Lab 5 - Data Addressing and Arithmetic

5.1 Addition and Subtraction

Arithmetic is a big and most important topic in assembly language. In this Lab we will focus on addition and subtraction as well as the addressing and retrieval of the data stored in the memory. In this Lab we will also see how the CPU status flags (Carry, Sign, Zero, etc.) are affected by arithmetic instructions.

5.1.1 INC and DEC Instructions

The **INC** (increment) and **DEC** (decrement) instructions, respectively, add 1 and subtract 1 from a register or memory operand. The syntax is:

```
        INC reg/mem
        DEC reg/mem
```

For example:

```
Include Irvine32.inc
.data
        myWord WORD 1000h
.code
main proc
        ;increment data
        inc myWord                      ;myWord = 1001h
        mov bx,myWord
        dec bx                          ; BX = 1000h

        ;increment address
        mov EAX, OFFSET myWord          ; get address of myWord
        call WriteInt
        inc EAX                         ; address of myWord + 1
        call WriteInt

        invoke ExitProcess,0
main endp
end main
```

Note: INC and DEC instructions do not affect the Carry flag.

5.1.2 ADD Instruction

The ADD instruction adds a source operand to a destination operand of the same size. The syntax is:

```
        ADD dest,source
```

Source remains unchanged by the ADD operation, and the sum is stored in the destination operand. The set of possible operands is the same as for the MOV instruction.

```
.data
        var1 DWORD 10000h
        var2 DWORD 20000h
.code
        mov eax,var1            ; EAX = 10000h
        add eax,var2            ; EAX = 30000h
```

5.1.3 SUB Instruction

The SUB instruction subtracts a source operand from a destination operand. The set of possible operands is the same as for the ADD and MOV instructions. The syntax is:

```
SUB dest,source
```

For example:

```
.data
	var1 DWORD 30000h
	var2 DWORD 10000h
.code
	mov eax,var1 ; EAX = 30000h
	sub eax,var2 ; EAX = 20000h
```

5.1.4 NEG Instruction

The NEG (negate) instruction reverses the sign of a number by converting the number to its two's complement. The syntax is:

```
NEG reg
NEG mem
```

For example:

```
.data
	var1 DWORD 30000h
.code
	NEG var1		; var1 = FFFFD000h (negative of 30000h)
	mov eax,var1		; EAX = FFFFD000h
	NEG EAX			; EAX = 30000h
	Call WriteInt
```

5.1.5 Implementing Arithmetic Expressions

Using the ADD, SUB, and NEG instructions, we can implement arithmetic expressions involving addition, subtraction, and negation in assembly language.

Let's solve this equation in assembly language: $sum = -x + (y - z), where\ x = 15, y = 20\ and\ z = 25.$

```
Include Irvine32.inc

.data
	sum SDWORD ?
	x1 SDWORD 15
	y1 SDWORD 20
	z1 SDWORD 25
.code
main proc
	; first term: -x
	mov eax,x1
	neg eax			; EAX = -15

	; second term: (y - z)
	mov ebx,y1
	sub ebx,z1		; EBX = -5

	; add the terms and store:
        add eax,ebx
        mov sum,eax         ; -20
        call WriteInt

        invoke ExitProcess,0
main endp
end main
```

Student Task: solve the following equation by utilizing the appropriate datatypes and constants:

$$\left(\left(-var1+4\right)*var2\right)-var3 \quad where\ var1=17, var2=19\ and\ var3=21$$

5.2 Flags Affected by Addition and Subtraction

5.2.1 Zero Flag

The Zero flag is set when the result of an arithmetic operation equals zero.

```
mov ecx,1
sub ecx,1             ; ECX = 0, ZF = 1
mov eax,0FFFFFFFFh
inc eax               ; EAX = 0, ZF = 1
inc eax               ; EAX = 1, ZF = 0
dec eax               ; EAX = 0, ZF = 1
```

5.2.2 Carry Flag

When adding two unsigned integers, the Carry flag is a copy of the carry out of the most significant bit of the destination operand. Intuitively, we can say CF = 1 when the sum exceeds the storage size of its destination operand.

For addition:

```
mov al,0FFh
add al,1              ; AL = 00, CF = 1
mov ax,00FFh
add ax,1              ; AX = 0100h, CF = 0
```

For subtraction:

```
mov al,1
sub al,2              ; AL = FFh, CF = 1
```

5.2.3 Auxiliary Carry Flag

The Auxiliary Carry (AC) flag indicates a carry or borrow out of bit 3 in the destination operand.

```
                 ↓
     0  0  0  0  1  1  1  1
  +  0  0  0  0  0  0  0  1
  -----------------------
     0  0  0  1  0  0  0  0
```

```
mov al,0Fh
add al,1              ; AC = 1
```

5.2.4 Parity Flag

The Parity flag (PF) is set when the least significant byte of the destination has an even number of 1 bits.

```
mov al,10001100b
add al,00000010b          ; AL = 10001110, PF = 1
sub al,10000000b          ; AL = 00001110, PF = 0
```

5.2.5 Sign Flag

The Sign flag is set when the result of a signed arithmetic operation is negative. For example, subtracting integer 5 from 4:

```
mov eax,4
sub eax,5                 ; EAX = -1, SF = 1
```

5.2.6 Overflow Flag

The Overflow flag is set when the result of a signed arithmetic operation overflows or underflows the destination operand.

```
mov al,+126
add al,1                  ; OF = 0
add al,1                  ; OF = 1
```

5.2.7 Example Program

The following example program implements various arithmetic expressions using the ADD, SUB, INC, DEC, and NEG instructions, and shows how status flags are affected:

```
Include Irvine32.inc

.code
main proc
      ; Zero flag example:
      mov cx,1
      add cx,1            ; ZF = 0
      sub cx,2            ; ZF = 1
      mov ax,0FFFFh
      inc ax              ; ZF = 1

      ; Carry flag example:
      ;For adition:
      mov al,0FFh
      add al,1            ; AL = 00, CF = 1
      mov ax,00FFh
      add ax,1            ; AX = 0100h, CF = 0
      ;For subtraction:
      mov al,1
      sub al,2            ; AL = FFh, CF = 1

      ; Auxiliary Carry flag example:
      mov al,00001111b
      add al,00000001b          ; AC = 1
      mov al,00000111b
      add al,00000001b          ; AC = 0

      ; Parity flag example:
      mov al,10001100b
      add al,00000010b          ; AL = 10001110, PF = 1
      sub al,10000000b          ; AL = 00001110, PF = 0

      ; Sign flag example:
      mov eax,4
      sub eax,5                 ; EAX = -1, SF = 1
      mov eax,+5
      add eax,+1                ; EAX = 6, SF = 0

      ; Overflow flag example:
      mov al,+126
      add al,1                  ; OF = 0
      add al,1                  ; OF = 1

      invoke ExitProcess,0
main endp
end main
```

Student Task: Execute the above assembly program in debugging and watch the behavior of flags registers.

5.3 Data-Related Operators and Directives

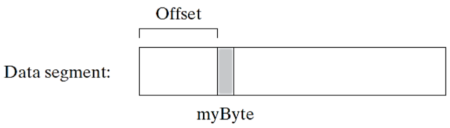
Operators and directives are not executable instructions. They are interpreted by the assembler. You can use these directives to get information about the addresses and size characteristics of data.

These are some important data operators:

- **OFFSET**: returns the distance of a variable from the beginning of its enclosing segment.
- **PTR**: lets you override an operand's default size.
- **TYPE**: returns the size (in bytes) of an operand or of each element in an array.
- **LENGTHOF**: returns the number of elements in an array.
- **SIZEOF**: returns the number of bytes used by an array initializer.
- **LABEL**: provides a way to redefine the same variable with different size attributes.
- **ALIGH**: aligns a variable on a byte, word, doubleword, or paragraph boundary.

5.3.1 OFFSET Operator

The OFFSET operator returns the offset of a data label. The offset represents the distance, in bytes, of the label from the beginning of the data segment.



```
.data
      var1 BYTE 135
      var2 WORD 3AF5h
      var3 DWORD 12345678h
      var4 BYTE 5
.code
      mov ESI,OFFSET var1       ; ESI = 00404000h
      mov ESI,OFFSET var2       ; ESI = 00404001h
      mov ESI,OFFSET var3       ; ESI = 00404003h
      mov ESI,OFFSET var4       ; ESI = 00404007h
```

Variables	Addresses	Memory
var1	**00404000h**	**135**
var2	**00404001h**	**F5**
	00404002h	3A
var3	**00404003h**	**78**
	00404004h	56
	00404005h	34
	00404006h	12
var4	**00404007h**	**5**

You can initialize a doubleword variable with the offset of another variable, effectively creating a pointer.

```
.data
       bigArray DWORD 500 DUP(?)
       pArray DWORD bigArray
.code
       mov esi,pArray             ; ESI = 00404000h
```

5.3.2 PTR Operator

PTR operator is used to override the declared size of an operand. This is only necessary when you're trying to access the operand using a size attribute that is different from the one assumed by the assembler.

For example, we move the lower 16-bits of a doubleword variable into AX.

```
.data
       var1 DWORD 12345678h
.code
       mov ax, var1               ; error
       mov ax, WORD PTR var1      ; successfully moves first 2 bytes to AX, AX = 5678h
```

Why wasn't 1234h moved into AX? x86 processors use the *little-endian* storage format in which the low-order byte is stored at the variable's starting address.

Variable	Addresses	Memory
var1	00404000h	78
	00404001h	56
	00404002h	34
	00404003h	12

We can access more data using the direct-offset method:

```
mov ax, WORD PTR [var1+2]         ; 1234h
mov al, BYTE PTR [var1+3]         ; 12h
mov ax, WORD PTR [var1+1]         ; 3456h
```

5.3.3 TYPE Operator

The TYPE operator returns the size, in bytes, of a single element of a variable. For example, the TYPE of a byte equals 1, the TYPE of a word equals 2, the TYPE of a doubleword is 4, and the TYPE of a quadword is 8.

```
.data
      var1 BYTE ?
      var2 WORD ?
      var3 DWORD ?
      var4 QWORD ?
.code
      mov al, TYPE var1         ; AL = 1
      mov al, TYPE var2         ; AL = 2
      mov al, TYPE var3         ; AL = 4
      mov al, TYPE var4         ; AL = 8
```

5.3.4 LENGTHOF Operator

The LENGTHOF operator counts the number of elements in an array, defined by the values appearing on the same line as its label.

```
.data
      var1 BYTE 10,20,30
      var2 WORD 30 DUP(?),0,0
      var3 WORD 5 DUP(3 DUP(?))
      var4 DWORD 1,2,3,4
      var5 BYTE "12345678",0
.code
      mov al, LENGTHOF var1     ; AL = 3
      mov al, LENGTHOF var2     ; AL = 32
      mov al, LENGTHOF var3     ; AL = 15
      mov al, LENGTHOF var4     ; AL = 4
      mov al, LENGTHOF var5     ; AL = 9
```

If you declare an array that spans multiple program lines, LENGTHOF only regards the data from the first line as part of the array.

```
.data
      myArray BYTE 10,20,30,40,50
              BYTE 60,70,80,90,100
.code
      mov al, LENGTHOF myArray        ; AL = 5
```

But if we end the first line with a comma and continue the list of initializers onto the next line then LENGTHOF would return the correct length:

```
.data
      myArray BYTE 10,20,30,40,50,
                   60,70,80,90,100
.code
      mov al, LENGTHOF myArray        ; AL = 10
```

5.3.5 SIZEOF Operator

The SIZEOF operator returns the total bytes consumed by the variable. It is a value that is equivalent to multiplying LENGTHOF by TYPE of the variable.

```
.data
      var1 WORD ?
      var2 DWORD 0000FFFFh
      var3 QWORD ?
      var4 BYTE 10,20,30
      var5 WORD 10,20,30
      intArray WORD 32 DUP(0)
.code
      mov eax,SIZEOF var1        ; EAX = 2
      mov eax,SIZEOF var2        ; EAX = 4
      mov eax,SIZEOF var3        ; EAX = 8
      mov eax,SIZEOF var4        ; EAX = 3
      mov eax,SIZEOF var5        ; EAX = 6
      mov eax,SIZEOF intArray    ; EAX = 64
```

5.3.6 LABEL Operator

The LABEL directive lets you insert a label and give it a size attribute without allocating any storage. That LABEL will pints toward the memory location where the label is declared. The LABEL directive itself allocates no storage.

All standard size attributes can be used with LABEL, such as BYTE, WORD, DWORD, QWORD or TBYTE. A common use of LABEL is to provide an alternative name and size attribute for the variable declared next in the data segment.

```
.data
      var1 LABEL WORD
      var2 DWORD 12345678h
      var3 LABEL BYTE
      var4 WORD 0Fh
.code
      mov eax, var2        ; EAX = 12345678h
      mov ax, var1         ; EAX = 5678h
      mov ax, [var1+2]     ; EAX = 1234h
      mov al, var3         ; EAX = Fh
```

5.3.7 ALIGN Operator

The ALIGN directive aligns a variable on a byte, word, doubleword, or paragraph boundary. The syntax is

```
ALIGN bound
```

Bound value can be 1, 2, 4, 8, or 16.

- ***bound* = 1:** aligns the next variable on a 1-byte boundary (the default).
- ***bound* = 2:** the next variable is aligned on an even-numbered address.
- **bound = 4:** the next address is a multiple of 4.
- **bound = 16:** the next address is a multiple of 16, a paragraph boundary.
- The assembler can insert one or more empty bytes before the variable to fix the alignment.
- Why aligning data? Because the CPU can process data stored at even numbered addresses more quickly than those at odd-numbered addresses.

```
.data
      var1 BYTE 105              ; 00404000h
      ALIGN 2
      var2 WORD 4BF9h            ; 00404002h
```

```
        var3 BYTE 9                ; 00404004h
        ALIGN 4
        var4 DWORD 12345678h       ; 00404008h
```

Variables	Addresses	Memory
var1	**00404000h**	**105**
-	00404001h	0
var2	**00404002h**	**F9**
	00404003h	**4B**
var3	**00404004h**	**9**
-	00404005h	0
-	00404006h	0
-	00404007h	0
var4	**00404008h**	**78**

5.4 Types of Operands while Accessing Data from Memory

5.4.1 Direct Operand

A direct operand is the name of a variable and represents the variable’s address.

```
.data
        var1 DWORD 12345678h
.code
        mov eax, var1       ; var1 is Direct Operand
        mov eax, [var1]     ; alternate method
```

5.4.2 Direct-Offset Operand

A direct-offset operand adds a displacement to the name of a variable, generating a new offset. This new offset can be used to access data in memory.

```
.data
        var1 BYTE 5,6,7
        var2 BYTE 9
.code
        mov al, var1        ; var1 is Direct Operand (AL = 5)
        mov al, [var1+1]    ; var1+1 is Direct-Offset Operand (AL = 6)
        mov al, [var1+3]    ; (AL = 9)
```

5.4.3 Indirect Operand

An indirect operand is a register containing the address of data. By surrounding the register with brackets (as in [esi]), a program dereferences the address and retrieves the memory data.

```
.data
        var1 BYTE 10h
.code
        mov esi,OFFSET var1        ; ESI = 00404000h
        mov al,[esi]               ; AL = 10h
```

If the destination operand uses indirect addressing, a new value is placed in memory at the location pointed to by the register. In the following example, the contents of the BL register are copied to the memory location addressed by ESI.

```
.data
      var1 BYTE 10h
.code
      mov esi, OSSFET var1      ; ESI = 00404000h
      mov al, 0FFh              ; AL = FFh
      mov [esi], al             ; FFh will store at var1 (var1 = FFh)
```

The size of an operand cannot be guessed by just the context of an instruction. For example, the following instruction causes the assembler to generate an "operand must have size" error message:

```
inc [esi]           ; error: operand must have size
```

The assembler does not know whether ESI points to a byte, word, doubleword, or some other size. The PTR operator confirms the operand size:

```
inc BYTE PTR [esi]
```

5.4.4 Indexed Operands

An indexed operand combines a constant with an indirect operand. The constant and register value are added, and the resulting offset is dereferenced. For example, [array+esi] and array[esi] are indexed operands.

Any of the 32-bit general-purpose registers may be used as index registers. There are different notational forms permitted by MASM (the brackets are part of the notation):

```
      constant[reg]
      [constant + reg]
```

The first notational form combines the name of a variable with a register. The variable name is translated by the assembler into a constant that represents the variable's offset.

Indexed operands are ideally suited to array processing. The index register should be initialized to zero before accessing the first array element:

```
.data
      arrayB BYTE 10h,20h,30h
.code
      mov esi,0
      mov al, [arrayB+esi]            ; AL = 10h
      mov al, arrayB[esi]             ; alternate method
      inc esi
      mov al, [arrayB+esi]            ; AL = 20h
      inc esi
      mov al, [arrayB+esi]            ; AL = 30h
```

The second type of indexed addressing combines a register with a constant offset. The index register holds the base address of an array or structure, and the constant identifies offsets of various array elements.

```
.data
      arrayW WORD 1000h,2000h,3000h
.code
      mov esi,OFFSET arrayW     ; ESI = 00404000h
```

```
        mov ax,[esi]        ; AX = 1000h
        mov ax,[esi+2]      ; AX = 2000h
        mov ax,[esi+4]      ; AX = 3000h
```

5.4.4.1 Scale Factors in Indexed Operands

The *scale factor* is the size of the array component (word = 2, doubleword = 4, or quadword = 8).

To traverse an array, we can use the indexed operands method. But to get each item of the array we have to move the address according to the array datatype (BYTE, WORD or DWORD etc.). For example, to next 2nd value from WORD array we have to add 2 in the first address and so on. And to get the 2nd value of a DWORS array we have to add 4 in the first address.

```
.data
        arrayD DWORD 1,2,3,4
.code
        mov esi, 3                      ; we want to access 4rd index of array
        mov eax, arrayD[esi*4]          ; EAX = 4
```

The TYPE operator can make the indexing more flexible should **arrayD** be redefined as another type in the future:

```
        mov esi, 3                                 ; we want to access 4rd index of array
        mov eax, arrayD[esi*TYPE arrayD]           ; EAX = 4
```

5.5 Pointers

A variable containing the address of another variable is called a *pointer*. Pointers are a great tool for manipulating arrays and data structures because the address they hold can be modified at runtime. A pointer's size is affected by the processor's current mode (32-bit or 64-bit).

```
.data
        arrayB byte 10h,20h,30h,40h
        ptrB dword arrayB
```

Optionally, you can declare **ptrB** with the OFFSET operator to make the relationship clearer:

```
ptrB dword OFFSET arrayB
```

5.5.1 TYPEDEF Operator

The TYPEDEF operator lets you create a user-defined type that has all the status of a built-in type when defining variables. TYPEDEF is ideal for creating pointer variables.

For example, the following declaration creates a new data type PBYTE that is a pointer to bytes:

```
PBYTE TYPEDEF PTR BYTE
```

This declaration would be placed near the beginning of a program before the data segment. Then, variables could be defined using PBYTE:

```
PBYTE TYPEDEF PTR BYTE
.data
        arrayB BYTE 10h,20h,30h,40h
        ptr1 PBYTE ? ; uninitialized
        ptr2 PBYTE arrayB ; points to an array
```

5.5.2 Example Program: Pointers

The following program uses TYPDEF to create three pointer types (PBYTE, PWORD, PDWORD). It creates several pointers, assigns several array offsets, and dereferences the pointers:

```
Include Irvine32.inc

; Create user-defined types.
PBYTE TYPEDEF PTR BYTE ; pointer to bytes
PWORD TYPEDEF PTR WORD ; pointer to words
PDWORD TYPEDEF PTR DWORD ; pointer to doublewords

.data
	arrayB BYTE 10h,20h,30h
	arrayW WORD 1,2,3
	arrayD DWORD 4,5,6
	; Create some pointer variables.
	ptr1 PBYTE arrayB
	ptr2 PWORD arrayW
	ptr3 PDWORD arrayD
.code
main PROC
	; Use the pointers to access data.
	mov esi,ptr1
	mov al,[esi] ; 10h
	mov esi,ptr2
	mov ax,[esi] ; 1
	mov esi,ptr3
	mov eax,[esi] ; 4

	invoke ExitProcess,0
main ENDP
END main
```

Student Task: Execute the above assembly program in debugging and watch the behavior of relevant registers.

---Half Time--

5.6 JMP and LOOP Instructions

A transfer of control, or branch, is a way of altering the order in which statements are executed. There are two basic types of transfers:

- **Unconditional Transfer:** Control is transferred to a new location in all cases; a new address is loaded into the instruction pointer, causing execution to continue at the new address. The **JMP** instruction does this.
- **Conditional Transfer:** The program branches if a certain condition is true. A wide variety of conditional transfer instructions can be combined to create conditional logic structures. The CPU interprets true/false conditions based on the contents of the ECX and Flags registers.

5.6.1 JMP Instruction

The JMP instruction causes an unconditional transfer to a destination, identified by a code label that is translated by the assembler into an offset. The syntax is:

```
JMP destination
```

The JMP instruction provides an easy way to create a loop by jumping to a label at the top of the loop:

```
label:
      .
      .
      jmp label          ; repeat the endless loop
```

JMP is unconditional, so a loop like this will continue endlessly unless another way is found to exit the loop.

5.6.2 Loop Instruction

The LOOP instruction, formally known as **Loop According to ECX Counter**, repeats a block of statements a specific number of times. ECX is automatically used as a counter and is decremented each time the loop repeats. Its syntax is:

```
      LOOP destination
```

The loop destination must be within -128 to +127 bytes of the current location counter. The execution of the LOOP instruction involves two steps:

- First, it subtracts 1 from ECX.
- Next, it compares ECX to zero. If ECX is not equal to zero, a jump is taken to the label identified by destination. Otherwise, if ECX equals zero, no jump takes place, and control passes to the instruction following the loop.

```
.code
      mov ax,0
      mov ecx,5
L1:
      inc ax
      loop L1
```

A common programming error is to inadvertently initialize ECX to zero before beginning a loop. If this happens, the LOOP instruction decrements ECX to FFFFFFFFh, and the loop repeats 4,294,967,296 times! If CX is the loop counter (in real-address mode), it repeats 65,536 times.

```
.code
      mov ax,0
      mov ecx,0     ; logical error
L1:
      inc ax
      loop L1       ; it will decrement ECX until FFFFFFFFh
```

The ECX register is used by default by the LOOP instruction that is why we should not change the ECX register inside the loop body because it will alter the loop behavior.

```
L1:
      .
      .
      inc ecx       ;logical error
      loop L1
```

If you need to modify ECX inside a loop, you can save it in a variable at the beginning of the loop and restore it just before the LOOP instruction:

```
.data
      count DWORD ?
.code
      mov ecx,100         ; set loop count
top:
      mov count,ecx       ; save the count

      mov ecx,20          ; modify ECX
      ; use the ECX for your tasks

      mov ecx,count       ; and before LOOP instruction, restore loop count
      loop top
```

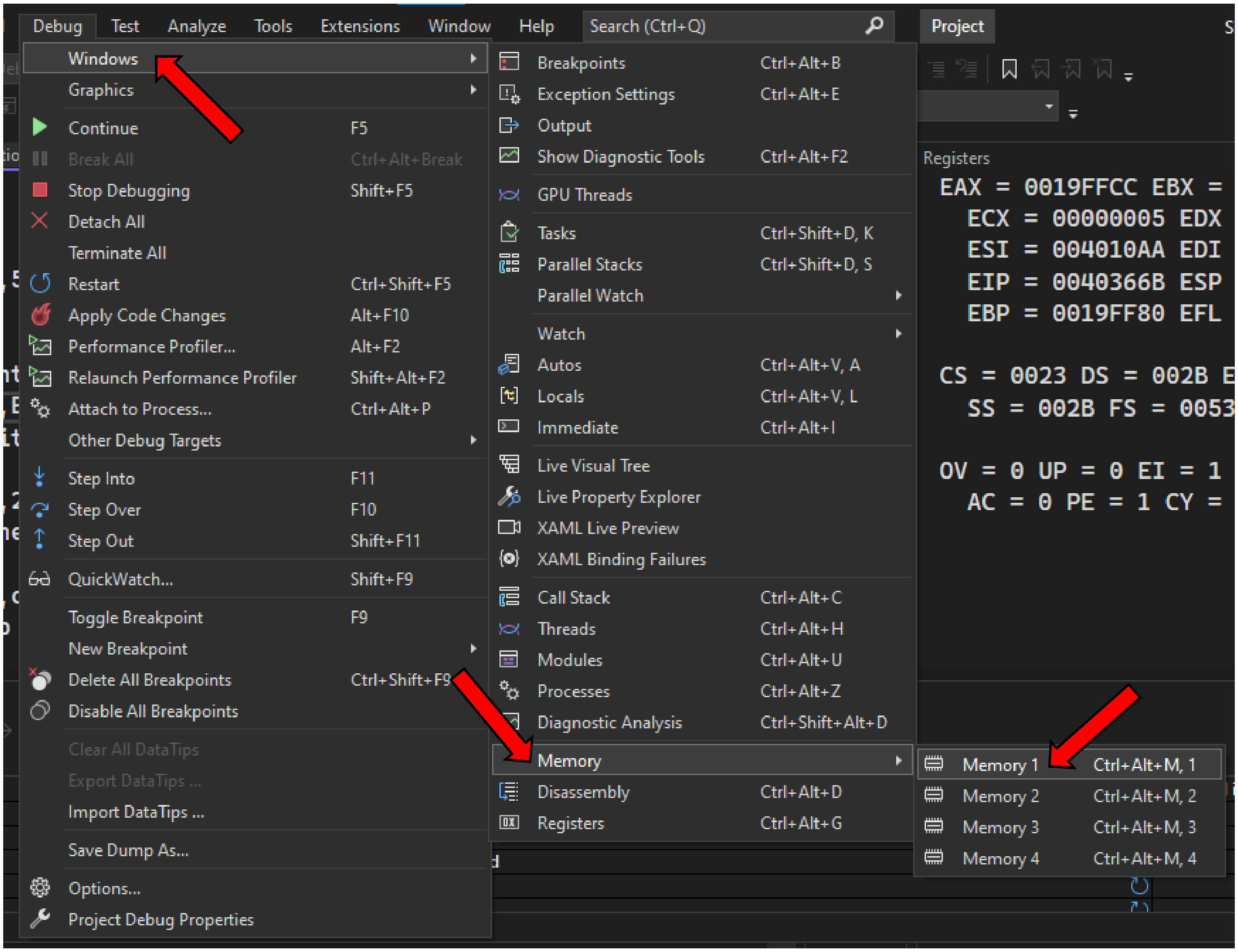
5.6.3 Nested Loops

When creating a loop inside another loop, special consideration must be given to the outer loop counter in ECX. You can save it in a variable:

```
.data
      count DWORD ?
.code
      mov ecx,100         ; set outer loop count
L1:
      mov count,ecx       ; save outer loop count
      mov ecx,20          ; set inner loop count
L2:
      .
      .
      loop L2      ; repeat the inner loop
      mov ecx,count       ; restore outer loop count
      loop L1             ; repeat the outer loop
```

5.7 Displaying an Array in the Visual Studio Debugger

In a debugging session, if you want to display the contents of an array, go to “Debug” menu, select “Windows”, select “Memory”, then select “Memory 1”. A memory window will appear.

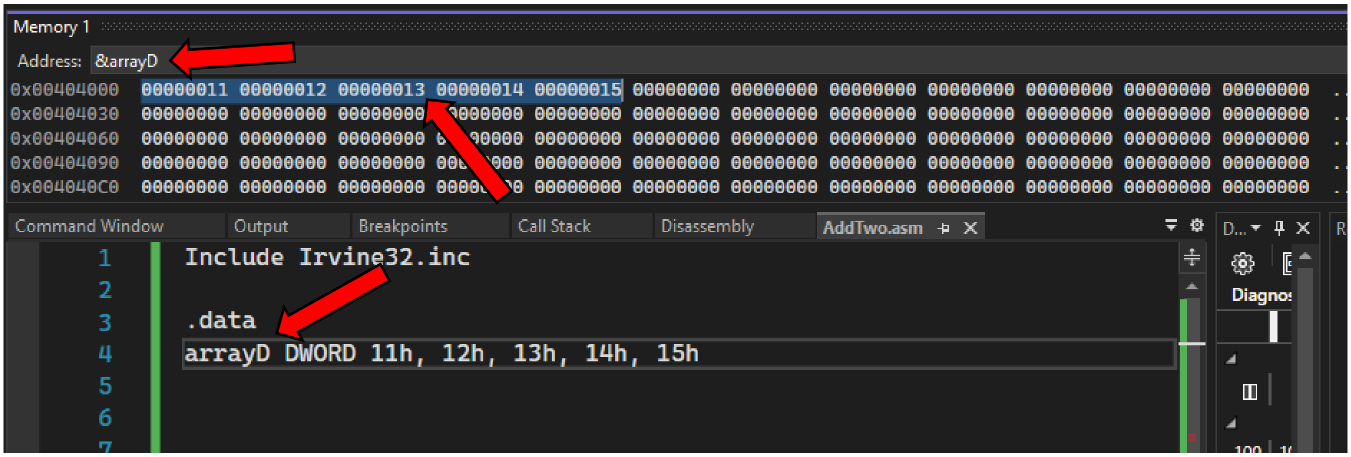

Debug
Test
Analyze
Tools
Extensions
Window
Help
Search (Ctrl+Q)
Project
Windows
Graphics
Continue F5
Break All Ctrl+Alt+Break
Stop Debugging Shift+F5
Detach All
Terminate All
Restart Ctrl+Shift+F5
Apply Code Changes Alt+F10
Performance Profiler... Alt+F2
Relaunch Performance Profiler Shift+Alt+F2
Attach to Process... Ctrl+Alt+P
Other Debug Targets
Step Into F11
Step Over F10
Step Out Shift+F11
QuickWatch... Shift+F9
Toggle Breakpoint F9
New Breakpoint
Delete All Breakpoints Ctrl+Shift+F9
Disable All Breakpoints
Clear All DataTips
Export DataTips ...
Import DataTips ...
Save Dump As...
Options...
Project Debug Properties
Breakpoints Ctrl+Alt+B
Exception Settings Ctrl+Alt+E
Output
Show Diagnostic Tools Ctrl+Alt+F2
GPU Threads
Tasks Ctrl+Shift+D, K
Parallel Stacks Ctrl+Shift+D, S
Parallel Watch
Watch
Autos Ctrl+Alt+V, A
Locals Ctrl+Alt+V, L
Immediate Ctrl+Alt+I
Live Visual Tree
Live Property Explorer
XAML Live Preview
XAML Binding Failures
Call Stack Ctrl+Alt+C
Threads Ctrl+Alt+H
Modules Ctrl+Alt+U
Processes Ctrl+Alt+Z
Diagnostic Analysis Ctrl+Shift+Alt+D
Memory
Disassembly Ctrl+Alt+D
Registers Ctrl+Alt+G
Memory 1 Ctrl+Alt+M, 1
Memory 2 Ctrl+Alt+M, 2
Memory 3 Ctrl+Alt+M, 3
Memory 4 Ctrl+Alt+M, 4
Registers

```
EAX = 0019FFCC EBX =
 ECX = 00000005 EDX
 ESI = 004010AA EDI
 EIP = 0040366B ESP
 EBP = 0019FF80 EFL

CS = 0023 DS = 002B E
 SS = 002B FS = 0053

OV = 0 UP = 0 EI = 1
 AC = 0 PE = 1 CY =
```

To view the array, in the Address field at the top of the memory window, type the "&" character, followed by the name of the array, and press Enter. For example, **&arrayD**. The memory window will display a block of memory starting at the array's address.

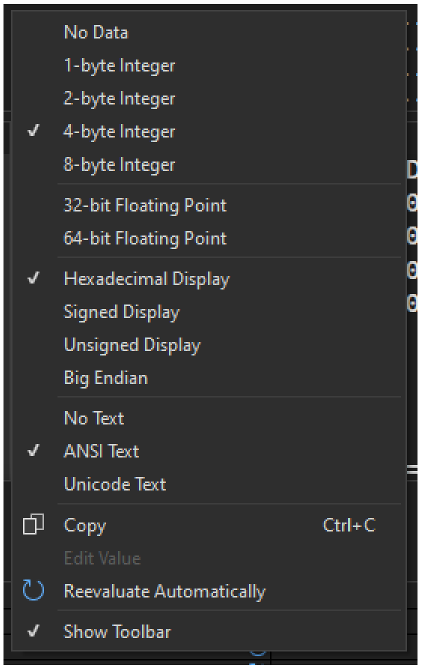

Memory 1
Address: &arrayD
Command Window
Output
Breakpoints
Call Stack
Disassembly
AddTwo.asm
Diagnos

```
0x00404000  00000011 00000012 00000013 00000014 00000015 00000000 00000000 00000000 00000000 00000000 00000000 00000000
0x00404030  00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000
0x00404060  00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000
0x00404090  00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000
0x004040C0  00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000
```

```
Include Irvine32.inc

.data
arrayD DWORD 11h, 12h, 13h, 14h, 15h
```

If your array values are doublewords, you can right-click inside the memory window and select "4-byte integer" from the popup menu. You can also select from different formats, including Hexadecimal Display, signed decimal integer (called Signed Display), or unsigned decimal integer (called Unsigned Display) formats.


No Data
1-byte Integer
2-byte Integer
✓ 4-byte Integer
8-byte Integer
32-bit Floating Point
64-bit Floating Point
✓ Hexadecimal Display
Signed Display
Unsigned Display
Big Endian
No Text
✓ ANSI Text
Unicode Text
Copy Ctrl+C
Edit Value
Reevaluate Automatically
✓ Show Toolbar

5.8 Summing an Integer Array

In assembly language, you would follow these 7 steps to add the elements of an array:

1. Assign the array's address to a register that will serve as an indexed operand.
2. Initialize the loop counter to the length of the array.
3. Assign zero to the register that accumulates the sum.
4. Create a label to mark the beginning of the loop.
5. In the loop body, add a single array element to the sum.
6. Point to the next array element.
7. Use a LOOP instruction to repeat the loop.

```
Include Irvine32.inc

.data
      intarray DWORD 10000h,20000h,30000h,40000h
.code
main PROC
      mov edi,OFFSET intarray          ; 1: EDI = address of intarray
      mov ecx,LENGTHOF intarray        ; 2: initialize loop counter
      mov eax,0                        ; 3: sum = 0
L1:                                    ; 4: mark beginning of loop
      add eax,[edi]                    ; 5: add an integer
      add edi,TYPE intarray            ; 6: point to next element
      loop L1                          ; 7: repeat until ECX = 0

      call WriteInt

      invoke ExitProcess,0
main ENDP
END main
```

Student Task: Execute the above assembly program in debugging and watch the behavior of relevant registers.

5.9 Copying an Array

```
Include Irvine32.inc

.data
       source BYTE "This is the source string",0
       target BYTE SIZEOF source DUP(0)
.code
main PROC
       mov esi,0                       ; index register
       mov ecx,SIZEOF source           ; loop counter
L1:
       mov al,source[esi]              ; get a character from source
       mov target[esi],al              ; store it in the target
       inc esi                         ; move to next character
       loop L1                         ; repeat for entire string

       mov edx,OFFSET target
       call WriteString                ; writes a null-terminated string to the console

       invoke ExitProcess,0
main ENDP
END main
```

Student Task: Execute the above assembly program in debugging and watch the behavior of relevant registers.

5.10 64-Bit Programming

5.10.1 Summing an Array

This is the example program to sum the elements of array in 64-bit mode.

```
ExitProcess proto
.data
intarray QWORD 1000000000000h,2000000000000h
           QWORD 3000000000000h,4000000000000h

.code
main proc

       mov  rdi,OFFSET intarray        ; 1: RDI = address of intarray
       mov  rcx,LENGTHOF intarray            ; 2: initialize loop counter
       mov  rax,0                                  ; 3: sum = 0
L1:                                                      ; 4: mark beginning of loop
       add  rax,[rdi]                              ; 5: add an integer
       add  rdi,TYPE intarray          ; 6: point to next element
       loop L1                                           ; 7: repeat until RCX = 0

       mov  ecx,0                                  ; ExitProcess return value
       call ExitProcess
main endp
end
```

Student Task: Execute the above assembly program in debugging and watch the behavior of relevant registers.

5.10.2 Testing the 64-bit Move Operations

5.10.2.1 Example 1

```
ExitProcess proto

.data
      initval qword 0
      myByte byte 55h
      myWord word 6666h
      myDword dword 80000000h

.code
main proc
      ; Moving immediate values:
      mov  rax,0FFFFFFFFh
      add  rax,1                        ; RAX = 100000000h

      mov  rax,0FFFFh
      mov  bx,1
      add  ax,bx                        ; RAX = 0

      mov  rax,0
      mov  ebx,1
      sub  eax,ebx                      ; RAX = 00000000FFFFFFFF

      mov  rax,0
      mov  bx,1
      sub  ax,bx                        ; RAX = 000000000000FFFF

      mov  rax,0FFh
      mov  bl,1
      add  al,bl                        ; RAX = 0

      mov  rcx,OFFSET myByte
      inc  BYTE PTR [rcx]               ; requires BYTE PTR
      dec  BYTE PTR [rcx]


      mov   ecx,0
      call  ExitProcess
main endp
end
```

Student Task: Execute the above assembly program in debugging and watch the behavior of relevant registers.

5.10.2.2 Example 2

```
ExitProcess proto

.data
       message BYTE "Welcome to my 64-bit Library!",0
       maxuint qword 0FFFFFFFFFFFFFFFFh
       myByte byte 55h
       myWord word 6666h
       myDword dword 80000000h

.code
main proc
       ; Moving immediate values:
       mov  rax,maxuint                ; fill all bits in RAX
       mov  rax,81111111h              ; clears bits 32-63 (no sign extension)
       mov  rax,06666h                 ; clears bits 16-63
       mov  rax,055h                   ; clears bits 8-63

       ; Moving memory operands:
       mov  rax,maxuint                ; fill all bits in RAX
       mov  eax,myDword                ; clears bits 32-63 (no sign extension)
       mov  ax,myWord                  ; affects only bits 0-15
       mov  al,myByte                  ; affects only bits 0-7

       ; 32-bit sign extension works like this
       mov   myWord,8111h              ; make it negative
       movsx eax,myWord                ; EAX = FFFF8111h

       ; The MOVSXD instruction (move with sign-extension) permits the
       ; source operand to be a 32-bit register or memory operand:
       mov     ebx,0FFFFFFFFh
       movsxd  rax,ebx                 ; rax = FFFFFFFFFFFFFFFF

       mov   ecx,0
       call  ExitProcess
main endp
end
```

Student Task: Execute the above assembly program in debugging and watch the behavior of relevant registers.