4

Data Transfers, Addressing, and Arithmetic

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This chapter introduces some essential instructions for transferring data and performing arithmetic. A large part of this chapter is devoted to the basic addressing modes, such as direct, immediate, and indirect, which make it possible to process arrays. Along with that, we show how to create loops, and use some of the basic operators, such as OFFSET, PTR, and LENGTHOF. After reading this chapter, you should have a basic working knowledge of assembly language, with the exception of conditional statements.

4.1 Data Transfer Instructions

4.1.1 Introduction

When programming in languages like Java or C++, it's easy for beginners to be annoyed when the compilers generate lots of syntax error messages. Compilers perform strict type checking in order to help you avoid possible errors such as mismatching variables and data. Assemblers, on the other hand, let you do just about anything you want, as long as the processor's instruction set can do what you ask. In other words, assembly language forces you to pay attention to data storage and machine-specific details. You must understand the processor's limitations when you write assembly language code. As it happens, x86 processors have what is commonly known as a *complex instruction set,* so they offer a lot of ways of doing things.

If you take the time to thoroughly learn the material presented in this chapter, the rest of this book will read a lot more smoothly. As the example programs become more complicated, you will rely on mastery of fundamental tools presented in this chapter.

4.1.2 Operand Types

Chapter 3 introduced x86 instruction formats:

```
[label:] mnemonic [operands][ ; comment ]
```

Instructions can have zero, one, two, or three operands. Here, we omit the label and comment fields for clarity:

```
mnemonic
mnemonic [destination]
mnemonic [destination],[source]
mnemonic [destination],[source-1],[source-2]
```

There are three basic types of operands:

- Immediate—uses a numeric literal expression
- Register—uses a named register in the CPU
- Memory—references a memory location

Table 4-1 describes the standard operand types. It uses a simple notation for operands (in 32-bit mode) freely adapted from the Intel manuals. We will use it from this point on to describe the syntax of individual instructions.

4.1.3 Direct Memory Operands

Variable names are references to offsets within the data segment. For example, the following declaration for a variable named **var1** says that its size attribute is **byte** and it contains the value 10 hexadecimal:

Table 4-1 Instruction Operand Notation, 32-Bit Mode.

Operand	Description
reg8	8-bit general-purpose register: AH, AL, BH, BL, CH, CL, DH, DL
reg16	16-bit general-purpose register: AX, BX, CX, DX, SI, DI, SP, BP
reg32	32-bit general-purpose register: EAX, EBX, ECX, EDX, ESI, EDI, ESP, EBP
reg	Any general-purpose register
sreg	16-bit segment register: CS, DS, SS, ES, FS, GS
imm	8-, 16-, or 32-bit immediate value
imm8	8-bit immediate byte value
imm16	16-bit immediate word value
imm32	32-bit immediate doubleword value
reg/mem8	8-bit operand, which can be an 8-bit general register or memory byte
reg/mem16	16-bit operand, which can be a 16-bit general register or memory word
reg/mem32	32-bit operand, which can be a 32-bit general register or memory doubleword
mem	An 8-, 16-, or 32-bit memory operand

```
.data
var1 BYTE 10h
```

We can write instructions that dereference (look up) memory operands using their addresses. Suppose **var1** were located at offset 10400h. The following instruction copies its value into the AL register:

```
mov al var1
```

It would be assembled into the following machine instruction:

```
A0 00010400
```

The first byte in the machine instruction is the operation code (known as the *opcode*). The remaining part is the 32-bit hexadecimal address of **var1**. Although it might be possible to write programs using only numeric addresses, symbolic names such as **var1** make it easier to reference memory.

Alternative Notation. Some programmers prefer to use the following notation with direct operands because the brackets imply a dereference operation:

```
mov  al,[var1]
```

MASM permits this notation, so you can use it in your own programs if you want. Because so many programs (including those from Microsoft) are printed without the brackets, we will only use them in this book when an arithmetic expression is involved:

```
mov  al,[var1 + 5]
```

(This is called a direct-offset operand, a subject discussed at length in Section 4.1.8.)

4.1.4 MOV Instruction

The MOV instruction copies data from a source operand to a destination operand. Known as a *data transfer* instruction, it is used in virtually every program. Its basic format shows that the first operand is the destination and the second operand is the source:

```
MOV destination,source
```

The destination operand's contents change, but the source operand is unchanged. The right to left movement of data is similar to the assignment statement in C++ or Java:

```
dest = source;
```

In nearly all assembly language instructions, the left-hand operand is the destination and the right-hand operand is the source. MOV is very flexible in its use of operands, as long as the following rules are observed:

- Both operands must be the same size.
- Both operands cannot be memory operands.
- The instruction pointer register (IP, EIP, or RIP) cannot be a destination operand.

Here is a list of the standard MOV instruction formats:

```
MOV reg,reg
MOV mem,reg
MOV reg,mem
MOV mem,imm
MOV reg,imm
```

Memory to Memory A single MOV instruction cannot be used to move data directly from one memory location to another. Instead, you must move the source operand's value to a register before assigning its value to a memory operand:

```
.data
var1 WORD ?
var2 WORD ?
.code
mov  ax,var1
mov  var2,ax
```

You must consider the minimum number of bytes required by an integer constant when copying it to a variable or register. For unsigned integer constant sizes, refer to Table 1-4 in Chapter 1. For signed integer constants, refer to Table 1-7.

Overlapping Values

The following code example shows how the same 32-bit register can be modified using differently sized data. When **oneWord** is moved to AX, it overwrites the existing value of AL. When **oneDword** is moved to EAX, it overwrites AX. Finally, when 0 is moved to AX, it overwrites the lower half of EAX.

```
.data
oneByte BYTE 78h
oneWord WORD 1234h
oneDword DWORD 12345678h
```

```
.code
mov  eax,0            ; EAX = 00000000h
mov  al,oneByte       ; EAX = 00000078h
mov  ax,oneWord       ; EAX = 00001234h
mov  eax,oneDword     ; EAX = 12345678h
mov  ax,0             ; EAX = 12340000h
```

4.1.5 Zero/Sign Extension of Integers

Copying Smaller Values to Larger Ones

Although MOV cannot directly copy data from a smaller operand to a larger one, programmers can create workarounds. Suppose **count** (unsigned, 16 bits) must be moved to ECX (32 bits). We can set ECX to zero and move **count** to CX:

```
.data
count WORD 1
.code
mov ecx,0
mov cx,count
```

What happens if we try the same approach with a signed integer equal to −16?

```
.data
signedVal SWORD -16             ; FFF0h (-16)
.code
mov ecx,0
mov cx,signedVal                ; ECX = 0000FFF0h (+65,520)
```

The value in ECX (+65,520) is completely different from −16. On the other hand, if we had filled ECX first with FFFFFFFFh and then copied **signedVal** to CX, the final value would have been correct:

```
mov ecx,0FFFFFFFFh
mov cx,signedVal                ; ECX = FFFFFFF0h (-16)
```

The effective result of this example was to use the highest bit of the source operand (1) to fill the upper 16 bits of the destination operand, ECX. This technique is called *sign extension*. Of course, we cannot always assume that the highest bit of the source is a 1. Fortunately, the engineers at Intel anticipated this problem when designing the instruction set and introduced the MOVZX and MOVSX instructions to deal with both unsigned and signed integers.

MOVZX Instruction

The MOVZX instruction (*move with zero-extend*) copies the contents of a source operand into a destination operand and zero-extends the value to 16 or 32 bits. This instruction is only used with unsigned integers. There are three variants:

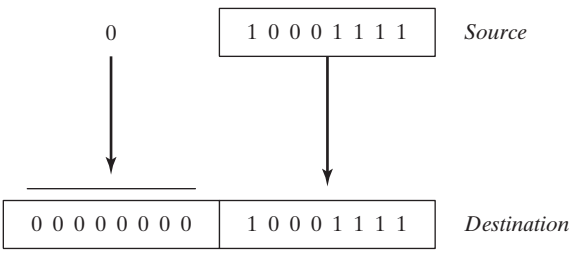
```
MOVZX  reg32,reg/mem8
MOVZX  reg32,reg/mem16
MOVZX  reg16,reg/mem8
```

(Operand notation was explained in Table 4-1.) In each of the three variants, the first operand (a register) is the destination and the second is the source. Notice that the source operand cannot be a constant. The following example zero-extends binary 10001111 into AX:

```
.data
byteVal BYTE 10001111b
.code
movzx  ax,byteVal              ; AX = 0000000010001111b
```

Figure 4-1 shows how the source operand is zero-extended into the 16-bit destination.

Figure 4–1 Using MOVZX to copy a byte into a 16-bit destination.



The following examples use registers for all operands, showing all the size variations:

```
mov    bx,0A69Bh
movzx  eax,bx                  ; EAX = 0000A69Bh
movzx  edx,bl                  ; EDX = 0000009Bh
movzx  cx,bl                   ; CX  = 009Bh
```

The following examples use memory operands for the source and produce the same results:

```
.data
byte1  BYTE 9Bh
word1  WORD 0A69Bh
.code
movzx  eax,word1               ; EAX = 0000A69Bh
movzx  edx,byte1               ; EDX = 0000009Bh
movzx  cx,byte1                ; CX  = 009Bh
```

MOVSX Instruction

The MOVSX instruction (move with sign-extend) copies the contents of a source operand into a destination operand and sign-extends the value to 16 or 32 bits. This instruction is only used with signed integers. There are three variants:

```
MOVSX  reg32,reg/mem8
MOVSX  reg32,reg/mem16
MOVSX  reg16,reg/mem8
```

An operand is sign-extended by taking the smaller operand's highest bit and repeating (replicating) the bit throughout the extended bits in the destination operand. The following example sign-extends binary 10001111b into AX:

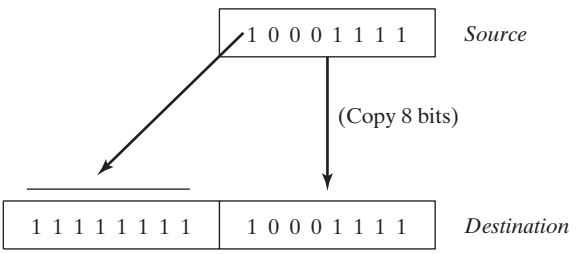
```
.data
byteVal BYTE 10001111b
.code
movsx  ax,byteVal                ; AX = 1111111110001111b
```

The lowest 8 bits are copied as in Figure 4-2. The highest bit of the source is copied into each of the upper 8 bit positions of the destination.

A hexadecimal constant has its highest bit set if its most significant hexadecimal digit is greater than 7. In the following example, the hexadecimal value moved to BX is A69B, so the leading "A" digit tells us that the highest bit is set. (The leading zero appearing before A69B is just a notational convenience so the assembler does not mistake the constant for the name of an identifier.)

```
mov    bx,0A69Bh
movsx  eax,bx                    ; EAX = FFFFA69Bh
movsx  edx,bl                    ; EDX = FFFFFF9Bh
movsx  cx,bl                     ; CX  = FF9Bh
```

Figure 4–2 Using MOVSX to copy a byte into a 16-bit destination.



4.1.6 LAHF and SAHF Instructions

The LAHF (load status flags into AH) instruction copies the low byte of the EFLAGS register into AH. The following flags are copied: Sign, Zero, Auxiliary Carry, Parity, and Carry. Using this instruction, you can easily save a copy of the flags in a variable for safekeeping:

```
.data
saveflags BYTE ?
.code
lahf                             ; load flags into AH
mov  saveflags,ah                ; save them in a variable
```

The SAHF (store AH into status flags) instruction copies AH into the low byte of the EFLAGS (or RFLAGS) register. For example, you can retrieve the values of flags saved earlier in a variable:

```
mov  ah,saveflags                ; load saved flags into AH
sahf                             ; copy into Flags register
```

4.1.7 XCHG Instruction

The XCHG (exchange data) instruction exchanges the contents of two operands. There are three variants:

```
XCHG  reg,reg
XCHG  reg,mem
XCHG  mem,reg
```

The rules for operands in the XCHG instruction are the same as those for the MOV instruction (Section 4.1.4), except that XCHG does not accept immediate operands. In array sorting applications, XCHG provides a simple way to exchange two array elements. Here are a few examples using XCHG:

```
xchg  ax,bx                ; exchange 16-bit regs
xchg  ah,al                ; exchange 8-bit regs
xchg  var1,bx              ; exchange 16-bit mem op with BX
xchg  eax,ebx              ; exchange 32-bit regs
```

To exchange two memory operands, use a register as a temporary container and combine MOV with XCHG:

```
mov   ax,val1
xchg  ax,val2
mov   val1,ax
```

4.1.8 Direct-Offset Operands

You can add a displacement to the name of a variable, creating a direct-offset operand. This lets you access memory locations that may not have explicit labels. Let's begin with an array of bytes named **arrayB**:

```
arrayB  BYTE 10h,20h,30h,40h,50h
```

If we use MOV with **arrayB** as the source operand, we automatically move the first byte in the array:

```
mov  al,arrayB                  ; AL = 10h
```

We can access the second byte in the array by adding 1 to the offset of **arrayB**:

```
mov  al,[arrayB+1]              ; AL = 20h
```

The third byte is accessed by adding 2:

```
mov  al,[arrayB+2]              ; AL = 30h
```

An expression such as **arrayB+1** produces what is called an *effective address* by adding a constant to the variable's offset. Surrounding an effective address with brackets makes it clear that the expression is dereferenced to obtain the contents of memory at the address. The assembler does not require you to surround address expressions with brackets, but we highly recommend their use for clarity.

MASM has no built-in range checking for effective addresses. In the following example, assuming **arrayB** holds five bytes, the instruction retrieves a byte of memory outside the array. The result is a sneaky logic bug, so be extra careful when checking array references:

```
mov  al,[arrayB+20]             ; AL = ??
```

Word and Doubleword Arrays In an array of 16-bit words, the offset of each array element is 2 bytes beyond the previous one. That is why we add 2 to **ArrayW** in the next example to reach the second element:

```
.data
arrayW WORD 100h,200h,300h
.code
mov  ax,arrayW                  ; AX = 100h
mov  ax,[arrayW+2]              ; AX = 200h
```

Similarly, the second element in a doubleword array is 4 bytes beyond the first one:

```
.data
arrayD DWORD 10000h,20000h
.code
mov  eax,arrayD                 ; EAX = 10000h
mov  eax,[arrayD+4]             ; EAX = 20000h
```

4.1.9 Example Program (Moves)

Let's combine all the instructions we've covered so far in this chapter, including MOV, XCHG, MOVSX, and MOVDX, to show how bytes, words, and doublewords are affected. We will also include some direct-offset operands.

```
; Data Transfer Examples            (Moves.asm)

.386
.model flat,stdcall
.stack 4096
ExitProcess PROTO,dwExitCode:DWORD
.data
val1 WORD 1000h
val2 WORD 2000h
arrayB BYTE 10h,20h,30h,40h,50h
arrayW WORD 100h,200h,300h
arrayD DWORD 10000h,20000h

.code
main PROC

;  Demonstrating MOVZX instruction:
     mov   bx,0A69Bh
     movzx eax,bx                     ; EAX = 0000A69Bh
     movzx edx,bl                     ; EDX = 0000009Bh
     movzx cx,bl                      ; CX  = 009Bh

;  Demonstrating MOVSX instruction:
     mov   bx,0A69Bh
     movsx eax,bx                     ; EAX = FFFFA69Bh
     movsx edx,bl                     ; EDX = FFFFFF9Bh
     mov   bl,7Bh
     movsx cx,bl                      ; CX  = 007Bh

;  Memory-to-memory exchange:
     mov   ax,val1                    ; AX = 1000h
```

```
    xchg  ax,val2                    ; AX=2000h, val2=1000h
    mov   val1,ax                    ; val1 = 2000h

; Direct-Offset Addressing (byte array):
    mov   al,arrayB                  ; AL = 10h
    mov   al,[arrayB+1]              ; AL = 20h
    mov   al,[arrayB+2]              ; AL = 30h

; Direct-Offset Addressing (word array):
    mov   ax,arrayW                  ; AX = 100h
    mov   ax,[arrayW+2]              ; AX = 200h

; Direct-Offset Addressing (doubleword array):
    mov   eax,arrayD                 ; EAX = 10000h
    mov   eax,[arrayD+4]             ; EAX = 20000h
    mov   eax,[arrayD+4]             ; EAX = 20000h

    INVOKE ExitProcess,0
main ENDP
END main
```

This program generates no screen output, but you can (and should) run it using a debugger.

Displaying CPU Flags in the Visual Studio Debugger

To display the CPU status flags during a debugging session, select *Windows* from the *Debug* menu, then select *Registers* from the *Windows* menu. Inside the *Registers* window, right-click and select *Flags* from the dropdown list. You must be currently debugging a program in order to see these menu options. The following table identifies the flag symbols used inside the *Registers* window:

Flag Name	Overflow	Direction	Interrupt	Sign	Zero	Aux Carry	Parity	Carry
Symbol	OV	UP	EI	PL	ZR	AC	PE	CY

Each flag is assigned a value of 0 (*clear*) or 1 (*set*). Here's an example:

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

As you step through your code during a debugging session, each flag displays in red when an instruction modifies the flag's value. You can learn how instructions affect the flags by stepping through instructions and keeping an eye on the changing values of the flags.

4.1.10 Section Review

1. What are the three basic types of operands?
2. *(True/False):* The destination operand of a MOV instruction cannot be a segment register.
3. *(True/False):* In a MOV instruction, the second operand is known as the *destination* operand.

4. *(True/False):* The EIP register cannot be the destination operand of a MOV instruction.
5. In the operand notation used by Intel, what does *reg/mem32* indicate?
6. In the operand notation used by Intel, what does *imm16* indicate?

4.2 Addition and Subtraction

Arithmetic is a surprisingly big topic in assembly language! This chapter will focus on addition and subtraction. Then we will talk about multiplication and division later in Chapter 7. Then we'll switch over to floating point arithmetic in Chapter 12.

Let's start with the easiest and most efficient instructions of them all: INC (increment) and DEC (decrement), which add 1 and subtract 1. Then we will move on to the ADD, SUB, and NEG (negate) instructions, which offer more possibilities. Last of all, we will get into a discussion about how the CPU status flags (Carry, Sign, Zero, etc.) are affected by arithmetic instructions. Remember, assembly language is all about the details.

4.2.1 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
```

Following are some examples:

```
.data
myWord WORD 1000h
.code
inc  myWord                    ; myWord = 1001h
mov  bx,myWord
dec  bx                        ; BX = 1000h
```

The Overflow, Sign, Zero, Auxiliary Carry, and Parity flags are changed according to the value of the destination operand. The INC and DEC instructions do not affect the Carry flag (which is something of a surprise).

4.2.2 ADD Instruction

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

```
ADD dest,source
```

Source is unchanged by the operation, and the sum is stored in the destination operand. The set of possible operands is the same as for the MOV instruction (Section 4.1.4). Here is a short code example that adds two 32-bit integers:

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

Flags The Carry, Zero, Sign, Overflow, Auxiliary Carry, and Parity flags are changed according to the value that is placed in the destination operand. We will explain how the flags work in Section 4.2.6.

4.2.3 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
```

Here is a short code example that subtracts two 32-bit integers:

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

Flags The Carry, Zero, Sign, Overflow, Auxiliary Carry, and Parity flags are changed according to the value that is placed in the destination operand.

4.2.4 NEG Instruction

The NEG (negate) instruction reverses the sign of a number by converting the number to its two's complement. The following operands are permitted:

```
NEG reg
NEG mem
```

(Recall that the two's complement of a number can be found by reversing all the bits in the destination operand and adding 1.)

Flags The Carry, Zero, Sign, Overflow, Auxiliary Carry, and Parity flags are changed according to the value that is placed in the destination operand.

4.2.5 Implementing Arithmetic Expressions

Armed with the ADD, SUB, and NEG instructions, you have the means to implement arithmetic expressions involving addition, subtraction, and negation in assembly language. In other words, you can simulate what a C++ compiler might do when a statement such as this:

```
Rval = -Xval + (Yval - Zval);
```

Let's see how the sample statement would be implemented in assembly language. The following signed 32-bit variables will be used:

```
Rval SDWORD ?
Xval SDWORD 26
Yval SDWORD 30
Zval SDWORD 40
```

When translating an expression, evaluate each term separately and combine the terms at the end. First, we negate a copy of **Xval** and store it in a register:

```
; first term: -Xval
mov  eax,Xval
neg  eax                        ; EAX = -26
```

Then **Yval** is copied to a register and **Zval** is subtracted:

```
; second term: (Yval - Zval)
mov  ebx,Yval
sub  ebx,Zval                   ; EBX = -10
```

Finally, the two terms (in EAX and EBX) are added:

```
; add the terms and store:
add  eax,ebx
mov  Rval,eax                   ; -36
```

4.2.6 Flags Affected by Addition and Subtraction

When executing arithmetic instructions, we often want to know something about the result. Is it negative, positive, or zero? Is it too large or too small to fit into the destination operand? Answers to such questions can help us detect calculation errors that might otherwise cause erratic program behavior. We use the values of CPU status flags to check the outcome of arithmetic operations. We also use status flag values to activate conditional branching instructions, the basic tools of program logic. Here's a quick overview of the status flags.

- The Carry flag indicates unsigned integer overflow. For example, if an instruction has an 8-bit destination operand but the instruction generates a result larger than 11111111 binary, the Carry flag is set.
- The Overflow flag indicates signed integer overflow. For example, if an instruction has a 16-bit destination operand but it generates a negative result smaller than −32,768 decimal, the Overflow flag is set.
- The Zero flag indicates that an operation produced zero. For example, if an operand is subtracted from another of equal value, the Zero flag is set.
- The Sign flag indicates that an operation produced a negative result. If the most significant bit (MSB) of the destination operand is set, the Sign flag is set.
- The Parity flag indicates whether or not an even number of 1 bits occurs in the least significant byte of the destination operand, immediately after an arithmetic or boolean instruction has executed.
- The Auxiliary Carry flag is set when a 1 bit carries out of position 3 in the least significant byte of the destination operand.

> To display CPU status flag values when debugging, open the Registers window, right-click in the window, and select *Flags*.

Unsigned Operations: Zero, Carry, and Auxiliary Carry

The Zero flag is set when the result of an arithmetic operation equals zero. The following examples show the state of the destination register and Zero flag after executing the SUB, INC, and DEC instructions:

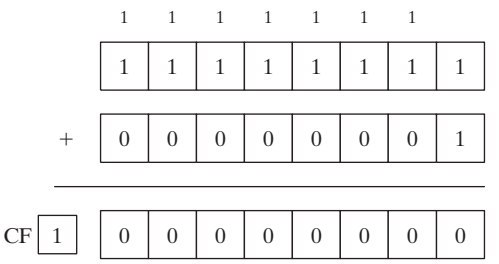
```
mov  ecx,1
sub  ecx,1                      ; ECX = 0, ZF = 1
mov  eax,0FFFFFFFFh
inc  eax                        ; EAX = 0, ZF = 1
inc  eax                        ; EAX = 1, ZF = 0
dec  eax                        ; EAX = 0, ZF = 1
```

Addition and the Carry Flag The Carry flag's operation is easiest to explain if we consider addition and subtraction separately. 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. In the next example, ADD sets the Carry flag because the sum (100h) is too large for AL:

```
mov  al,0FFh
add  al,1                       ; AL = 00, CF = 1
```

Figure 4-3 shows what happens at the bit level when 1 is added to 0FFh. The carry out of the highest bit position of AL is copied into the Carry flag.

Figure 4–3 Adding 1 to 0FFh sets the Carry flag.



On the other hand, if 1 is added to 00FFh in AX, the sum easily fits into 16 bits and the Carry flag is clear:

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

But adding 1 to FFFFh in the AX register generates a Carry out of the high bit position of AX:

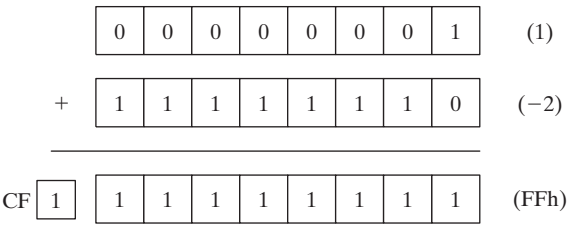
```
mov  ax,0FFFFh
add  ax,1                       ; AX = 0000, CF = 1
```

Subtraction and the Carry Flag A subtract operation sets the Carry flag when a larger unsigned integer is subtracted from a smaller one. Figure 4-4 shows what happens when we subtract 2 from 1, using 8-bit operands. Here is the corresponding assembly code:

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

> ***Tip:*** The INC and DEC instructions do not affect the Carry flag. Applying the NEG instruction to a nonzero operand always sets the Carry flag.

Figure 4–4 Subtracting 2 from 1 sets the Carry flag.



Auxiliary Carry The Auxiliary Carry (AC) flag indicates a carry or borrow out of bit 3 in the destination operand. It is primarily used in binary coded decimal (BCD) arithmetic, but can be used in other contexts. Suppose we add 1 to 0Fh. The sum (10h) contains a 1 in bit position 4 that was carried out of bit position 3:

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

Here is the arithmetic:

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

Parity The Parity flag (PF) is set when the least significant byte of the destination has an even number of 1 bits. The following ADD and SUB instructions alter the parity of AL:

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

After the ADD instruction executes, AL contains binary 10001110 (four 0 bits and four 1 bits), and PF = 1. After the SUB instruction executes, AL contains an odd number of 1 bits, so the Parity flag equals 0.

Signed Operations: Sign and Overflow Flags

Sign Flag The Sign flag is set when the result of a signed arithmetic operation is negative. The next example subtracts a larger integer (5) from a smaller one (4):

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

From a mechanical point of view, the Sign flag is a copy of the destination operand's high bit. The next example shows the hexadecimal values of BL when a negative result is generated:

```
mov  bl,1                          ; BL = 01h
sub  bl,2                          ; BL = FFh (-1), SF = 1
```

Overflow Flag The Overflow flag is set when the result of a signed arithmetic operation overflows or underflows the destination operand. For example, from Chapter 1 we know that the largest possible integer signed byte value is +127; adding 1 to it causes overflow:

```
mov  al,+127
add  al,1                       ; OF = 1
```

Similarly, the smallest possible negative integer byte value is −128. Subtracting 1 from it causes underflow. The destination operand value does not hold a valid arithmetic result, and the Overflow flag is set:

```
mov  al,-128
sub  al,1                       ; OF = 1
```

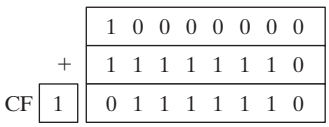
The Addition Test There is a very easy way to tell whether signed overflow has occurred when adding two operands. Overflow occurs when:

- Adding two positive operands generates a negative sum
- Adding two negative operands generates a positive sum

Overflow never occurs when the signs of two addition operands are different.

How the Hardware Detects Overflow The CPU uses an interesting mechanism to determine the state of the Overflow flag after an addition or subtraction operation. The value that carries out of the highest bit position is exclusive ORed with the carry into the high bit of the result. The resulting value is placed in the Overflow flag. In Figure 4-5, we show that adding the 8-bit binary integers 10000000 and 11111110 produces CF = 1, with carryIn(bit7) = 0. In other words, 1 XOR 0 produces OF = 1.

Figure 4–5 Demonstration of how the Overflow flag is set.



NEG Instruction The NEG instruction produces an invalid result if the destination operand cannot be stored correctly. For example, if we move −128 to AL and try to negate it, the correct value (+128) will not fit into AL. The Overflow flag is set, indicating that AL contains an invalid value:

```
mov al,-128                     ; AL = 10000000b
neg al                          ; AL = 10000000b, OF = 1
```

On the other hand, if +127 is negated, the result is valid and the Overflow flag is clear:

```
mov al,+127                     ; AL = 01111111b
neg al                          ; AL = 10000001b, OF = 0
```

How does the CPU know whether an arithmetic operation is signed or unsigned? We can only give what seems a dumb answer: It doesn't! The CPU sets all status flags after an arithmetic operation using a set of boolean rules, regardless of which flags are relevant. You (the programmer) decide which flags to interpret and which to ignore, based on your knowledge of the type of operation performed.

4.2.7 Example Program (*AddSubTest*)

The *AddSubTest* program shown below implements various arithmetic expressions using the ADD, SUB, INC, DEC, and NEG instructions, and shows how certain status flags are affected:

```
; Addition and Subtraction     (AddSubTest.asm)

.386
.model flat,stdcall
.stack 4096
ExitProcess proto,dwExitCode:dword
.data
Rval   SDWORD ?
Xval   SDWORD 26
Yval   SDWORD 30
Zval   SDWORD 40

.code
main PROC
     ; INC and DEC
     mov   ax,1000h
     inc   ax                    ; 1001h
     dec   ax                    ; 1000h

     ; Expression: Rval = -Xval + (Yval - Zval)
     mov   eax,Xval
     neg   eax                   ; -26
     mov   ebx,Yval
     sub   ebx,Zval              ; -10
     add   eax,ebx
     mov   Rval,eax              ; -36

     ; Zero flag example:
     mov   cx,1
     sub   cx,1                  ; ZF = 1
     mov   ax,0FFFFh
     inc   ax                    ; ZF = 1

     ; Sign flag example:
     mov   cx,0
     sub   cx,1                  ; SF = 1
     mov   ax,7FFFh
     add   ax,2                  ; SF = 1

     ; Carry flag example:
     mov   al,0FFh
     add   al,1                  ; CF = 1,  AL = 00

     ; Overflow flag example:
     mov   al,+127
     add   al,1                  ; OF = 1
     mov   al,-128
     sub   al,1                  ; OF = 1

     INVOKE ExitProcess,0
main ENDP
END main
```

4.2.8 Section Review

Use the following data for Questions 1-5:

```
.data
val1 BYTE  10h
val2 WORD  8000h
val3 DWORD 0FFFFh
val4 WORD  7FFFh
```

1. Write an instruction that increments **val2**.
2. Write an instruction that subtracts **val3** from EAX.
3. Write instructions that subtract **val4** from **val2**.
4. If **val2** is incremented by 1 using the ADD instruction, what will be the values of the Carry and Sign flags?
5. If **val4** is incremented by 1 using the ADD instruction, what will be the values of the Overflow and Sign flags?
6. Where indicated, write down the values of the Carry, Sign, Zero, and Overflow flags after each instruction has executed:

```
mov  ax,7FF0h
add  al,10h        ; a. CF =    SF =    ZF =    OF =
add  ah,1          ; b. CF =    SF =    ZF =    OF =
add  ax,2          ; c. CF =    SF =    ZF =    OF =
```

4.3 Data-Related Operators and Directives

Operators and directives are not executable instructions; instead, they are interpreted by the assembler. You can use a number of assembly language directives to get information about the addresses and size characteristics of data:

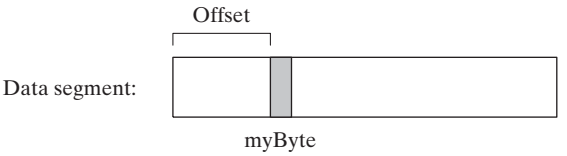
- The OFFSET operator returns the distance of a variable from the beginning of its enclosing segment.
- The PTR operator lets you override an operand's default size.
- The TYPE operator returns the size (in bytes) of an operand or of each element in an array.
- The LENGTHOF operator returns the number of elements in an array.
- The SIZEOF operator returns the number of bytes used by an array initializer.

In addition, the LABEL directive provides a way to redefine the same variable with different size attributes. The operators and directives in this chapter represent only a small subset of the operators supported by MASM. You may want to view the complete list in Appendix D.

4.3.1 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. To illustrate, Figure 4-6 shows a variable named **myByte** inside the data segment.

Figure 4–6 A variable named myByte.



OFFSET Examples

In the next example, we declare three different types of variables:

```
.data
bVal  BYTE  ?
wVal  WORD  ?
dVal  DWORD ?
dVal2 DWORD ?
```

If **bVal** were located at offset 00404000 (hexadecimal), the OFFSET operator would return the following values:

```
mov  esi,OFFSET bVal                ; ESI = 00404000h
mov  esi,OFFSET wVal                ; ESI = 00404001h
mov  esi,OFFSET dVal                ; ESI = 00404003h
mov  esi,OFFSET dVal2               ; ESI = 00404007h
```

OFFSET can also be applied to a direct-offset operand. Suppose **myArray** contains five 16-bit words. The following MOV instruction obtains the offset of **myArray**, adds 4, and moves the resulting address to ESI. We can say that ESI points to the third integer in the array:

```
.data
myArray WORD 1,2,3,4,5
.code
mov  esi,OFFSET myArray + 4
```

You can initialize a doubleword variable with the offset of another variable, effectively creating a pointer. In the following example, **pArray** points to the beginning of **bigArray**:

```
.data
bigArray DWORD 500 DUP(?)
pArray DWORD bigArray
```

The following statement loads the pointer's value into ESI, so the register can point to the beginning of the array:

```
mov esi,pArray
```

4.3.2 ALIGN Directive

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

ALIGN *bound*

Bound can be 1, 2, 4, 8, or 16. A value of 1 aligns the next variable on a 1-byte boundary (the default). If *bound* is 2, the next variable is aligned on an even-numbered address. If bound is 4, the next address is a multiple of 4. If *bound* is 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 bother aligning data? Because the CPU can process data stored at even-numbered addresses more quickly than those at odd-numbered addresses.

In the following example, **bVal** is arbitrarily located at offset 00404000. Inserting the ALIGN 2 directive before **wVal** causes it to be assigned an even-numbered offset:

```
bVal  BYTE  ?                  ; 00404000h
ALIGN 2
wVal  WORD  ?                  ; 00404002h
bVal2 BYTE  ?                  ; 00404004h
ALIGN 4
dVal  DWORD ?                  ; 00404008h
dVal2 DWORD ?                  ; 0040400Ch
```

Note that **dVal** would have been at offset 00404005, but the ALIGN 4 directive bumped it up to offset 00404008.

4.3.3 PTR Operator

You can use the PTR operator 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.

Suppose, for example, that you would like to move the lower 16 bits of a doubleword variable named **myDouble** into AX. The assembler will not permit the following move because the operand sizes do not match:

```
.data
myDouble  DWORD  12345678h
.code
mov  ax,myDouble               ; error
```

But the WORD PTR operator makes it possible to move the low-order word (5678h) to AX:

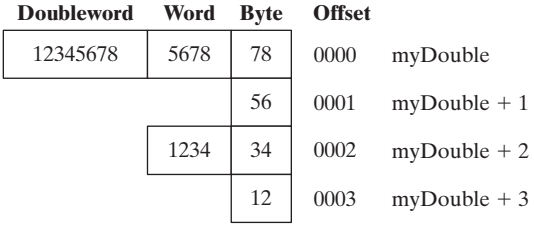
```
mov  ax,WORD PTR myDouble
```

Why wasn't 1234h moved into AX? x86 processors use the *little endian* storage format (Section 3.4.9), in which the low-order byte is stored at the variable's starting address. In Figure 4-7, the memory layout of **myDouble** is shown three ways: first as a doubleword, then as two words (5678h, 1234h), and finally as four bytes (78h, 56h, 34h, 12h).

We can access memory in any of these three ways, independent of the way a variable was defined. For example, if **myDouble** begins at offset 0000, the 16-bit value stored at that address is 5678h. We could also retrieve 1234h, the word at location **myDouble+2**, using the following statement:

```
mov   ax,WORD PTR [myDouble+2]        ; 1234h
```

Figure 4–7 Memory layout of myDouble.



Similarly, we could use the BYTE PTR operator to move a single byte from **myDouble** to BL:

```
mov   bl,BYTE PTR myDouble            ; 78h
```

Note that PTR must be used in combination with one of the standard assembler data types, BYTE, SBYTE, WORD, SWORD, DWORD, SDWORD, FWORD, QWORD, or TBYTE.

Moving Smaller Values into Larger Destinations We might want to move two smaller values from memory to a larger destination operand. In the next example, the first word is copied to the lower half of EAX and the second word is copied to the upper half. The DWORD PTR operator makes this possible:

```
.data
wordList WORD 5678h,1234h
.code
mov  eax,DWORD PTR wordList           ; EAX = 12345678h
```

4.3.4 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. Here are examples of each:

```
.data
var1 BYTE  ?
var2 WORD  ?
var3 DWORD ?
var4 QWORD ?
```

The following table shows the value of each TYPE expression.

Expression	Value
TYPE var1	1
TYPE var2	2
TYPE var3	4
TYPE var4	8

4.3.5 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. We will use the following data as an example:

```
.data
byte1    BYTE  10,20,30
array1   WORD  30 DUP(?),0,0
array2   WORD  5 DUP(3 DUP(?))
array3   DWORD 1,2,3,4
digitStr BYTE  "12345678",0
```

When nested DUP operators are used in an array definition, LENGTHOF returns the product of the two counters. The following table lists the values returned by each LENGTHOF expression:

Expression	Value
LENGTHOF byte1	3
LENGTHOF array1	30 + 2
LENGTHOF array2	5 * 3
LENGTHOF array3	4
LENGTHOF digitStr	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. Given the following data, LENGTHOF myArray would return the value 5:

```
myArray BYTE 10,20,30,40,50
        BYTE 60,70,80,90,100
```

Alternatively, you can end the first line with a comma and continue the list of initializers onto the next line. Given the following data, LENGTHOF myArray would return the value 10:

```
myArray BYTE 10,20,30,40,50,
             60,70,80,90,100
```

4.3.6 SIZEOF Operator

The SIZEOF operator returns a value that is equivalent to multiplying LENGTHOF by TYPE. In the following example, **intArray** has TYPE = 2 and LENGTHOF = 32. Therefore, SIZEOF **intArray** equals 64:

```
.data
intArray WORD 32 DUP(0)
.code
mov  eax,SIZEOF intArray        ; EAX = 64
```

4.3.7 LABEL Directive

The LABEL directive lets you insert a label and give it a size attribute without allocating any 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. In the following example, we declare a label just before **val32** named **val16** and give it a WORD attribute:

```
.data
val16 LABEL WORD
val32 DWORD 12345678h
.code
mov  ax,val16                    ; AX = 5678h
mov  dx,[val16+2]                ; DX = 1234h
```

val16 is an alias for the same storage location as **val32**. The LABEL directive itself allocates no storage.

Sometimes we need to construct a larger integer from two smaller integers. In the next example, a 32-bit value is loaded into EAX from two 16-bit variables:

```
.data
LongValue LABEL DWORD
val1  WORD  5678h
val2  WORD  1234h
.code
mov eax,LongValue                ; EAX = 12345678h
```

4.3.8 Section Review

1. *(True/False):* The OFFSET operator always returns a 16-bit value.
2. *(True/False):* The PTR operator returns the 32-bit address of a variable.
3. *(True/False):* The TYPE operator returns a value of 4 for doubleword operands.
4. *(True/False):* The LENGTHOF operator returns the number of bytes in an operand.
5. *(True/False):* The SIZEOF operator returns the number of bytes in an operand.

4.4 Indirect Addressing

Direct addressing is rarely used for array processing because it is impractical to use constant offsets to address more than a few array elements. Instead, we use a register as a pointer (called *indirect addressing*) and manipulate the register's value. When an operand uses indirect addressing, it is called an *indirect operand*.

4.4.1 Indirect Operands

Protected Mode An indirect operand can be any 32-bit general-purpose register (EAX, EBX, ECX, EDX, ESI, EDI, EBP, and ESP) surrounded by brackets. The register is assumed to contain the address of some data. In the next example, ESI contains the offset of **byteVal**. The MOV instruction uses the indirect operand as the source, the offset in ESI is dereferenced, and a byte is moved to AL:

```
.data
byteVal BYTE 10h
.code
mov  esi,OFFSET byteVal
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.

```
mov [esi],bl
```

Using PTR with Indirect Operands The size of an operand may not be evident from the context of an instruction. 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]
```

4.4.2 Arrays

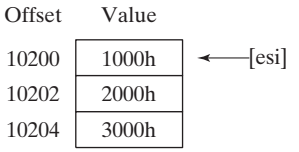
Indirect operands are ideal tools for stepping through arrays. In the next example, **arrayB** contains 3 bytes. As ESI is incremented, it points to each byte, in order:

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

If we use an array of 16-bit integers, we add 2 to ESI to address each subsequent array element:

```
.data
arrayW  WORD 1000h,2000h,3000h
.code
mov esi,OFFSET arrayW
mov ax,[esi]                    ; AX = 1000h
add esi,2
mov ax,[esi]                    ; AX = 2000h
add esi,2
mov ax,[esi]                    ; AX = 3000h
```

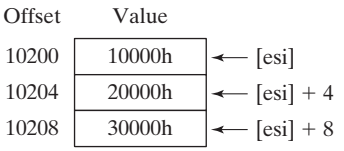
Suppose **arrayW** is located at offset 10200h. The following illustration shows the initial value of ESI in relation to the array data:



Example: Adding 32-Bit Integers The following code example adds three doublewords. A displacement of 4 must be added to ESI as it points to each subsequent array value because doublewords are 4 bytes long:

```
.data
arrayD DWORD 10000h,20000h,30000h
.code
mov  esi,OFFSET arrayD
mov  eax,[esi]           ; first number
add  esi,4
add  eax,[esi]           ; second number
add  esi,4
add  eax,[esi]           ; third number
```

Suppose **arrayD** is located at offset 10200h. Then the following illustration shows the initial value of ESI in relation to the array data:



4.4.3 Indexed Operands

An *indexed operand* adds a constant to a register to generate an effective address. 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. Here are examples that show both notational forms:

`arrayB[esi]`	`[arrayB + esi]`
`arrayD[ebx]`	`[arrayD + ebx]`

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
```

The last statement adds ESI to the offset of **arrayB**. The address generated by the expression **[arrayB + ESI]** is dereferenced and the byte in memory is copied to AL.

Adding Displacements 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. The following example shows how to do this with an array of 16-bit words:

```
.data
arrayW  WORD 1000h,2000h,3000h
.code
mov  esi,OFFSET arrayW
mov  ax,[esi]                   ; AX = 1000h
mov  ax,[esi+2]                 ; AX = 2000h
mov  ax,[esi+4]                 ; AX = 3000h
```

Using 16-Bit Registers It is usual to use 16-bit registers as indexed operands in real-address mode. In that case, you are limited to using SI, DI, BX, or BP:

```
mov  al,arrayB[si]
mov  ax,arrayW[di]
mov  eax,arrayD[bx]
```

As is the case with indirect operands, avoid using BP except when addressing data on the stack.

Scale Factors in Indexed Operands

Indexed operands must take into account the size of each array element when calculating offsets. Using an array of doublewords, as in the following example, we multiply the subscript (3) by 4 (the size of a doubleword) to generate the offset of the array element containing 400h:

```
.data
arrayD  DWORD 100h, 200h, 300h, 400h
.code
mov  esi,3 * TYPE arrayD            ; offset of arrayD[3]
mov  eax,arrayD[esi]                ; EAX = 400h
```

Intel designers wanted to make a common operation easier for compiler writers, so they provided a way for offsets to be calculated, using a *scale factor*. The scale factor is the size of the array component (word = 2, doubleword = 4, or quadword = 8). Let's revise our previous example by setting ESI to the array subscript (3) and multiplying ESI by the scale factor (4) for doublewords:

```
.data
arrayD  DWORD 1,2,3,4
.code
mov  esi,3                          ; subscript
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                              ; subscript
mov  eax,arrayD[esi*TYPE arrayD]        ; EAX = 4
```

4.4.4 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. You might use a system call to allocate (reserve) a block of memory, for example, and save the address of that block in a variable. A pointer's size is affected by the processor's current mode (32-bit or 64-bit). In the following 32-bit code example, **ptrB** contains the offset of arrayB:

```
.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
```

The 32-bit mode programs in this book use near pointers, so they are stored in doubleword variables. Here are two examples: **ptrB** contains the offset of **arrayB**, and **ptrW** contains the offset of **arrayW**:

```
arrayB   BYTE   10h,20h,30h,40h
arrayW   WORD   1000h,2000h,3000h
ptrB     DWORD  arrayB
ptrW     DWORD  arrayW
```

Optionally, you can use the OFFSET operator to make the relationship clearer:

```
ptrB   DWORD OFFSET arrayB
ptrW   DWORD OFFSET arrayW
```

> High-level languages purposely hide physical details about pointers because their implementations vary among different machine architectures. In assembly language, because we deal with a single implementation, we examine and use pointers at the physical level. This approach helps to remove some of the mystery surrounding pointers.

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

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

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

```
TITLE Pointers                          (Pointers.asm)

.386
.model flat,stdcall
.stack 4096
ExitProcess proto,dwExitCode:dword

; 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
```

4.4.5 Section Review

1. *(True/False):* Any 32-bit general-purpose register can be used as an indirect operand.
2. *(True/False):* The EBX register is usually reserved for addressing the stack.
3. *(True/False):* The following instruction is invalid: inc [esi]
4. *(True/False):* The following is an indexed operand: array[esi]

Use the following data definitions for Questions 5 and 6:

```
myBytes  BYTE 10h,20h,30h,40h
myWords  WORD 8Ah,3Bh,72h,44h,66h
myDoubles  DWORD 1,2,3,4,5
myPointer  DWORD myDoubles
```

5. Fill in the requested register values on the right side of the following instruction sequence:

```
mov  esi,OFFSET myBytes
mov  al,[esi]                    ; a. AL =
mov  al,[esi+3]                  ; b. AL =
mov  esi,OFFSET myWords + 2
mov  ax,[esi]                    ; c. AX =
mov  edi,8
mov  edx,[myDoubles + edi]       ; d. EDX =
mov  edx,myDoubles[edi]          ; e. EDX =
mov  ebx,myPointer
mov  eax,[ebx+4]                 ; f. EAX =
```

6. Fill in the requested register values on the right side of the following instruction sequence:

```
mov  esi,OFFSET myBytes
mov  ax,[esi]                    ; a. AX =
mov  eax,DWORD PTR myWords       ; b. EAX =
mov  esi,myPointer
mov  ax,[esi+2]                  ; c. AX =
mov  ax,[esi+6]                  ; d. AX =
mov  ax,[esi-4]                  ; e. AX =
```

4.5 JMP and LOOP Instructions

By default, the CPU loads and executes programs sequentially. But the current instruction might be *conditional*, meaning that it transfers control to a new location in the program based on the values of CPU status flags (Zero, Sign, Carry, etc.). Assembly language programs use conditional instructions to implement high-level statements such as IF statements and loops. Each of the conditional statements involves a possible transfer of control (jump) to a different memory address. 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.

4.5.1 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
```

When the CPU executes an unconditional transfer, the offset of *destination* is moved into the instruction pointer, causing execution to continue at the new location.

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

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

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

4.5.2 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.

> In real-address mode, CX is the default loop counter for the LOOP instruction. On the other hand, the LOOPD instruction uses ECX as the loop counter, and the LOOPW instruction uses CX as the loop counter.

In the following example, we add 1 to AX each time the loop repeats. When the loop ends, AX = 5 and ECX = 0:

```
     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.

Occasionally, you might create a loop that is large enough to exceed the allowed relative jump range of the LOOP instruction. Following is an example of an error message generated by MASM because the target label of a LOOP instruction was too far away:

```
error A2075: jump destination too far : by 14 byte(s)
```

Rarely should you explicitly modify ECX inside a loop. If you do, the LOOP instruction may not work as expected. In the following example, ECX is incremented within the loop. It never reaches zero, so the loop never stops:

```
top:
     .
     .
     inc  ecx
     loop top
```

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
     .
     mov   ecx,count            ; restore loop count
     loop  top
```

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:

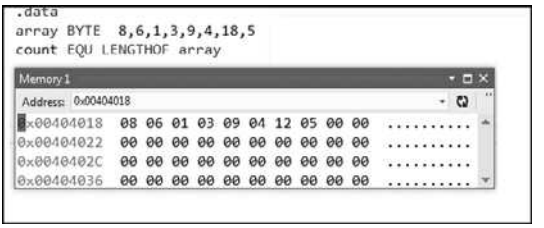
```
.data
count DWORD ?
.code
     mov   ecx,100              ; set outer loop count
L1:
     mov   count,ecx            ; save outer loop count
     mov   ecx,20               ; set inner loop count
L2:
     .
     .
     loop  L2                   ; repeat the inner loop

     mov   ecx,count            ; restore outer loop count
     loop  L1                   ; repeat the outer loop
```

As a general rule, nested loops more than two levels deep are difficult to write. If the algorithm you're using requires deep loop nesting, move some of the inner loops into subroutines.

4.5.3 Displaying an Array in the Visual Studio Debugger

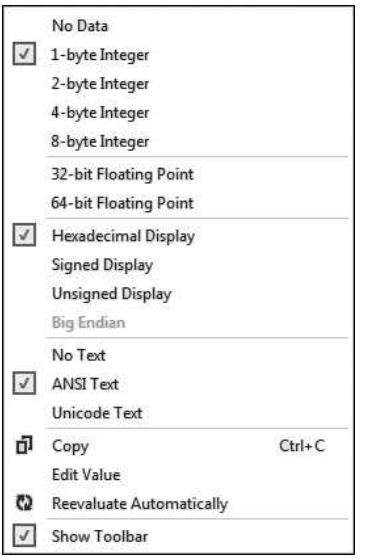
In a debugging session, if you want to display the contents of an array, here's how to do it: From the *Debug* menu, select *Windows*, select *Memory*, then select *Memory 1*. A memory window will appear, and you can use the mouse to drag and dock it to any side of the Visual Studio workspace. You can also right-click the window's title bar and indicate that you want the window to float above the editor window. In the *Address* field at the top of the memory window, type the & (ampersand) character, followed by the name of the array, and press *Enter*. For example, **&myArray** would be a valid address expression. The memory window will display a block of memory starting at the array's address. Figure 4-8 shows an example.

Figure 4–8 Using the debugger's memory window to display an array.



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. The full set of choices is shown in Figure 4-9.

Figure 4–9 Popup menu for the debugger's memory window.



4.5.4 Summing an Integer Array

There's hardly any task more common in beginning programming than calculating the sum of the elements in an array. In assembly language, you would follow these steps:

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.

Steps 1 through 3 may be performed in any order. Here's a short program that sums an array of 16-bit integers.

```
; Summing an Array                (SumArray.asm)

.386
.model flat,stdcall
.stack 4096
ExitProcess proto,dwExitCode:dword
.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

     invoke ExitProcess,0
main ENDP
END main
```

4.5.5 Copying a String

Programs often copy large blocks of data from one location to another. The data may be arrays or strings, but they can contain any type of objects. Let's see how this can be done in assembly language, using a loop that copies a string, represented as an array of bytes with a null terminator value. Indexed addressing works well for this type of operation because the same index register references both strings. The target string must have enough available space to receive the copied characters, including the null byte at the end:

```
; Copying a String                    (CopyStr.asm)

.386
.model flat,stdcall
.stack 4096
ExitProcess proto,dwExitCode:dword
.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

     invoke ExitProcess,0
main ENDP
END main
```

The MOV instruction cannot have two memory operands, so each character is moved from the source string to AL, then from AL to the target string.

4.5.6 Section Review

1. *(True/False):* A JMP instruction can only jump to a label inside the current procedure.
2. *(True/False):* JMP is a conditional transfer instruction.
3. If ECX is initialized to zero before beginning a loop, how many times will the LOOP instruction repeat? (Assume ECX is not modified by any other instructions inside the loop.)
4. *(True/False):* The LOOP instruction first checks to see whether ECX is not equal to zero; then LOOP decrements ECX and jumps to the destination label.
5. *(True/False):* The LOOP instruction does the following: It decrements ECX; then, if ECX is not equal to zero, LOOP jumps to the destination label.
6. In real-address mode, which register is used as the counter by the LOOP instruction?
7. In real-address mode, which register is used as the counter by the LOOPD instruction?
8. *(True/False):* The target of a LOOP instruction must be within 256 bytes of the current location.
9. *(Challenge):* What will be the final value of EAX in this example?

```
     mov   eax,0
     mov   ecx,10               ; outer loop counter
L1:
     mov   eax,3
     mov   ecx,5                ; inner loop counter
L2:
     add   eax,5
     loop  L2                   ; repeat inner loop
     loop  L1                   ; repeat outer loop
```

10. Revise the code from the preceding question so the outer loop counter is not erased when the inner loop starts.

4.6 64-Bit Programming

4.6.1 MOV Instruction

The MOV instruction in 64-bit mode has a great deal in common with 32-bit mode. There are just a few differences, which we will discuss here. Immediate operands (constants) may be 8, 16, 32, or 64 bits. Here's a 64-bit example:

```
mov    rax,0ABCDEFGAFFFFFFFFh   ; 64-bit immediate operand
```

When you move a 32-bit constant to a 64-bit register, the upper 32 bits (bits 32–63) of the destination are cleared (equal to zero):

```
mov    rax,0FFFFFFFFh           ; rax = 00000000FFFFFFFF
```

When you move a 16-bit constant or an 8-bit constant into a 64-bit register, the upper bits are also cleared:

```
mov    rax,06666h               ; clears bits 16-63
mov    rax,055h                 ; clears bits 8-63
```

When you move memory operands into 64-bit registers, however, the results are mixed. For example, moving a 32-bit memory operand into EAX (the lower half of RAX) causes the upper 32 bits in RAX to be cleared:

```
.data
myDword DWORD 80000000h
.code
mov    rax,0FFFFFFFFFFFFFFFFh
mov    eax,myDword              ; RAX = 0000000080000000
```

But when you move an 8-bit or a 16-bit memory operand into the lower bits of RAX, the highest bits in the destination register are not affected:

```
.data
myByte BYTE 55h
myWord WORD 6666h
.code
mov    ax,myWord                ; bits 16-63 are not affected
mov    al,myByte                ; bits 8-63 are not affected
```

The MOVSXD instruction (move with sign-extension) permits the source operand to be a 32-bit register or memory operand. The following instructions cause RAX to equal FFFFFFFFFFFFFFFFh:

```
mov     ebx,0FFFFFFFFh
movsxd rax,ebx
```

The OFFSET operator generates a 64-bit address, which must be held by a 64-bit register or variable. In the following example, we use the RSI register:

```
.data
myArray WORD 10,20,30,40
.code
mov  rsi,OFFSET myArray
```

The LOOP instruction in 64-bit mode uses the RCX register as the loop counter.

With these basic concepts, you can write quite a few programs in 64-bit mode. Most of the time, programming is easier if you consistently use 64-bit integer variables and 64-bit registers. ASCII strings are a special case because they always contain bytes. Usually, you use indirect or indexed addressing when processing them.

4.6.2 64-Bit Version of SumArray

Let's recreate the **SumArray** program in 64-bit mode. It calculates the sum of an array of 64-bit integers. First, we use the QWORD directive to create an array of quadwords. Then, we change all 32-bit register names to 64-bit names. This is the complete program listing:

```
; Summing an Array              (SumArray_64.asm)

ExitProcess PROTO
.data
intarray  QWORD 1000000000000h,2000000000000h
          QWORD 3000000000000h,4000000000000h
.code
main PROC
     mov  rdi,OFFSET intarray     ; RDI = address of intarray
     mov  rcx,LENGTHOF intarray   ; initialize loop counter
     mov  rax,0                   ; sum = 0
L1:                               ; mark beginning of loop
     add  rax,[rdi]               ; add an integer
     add  rdi,TYPE intarray       ; point to next element
     loop L1                      ; repeat until RCX = 0
     mov  ecx,0                   ; ExitProcess return value
     call ExitProcess
main ENDP
END
```

4.6.3 Addition and Subtraction

The ADD, SUB, INC, and DEC instructions affect the CPU status flags in the same way in 64-bit mode as in 32-bit mode. In the following example, we add 1 to a 32-bit number in RAX. Each bit carries to the left, causing a 1 to be inserted in bit 32:

```
mov  rax,0FFFFFFFFh              ; fill the lower 32 bits
add  rax,1                       ; RAX = 100000000h
```

It always pays to know the sizes of your operands. When you use a partial register operand, be aware that the remainder of the register is not modified. In the next example, the 16-bit sum in AX rolls over to zero without affecting the upper bits in RAX. This happens because the operation uses 16-bit registers (AX and BX):

```
mov  rax,0FFFFh                  ; RAX = 000000000000FFFF
mov  bx,1
add  ax,bx                       ; RAX = 0000000000000000
```

Similarly, in the following example, the sum in AL does not carry into any other bits within RAX. After the ADD, RAX equals zero:

```
mov  rax,0FFh                    ; RAX = 00000000000000FF
mov  bl,1
add  al,bl                       ; RAX = 0000000000000000
```

The same principle applies to subtraction. In the following code excerpt, subtracting 1 from zero in EAX causes the lower 32 bits of RAX to become equal to –1 (FFFFFFFFh). Similarly, subtracting 1 from zero in AX causes the lower 16 bits of RAX to become equal to –1 (FFFFh).

```
mov  rax,0                    ; RAX = 0000000000000000
mov  ebx,1
sub  eax,ebx                  ; RAX = 00000000FFFFFFFF
mov  rax,0                    ; RAX = 0000000000000000
mov  bx,1
sub  ax,bx                    ; RAX = 000000000000FFFF
```

A 64-bit general-purpose register must be used when an instruction contains an indirect operand. Remember that you must use the PTR operator to clarify the target operand's size. Here are examples, including one with a 64-bit target:

```
dec  BYTE PTR [rdi]           ; 8-bit  target
inc  WORD PTR [rbx]           ; 16-bit target
inc  QWORD PTR [rsi]          ; 64-bit target
```

In 64-bit mode, you can use scale factors in indexed operands, just as you do in 32-bit mode. If you're working with an array of 64-bit integers, use a scale factor of 8. Here's an example

```
.data
array QWORD 1,2,3,4
.code
mov  esi,3                    ; subscript
mov  eax,array[rsi*8]         ; EAX = 4
```

In 64-bit mode, a pointer variable holds a 64-bit offset. In the following example, the **ptrB** variable holds the offset of arrayB:

```
.data
arrayB BYTE 10h,20h,30h,40h
ptrB QWORD arrayB
```

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

```
ptrB QWORD OFFSET arrayB
```

4.6.4 Section Review

1. *(True/False):* Moving a constant value of 0FFh to the RAX register clears bits 8 through 63.
2. *(True/False):* A 32-bit constant may be moved to a 64-bit register, but 64-bit constants are not permitted.
3. What value will RCX contain after executing the following instructions?

```
mov  rcx,1234567800000000h
sub  ecx,1
```

4. What value will RCX contain after executing the following instructions?

```
mov  rcx,1234567800000000h
add  rcx,0ABABABABh
```

5. What value will the AL register contain after executing the following instructions?

```
.data
bArray BYTE 10h,20h,30h,40h,50h
.code
```

```
mov  rdi,OFFSET bArray
dec  BYTE PTR [rdi+1]
inc  rdi
mov  al,[rdi]
```

6. What value will RCX contain after executing the following instructions?

```
mov  rcx,0DFFFh
mov  bx,3
add  cx,bx
```

4.7 Chapter Summary

MOV, a data transfer instruction, copies a source operand to a destination operand. The MOVZX instruction zero-extends a smaller operand into a larger one. The MOVSX instruction sign-extends a smaller operand into a larger one. The XCHG instruction exchanges the contents of two operands. At least one operand must be a register.

Operand Types The following types of operands are presented in this chapter:

- A *direct* operand is the name of a variable, and represents the variable's address.
- 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.
- 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.
- 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.

The following arithmetic instructions are important:

- The INC instruction adds 1 to an operand.
- The DEC instruction subtracts 1 from an operand.
- The ADD instruction adds a source operand to a destination operand.
- The SUB instruction subtracts a source operand from a destination operand.
- The NEG instruction reverses the sign of an operand.

When converting simple arithmetic expressions to assembly language, use standard operator precedence rules to select which expressions to evaluate first.

Status Flags The following CPU status flags are affected by arithmetic operations:

- The Sign flag is set when the outcome of an arithmetic operation is negative.
- The Carry flag is set when the result of an unsigned arithmetic operation is too large for the destination operand.
- The Parity flag indicates whether or not an even number of 1 bits occurs in the least significant byte of the destination operand immediately after an arithmetic or boolean instruction has executed.
- The Auxiliary Carry flag is set when a carry or borrow occurs in bit position 3 of the destination operand.
- The Zero flag is set when the outcome of an arithmetic operation is zero.

- The Overflow flag is set when the result of an signed arithmetic operation is out of range for the destination operand.

Operators The following operators are common in assembly language:

- The OFFSET operator returns the distance (in bytes) of a variable from the beginning of its enclosing segment.
- The PTR operator overrides a variable's declared size.
- The TYPE operator returns the size (in bytes) of a single variable or of a single element in an array.
- The LENGTHOF operator returns the number of elements in an array.
- The SIZEOF operator returns the number bytes used by an array initializer.
- The TYPEDEF operator creates a user-defined type.

Loops The JMP (Jump) instruction unconditionally branches to another location. The LOOP (Loop According to ECX Counter) instruction is used in counting-type loops. In 32-bit mode, LOOP uses ECX as the counter; in 64-bit mode, RCX is the counter. In both modes, LOOPD uses ECX as the counter and LOOPW uses CX as the counter.

The MOV instruction works almost the same in 64-bit mode as in 32-bit mode. However, the rules for moving constants and memory operands to 64-bit registers are a bit tricky. Whenever possible, try to use 64-bit operands in 64-bit mode. Indirect and indexed operands always use 64-bit registers.

4.8 Key Terms

4.8.1 Terms

Auxiliary Carry flag
Carry flag
conditional transfer
data transfer instruction
direct memory operand
direct-offset operand
effective address
immediate operand
indexed operand
indirect operand
memory operand
Overflow flag
Parity flag
pointer
register operand
scale factor
sign extension
unconditional transfer
zero extension
Zero flag

4.8.2 Instructions, Operators, and Directives

ADD
ALIGN
DEC
INC
JMP
LABEL
LOOP
MOV

MOVSX
MOVZX
NEG
LABEL
LAHF
LENGTHOF
OFFSET
PTR
SAHF
SIZEOF
SUB
TYPE
TYPEDEF
XCHG

4.9 Review Questions and Exercises

4.9.1 Short Answer

1. What will be the value in EDX after each of the lines marked (a) and (b) execute?

```
.data
one WORD 8002h
two WORD 4321h
.code
mov   edx,21348041h
movsx edx,one                          ; (a)
movsx edx,two                          ; (b)
```

2. What will be the value in EAX after the following lines execute?

```
mov  eax,1002FFFFh
inc  ax
```

3. What will be the value in EAX after the following lines execute?

```
mov  eax,30020000h
dec  ax
```

4. What will be the value in EAX after the following lines execute?

```
mov  eax,1002FFFFh
neg  ax
```

5. What will be the value of the Parity flag after the following lines execute?

```
mov  al,1
add  al,3
```

6. What will be the value of EAX and the Sign flag after the following lines execute?

```
mov  eax,5
sub  eax,6
```

7. In the following code, the value in AL is intended to be a signed byte. Explain how the Overflow flag helps, or does not help you, to determine whether the final value in AL falls within a valid signed range.

```
mov  al,-1
add  al,130
```

8. What value will RAX contain after the following instruction executes?

```
mov  rax,44445555h
```

9. What value will RAX contain after the following instructions execute?

```
.data
dwordVal DWORD 84326732h
.code
mov  rax,0FFFFFFFF00000000h
mov  rax,dwordVal
```

10. What value will EAX contain after the following instructions execute?

```
.data
dVal DWORD 12345678h
.code
mov  ax,3
mov  WORD PTR dVal+2,ax
mov  eax,dVal
```

11. What will EAX contain after the following instructions execute?

```
.data
.dVal DWORD ?
.code
mov  dVal,12345678h
mov  ax,WORD PTR dVal+2
add  ax,3
mov  WORD PTR dVal,ax
mov  eax,dVal
```

12. *(Yes/No):* Is it possible to set the Overflow flag if you add a positive integer to a negative integer?
13. *(Yes/No):* Will the Overflow flag be set if you add a negative integer to a negative integer and produce a positive result?
14. *(Yes/No):* Is it possible for the NEG instruction to set the Overflow flag?
15. *(Yes/No):* Is it possible for both the Sign and Zero flags to be set at the same time?

Use the following variable definitions for Questions 16–19:

```
.data
var1 SBYTE -4,-2,3,1
var2 WORD 1000h,2000h,3000h,4000h
var3 SWORD -16,-42
var4 DWORD 1,2,3,4,5
```

16. For each of the following statements, state whether or not the instruction is valid:

```
a.  mov   ax,var1?
b.  mov   ax,var2
c.  mov   eax,var3
d.  mov   var2,var3
e.  movzx ax,var2
f.  movzx var2,al
```

```
g.  mov   ds,ax
h.  mov   ds,1000h
```

17. What will be the hexadecimal value of the destination operand after each of the following instructions execute in sequence?

```
mov  al,var1                    ; a.
mov  ah,[var1+3]                ; b.
```

18. What will be the value of the destination operand after each of the following instructions execute in sequence?

```
mov  ax,var2                    ; a.
mov  ax,[var2+4]                ; b.
mov  ax,var3                    ; c.
mov  ax,[var3-2]                ; d.
```

19. What will be the value of the destination operand after each of the following instructions execute in sequence?

```
mov    edx,var4                 ; a.
movzx  edx,var2                 ; b.
mov    edx,[var4+4]             ; c.
movsx  edx,var1                 ; d.
```

4.9.2 Algorithm Workbench

1. Write a sequence of MOV instructions that will exchange the upper and lower words in a doubleword variable named **three**.
2. Using the XCHG instruction no more than three times, reorder the values in four 8-bit registers from the order A,B,C,D to B,C,D,A.
3. Transmitted messages often include a parity bit whose value is combined with a data byte to produce an even number of 1 bits. Suppose a message byte in the AL register contains 01110101. Show how you could use the Parity flag combined with an arithmetic instruction to determine if this message byte has even or odd parity.
4. Write code using byte operands that adds two negative integers and causes the Overflow flag to be set.
5. Write a sequence of two instructions that use addition to set the Zero and Carry flags at the same time.
6. Write a sequence of two instructions that set the Carry flag using subtraction.
7. Implement the following arithmetic expression in assembly language: EAX = –val2 + 7 – val3 + val1. Assume that val1, val2, and val3 are 32-bit integer variables.
8. Write a loop that iterates through a doubleword array and calculates the sum of its elements using a scale factor with indexed addressing.
9. Implement the following expression in assembly language: AX = (val2 + BX) –val4. Assume that val2 and val4 are 16-bit integer variables.
10. Write a sequence of two instructions that set both the Carry and Overflow flags at the same time.
11. Write a sequence of instructions showing how the Zero flag could be used to indicate unsigned overflow after executing INC and DEC instructions.

Use the following data definitions for Questions 12–18:

```
.data
myBytes  BYTE 10h,20h,30h,40h
myWords  WORD 3 DUP(?),2000h
myString BYTE "ABCDE"
```

12. Insert a directive in the given data that aligns **myBytes** to an even-numbered address.
13. What will be the value of EAX after each of the following instructions execute?

```
mov  eax,TYPE myBytes          ; a.
mov  eax,LENGTHOF myBytes      ; b.
mov  eax,SIZEOF myBytes        ; c.
mov  eax,TYPE myWords          ; d.
mov  eax,LENGTHOF myWords      ; e.
mov  eax,SIZEOF myWords        ; f.
mov  eax,SIZEOF myString       ; g.
```

14. Write a single instruction that moves the first two bytes in **myBytes** to the DX register. The resulting value will be 2010h.
15. Write an instruction that moves the second byte in **myWords** to the AL register.
16. Write an instruction that moves all four bytes in **myBytes** to the EAX register.
17. Insert a LABEL directive in the given data that permits **myWords** to be moved directly to a 32-bit register.
18. Insert a LABEL directive in the given data that permits **myBytes** to be moved directly to a 16-bit register.

4.10 Programming Exercises

The following exercises may be completed in either 32-bit mode or 64-bit mode.

★ **1. Converting from Big Endian to Little Endian**

Write a program that uses the variables below and MOV instructions to copy the value from **bigEndian** to **littleEndian**, reversing the order of the bytes. The number's 32-bit value is understood to be 12345678 hexadecimal.

```
.data
bigEndian BYTE 12h,34h,56h,78h
littleEndian DWORD?
```

★★ **2. Exchanging Pairs of Array Values**

Write a program with a loop and indexed addressing that exchanges every pair of values in an array with an even number of elements. Therefore, item i will exchange with item i+1, and item i+2 will exchange with item i+3, and so on.

★★ **3. Summing the Gaps between Array Values**

Write a program with a loop and indexed addressing that calculates the sum of all the gaps between successive array elements. The array elements are doublewords, sequenced in nondecreasing order. So, for example, the array {0, 2, 5, 9, 10} has gaps of 2, 3, 4, and 1, whose sum equals 10.

★★ **4. Copying a Word Array to a DoubleWord array**

Write a program that uses a loop to copy all the elements from an unsigned Word (16-bit) array into an unsigned doubleword (32-bit) array.

★★ **5. Fibonacci Numbers**

Write a program that uses a loop to calculate the first seven values of the Fibonacci number sequence, described by the following formula: Fib(1) = 1, Fib(2) = 1, Fib(n) = Fib(n – 1) + Fib(n – 2).

★★★ **6. Reverse an Array**

Use a loop with indirect or indexed addressing to reverse the elements of an integer array in place. Do not copy the elements to any other array. Use the SIZEOF, TYPE, and LENGTHOF operators to make the program as flexible as possible if the array size and type should be changed in the future.

★★★ **7. Copy a String in Reverse Order**

Write a program with a loop and indirect addressing that copies a string from **source** to **target**, reversing the character order in the process. Use the following variables:

```
source BYTE "This is the source string",0
target BYTE SIZEOF source DUP('#')
```

★★★ **8. Shifting the Elements in an Array**

Using a loop and indexed addressing, write code that rotates the members of a 32-bit integer array forward one position. The value at the end of the array must wrap around to the first position. For example, the array [10,20,30,40] would be transformed into [40,10,20,30].