Chapter 9: Strings and Arrays

Kip R. Irvine

Chapter Overview

- **String Primitive Instructions**
- Selected String Procedures
- Two-Dimensional Arrays
- Searching and Sorting Integer Arrays
- Java Bytecodes: String Processing (optional topic)

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
```


Exercise . . .

- 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 often used
  - REPE (REPZ)
  - REPNE (REPNZ)

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
```


Exercise . . .

- 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:

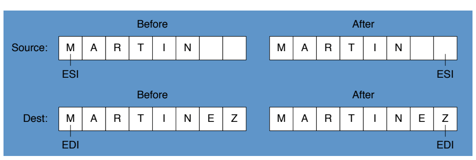
```
Source is smaller
```


Example: Comparing Two Strings (2 of 3)

```
.code
main PROC
    cld                        ; direction = forward
    mov  esi,OFFSET source
    mov  edi,OFFSET dest
    mov  ecx,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:



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

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

```
.data
array BYTE 1,2,3,4,5,6,7,8,9
.code
     mov esi,OFFSET array
     mov ecx,LENGTHOF array
     cld
L1:  lodsb                  ; load byte into AL
     or al,30h              ; convert to ASCII
     call WriteChar         ; display it
     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
```


Exercise . . .

- 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
```


What's Next

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

Selected 32-Bit String Procedures

The following string procedures are some examples that may be useful in future assignments:

- 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

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

Relation	Carry Flag	Zero Flag	Branch if True
string1 < string2	1	0	JB
string1 == string2	0	1	JE
string1 > string2	0	0	JA

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
```


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"
```

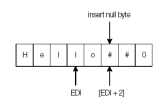
Str_trim Procedure

- 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".

Testing the Str_trim Procedure

String Definition	EDI, When SCASB Stops	Zero Flag	ECX	Position to Store the Null
str BYTE "Hello##",0	str + 3	0	> 0	[edi + 2]
str BYTE "#",0	str – 1	1	0	[edi + 1]
str BYTE "Hello",0	str + 3	0	> 0	[edi + 2]
str BYTE "H",0	str – 1	0	0	[edi + 2]
str BYTE "#H",0	str + 0	0	> 0	[edi + 2]

Using the first definition in the table, position of EDI when SCASB stops:



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
```


Example: 64-Bit Str_length

```
Gets the length of a string. Receives: RCX points to the
string. Returns length of string in RAX.

Str_length PROC USES rdi
   mov  rdi,rcx      ; get pointer
   mov  eax,0        ; character counter
L1:
   cmp  BYTE PTR [rdi],0  ; end of string?
   je   L2           ; yes: quit
   inc  rdi          ; no: point to next
   inc  rax          ; add 1 to count
   jmp  L1
L2: ret              ; return count in RAX
Str_length ENDP
```

What's Next

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

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. *(Note: esp is not a general-purpose register)*
  - In 64-bit mode, you use 64-bit registers for bases and indexes
- 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 defines 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 register can be used.
- Common formats:

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

displacement [*base* + *index*]

64-bit Base-Index-Displacement Operand

- A 64-bit base-index-displacement operand adds base and index registers to a constant, producing a 64-bit effective address. Any two 64-bit general-purpose registers can 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:

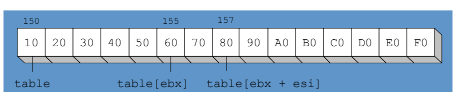
```
table  BYTE  10h,20h,30h,40h,50h,60h,70h,
        80h,90h,0A0h,
        0B0h,0C0h,0D0h,
        0E0h,0F0h
NumCols = 5
```


Two-Dimensional Table Example

The following 32-bit 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]
```

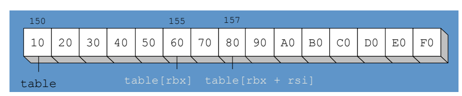


Two-Dimensional Table Example (64-bit)

The following 64-bit code loads the table element stored in row 1, column 2:

```
RowNumber = 1
ColumnNumber = 2

mov  rbx,NumCols * RowNumber
mov  rsi,ColumnNumber
mov  al,table[rbx + rsi]
```



What's Next

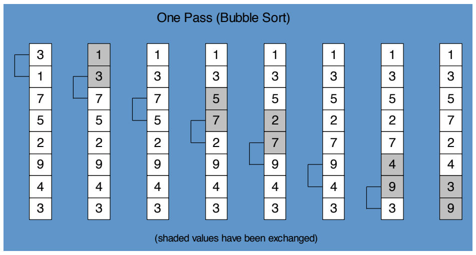
- String Primitive Instructions
- Selected String Procedures
- Two-Dimensional Arrays
- **Searching and Sorting Integer Arrays**

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:



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
```

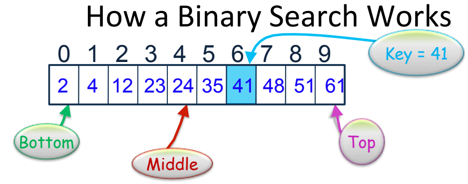

Binary Search

- 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*.

Sample 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

How a Binary Search Works



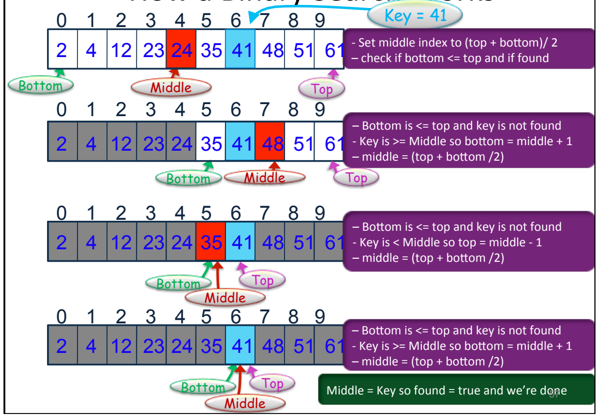
Keep track of the top, bottom and middle indices

Each time we discard ½ the remaining list

CHECK the middle value

IF the middle value is equal to the KEY
we're done!
ELSE IF the middle value is less than the KEY
MOVE the bottom index to middle + 1
ELSE
MOVE the top index to middle - 1
Middle = (Top + Bottom) / 2

How a Binary Search Works



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
```


Java Bytecodes: String Processing

- In Java, strings identifiers are references to other storage
  - think of a reference as a pointer, or address

  Ways to load and store a string:
  - ldc - loads a reference to a string literal from the constant pool
  - astore - pops a string reference from the stack and stores it in a local variable

String Processing Example

- Java:

```
String empInfo = "10034Smith";
String id = empInfo.substring(0,5);
```

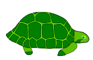
- **Bytecode disassembly:**

```
0: ldc #32;              // String 10034Smith
2: astore_0
3: aload_0
4: iconst_0
5: iconst_5
6: invokevirtual #34;    // Method java/lang/String.substring
9: astore_1
```

invokevirtual calls a class method

Summary

- String primitives are optimized for efficiency
- Strings and arrays are essentially the same
- Keep code inside loops simple
- Use base-index operands with two-dimensional arrays
- Avoid the bubble sort for large arrays
- Use binary search for large sequentially ordered arrays



45 6E 64 65