Conditional Processing

COE 205

Computer Organization and Assembly Language

Computer Engineering Department

King Fahd University of Petroleum and Minerals

Presentation Outline

- ❖ Boolean and Comparison Instructions
- ❖ Conditional Jumps
- ❖ Conditional Loop Instructions
- ❖ Translating Conditional Structures
- ❖ Indirect Jump and Table-Driven Selection
- ❖ Application: Sorting an Integer Array

AND Instruction

❖ Bitwise AND between each pair of matching bits

AND *destination, source*

❖ Following operand combinations are allowed

```
AND reg, reg
AND reg, mem
AND reg, imm
AND mem, reg
AND mem, imm
```

Operands can be 8, 16, or 32 bits and they must be of the same size

AND

x	y	x ∧ y
0	0	0
0	1	0
1	0	0
1	1	1

❖ AND instruction is often used to clear selected bits

```
       0 0 1 1 1 0 1 1
AND    0 0 0 0 1 1 1 1
cleared  0 0 0 0 1 0 1 1  unchanged
```

Converting Characters to Uppercase

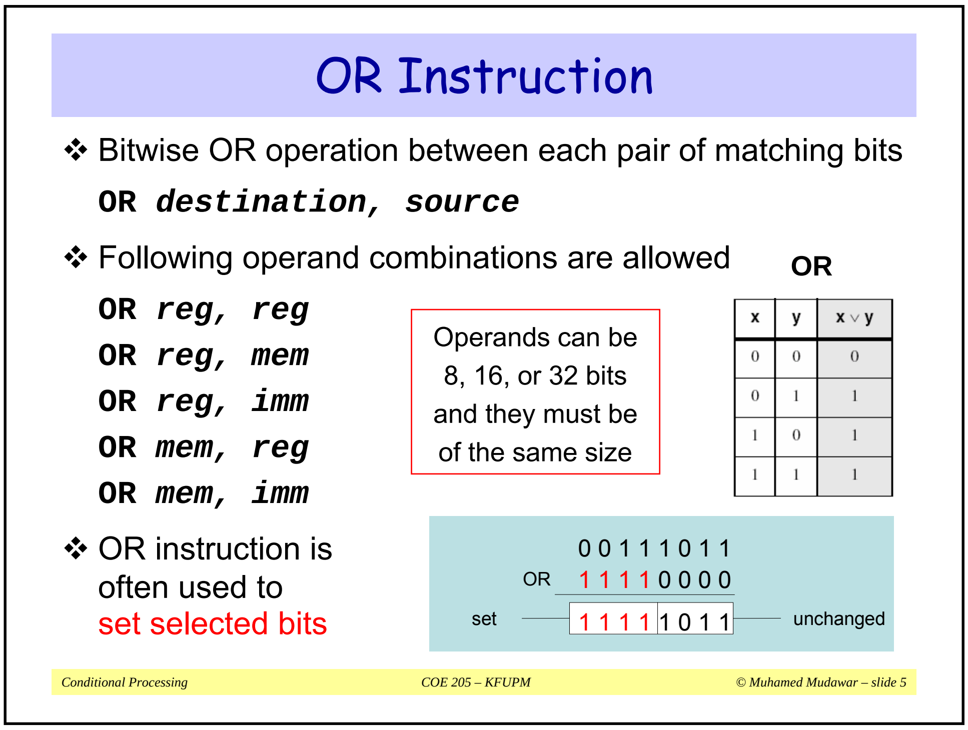
❖ AND instruction can convert characters to uppercase

'a' = 0 1 **1** 0 0 0 0 1   'b' = 0 1 **1** 0 0 0 1 0

'A' = 0 1 **0** 0 0 0 0 1   'B' = 0 1 **0** 0 0 0 1 0

❖ Solution: Use the AND instruction to **clear bit 5**

```
     mov  ecx, LENGTHOF mystring
     mov  esi, OFFSET mystring
L1:  and  BYTE PTR [esi], 11011111b ; clear bit 5
     inc  esi
     loop L1
```



OR Instruction

- Bitwise OR operation between each pair of matching bits

  OR *destination, source*

- Following operand combinations are allowed

  OR *reg, reg*
  OR *reg, mem*
  OR *reg, imm*
  OR *mem, reg*
  OR *mem, imm*

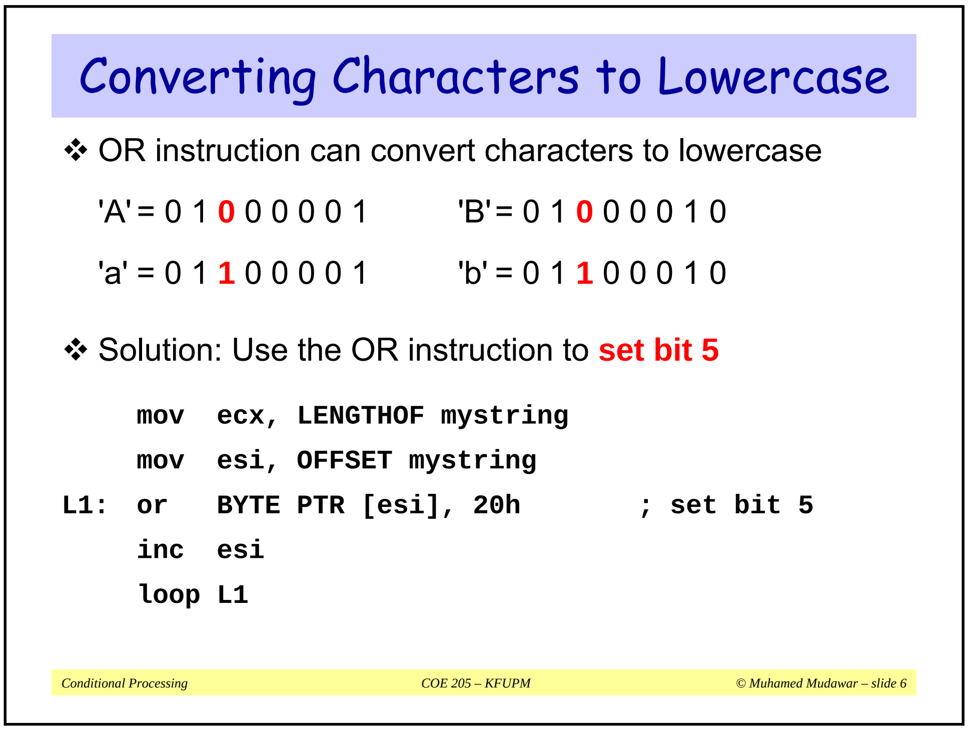
Operands can be 8, 16, or 32 bits and they must be of the same size

OR

x	y	x ∨ y
0	0	0
0	1	1
1	0	1
1	1	1

- OR instruction is often used to set selected bits

```
         0 0 1 1 1 0 1 1
      OR 1 1 1 1 0 0 0 0
set      1 1 1 1 1 0 1 1   unchanged
```



Converting Characters to Lowercase

- OR instruction can convert characters to lowercase

  'A' = 0 1 **0** 0 0 0 0 1 'B' = 0 1 **0** 0 0 0 1 0

  'a' = 0 1 **1** 0 0 0 0 1 'b' = 0 1 **1** 0 0 0 1 0

- Solution: Use the OR instruction to **set bit 5**

```
    mov  ecx, LENGTHOF mystring
    mov  esi, OFFSET mystring
L1: or   BYTE PTR [esi], 20h       ; set bit 5
    inc  esi
    loop L1
```

Converting Binary Digits to ASCII

❖ OR instruction can convert a binary digit to ASCII

0 = 0 0 **0 0** 0 0 0 0 1 = 0 0 **0 0** 0 0 0 1

'0' = 0 0 **1 1** 0 0 0 0 '1' = 0 0 **1 1** 0 0 0 1

❖ Solution: Use the OR instruction to **set bits 4 and 5**

```
or  al,30h  ; Convert binary digit 0 to 9 to ASCII
```

❖ What if we want to convert an ASCII digit to binary?

❖ Solution: Use the AND instruction to **clear bits 4 to 7**

```
and al,0Fh  ; Convert ASCII '0' to '9' to binary
```

XOR Instruction

❖ Bitwise XOR between each pair of matching bits

XOR *destination, source*

❖ Following operand combinations are allowed

XOR *reg, reg*
XOR *reg, mem*
XOR *reg, imm*
XOR *mem, reg*
XOR *mem, imm*

Operands can be 8, 16, or 32 bits and they must be of the same size

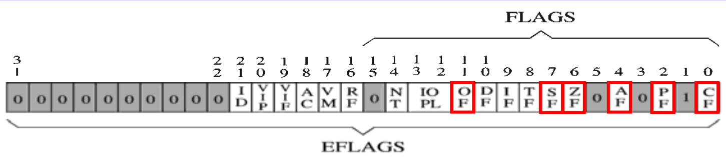
XOR

x	y	$x \oplus y$
0	0	0
0	1	1
1	0	1
1	1	0

❖ XOR instruction is often used to invert selected bits

```
                0 0 1 1 1 0 1 1
        XOR     1 1 1 1 0 0 0 0
inverted ——     1 1 0 0 1 0 1 1 —— unchanged
```

Affected Status Flags



The six status flags are affected

1. Carry Flag: Cleared by AND, OR, and XOR
2. Overflow Flag: Cleared by AND, OR, and XOR
3. Sign Flag: Copy of the sign bit in result
4. Zero Flag: Set when result is zero
5. Parity Flag: Set when parity in least-significant byte is even
6. Auxiliary Flag: Undefined by AND, OR, and XOR

String Encryption Program

❖ Tasks:
- ✧ Input a message (string) from the user
- ✧ Encrypt the message
- ✧ Display the encrypted message
- ✧ Decrypt the message
- ✧ Display the decrypted message

❖ Sample Output

```
Enter the plain text: Attack at dawn.
Cipher text: «¢¢Äîä-Ä¢-ïÄÿü-Gs
Decrypted: Attack at dawn.
```

Encrypting a String

```
KEY     = 239               ; Can be any byte value
BUFMAX = 128
.data
buffer  BYTE  BUFMAX+1 DUP(0)
bufSize DWORD BUFMAX
```

The following loop uses the XOR instruction to transform every character in a string into a new value

```
   mov ecx, bufSize     ; loop counter
   mov esi, 0           ; index 0 in buffer
L1:
   xor buffer[esi], KEY ; translate a byte
   inc esi              ; point to next byte
   loop L1
```

TEST Instruction

❖ Bitwise AND operation between each pair of bits

TEST ***destination, source***

❖ The flags are affected similar to the AND Instruction

❖ However, TEST does NOT modify the destination operand

❖ TEST instruction can check several bits at once

- ✧ Example: Test whether bit 0 or bit 3 is set in AL
- ✧ Solution: `test al, 00001001b   ; test bits 0 & 3`
- ✧ We only need to check the zero flag

```
; If zero flag => both bits 0 and 3 are clear
; If Not zero  => either bit 0 or 3 is set
```

NOT Instruction

❖ Inverts all the bits in a destination operand

`NOT destination`

❖ Result is called the 1's complement

❖ Destination can be a register or memory

`NOT reg`

`NOT mem`

```
NOT   0 0 1 1 1 0 1 1
      ---------------
      1 1 0 0 0 1 0 0 ——— inverted
```

NOT

X	¬X
F	T
T	F

❖ None of the Flags is affected by the NOT instruction

CMP Instruction

❖ CMP (Compare) instruction performs a subtraction

Syntax: **`CMP destination, source`**

Computes: **`destination – source`**

❖ Destination operand is NOT modified

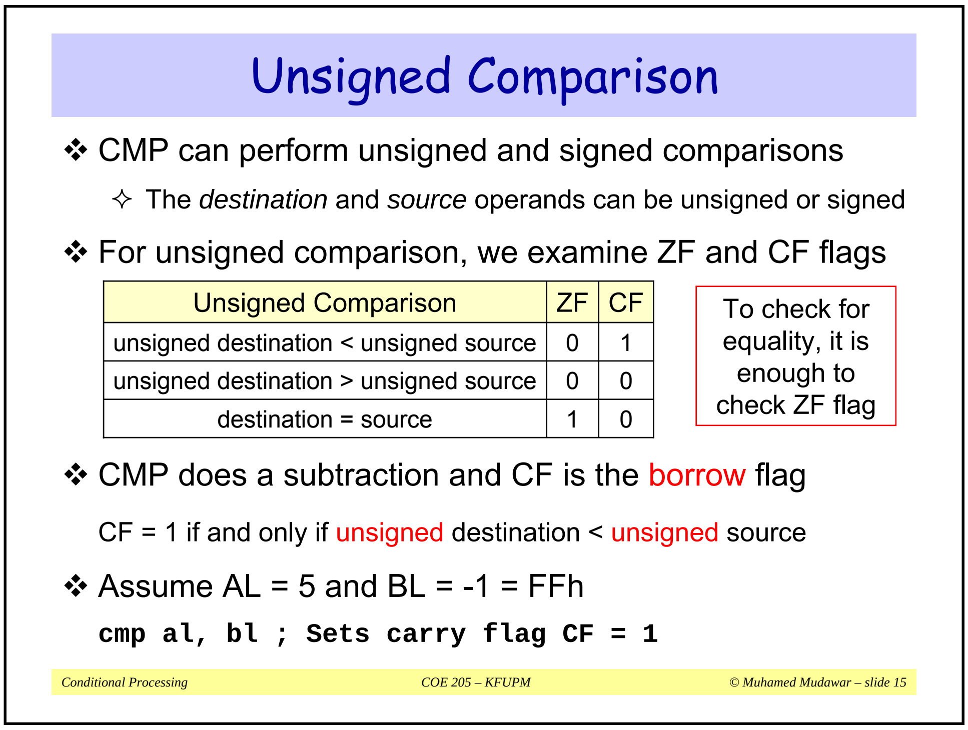
❖ All six flags: OF, CF, SF, ZF, AF, and PF are affected

❖ CMP uses the same operand combinations as AND

- ✧ Operands can be 8, 16, or 32 bits and must be of the same size

❖ Examples: assume EAX = 5, EBX = 10, and ECX = 5

```
cmp eax, ebx     ; OF=0, CF=1, SF=1, ZF=0
cmp eax, ecx     ; OF=0, CF=0, SF=0, ZF=1
```



Unsigned Comparison

- ❖ CMP can perform unsigned and signed comparisons
  - ✧ The *destination* and *source* operands can be unsigned or signed
- ❖ For unsigned comparison, we examine ZF and CF flags

Unsigned Comparison	ZF	CF
unsigned destination < unsigned source	0	1
unsigned destination > unsigned source	0	0
destination = source	1	0

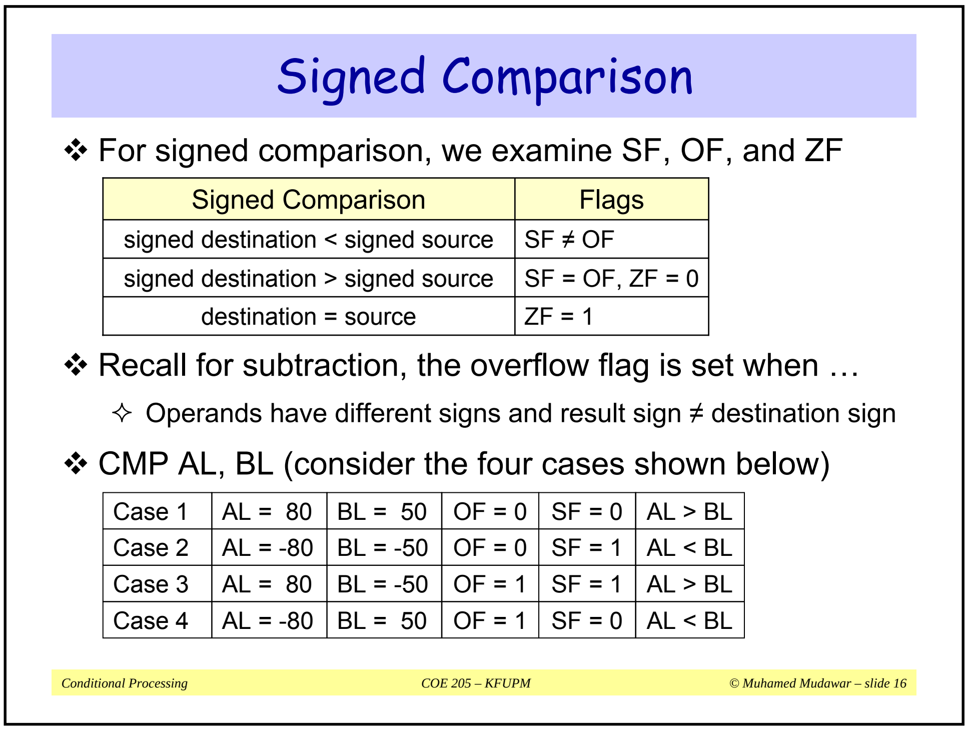
To check for equality, it is enough to check ZF flag

- ❖ CMP does a subtraction and CF is the borrow flag

CF = 1 if and only if unsigned destination < unsigned source

- ❖ Assume AL = 5 and BL = -1 = FFh

```
cmp al, bl ; Sets carry flag CF = 1
```



Signed Comparison

- ❖ For signed comparison, we examine SF, OF, and ZF

Signed Comparison	Flags
signed destination < signed source	SF ≠ OF
signed destination > signed source	SF = OF, ZF = 0
destination = source	ZF = 1

- ❖ Recall for subtraction, the overflow flag is set when …
  - ✧ Operands have different signs and result sign ≠ destination sign
- ❖ CMP AL, BL (consider the four cases shown below)

Case 1	AL = 80	BL = 50	OF = 0	SF = 0	AL > BL
Case 2	AL = -80	BL = -50	OF = 0	SF = 1	AL < BL
Case 3	AL = 80	BL = -50	OF = 1	SF = 1	AL > BL
Case 4	AL = -80	BL = 50	OF = 1	SF = 0	AL < BL

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Conditional Structures

- ❖ No high-level control structures in assembly language
- ❖ Comparisons and conditional jumps are used to …
  - ✧ Implement conditional structures such as IF statements
  - ✧ Implement conditional loops
- ❖ Types of Conditional Jump Instructions
  - ✧ Jumps based on specific flags
  - ✧ Jumps based on equality
  - ✧ Jumps based on the value of CX or ECX
  - ✧ Jumps based on unsigned comparisons
  - ✧ Jumps based on signed comparisons

Jumps Based on Specific Flags

- Conditional Jump Instruction has the following syntax:

```
Jcond destination     ; cond is the jump condition
```

- Destination
  Destination Label
- Prior to 386
  Jump must be within –128 to +127 bytes from current location
- IA-32
  32-bit offset permits jump anywhere in memory

Mnemonic	Description	Flags
JZ	Jump if zero	ZF = 1
JNZ	Jump if not zero	ZF = 0
JC	Jump if carry	CF = 1
JNC	Jump if not carry	CF = 0
JO	Jump if overflow	OF = 1
JNO	Jump if not overflow	OF = 0
JS	Jump if signed	SF = 1
JNS	Jump if not signed	SF = 0
JP	Jump if parity (even)	PF = 1
JNP	Jump if not parity (odd)	PF = 0

Jumps Based on Equality

Mnemonic	Description
JE	Jump if equal (*leftOp* = *rightOp*)
JNE	Jump if not equal (*leftOp* ≠ *rightOp*)
JCXZ	Jump if CX = 0
JECXZ	Jump if ECX = 0

- JE is equivalent to JZ
- JNE is equivalent to JNZ
- JECXZ
  Checked once at the beginning
  Terminate a loop if ECX is zero

```
   jecxz L2  ; exit loop
L1: . . .    ; loop body
   loop L1
L2:
```

Examples of Jump on Zero

❖ Task: Check whether integer value in EAX is even

Solution: TEST whether the least significant bit is 0

If zero, then EAX is even, otherwise it is odd

```
test eax, 1          ; test bit 0 of eax
jz   EvenVal         ; jump if Zero flag is set
```

❖ Task: Jump to label L1 if bits 0, 1, and 3 in AL are all set

Solution:

```
and al,00001011b   ; clear bits except 0,1,3
cmp al,00001011b   ; check bits 0,1,3
je  L1             ; all set? jump to L1
```

Jumps Based on Unsigned Comparison

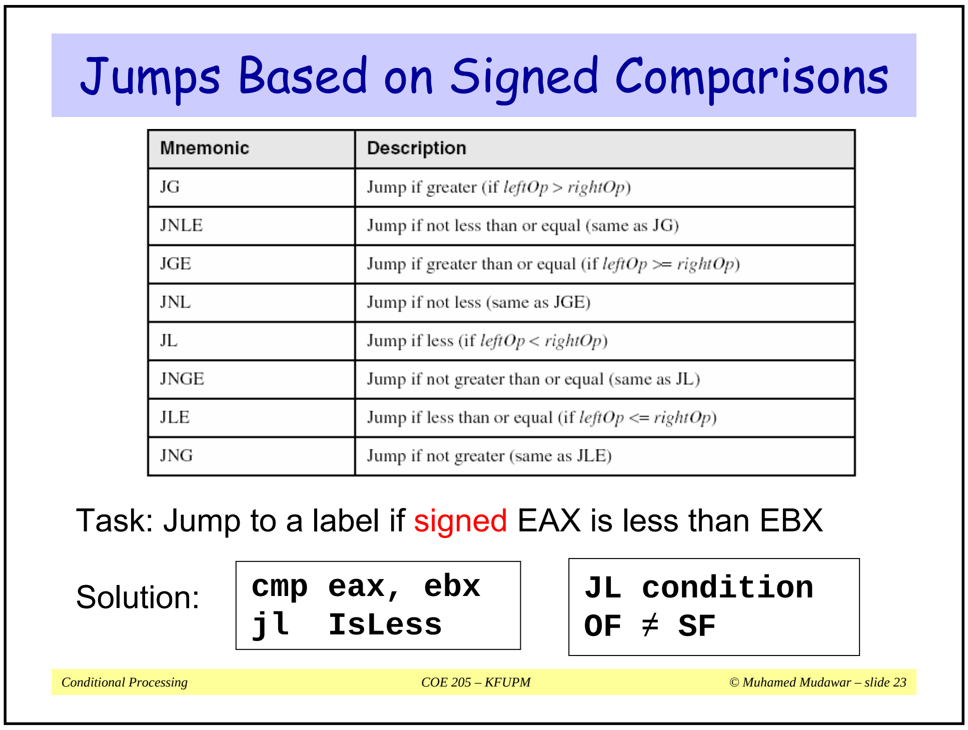
Mnemonic	Description
JA	Jump if above (if *leftOp* > *rightOp*)
JNBE	Jump if not below or equal (same as JA)
JAE	Jump if above or equal (if *leftOp* >= *rightOp*)
JNB	Jump if not below (same as JAE)
JB	Jump if below (if *leftOp* < *rightOp*)
JNAE	Jump if not above or equal (same as JB)
JBE	Jump if below or equal (if *leftOp* <= *rightOp*)
JNA	Jump if not above (same as JBE)

Task: Jump to a label if unsigned EAX is less than EBX

Solution:

```
cmp eax, ebx
jb  IsBelow
```

```
JB condition
CF = 1
```



Jumps Based on Signed Comparisons

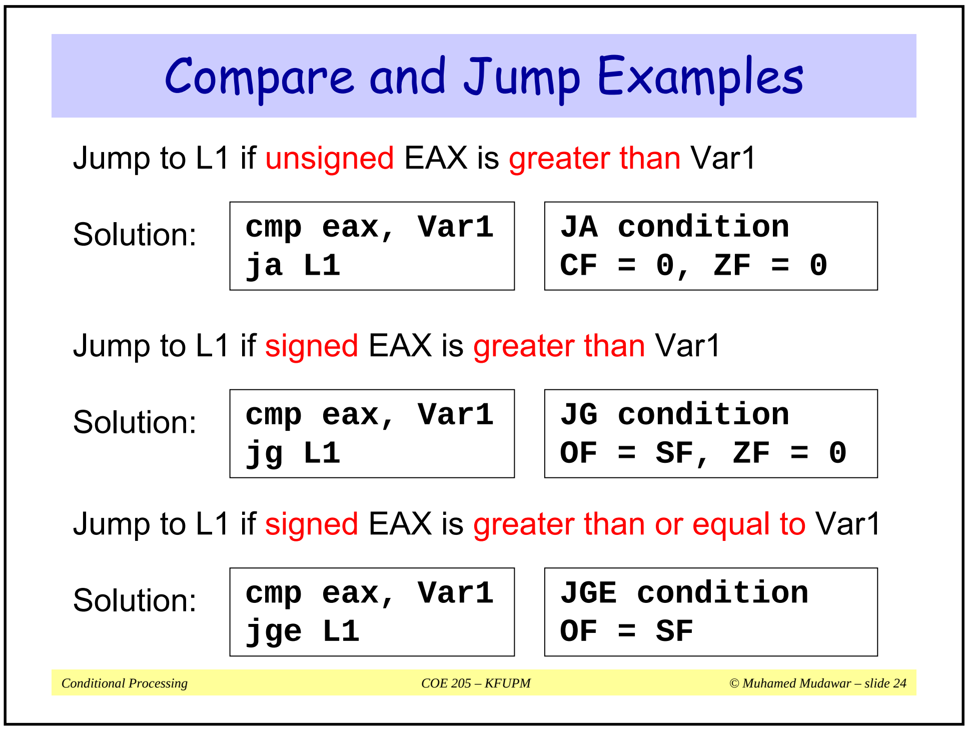
Mnemonic	Description
JG	Jump if greater (if *leftOp* > *rightOp*)
JNLE	Jump if not less than or equal (same as JG)
JGE	Jump if greater than or equal (if *leftOp* >= *rightOp*)
JNL	Jump if not less (same as JGE)
JL	Jump if less (if *leftOp* < *rightOp*)
JNGE	Jump if not greater than or equal (same as JL)
JLE	Jump if less than or equal (if *leftOp* <= *rightOp*)
JNG	Jump if not greater (same as JLE)

Task: Jump to a label if signed EAX is less than EBX

Solution:

```
cmp eax, ebx
jl  IsLess
```

```
JL condition
OF ≠ SF
```



Compare and Jump Examples

Jump to L1 if unsigned EAX is greater than Var1

Solution:

```
cmp eax, Var1
ja L1
```

```
JA condition
CF = 0, ZF = 0
```

Jump to L1 if signed EAX is greater than Var1

Solution:

```
cmp eax, Var1
jg L1
```

```
JG condition
OF = SF, ZF = 0
```

Jump to L1 if signed EAX is greater than or equal to Var1

Solution:

```
cmp eax, Var1
jge L1
```

```
JGE condition
OF = SF
```

Computing the Max and Min

❖ Compute the Max of unsigned EAX and EBX

Solution:

```
    mov Max, eax    ; assume Max = eax
    cmp Max, ebx
    jae done
    mov Max, ebx    ; Max = ebx
done:
```

❖ Compute the Min of signed EAX and EBX

Solution:

```
    mov Min, eax    ; assume Min = eax
    cmp Min, ebx
    jle done
    mov Min, ebx    ; Min = ebx
done:
```

Application: Sequential Search

```
; Receives: esi = array address
;           ecx = array size
;           eax = search value
; Returns:  esi = address of found element

search PROC USES ecx
  jecxz notfound
L1:
  cmp  [esi], eax  ; array element = search value?
  je   found       ; yes? found element
  add  esi, 4      ; no? point to next array element
  loop L1
notfound:
  mov  esi, 0      ; if not found then esi = 0
found:
  ret              ; if found, esi = element address
search ENDP
```

BT Instruction

- ❖ BT = Bit Test Instruction
- ❖ Syntax:

  BT *r/m16, r16*

  BT *r/m32, r32*

  BT *r/m16, imm8*

  BT *r/m32, imm8*
- ❖ Copies bit *n* from an operand into the Carry flag
- ❖ Example: jump to label L1 if bit 9 is set in AX register

```
bt AX, 9          ; CF = bit 9
jc L1             ; jump if Carry to L1
```

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LOOPZ and LOOPE

❖ Syntax:

LOOPE *destination*

LOOPZ *destination*

❖ Logic:

- ✧ ECX = ECX – 1
- ✧ if ECX > 0 and ZF=1, jump to *destination*

❖ Useful when scanning an array for the first element that does not match a given value.

LOOPNZ and LOOPNE

❖ Syntax:

LOOPNZ *destination*

LOOPNE *destination*

❖ Logic:

- ✧ ECX ← ECX – 1;
- ✧ if ECX > 0 and ZF=0, jump to *destination*

❖ Useful when scanning an array for the first element that matches a given value.

LOOPZ Example

The following code finds the first negative value in an array

```
.data
array SWORD 17,10,30,40,4,-5,8
.code
   mov esi, OFFSET array – 2  ; start before first
   mov ecx, LENGTHOF array    ; loop counter
L1:
   add esi, 2                 ; point to next element
   test WORD PTR [esi], 8000h ; test sign bit
   loopz L1                   ; ZF = 1 if value >= 0
   jnz found                  ; found negative value
notfound:
   . . .          ; ESI points to last array element
found:
   . . .          ; ESI points to first negative value
```

Your Turn . . .

Locate the first zero value in an array

If none is found, let ESI point to last array element

```
.data
array SWORD -3,7,20,-50,10,0,40,4
.code
   mov esi, OFFSET array – 2  ; start before first
   mov ecx, LENGTHOF array    ; loop counter
L1:
   add esi, 2                 ; point to next element
   cmp WORD PTR [esi], 0      ; check for zero
   loopne L1                  ; continue if not zero
   jz found                   ; found zero
notfound:
   . . .             ; ESI points to last array value
found:
   . . .             ; ESI points to first zero value
```

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Block-Structured IF Statements

- ❖ IF statement in high-level languages (such as C or Java)
  - ✧ Boolean expression (evaluates to true or false)
  - ✧ List of statements performed when the expression is true
  - ✧ Optional list of statements performed when expression is false
- ❖ Task: Translate IF statements into assembly language
- ❖ Example:

```
if( var1 == var2 )
  X = 1;
else
  X = 2;
```

```
    mov eax,var1
    cmp eax,var2
    jne elsepart
    mov X,1
    jmp next
elsepart:
    mov X,2
next:
```

Your Turn . . .

❖ Translate the IF statement to assembly language

❖ All values are unsigned

```
if( ebx <= ecx )
{
  eax = 5;
  edx = 6;
}
```

```
   cmp ebx,ecx
   ja  next
   mov eax,5
   mov edx,6
next:
```

There can be multiple correct solutions

Your Turn . . .

❖ Implement the following IF in assembly language

❖ All variables are 32-bit signed integers

```
if (var1 <= var2) {
  var3 = 10;
}
else {
  var3 = 6;
  var4 = 7;
}
```

```
   mov eax,var1
   cmp eax,var2
   jle ifpart
   mov var3,6
   mov var4,7
   jmp next
ifpart:
   mov var3,10
next:
```

There can be multiple correct solutions

Compound Expression with AND

- HLLs use short-circuit evaluation for logical AND
- If first expression is false, second expression is skipped

```
if ((al > bl) && (bl > cl)) {X = 1;}
```

```
; One Possible Implementation ...
    cmp al, bl      ; first expression ...
    ja  L1          ; unsigned comparison
    jmp next
L1: cmp bl,cl       ; second expression ...
    ja  L2          ; unsigned comparison
    jmp next
L2: mov X,1         ; both are true
next:
```

Better Implementation for AND

```
if ((al > bl) && (bl > cl)) {X = 1;}
```

The following implementation uses less code

By reversing the relational operator, We allow the program to fall through to the second expression

Number of instructions is reduced from 7 to 5

```
   cmp al,bl        ; first expression...
   jbe next         ; quit if false
   cmp bl,cl        ; second expression...
   jbe next         ; quit if false
   mov X,1          ; both are true
next:
```

Your Turn . . .

❖ Implement the following IF in assembly language

❖ All values are unsigned

```
if ((ebx <= ecx) &&
    (ecx > edx))
{
  eax = 5;
  edx = 6;
}
```

```
   cmp ebx,ecx
   ja  next
   cmp ecx,edx
   jbe next
   mov eax,5
   mov edx,6
next:
```

Application: IsDigit Procedure

Receives a character in AL

Sets the Zero flag if the character is a decimal digit

```
if (al >= '0' && al <= '9') {ZF = 1;}
```

```
IsDigit PROC
    cmp   al,'0'     ; AL < '0' ?
    jb    L1         ; yes? ZF=0, return
    cmp   al,'9'     ; AL > '9' ?
    ja    L1         ; yes? ZF=0, return
    test  al, 0      ; ZF = 1
L1: ret
IsDigit ENDP
```

Compound Expression with OR

- ❖ HLLs use short-circuit evaluation for logical OR
- ❖ If first expression is true, second expression is skipped

```
if ((al > bl) || (bl > cl)) {X = 1;}
```

- ❖ Use fall-through to keep the code as short as possible

```
    cmp al,bl      ; is AL > BL?
    ja  L1         ; yes, execute if part
    cmp bl,cl      ; no: is BL > CL?
    jbe next       ; no: skip if part
L1: mov X,1        ; set X to 1
next:
```

WHILE Loops

A WHILE loop can be viewed as

IF statement followed by

The body of the loop, followed by

Unconditional jump to the top of the loop

```
while( eax < ebx) { eax = eax + 1; }
```

This is a possible implementation:

```
top: cmp eax,ebx         ; eax < ebx ?
     jae next            ; false? then exit loop
     inc eax             ; body of loop
     jmp top             ; repeat the loop
next:
```

Your Turn . . .

Implement the following loop, assuming unsigned integers

```
while (ebx <= var1) {
   ebx  = ebx + 5;
   var1 = var1 - 1
}
```

```
top: cmp ebx,var1     ; ebx <= var1?
     ja  next         ; false? exit loop
     add ebx,5        ; execute body of loop
     dec var1
     jmp top          ; repeat the loop
next:
```

Yet Another Solution for While

Check the loop condition at the end of the loop

No need for JMP, loop body is reduced by 1 instruction

```
while (ebx <= var1) {
   ebx  = ebx + 5;
   var1 = var1 - 1
}
```

```
     cmp ebx,var1     ; ebx <= var1?
     ja  next         ; false? exit loop
top: add ebx,5        ; execute body of loop
     dec var1
     cmp ebx, var1    ; ebx <= var1?
     jbe top          ; true? repeat the loop
next:
```

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Indirect Jump

- ❖ Direct Jump: Jump to a Labeled Destination
  - ✧ Destination address is a constant
    - ▪ Address is encoded in the jump instruction
    - ▪ Address is an offset relative to EIP (Instruction Pointer)
- ❖ Indirect jump
  - ✧ Destination address is a variable
    - ▪ Address is stored in memory
    - ▪ Address is absolute
- ❖ Syntax: **`JMP`** ***`mem32`***
  - ✧ 32-bit absolute address is stored in *mem32* for FLAT memory
- ❖ Indirect jump is used to implement switch statements

Switch Statement

❖ Consider the following switch statement:

```
Switch (ch) {
  case '0': exit();
  case '1': count++; break;
  case '2': count--; break;
  case '3': count += 5; break;
  case '4': count -= 5; break;
  default : count = 0;
}
```

❖ How to translate above statement into assembly code?

❖ We can use a sequence of compares and jumps

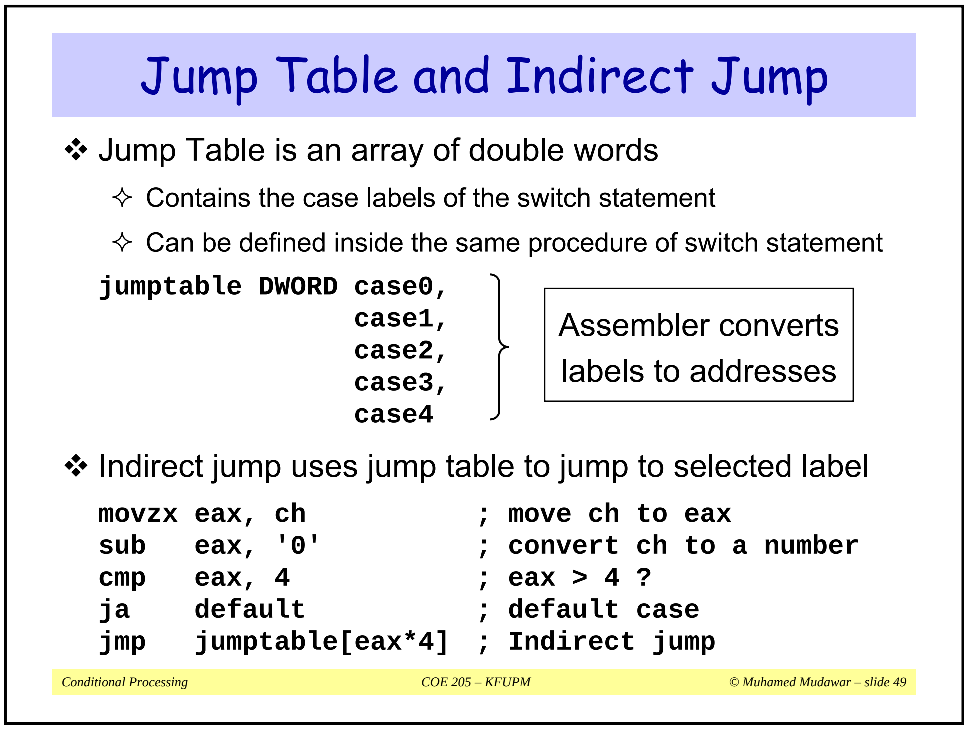
❖ A better solution is to use the indirect jump

Implementing the Switch Statement

```
case0:
    exit
case1:
    inc count
    jmp exitswitch
case2:
    dec count
    jmp exitswitch
case3:
    add count, 5
    jmp exitswitch
case4:
    sub count, 5
    jmp exitswitch
default:
    mov count, 0
exitswitch:
```

There are many case labels. How to jump to the correct one?

Answer: Define a jump table and use indirect jump to jump to the correct label



Jump Table and Indirect Jump

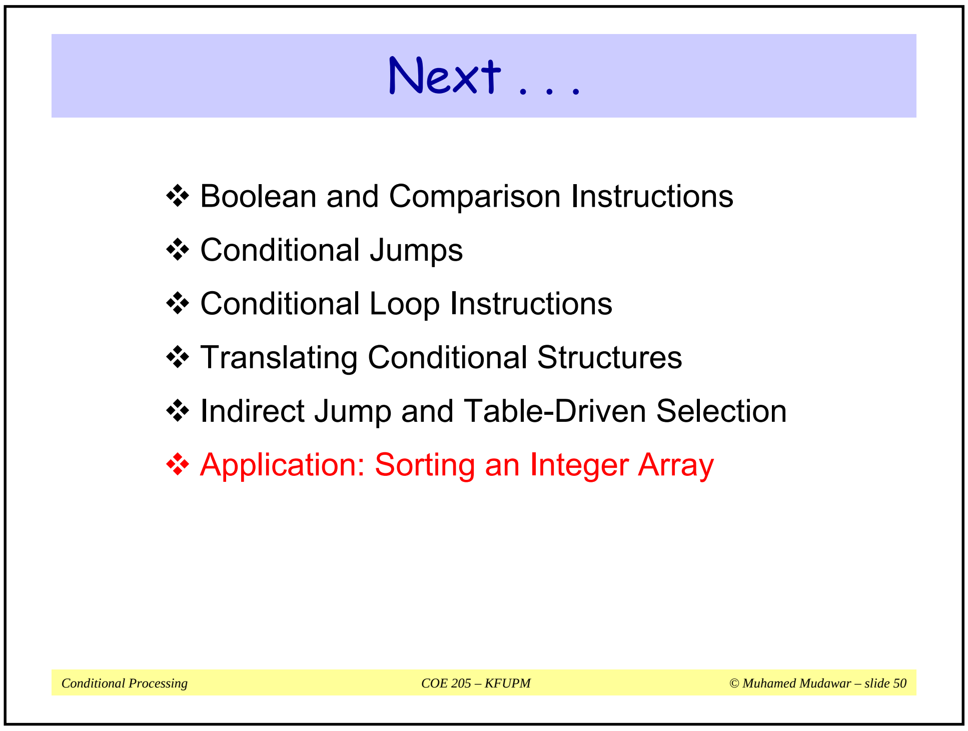
- ❖ Jump Table is an array of double words
  - ✧ Contains the case labels of the switch statement
  - ✧ Can be defined inside the same procedure of switch statement

```
jumptable DWORD case0,
                case1,
                case2,
                case3,
                case4
```

Assembler converts labels to addresses

- ❖ Indirect jump uses jump table to jump to selected label

```
movzx eax, ch              ; move ch to eax
sub   eax, '0'             ; convert ch to a number
cmp   eax, 4               ; eax > 4 ?
ja    default              ; default case
jmp   jumptable[eax*4]     ; Indirect jump
```



Next . . .

- ❖ Boolean and Comparison Instructions
- ❖ Conditional Jumps
- ❖ Conditional Loop Instructions
- ❖ Translating Conditional Structures
- ❖ Indirect Jump and Table-Driven Selection
- ❖ Application: Sorting an Integer Array

Bubble Sort

❖ Consider sorting an array of 5 elements: 5 1 3 2 4

First Pass (4 comparisons)	5 1 3 2 4	
Compare 5 with 1 and swap:	1 5 3 2 4	(swap)
Compare 5 with 3 and swap:	1 3 5 2 4	(swap)
Compare 5 with 2 and swap:	1 3 2 5 4	(swap)
Compare 5 with 4 and swap:	1 3 2 4 5	(swap)
	largest	
Second Pass (3 comparisons)		
Compare 1 with 3 (No swap):	1 3 2 4 5	(no swap)
Compare 3 with 2 and swap:	1 2 3 4 5	(swap)
Compare 3 with 4 (No swap):	1 2 3 4 5	(no swap)
Third Pass (2 comparisons)		
Compare 1 with 2 (No swap):	1 2 3 4 5	(no swap)
Compare 2 with 3 (No swap):	1 2 3 4 5	(no swap)

No swapping during 3rd pass ⇒ array is now sorted

Bubble Sort Algorithm

❖ Algorithm: Sort *array* of given *size*

```
bubbleSort(array, size) {
  comparisons = size
  do {
    comparisons--;
    sorted = true;    // assume initially
    for (i = 0; i<comparisons; i++) {
      if (array[i] > array[i+1]) {
        swap(array[i], array[i+1]);
        sorted = false;
      }
    }
  } while (! sorted)
}
```

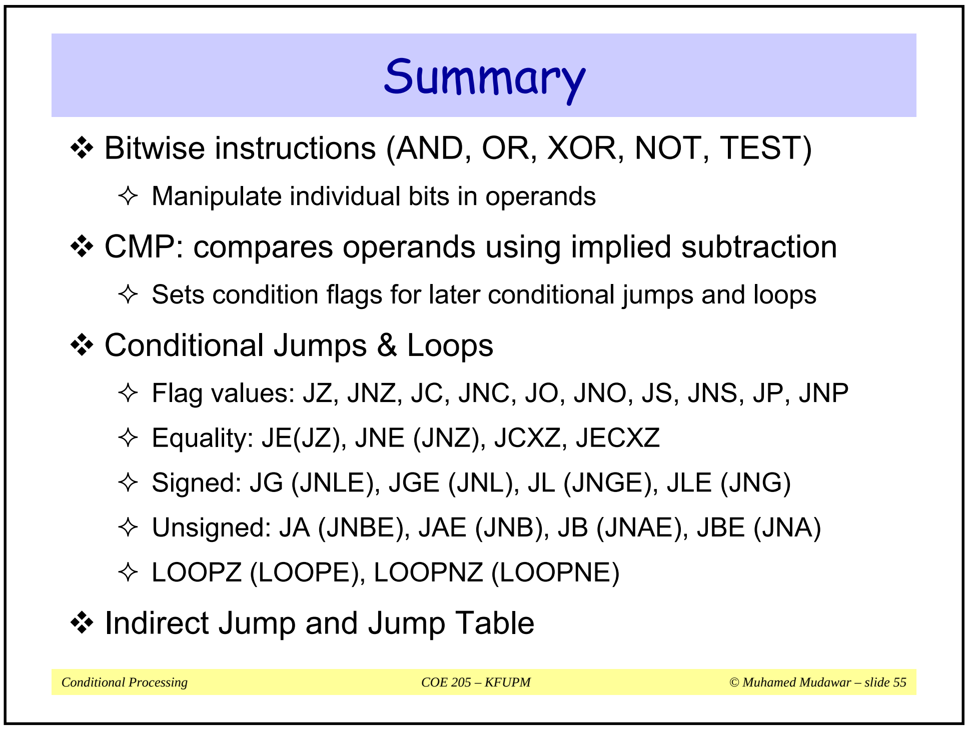
Bubble Sort Procedure - Slide 1 of 2

```
;---------------------------------------------------
; bubbleSort: Sorts a DWORD array in ascending order
;             Uses the bubble sort algorithm
; Receives:   ESI = Array Address
;             ECX = Array Length
; Returns:    Array is sorted in place
;---------------------------------------------------

bubbleSort PROC USES eax ecx edx
outerloop:
   dec  ECX        ; ECX = comparisons
   jz   sortdone   ; if ECX == 0 then we are done
   mov  EDX, 1     ; EDX = sorted = 1 (true)
   push ECX        ; save ECX = comparisons
   push ESI        ; save ESI = array address
```

Bubble Sort Procedure - Slide 2 of 2

```
innerloop:
   mov  EAX,[ESI]
   cmp  EAX,[ESI+4]    ; compare [ESI] and [ESI+4]
   jle  increment      ; [ESI]<=[ESI+4]? don't swap
   xchg EAX,[ESI+4]    ; swap [ESI] and [ESI+4]
   mov  [ESI],EAX
   mov  EDX,0          ; EDX = sorted = 0 (false)
increment:
   add  ESI,4          ; point to next element
   loop innerloop      ; end of inner loop
   pop  ESI            ; restore ESI = array address
   pop  ECX            ; restore ECX = comparisons
   cmp  EDX,1          ; sorted == 1?
   jne  outerloop      ; No? loop back
sortdone:
   ret                 ; return
bubbleSort ENDP
```



Summary

- ❖ Bitwise instructions (AND, OR, XOR, NOT, TEST)
  - ✧ Manipulate individual bits in operands
- ❖ CMP: compares operands using implied subtraction
  - ✧ Sets condition flags for later conditional jumps and loops
- ❖ Conditional Jumps & Loops
  - ✧ Flag values: JZ, JNZ, JC, JNC, JO, JNO, JS, JNS, JP, JNP
  - ✧ Equality: JE(JZ), JNE (JNZ), JCXZ, JECXZ
  - ✧ Signed: JG (JNLE), JGE (JNL), JL (JNGE), JLE (JNG)
  - ✧ Unsigned: JA (JNBE), JAE (JNB), JB (JNAE), JBE (JNA)
  - ✧ LOOPZ (LOOPE), LOOPNZ (LOOPNE)
- ❖ Indirect Jump and Jump Table