025   = %ld..Char = %
 …
```

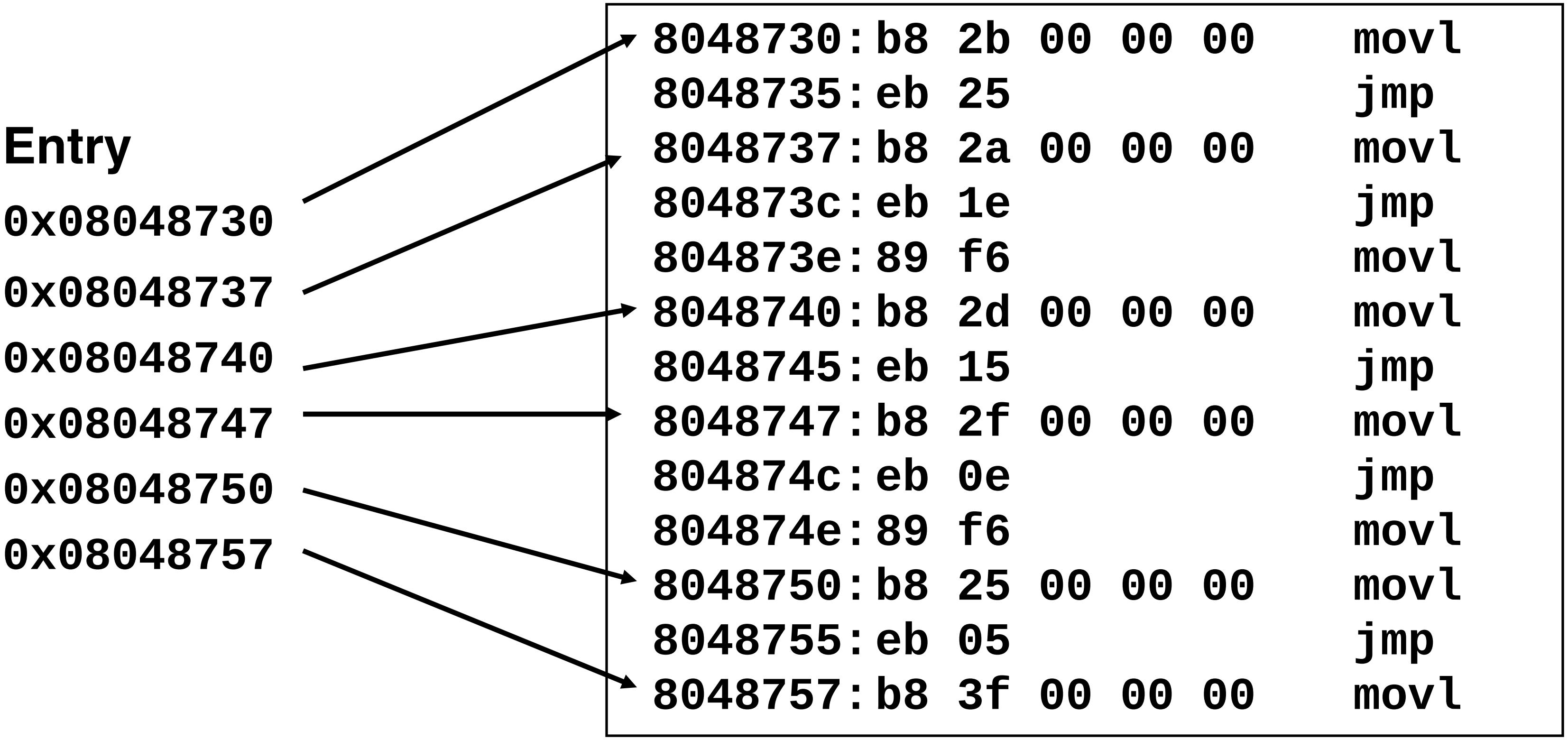
- E.g., `30870408` really means `0x08048730`

Disassembled Targets

```
8048730:b8 2b 00 00 00   movl   $0x2b,%eax
8048735:eb 25            jmp    804875c <unparse_symbol+0x44>
8048737:b8 2a 00 00 00   movl   $0x2a,%eax
804873c:eb 1e            jmp    804875c <unparse_symbol+0x44>
804873e:89 f6            movl   %esi,%esi
8048740:b8 2d 00 00 00   movl   $0x2d,%eax
8048745:eb 15            jmp    804875c <unparse_symbol+0x44>
8048747:b8 2f 00 00 00   movl   $0x2f,%eax
804874c:eb 0e            jmp    804875c <unparse_symbol+0x44>
804874e:89 f6            movl   %esi,%esi
8048750:b8 25 00 00 00   movl   $0x25,%eax
8048755:eb 05            jmp    804875c <unparse_symbol+0x44>
8048757:b8 3f 00 00 00   movl   $0x3f,%eax
```

- `movl %esi,%esi` does nothing
- Inserted to align instructions for better cache performance

Matching Disassembled Targets



Entry

```
0x08048730
0x08048737
0x08048740
0x08048747
0x08048750
0x08048757
```

```
8048730: b8 2b 00 00 00    movl
8048735: eb 25             jmp
8048737: b8 2a 00 00 00    movl
804873c: eb 1e             jmp
804873e: 89 f6             movl
8048740: b8 2d 00 00 00    movl
8048745: eb 15             jmp
8048747: b8 2f 00 00 00    movl
804874c: eb 0e             jmp
804874e: 89 f6             movl
8048750: b8 25 00 00 00    movl
8048755: eb 05             jmp
8048757: b8 3f 00 00 00    movl
```

Sparse Switch Example

```
/* Return x/111 if x is multiple
   && <= 999.  -1 otherwise */
int div111(int x)
{
  switch(x) {
  case   0: return 0;
  case 111: return 1;
  case 222: return 2;
  case 333: return 3;
  case 444: return 4;
  case 555: return 5;
  case 666: return 6;
  case 777: return 7;
  case 888: return 8;
  case 999: return 9;
  default: return -1;
  }
}
```

- Not practical to use jump table
  - Would require 1000 entries
- Obvious translation into if-then-else would have max. of 9 tests

Sparse Switch Code

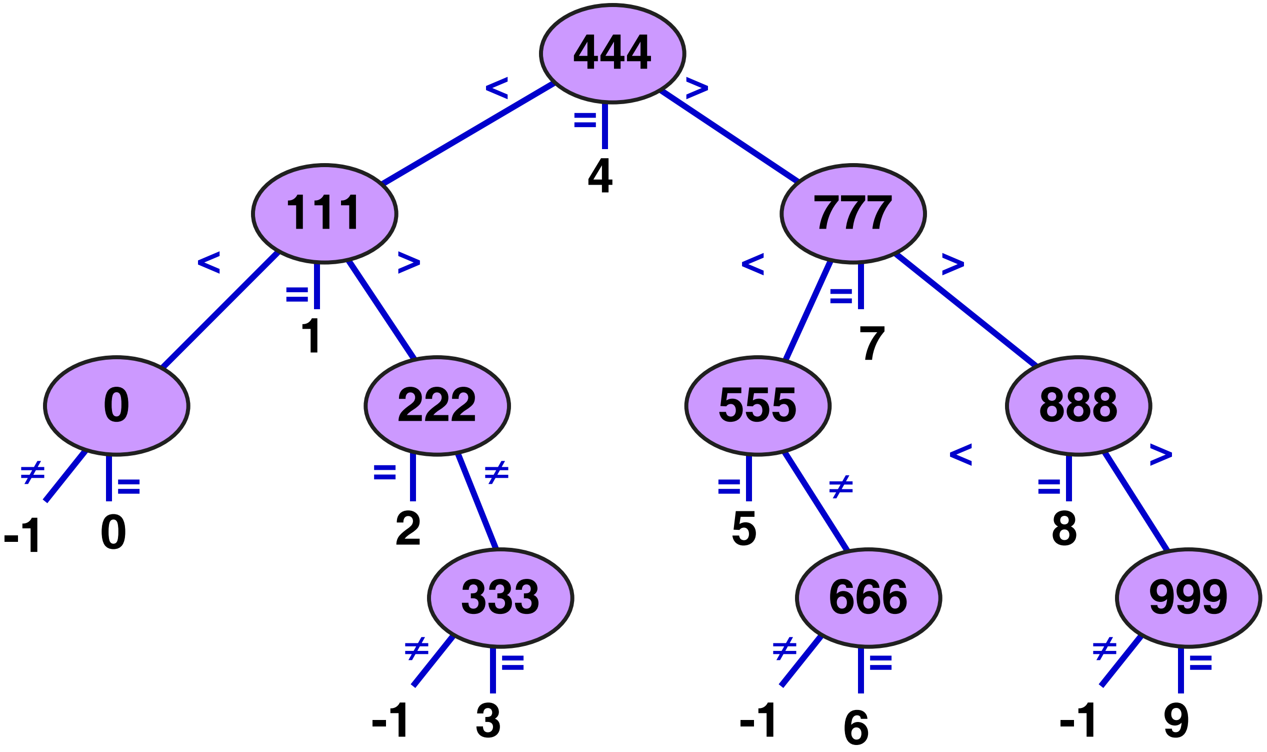
```
    movl 8(%ebp),%eax  # get x
    cmpl $444,%eax     # x:444
    je L8
    jg L16
    cmpl $111,%eax     # x:111
    je L5
    jg L17
    testl %eax,%eax    # x:0
    je L4
    jmp L14

    . . .
```

- Compares x to possible case values
- Jumps different places depending on outcomes

```
    . . .
L5:
    movl $1,%eax
    jmp L19
L6:
    movl $2,%eax
    jmp L19
L7:
    movl $3,%eax
    jmp L19
L8:
    movl $4,%eax
    jmp L19
    . . .
```

Sparse Switch Code Structure



- Organizes cases as binary tree
- Logarithmic performance

Summarizing

- C Control
  - if-then-else
  - do-while
  - while
  - switch
- Assembler Control
  - jump
  - Conditional jump
- Compiler
  - Must generate assembly code to implement more complex control

- Standard Techniques
  - All loops converted to do-while form
  - Large switch statements use jump tables
- Conditions in CISC
  - CISC machines generally have condition code registers
- Conditions in RISC
  - Use general registers to store condition information
  - Special comparison instructions
  - E.g., on Alpha:

    ```
    cmple $16,1,$1
    ```

    - Sets register $1 to 1 when Register $16 <= 1