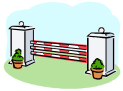
Chapter 6:
Conditional Processing

CS 238

Amarnath Jasti

Chapter Overview

- Boolean and Comparison Instructions
- Conditional Jumps
- Conditional Loop Instructions
- Conditional Structures
- Application: Finite-State Machines



Boolean and Comparison Instructions

- CPU Status Flags
- AND Instruction
- OR Instruction
- XOR Instruction
- NOT Instruction
- Applications
- TEST Instruction
- CMP Instruction

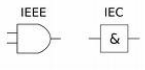
Status Flags - Review

- The Zero flag is set when the result of an operation equals zero.
- The Carry flag is set when an instruction generates a result that is too large (or too small) for the destination operand.
- The Sign flag is set if the destination operand is negative, and it is clear if the destination operand is positive.
- The Overflow flag is set when an instruction generates an invalid signed result.
- Less important:
  - The Parity flag is set when an instruction generates an even number of 1 bits in the low byte of the destination operand.
  - The Auxiliary Carry flag is set when an operation produces a carry out from bit 3 to bit 4

AND Instruction

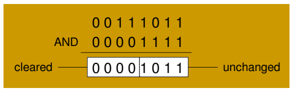
- Performs a Boolean AND operation between each pair of matching bits in two operands
- Syntax:

  AND *destination, source*



AND

x	y	x ∧ y
0	0	0
0	1	0
1	0	0
1	1	1

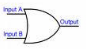


```
        0 0 1 1 1 0 1 1
AND     0 0 0 0 1 1 1 1
cleared 0 0 0 0 1 0 1 1 unchanged
```

OR Instruction

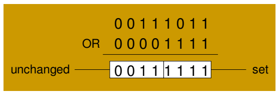
- Performs a Boolean OR operation between each pair of matching bits in two operands
- Syntax:

  OR *destination, source*



OR

x	y	x ∨ y
0	0	0
0	1	1
1	0	1
1	1	1

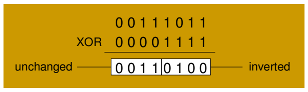


```
          0 0 1 1 1 0 1 1
OR        0 0 0 0 1 1 1 1
unchanged 0 0 1 1 1 1 1 1 set
```

XOR Instruction

- Performs a Boolean exclusive-OR operation between each pair of matching bits in two operands
- Syntax:

  XOR *destination, source*


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

XOR

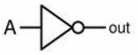
x	y	x ⊕ y
0	0	0
0	1	1
1	0	1
1	1	0

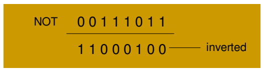
XOR is a useful way to toggle (invert) the bits in an operand.

NOT Instruction

- Performs a Boolean NOT operation on a single destination operand
- Syntax:

  NOT *destination*




```
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

Applications (1 of 5)

- Task: Convert the character in AL to upper case.
- Solution: Use the AND instruction to clear bit 5.

```
mov al,'a'                    ; AL = 01100001b
and al,11011111b              ; AL = 01000001b
```

Applications (2 of 5)

- Task: Convert a binary decimal byte into its equivalent ASCII decimal digit.
- Solution: Use the OR instruction to set bits 4 and 5.

```
mov al,6                      ; AL = 00000110b
or  al,00110000b              ; AL = 00110110b
```

The ASCII digit '6' = 00110110b

Applications (3 of 5)

- Task: Turn on the keyboard CapsLock key
- Solution: Use the OR instruction to set bit 6 in the keyboard flag byte at 0040:0017h in the BIOS data area.

```
mov ax,40h                    ; BIOS segment
mov ds,ax
mov bx,17h                    ; keyboard flag byte
or BYTE PTR [bx],01000000b    ; CapsLock on
```

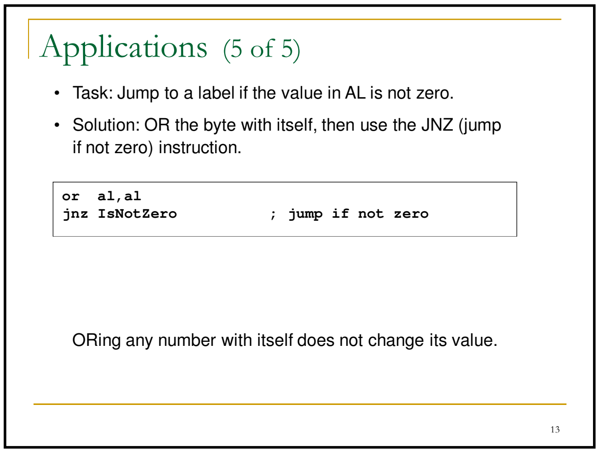
This code only runs in Real-address mode, and it does not work under Windows NT, 2000, or XP.

Applications (4 of 5)

- Task: Jump to a label if an integer is even.
- Solution: AND the lowest bit with a 1. If the result is Zero, the number was even.

```
mov ax,wordVal
and ax,1               ; low bit set?
jz  EvenValue          ; jump if Zero flag set
```

JZ (jump if Zero) is covered later in chapter 6.

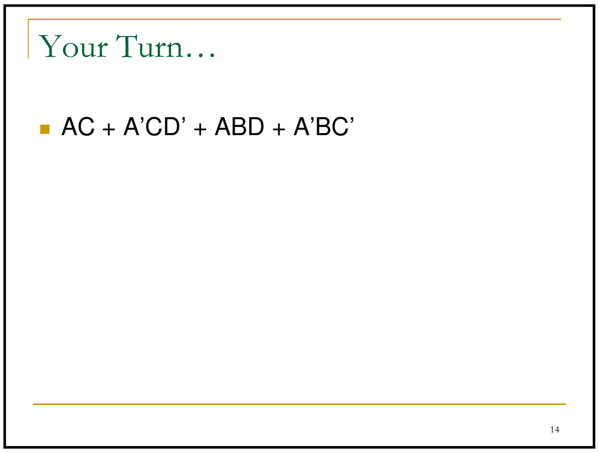


Applications (5 of 5)

- Task: Jump to a label if the value in AL is not zero.
- Solution: OR the byte with itself, then use the JNZ (jump if not zero) instruction.

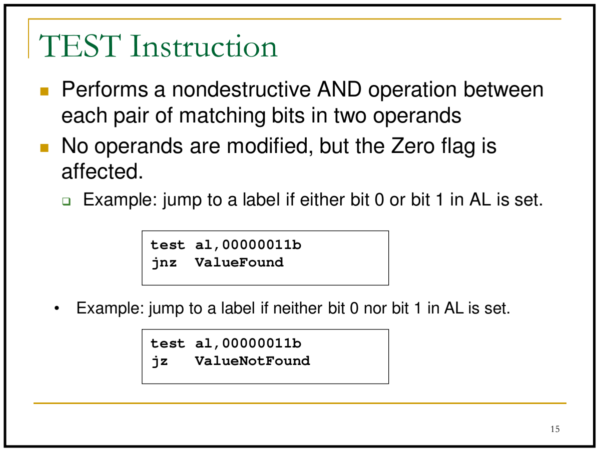
```
or  al,al
jnz IsNotZero           ; jump if not zero
```

ORing any number with itself does not change its value.



Your Turn…

- AC + A’CD’ + ABD + A’BC’



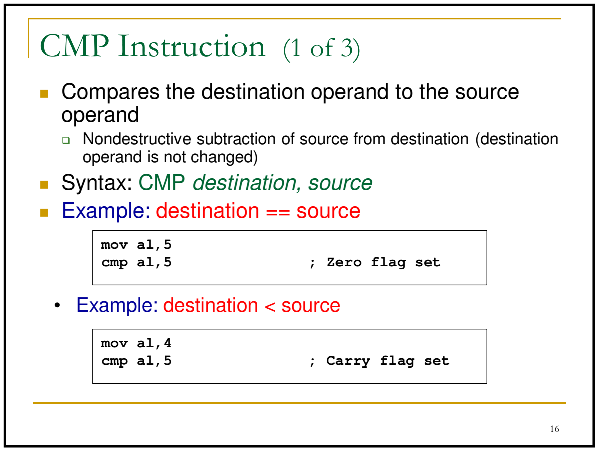
TEST Instruction

- Performs a nondestructive AND operation between each pair of matching bits in two operands
- No operands are modified, but the Zero flag is affected.
  - Example: jump to a label if either bit 0 or bit 1 in AL is set.

```
test al,00000011b
jnz  ValueFound
```

- Example: jump to a label if neither bit 0 nor bit 1 in AL is set.

```
test al,00000011b
jz   ValueNotFound
```



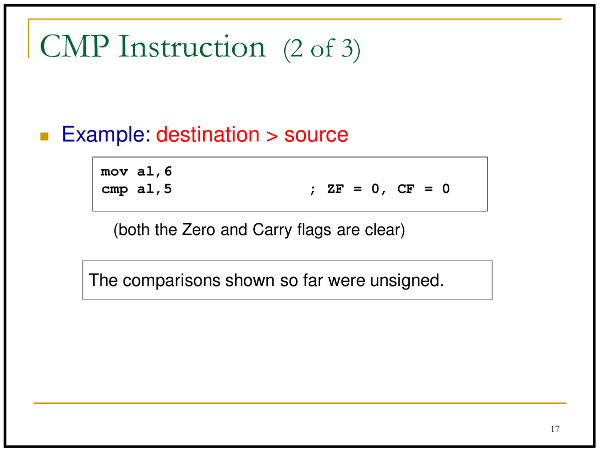
CMP Instruction (1 of 3)

- Compares the destination operand to the source operand
  - Nondestructive subtraction of source from destination (destination operand is not changed)
- Syntax: CMP *destination, source*
- Example: destination == source

```
mov al,5
cmp al,5                 ; Zero flag set
```

- Example: destination < source

```
mov al,4
cmp al,5                 ; Carry flag set
```



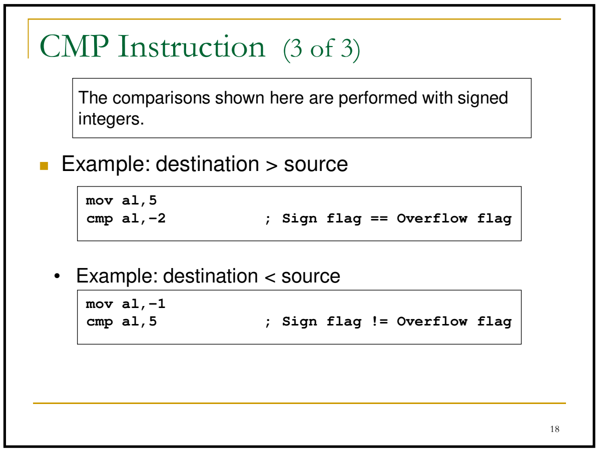
CMP Instruction (2 of 3)

- Example: destination > source

```
mov al,6
cmp al,5                ; ZF = 0, CF = 0
```

(both the Zero and Carry flags are clear)

The comparisons shown so far were unsigned.



CMP Instruction (3 of 3)

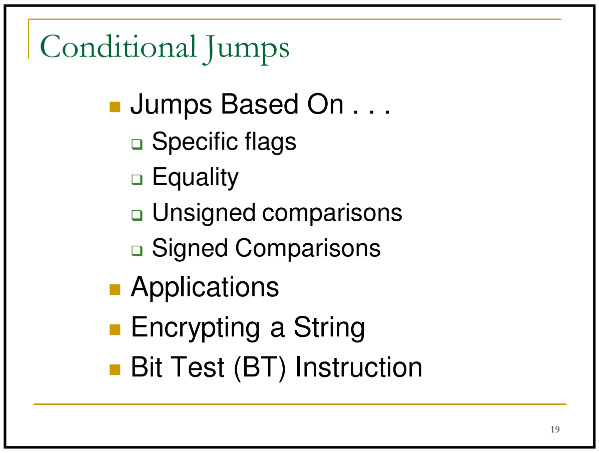
The comparisons shown here are performed with signed integers.

- Example: destination > source

```
mov al,5
cmp al,-2          ; Sign flag == Overflow flag
```

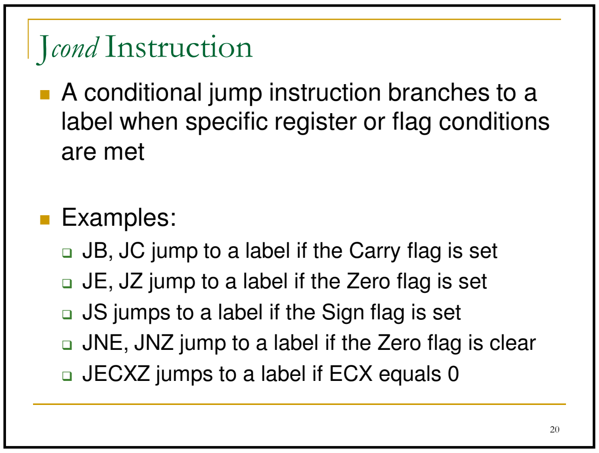
- Example: destination < source

```
mov al,-1
cmp al,5           ; Sign flag != Overflow flag
```



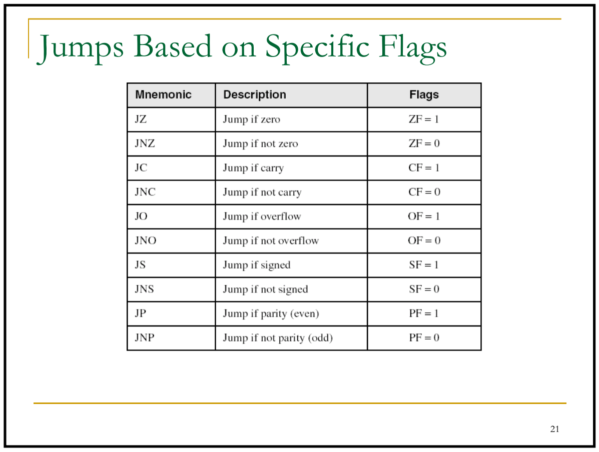
Conditional Jumps

- Jumps Based On . . .
  - Specific flags
  - Equality
  - Unsigned comparisons
  - Signed Comparisons
- Applications
- Encrypting a String
- Bit Test (BT) Instruction



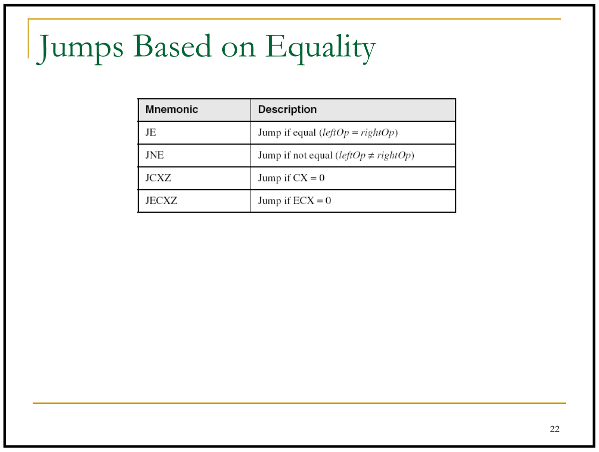
Jcond Instruction

- A conditional jump instruction branches to a label when specific register or flag conditions are met
- Examples:
  - JB, JC jump to a label if the Carry flag is set
  - JE, JZ jump to a label if the Zero flag is set
  - JS jumps to a label if the Sign flag is set
  - JNE, JNZ jump to a label if the Zero flag is clear
  - JECXZ jumps to a label if ECX equals 0



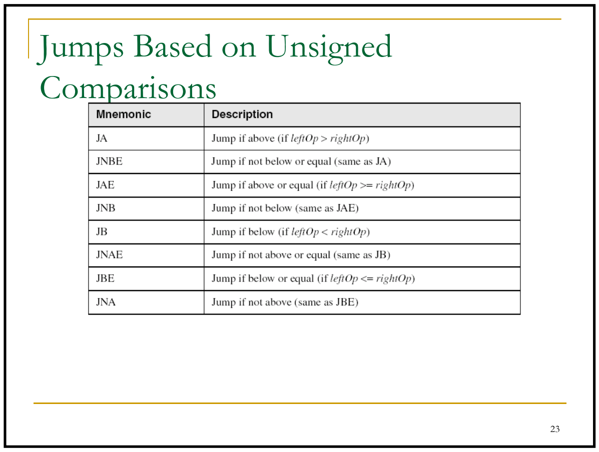
Jumps Based on Specific Flags

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



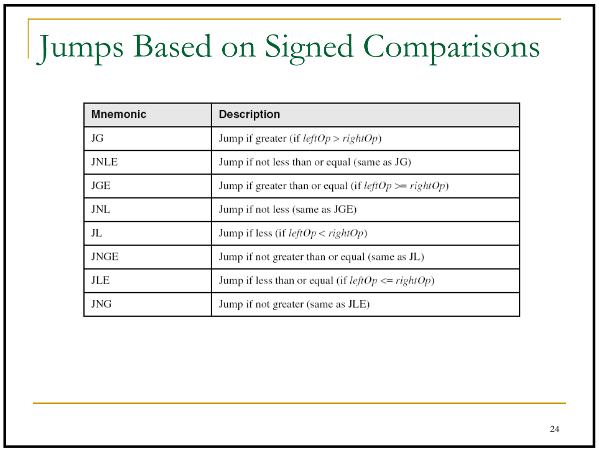
Jumps Based on Equality

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



Jumps Based on Unsigned Comparisons

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)



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)

Applications (1 of 5)

- Task: Jump to a label if unsigned EAX is greater than EBX
- Solution: Use CMP, followed by JA

```
cmp eax,ebx
ja  Larger
```

- Task: Jump to a label if signed EAX is greater than EBX
- Solution: Use CMP, followed by JG

```
cmp eax,ebx
jg  Greater
```

Applications (2 of 5)

- Jump to label L1 if unsigned EAX is less than or equal to Val1

```
cmp eax,Val1
jbe L1           ; below or equal
```

- Jump to label L1 if signed EAX is less than or equal to Val1

```
cmp eax,Val1
jle L1
```

Applications (3 of 5)

- Compare unsigned AX to BX, and copy the larger of the two into a variable named Large

```
    mov Large,bx
    cmp ax,bx
    jna Next
    mov Large,ax
Next:
```

- Compare signed AX to BX, and copy the smaller of the two into a variable named Small

```
    mov Small,ax
    cmp bx,ax
    jnl Next
    mov Small,bx
Next:
```

Applications (4 of 5)

- Jump to label L1 if the memory word pointed to by ESI equals Zero

```
    cmp WORD PTR [esi],0
    je  L1
```

- Jump to label L2 if the doubleword in memory pointed to by EDI is even

```
test DWORD PTR [edi],1
jz   L2
```

Applications (5 of 5)

- Task: Jump to label L1 if bits 0, 1, and 3 in AL are all set.
- Solution: Clear all bits except bits 0, 1,and 3. Then compare the result with 00001011 binary.

```
and al,00001011b        ; clear unwanted bits
cmp al,00001011b        ; check remaining bits
je  L1                  ; all set? jump to L1
```

Your turn . . .

- Write code that jumps to label L1 if either bit 4, 5, or 6 is set in the BL register.
- Write code that jumps to label L1 if bits 4, 5, and 6 are all set in the BL register.
- Write code that jumps to label L2 if AL has even parity.
- Write code that jumps to label L3 if EAX is negative.
- Write code that jumps to label L4 if the expression (EBX – ECX) is greater than zero.

Encrypting a String

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

```
KEY = 239
.data
buffer BYTE BUFMAX DUP(0)
bufSize DWORD ?
.code
    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
```

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

View the Encrypt.asm program's source code. Sample output:

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

BT (Bit Test) Instruction

- Copies bit *n* from an operand into the Carry flag
- Syntax: BT *bitBase, n*
  - bitBase may be *r/m16* or *r/m32*
  - n may be *r16, r32*, or *imm8*
- Example: jump to label L1 if bit 9 is set in the AX register:

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

Conditional Loop Instructions

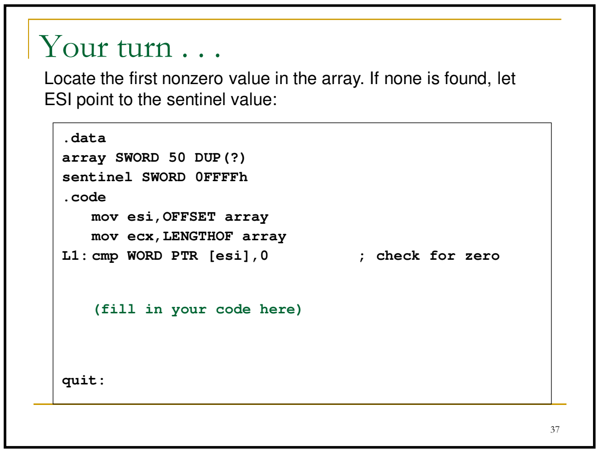
- LOOPZ and LOOPE
- LOOPNZ and LOOPNE

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

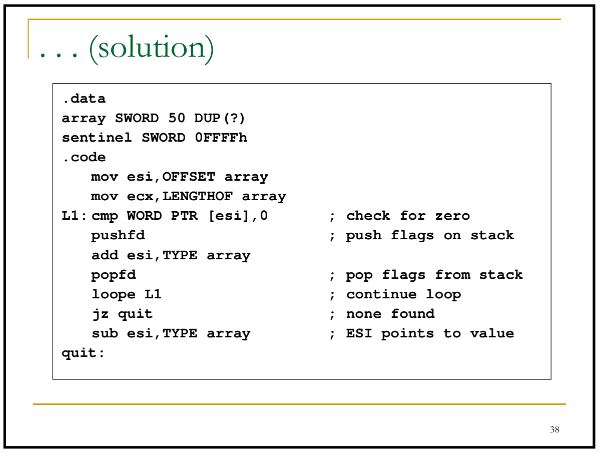
- LOOPNZ (LOOPNE) is a conditional loop instruction
- Syntax:
  LOOPNZ *destination*
  LOOPNE *destination*
- Logic:
  - ECX ← ECX – 1;
  - if ECX > 0 and ZF=0, jump to *destination*
- Useful when scanning an array for the first element that matches a given value.



Your turn . . .

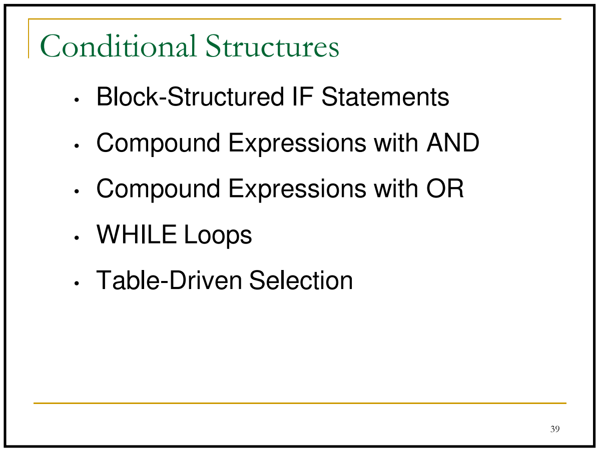
Locate the first nonzero value in the array. If none is found, let ESI point to the sentinel value:

```
.data
array SWORD 50 DUP(?)
sentinel SWORD 0FFFFh
.code
   mov esi,OFFSET array
   mov ecx,LENGTHOF array
L1: cmp WORD PTR [esi],0           ; check for zero


   (fill in your code here)



quit:
```



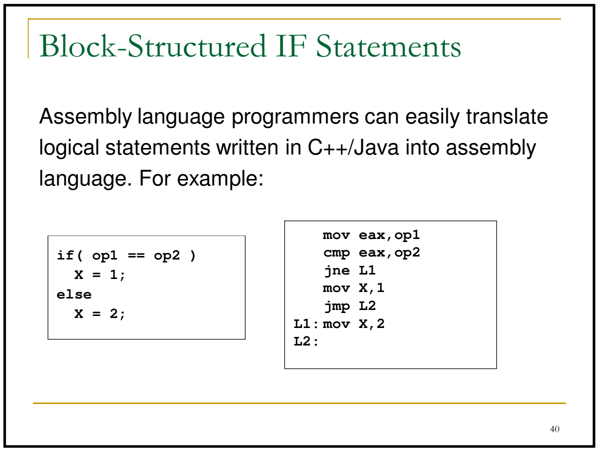
. . . (solution)

```
.data
array SWORD 50 DUP(?)
sentinel SWORD 0FFFFh
.code
   mov esi,OFFSET array
   mov ecx,LENGTHOF array
L1: cmp WORD PTR [esi],0        ; check for zero
   pushfd                       ; push flags on stack
   add esi,TYPE array
   popfd                        ; pop flags from stack
   loope L1                     ; continue loop
   jz quit                      ; none found
   sub esi,TYPE array           ; ESI points to value
quit:
```



Conditional Structures

- Block-Structured IF Statements
- Compound Expressions with AND
- Compound Expressions with OR
- WHILE Loops
- Table-Driven Selection

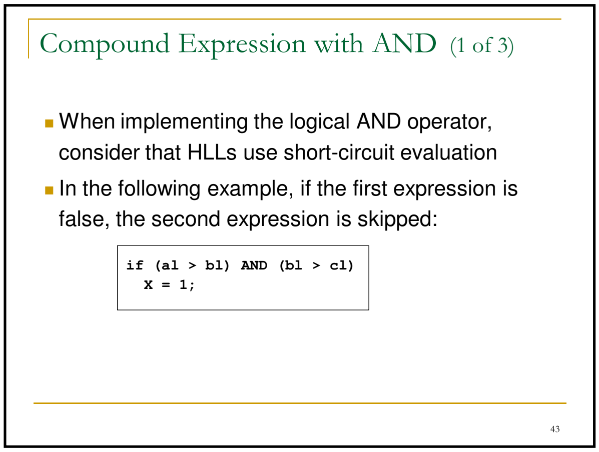


Block-Structured IF Statements

Assembly language programmers can easily translate logical statements written in C++/Java into assembly language. For example:

```
if( op1 == op2 )
  X = 1;
else
  X = 2;
```

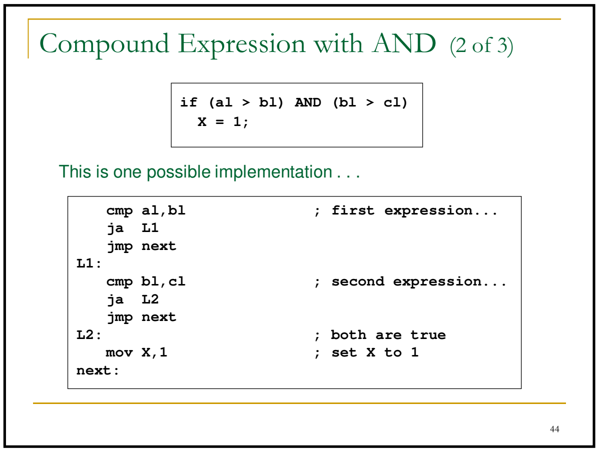
```
    mov eax,op1
    cmp eax,op2
    jne L1
    mov X,1
    jmp L2
L1: mov X,2
L2:
```



Compound Expression with AND (1 of 3)

- When implementing the logical AND operator, consider that HLLs use short-circuit evaluation
- In the following example, if the first expression is false, the second expression is skipped:

```
if (al > bl) AND (bl > cl)
  X = 1;
```

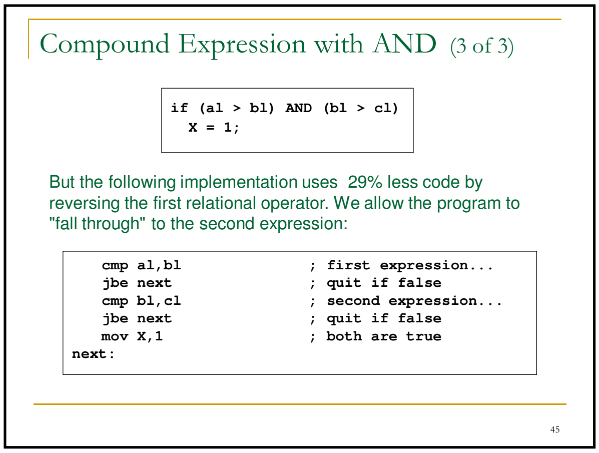


Compound Expression with AND (2 of 3)

```
if (al > bl) AND (bl > cl)
  X = 1;
```

This is one possible implementation . . .

```
   cmp al,bl                 ; first expression...
   ja  L1
   jmp next
L1:
   cmp bl,cl                 ; second expression...
   ja  L2
   jmp next
L2:                          ; both are true
   mov X,1                   ; set X to 1
next:
```

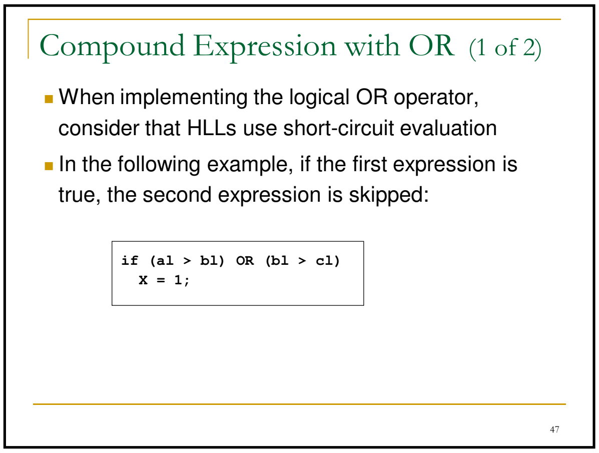


Compound Expression with AND (3 of 3)

```
if (al > bl) AND (bl > cl)
  X = 1;
```

But the following implementation uses 29% less code by reversing the first relational operator. We allow the program to "fall through" to the second expression:

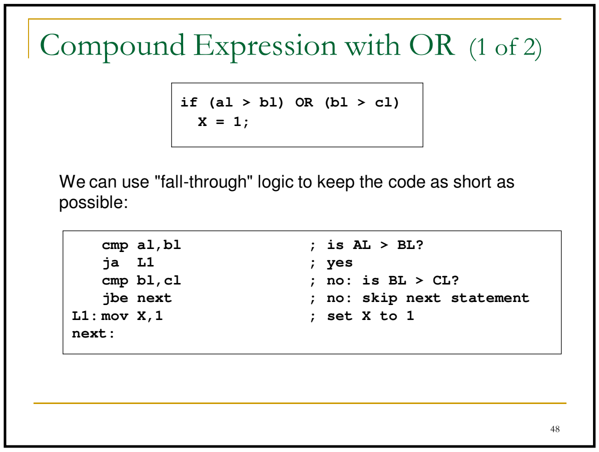
```
    cmp al,bl              ; first expression...
    jbe next               ; quit if false
    cmp bl,cl              ; second expression...
    jbe next               ; quit if false
    mov X,1                ; both are true
next:
```



Compound Expression with OR (1 of 2)

- When implementing the logical OR operator, consider that HLLs use short-circuit evaluation
- In the following example, if the first expression is true, the second expression is skipped:

```
if (al > bl) OR (bl > cl)
  X = 1;
```

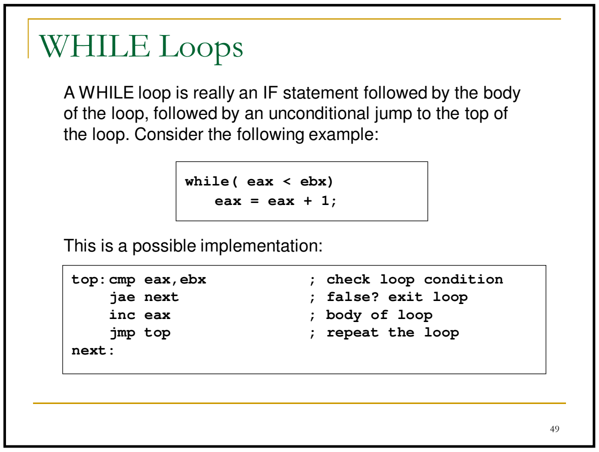


Compound Expression with OR (1 of 2)

```
if (al > bl) OR (bl > cl)
  X = 1;
```

We can use "fall-through" logic to keep the code as short as possible:

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



WHILE Loops

A WHILE loop is really an IF statement followed by the body of the loop, followed by an unconditional jump to the top of the loop. Consider the following example:

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

This is a possible implementation:

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

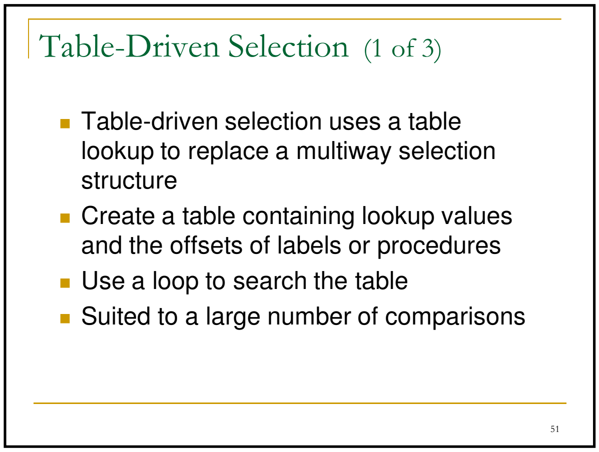


Table-Driven Selection (1 of 3)

- Table-driven selection uses a table lookup to replace a multiway selection structure
- Create a table containing lookup values and the offsets of labels or procedures
- Use a loop to search the table
- Suited to a large number of comparisons

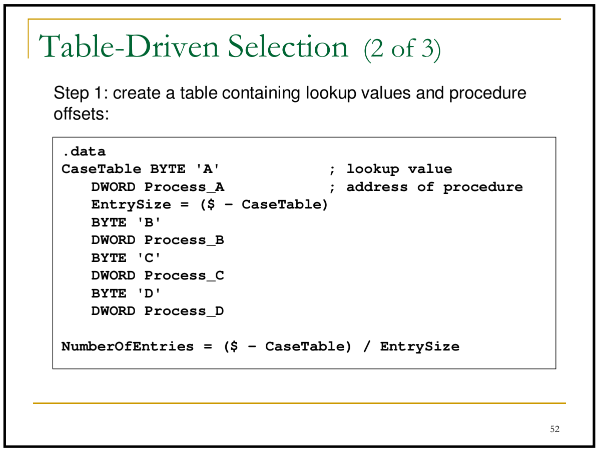


Table-Driven Selection (2 of 3)

Step 1: create a table containing lookup values and procedure offsets:

```
.data
CaseTable BYTE 'A'              ; lookup value
   DWORD Process_A              ; address of procedure
   EntrySize = ($ - CaseTable)
   BYTE 'B'
   DWORD Process_B
   BYTE 'C'
   DWORD Process_C
   BYTE 'D'
   DWORD Process_D

NumberOfEntries = ($ - CaseTable) / EntrySize
```

Table-Driven Selection (3 of 3)

Step 2: Use a loop to search the table. When a match is found, we call the procedure offset stored in the current table entry:

```
    mov ebx,OFFSET CaseTable        ; point EBX to the table
    mov ecx,NumberOfEntries         ; loop counter

L1: cmp al,[ebx]                    ; match found?
    jne L2                          ; no: continue
    call NEAR PTR [ebx + 1]         ; yes: call the procedure
    jmp L3                          ; and exit the loop
L2: add ebx,EntrySize               ; point to next entry
    loop L1                         ; repeat until ECX = 0

L3:
```

required for procedure pointers

Application: Finite-State Machines

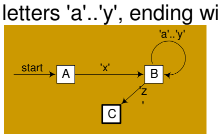
- A finite-state machine (FSM) is a graph structure that changes state based on some input. Also called a state-transition diagram.
- We use a graph to represent an FSM, with squares or circles called nodes, and lines with arrows between the circles called edges (or arcs).
- A FSM is a specific instance of a more general structure called a directed graph (or digraph).
- Three basic states, represented by nodes:
  - Start state
  - Terminal state(s)
  - Nonterminal state(s)

Finite-State Machine

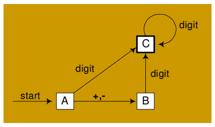
- Accepts any sequence of symbols that puts it into an accepting (final) state
- Can be used to recognize, or validate a sequence of characters that is governed by language rules (called a regular expression)
- Advantages:
  - Provides visual tracking of program's flow of control
  - Easy to modify
  - Easily implemented in assembly language

FSM Examples

- FSM that recognizes strings beginning with 'x', followed by letters 'a'..'y', ending with 'z':



- FSM that recognizes signed integers:



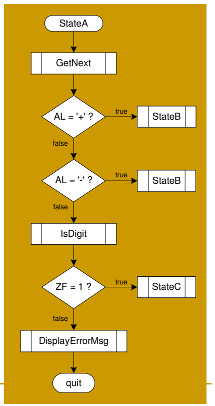
Implementing an FSM

The following is code from State A in the Integer FSM:

```
StateA:
    call Getnext            ; read next char into AL
    cmp al,'+'              ; leading + sign?
    je StateB               ; go to State B
    cmp al,'-'              ; leading - sign?
    je StateB               ; go to State B
    call IsDigit            ; ZF = 1 if AL = digit
    jz StateC               ; go to State C
    call DisplayErrorMsg    ; invalid input found
    jmp Quit
```

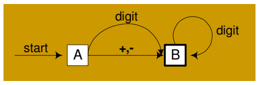
Flowchart of State A

State A accepts a plus or minus sign, or a decimal digit.



Your turn . . .

- Explain why the following FSM does not work as well for signed integers as the one shown on the previous slide:



Your turn . . .

- Draw a FSM diagram for hexadecimal integer constant that conforms to MASM syntax.
- Draw a flowchart for one of the states in your FSM.
- Implement your FSM in assembly language. Let the user input a hexadecimal constant from the keyboard.

Using the .IF Directive

- Runtime Expressions
- Relational and Logical Operators
- MASM-Generated Code
- .REPEAT Directive
- .WHILE Directive

Runtime Expressions

- .IF, .ELSE, .ELSEIF, and .ENDIF can be used to evaluate runtime expressions and create block-structured IF statements.
- Examples:

```
.IF eax > ebx
    mov edx,1
.ELSE
    mov edx,2
.ENDIF
```

```
.IF eax > ebx && eax > ecx
    mov edx,1
.ELSE
    mov edx,2
.ENDIF
```

- MASM generates "hidden" code for you, consisting of code labels, CMP and conditional jump instructions.

Relational and Logical Operators

Operator	Description
expr1 == *expr2*	Returns true when *expression1* is equal to *expr2*.
expr1 != *expr2*	Returns true when *expr1* is not equal to *expr2*.
expr1 > *expr2*	Returns true when *expr1* is greater than *expr2*.
expr1 >= *expr2*	Returns true when *expr1* is greater than or equal to *expr2*.
expr1 < *expr2*	Returns true when *expr1* is less than *expr2*.
expr1 <= *expr2*	Returns true when *expr1* is less than or equal to *expr2*.
! *expr*	Returns true when *expr* is false.
expr1 && *expr2*	Performs logical AND between *expr1* and *expr2*.
expr1 || *expr2*	Performs logical OR between *expr1* and *expr2*.
expr1 & *expr2*	Performs bitwise AND between *expr1* and *expr2*.
CARRY?	Returns true if the Carry flag is set.
OVERFLOW?	Returns true if the Overflow flag is set.
PARITY?	Returns true if the Parity flag is set.
SIGN?	Returns true if the Sign flag is set.
ZERO?	Returns true if the Zero flag is set.

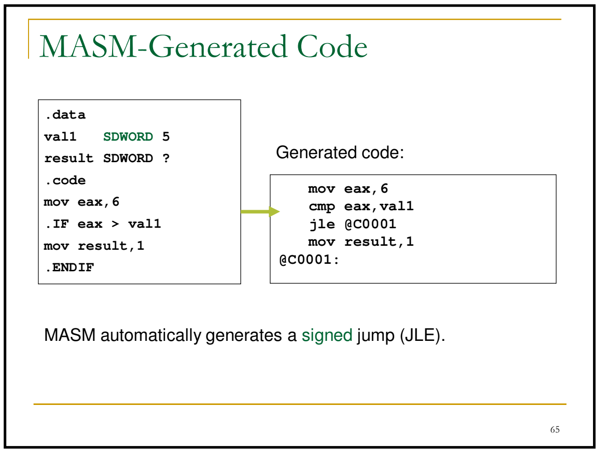
MASM-Generated Code

```
.data
val1   DWORD 5
result DWORD ?
.code
mov eax,6
.IF eax > val1
mov result,1
.ENDIF
```

Generated code:

```
    mov eax,6
    cmp eax,val1
    jbe @C0001
    mov result,1
@C0001:
```

MASM automatically generates an unsigned jump (JBE).



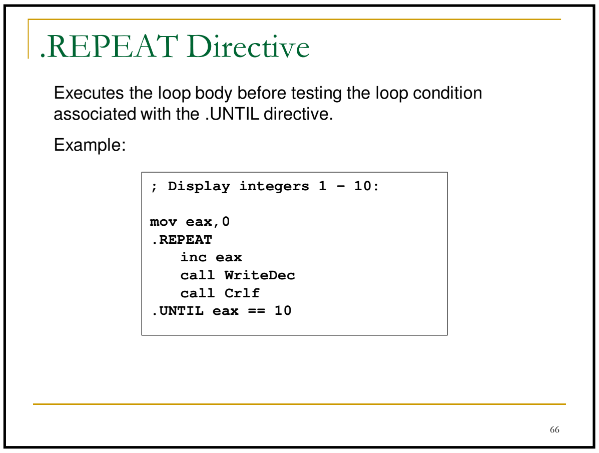
MASM-Generated Code

```
.data
val1   SDWORD 5
result SDWORD ?
.code
mov eax,6
.IF eax > val1
mov result,1
.ENDIF
```

Generated code:

```
    mov eax,6
    cmp eax,val1
    jle @C0001
    mov result,1
@C0001:
```

MASM automatically generates a signed jump (JLE).

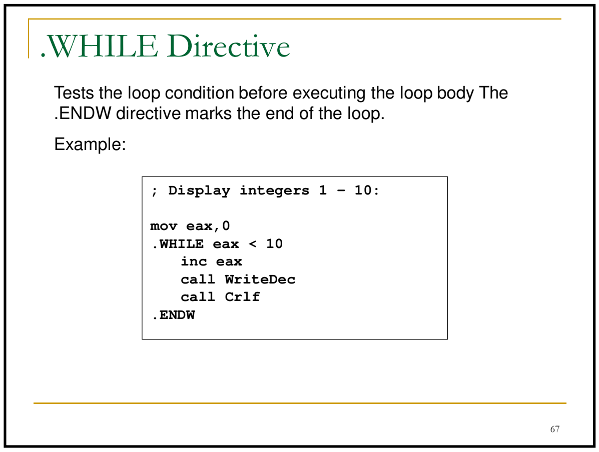


.REPEAT Directive

Executes the loop body before testing the loop condition associated with the .UNTIL directive.

Example:

```
; Display integers 1 – 10:

mov eax,0
.REPEAT
   inc eax
   call WriteDec
   call Crlf
.UNTIL eax == 10
```

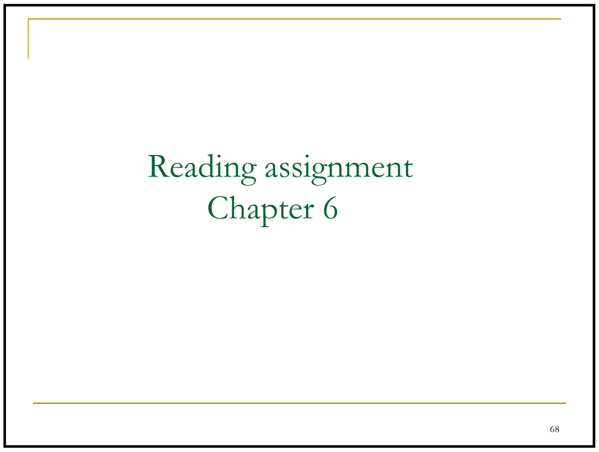


.WHILE Directive

Tests the loop condition before executing the loop body The .ENDW directive marks the end of the loop.

Example:

```
; Display integers 1 – 10:

mov eax,0
.WHILE eax < 10
   inc eax
   call WriteDec
   call Crlf
.ENDW
```



Reading assignment
Chapter 6