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# STRING OPERATIONS

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## *String Primitive Instructions*

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String primitive instructions are a set of instructions that are designed to manipulate strings of data. They are particularly useful for moving, comparing, loading, and storing blocks of data.

The x86 instruction set has five groups of string primitive instructions:

- **Move string data: MOVSB, MOVSW, MOVSD**
- **Compare strings: CMPSB, CMPSW, CMPSD**
- **Scan string: SCASB, SCASW, SCASD**
- **Store string data: STOSB, STOSW, STOSD**
- **Load accumulator from string: LODSB, LODSW, LODSD** **Image Description**

The image below shows a table of string primitive instructions, including their descriptions and mnemonics.

Table 9-1 String Primitive Instructions.

Instruction	Description
MOVSB, MOVSW, MOVSD	Move string data: Copy data from memory addressed by ESI to memory addressed by EDI.
CMPSB, CMPSW, CMPSD	Compare strings: Compare the contents of two memory locations addressed by ESI and EDI.
SCASB, SCASW, SCASD	Scan string: Compare the accumulator (AL, AX, or EAX) to the contents of memory addressed by EDI.
STOSB, STOSW, STOSD	Store string data: Store the accumulator contents into memory addressed by EDI.
LODSB, LODSW, LODSD	Load accumulator from string: Load memory addressed by ESI into the accumulator.

## *Using a Repeat Prefix*

By itself, a string primitive instruction only processes a single memory value or pair of values.

However, you can use a repeat prefix to cause the instruction to repeat until a certain condition is met.

The most common repeat prefix is REP, which causes the instruction to repeat while the ECX register is greater than zero.

For example, the following code would copy 10 bytes from the string1 buffer to the string2 buffer:

---

```
001 cld ; clear Direction flag
002 mov esi, OFFSET string1 ; ESI points to source
003 mov edi, OFFSET string2 ; EDI points to target
004 mov ecx, 10 ; set counter to 10
005 rep movsb ; move 10 bytes
```

### **Direction Flag**

String primitive instructions increment or decrement the ESI and EDI registers based on the state of the Direction flag. The Direction flag can be explicitly modified using the CLD and STD instructions:

**CLD clears the Direction flag**, causing the ESI and EDI registers to increment.

**STD sets the Direction flag**, causing the ESI and EDI registers to decrement.

Table 9-2 Direction Flag Usage in String Primitive Instructions.

Value of the Direction Flag	Effect on ESI and EDI	Address Sequence
Clear	Incremented	Low-high
Set	Decrement	High-low

When the Direction flag is clear, the ESI and EDI registers are incremented after each operation. This means that the string operation will move from a lower address to a higher address.

When the Direction flag is set, the ESI and EDI registers are decremented after each operation. This means that the string operation will move from a higher address to a lower address.

It is important to set the Direction flag correctly before using a string primitive instruction, as otherwise the ESI and EDI registers may not increment or decrement as intended.

For example, if you want to copy a string from one buffer to another, you would need to clear the Direction flag first. Otherwise, the ESI and EDI registers would be decremented after each operation, and the string would be copied in reverse order.

It is important to set the Direction flag correctly before using a string primitive instruction, as otherwise the ESI and EDI registers may not increment or decrement as intended.

The following example shows how to use the MOVSB instruction to copy a string from one buffer to another:

```
009 ; Copy string1 to string2
010 cld ; clear Direction flag
011 mov esi, OFFSET string1 ; ESI points to source
012 mov edi, OFFSET string2 ; EDI points to target
013 mov ecx, 10 ; set counter to 10
014 rep movsb ; move 10 bytes
```

### ***MOVSB, MOVSW, and MOVSd***

The MOVSB, MOVSW, and MOVSd instructions are used to copy data from one memory location to another. They differ in the size of the data that they copy:

- • **MOVSB copies bytes.**
- **MOVSW copies words.**
- **MOVSd copies doublewords.**

All three instructions use the ESI and EDI registers to address the source and destination memory locations, respectively.

The Direction flag determines whether the ESI and EDI registers are incremented or decremented after each operation.

The following code shows how to use the MOVSd instruction to copy a doubleword array from one buffer to another:

```
026 ; Copy source to target
027 cld ; clear Direction flag
028 mov ecx, LENGTHOF source ; set REP counter
029 mov esi, OFFSET source ; ESI points to source
030 mov edi, OFFSET target ; EDI points to target
031 rep movsd ; copy doublewords
```

The **CLD instruction** clears the Direction flag, causing the ESI and EDI registers to be incremented after each operation.

The **REP prefix** causes the MOVSd instruction to repeat while the ECX register is greater than zero.

After the code is executed, the ESI and EDI registers will point one position (4 bytes) beyond the end of each array.

This is because the MOVSd instruction copies 4 bytes of data each time it executes.

The notes you provided are unclear and hard to understand because they are missing some key information.

For example, the notes do not explain what the LENGTHOF macro is or how it is used. The notes also do not explain why the ESI and EDI registers are incremented or decremented after each operation.

### **CMPSB, CMPSW, and CMPSD**

The CMPSB, CMPSW, and CMPSD instructions are used to compare two memory operands. They differ in the size of the operands that they compare:

- **CMPSB compares bytes**
- **CMPSW compares words**
- **CMPSD compares doublewords**

All three instructions use the ESI and EDI registers to address the source and destination operands, respectively.

The Direction flag determines whether the ESI and EDI registers are incremented or decremented after each operation.

#### **Example: Comparing Doublewords:**

```
035 ; Compare source and target
036 mov esi, OFFSET source
037 mov edi, OFFSET target
038 cmpsd
039 ; compare doublewords
```

If the two doubleword values are equal, the Zero flag is set. If the source doubleword is greater than the target doubleword, the Carry flag is set. Otherwise, the Carry flag is cleared.

To compare multiple doublewords, you can use a repeat prefix with the CMPSD instruction:

```
042 mov esi, OFFSET source
043 mov edi, OFFSET target
044 cld ; clear Direction flag
045 mov ecx, LENGTHOF source ; repetition counter
046 repe cmpsd ; repeat while equal
```

**REPE (Repeat While Equal).** It's used to indicate that a repetitive operation should continue while a certain condition holds, in this case, while the comparison with CMPSD yields equality.

The REPE prefix repeats the comparison until ECX equals zero or a pair of doublewords is found to be different.

The notes you provided are missing some key information, such as an explanation of the LENGTHOF macro and the Direction flag.

The notes also do not provide a complete example of how to compare multiple doublewords using a repeat prefix.

The CMPSB, CMPSW, and CMPSD instructions can be used to implement a variety of string operations, such as searching for a specific character in a string or comparing two strings.

For example, the following code shows how to use the CMPSB instruction to search for the letter 'A' in a string:

```
050 mov esi, OFFSET string
051 mov edi, OFFSET 'A'
052 repe cmpsb ; repeat while equal
053 jne not_found ; jump if not equal
```

If the letter 'A' is found in the string, the jne instruction will jump to the not\_found label. Otherwise, the jne instruction will not jump.

The CMPSB, CMPSW, and CMPSD instructions are powerful tools for comparing memory operands.

### ***SCASB, SCASW, and SCASD***

The SCASB, SCASW, and SCASD instructions compare the value in the AL, AX, or EAX register, respectively, to the byte, word, or doubleword, respectively, addressed by the EDI register.

These instructions are useful for searching for a single value in a string or array.

Combined with the REPE (or REPZ) prefix, the string or array is scanned while ECX > 0 and the value in the AL, AX, or EAX register matches each subsequent value in memory.

The REPNE prefix scans until either the value in the AL, AX, or EAX register matches a value in memory or ECX = 0.

**Example: Scan for a Matching Character. The following code shows how to use the SCASB instruction to search for the letter 'F' in the string alpha:**

```

059 .data
060     alpha BYTE "ABCDEFGH",0
061 .code
062     mov edi, OFFSET alpha ; EDI points to the string
063     mov al, 'F' ; search for the letter F
064     mov ecx, LENGTHOF alpha ; set the search count
065     cld ; direction = forward
066     repne scasb ; repeat while not equal
067
068     ; Test if the loop stopped because ECX = 0 and the character in AL was not found
069     jnz quit
070
071     ; Found: back up EDI
072     dec edi
073
074     ; Otherwise, the letter F was found

```

The REPNE prefix causes the SCASB instruction to repeat while the Zero flag is cleared and ECX is greater than zero.

The Zero flag is cleared when the value in the AL register does not match the byte at the memory address pointed to by the EDI register.

The jnz instruction jumps to the quit label if the Zero flag is set, meaning that the letter 'F' was not found.

Otherwise, the letter 'F' was found and the dec edi instruction is executed to back up the EDI register one position.

The jnz instruction is needed to test for the possibility that the loop stopped because ECX = 0 and the character in AL was not found.

If the loop stopped because ECX = 0, then the Zero flag will be set, and the jnz instruction will jump to the quit label.

Otherwise, the letter 'F' was found and the dec edi instruction is executed to back up the EDI register one position.

The SCASB, SCASW, and SCASD instructions are powerful tools for searching for a single value in a string or array.

### ***STOSB, STOSW, and STOSD***

The STOSB, STOSW, and STOSD instructions store the contents of the AL, AX, or EAX register, respectively, in memory at the offset pointed to by the EDI register.

- • • **STOSB: Store byte.**
- **STOSW: Store word.**
- **STOSD: Store doubleword.**

The EDI register is incremented or decremented based on the state of the Direction flag.

When used with the REP prefix, these instructions are useful for filling all elements of a string or array with a single value.

**Example: Initialize an Array.** The following code shows how to use the STOSB instruction to initialize each byte in the string1 array to 0xFFh:

```
080 ; Initialize each byte in string1 to 0xFFh
081
082 .data
083     Count = 100
084     string1 BYTE Count DUP(?)
085 .code
086     mov al, 0xFFh ; value to be stored
087     mov edi, OFFSET string1 ; EDI points to target
088     mov ecx, Count ; character count
089     cld ; direction = forward
090     rep stosb ; fill with contents of AL
```

The REP prefix causes the STOSB instruction to repeat while ECX is greater than zero.

The CLD instruction clears the Direction flag, causing the EDI register to be incremented after each operation.

After the code is executed, each byte in the string1 array will be set to 0xFFh.

The original notes are unclear and hard to understand because they do not explain why the CLD instruction is needed.

The CLD instruction is needed to clear the Direction flag.

If the Direction flag is set, then the EDI register will be decremented after each operation, and the STOSB instruction will fill the string1 array in reverse order.

The STOSB, STOSW, and STOSD instructions are powerful tools for filling all elements of a string or array with a single value.

```
094 mov al, 0xFFh
095 mov edi, OFFSET string1
096 mov ecx, LENGTHOF string1
097 cld
098 rep stosb
```

This code would first move the value 0xFFh into the AL register.

It would then move the value of the EDI register into the ECX register.

Next, it would clear the Direction flag.

Finally, it would repeat the STOSB instruction while ECX is greater than zero.

After this code is executed, each byte in the string1 array would be set to 0xFFh.

### ***LODSB, LODSW, and LODSD***

The LODSB, LODSW, and LODSD instructions load a byte, word, or doubleword, respectively, from memory at the offset pointed to by the ESI register into the AL, AX, or EAX register, respectively.

The ESI register is incremented or decremented based on the state of the Direction flag.

The REP prefix is rarely used with LODS because each new value loaded into the accumulator overwrites its previous contents. Instead, LODS is used to load a single value.

**Example: Load a Single Value. The following code shows how to use the LODSB instruction to load a single byte from memory into the AL register:**

```
101 ; Load a single byte from memory into the AL register  
102 lod sb
```

This instruction will load the byte at the memory address pointed to by the ESI register into the AL register. The ESI register will then be incremented by one.

**Array Multiplication Example. The following code shows how to use the LODSD and STOSD instructions to multiply each element of an array by a constant value:**

---

```
105 ; Array Multiplication Example
106 .data
107     array DWORD 1,2,3,4,5,6,7,8,9,10
108     ; test data
109     multiplier DWORD 10
110     ; test data
111 .code
112     main PROC
113     cld
114     ; direction = forward
115     mov
116     esi,OFFSET array
117     ; source index
118     mov
119     edi,esi
120     ; destination index
121     mov
122     ecx,LENGTHOF array
123     ; loop counter
124     L1:
125     lodsd
126     ; load [ESI] into EAX
127     mul
128     multiplier ; multiply by a value
129     stosd       ; store EAX into [EDI]
130     loop
131     L1
132     exit
133     main ENDP
134     END main
```

This code first clears the Direction flag. It then moves the offset of the array variable to the ESI and EDI registers.

The ESI register will be used to address the source array, and the EDI register will be used to address the destination array.

The code then moves the length of the array variable to the ECX register. This will be used as the loop counter.

The code then enters a loop. On each iteration of the loop, the LODSD instruction is used to load a doubleword from the source array into the EAX register.

The EAX register is then multiplied by the value of the multiplier variable. The result is then stored in the destination array using the STOSD instruction.

The loop is repeated until the ECX register is equal to zero. After the loop is finished, the code exits.

The original notes are unclear and hard to understand because they do not explain why the Direction flag is cleared and why the ECX register is used as a loop counter.

The Direction flag is cleared so that the ESI and EDI registers will be incremented after each iteration of the loop.

This ensures that the LODSD and STOSD instructions will access the next element of the source and destination arrays, respectively.

The ECX register is used as a loop counter to ensure that the loop will repeat the correct number of times.

The loop will repeat until the ECX register is equal to zero. This means that the loop will repeat the same number of times as the length of the array variable.

The LODSB, LODSW, and LODSD instructions are powerful tools for loading data from memory into the accumulator.

## STRING PROCEDURES IN IRVINE32

The Irvine32 library provides a number of procedures for manipulating null-terminated strings. These procedures are similar to the functions in the standard C library.

### Str\_copy

The Str\_copy procedure copies a source string to a target string. It takes two arguments: a pointer to the source string and a pointer to the target string. The procedure returns a pointer to the target string.

```
140 ; Copy a source string to a target string.  
141 Str_copy PROTO,  
142 source:PTR BYTE,  
143 target:PTR BYTE
```

The following code shows how to use the **Str\_copy procedure** to copy the string "Hello, world!" to the string "buffer":

```
145 mov eax, OFFSET "Hello, world!"  
146 mov ebx, OFFSET buffer  
147 call Str_copy  
148 ; buffer now contains the string "Hello, world!"
```

### Str\_length

The Str\_length procedure returns the length of a string (excluding the null byte) in the EAX register. It takes one argument: a pointer to the string.

```
152 ; Return the length of a string (excluding the null byte) in EAX.  
153 Str_length PROTO,  
154 pString:PTR BYTE
```

The following code shows how to use the Str\_length procedure to get the length of the string "Hello, world!" and store it in the EAX register:

```
157 mov eax, OFFSET "Hello, world!"  
158 call Str_length  
159 ; EAX now contains the value 12, which is the length of the string "Hello, world!"
```

### Str\_compare

The Str\_compare procedure compares two strings and sets the Zero and Carry flags in the same way as the CMP instruction. It takes two arguments: pointers to the two strings.

```
162 ; Compare string1 to string2. Set the Zero and  
163 ; Carry flags in the same way as the CMP instruction.  
164 Str_compare PROTO,  
165 string1:PTR BYTE,  
166 string2:PTR BYTE
```

The following code shows how to use the Str\_compare procedure to compare the strings "Hello, world!" and "Hello, world!":

```
170 mov eax, OFFSET "Hello, world!"  
171 mov ebx, OFFSET "Hello, world!"  
172 call Str_compare  
173 ; The Zero flag will be set, indicating that the two strings are equal.
```

### Str\_trim

The Str\_trim procedure trims a given trailing character from a string. It takes two arguments: a pointer to the string and the character to trim.

```
180 ; Trim a given trailing character from a string.  
181 ; The second argument is the character to trim.  
182 Str_trim PROTO,  
183 pString:PTR BYTE,  
184 char:BYTE
```

The following code shows how to use the Str\_trim procedure to trim the trailing newline character from the string "Hello, world!\n":

```
185 mov eax, OFFSET "Hello, world!\n"  
186 mov ebx, AL ; '\n' character  
187 call Str_trim  
188 ; The string "Hello, world!" is now stored in the memory location pointed to by EAX.
```

### Str\_ucase

The Str\_ucase procedure converts a string to upper case. It takes one argument: a pointer to the string.

```
190 ; Convert a string to upper case.  
191 Str_ucase PROTO,  
192 pString:PTR BYTE
```

The following code shows how to use the Str\_ucase procedure to convert the string "hello, world!" to upper case:

```
195 mov eax, OFFSET "hello, world!"  
196 call Str_ucase  
197 ; The string "HELLO, WORLD!" is now stored in the memory location pointed to by EAX.
```

## STR\_COMPARE PROCEDURE

The Str\_compare procedure compares two strings and sets the Carry and Zero flags in the same way as the CMP instruction. It takes two arguments: pointers to the two strings.

The Str\_compare procedure works by comparing byte by byte of the two strings.

If a byte is found that is not equal in both strings, the Str\_compare procedure sets the Carry flag and exits the loop.

If the end of both strings is reached, the Str\_compare procedure sets the Zero flag and exits the loop.

*The following is a more detailed explanation of the Str\_compare procedure:*

---

```

220 Str_compare PROC USES eax edx esi edi,
221     string1:PTR BYTE,
222     string2:PTR BYTE
223     ; Initialize esi and edi to point to the beginning of the strings.
224     mov esi, string1
225     mov edi, string2
226     ; Start of the loop to compare characters in the strings.
227 L1:
228     ; Load the characters from string1 and string2 into AL and DL.
229     mov al, [esi]
230     mov dl, [edi]
231     ; Check if we have reached the end of string1 (null terminator).
232     cmp al, 0
233     jne L2 ; If not, continue comparing.
234     ; If we have reached the end of string1, check if we have also reached the end of string2.
235     cmp dl, 0
236     jne L2 ; If not, continue comparing.
237     ; If we reach this point, both strings are equal, and we exit with ZF = 1.
238     jmp L3
239 L2:
240     ; Increment esi and edi to move to the next characters in the strings.
241     inc esi
242     inc edi
243     ; Compare the characters in AL and DL. If they are equal, continue the loop.
244     cmp al, dl
245     je L1 ; Characters are equal; continue comparing.
246
247     ; If characters are not equal, exit the loop with flags set.
248 L3:
249     ret
250 Str_compare ENDP

```

**Line 1:** The Str\_compare procedure pushes the EAX, EDX, ESI, and EDI registers onto the stack. This is necessary because the procedure uses these registers.

**Line 2:** The Str\_compare procedure moves the pointers to the two strings into the ESI and EDI registers, respectively.

**Line 3:** The Str\_compare procedure enters a loop. On each iteration of the loop, the following steps are performed:

- The Str\_compare procedure compares the bytes at the memory locations pointed to by the ESI and EDI registers.
- If the bytes are equal, the Str\_compare procedure increments the ESI and EDI registers and continues to the next iteration of the loop.
- If the bytes are not equal, the Str\_compare procedure sets the Carry flag and exits the loop.

**Line 10:** The Str\_compare procedure checks if the end of the string pointed to by the ESI register has been reached. If the end of the string has been reached, the Str\_compare procedure checks if the end of the string pointed to by the EDI register has also been reached.

**Line 12:** If the end of both strings has been reached, the Str\_compare procedure sets the Zero flag and exits the loop.

**Line 14:** The Str\_compare procedure increments the ESI and EDI registers so that they point to the next byte in the respective strings.

**Line 16:** The Str\_compare procedure compares the bytes at the memory locations pointed to by the ESI and EDI registers. If the bytes are equal, the Str\_compare procedure continues to the next iteration of the loop. If the bytes are not equal, the Str\_compare procedure sets the Carry flag and exits the loop.

**Line 20:** The Str\_compare procedure exits the loop and returns to the caller.

*The following is a table of the flags affected by the Str\_compare procedure:*

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

This code defines the Str\_compare procedure, which compares two strings character by character. It uses esi and edi to traverse the strings and compares characters while checking for the end of the strings.

The procedure exits with the Zero and Carry flags set according to the result of the comparison. If both strings are equal, ZF is set to 1; otherwise, ZF is set to 0.

The Carry flag is set to indicate the relation between the strings:

(JB for "string1 < string2," JA for "string1 > string2," JE for "string1 = string2")

## STR\_LENGTH PROCEDURE

The Str\_length procedure returns the length of a string in the EAX register. It takes one argument: a pointer to the string.

The Str\_length procedure works by scanning the string byte by byte until it reaches the null terminator.

The procedure increments the EAX register for each byte in the string. After reaching the null terminator, the procedure returns the value in the EAX register.

*The following is a more detailed explanation of the Str\_length procedure:*

This code works by scanning the string byte by byte until it reaches the null terminator. The code increments the EAX register for each byte in the string. After reaching the null terminator, the code returns the value in the EAX register.

To use the Str\_length procedure, you would pass the address of the string to the procedure as an argument.

```
255 ;-----  
256 ; Str_length Procedure  
257 ; Calculates the length of a null-terminated string.  
258 ; Returns the length of the string in EAX.  
259 ;-----  
260 Str_length PROC USES edi,  
261     pString:PTR BYTE    ; pointer to the string  
262  
263     mov edi, pString    ; Initialize edi with the pointer to the string.  
264     mov eax, 0            ; Initialize eax to 0, which will store the character count.  
265  
266 L1:  
267     cmp BYTE PTR [edi], 0  ; Check if the current character is the null terminator (end of string).  
268     je L2                 ; If it's the end of the string, exit the loop.  
269  
270     inc edi              ; Move to the next character in the string.  
271     inc eax              ; Increment the character count by 1.  
272  
273     jmp L1                ; Repeat the loop to process the next character.  
274  
275 L2:  
276     ret                  ; Return with the length of the string in EAX.  
277  
278 Str_length ENDP
```

**Line 1:** The Str\_length procedure pushes the EDI register onto the stack. This is necessary because the procedure uses this register.

**Line 2:** The Str\_length procedure moves the pointer to the string into the EDI register.

**Line 3:** The Str\_length procedure moves the value 0 into the EAX register. This will be used to store the length of the string.

**Line 4:** The Str\_length procedure enters a loop. On each iteration of the loop, the following steps are performed:

- The Str\_length procedure compares the byte at the memory location pointed to by the EDI register to the null terminator (0x00).
- If the byte is equal to the null terminator, the Str\_length procedure exits the loop.
- If the byte is not equal to the null terminator, the Str\_length procedure increments the EDI register and the EAX register.

Line 10: The Str\_length procedure exits the loop and returns to the caller.

*The following is an example of how to use the Str\_length procedure:*

```
282 ; Get the length of the string "Hello, world!"  
283 mov eax, OFFSET "Hello, world!"  
284 call Str_length  
285  
286 ; The EAX register will now contain the value 12, which is the length of the string "Hello, world!"
```

## STR\_COPY PROCEDURE

The Str\_copy procedure copies a null-terminated string from a source location to a target location.

It takes two arguments: pointers to the source and target strings, respectively.

The Str\_copy procedure works by first calling the Str\_length procedure to get the length of the source string.

The Str\_copy procedure then copies the source string to the target string byte by byte using the REP MOVS B instruction.

*The following is the MASM code for the Str\_copy procedure:*

---

```
325 ;-----  
326 ; Str_copy Procedure  
327 ; Copies a string from the source to the target.  
328 ; Requires: the target string must contain enough space  
329 ; to hold a copy of the source string.  
330 ;-----  
331 Str_copy PROC USES eax ecx esi edi,  
332     source:PTR BYTE,    ; source string  
333     target:PTR BYTE    ; target string  
334  
335     INVOKE Str_length, source    ; Calculate the length of the source string and store it in EAX.  
336     mov ecx, eax            ; Copy the length into ECX for REP count.  
337     inc ecx                ; Add 1 for the null byte at the end of the string.  
338  
339     mov esi, source        ; Initialize esi with the source pointer.  
340     mov edi, target        ; Initialize edi with the target pointer.  
341  
342     cld                    ; Set the direction flag to forward.  
343  
344     rep movsb              ; Use REP to copy the string byte by byte from source to target.  
345  
346     ret                    ; Return when the string is copied.  
347  
348 Str_copy ENDP
```

This code defines the Str\_copy procedure, which copies a null-terminated string from the source to the target.

It uses the Str\_length procedure to calculate the length of the source string, sets up pointers to both source and target strings, and then uses the rep movsb instruction to copy the string byte by byte.

The procedure returns once the entire string is copied to the target.

To use the Str\_copy procedure, you would pass the addresses of the source and target strings to the procedure as arguments.

For example, to copy the string "Hello, world!" from one location to another, you would use the following code:

```
350 mov eax, OFFSET "Hello, world!"
351 mov ebx, OFFSET target_string
352 call Str_copy
353
354 ; The target_string variable will now contain a copy of the string "Hello, world!"
```

## STR\_TRIM PROCEDURE

The Str\_trim procedure removes all occurrences of a specified trailing character from the end of a null-terminated string. For example, it can trim trailing spaces from a string.

It takes two parameters:

pString - Pointer to the null-terminated ASCII string to trim.

char - The ASCII character to trim from the end of the string It does not return anything, but modifies the string in-place by truncating it.

### Logic

It handles several cases:

1. Empty string - nothing to do
2. String with trailing character(s) - remove them
3. String with only the trailing char - truncate to empty string
4. String without any trailing char - leave unchanged
5. String with trailing char(s) followed by other chars - remove only trailing char(s)

To trim the string, it inserts a null byte (\0) after the last character to keep. Any chars after the null become insignificant.

It uses these steps:

1. Get length of string
2. Check if length is 0 and exit if so (empty string case)
3. Initialize loop counter to string length

4. Point to last character
5. Loop backwards until beginning
  - Check if current char matches trailing char to trim
  - If yes, decrement counter to keep backing up
  - If no, insert null byte after current char and exit loop
  - Insert null byte truncates the string

```

360 Str_trim PROC USES eax ecx edi,
361             pString:PTR BYTE, ; string pointer
362             char: BYTE          ; trailing char to trim
363
364
365     mov edi,pString      ; point EDI to string
366     INVOKE Str_length,edi ; get length in EAX
367
368     cmp eax,0            ; is length 0?
369     je L3                ; yes, exit
370
371     mov ecx,eax          ; ECX = length
372     dec eax              ; EAX = length - 1
373     add edi,eax          ; point to last char
374
375 L1:
376     mov al,[edi]          ; load character
377     cmp al,char           ; compare to trailing char
378     jne L2                ; no match, insert null
379     dec edi              ; match, keep backing up
380     loop L1
381
382 L2:
383     mov BYTE PTR [edi+1],0 ; insert null byte
384
385 L3:
386     ret
387 Str_trim ENDP

```

**Line 1:** The Str\_trim procedure pushes the EAX, ECX, and EDI registers onto the stack. This is necessary because the procedure uses these registers.

**Line 2:** The Str\_trim procedure moves the pointer to the string to be trimmed into the EDI register.

**Line 3:** The Str\_trim procedure calls the Str\_length procedure to get the length of the string. The length of the string is stored in the EAX register.

**Line 4:** The Str\_trim procedure compares the length of the string to 0. If the length of the string is equal to 0, then the string is empty and the procedure exits.

**Line 6:** The Str\_trim procedure moves the length of the string to the ECX register. This will be used as the loop counter.

**Line 7:** The Str\_trim procedure decrements the EAX register. This will be used to point to the last character in the string.

**Line 8:** The Str\_trim procedure adds the EAX register to the EDI register. This will point the EDI register to the last character in the string.

**Line 9:** The Str\_trim procedure enters a loop. On each iteration of the loop, the following steps are performed:

- The Str\_trim procedure moves the byte at the memory location pointed to by the EDI register into the AL register.
- The Str\_trim procedure compares the AL register to the character to be trimmed.
- If the two characters are equal, then the Str\_trim procedure decrements the EDI register and continues to the next iteration of the loop.
- If the two characters are not equal, then the Str\_trim procedure breaks out of the loop.

Line 14: The Str\_trim procedure inserts a null byte at the memory location pointed to by the EDI register plus one. This will terminate the string at the last character that is not the character to be trimmed.

**Line 15:** The Str\_trim procedure exits the loop.

**Line 16:** The Str\_trim procedure pops the EAX, ECX, and EDI registers from the stack.

**Line 17:** The Str\_trim procedure returns.

Here is an example of how to use the Str\_trim procedure:

```
390 ; Trim all trailing spaces from the string "Hello, world!      "
391 mov eax, OFFSET "Hello, world!      "
392 call Str_trim
393 ; The EAX register will now contain a pointer to the string "Hello, world!"
```

## STR\_UCASE PROCEDURE

```
397 ;-----  
398 ; Str_ucase Procedure  
399 ; Converts a null-terminated string to uppercase.  
400 ; Returns: nothing  
401 ;-----  
402 Str_ucase PROC USES eax esi,  
403     pString:PTR BYTE  ; Pointer to the string  
404  
405     mov esi, pString ; Initialize esi with the address of the string.  
406 L1:  
407     mov al, [esi]      ; Load the character from the string.  
408     cmp al, 0          ; Check if it's the end of the string.  
409     je L3              ; If yes, exit the loop.  
410     cmp al, 'a'        ; Compare the character with 'a'.  
411     jb L2              ; If it's below 'a', go to L2.  
412     cmp al, 'z'        ; Compare the character with 'z'.  
413     ja L2              ; If it's above 'z', go to L2.  
414  
415     and BYTE PTR [esi], 11011111b  
416     ; Convert the character to uppercase by clearing the 6th bit.  
417 L2:  
418     inc esi            ; Move to the next character.  
419     jmp L1              ; Repeat the loop.  
420 L3:  
421     ret                ; Return when the entire string is converted to uppercase.  
422 Str_ucase ENDP
```

The first part of the code sets up the procedure. It expects a pointer to a string (null-terminated) in pString, and it initializes esi with the address of this string.

Here's what's happening within the loop:

**mov al, [esi]** loads the character at the memory address pointed to by esi into the al register.

**cmp al, 0** checks if the character is the null terminator (end of the string). If it is, the loop exits (je L3).

**cmp al, 'a'** compares the character with the ASCII value of 'a'. If the character is below 'a', it jumps to L2.

**cmp al, 'z'** compares the character with the ASCII value of 'z'. If the character is above 'z', it also jumps to L2.

**and BYTE PTR [esi], 11011111b** converts the character to uppercase by clearing the 6th bit (bit 5) in the ASCII code. This changes lowercase letters to uppercase.

**L2:** marks the location to which the code jumps when the character is not a lowercase letter, ensuring it's skipped.

**inc esi** increments the esi register to point to the next character in the string.

**jmp L1** jumps back to the beginning of the loop, continuing the process until the end of the string is reached.

**Finally, L3:** is the label that is reached when the end of the string is detected. At this point, the loop exits, and the procedure returns.

The entire string is converted to uppercase by iterating through each character, and no value is returned; the original string is modified in memory.

## STRING LIBRARY DEMO PROGRAM

The "String Library Demo" program demonstrates the usage of string-handling procedures from the Irvine32 library. It performs the following tasks:

Trimming trailing characters from string\_1 using the Str\_trim procedure.

Converting string\_1 to uppercase using the Str\_ucase procedure.

Comparing string\_1 to string\_2 using the Str\_compare procedure.

Displaying the length of string\_2 using the Str\_length procedure. Here's the code with detailed explanations:

```
INCLUDE Irvine32.inc
.data
string_1 BYTE "abcde///", 0
string_2 BYTE "ABCDE", 0
msg0 BYTE "string_1 in upper case: ", 0
msg1 BYTE "string_1 and string_2 are equal", 0
msg2 BYTE "string_1 is less than string_2", 0
msg3 BYTE "string_2 is less than string_1", 0
msg4 BYTE "Length of string_2 is ", 0
msg5 BYTE "string_1 after trimming: ", 0

.code
main PROC
    call trim_string ; Remove trailing characters from string_1.
    call upper_case ; Convert string_1 to uppercase.
    call compare_strings ; Compare string_1 to string_2.
    call print_length ; Display the length of string_2.
    exit
main ENDP
```

```
trim_string PROC
; Remove trailing characters from string_1.
INVOKE Str_trim, ADDR string_1, '/'
mov edx, OFFSET msg5
call WriteString
mov edx, OFFSET string_1
call WriteString
call Crlf
ret
trim_string ENDP
```

```
upper_case PROC
; Convert string_1 to upper case.
mov edx, OFFSET msg0
call WriteString
INVOKE Str_ucase, ADDR string_1
mov edx, OFFSET string_1
call WriteString
call Crlf
ret
upper_case ENDP
```

```
compare_strings PROC
; Compare string_1 to string_2.
INVOKE Str_compare, ADDR string_1, ADDR string_2
.JF ZERO?
mov edx, OFFSET msg1
.ELSEIF CARRY?
mov edx, OFFSET msg2
.ELSE
mov edx, OFFSET msg3
.ENDIF
call WriteString
call Crlf
ret
compare_strings ENDP
```

```
print_length PROC
; Display the length of string_2.
mov edx, OFFSET msg4
call WriteString
INVOKE Str_length, ADDR string_2
```

```
call WriteDec
call Crlf
ret
print_length ENDP
```

END main

The program's output is as follows:

After trimming string\_1, it displays "string\_1 after trimming: abcde."

After converting string\_1 to uppercase, it displays "string\_1 in upper case: ABCDE."

It then compares string\_1 and string\_2 and displays one of the messages depending on the result.

Finally, it displays the length of string\_2.

This program showcases the use of various string-handling procedures from the Irvine32 library and provides informative messages for each step.

### ***Strings using Irvine64***

```
427 INCLUDE Irvine64.inc
428 .data
429     source BYTE "AABCDEFGAABCDFG", 0
430     ; size = 15
431     target BYTE 20 DUP(0)
432
433 .code
434     Str_compare PROTO
435     Str_length PROTO
436     Str_copy PROTO
437     ExitProcess PROTO
438
439 main PROC
440     mov rcx, OFFSET source
441     call Str_length
442     ; Returns length in RAX
443     mov rsi, OFFSET source
444     mov rdi, OFFSET target
445     call Str_copy
446     ; We just copied the string, so they should be equal.
447     call Str_compare
448     ; ZF = 1, strings are equal
449     ; Change the first character of the target string, and
450     ; compare them again.
451     mov BYTE PTR [rdi], 'B'
452     call Str_compare
453     ; CF = 1, source < target
454     mov ecx, 0
455     call ExitProcess
456 main ENDP
```

#### ***Actual Implementation of Procedures:***

To have a complete working program, you need to provide the actual implementation of the Str\_compare, Str\_length, and Str\_copy procedures.

These procedures are essential for the functionality of your program. They should be implemented with appropriate assembly code to perform the desired operations.

I'll provide you with the implementation of these procedures in Irvine64 assembly:

```
; Str_compare Procedure
; Compares two strings
; Receives:
```

```
; RSI points to the source string  
; RDI points to the target string  
; Returns:  
; Sets ZF if the strings are equal  
; Sets CF if source < target
```

```
Str_compare PROC  
    ; Implementation of Str_compare  
    ; ...  
    ret  
Str_compare ENDP
```

```
; Str_length Procedure  
; Gets the length of a string  
; Receives: RCX points to the string  
; Returns: length of string in RAX
```

```
Str_length PROC  
    ; Implementation of Str_length  
    ; ...  
    ret  
Str_length ENDP
```

```
; Str_copy Procedure  
; Copies a source string to a location indicated by a target pointer  
; Receives:  
; RSI points to the source string  
; RDI points to the target string  
; Returns: nothing
```

```
Str_copy PROC  
    ; Implementation of Str_copy  
    ; ...  
    ret  
Str_copy ENDP
```

### ***Output and Display:***

In the provided test program, there is no code for displaying the results of these operations. You should add code to display whether the strings are equal, the length of the string, and the comparison results. For example, you can use WriteString and WriteDec functions to display these results:

```
500 mov rsi, OFFSET msg1
501 call WriteString ; Display result message
502 call Crlf
503 ; Check ZF and CF flags to determine equality or comparison result
504 ; Display results accordingly
```

### *Irvine64 Library Setup:*

The Irvine64 library needs to be included and set up properly in your assembly environment. You should have instructions at the beginning of your program to include the Irvine64 library and set it up. This usually involves specifying the paths and configurations for the Irvine64 library. Here is an example:

```
512 INCLUDE Irvine64.inc ; Include Irvine64 library
513
514 .data
515 ; Your data declarations go here
516
517 .code
518 main PROC
519 ; Your program's main code goes here
520
521 main ENDP
522
523 END main
```

### *Actual Program:*

```
532 INCLUDE Irvine64.inc
533
534 ; -----
535 ; Str_compare
536 ; Compares two strings
537 ; Receives:
538 ; RSI points to the source string
539 ; RDI points to the target string
540 ; Returns:
541 ; Sets ZF if the strings are equal
542 ; Sets CF if source < target
543 ; -----
544 Str_compare PROC
545     USES rax rdx rsi rdi
546
547 L1:
548     mov al, [rsi]
549     mov dl, [rdi]
550     cmp al, 0      ; End of string1?
551     jne L2        ; No
552     cmp dl, 0      ; Yes: End of string2?
553     jne L2        ; No
554     jmp L3        ; Yes, exit with ZF = 1
555
```

---

```
556 L2:
557     inc rsi          ; Point to next
558     inc rdi
559     cmp al, dl      ; Characters equal?
560     je L1           ; Yes, continue loop
561                 ; No: Exit with flags set
562
563 L3:
564     ret
565
566 Str_compare ENDP
567
568 ; -----
569 ; Str_copy
570 ; Copies a source string to a location indicated by a target pointer
571 ; Receives:
572 ; RSI points to the source string
573 ; RDI points to the location where the copied string will be stored
574 ; Returns: nothing
575 ; -----
576 Str_copy PROC
577     USES rax rcx rsi rdi
578
579     mov rcx, rsi    ; Get length of the source string
580     call Str_length ; Returns length in RAX
581     mov rcx, rax    ; Loop counter
582     inc rcx        ; Add 1 for the null byte
583     cld             ; Direction = up
584     rep movsb       ; Copy the string
585     ret
```

```
587 Str_copy ENDP
588
589 ; -----
590 ; Str_length
591 ; Gets the length of a string
592 ; Receives: RCX points to the string
593 ; Returns: length of the string in RAX
594 ; -----
595 Str_length PROC
596     USES rdi
597
598     mov rdi, rcx      ; Get the pointer
599     mov eax, 0        ; Character count
600 L1:
601     cmp BYTE PTR [rdi], 0  ; End of string?
602     je L2              ; Yes: quit
603     inc rdi            ; No: Point to the next
604     inc rax             ; Add 1 to count
605     jmp L1
606 L2:
607     ret                ; Return count in RAX
608
609 Str_length ENDP
```

---

```

611 .data
612     source BYTE "AABCDEFGAABCDEFG",0
613     target BYTE 20 dup(0)
614
615 .code
616     main PROC
617         mov rcx, offset source
618         call Str_length      ; Returns length in RAX
619         mov rsi, offset source
620         mov rdi, offset target
621         call Str_copy
622         ; We just copied the string, so they should be equal.
623         call Str_compare
624         ; ZF = 1, strings are equal
625         ; Change the first character of the target string, and compare them again.
626         mov target, 'B'
627         call Str_compare
628         ; CF = 1, source < target
629         mov ecx, 0
630         call ExitProcess
631
632     main ENDP
633
634 END main

```

**Explanation:**

**Irvine64 Library:** The INCLUDE Irvine64.inc statement includes the Irvine64 library, providing access to Irvine's assembly functions and features.

**USES Keyword:** In the Str\_compare and Str\_copy procedures, the USES keyword is used to specify registers that will be pushed onto the stack and popped off the stack upon return from the procedure. This helps maintain the calling conventions.

**Str\_compare Procedure:** Compares two strings pointed to by RSI and RDI. It sets the Zero Flag (ZF) if the strings are equal and the Carry Flag (CF) if the source is less than the target.

**Str\_copy Procedure:** Copies a source string (pointed to by RSI) to a location indicated by the target pointer (RDI). It calculates the length of the source string using Str\_length, then uses rep movsb to perform the copy.

**Str\_length Procedure:** Calculates the length of a null-terminated string. It receives a pointer in RCX, and the result is returned in RAX.

**.data Section:** Data declarations for source and target strings.

**.code Section:** The main procedure demonstrates the use of these string procedures, copying the string, comparing strings, and changing a character for comparison.

This code illustrates how to use these string procedures in Irvine64 assembly, focusing on the Irvine64 register usage, stack management, and proper procedure calling conventions.

It's essential to configure your environment correctly to work with Irvine64 and ensure you have the Irvine64 library properly set up.

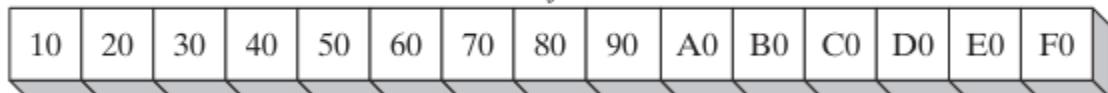
## 2D ARRAYS

**Row-major order** and **column-major order** are two different ways of storing a two-dimensional array in memory. The main difference is the order in which the elements of the array are stored.

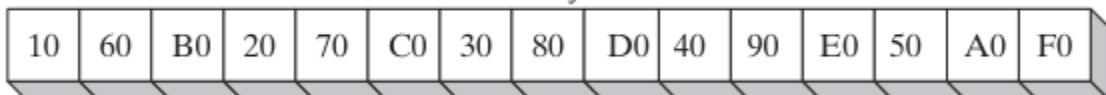
Logical arrangement:

10	20	30	40	50
60	70	80	90	A0
B0	C0	D0	E0	F0

Row-major order



Column-major order



### Row-major order

**Row-major order** is the most common method, and it is the method used by most high-level programming languages. In row-major order, the elements of each row are stored contiguously in memory.

#### Row-major order:

```
[0][0] [0][1] [0][2]  
[1][0] [1][1] [1][2]  
[2][0] [2][1] [2][2]
```

This means that the first element of the first row is stored at the beginning of the memory block, followed by the second element of the first row, and so on. The last element of the first row is followed by the first element of the second row, and so on. This continues until the last element of the last row is stored.

## Row-major order

$$\begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix}$$

### Column-major order

**Column-major order** is less common, but it is used in some applications, such as linear algebra. In column-major order, the elements of each column are stored contiguously in memory.

Column-major order:

```
[0][0] [1][0] [2][0]  
[0][1] [1][1] [2][1]  
[0][2] [1][2] [2][2]
```

This means that the first element of the first column is stored at the beginning of the memory block, followed by the first element of the second column, and so on. The last element of the first column is followed by the second element of the second column, and so on. This continues until the last element of the last column is stored.

## Column-major order

$$\begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix}$$

### Which order to use?

The choice of which order to use depends on the application. Row-major order is generally more efficient for accessing elements of the array by row, while column-major order is more efficient for accessing elements of the array by column.

How to implement a two-dimensional array in MASM To implement a two-dimensional array in MASM, you can use either row-major order or column-major order. However, it is important to be **consistent with the ordering that you choose**.

## Implementations

*To implement a two-dimensional array in row-major order, you can use the following steps:*

- Allocate a block of memory for the array.
- The size of the memory block depends on the size of the array and the data type of the elements of the array.
- Initialize the elements of the array. To access an element of the array, you can use the following formula:

```
element[i][j] = array[i * number_of_columns + j]
```

where i is the row index and j is the column index.

For example, the following code implements a two-dimensional array of integers in row-major order:

```
655 ; Declare a two-dimensional array of integers.  
656 array dw 100 dup(0)  
657  
658 ; Initialize the elements of the array.  
659 mov ebx, 1  
660 mov ecx, 100  
661 mov edi, array  
662 loop:  
663 mov dword ptr [edi], ebx  
664 inc ebx  
665 inc edi  
666 loop loop  
667  
668 ; Access an element of the array.  
669 mov eax, array[1 * 10 + 2]
```

Explanation:

- The array is declared as 100 contiguous DWORDS initialized to 0. This creates a 10x10 array since each DWORD is 2 bytes ( $10 * 10 = 100$ ).
- EBX is used as a counter from 1 to 100 to store sequential values in the array.
- EDI points to the start of the array and is incremented each iteration to move through the elements.

- ECX counts iterations from 1 to 100 to fill all elements.
- Array elements are accessed using ***rownumCols + col***. Here ***row 1, col 2 is at offset 10 + 2 = 12***.
- The elements are stored in row-major order - row 1, then row 2, etc sequentially in memory.

So this shows a typical way to declare, initialize, and access a 2D array in MASM using row-major layout.

## Base-Index Operands

A base-index operand is a type of operand that allows you to access memory using the sum of two register values: the base register and the index register.

Base-index operands are very useful for accessing arrays, because they allow you to calculate the address of an element of an array using the row and column indices of the element.

To use a base-index operand, you must first load the base register with the address of the array.

You can then load the index register with the row and/or column index of the element of the array that you want to access.

Finally, you can use the base-index operand to access the element of the array.

The following example shows how to use a base-index operand to access an element of a two-dimensional array:

```

672 ; Declare a two-dimensional array of integers.
673 array dw 1000h, 2000h, 3000h
674
675 ; Load the base register with the address of the array.
676 mov ebx, OFFSET array
677
678 ; Load the index register with the row and column indices of the element that we want to access.
679 mov esi, 1 ; row index
680 mov edi, 2 ; column index
681
682 ; Calculate the address of the element using the base-index operand.
683 mov eax, [ebx + esi * 2 + edi * 4]
684
685 ; Display the value of the element.
686 mov edx, 0 ; service number
687 mov ecx, 1 ; buffer offset
688 mov al, [eax] ; buffer byte
689 int 21h ; system call

```

The above code will display the value 2000h, which is the value of the element at row 1, column 2 of the array.

## Column-Major Order vs. Row-Major Order

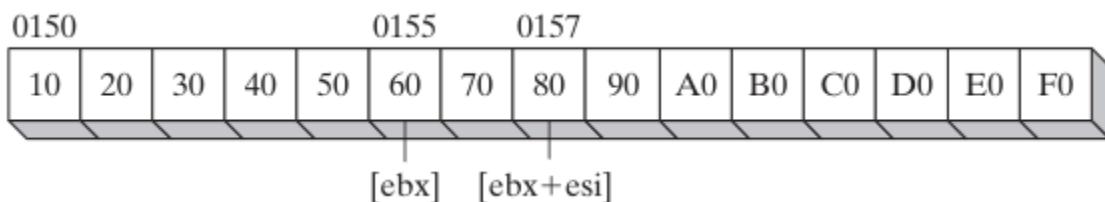
Two-dimensional arrays can be stored in memory in two different ways: column-major order and row-major order.

In **column-major order**, the elements of each column are stored contiguously in memory.

In **row-major order**, the elements of each row are stored contiguously in memory.

Most high-level programming languages use row-major order to store two-dimensional arrays.

Therefore, if you are writing assembly language code that will be used with a high-level language, you should use row-major order to store your two-dimensional arrays.



To access an elements of the array above, you can use the following formula:

```
element[row_index][column_index] = array[row_index * number_of_columns + column_index]
```

where `row_index` is the row index of the element and `column_index` is the column index of the element.

For example, to access the element at row 1, column 2 of the array, you would use the following code:

```
698 mov ebx, OFFSET array ; load the base register with the address of the array
699 mov esi, 1 ; load the index register with the row index
700 mov al, [ebx + esi * 2] ; access the element at row 1, column 2
```

The `al` register will now contain the value of the element at row 1, column 2 of the array.

## Calculating a Row Sum

The `calc_row_sum` procedure calculates the sum of a selected row in a matrix of 8-bit integers. It receives the following inputs:

- **EBX:** The offset of the matrix in memory.
- **EAX:** The index of the row to calculate the sum for.
- **ECX:** The size of each row in the matrix, in bytes.
- The procedure returns the sum of the row in the `EAX` register.

The procedure works by first calculating the offset of the row in the matrix. This is done by multiplying the row index by the row size.

The procedure then adds this offset to the base address of the matrix to get the address of the first element in the row.

The procedure then iterates over the row, adding each element to the accumulator. The accumulator is initialized to 0 before the loop starts.

The loop iterates until the end of the row is reached.

After the loop finishes, the procedure returns the sum in the accumulator in the EAX register.

Here is a more detailed explanation of the code:

```
707 ;-----  
708 ; calc_row_sum  
709 ; Calculates the sum of a row in a byte matrix.  
710 ; Receives: EBX = table offset, EAX = row index,  
711 ; ECX = row size, in bytes.  
712 ; Returns: EAX holds the sum.  
713 ;-----  
714 calc_row_sum PROC USES ebx ecx edx esi  
715  
716 ; Calculate the offset of the row.  
717 mul ecx ; row index * row size  
718  
719 ; Add the offset to the base address of the matrix to get the address of the first element in the row.  
720 add ebx,eax ; row offset  
721  
722 ; Initialize the accumulator.  
723 mov eax,0 ; accumulator  
724  
725 ; Set the column index to 0.  
726 mov esi,0 ; column index  
727  
728 ; Loop over the row, adding each element to the accumulator.  
729 L1:  
730 movzx edx,BYTE PTR[ebx + esi] ; get a byte  
731 add eax,edx ; add to accumulator  
732 inc esi ; next byte in row  
733 loop L1  
734  
735 ; Return the sum in the accumulator.  
736 ret  
737 calc_row_sum ENDP
```

The BYTE PTR operand size in the MOVZX instruction is required to clarify the operand size. The MOVZX instruction converts a byte to a doubleword.

The BYTE PTR operand size tells the assembler that the operand at the address specified by the ebx + esi register is a byte.

The calc\_row\_sum procedure is a useful example of how to use base-index addressing to access elements of a two-dimensional array and to perform common tasks on arrays, such as calculating the sum of a row.

## Scale Factors

A scale factor is a multiplier that is used to scale the index operand when accessing elements of an array using base-index addressing.

The scale factor is required because the size of the elements in an array can vary.

For example, if an array contains bytes, then the scale factor is 1. If an array contains words, then the scale factor is 2. If an array contains doublewords, then the scale factor is 4.

The following table shows the scale factor for different types of data:

Data type	Scale factor
Byte	1
Word	2
Doubleword	4
Quadword	8

To use a scale factor, you simply multiply the index operand by the scale factor before adding it to the base address of the array.

This will give you the address of the element in the array at the specified index.

For example, the following code accesses the element at row 1, column 2 of an array of words:

```
745 ; tableW is an array of words.  
746 mov ebx, OFFSET tableW ; load the base register with the address of the array  
747 mov esi, 2 ; load the index register with the column index  
748 mov ax, [ebx + esi * TYPE tableW] ; access the element at row 1, column 2
```

The TYPE tableW operand size in the MOV instruction tells the assembler that the elements in the array are words.

Therefore, the scale factor is 2. The esi \* TYPE tableW operand is multiplied by 2 before it is added to the base address of the array.

This gives us the address of the element at row 1, column 2.

Scale factors can be useful for writing efficient code to access arrays.

By using scale factors, you can avoid having to keep track of the size of the elements in the array. This can make your code more readable and maintainable.

## Base-Index-Displacement Operands

A base-index-displacement operand is a type of operand that allows you to access memory using the sum of the following values:

- **A displacement.**
- **A base register.**
- **An index register.**
- **An optional scale factor.**

Base-index-displacement operands are well suited for processing two-dimensional arrays. The displacement can be an array name, the base operand can hold the row offset, and the index operand can hold the column offset.

The following example shows how to use a base-index-displacement operand to access an element of a two-dimensional array of doublewords:

```
759 ; tableD is a two-dimensional array of doublewords.  
760 ; Rowsize is the size of each row in the array, in bytes.  
761  
762 mov ebx, Rowsize ; load the base register with the row offset  
763 mov esi, 2 ; load the index register with the column offset  
764 mov eax, tableD[ebx + esi * TYPE tableD] ; access the element at row 1, column 2
```

The `tableD[ebx + esi * TYPE tableD]` operand specifies the address of the element at row 1, column 2 of the array.

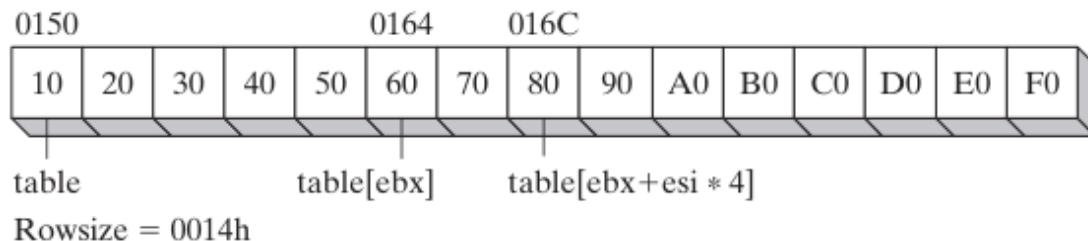
The ebx register contains the row offset, and the esi register contains the column offset.

The `TYPE tableD` operand size tells the assembler that the elements in the array are doublewords. Therefore, the scale factor is 4.

Base-index-displacement operands can be useful for writing efficient code to access arrays.

By using base-index-displacement operands, you can avoid having to keep track of the size of the elements in the array and the offset of each row in the array.

This can make your code more readable and maintainable.



The diagram you provided shows the positions of the EBX and ESI registers relative to the array `tableD`. The EBX register contains the row offset, and the ESI register contains the column offset.

The tableD array begins at offset 0150h. The EBX register contains the value 20h, which is the size of each row in the array, in bytes. Therefore, the EBX register points to the beginning of the second row in the array.

The ESI register contains the value 2, which is the column index of the element that we want to access. Therefore, the ESI register points to the third element in the second row of the array.

Base-index-displacement operands are a powerful tool for accessing arrays in assembly language.

### **Base-Index Operands in 64-Bit Mode.**

The program below is a short program that uses a procedure named get\_tableVal to locate a value in a two-dimensional table of 64-bit integers. The program demonstrates how to use base-index-displacement operands in 64-bit mode.

---

```
0804 ; Two-dimensional arrays in 64-bit mode (TwoDimArrays.asm)
0805 ; Prototypes for procedures
0806 Crlf proto
0807 WriteInt64 proto
0808 ExitProcess proto
0809
0810 .data
0811     table QWORD 1,2,3,4,5      ; Define a two-dimensional array with 3 rows and 5 columns
0812     RowSize = ($ - table)    ; Calculate the size of one row in bytes
0813
0814     QWORD 6,7,8,9,10        ; Define the second row
0815     QWORD 11,12,13,14,15    ; Define the third row
0816
0817 .code
0818 main PROC
0819     ; Set row and column indices
0820     mov rax, 1              ; Row index (zero-based)
0821     mov rsi, 4              ; Column index (zero-based)
0822
0823     call get_tableVal       ; Call the get_tableVal procedure to retrieve the value
0824     call WriteInt64         ; Display the retrieved value
0825     call Crlf               ; Insert a line break
0826
0827     mov ecx, 0
0828     call ExitProcess        ; End the program
0829
0830 main ENDP
```

***The main procedure performs the following steps:***

It loads the row index (1) into the RAX register.

It loads the column index (4) into the RSI register.

It calls the get\_tableVal procedure to get the value at the specified row and column in the table array.

It calls the WriteInt64 procedure to display the value in the RAX register.

It calls the ExitProcess procedure to end the program.

***The get\_tableVal procedure performs the following steps:***

It loads the row offset into the RBX register.

It multiplies the row offset by the size of a quadword to get the offset of the row in the array.

It adds the column offset to the row offset to get the offset of the element in the array.

It loads the value at the specified offset into the RAX register.

It returns from the procedure.

The get\_tableVal procedure uses a base-index-displacement operand to access the element in the array.

The base operand is the RBX register, which contains the row offset.

The index operand is the RSI register, which contains the column offset.

The scale factor is omitted, because the elements in the array are quadwords, and the size of a quadword is 1.

The program you provided demonstrates how to use base-index-displacement operands in 64-bit mode.

Base-index-displacement operands are a powerful tool for accessing arrays in assembly language.

## SEARCHING AND SORTING ALGORITHMS

### Bubble sort

The bubble sort algorithm is a simple sorting algorithm that works by repeatedly comparing adjacent elements in an array and swapping them if they are in the wrong order. The algorithm starts at the beginning of the array and compares the first two elements.

If the first element is greater than the second element, the two elements are swapped. The algorithm then moves on to the next two elements and repeats the process.

The algorithm continues to iterate through the array until it reaches the end.

The following is a pseudocode implementation of the bubble sort algorithm:

```
0839 bubble_sort(array):
0840     for i in range(len(array) - 1):
0841         for j in range(len(array) - i - 1):
0842             if array[j] > array[j + 1]:
0843                 array[j], array[j + 1] = array[j + 1], array[j]
```

The bubble sort algorithm is a simple and straightforward algorithm, but it is not very efficient for large arrays.

This is because the algorithm has to compare every pair of elements in the array for each iteration. For an array of size  $n$ , the bubble sort algorithm has a **time complexity of  $O(n^2)$** .

#### *Analysis of bubble sort performance.*

The following table shows the sort times for various array sizes, assuming that 1000 array elements can be sorted in 0.1 second:

Array Size	Time (seconds)
1,000	0.1
10,000	10.0
100,000	1000
1,000,000	100,000 (27.78 hours)

As you can see, the sort time increases quadratically with the array size. This means that the bubble sort algorithm is not very efficient for large arrays.

The bubble sort algorithm is a simple and straightforward sorting algorithm, but it is not very efficient for large arrays.

If you need to sort a large array, you should use a more efficient sorting algorithm, such as the quicksort algorithm or the merge sort algorithm.

---

```

0847 ; Bubble sort algorithm in MASM
0848 section .data
0849     array: dw 5, 3, 2, 1, 4
0850 section .code
0851     start:
0852
0853     mov esi, array
0854     mov ecx, 5 ; length of the array
0855     L1:
0856     mov edi, esi
0857     add edi, 4
0858     L2:
0859     cmp [esi], [edi]
0860     jg L3 ; swap if esi > edi
0861     xchg [esi], [edi]
0862     add esi, 4
0863     cmp esi, array + ecx * 4 - 4
0864     jne L2
0865     loop L1
0866     ; array is now sorted
0867     exit

```

The array section in the data segment initializes an array with values to be sorted.

The code begins by setting up registers, with esi pointing to the start of the array and ecx containing the length of the array (in this case, 5).

The outer loop, labeled as L1, iterates through the array. This corresponds to the outer loop counter (cx1) in the notes.

Inside the outer loop, the inner loop labeled as L2 is used to compare and swap elements, corresponding to the inner loop counter (cx2) in the notes.

The comparison is done using cmp, and if the current element ([esi]) is greater than the next element ([edi]), a swap is performed using xchg.

The code ensures that the inner loop (L2) iterates through the entire array by comparing esi to the end of the array (array + ecx \* 4 - 4).

After completing the inner loop for a given pass through the array, it uses loop to decrement the outer loop counter and repeats the process until the outer loop counter is equal to 0.

Once the sorting is complete, the array is in ascending order.

C++ version:

```
0870 int BinSearch(int values[], const int searchVal, int count) {  
0871     int first = 0;  
0872     int last = count - 1;  
0873  
0874     while (first <= last) {  
0875         int mid = (last + first) / 2;  
0876  
0877         if (values[mid] < searchVal)  
0878             first = mid + 1;  
0879         else if (values[mid] > searchVal)  
0880             last = mid - 1;  
0881         else  
0882             return mid; // success  
0883     }  
0884  
0885     return -1; // not found  
0886 }
```

Assembly version:

```
; BinarySearch  
; Searches an array of signed integers for a single value.  
; Receives: Pointer to array, array size, search value.  
; Returns: If a match is found, EAX = the array position of the  
; matching element; otherwise, EAX = -1.  
BinarySearch PROC USES ebx edx esi edi,  
    pArray:PTR DWORD,  
    Count:DWORD,  
    searchVal:DWORD  
  
    LOCAL first:DWORD,  
          last:DWORD,  
          mid:DWORD  
  
    mov first, 0  
    mov eax, Count  
    dec eax  
    mov last, eax  
    mov edi, searchVal  
    mov ebx, pArray
```

L1:

```
mov eax, first
cmp eax, last
jg L5
```

```
mov eax, last
add eax, first
shr eax, 1
mov mid, eax
```

```
mov esi, mid
shl esi, 2
mov edx, [ebx+esi]
```

```
cmp edx, edi
jge L2
mov eax, mid
inc eax
mov first, eax
jmp L4
```

L2:

```
cmp edx, edi
jle L3
mov eax, mid
dec eax
mov last, eax
jmp L4
```

L3:

```
mov eax, mid
jmp L9
```

L4:

```
jmp L1
```

L5:

```
mov eax, -1
```

L9:

```
ret
```

```
BinarySearch ENDP
```

Program 2:

```
; Bubble Sort and Binary Search (BinarySearchTest.asm)
; Bubble sort an array of signed integers and perform a binary search.
```

```
INCLUDE Irvine32.inc
```

```
INCLUDE BinarySearch.inc ; Include procedure prototypes
```

```
LOWVAL = -5000
```

```
HIGHVAL = +5000
```

```
ARRAY_SIZE = 50
```

```
.data
```

```
array DWORD ARRAY_SIZE DUP(?)
```

```
.code
```

```
main PROC
```

```
    call Randomize ; Initialize random number generator
```

```
; Fill an array with random signed integers
```

```
    INVOKE FillArray, ADDR array, ARRAY_SIZE, LOWVAL, HIGHVAL
```

```
; Display the array
```

```
    INVOKE PrintArray, ADDR array, ARRAY_SIZE
```

```
    call WaitMsg
```

```
; Perform a bubble sort and redisplay the array
```

```
    INVOKE BubbleSort, ADDR array, ARRAY_SIZE
```

```
    INVOKE PrintArray, ADDR array, ARRAY_SIZE
```

```
; Demonstrate a binary search
```

```
    call AskForSearchVal
```

```
; Perform the binary search and display the results
```

```
    INVOKE BinarySearch, ADDR array, ARRAY_SIZE, eax
```

```
    call ShowResults
```

```
exit
```

```
main ENDP
```

```

; Prompt the user for a signed integer
AskForSearchVal PROC
    .data
    prompt BYTE "Enter a signed decimal integer in the range of -5000 to +5000 to find in
the array: ",0
    .code
    call Crlf
    mov edx, OFFSET prompt
    call WriteString
    call ReadInt
    ret
AskForSearchVal ENDP

; Display the resulting value from the binary search
ShowResults PROC
    .data
    msg1 BYTE "The value was not found.",0
    msg2 BYTE "The value was found at position ",0
    .code
    IF eax == -1
        mov edx, OFFSET msg1
        call WriteString
    ELSE
        mov edx, OFFSET msg2
        call WriteString
        call WriteDec
    ENDIF
    call Crlf
    call Crlf
    ret
ShowResults ENDP

END main

```

The provided assembly code, BinarySearchTest.asm, is a program that demonstrates the use of the bubble sort and binary search functions to work with an array of signed integers. Here's an overview of what the code does:

### **Initialization:**

It starts by including necessary libraries and defining constants for the minimum and maximum values (LOWVAL and HIGHVAL) and the size of the array (ARRAY\_SIZE).

The code also defines the array array and contains the .data and .code sections.

### **Main Procedure (main):**

Calls the Randomize function to initialize the random number generator.

Invokes the FillArray procedure to fill the array with random signed integers within the specified range (LOWVAL to HIGHVAL).

Displays the original content of the array using the PrintArray procedure and waits for a message (WaitMsg).

Performs a bubble sort on the array using the BubbleSort procedure to sort the integers in ascending order.

Displays the sorted array using the PrintArray procedure. Prompts the user to enter a signed integer with the AskForSearchVal procedure.

### **AskForSearchVal Procedure:**

Prompts the user to enter a signed integer within the specified range. Reads the integer entered by the user and returns it in the EAX register.

### **ShowResults Procedure:**

Displays the result of the binary search.

If the binary search returns -1, indicating that the value was not found, it prints "The value was not found."

If the binary search returns the position of the value in the array, it prints "The value was found at position X," where X is the position.

In summary, this program generates a random array of signed integers, sorts the array using the bubble sort algorithm, and then performs a binary search on the sorted array to find a user-specified value.

It displays the results of the binary search, indicating whether the value was found and, if so, at what position in the array.