Assembly Language for Intel-Based Computers, 4th Edition

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Lecture 28: Strings and Arrays

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- Chapter corrections (Web)   Assembly language sources (Web)

Chapter Overview

- String Primitive Instructions
- Selected String Procedures
- Two-Dimensional Arrays
- Searching and Sorting Integer Arrays

String Primitive Instructions

- MOVSB, MOVSW, and MOVSD
- CMPSB, CMPSW, and CMPSD
- SCASB, SCASW, and SCASD
- STOSB, STOSW, and STOSD
- LODSB, LODSW, and LODSD

MOVSB, MOVSW, and MOVSD (1 of 2)

- The MOVSB, MOVSW, and MOVSD instructions copy data from the memory location pointed to by ESI to the memory location pointed to by EDI.

```
.data
source DWORD 0FFFFFFFFh
target DWORD ?
.code
mov esi,OFFSET source
mov edi,OFFSET target
movsd
```

MOVSB, MOVSW, and MOVSD (2 of 2)

- ESI and EDI are automatically incremented or decremented:
  - MOVSB increments/decrements by 1
  - MOVSW increments/decrements by 2
  - MOVSD increments/decrements by 4

Direction Flag

- The Direction flag controls the incrementing or decrementing of ESI and EDI.
  - DF = clear (0): increment ESI and EDI
  - DF = set (1): decrement ESI and EDI

The Direction flag can be explicitly changed using the CLD and STD instructions:

```
CLD        ; clear Direction flag
STD        ; set Direction flag
```

Using a Repeat Prefix

- REP (a repeat prefix) can be inserted just before MOVSB, MOVSW, or MOVSD.
- ECX controls the number of repetitions
- Example: Copy 20 doublewords from source to target

```
.data
source DWORD 20 DUP(?)
target DWORD 20 DUP(?)
.code
cld                         ; direction = forward
mov ecx,LENGTHOF source     ; set REP counter
mov esi,OFFSET source
mov edi,OFFSET target
rep movsd
```

Your turn . . .

- Use MOVSD to delete the first element of the following doubleword array. All subsequent array values must be moved one position forward toward the beginning of the array:

```
array DWORD 1,1,2,3,4,5,6,7,8,9,10
```

```
.data
array DWORD 1,1,2,3,4,5,6,7,8,9,10
.code
cld
mov ecx,(LENGTHOF array) - 1
mov esi,OFFSET array+4
mov edi,OFFSET array
rep movsd
```

CMPSB, CMPSW, and CMPSD

- The CMPSB, CMPSW, and CMPSD instructions each compare a memory operand pointed to by ESI to a memory operand pointed to by EDI.
  - CMPSB compares bytes
  - CMPSW compares words
  - CMPSD compares doublewords
- Repeat prefix (REP) is often used

Comparing a Pair of Doublewords

If source > target, the code jumps to label L1; otherwise, it jumps to label L2

```
.data
source DWORD 1234h
target DWORD 5678h

.code
mov esi,OFFSET source
mov edi,OFFSET target
cmpsd                 ; compare doublewords
ja L1                 ; jump if source > target
jmp L2                ; jump if source <= target
```

Your turn . . .

- Modify the program in the previous slide by declaring both source and target as WORD variables. Make any other necessary changes.

Comparing Arrays

Use a REPE (repeat while equal) prefix to compare corresponding elements of two arrays.

```
.data
source DWORD COUNT DUP(?)
target DWORD COUNT DUP(?)
.code
mov ecx,COUNT                ; repetition count
mov esi,OFFSET source
mov edi,OFFSET target
cld                          ; direction = forward
repe cmpsd                   ; repeat while equal
```

Example: Comparing Two Strings (1 of 3)

This program compares two strings (source and destination). It displays a message indicating whether the lexical value of the source string is less than the destination string.

```
.data
source BYTE "MARTIN  "
dest BYTE "MARTINEZ"
str1 BYTE "Source is smaller",0dh,0ah,0
str2 BYTE "Source is not smaller",0dh,0ah,0
```

Screen output:

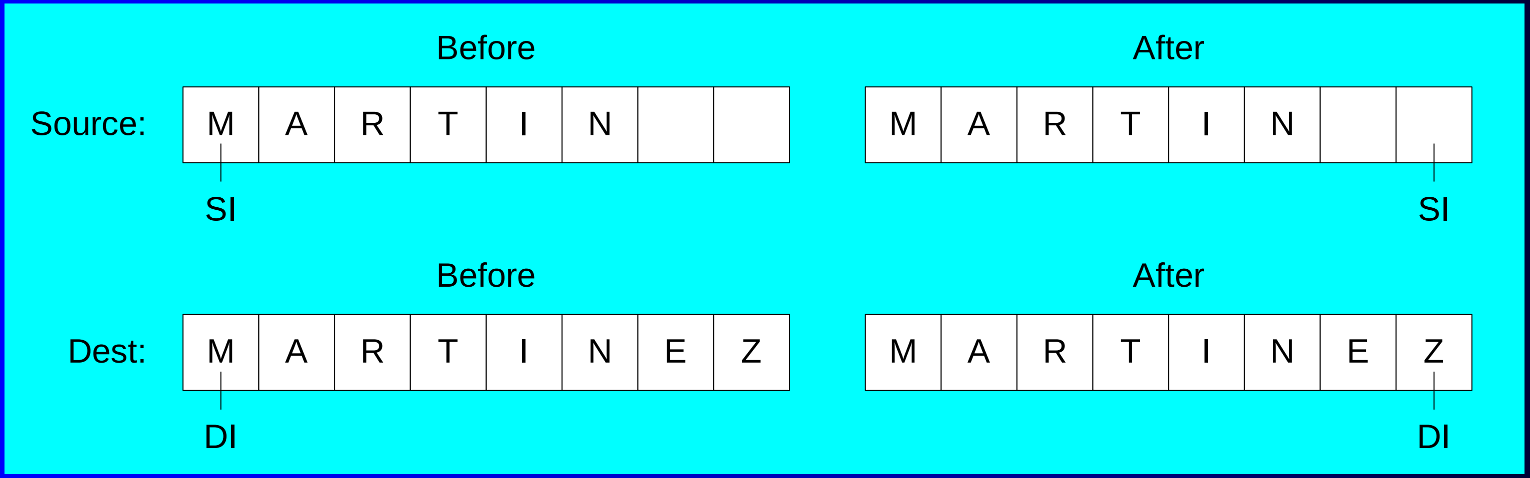
```
Source is smaller
```

Example: Comparing Two Strings (2 of 3)

```
.code
main PROC
    cld                             ; direction = forward
    mov esi,OFFSET source
    mov edi,OFFSET dest
    mov cx,LENGTHOF source
    repe cmpsb
    jb source_smaller
    mov edx,OFFSET str2             ; "source is not smaller"
    jmp done
source_smaller:
    mov edx,OFFSET str1             ; "source is smaller"
done:
    call WriteString
    exit
main ENDP
END main
```

Example: Comparing Two Strings (3 of 3)

- The following diagram shows the final values of ESI and EDI after comparing the strings:



Your turn . . .

- Modify the String Comparison program from the previous two slides. Prompt the user for both the source and destination strings.
- Sample output:

```
Input first string:  ABCDEFG
Input second string: ABCDDG

The first string is not smaller.
```

Console screen (template)

```
Source is smaller
```

SCASB, SCASW, and SCASD

- The SCASB, SCASW, and SCASD instructions compare a value in AL/AX/EAX to a byte, word, or doubleword, respectively, addressed by EDI.
- Useful types of searches:
  - Search for a specific element in a long string or array.
  - Search for the first element that does not match a given value.

SCASB Example

Search for the letter 'F' in a string named alpha:

```
.data
alpha BYTE "ABCDEFGH",0
.code
mov edi,OFFSET alpha
mov al,'F'                    ; search for 'F'
mov ecx,LENGTHOF alpha
cld
repne scasb                   ; repeat while not equal
jnz quit
dec edi                       ; EDI points to 'F'
```

What is the purpose of the JNZ instruction?

STOSB, STOSW, and STOSD

- The STOSB, STOSW, and STOSD instructions store the contents of AL/AX/EAX, respectively, in memory at the offset pointed to by EDI.
- Example: fill an array with 0FFh

```
.data
Count = 100
string1 BYTE Count DUP(?)
.code
mov al,0FFh                 ; value to be stored
mov edi,OFFSET string1      ; ES:DI points to target
mov ecx,Count               ; character count
cld                         ; direction = forward
rep stosb                   ; fill with contents of AL
```

LODSB, LODSW, and LODSD

- The LODSB, LODSW, and LODSD instructions load a byte or word from memory at ESI into AL/AX/EAX, respectively.

```
.data
array 1,2,3,4,5,6,7,8,9
dest  9 DUP(?)
.code
    mov esi,OFFSET array
    mov edi,OFFSET dest
    mov ecx,LENGTHOF array
    cld
L1: lodsb
    or al,30h
    stosb
    loop L1
```

Array Multiplication Example

Multiply each element of a doubleword array by a constant value.

```
.data
array DWORD 1,2,3,4,5,6,7,8,9,10
multiplier DWORD 10
.code
    cld                           ; direction = up
    mov esi,OFFSET array          ; source index
    mov edi,esi                   ; destination index
    mov ecx,LENGTHOF array        ; loop counter

L1: lodsd                         ; copy [ESI] into EAX
    mul multiplier                ; multiply by a value
    stosd                         ; store EAX at [EDI]
    loop L1
```

Your turn . . .

- Write a program that converts each unpacked binary-coded decimal byte belonging to an array into an ASCII decimal byte and copies it to a new array.

```
.data
array BYTE 1,2,3,4,5,6,7,8,9
dest  BYTE (LENGTHOF array) DUP(?)
```

```
    mov esi,OFFSET array
    mov edi,OFFSET dest
    mov ecx,LENGTHOF array
    cld
L1: lodsb                       ; load into AL
    or al,30h                   ; convert to ASCII
    stosb                       ; store into memory
    loop L1
```

Selected String Procedures

The following string procedures may be found in the Irvine32 and Irvine16 libraries:

- Str_compare Procedure
- Str_length Procedure
- Str_copy Procedure
- Str_trim Procedure
- Str_ucase Procedure

Str_compare Procedure

- Compares *string1* to *string2*, setting the Carry and Zero flags accordingly
- Prototype:

```
Str_compare PROTO,
  string1:PTR BYTE,         ; pointer to string
  string2:PTR BYTE          ; pointer to string
```

For example, if string1 > string2, CF=0, ZF=0

Or, if string1 < string2, CF=1, ZF=0

Str_compare Source Code

```
Str_compare PROC USES eax edx esi edi,
      string1:PTR BYTE, string2:PTR BYTE
    mov esi,string1
    mov edi,string2
L1: mov  al,[esi]
    mov  dl,[edi]
    cmp  al,0               ; end of string1?
    jne  L2                 ; no
    cmp  dl,0               ; yes: end of string2?
    jne  L2                 ; no
    jmp  L3                 ; yes, exit with ZF = 1
L2: inc  esi                ; point to next
    inc  edi
    cmp  al,dl              ; chars equal?
    je   L1                 ; yes: continue loop
L3: ret
Str_compare ENDP
```

Str_length Procedure

- Calculates the length of a null-terminated string and returns the length in the EAX register.
- Prototype:

```
Str_length PROTO,
  pString:PTR BYTE        ; pointer to string
```

Example:

```
.data
myString BYTE "abcdefg",0
.code
    INVOKE Str_length,
      ADDR myString
; EAX = 7
```

Str_length Source Code

```
Str_length PROC USES edi,
      pString:PTR BYTE              ; pointer to string

      mov edi,pString
      mov eax,0                     ; character count
L1:
      cmp byte ptr [edi],0          ; end of string?
      je  L2                        ; yes: quit
      inc edi                       ; no: point to next
      inc eax                       ; add 1 to count
      jmp L1
L2: ret
Str_length ENDP
```

Str_copy Procedure

- Copies a null-terminated string from a source location to a target location.
- Prototype:

```
Str_copy PROTO,
  source:PTR BYTE,          ; pointer to string
  target:PTR BYTE           ; pointer to string
```

See the CopyStr.asm program for a working example.

Str_copy Source Code

```
Str_copy PROC USES eax ecx esi edi,
	source:PTR BYTE,		; source string
	target:PTR BYTE			; target string

	INVOKE Str_length,source	; EAX = length source
	mov ecx,eax			; REP count
	inc ecx				; add 1 for null byte
	mov esi,source
	mov edi,target
	cld				; direction = up
	rep movsb			; copy the string
	ret
Str_copy ENDP
```

Str_trim Procedure

- The Str_trim procedure removes all occurrences of a selected trailing character from a null-terminated string.
- Prototype:

```
Str_trim PROTO,
  pString:PTR BYTE,          ; points to string
  char:BYTE                  ; char to remove
```

Example:

```
.data
myString BYTE "Hello###",0
.code
   INVOKE Str_trim, ADDR myString

myString = "Hello"
```

Str_trim Procedure

- Str_trim checks a number of possible cases (shown here with # as the trailing character):
  - The string is empty.
  - The string contains other characters followed by one or more trailing characters, as in "Hello##".
  - The string contains only one character, the trailing character, as in "#"
  - The string contains no trailing character, as in "Hello" or "H".
  - The string contains one or more trailing characters followed by one or more nontrailing characters, as in "#H" or "###Hello".

Str_trim Source Code

```
Str_trim PROC USES eax ecx edi,
    pString:PTR BYTE,          ; points to string
    char:BYTE                  ; char to remove
    mov  edi,pString
    INVOKE Str_length,edi      ; returns length in EAX
    cmp  eax,0                 ; zero-length string?
    je   L2                    ; yes: exit
    mov  ecx,eax               ; no: counter = string length
    dec  eax
    add  edi,eax               ; EDI points to last char
    mov  al,char               ; char to trim
    std                        ; direction = reverse
    repe scasb                 ; skip past trim character
    jne  L1                    ; removed first character?
    dec  edi                   ; adjust EDI: ZF=1 && ECX=0
L1: mov  BYTE PTR [edi+2],0    ; insert null byte
L2: ret
Str_trim ENDP
```

Str_ucase Procedure

- The Str_ucase procedure converts a string to all uppercase characters. It returns no value.
- Prototype:

```
Str_ucase PROTO,
  pString:PTR BYTE          ; pointer to string
```

Example:

```
.data
myString BYTE "Hello",0
.code
    INVOKE Str_ucase,
      ADDR myString
```

Str_ucase Source Code

```
Str_ucase PROC USES eax esi,
    pString:PTR BYTE
    mov esi,pString

L1: mov al,[esi]                        ; get char
    cmp al,0                            ; end of string?
    je  L3                              ; yes: quit
    cmp al,'a'                          ; below "a"?
    jb  L2
    cmp al,'z'                          ; above "z"?
    ja  L2
    and BYTE PTR [esi],11011111b   ; convert the char

L2: inc esi                             ; next char
    jmp L1

L3:  ret
Str_ucase ENDP
```

Two-Dimensional Arrays

- Base-Index Operands
- Base-Index Displacement

Base-Index Operand

- A base-index operand adds the values of two registers (called base and index), producing an effective address. Any two 32-bit general-purpose registers may be used.
- Base-index operands are great for accessing arrays of structures. (A structure groups together data under a single name.)

Structure Application

A common application of base-index addressing has to do with addressing arrays of structures (Chapter 10). The following definds a structure named COORD containing X and Y screen coordinates:

```
COORD STRUCT
  X WORD ?          ; offset 00
  Y WORD ?          ; offset 02
COORD ENDS
```

Then we can define an array of COORD objects:

```
.data
setOfCoordinates COORD 10 DUP(<>)
```

Structure Application

The following code loops through the array and displays each Y-coordinate:

```
    mov  ebx,OFFSET setOfCoordinates
    mov  esi,2                  ; offset of Y value
    mov  eax,0
L1: mov  ax,[ebx+esi]
    call WriteDec
    add  ebx,SIZEOF COORD
    loop L1
```

Base-Index-Displacement Operand

- A base-index-displacement operand adds base and index registers to a constant, producing an effective address. Any two 32-bit general-purpose registers may be used.
- Common formats:

[*base* + *index* + *displacement*]

displacement [*base* + *index*]

Two-Dimensional Table Example

Imagine a table with three rows and five columns. The data can be arranged in any format on the page:

```
table  BYTE  10h,  20h,  30h,  40h,  50h
        BYTE  60h,  70h,  80h,  90h, 0A0h
        BYTE 0B0h, 0C0h, 0D0h, 0E0h, 0F0h
NumCols = 5
```

Alternative format:

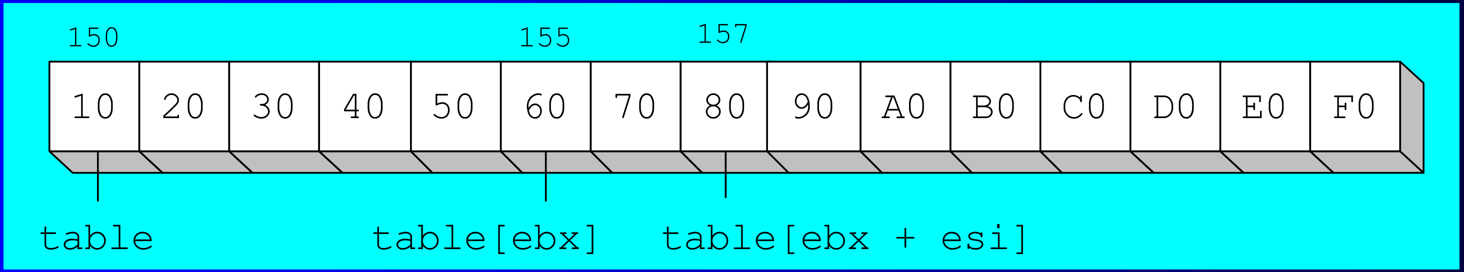
```
table  BYTE  10h,20h,30h,40h,50h,60h,70h,
        80h,90h,0A0h,
        0B0h,0C0h,0D0h,
        0E0h,0F0h
NumCols = 5
```

Two-Dimensional Table Example

The following code loads the table element stored in row 1, column 2:

```
RowNumber = 1
ColumnNumber = 2

mov ebx,NumCols * RowNumber
mov esi,ColumnNumber
mov al,table[ebx + esi]
```



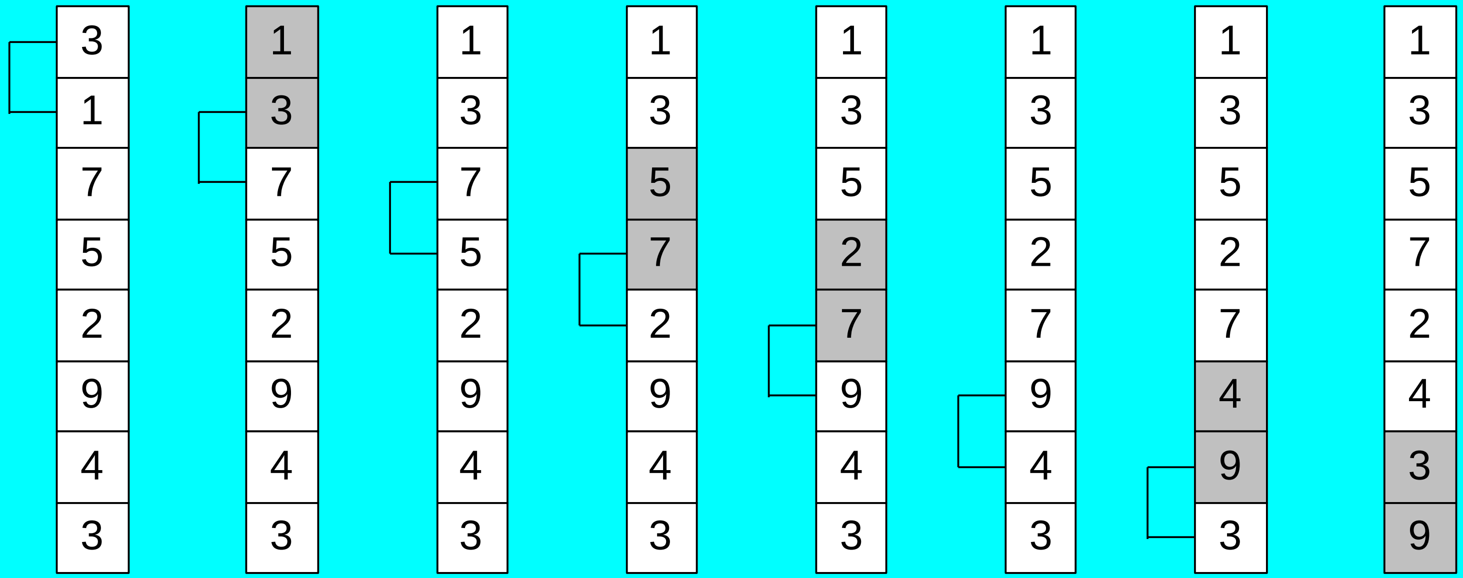
Searching and Sorting Integer Arrays

- Bubble Sort
  - A simple sorting algorithm that works well for small arrays
- Binary Search
  - A simple searching algorithm that works well for large arrays of values that have been placed in either ascending or descending order

Bubble Sort

Each pair of adjacent values is compared, and exchanged if the values are not ordered correctly:

One Pass (Bubble Sort)



(shaded values have been exchanged)

Bubble Sort Pseudocode

N = array size, cx1 = outer loop counter, cx2 = inner loop counter:

```
cx1 = N - 1
while( cx1 > 0 )
{
  esi = addr(array)
  cx2 = cx1
  while( cx2 > 0 )
  {
    if( array[esi] < array[esi+4] )
      exchange( array[esi], array[esi+4] )
    add esi,4
    dec cx2
  }
  dec cx1
}
```

Bubble Sort Implementation

```
BubbleSort PROC USES eax ecx esi,
    pArray:PTR DWORD,Count:DWORD
    mov  ecx,Count
    dec  ecx                ; decrement count by 1
L1: push ecx                ; save outer loop count
    mov  esi,pArray         ; point to first value
L2: mov  eax,[esi]          ; get array value
    cmp  [esi+4],eax        ; compare a pair of values
    jge  L3                 ; if [esi] <= [edi], skip
    xchg eax,[esi+4]        ; else exchange the pair
    mov  [esi],eax
L3: add  esi,4              ; move both pointers forward
    loop L2                 ; inner loop
    pop  ecx                ; retrieve outer loop count
    loop L1                 ; else repeat outer loop
L4: ret
BubbleSort ENDP
```

Binary Search

- Searching algorithm, well-suited to large ordered data sets
- Divide and conquer strategy
- Each "guess" divides the list in half
- Classified as an O(log n) algorithm:
  - As the number of array elements increases by a factor of *n*, the average search time increases by a factor of *log n*.

Binary Search Estimates

Array Size (n)	Maximum Number of Comparisons: $(\log_2 n) + 1$
64	7
1,024	11
65,536	17
1,048,576	21
4,294,967,296	33

Binary Search Pseudocode

```
int BinSearch( int values[],
    const int searchVal, int count )
{
    int first = 0;
    int last = count - 1;
    while( first <= last )
    {
        int mid = (last + first) / 2;
        if( values[mid] < searchVal )
            first = mid + 1;
        else if( values[mid] > searchVal )
            last = mid - 1;
        else
            return mid;      // success
    }
    return -1;               // not found
}
```

Binary Search Implementation (1 of 3)

```
BinarySearch PROC uses ebx edx esi edi,
     pArray:PTR DWORD,       ; pointer to array
     Count:DWORD,            ; array size
     searchVal:DWORD         ; search value

LOCAL first:DWORD,           ; first position
     last:DWORD,             ; last position
     mid:DWORD               ; midpoint
     mov  first,0            ; first = 0
     mov  eax,Count          ; last = (count - 1)
     dec  eax
     mov  last,eax
     mov  edi,searchVal      ; EDI = searchVal
     mov  ebx,pArray         ; EBX points to the array
L1:                          ; while first <= last
     mov  eax,first
     cmp  eax,last
     jg   L5                 ; exit search
```

Binary Search Implementation (2 of 3)

```
; mid = (last + first) / 2
    mov   eax,last
    add   eax,first
    shr   eax,1
    mov   mid,eax

; EDX = values[mid]
    mov   esi,mid
    shl   esi,2              ; scale mid value by 4
    mov   edx,[ebx+esi]      ; EDX = values[mid]

; if ( EDX < searchval(EDI) )
;    first = mid + 1;
    cmp   edx,edi
    jge   L2
    mov   eax,mid            ; first = mid + 1
    inc   eax
    mov   first,eax
    jmp   L4                 ; continue the loop
```

base-index addressing

Binary Search Implementation (3 of 3)

```
; else if( EDX > searchVal(EDI) )
;   last = mid - 1;
L2: cmp   edx,edi              ; (could be removed)
    jle   L3
    mov   eax,mid              ; last = mid - 1
    dec   eax
    mov   last,eax
    jmp   L4                   ; continue the loop

; else return mid
L3: mov   eax,mid              ; value found
    jmp   L9                   ; return (mid)

L4: jmp   L1                   ; continue the loop
L5: mov   eax,-1               ; search failed
L9: ret
BinarySearch ENDP
```

The End