

Assembly Language for Intel-Based
Computers, 4th Edition

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Chapter 5: Procedures

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• [Chapter corrections](#) (Web)

[Assembly language sources](#) (Web)

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Chapter Overview

- Linking to an External Library
- The Book's Link Library
- Stack Operations
- Defining and Using Procedures
- Program Design Using Procedures

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The Book's Link Library

- Link Library Overview
- Calling a Library Procedure
- Linking to a Library
- Library Procedures – Overview
- Six Examples

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Link Library Overview

- A file containing procedures that have been compiled into machine code
 - constructed from one or more OBJ files
- To build a library, . . .
 - start with one or more ASM source files
 - assemble each into an OBJ file
 - create an empty library file (extension .LIB)
 - add the OBJ file(s) to the library file, using the Microsoft LIB utility

Take a quick look at Irvine32.asm by clicking on Examples at the bottom of this screen.

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Calling a Library Procedure

- Call a library procedure using the CALL instruction. Some procedures require input arguments. The INCLUDE directive copies in the procedure prototypes (declarations).
- The following example displays "1234" on the console:

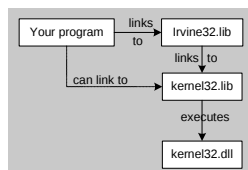
```
INCLUDE Irvine32.inc
.code
mov  eax, 1234h      ; input argument
call WriteHex        ; show hex number
call CrLf            ; end of line
```

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Linking to a Library

- Your programs link to Irvine32.lib using the linker command inside a batch file named make32.bat.
- Notice the two LIB files: Irvine32.lib, and kernel32.lib
 - the latter is part of the Microsoft Win32 Software Development Kit (SDK)



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Library Procedures - Overview (1 of 3)

Clrscr - Clears the console and locates the cursor at the upper left corner.

Crlf - Writes an end of line sequence to standard output.

Delay - Pauses the program execution for a specified *n* millisecond interval.

DumpMem - Writes a block of memory to standard output in hexadecimal.

DumpRegs - Displays the EAX, EBX, ECX, EDX, ESI, EDI, EBP, ESP, EFLAGS, and EIP registers in hexadecimal. Also displays the Carry, Sign, Zero, and Overflow flags.

GetCommandtail - Copies the program's command-line arguments (called the *command tail*) into an array of bytes.

GetMseconds - Returns the number of milliseconds that have elapsed since midnight.

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Library Procedures - Overview (2 of 3)

Gotoxy - Locates cursor at row and column on the console.

Random32 - Generates a 32-bit pseudorandom integer in the range 0 to FFFFFFFFh.

Randomize - Seeds the random number generator.

RandomRange - Generates a pseudorandom integer within a specified range.

ReadChar - Reads a single character from standard input.

ReadHex - Reads a 32-bit hexadecimal integer from standard input, terminated by the Enter key.

ReadInt - Reads a 32-bit signed decimal integer from standard input, terminated by the Enter key.

ReadString - Reads a string from standard input, terminated by the Enter key.

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Library Procedures - Overview (3 of 3)

SetTextColor - Sets the foreground and background colors of all subsequent text output to the console.

WaitMsg - Displays message, waits for Enter key to be pressed.

WriteBin - Writes an unsigned 32-bit integer to standard output in ASCII binary format.

WriteChar - Writes a single character to standard output.

WriteDec - Writes an unsigned 32-bit integer to standard output in decimal format.

WriteHex - Writes an unsigned 32-bit integer to standard output in hexadecimal format.

WriteInt - Writes a signed 32-bit integer to standard output in decimal format.

WriteString - Writes a null-terminated string to standard output.

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Example 1

Clear the screen, delay the program for 500 milliseconds, and dump the registers and flags.

```
.code
call clrscr
mov  eax,500
call Delay
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
```

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Example 2

Display a null-terminated string and move the cursor to the beginning of the next screen line.

```
.data
str1 BYTE "Assembly language is easy!",0

.code
mov  edx,OFFSET str1
call WriteString
call CrLf
```

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Example 2a

Display a null-terminated string and move the cursor to the beginning of the next screen line (use embedded CR/LF)

```
.data
str1 BYTE "Assembly language is easy!",0Dh,0Ah,0

.code
mov  edx,OFFSET str1
call WriteString
```

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Example 3

Display an unsigned integer in binary, decimal, and hexadecimal, each on a separate line.

```
IntVal = 35
.code
mov  eax,IntVal
call WriteBin      ; display binary
call CrLf
call WriteDec      ; display decimal
call CrLf
call WriteHex      ; display hexadecimal
call CrLf
```

Sample output:

```
0000 0000 0000 0000 0000 0010 0011
35
23
```

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Example 4

Input a string from the user. EDX points to the string and ECX specifies the maximum number of characters the user is permitted to enter.

```
.data
fileName BYTE 80 DUP(0)
.code
mov  edx,OFFSET fileName
mov  ecx,SIZEOF fileName - 1
call ReadString
```

A null byte is automatically appended to the string.

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Example 5

Generate and display ten pseudorandom signed integers in the range 0 – 99. Pass each integer to WriteInt in EAX and display it on a separate line.

```
.code
mov  ecx,10      ; loop counter

L1: mov  eax,100  ; ceiling value
    call RandomRange ; generate random int
    call WriteInt   ; display signed int
    call CrLf       ; goto next display line
    loop L1         ; repeat loop
```

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Example 6

Display a null-terminated string with yellow characters on a blue background.

```
.data
str1 BYTE "Color output is easy!",0

.code
mov  eax,yellow + (blue * 16)
call SetTextColor
mov  edx,OFFSET str1
call WriteString
call CrLf
```

The background color is multiplied by 16 before being added to the foreground color.

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Stack Operations

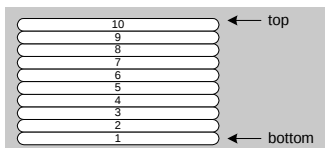
- Runtime Stack
- PUSH Operation
- POP Operation
- PUSH and POP Instructions
- Using PUSH and POP
- Example: Reversing a String
- Related Instructions

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Runtime Stack

- Imagine a stack of plates . . .
 - plates are only added to the top
 - plates are only removed from the top
 - LIFO structure

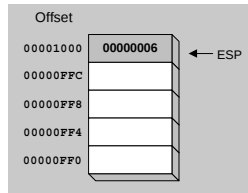


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Runtime Stack

- Managed by the CPU, using two registers
 - SS (stack segment)
 - ESP (stack pointer) *



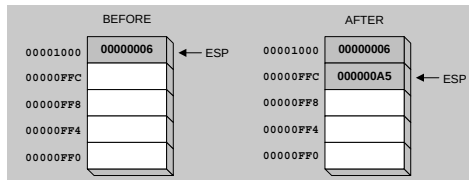
* SP in Real-address mode

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PUSH Operation (1 of 2)

- A 32-bit push operation decrements the stack pointer by 4 and copies a value into the location pointed to by the stack pointer.

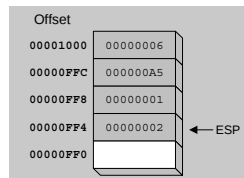


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PUSH Operation (2 of 2)

- Same stack after pushing two more integers:



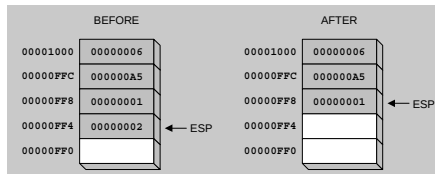
The stack grows downward. The area below ESP is always available (unless the stack has overflowed).

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POP Operation

- Copies value at stack[ESP] into a register or variable.
- Adds n to ESP, where n is either 2 or 4.
 - value of n depends on the attribute of the operand receiving the data



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PUSH and POP Instructions

- PUSH syntax:
 - PUSH $r/m16$
 - PUSH $r/m32$
 - PUSH $imm32$
- POP syntax:
 - POP $r/m16$
 - POP $r/m32$

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Using PUSH and POP

Save and restore registers when they contain important values. PUSH and POP instructions occur in the opposite order.

```
push esi           ; push registers
push ecx
push ebx

mov esi,OFFSET dwordVal ; display some memory
mov ecx,LENGTHOF dwordVal
mov ebx,TYPE dwordVal
call DumpMem

pop ebx           ; restore registers
pop ecx
pop esi
```

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Example: Nested Loop

Remember the nested loop we created on page 129? It's easy to push the outer loop counter before entering the inner loop:

```
mov ecx,100      ; set outer loop count
L1:              ; begin the outer loop
push ecx         ; save outer loop count

mov ecx,20       ; set inner loop count
L2:              ; begin the inner loop
;
;
loop L2          ; repeat the inner loop

pop ecx          ; restore outer loop count
loop L1          ; repeat the outer loop
```

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Example: Reversing a String

- Use a loop with indexed addressing
- Push each character on the stack
- Start at the beginning of the string, pop the stack in reverse order, insert each character back into the string
- [Source code](#)
- Q: Why must each character be put in EAX before it is pushed?

Because only word (16-bit) or doubleword (32-bit) values can be pushed on the stack.

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Your turn . . .

- Using the String Reverse program as a starting point,
- #1: Modify the program so the user can input a string containing between 1 and 50 characters.
- #2: Modify the program so it inputs a list of 32-bit integers from the user, and then displays the integers in reverse order.

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Related Instructions

- PUSHFD and POPFD
 - push and pop the EFLAGS register
- PUSHAD pushes the 32-bit general-purpose registers on the stack
 - order: EAX, ECX, EDX, EBX, ESP, EBP, ESI, EDI
- POPAD pops the same registers off the stack in reverse order
 - PUSHA and POPA do the same for 16-bit registers

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Your Turn . . .

- Write a program that does the following:
 - Assigns integer values to EAX, EBX, ECX, EDX, ESI, and EDI
 - Uses PUSHAD to push the general-purpose registers on the stack
 - Using a loop, your program should pop each integer from the stack and display it on the screen

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Defining and Using Procedures

- Creating Procedures
- Documenting Procedures
- Example: SumOf Procedure
- CALL and RET Instructions
- Nested Procedure Calls
- Local and Global Labels
- Procedure Parameters
- Flowchart Symbols
- USES Operator

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Creating Procedures

- Large problems can be divided into smaller tasks to make them more manageable
- A procedure is the ASM equivalent of a Java or C++ function
- Following is an assembly language procedure named sample:

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

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Documenting Procedures

Suggested documentation for each procedure:

- A description of all tasks accomplished by the procedure.
- Receives: A list of input parameters; state their usage and requirements.
- Returns: A description of values returned by the procedure.
- Requires: Optional list of requirements called preconditions that must be satisfied before the procedure is called.

If a procedure is called without its preconditions having been satisfied, the procedure's creator makes no promise that it will work.

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Example: SumOf Procedure

```
-----
SumOf PROC
;
; 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, and the status flags (Carry,
; Overflow, etc.) are changed.
; Requires: nothing
;-----
add eax,ebx
add eax,ecx
ret
SumOf ENDP
```

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CALL and RET Instructions

- The CALL instruction calls a procedure
 - pushes offset of next instruction on the stack
 - copies the address of the called procedure into EIP
- The RET instruction returns from a procedure
 - pops top of stack into EIP

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CALL-RET Example (1 of 2)

00000025 is the offset of the instruction immediately following the CALL instruction

00000040 is the offset of the first instruction inside MySub

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

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

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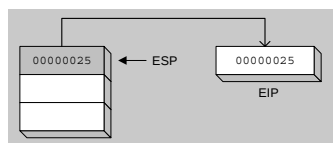
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CALL-RET Example (2 of 2)

The CALL instruction pushes 00000025 onto the stack, and loads 00000040 into EIP



The RET instruction pops 00000025 from the stack into EIP



(stack shown before RET executes)

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Nested Procedure Calls

```

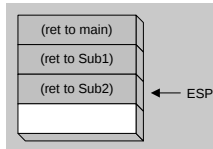
main PROC
    .
    .
    call Sub1
    exit
main ENDP

Sub1 PROC
    .
    .
    call Sub2
    ret
Sub1 ENDP

Sub2 PROC
    .
    .
    call Sub3
    ret
Sub2 ENDP

Sub3 PROC
    .
    .
    ret
Sub3 ENDP
    
```

By the time Sub3 is called, the stack contains all three return addresses:



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Local and Global Labels

A local label is visible only to statements inside the same procedure. A global label is visible everywhere.

```

main PROC
    jmp L2                ; error
L1:                       ; global label1
    exit
main ENDP

sub2 PROC
    L2:                   ; local label1
    jmp L1                ; ok
    ret
sub2 ENDP
    
```

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Procedure Parameters (1 of 3)

- A good procedure might be usable in many different programs
 - but not if it refers to specific variable names
- Parameters help to make procedures flexible because parameter values can change at runtime

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Procedure Parameters (2 of 3)

The ArraySum procedure calculates the sum of an array. It makes two references to specific variable names:

```
ArraySum PROC
    mov esi,0           ; array index
    mov eax,0           ; set the sum to zero
    mov ecx,LENGTHOF myarray ; set number of elements

L1: add eax,myArray[esi] ; add each integer to sum
    add esi,4           ; point to next integer
    loop L1             ; repeat for array size

    mov theSum,eax      ; store the sum
    ret
ArraySum ENDP
```

What if you wanted to calculate the sum of two or three arrays within the same program?

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Procedure Parameters (3 of 3)

This version of ArraySum returns the sum of any doubleword array whose address is in ESI. The sum is returned in EAX:

```
ArraySum PROC
; Receives: ESI points to an array of doublewords,
; ECX = number of array elements.
; Returns: EAX = sum
;-----
    mov eax,0           ; set the sum to zero

L1: add eax,[esi]        ; add each integer to sum
    add esi,4           ; point to next integer
    loop L1             ; repeat for array size

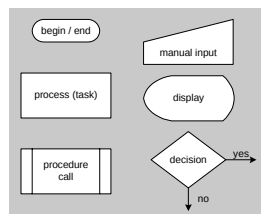
    ret
ArraySum ENDP
```

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Flowchart Symbols

- The following symbols are the basic building blocks of flowcharts:

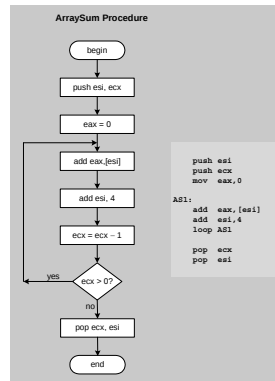


(Includes two symbols not listed on page 166 of the book.)

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Flowchart for the ArraySum Procedure



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Your turn . . .

Draw a flowchart that expresses the following pseudocode:

```

input exam grade from the user
if( grade > 70 )
    display "Pass"
else
    display "Fail"
endif

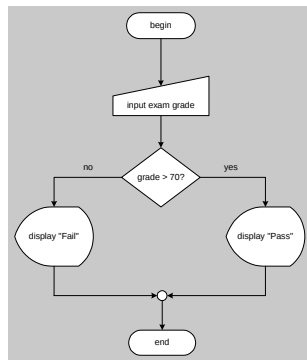
```



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. . . (Solution)



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Your turn . . .

- Modify the flowchart in the previous slide to allow the user to continue to input exam scores until a value of -1 is entered

USES Operator

- Lists the registers that will be preserved

```
ArraySum PROC USES esi ecx  
    mov eax,0          ; set the sum to zero  
    etc.
```

MASM generates the code shown in gold:

```
ArraySum PROC  
    push esi  
    push ecx  
    .  
    .  
    pop ecx  
    pop esi  
    ret  
ArraySum ENDP
```

When not to push a register

The sum of the three registers is stored in EAX on line (3), but the POP instruction replaces it with the starting value of EAX on line (4):

```
SumOf PROC          ; sum of three integers  
    push eax        ; 1  
    add eax,ebx      ; 2  
    add eax,ecx      ; 3  
    pop eax         ; 4  
    ret  
SumOf ENDP
```

Program Design Using Procedures

- Top-Down Design (functional decomposition) involves the following:
 - design your program before starting to code
 - break large tasks into smaller ones
 - use a hierarchical structure based on procedure calls
 - test individual procedures separately

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Integer Summation Program (1 of 4)

Description: Write a program that prompts the user for multiple 32-bit integers, stores them in an array, calculates the sum of the array, and displays the sum on the screen.

Main steps:

- Prompt user for multiple integers
- Calculate the sum of the array
- Display the sum

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Procedure Design (2 of 4)

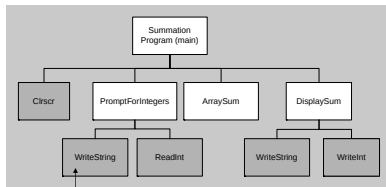
Main

```
Clrscr           ; clear screen
PromptForIntegers
    WriteString   ; display string
    ReadInt       ; input integer
ArraySum         ; sum the integers
DisplaySum
    WriteString   ; display string
    WriteInt      ; display integer
```

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Structure Chart (3 of 4)



gray indicates
library
procedure

- View the [stub program](#)
- View the [final program](#)

Sample Output (4 of 4)

```
Enter a signed integer: 550
Enter a signed integer: -23
Enter a signed integer: -96
The sum of the integers is: +431
```

The End

