5

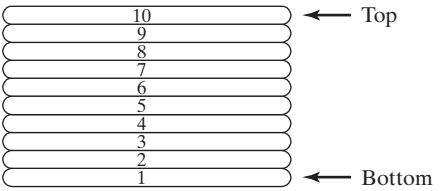
Procedures

This chapter introduces you to procedures, also known subroutines and functions. Any program of reasonable size needs to be divided into parts, and certain parts need to be used more than once. You will see that parameters can be passed in registers, and you will learn about the runtime stack that the CPU uses to track the calling location of procedures. Finally, we will introduce you to two code libraries supplied with this book, named Irvine32 and Irvine64, containing useful utilities that simplify input–output.

5.1 Stack Operations

If we place ten plates on each other as in the following diagram, the result can be called a stack. While it might be possible to remove a dish from the middle of the stack, it is much more common to remove from the top. New plates can be added to the top of the stack, but never to the bottom or middle (Fig. 5–1):

Figure 5–1 Stack of plates



A *stack data structure* follows the same principle as a stack of plates: New values are added to the top of the stack, and existing values are removed from the top. Stacks in general are useful structures for a variety of programming applications, and they can easily be implemented using object-oriented programming methods. If you have taken a programming course that used data structures, you have worked with the *stack abstract data type*. A stack is also called a LIFO structure (*Last-In, First-Out*) because the last value put into the stack is always the first value taken out.

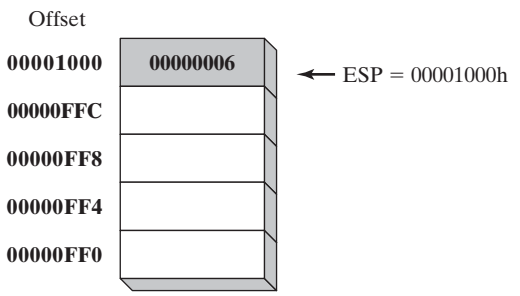
In this chapter, we concentrate specifically on the *runtime stack*. It is supported directly by hardware in the CPU, and it is an essential part of the mechanism for calling and returning from procedures. Most of the time, we just call it the stack.

5.1.1 Runtime Stack (32-Bit Mode)

The *runtime stack* is a memory array managed directly by the CPU, using the ESP (extended stack pointer) register, known as the *stack pointer register*. In 32-bit mode, ESP register holds a 32-bit offset into some location on the stack. We rarely manipulate ESP directly; instead, it is indirectly modified by instructions such as CALL, RET, PUSH, and POP.

ESP always points to the last value to be added to, or *pushed* on, the top of stack. To demonstrate, let's begin with a stack containing one value. In Fig. 5-2, the ESP contains hexadecimal 00001000, the offset of the most recently pushed value (00000006). In our diagrams, the top of the stack moves downward when the stack pointer decreases in value:

Figure 5–2 A stack containing a single value



Each stack location in this figure contains 32 bits, which is the case when a program is running in 32-bit mode.

> The runtime stack discussed here is not the same as the *stack abstract data type* (ADT) discussed in data structures courses. The runtime stack works at the system level to handle subroutine calls. The stack ADT is a programming construct typically written in a high-level programming language such as C++ or Java. It is used when implementing algorithms that depend on last-in, first-out operations.

Push Operation

A 32-bit *push operation* decrements the stack pointer by 4 and copies a value into the location in the stack pointed to by the stack pointer. Figure 5-3 shows the effect of pushing 000000A5 on a stack that already contains one value (00000006). Notice that the ESP register always points to the last item pushed on the stack. The figure shows the stack ordering opposite to that of the stack of plates we saw earlier, because the runtime stack grows downward in memory, from higher addresses to lower addresses. Before the push, ESP = 00001000h; after the push, ESP = 00000FFCh. Figure 5-4 shows the same stack after pushing a total of four integers.

Figure 5–3 Pushing integers on the stack.

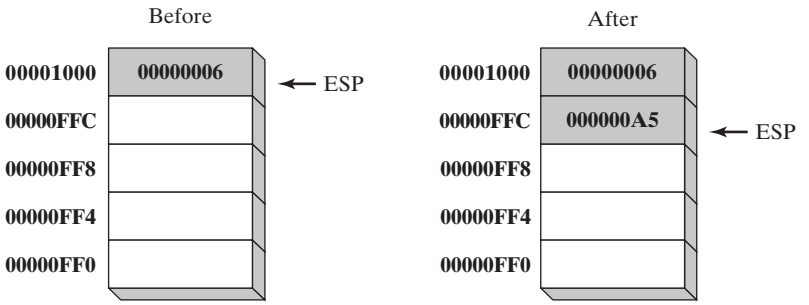
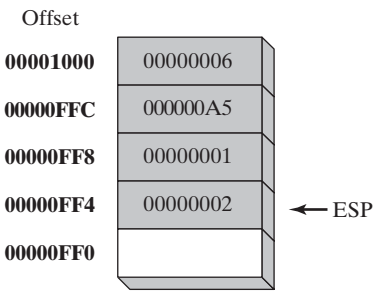


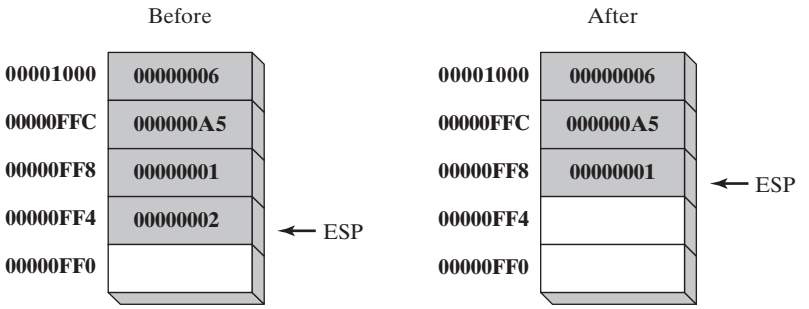
Figure 5–4 Stack, after pushing 00000001 and 00000002.



Pop Operation

A *pop operation* removes a value from the stack. After the value is popped from the stack, the stack pointer is incremented (by the stack element size) to point to the next-highest location in the stack. Figure 5-5 shows the stack before and after the value 00000002 is popped.

FIGURE 5–5 Popping a value from the runtime stack.



The area of the stack below ESP is logically empty, and will be overwritten the next time the current program executes any instruction that pushes a value on the stack.

Stack Applications

There are several important uses of runtime stacks in programs:

- A stack makes a convenient temporary save area for registers when they are used for more than one purpose. After they are modified, they can be restored to their original values.
- When the CALL instruction executes, the CPU saves the current subroutine's return address on the stack.
- When calling a subroutine, you pass input values called *arguments* by pushing them on the stack.
- The stack provides temporary storage for local variables inside subroutines.

5.1.2 PUSH and POP Instructions

PUSH Instruction

The PUSH instruction first decrements ESP and then copies a source operand into the stack. A 16-bit operand causes ESP to be decremented by 2. A 32-bit operand causes ESP to be decremented by 4. There are three instruction formats:

```
PUSH reg/mem16
PUSH reg/mem32
PUSH imm32
```

POP Instruction

The POP instruction first copies the contents of the stack element pointed to by ESP into a 16- or 32-bit destination operand and then increments ESP. If the operand is 16 bits, ESP is incremented by 2; if the operand is 32 bits, ESP is incremented by 4:

```
POP reg/mem16
POP reg/mem32
```

PUSHFD and POPFD Instructions

The PUSHFD instruction pushes the 32-bit EFLAGS register on the stack, and POPFD pops the stack into EFLAGS:

```
pushfd
popfd
```

The MOV instruction cannot be used to copy the flags to a variable, so PUSHFD may be the best way to save the flags. There are times when it is useful to make a backup copy of the flags so you can restore them to their former values later. Often, we enclose a block of code within PUSHFD and POPFD:

```
pushfd                          ; save the flags
;
; any sequence of statements here...
;
popfd                           ; restore the flags
```

When using pushes and pops of this type, be sure the program's execution path does not skip over the POPFD instruction. When a program is modified over time, it can be tricky to remember where all the pushes and pops are located. The need for precise documentation is critical!

A less error-prone way to save and restore the flags is to push them on the stack and immediately pop them into a variable:

```
.data
saveFlags DWORD ?
.code
pushfd                          ; push flags on stack
pop  saveFlags                  ; copy into a variable
```

The following statements restore the flags from the same variable:

```
push saveFlags                  ; push saved flag values
popfd                           ; copy into the flags
```

PUSHAD, PUSHA, POPAD, and POPA

The PUSHAD instruction pushes all of the 32-bit general-purpose registers on the stack in the following order: EAX, ECX, EDX, EBX, ESP (value before executing PUSHAD), EBP, ESI, and EDI. The POPAD instruction pops the same registers off the stack in reverse order. Similarly, the PUSHA instruction, pushes the 16-bit general-purpose registers (AX, CX, DX, BX, SP, BP, SI, DI) on the stack in the order listed. The POPA instruction pops the same registers in reverse. You should only use PUSHA and POPA when programming in 16-bit mode. We cover 16-bit programming in Chapters 14–17.

If you write a procedure that modifies a number of 32-bit registers, use PUSHAD at the beginning of the procedure and POPAD at the end to save and restore the registers. The following code fragment is an example:

```
MySub PROC
     pushad                     ; save general-purpose registers
     .
     .
     mov eax,...
     mov edx,...
     mov ecx,...
     .
     .
     popad                      ; restore general-purpose registers
     ret
MySub ENDP
```

An important exception to the foregoing example must be pointed out; procedures returning results in one or more registers should not use PUSHA and PUSHAD. Suppose the following **ReadValue** procedure returns an integer in EAX; the call to POPAD overwrites the return value from EAX:

```
ReadValue PROC
    pushad                      ; save general-purpose registers
    .
    .
    mov   eax,return_value
    .
    .
    popad                       ; overwrites EAX!
    ret
ReadValue ENDP
```

Example: Reversing a String

Let's look at a program named *RevStr* that loops through a string and pushes each character on the stack. It then pops the letters from the stack (in reverse order) and stores them back into the same string variable. Because the stack is a LIFO (*last-in, first-out*) structure, the letters in the string are reversed:

```
; Reversing a String           (RevStr.asm)

.386
.model flat,stdcall
.stack 4096
ExitProcess PROTO,dwExitCode:DWORD

.data
aName BYTE "Abraham Lincoln",0
nameSize = ($ - aName) - 1

.code
main PROC
; Push the name on the stack.
    mov   ecx,nameSize
    mov   esi,0

L1: movzx eax,aName[esi]            ; get character
    push  eax                       ; push on stack
    inc   esi
    loop  L1

; Pop the name from the stack, in reverse,
; and store in the aName array.
    mov   ecx,nameSize
    mov   esi,0

L2: pop   eax                       ; get character
    mov   aName[esi],al             ; store in string
    inc   esi
```

```
    loop  L2

    INVOKE ExitProcess,0
main ENDP
END main
```

5.1.3 Section Review

1. Which register (in 32-bit mode) manages the stack?
2. How is the runtime stack different from the stack abstract data type?
3. Why is the stack called a LIFO structure?
4. When a 32-bit value is pushed on the stack, what happens to ESP?
5. *(True/False):* Local variables in procedures are created on the stack.
6. *(True/False):* The PUSH instruction cannot have an immediate operand.

5.2 Defining and Using Procedures

If you've already studied a high-level programming language, you know how useful it can be to divide programs into *subroutines*. A complicated problem is usually divided into separate tasks before it can be understood, implemented, and tested effectively. In assembly language, we typically use the term *procedure* to mean a subroutine. In other languages, subroutines are called methods or functions.

In terms of object-oriented programming, the functions or methods in a single class are roughly equivalent to the collection of procedures and data encapsulated in an assembly language module. Assembly language was created long before object-oriented programming, so it doesn't have the formal structure found in object-oriented languages. Assembly programmers must impose their own formal structure on programs.

5.2.1 PROC Directive

Defining a Procedure

Informally, we can define a *procedure* as a named block of statements that ends in a return statement. A procedure is declared using the PROC and ENDP directives. It must be assigned a name (a valid identifier). Each program we've written so far contains a procedure named **main**, for example,

```
main PROC
.
.
main ENDP
```

When you create a procedure other than your program's startup procedure, end it with a RET instruction. RET forces the CPU to return to the location from where the procedure was called:

```
sample PROC
    .
    .
    ret
sample ENDP
```

Labels in Procedures

By default, labels are visible only within the procedure in which they are declared. This rule often affects jump and loop instructions. In the following example, the label named *Destination* must be located in the same procedure as the JMP instruction:

```
jmp Destination
```

It is possible to work around this limitation by declaring a *global label*, identified by a double colon (::) after its name:

```
Destination::
```

In terms of program design, it's not a good idea to jump or loop outside of the current procedure. Procedures have an automated way of returning and adjusting the runtime stack. If you directly transfer out of a procedure, the runtime stack can easily become corrupted. For more information about the runtime stack, see Section 8.2.

Example: SumOf Three Integers

Let's create a procedure named **SumOf** that calculates the sum of three 32-bit integers. We will assume that relevant integers are assigned to EAX, EBX, and ECX before the procedure is called. The procedure returns the sum in EAX:

```
SumOf PROC
    add  eax,ebx
    add  eax,ecx
    ret
SumOf ENDP
```

Documenting Procedures

A good habit to cultivate is that of adding clear and readable documentation to your programs. The following are a few suggestions for information that you can put at the beginning of each procedure:

- A description of all tasks accomplished by the procedure.
- A list of input parameters and their usage, labeled by a word such as **Receives**. If any input parameters have specific requirements for their input values, list them here.
- A description of any values returned by the procedure, labeled by a word such as **Returns**.
- A list of any special requirements, called *preconditions*, that must be satisfied before the procedure is called. These can be labeled by the word **Requires**. For example, for a procedure that draws a graphics line, a useful precondition would be that the video display adapter must already be in graphics mode.

> The descriptive labels we've chosen, such as Receives, Returns, and Requires, are not absolutes; other useful names are often used.

With these ideas in mind, let's add appropriate documentation to the **SumOf** procedure:

```
;-----------------------------------------------------
; sumof
;
; Calculates and returns the sum of three 32-bit integers.
; Receives: EAX, EBX, ECX, the three integers. May be
;           signed or unsigned.
; Returns:  EAX = sum
;-----------------------------------------------------
SumOf PROC
     add   eax,ebx
     add   eax,ecx
     ret
SumOf ENDP
```

Functions written in high-level languages like C and C++ typically return 8-bit values in AL, 16-bit values in AX, and 32-bit values in EAX.

5.2.2 CALL and RET Instructions

The CALL instruction calls a procedure by directing the processor to begin execution at a new memory location. The procedure uses a RET (return from procedure) instruction to bring the processor back to the point in the program where the procedure was called. Mechanically speaking, the CALL instruction pushes its return address on the stack and copies the called procedure's address into the instruction pointer. When the procedure is ready to return, its RET instruction pops the return address from the stack into the instruction pointer. In 32-bit mode, the CPU executes the instruction in memory pointed to by EIP (instruction pointer register). In 16-bit mode, IP points to the instruction.

Call and Return Example

Suppose that in **main**, a CALL statement is located at offset 00000020. Typically, this instruction requires 5 bytes of machine code, so the next statement (a MOV in this case) is located at offset 00000025:

```
            main PROC
00000020      call MySub
00000025      mov  eax,ebx
```

Next, suppose that the first executable instruction in **MySub** is located at offset 00000040:

```
            MySub PROC
00000040     mov eax,edx
               .
               .
             ret
            MySub ENDP
```

When the CALL instruction executes (Fig. 5-6), the address following the call (00000025) is pushed on the stack and the address of **MySub** is loaded into EIP. All instructions in **MySub** execute up to its RET instruction. When the RET instruction executes, the value in the stack

pointed to by ESP is popped into EIP (step 1 in Fig. 5-7). In step 2, ESP is incremented so it points to the previous value on the stack (step 2).

FIGURE 5–6 Executing a CALL instruction.

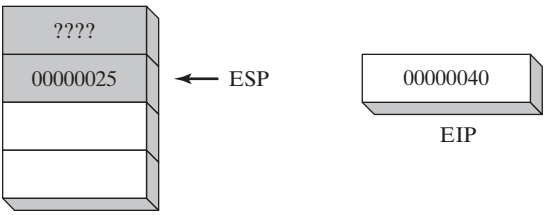
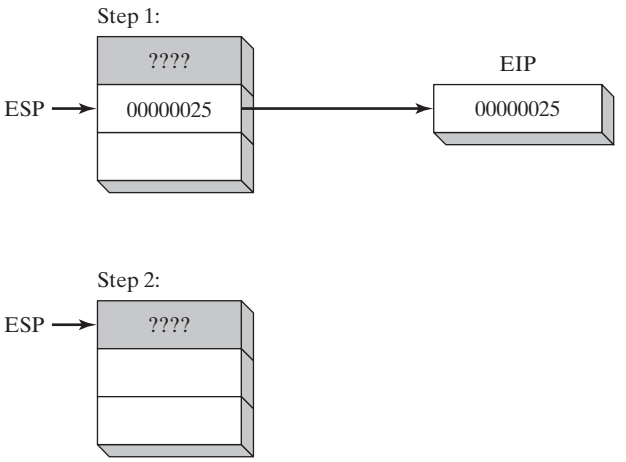


FIGURE 5–7 Executing the RET instruction.



5.2.3 Nested Procedure Calls

A *nested procedure call* occurs when a called procedure calls another procedure before the first procedure returns. Suppose that **main** calls a procedure named **Sub1**. While **Sub1** is executing, it calls the **Sub2** procedure. While **Sub2** is executing, it calls the **Sub3** procedure. The process is shown in Fig. 5-8.

When the RET instruction at the end of **Sub3** executes, it pops the value at stack[ESP] into the instruction pointer. This causes execution to resume at the instruction following the call **Sub3** instruction. The following diagram shows the stack just before the return from **Sub3** is executed:

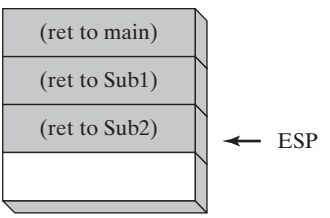
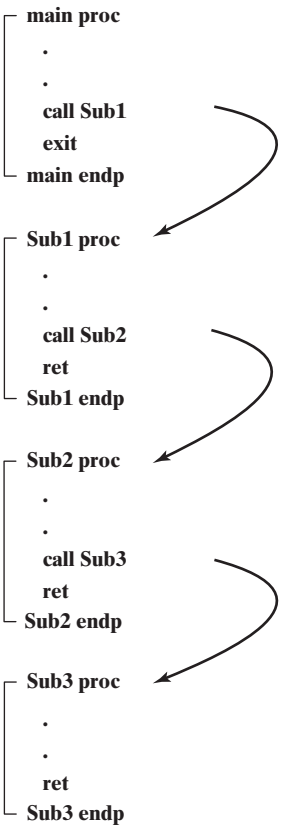
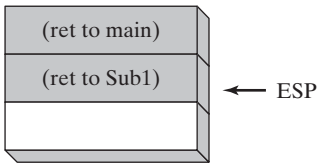


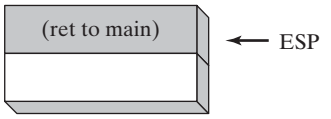
Figure 5–8 Nested procedure calls.



After the return, ESP points to the next-highest stack entry. When the RET instruction at the end of **Sub2** is about to execute, the stack appears as follows:



Finally, when **Sub1** returns, stack[ESP] is popped into the instruction pointer, and execution resumes in **main**:



Clearly, the stack proves itself a useful device for remembering information, including nested procedure calls. Stack structures, in general, are used in situations where programs must retrace their steps in a specific order.

5.2.4 Passing Register Arguments to Procedures

If you write a procedure that performs some standard operation such as calculating the sum of an integer array, it's not a good idea to include references to specific variable names inside the procedure. If you did, the procedure could only be used with one array. A better approach is to pass the offset of an array to the procedure and pass an integer specifying the number of array elements. We call these *arguments* (or *input parameters)*. In assembly language, it is common to pass arguments inside general-purpose registers.

In the preceding section we created a simple procedure named **SumOf** that added the integers in the EAX, EBX, and ECX registers. In **main**, before calling **SumOf**, we assign values to EAX, EBX, and ECX:

```
.data
theSum  DWORD  ?
.code
main PROC
     mov   eax,10000h                ; argument
     mov   ebx,20000h                ; argument
     mov   ecx,30000h                ; argument
     call  Sumof                     ; EAX = (EAX + EBX + ECX)
     mov   theSum,eax                ; save the sum
```

After the CALL statement, we have the option of copying the sum in EAX to a variable.

5.2.5 Example: Summing an Integer Array

A very common type of loop that you may have already coded in C++ or Java is one that calculates the sum of an integer array. This is very easy to implement in assembly language, and it can be coded in such a way that it will run as fast as possible. For example, one can use registers rather than variables inside a loop.

Let's create a procedure named **ArraySum** that receives two parameters from a calling program: a pointer to an array of 32-bit integers, and a count of the number of array values. It calculates and returns the sum of the array in EAX:

```
;-----------------------------------------------------
; ArraySum
;
; Calculates the sum of an array of 32-bit integers.
; Receives: ESI = the array offset
;           ECX = number of elements in the array
; Returns:  EAX = sum of the array elements
;-----------------------------------------------------
ArraySum PROC
     push  esi                  ; save ESI, ECX
     push  ecx
     mov   eax,0                ; set the sum to zero

L1:  add   eax,[esi]            ; add each integer to sum
     add   esi,TYPE DWORD       ; point to next integer
```

```
    loop  L1                    ; repeat for array size
    pop   ecx                   ; restore ECX, ESI
    pop   esi
    ret                         ; sum is in EAX
ArraySum ENDP
```

Nothing in this procedure is specific to a certain array name or array size. It could be used in any program that needs to sum an array of 32-bit integers. Whenever possible, you should also create procedures that are flexible and adaptable.

Testing the ArraySum Procedure

The following program tests the ArraySum procedure by calling it and passing the offset and length of an array of 32-bit integers. After calling ArraySum, it saves the procedure's return value in a variable named theSum.

```
; Testing the ArraySum procedure (TestArraySum.asm)

.386
.model flat, stdcall
.stack 4096
ExitProcess PROTO, dwExitCode:DWORD

.data
array DWORD 10000h,20000h,30000h,40000h,50000h
theSum DWORD ?

.code
main PROC
    mov   esi,OFFSET array     ; ESI points to array
    mov   ecx,LENGTHOF array   ; ECX = array count
    call  ArraySum             ; calculate the sum
    mov   theSum,eax           ; returned in EAX

    INVOKE ExitProcess,0
main ENDP

;-----------------------------------------------------
; ArraySum
; Calculates the sum of an array of 32-bit integers.
; Receives: ESI = the array offset
; ECX = number of elements in the array
; Returns: EAX = sum of the array elements
;-----------------------------------------------------

ArraySum PROC
    push  esi                  ; save ESI, ECX
    push  ecx
    mov   eax,0                ; set the sum to zero

L1:
    add   eax,[esi]            ; add each integer to sum
    add   esi,TYPE DWORD       ; point to next integer
    loop  L1                   ; repeat for array size
```

```
    pop   ecx                   ; restore ECX, ESI
    pop   esi
    ret                         ; sum is in EAX
ArraySum ENDP

END main
```

5.2.6 Saving and Restoring Registers

In the **ArraySum** example, ECX and ESI were pushed on the stack at the beginning of the procedure and popped at the end. This action is typical of most procedures that modify registers. Always save and restore registers that are modified by a procedure so the calling program can be sure that none of its own register values will be overwritten. The exception to this rule pertains to registers used as return values, usually EAX. Do not push and pop them.

USES Operator

The USES operator, coupled with the PROC directive, lets you list the names of all registers modified within a procedure. USES tells the assembler to do two things: First, generate PUSH instructions that save the registers on the stack at the beginning of the procedure. Second, generate POP instructions that restore the register values at the end of the procedure. The USES operator immediately follows PROC, and is itself followed by a list of registers on the same line separated by spaces or tabs (not commas).

The ArraySum procedure from Section 5.2.5 used PUSH and POP instructions to save and restore ESI and ECX. The USES operator can more easily do the same:

```
ArraySum PROC USES esi ecx
    mov   eax,0                 ; set the sum to zero
L1:
    add   eax,[esi]             ; add each integer to sum
    add   esi,TYPE DWORD        ; point to next integer
    loop  L1                    ; repeat for array size

    ret                         ; sum is in EAX
ArraySum ENDP
```

The corresponding code generated by the assembler shows the effect of USES:

```
ArraySum PROC
    push  esi
    push  ecx
    mov   eax,0                 ; set the sum to zero
L1:
    add   eax,[esi]             ; add each integer to sum
    add   esi,TYPE DWORD        ; point to next integer
    loop  L1                    ; repeat for array size

    pop   ecx
    pop   esi
    ret
ArraySum ENDP
```

Debugging Tip: When using the Microsoft Visual Studio debugger, you can view the hidden machine instructions generated by MASM's advanced operators and directives. Right-click in the Debugging window and select *Go to Disassembly*. This window displays your program's source code along with hidden machine instructions generated by the assembler.

Exception There is an important exception to our standing rule about saving registers that applies when a procedure returns a value in a register (usually EAX). In this case, the return register should not be pushed and popped. For example, in the SumOf procedure in the following example, it pushes and pops EAX, causing the procedure's return value to be lost:

```
SumOf PROC                    ; sum of three integers
     push  eax                ; save EAX
     add   eax,ebx            ; calculate the sum
     add   eax,ecx            ; of EAX, EBX, ECX
     pop   eax                ; lost the sum!
     ret
SumOf ENDP
```

5.2.7 Section Review

1. *(True/False):* The PROC directive begins a procedure and the ENDP directive ends a procedure.
2. *(True/False):* It is possible to define a procedure inside an existing procedure.
3. What would happen if the RET instruction was omitted from a procedure?
4. How are the words *Receives* and *Returns* used in the suggested procedure documentation?
5. *(True/False):* The CALL instruction pushes the offset of the CALL instruction on the stack.
6. *(True/False):* The CALL instruction pushes the offset of the instruction following the CALL on the stack.

5.3 Linking to an External Library

If you spend the time, you can write detailed code for input–output in assembly language. It's a lot like building your own automobile from scratch so that you can drive somewhere. The work is both interesting and time consuming. In Chapter 11 you will get a chance to see how input–output is handled in MS-Windows protected mode. It is great fun, and a new world opens up when you see the available tools. For now, however, input–output should be easy while you are learning assembly language basics. Section 5.3 shows how to call procedures from the book's link libraries, named *Irvine32.lib* and *Irvine64.obj*. The complete library source code is available at the author's web site (asmirvine.com). It should be installed on your computer in the *Examples\Lib32* subfolder of the book's install file (usually named *C:\Irvine*).

The Irvine32 library can only be used by programs running in 32-bit mode. It contains procedures that link to the MS-Windows API when they generate input–output. The Irvine64 library is a more limited library for 64-bit applications that is limited to essential display and string operations.

5.3.1 Background Information

A *link library* is a file containing procedures (subroutines) that have been assembled into machine code. A link library begins as one or more source files, which are assembled into object files. The object files are inserted into a specially formatted file recognized by the linker utility. Suppose a program displays a string in the console window by calling a procedure named **WriteString**. The program source must contain a PROTO directive identifying the WriteString procedure:

```
WriteString proto
```

Next, a CALL instruction executes **WriteString**:

```
call WriteString
```

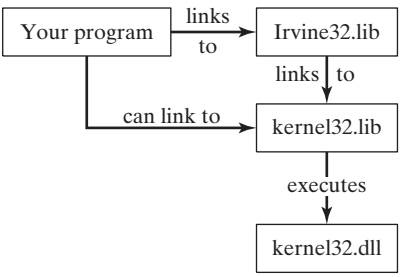
When the program is assembled, the assembler leaves the target address of the CALL instruction blank, knowing that it will be filled in by the linker. The linker looks for **WriteString** in the link library and copies the appropriate machine instructions from the library into the program's executable file. In addition, it inserts **WriteString's** address into the CALL instruction. If a procedure you're calling is not in the link library, the linker issues an error message and does not generate an executable file.

Linker Command Options The linker utility combines a program's object file with one or more object files and link libraries. The following command, for example, links hello.obj to the irvine32.lib and kernel32.lib libraries:

```
link hello.obj irvine32.lib kernel32.lib
```

Linking 32-Bit Programs The kernel32.lib file, part of the Microsoft Windows Platform *Software Development Kit*, contains linking information for system functions located in a file named kernel32.dll. The latter is a fundamental part of MS-Windows, and is called a *dynamic link library*. It contains executable functions that perform character-based input–output. Figure 5-9 shows how kernel32.lib is a bridge to kernel32.dll.

FIGURE 5–9 Linking 32-bit programs.



In Chapters 1 through 10, our programs link either Irvine32.lib or Irvine64.obj. Chapter 11 shows how to link programs directly to kernel32.lib.

5.3.2 Section Review

1. *(True/False)*: A link library consists of assembly language source code.
2. Use the PROTO directive to declare a procedure named **MyProc** in an external link library.
3. Write a CALL statement that calls a procedure named **MyProc** in an external link library.
4. What is the name of the 32-bit link library supplied with this book?
5. What type of file is **kernel32.dll**?

5.4 The Irvine32 Library

5.4.1 Motivation for Creating the Library

There is no Microsoft-sanctioned standard library for assembly language programming. When programmers first started writing assembly language for x86 processors in the early 1980s, MS-DOS was the commonly used operating system. These 16-bit programs were able to call MS-DOS functions (known as INT 21h services) to do simple input/output. Even at that time, if you wanted to display an integer on the console, you had to write a fairly complicated procedure that converted from the internal binary representation of integers to a sequence of ASCII characters that would display the integer on the screen. We called it **WriteInt**, and this is the logic, abstracted into pseudocode:

Initialization:

```
let n equal the binary value
let buffer be an array of char[size]
```

Algorithm:

```
i = size  -1                    ; last position of buffer
repeat
     r = n mod 10               ; remainder
     n = n / 10                 ; integer division
     digit = r OR 30h           ; conver r to ASCII digit
     buffer[i--] = digit        ; store in buffer
until n = 0

if n is negative
     buffer[i] = "-"            ; insert a negative sign

while i > 0
     print buffer[i]
     i++
```

Notice that the digits are generated in reverse order and inserted into a buffer, moving from the back to the front. Then the digits are written to the console in forward order. While this code is easy enough to implement in C/C++, it requires some advanced skills in assembly language.

Professional programmers often prefer to build their own libraries, and doing so is an excellent educational experience. In 32-bit mode running under Windows, an input–output library must make calls directly into the operating system. The learning curve is rather steep, and it presents some challenges for beginning programmers. Therefore, the *Irvine32*

library is designed to provide a simple interface for input–output for beginners. As you continue through the chapters in this book, you will acquire the knowledge and skills to create your own library. You are free to modify and reuse the library, as long as you give credit to its original author. Another alternative, which we will discuss in Chapter 13, is to call Standard C library functions from your assembly language programs. Again, that requires some additional background.

Table 5-1 contains a complete list of procedures in the Irvine32 library.

Table 5-1 Procedures in the Irvine32 Library.

Procedure	Description
CloseFile	Closes a disk file that was previously opened.
Clrscr	Clears the console window and locates the cursor at the upper left corner.
CreateOutputFile	Creates a new disk file for writing in output mode.
Crlf	Writes an end-of-line sequence to the console window.
Delay	Pauses the program execution for a specified *n*-millisecond interval.
DumpMem	Writes a block of memory to the console window in hexadecimal.
DumpRegs	Displays the EAX, EBX, ECX, EDX, ESI, EDI, EBP, ESP, EFLAGS, and EIP registers in hexadecimal. Also displays the most common CPU status flags.
GetCommandTail	Copies the program's command-line arguments (called the *command tail*) into an array of bytes.
GetDateTime	Gets the current date and time from the system.
GetMaxXY	Gets the number of columns and rows in the console window's buffer.
GetMseconds	Returns the number of milliseconds elapsed since midnight.
GetTextColor	Returns the active foreground and background text colors in the console window.
Gotoxy	Locates the cursor at a specific row and column in the console window.
IsDigit	Sets the Zero flag if the AL register contains the ASCII code for a decimal digit (0–9).
MsgBox	Displays a popup message box.
MsgBoxAsk	Display a yes/no question in a popup message box.
OpenInputFile	Opens an existing disk file for input.
ParseDecimal32	Converts an unsigned decimal integer string to 32-bit binary.
ParseInteger32	Converts a signed decimal integer string to 32-bit binary.
Random32	Generates a 32-bit pseudorandom integer in the range 0 to FFFFFFFFh.
Randomize	Seeds the random number generator with a unique value.
RandomRange	Generates a pseudorandom integer within a specified range.
ReadChar	Waits for a single character to be typed at the keyboard and returns the character.
ReadDec	Reads an unsigned 32-bit decimal integer from the keyboard, terminated by the Enter key.
ReadFromFile	Reads an input disk file into a buffer.
ReadHex	Reads a 32-bit hexadecimal integer from the keyboard, terminated by the Enter key.

Table 5-1 *(Continued)*

Procedure	Description
ReadInt	Reads a 32-bit signed decimal integer from the keyboard, terminated by the Enter key.
ReadKey	Reads a character from the keyboard's input buffer without waiting for input.
ReadString	Reads a string from the keyboard, terminated by the Enter key.
SetTextColor	Sets the foreground and background colors of all subsequent text output to the console.
Str_compare	Compares two strings.
Str_copy	Copies a source string to a destination string.
Str_length	Returns the length of a string in EAX.
Str_trim	Removes unwanted characters from a string.
Str_ucase	Converts a string to uppercase letters.
WaitMsg	Displays a message and waits for a key to be pressed.
WriteBin	Writes an unsigned 32-bit integer to the console window in ASCII binary format.
WriteBinB	Writes a binary integer to the console window in byte, word, or doubleword format.
WriteChar	Writes a single character to the console window.
WriteDec	Writes an unsigned 32-bit integer to the console window in decimal format.
WriteHex	Writes a 32-bit integer to the console window in hexadecimal format.
WriteHexB	Writes a byte, word, or doubleword integer to the console window in hexadecimal format.
WriteInt	Writes a signed 32-bit integer to the console window in decimal format.
WriteStackFrame	Writes the current procedure's stack frame to the console.
WriteStackFrameName	Writes the current procedure's name and stack frame to the console.
WriteString	Writes a null-terminated string to the console window.
WriteToFile	Writes a buffer to an output file.
WriteWindowsMsg	Displays a string containing the most recent error generated by MS-Windows.

5.4.2 Overview

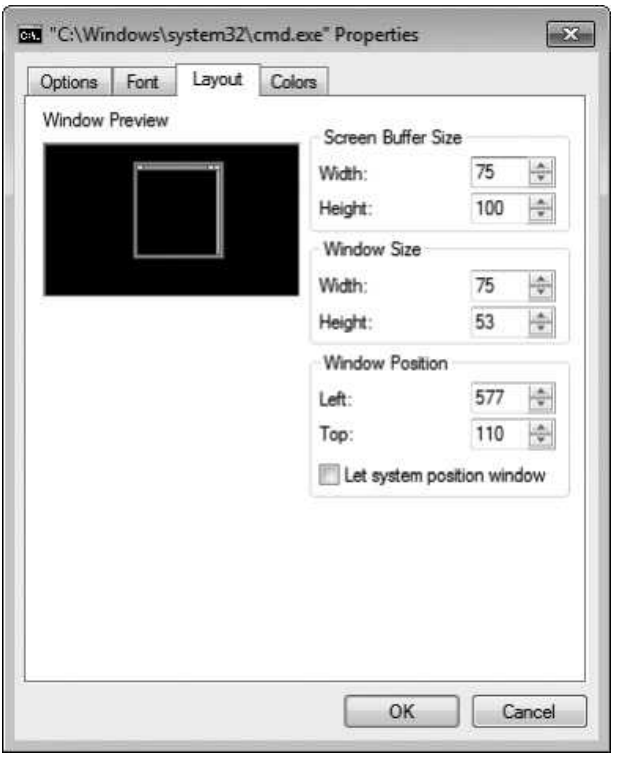
Console Window The *console window* (or *command window*) is a text-only window created by MS-Windows when a command prompt is displayed.

To display a console window in Microsoft Windows, click the Start button on the desktop, type *cmd* into the *Start Search* field, and press Enter. Once a console window is open, you can resize the console window buffer by right-clicking on the system menu in the window's upper-left corner, selecting *Properties* from the popup menu, and then modifying the values, as shown in Fig. 5-10.

You can also select various font sizes and colors. The console window defaults to 25 rows by 80 columns. You can use the *mode* command to change the number of columns and lines. The following, typed at the command prompt, sets the console window to 40 columns by 30 lines:

```
mode con cols=40 lines=30
```

Figure 5–10 Modifying the console window properties.



A *file handle* is a 32-bit integer used by the Windows operating system to identify a file that is currently open. When your program calls a Windows service to open or create a file, the operating system creates a new file handle and makes it available to your program. Each time you call an OS service method to read from or write to the file, you must pass the same file handle as a parameter to the service method.

Note: If your program calls procedures in the Irvine32 library, you must always push 32-bit values onto the runtime stack; if you do not, the Win32 Console functions called by the library will not work correctly.

5.4.3 Individual Procedure Descriptions

In this section, we describe how each of the procedures in the Irvine32 library is used. We will omit a few of the more advanced procedures, which will be explained in later chapters.

CloseFile The CloseFile procedure closes a file that was previously created or opened (see CreateOutputFile and OpenInputFile). The file is identified by a 32-bit integer *handle*, which is passed in EAX. If the file is closed successfully, the value returned in EAX will be nonzero. Sample call:

```
mov   eax,fileHandle
call  CloseFile
```

Clrscr The Clrscr procedure clears the console window. This procedure is typically called at the beginning and end of a program. If you call it at other times, you may need to pause the program by first calling WaitMsg. Doing this allows the user to view information already on the screen before it is erased. Sample call:

```
call  WaitMsg                    ; "Press any key..."
call  Clrscr
```

CreateOutputFile The CreateOutputFile procedure creates a new disk file and opens it for writing. When you call the procedure, place the offset of a filename in EDX. When the procedure returns, EAX will contain a valid file handle (32-bit integer) if the file was created successfully. Otherwise, EAX equals INVALID_HANDLE_VALUE (a predefined constant). Sample call:

```
.data
filename BYTE "newfile.txt",0
.code
mov  edx,OFFSET filename
call CreateOutputFile
```

The following pseudocode describes the possible outcomes after calling CreateOutputFile:

```
if EAX = INVALID_HANDLE_VALUE
     the file was not created successfully
else
     EAX = handle for the open file
endif
```

Crlf The Crlf procedure advances the cursor to the beginning of the next line in the console window. It writes a string containing the ASCII character codes 0Dh and 0Ah. Sample call:

```
call  Crlf
```

Delay The Delay procedure pauses the program for a specified number of milliseconds. Before calling Delay, set EAX to the desired interval. Sample call:

```
mov   eax,1000                   ; 1 second
call  Delay
```

DumpMem The DumpMem procedure writes a range of memory to the console window in hexadecimal. Pass it the starting address in ESI, the number of units in ECX, and the unit size in EBX (1 = byte, 2 = word, 4 = doubleword). The following sample call displays an array of 11 doublewords in hexadecimal:

```
.data
array DWORD 1,2,3,4,5,6,7,8,9,0Ah,0Bh
.code
main PROC
     mov   esi,OFFSET array            ; starting OFFSET
     mov   ecx,LENGTHOF array          ; number of units
     mov   ebx,TYPE array              ; doubleword format
     call  DumpMem
```

The following output is produced:

```
00000001  00000002  00000003  00000004  00000005  00000006
00000007  00000008  00000009  0000000A  0000000B
```

DumpRegs The DumpRegs procedure displays the EAX, EBX, ECX, EDX, ESI, EDI, EBP, ESP, EIP, and EFL (EFLAGS) registers in hexadecimal. It also displays the values of the Carry, Sign, Zero, Overflow, Auxiliary Carry, and Parity flags. Sample call:

```
call DumpRegs
```

Sample output:

```
EAX=00000613  EBX=00000000  ECX=000000FF  EDX=00000000
ESI=00000000  EDI=00000100  EBP=0000091E  ESP=000000F6
EIP=00401026  EFL=00000286  CF=0  SF=1  ZF=0  OF=0  AF=0  PF=1
```

The displayed value of EIP is the offset of the instruction following the call to DumpRegs. DumpRegs can be useful when debugging programs because it displays a snapshot of the CPU. It has no input parameters and no return value.

GetCommandTail The GetCommandTail procedure copies the program's command line into a null-terminated string. If the command line was found to be empty, the Carry flag is set; otherwise, the Carry flag is cleared. This procedure is useful because it permits the user of a program to pass parameters on the command line. Suppose a program named **Encrypt.exe** reads an input file named **file1.txt** and produces an output file named **file2.txt**. The user can pass both filenames on the command line when running the program:

```
Encrypt file1.txt file2.txt
```

When it starts up, the Encrypt program can call GetCommandTail and retrieve the two filenames. When calling GetCommandTail, EDX must contain the offset of an array of at least 129 bytes. Sample call:

```
.data
cmdTail BYTE 129 DUP(0)        ; empty buffer
.code
mov   edx,OFFSET cmdTail
call  GetCommandTail           ; fills the buffer
```

There is a way to pass command-line arguments when running an application in Visual Studio. From the Project menu, select *<projectname> Properties*. In the Property Pages window, expand the entry under *Configuration Properties*, and select *Debugging*. Then enter your command arguments into the edit line on the right panel named *Command Arguments*.

GetMaxXY The GetMaxXY procedure gets the size of the console window's buffer. If the console window buffer is larger than the visible window size, scroll bars appear automatically. GetMaxXY has no input parameters. When it returns, the DX register contains the number of buffer columns and AX contains the number of buffer rows. The possible range of each value can be no greater than 255, which may be smaller than the actual window buffer size. Sample call:

```
.data
rows  BYTE ?
cols  BYTE ?
.code
call  GetMaxXY
mov   rows,al
mov   cols,dl
```

GetMseconds The GetMseconds procedure gets the number of milliseconds elapsed since midnight on the host computer, and returns the value in the EAX register. The procedure is a great tool for measuring the time between events. No input parameters are required. The following example calls GetMseconds, storing its return value. After the loop executes, the code call GetMseconds a second time and subtract the two time values. The difference is the approximate execution time of the loop:

```
.data
startTime DWORD ?
.code
call GetMseconds
mov  startTime,eax
L1:
  ; (loop body)
  loop L1
call GetMseconds
sub  eax,startTime              ; EAX = loop time, in milliseconds
```

GetTextColor The GetTextColor procedure gets the current foreground and background colors of the console window. It has no input parameters. It returns the background color in the upper four bits of AL and the foreground color in the lower four bits. Sample call:

```
.data
color byte ?
.code
call  GetTextColor
mov   color,AL
```

Gotoxy The Gotoxy procedure locates the cursor at a given row and column in the console window. By default, the console window's X-coordinate range is 0 to 79 and the Y-coordinate range is 0 to 24. When you call Gotoxy, pass the Y-coordinate (row) in DH and the X-coordinate (column) in DL. Sample call:

```
mov   dh,10                     ; row 10
mov   dl,20                     ; column 20
call  Gotoxy                    ; locate cursor
```

The user may have resized the console window, so you can call GetMaxXY to find out the current number of rows and columns.

IsDigit The IsDigit procedure determines whether the value in AL is the ASCII code for a valid decimal digit. When calling it, pass an ASCII character in AL. The procedure sets the Zero flag if AL contains a valid decimal digit; otherwise, it clears Zero flag. Sample call:

```
mov   AL,somechar
call  IsDigit
```

MsgBox The MsgBox procedure displays a graphical popup message box with an optional caption. (This works when the program is running in a console window.) Pass it the offset of a string in EDX, which will appear inside the box. Optionally, pass the offset of a string for the box's title in EBX. To leave the title blank, set EBX to zero. Sample call:

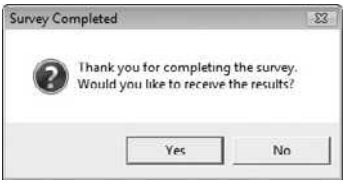
```
.data
caption BYTE "Dialog Title", 0
HelloMsg BYTE "This is a pop-up message box.", 0dh,0ah
        BYTE "Click OK to continue...", 0
.code
mov   ebx,OFFSET caption
mov   edx,OFFSET HelloMsg
call  MsgBox
```

Sample output:

MsgBoxAsk The MsgBoxAsk procedure displays a graphical popup message box with Yes and No buttons. (This works when the program is running in a console window.) Pass it the offset of a question string in EDX, which will appear inside the box. Optionally, pass the offset of a string for the box's title in EBX. To leave the title blank, set EBX to zero. MsgBoxAsk returns an integer in EAX that tells you which button was selected by the user. The value will be one of two predefined Windows constants: IDYES (equal to 6) or IDNO (equal to 7). Sample call:

```
.data
caption BYTE "Survey Completed",0
question BYTE "Thank you for completing the survey."
  BYTE 0dh,0ah
  BYTE "Would you like to receive the results?",0
.code
mov   ebx,OFFSET caption
mov   edx,OFFSET question
call  MsgBoxAsk
;(check return value in EAX)
```

Sample output:



OpenInputFile The OpenInputFile procedure opens an existing file for input. Pass it the offset of a filename in EDX. When it returns, if the file was opened successfully, EAX will contain a valid file handle. Otherwise, EAX will equal INVALID_HANDLE_VALUE (a predefined constant).

Sample call:

```
.data
filename BYTE "myfile.txt",0
.code
mov  edx,OFFSET filename
call OpenInputFile
```

The following pseudocode describes the possible outcomes after calling OpenInputFile:

```
if EAX = INVALID_HANDLE_VALUE
     the file was not opened successfully
else
     EAX = handle for the open file
endif
```

ParseDecimal32 The ParseDecimal32 procedure converts an unsigned decimal integer string to 32-bit binary. All valid digits occurring before a nonnumeric character are converted. Leading spaces are ignored. Pass it the offset of a string in EDX and the string's length in ECX. The binary value is returned in EAX. Sample call:

```
.data
buffer BYTE "8193"
bufSize = ($ - buffer)
.code
mov   edx,OFFSET buffer
mov   ecx,bufSize
call  ParseDecimal32            ; returns EAX
```

- If the integer is blank, EAX = 0 and CF = 1
- If the integer contains only spaces, EAX = 0 and CF = 1
- If the integer is larger than $2^{32}-1$, EAX = 0 and CF = 1
- Otherwise, EAX contains the converted integer and CF = 0

See the description of the **ReadDec** procedure for details about how the Carry flag is affected.

ParseInteger32 The ParseInteger32 procedure converts a signed decimal integer string to 32-bit binary. All valid digits from the beginning of the string to the first nonnumeric character are converted. Leading spaces are ignored. Pass it the offset of a string in EDX and the string's length in ECX. The binary value is returned in EAX. Sample call:

```
.data
buffer byte "-8193"
bufSize = ($ - buffer)
.code
mov   edx,OFFSET buffer
mov   ecx,bufSize
call  ParseInteger32           ; returns EAX
```

The string may contain an optional leading plus or minus sign, followed only by decimal digits. The Overflow flag is set and an error message is displayed on the console if the value cannot be represented as a 32-bit signed integer (range: −2,147,483,648 to +2,147,483,647).

Random32 The Random32 procedure generates and returns a 32-bit random integer in EAX. When called repeatedly, Random32 generates a simulated random sequence. The numbers are created using a simple function having an input called a *seed*. The function uses the seed in a formula that generates the random value. Subsequent random values are generated using each previously generated random value as their seeds. The following code snippet shows a sample call to Random32:

```
.data
randVal DWORD ?
.code
call  Random32
mov   randVal,eax
```

Randomize The Randomize procedure initializes the starting seed value of the Random32 and RandomRange procedures. The seed equals the time of day, accurate to 1/100 of a second. Each time you run a program that calls Random32 and RandomRange, the generated sequence of random numbers will be unique. You need only to call Randomize once at the beginning of a program. The following example produces 10 random integers:

```
     call  Randomize
     mov   ecx,10
L1:  call  Random32

     ; use or display random value in EAX here...

     loop  L1
```

RandomRange The RandomRange procedure produces a random integer within the range of 0 to $n - 1$, where n is an input parameter passed in the EAX register. The random integer is returned in EAX. The following example generates a single random integer between 0 and 4999 and places it in a variable named *randVal*.

```
.data
randVal DWORD ?
```

```
.code
mov  eax,5000
call RandomRange
mov  randVal,eax
```

ReadChar The ReadChar procedure reads a single character from the keyboard and returns the character in the AL register. The character is not echoed in the console window. Sample call:

```
.data
char BYTE ?
.code
call ReadChar
mov  char,al
```

If the user presses an extended key such as a function key, arrow key, Ins, or Del, the procedure sets AL to zero, and AH contains a keyboard scan code. A list of scan codes is shown on the page facing the book's inside front cover. The upper half of EAX is not preserved. The following pseudocode describes the possible outcomes after calling ReadChar:

```
if an extended key was pressed
     AL = 0
     AH = keyboard scan code
else
     AL = ASCII key value
endif
```

ReadDec The ReadDec procedure reads a 32-bit unsigned decimal integer from the keyboard and returns the value in EAX. Leading spaces are ignored. The return value is calculated from all valid digits found until a nondigit character is encountered. For example, if the user enters 123ABC, the value returned in EAX is 123. Following is a sample call:

```
.data
intVal DWORD ?
.code
call ReadDec
mov  intVal,eax
```

ReadDec affects the Carry flag in the following ways:

- If the integer is blank, EAX = 0 and CF = 1
- If the integer contains only spaces, EAX = 0 and CF = 1
- If the integer is larger than $2^{32}-1$, EAX = 0 and CF = 1
- Otherwise, EAX holds the converted integer and CF = 0

ReadFromFile The ReadFromFile procedure reads an input disk file into a memory buffer. When you call ReadFromFile, pass it an open file handle in EAX, the offset of a buffer in EDX, and the maximum number of bytes to read in ECX. When ReadFromFile returns, check the value of the Carry flag: If CF is clear, EAX contains a count of the number of bytes read from the file. But if CF is set, EAX contains a numeric system error code. You can call the WriteWindowsMsg procedure to get a text representation of the error.

In the following example, as many as 5000 bytes are copied from the file into the buffer variable:

```
.data
BUFFER_SIZE = 5000
buffer BYTE BUFFER_SIZE DUP(?)
bytesRead DWORD ?

.code
mov   edx,OFFSET buffer         ; points to buffer
mov   ecx,BUFFER_SIZE           ; max bytes to read
call  ReadFromFile              ; read the file
```

If the Carry flag were clear at this point, you could execute the following instruction:

```
mov  bytesRead,eax              ; count of bytes actually read
```

But if the Carry flag were set, you would call WriteWindowsMsg procedure, which displays a string that contains the error code and description of the most recent error generated by the application:

```
call  WriteWindowsMsg
```

ReadHex The ReadHex procedure reads a 32-bit hexadecimal integer from the keyboard and returns the corresponding binary value in EAX. No error checking is performed for invalid characters. You can use both uppercase and lowercase letters for the digits A through F. A maximum of eight digits may be entered (additional characters are ignored). Leading spaces are ignored. Sample call:

```
.data
hexVal DWORD ?
.code
call ReadHex
mov  hexVal,eax
```

ReadInt The ReadInt procedure reads a 32-bit signed integer from the keyboard and returns the value in EAX. The user can type an optional leading plus or minus sign, and the rest of the number may only consist of digits. ReadInt sets the Overflow flag and display an error message if the value entered cannot be represented as a 32-bit signed integer (range: −2,147,483,648 to +2,147,483,647). The return value is calculated from all valid digits found until a nondigit character is encountered. For example, if the user enters +123ABC, the value returned is +123. Sample call:

```
.data
intVal SDWORD ?
.code
call  ReadInt
mov   intVal,eax
```

ReadKey The ReadKey procedure performs a no-wait keyboard check. In other words, it inspects the keyboard input buffer to see if a key has been pressed by the user. If no keyboard data is found, the Zero flag is set. If a keypress is found by ReadKey, the Zero flag is cleared and AL is assigned either zero or an ASCII code. If AL contains zero, the user may have pressed a special key (function key, arrow key, etc.) The AH register contains a virtual scan code, DX

contains a virtual key code, and EBX contains the keyboard flag bits. The following pseudocode describes the various outcomes when calling ReadKey:

```
if no_keyboard_data then
   ZF = 1
else
   ZF = 0
   if AL = 0 then
     extended key was pressed, and AH = scan code, DX = virtual
        key code, and EBX =  keyboard flag bits
   else
     AL = the key's ASCII code
   endif
endif
```

The upper halves of EAX and EDX are overwritten when ReadKey is called.

ReadString The ReadString procedure reads a string from the keyboard, stopping when the user presses the Enter key. Pass the offset of a buffer in EDX and set ECX to the maximum number of characters the user can enter, plus 1 (to save space for the terminating null byte). The procedure returns the count of the number of characters typed by the user in EAX. Sample call:

```
.data
buffer BYTE 21 DUP(0)          ; input buffer
byteCount DWORD ?              ; holds counter
.code
mov   edx,OFFSET buffer        ; point to the buffer
mov   ecx,SIZEOF buffer        ; specify max characters
call  ReadString               ; input the string
mov   byteCount,eax            ; number of characters
```

ReadString automatically inserts a null terminator in memory at the end of the string. The following is a hexadecimal and ASCII dump of the first 8 bytes of **buffer** after the user has entered the string "ABCDEFG":

```
41 42 43 44 45 46 47 00        ABCDEFG
```

The variable **byteCount** equals 7.

SetTextColor The SetTextColor procedure *(Irvine32 library only)* sets the foreground and background colors for text output. When calling SetTextColor, assign a color attribute to EAX. The following predefined color constants can be used for both foreground and background:

black = 0	red = 4	gray = 8	lightRed = 12
blue = 1	magenta = 5	lightBlue = 9	lightMagenta = 13
green = 2	brown = 6	lightGreen = 10	yellow = 14
cyan = 3	lightGray = 7	lightCyan = 11	white = 15

Color constants are defined in the *Irvine32.inc* file. To get a complete color byte value, multiply the background color by 16 and add it to the foreground color. The following constant, for example, indicates yellow characters on a blue background:

```
yellow + (blue * 16)
```

The following statements set the color to white on a blue background:

```
mov   eax,white + (blue * 16)  ; white on blue
call  SetTextColor
```

An alternative way to express color constants is to use the SHL operator. You shift the background color leftward by 4 bits before adding it to the foreground color.

```
yellow + (blue SHL 4)
```

The bit shifting is performed at assembly time, so it can only have constant operands. In Chapter 7, you will learn how to shift integers at runtime. You can find a detailed explanation of video attributes in Section 16.3.2.

Str_length The Str_length procedure returns the length of a null-terminated string. Pass the string's offset in EDX. The procedure returns the string's length in EAX. Sample call:

```
.data
buffer BYTE "abcde",0
bufLength DWORD ?
.code
mov   edx,OFFSET buffer         ; point to string
call  Str_length                ; EAX = 5
mov   bufLength,eax             ; save length
```

WaitMsg The WaitMsg procedure displays the message "Press any key to continue. . ." and waits for the user to press a key. This procedure is useful when you want to pause the screen display before data scrolls off and disappears. It has no input parameters. Sample call:

```
call  WaitMsg
```

WriteBin The WriteBin procedure writes an integer to the console window in ASCII binary format. Pass the integer in EAX. The binary bits are displayed in groups of four for easy reading. Sample call:

```
mov   eax,12346AF9h
call  WriteBin
```

The following output would be displayed by our sample code:

```
0001 0010 0011 0100 0110 1010 1111 1001
```

WriteBinB The WriteBinB procedure writes a 32-bit integer to the console window in ASCII binary format. Pass the value in the EAX register and let EBX indicate the display size in bytes (1, 2, or 4). The bits are displayed in groups of four for easy reading. Sample call:

```
mov   eax,00001234h
mov   ebx,TYPE WORD             ; 2 bytes
call  WriteBinB                 ; displays 0001 0010 0011 0100
```

WriteChar The WriteChar procedure writes a single character to the console window. Pass the character (or its ASCII code) in AL. Sample call:

```
mov   al,'A'
call  WriteChar                ; displays: "A"
```

WriteDec The WriteDec procedure writes a 32-bit unsigned integer to the console window in decimal format with no leading zeros. Pass the integer in EAX. Sample call:

```
mov   eax,295
call  WriteDec                 ; displays: "295"
```

WriteHex The WriteHex procedure writes a 32-bit unsigned integer to the console window in 8-digit hexadecimal format. Leading zeros are inserted if necessary. Pass the integer in EAX. Sample call:

```
mov   eax,7FFFh
call  WriteHex                 ; displays: "00007FFF"
```

WriteHexB The WriteHexB procedure writes a 32-bit unsigned integer to the console window in hexadecimal format. Leading zeros are inserted if necessary. Pass the integer in EAX and let EBX indicate the display format in bytes (1, 2, or 4). Sample call:

```
mov   eax,7FFFh
mov   ebx,TYPE WORD            ; 2 bytes
call  WriteHexB                ; displays: "7FFF"
```

WriteInt The WriteInt procedure writes a 32-bit signed integer to the console window in decimal format with a leading sign and no leading zeros. Pass the integer in EAX. Sample call:

```
mov   eax,216543
call  WriteInt                 ; displays: "+216543"
```

WriteString The WriteString procedure writes a null-terminated string to the console window. Pass the string's offset in EDX. Sample call:

```
.data
prompt BYTE "Enter your name: ",0
.code
mov   edx,OFFSET prompt
call  WriteString
```

WriteToFile The WriteToFile procedure writes the contents of a buffer to an output file. Pass it a valid file handle in EAX, the offset of the buffer in EDX, and the number of bytes to write in ECX. When the procedure returns, if EAX is greater than zero, it contains a count of the number of bytes written; otherwise, an error occurred. The following code calls WriteToFile:

```
BUFFER_SIZE = 5000
.data
fileHandle   DWORD ?
buffer       BYTE BUFFER_SIZE DUP(?)
```

```
.code
mov  eax,fileHandle
mov  edx,OFFSET buffer
mov  ecx,BUFFER_SIZE
call WriteToFile
```

The following pseudocode describes how to handle the value returned in EAX after calling WriteToFile:

```
if EAX = 0 then
   error occurred when writing to file
   call WriteWindowsMessage to see the error
else
   EAX = number of bytes written to the file
endif
```

WriteWindowsMsg The WriteWindowsMsg procedure writes a string containing the most recent error generated by your application to the Console window when executing a call to a system function. Sample call:

```
call WriteWindowsMsg
```

The following is an example of a message string:

```
Error 2: The system cannot find the file specified.
```

5.4.4 Library Test Programs

Tutorial: Library Test #1

In this hands-on tutorial, you will write a program that demonstrates integer input–output with screen colors.

Step 1: Begin the program with a standard heading:

```
; Library Test #1: Integer I/O (InputLoop.asm)

; Tests the Clrscr, Crlf, DumpMem, ReadInt, SetTextColor,
; WaitMsg, WriteBin, WriteHex, and WriteString procedures.
INCLUDE Irvine32.inc
```

Step 2: Declare a **COUNT** constant that will determine the number of times the program's loop repeats later on. Then two constants, **BlueTextOnGray** and **DefaultColor**, are defined here so they can be used later on when we change the console window colors. The color byte stores the background color in the upper 4 bits, and the foreground (text) color in the lower 4 bits. We have not yet discussed bit shifting instructions, but you can multiply the background color by 16 to shift it into the high 4 bits of the color attribute byte:

```
.data
COUNT = 4
BlueTextOnGray = blue + (lightGray * 16)
DefaultColor = lightGray + (black * 16)
```

Step 3: Declare an array of signed doubleword integers, using hexadecimal constants. Also, add a string that will be used as prompt when the program asks the user to input an integer:

```
arrayD SDWORD 12345678h,1A4B2000h,3434h,7AB9h
prompt BYTE "Enter a 32-bit signed integer: ",0
```

Step 4: In the code area, declare the main procedure and write code that initializes ECX to blue text on a light gray background. The **SetTextColor** method changes the foreground and background color attributes of all text written to the window from this point onward in the program's execution:

```
.code
main PROC
     mov   eax,BlueTextOnGray
     call  SetTextColor
```

In order to set the background of the console window to the new color, you must use the Clrscr procedure to clear the screen:

```
     call  Clrscr                      ; clear the screen
```

Next, the program will display a range of doubleword values in memory, identified by the variable named **arrayD**. The DumpMem procedure requires parameters to be passed in the ESI, EBX, and ECX registers.

Step 5: Assign to ESI the offset of **arrayD**, which marks the beginning of the range we wish to display:

```
     mov   esi,OFFSET arrayD
```

Step 6: EBX is assigned an integer value that specifies the size of each array element. Since we are displaying an array of doublewords, EBX equals 4. This is the value returned by the expression TYPE arrayD:

```
     mov   ebx,TYPE arrayD             ; doubleword = 4 bytes
```

Step 7: ECX must be set to the number of units that will be displayed, using the LENGTHOF operator. Then, when DumpMem is called, it has all the information it needs:

```
     mov   ecx,LENGTHOF arrayD  ; number of units in arrayD
     call  DumpMem              ; display memory
```

The following figure shows the type of output that would be generated by DumpMem:

```
Dump of offset 00405000
------------------------------
12345678  1A4B2000  00003434  00007AB9
```

Next, the user will be asked to input a sequence of four signed integers. After each integer is entered, it is redisplayed in signed decimal, hexadecimal, and binary.

Step 8: Output a blank line by calling the Crlf procedure. Then, initialize ECX to the constant value COUNT so ECX can be the counter for the loop that follows:

```
call  Crlf
mov   ecx,COUNT
```

Step 9: We need to display a string that asks the user to enter an integer. Assign the offset of the string to EDX, and call the WriteString procedure. Then, call the ReadInt procedure to receive input from the user. The value the user enters will be automatically stored in EAX:

```
L1: mov   edx,OFFSET prompt
    call  WriteString
    call  ReadInt                    ; input integer into EAX
    call  Crlf                       ; display a newline
```

Step 10: Display the integer stored in EAX in signed decimal format by calling the WriteInt procedure. Then call Crlf to move the cursor to the next output line:

```
    call  WriteInt                   ; display in signed decimal
    call  Crlf
```

Step 11: Display the same integer (still in EAX) in hexadecimal and binary formats, by calling the WriteHex and WriteBin procedures:

```
    call  WriteHex                   ; display in hexadecimal
    call  Crlf
    call  WriteBin                   ; display in binary
    call  Crlf
    call  Crlf
```

Step 12: You will insert a Loop instruction that allows the loop to repeat at Label L1. This instruction first decrements ECX, and then jumps to label L1 only if ECX is not equal to zero:

```
    Loop  L1                         ; repeat the loop
```

Step 13: After the loop ends, we want to display a "Press any key…" message and then pause the output and wait for a key to be pressed by the user. To do this, we call the WaitMsg procedure:

```
    call  WaitMsg                    ; "Press any key..."
```

Step 14: Just before the program ends, the console window attributes are returned to the default colors (light gray characters on a black background).

```
    mov   eax, DefaultColor
    call  SetTextColor
    call  Clrscr
```

Here are the closing lines of the program:

```
    exit
main ENDP
END main
```

The remainder of the program's output is shown in the following figure, using four sample integers entered by the user:

```
Enter a 32-bit signed integer: -42

-42
FFFFFFD6
1111 1111 1111 1111 1111 1111 1101 0110

Enter a 32-bit signed integer: 36

+36
00000024
0000 0000 0000 0000 0000 0000 0010 0100

Enter a 32-bit signed integer: 244324

+244324
0003BA64
0000 0000 0000 0011 1011 1010 0110 0100

Enter a 32-bit signed integer: -7979779

-7979779
FF863CFD
1111 1111 1000 0110 0011 1100 1111 1101
```

A complete listing of the program appears below, with a few added comment lines:

```
; Library Test #1: Integer I/O   (InputLoop.asm)

; Tests the Clrscr, Crlf, DumpMem, ReadInt, SetTextColor,
; WaitMsg, WriteBin, WriteHex, and WriteString procedures.

include Irvine32.inc

.data
COUNT = 4
BlueTextOnGray = blue + (lightGray * 16)
DefaultColor = lightGray + (black * 16)
arrayD SDWORD 12345678h,1A4B2000h,3434h,7AB9h
prompt BYTE "Enter a 32-bit signed integer: ",0

.code
main PROC

; Select blue text on a light gray background

    mov   eax,BlueTextOnGray
    call  SetTextColor
    call  Clrscr                    ; clear the screen

    ; Display an array using DumpMem.

    mov   esi,OFFSET arrayD         ; starting OFFSET
    mov   ebx,TYPE arrayD           ; doubleword = 4 bytes
    mov   ecx,LENGTHOF arrayD       ; number of units in arrayD
   call   DumpMem                   ; display memory
```

```
    ; Ask the user to input a sequence of signed integers
    call  Crlf                      ; new line
    mov   ecx,COUNT
L1: mov   edx,OFFSET prompt
    call  WriteString
    call  ReadInt                   ; input integer into EAX
    call  Crlf                      ; new line
; Display the integer in decimal, hexadecimal, and binary
    call  WriteInt                  ; display in signed decimal
    call  Crlf
    call  WriteHex                  ; display in hexadecimal
    call  Crlf
    call  WriteBin                  ; display in binary
    call  Crlf
    call  Crlf
    Loop  L1                        ; repeat the loop
; Return the console window to default colors
    call  WaitMsg                   ; "Press any key..."
    mov   eax,DefaultColor
    call  SetTextColor
    call  Clrscr
    exit
main ENDP
END main
```

Library Test #2: Random Integers

Let's look at a second library test program that demonstrates random-number-generation capabilities of the link library, and introduces the CALL instruction (to be covered fully in Section 5.5). First, it randomly generates 10 unsigned integers in the range 0 to 4,294,967,294. Next, it generates 10 signed integers in the range −50 to +49:

```
; Link Library Test #2 (TestLib2.asm)
; Testing the Irvine32 Library procedures.
include Irvine32.inc
TAB = 9                         ; ASCII code for Tab
.code
main PROC
    call  Randomize             ; init random generator
    call  Rand1
    call  Rand2
    exit
main ENDP
Rand1 PROC
; Generate ten pseudo-random integers.
    mov   ecx,10                ; loop 10 times
L1: call  Random32              ; generate random int
```

```
    call  WriteDec              ; write in unsigned decimal
    mov   al,TAB                ; horizontal tab
    call  WriteChar             ; write the tab
    loop  L1

    call  Crlf
    ret
Rand1 ENDP

Rand2 PROC
; Generate ten pseudo-random integers from -50 to +49
    mov   ecx,10                ; loop 10 times

L1: mov   eax,100               ; values 0-99
    call  RandomRange           ; generate random int
    sub   eax,50                ; values -50 to +49
    call  WriteInt              ; write signed decimal
    mov   al,TAB                ; horizontal tab
    call  WriteChar             ; write the tab
    loop  L1

    call  Crlf
    ret
Rand2 ENDP
END main
```

Here is sample output from the program:

```
3221236194   2210931702   974700167   367494257   2227888607
926772240    506254858    1769123448  2288603673  736071794
-34   +27   +38   -34   +31   -13   -29   +44   -48   -43
```

Library Test #3: Performance Timing

Assembly language is often used to optimize sections of code seen as critical to a program's performance. The *GetMseconds* procedure from the book's library returns the number of milliseconds elapsed since midnight. In our third library test program, we call *GetMseconds*, execute a nested loop, and call *GetMSeconds* a second time. The difference between the two values returned by these procedure calls gives us the elapsed time of the nested loop:

```
; Link Library Test #3          (TestLib3.asm)

; Calculate the elapsed execution time of a nested loop

include Irvine32.inc

.data
OUTER_LOOP_COUNT = 3
startTime DWORD ?
msg1 byte "Please wait...",0dh,0ah,0
msg2 byte "Elapsed milliseconds: ",0

.code
```

```
main PROC
     mov   edx,OFFSET msg1      ; "Please wait..."
     call  WriteString

; Save the starting time

     call  GetMSeconds
     mov   startTime,eax

; Start the outer loop

     mov   ecx,OUTER_LOOP_COUNT

L1:  call  innerLoop
     loop  L1

; Calculate the elapsed time

     call  GetMSeconds
     sub   eax,startTime

; Display the elapsed time

     mov   edx,OFFSET msg2      ; "Elapsed milliseconds: "
     call  WriteString
     call  WriteDec             ; write the milliseconds
     call  Crlf

     exit
main ENDP

innerLoop PROC
     push  ecx                  ; save current ECX value

     mov   ecx,0FFFFFFFh        ; set the loop counter
L1:  mul   eax                  ; use up some cycles
     mul   eax
     mul   eax
     loop  L1                   ; repeat the inner loop

     pop   ecx                  ; restore ECX's saved value
     ret
innerLoop ENDP

END main
```

Here is sample output from the program running on an Intel Core Duo processor:

```
Please wait....

Elapsed milliseconds: 4974
```

Detailed Analysis of the Program

Let us study Library Test #3 in greater detail. The *main* procedure displays the string "Please wait…" in the console window:

```
main PROC
     mov   edx,OFFSET msg1      ; "Please wait..."
     call  WriteString
```

When *GetMSeconds* is called, it returns the number of milliseconds that have elapsed since midnight into the EAX register. This value is saved in a variable for later use:

```
call  GetMSeconds
mov   startTime,eax
```

Next, we create a loop that executes based on the value of the OUTER_LOOP_COUNT constant. That value is moved to ECX for use later in the LOOP instruction:

```
mov   ecx,OUTER_LOOP_COUNT
```

The loop begins with label L1, where the *innerLoop* procedure is called. This CALL instruction repeats until ECX is decremented down to zero:

```
L1: call  innerLoop
    loop  L1
```

The **innerLoop** procedure uses an instruction named PUSH to save ECX on the stack before setting it to a new value. (We will discuss PUSH and POP in the upcoming Section 5.4.) Then, the loop itself has a few instructions designed to use up clock cycles:

```
innerLoop PROC
    push ecx                        ; save current ECX value
    mov   ecx,0FFFFFFFh             ; set the loop counter
L1: mul   eax                       ; use up some cycles
    mul   eax
    mul   eax
    loop  L1                        ; repeat the inner loop
```

The LOOP instruction will have decremented ECX down to zero at this point, so we pop the saved value of ECX off the stack. It will now have the same value on leaving this procedure that it had when entering. The PUSH and POP sequence is necessary because the *main* procedure was using ECX as a loop counter when it called the *innerLoop* procedure. Here are the last few lines of *innerLoop:*

```
    pop   ecx                       ; restore ECX's saved value
    ret
innerLoop ENDP
```

Back in the *main* procedure, after the loop finishes, we call GetMSeconds, which returns its result in EAX. All we have to do is subtract the starting time from this value to get the number of milliseconds that elapsed between the two calls to GetMSeconds:

```
call  GetMSeconds
sub   eax,startTime
```

The program displays a new string message, and then displays the integer in EAX that represents the number of elapsed milliseconds:

```
    mov   edx,OFFSET msg2           ; "Elapsed milliseconds: "
    call  WriteString
    call  WriteDec                  ; display the value in EAX
    call  Crlf
    exit
main ENDP
```

5.4.5 Section Review

1. Which procedure in the link library generates a random integer within a selected range?
2. Which procedure in the link library displays "Press [Enter] to continue. . ." and waits for the user to press the Enter key?
3. Write statements that cause a program to pause for 700 milliseconds.
4. Which procedure from the link library writes an unsigned integer to the console window in decimal format?
5. Which procedure from the link library places the cursor at a specific console window location?
6. Write the INCLUDE directive that is required when using the Irvine32 library.
7. What types of statements are inside the *Irvine32.inc* file?
8. What are the required input parameters for the DumpMem procedure?
9. What are the required input parameters for the ReadString procedure?
10. Which processor status flags are displayed by the DumpRegs procedure?
11. *Challenge:* Write statements that prompt the user for an identification number and input a string of digits into an array of bytes.

5.5 64-Bit Assembly Programming

5.5.1 The *Irvine64* Library

Our book provides a minimal library to assist you with 64-bit programming, containing the following procedures:

- **Crlf**: Writes an end-of-line sequence to the console.
- **Random64**: Generates a 64-bit pseudorandom integer in the range 0 to $2^{64}-1$. The random value is returned in the RAX register.
- **Randomize**: Seeds the random number generator with a unique value.
- **ReadInt64**: Reads a 64-bit signed integer from the keyboard, terminated by the Enter key. It returns the integer value in the RAX register.
- **ReadString**: Reads a string from the keyboard, terminated by the Enter key. Pass it the offset of the input buffer in RDX, and set RCX to the maximum number of characters the user can enter, plus 1 (for the null terminator byte). It returns a count (in RAX) of the number of characters typed by the user.
- **Str_compare:** Compares two strings. Pass it a pointer to the source string in RSI, and a pointer to the target string in RDI. Sets the Zero and Carry flags in the same way as the CMP (Compare) instruction.
- **Str_copy:** Copies a source string to the location indicated by a target pointer. Pass the source offset in RSI, and the target offset in RDI.
- **Str_length:** Returns the length of a null-terminated string in the RAX register. Pass it the string's offset in RCX.
- **WriteInt64**: Displays the contents of the RAX register as a 64-bit signed decimal integer, with a leading plus or minus sign. It has no return value.

- **WriteHex64**: Displays the contents of the RAX register as a 64-bit hexadecimal integer. It has no return value.
- **WriteHexB**: Displays the contents of the RAX register as a hexadecimal integer in either a 1-byte, 2-byte, 4-byte, or 8-byte format. Pass it the display size (1, 2, 4, or 8) in the RBX register. It has no return value.
- **WriteString**: Displays a null-terminated ASCII string. Pass it the string's 64-bit offset in RDX. It has no return value.

Although this library is much smaller than our 32-bit library, it contains many of the essential tools you need for making programs more interactive. You are also encouraged to expand this library with your own code as you progress through the book. The *Irvine64* library preserves the values of the RBX, RBP, RDI, RSI, R12, R14, R14, and R15 registers. On the other hand, the RAX, RCX, RDX, R8, R9, R10, and R11 register values are usually not preserved.

5.5.2 Calling 64-Bit Subroutines

If you want to call a subroutine you have created, or a subroutine in the *Irvine64* library, all you have to do is place input parameters in registers and execute the CALL instruction. For example:

```
mov    rax,12345678h
call   WriteHex64
```

There's one other small thing you have to do, which is to use the PROTO directive at the top of your program to identify each procedure you plan to call that's outside your own program:

```
ExitProcess   PROTO      ; located in the Windows API
WriteHex64    PROTO      ; located in the Irvine64 library
```

5.5.3 The x64 Calling Convention

Microsoft follows a consistent scheme for passing parameters and calling procedures in 64-bit programs known as the *Microsoft x64 Calling Convention*. This convention is used by C/C++ compilers, as well as by the Windows Application Programming Interface (API). The only times you need to use this calling convention is when you either call a function in the Windows API, or you call a function written in C or C++. Here are some of the basic characteristics of this calling convention:

1. The CALL instruction subtracts 8 from the RSP (stack pointer) register, since addresses are 64-bits long.
2. The first four parameters passed to a procedure are placed in the RCX, RDX, R8, and R9, registers, in that order. If only one parameter is passed, it will be placed in RCX. If there is a second parameter, it will be placed in RDX, and so on. Additional parameters are pushed on the stack, in left-to-right order.
3. It is the caller's responsibility to allocate at least 32 bytes of *shadow space* on the runtime stack, so the called procedures can optionally save the register parameters in this area.
4. When calling a subroutine, the stack pointer (RSP) must be aligned on a 16-byte boundary (a multiple of 16). The CALL instruction pushes an 8-byte return address on the stack, so the calling program must subtract 8 from the stack pointer, in addition to the 32 it already subtracts for the shadow space. We will soon show how this is done in a sample program.

The remaining details about the x64 calling convention will be introduced in Chapter 8, when we discuss the runtime stack in greater detail. Here's the good news: you do not have to use the Microsoft x64 calling convention when calling subroutines in the *Irvine64* library. You only need to use it when calling Windows API functions.

5.5.4 Sample Program that Calls a Procedure

Let's create a short program that uses the Microsoft x64 calling convention to call a subroutine named **AddFour**. This subroutine adds the values in the four parameter registers (RCX, RDX, R8, and R9) and saves the sum in RAX. Because procedures normally return integer values in RAX, the calling program expects that value to be in this register when the subroutine returns. In this way, we can say that the subroutine is a function, because it receives four inputs and (deterministically) produces a single output.

```
 1: ; Calling a subroutine in 64-bit mode    (CallProc_64.asm)
 2: ; Chapter 5 example
 3:
 4: ExitProcess PROTO
 5: WriteInt64 PROTO          ; Irvine64 library
 6: Crlf PROTO                ; Irvine64 library
 7:
 8: .code
 9: main PROC
10:    sub  rsp,8             ; align the stack pointer
11:    sub  rsp,20h           ; reserve 32 bytes for shadow params
12:
13:    mov  rcx,1             ; pass four parameters, in order
14:    mov  rdx,2
15:    mov  r8,3
16:    mov  r9,4
17:    call AddFour           ; look for return value in RAX
18:    call WriteInt64        ; display the number
19:    call Crlf              ; output a CR/LF
20:
21:    mov  ecx,0
22:    call ExitProcess
23: main ENDP
24:
25: AddFour PROC
26:    mov  rax,rcx
27:    add  rax,rdx
28:    add  rax,r8
29:    add  rax,r9            ; sum is in RAX
30:    ret
31: AddFour ENDP
32:
33: END
```

Let's examine a few other details in the example: Line 10 aligns the stack pointer to an even 16-byte boundary. Why does this work? Before the OS called main, we assume the stack pointer

was aligned on a 16-byte boundary. Then, when the OS called main, the CALL instruction pushed an 8-byte return address on stack. Subtracting another 8 from the stack pointer drops it down to a multiple of 16.

You can run this program in the Visual Studio debugger and watch the RSP register (stack pointer) change values. When we did this, we saw the hexadecimal values shown graphically in Fig. 5-11. The figure shows only the lower 32 bits of each address, since the upper 32 bits contained all zeros:

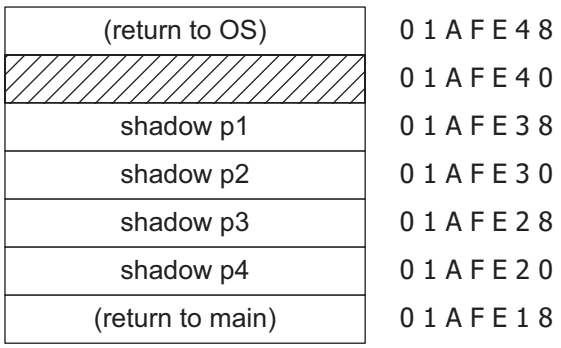
1. Before line 10 executed, RSP = 01AFE48. This tells us that RSP was equal to 01AFE50 before the OS called our program. (The CALL instruction subtracts 8 from the stack pointer.)
2. After line 10 executed, RSP = 01AFE40, showing that the stack was properly aligned on a 16-byte boundary.
3. After line 11 executed, RSP = 01AFE20, showing that 32 bytes of shadow space were reserved at addresses 01AFE20 through 01AFE3F.
4. Inside the AddFour procedure, RSP = 01AFE18, showing that the caller's return address had been pushed on the stack.
5. After AddFour returned, RSP again was equal to 01AFE20, the same value it had before calling AddFour.

Rather than calling ExitProcess to end the program, we might have chosen to execute a RET instruction, which would return to the process that launched our program. It would require, however, that we restore the stack pointer to the way it was when the **main** procedure began to execute. The following lines would be the replacement for lines 21–22 of the CallProc_64 program:

```
21:     add  rsp,28             ; restore the stack pointer
22:     mov  ecx,0              ; process return code
23:     ret                     ; return to the OS
```

> ***Tip:*** When using the Irvine64 library, add the file named *Irvine64.obj* to your Visual Studio project. To do this in Visual Studio, right-click the project name in the Solution Explorer window, select *Add*, select *Existing Item*, and select the *Irvine64.obj* filename.

Figure 5–11 Runtime stack for the CallProc_64 program.



5.6 Chapter Summary

This chapter introduces the book's link library to make it easier for you to process input–output in assembly language applications.

Table 5-1 lists most of the procedures from the Irvine32 link library. The most up-to-date listing of all procedures is available on the book's Web site (www.asmirvine.com).

The *library test program* in Section 5.4.4 demonstrates a number of input–output functions from the Irvine32 library. It generates and displays a list of random numbers, a register dump, and a memory dump. It displays integers in various formats and demonstrates string input–output.

The *runtime stack* is a special array that is used as a temporary holding area for addresses and data. The ESP register holds a 32-bit OFFSET into some location on the stack. The stack is called a LIFO structure (*last-in, first-out*) because the last value placed in the stack is the first value taken out. A *push operation* copies a value into the stack. A *pop operation* removes a value from the stack and copies it to a register or variable. Stacks often hold procedure return addresses, procedure parameters, local variables, and registers used internally by procedures.

The PUSH instruction first decrements the stack pointer and then copies a source operand into the stack. The POP instruction first copies the contents of the stack pointed to by ESP into a destination operand and then increments ESP.

The PUSHAD instruction pushes the 32-bit general-purpose registers on the stack, and the PUSHA instruction does the same for the 16-bit general-purpose registers. The POPAD instruction pops the stack into the 32-bit general-purpose registers, and the POPA instruction does the same for the 16-bit general-purpose registers. PUSHA and POPA should only be used for 16-bit programming.

The PUSHFD instruction pushes the 32-bit EFLAGS register on the stack, and POPFD pops the stack into EFLAGS. PUSHF and POPF do the same for the 16-bit FLAGS register.

The *RevStr* program (Section 5.1.2) uses the stack to reverse a string of characters.

A *procedure* is a named block of code declared using the PROC and ENDP directives. A procedure's execution ends with the RET instruction. The SumOf procedure, shown in Section 5.2.1, calculates the sum of three integers. The CALL instruction executes a procedure by inserting the procedure's address into the instruction pointer register. When the procedure finishes, the RET (return from procedure) instruction brings the processor back to the point in the program from where the procedure was called. A *nested procedure call* occurs when a called procedure calls another procedure before it returns.

A code label followed by a single colon is only visible within its enclosing procedure. A code label followed by :: is a global label, making it accessible from any statement in the same source code file.

The ArraySum procedure, shown in Section 5.2.5, calculates and returns the sum of the elements in an array.

The USES operator, coupled with the PROC directive, lets you list all registers modified by a procedure. The assembler generates code that pushes the registers at the beginning of the procedure and pops the registers before returning.

5.7 Key Terms

5.7.1 Terms

arguments
console window
file handle
global label
input parameter
label
last-in, first-out (LIFO)
link library
nested procedure call
precondition
pop operation
push operation
runtime stack
stack abstract data type
stack data structure
stack pointer register

5.7.2 Instructions, Operators, and Directives

ENDP
POP
POPA
POPAD
POPFD
PROC
PUSH
PUSHA
PUSHAD
PUSHFD
RET
USES