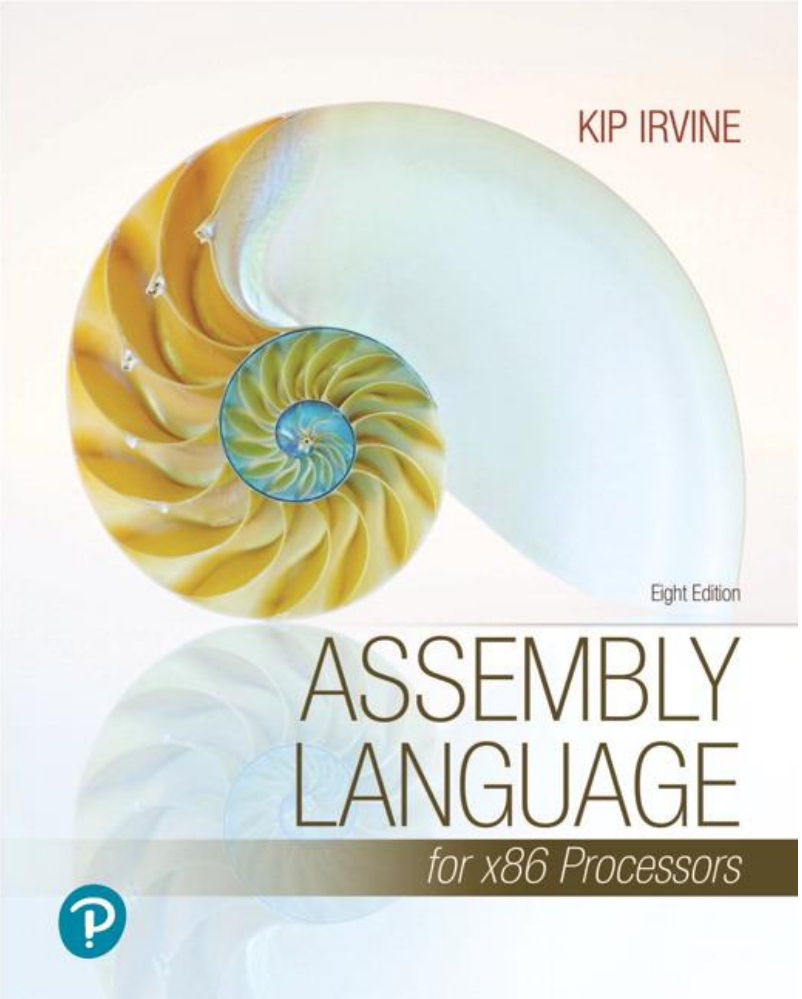
Assembly Language for x86 Processors

Eighth Edition



Chapter 5

Procedures

Slides 1-23, 61-62

Chapter Overview

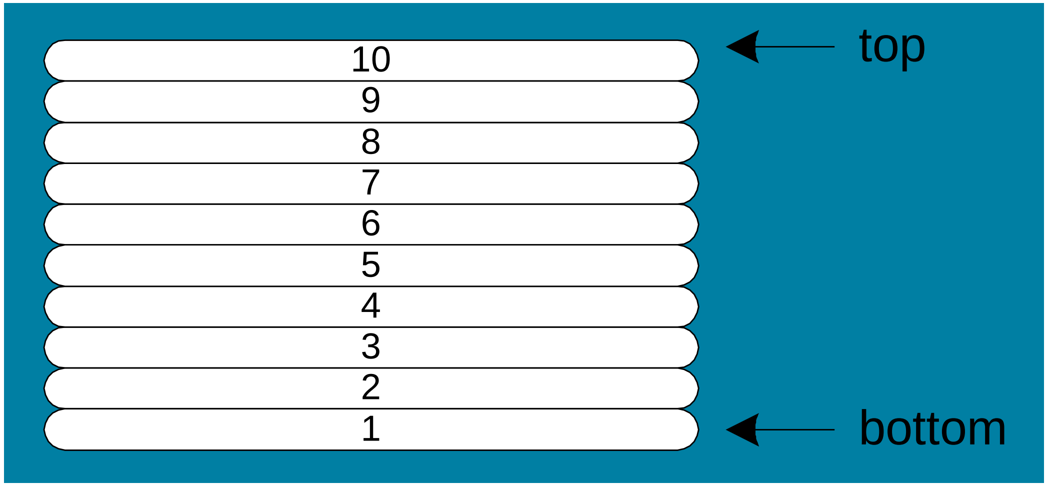
- Stack Operations
- Defining and Using Procedures
- Linking to an External Library
- The Irvine32 Library
- 64-Bit Assembly Programming

Stack Operations

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

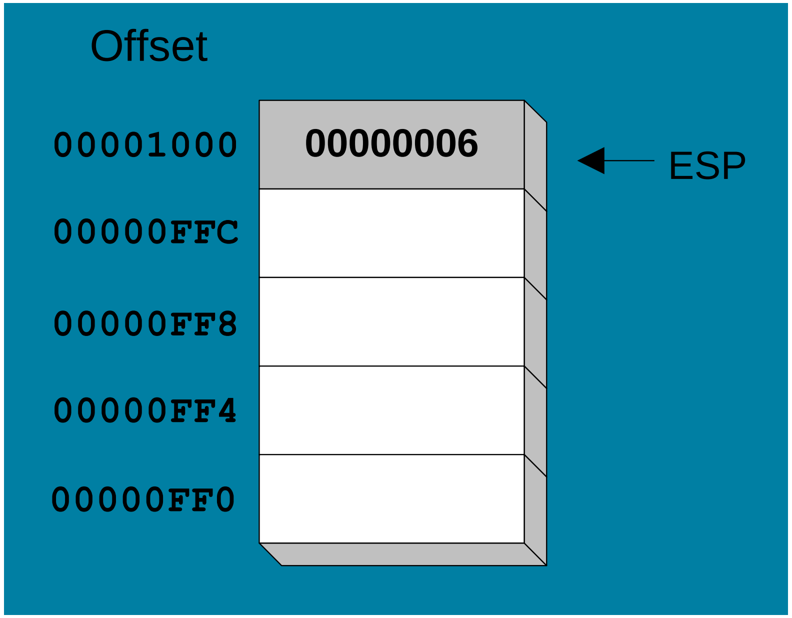
Runtime Stack (1 of 2)

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



Runtime Stack (2 of 2)

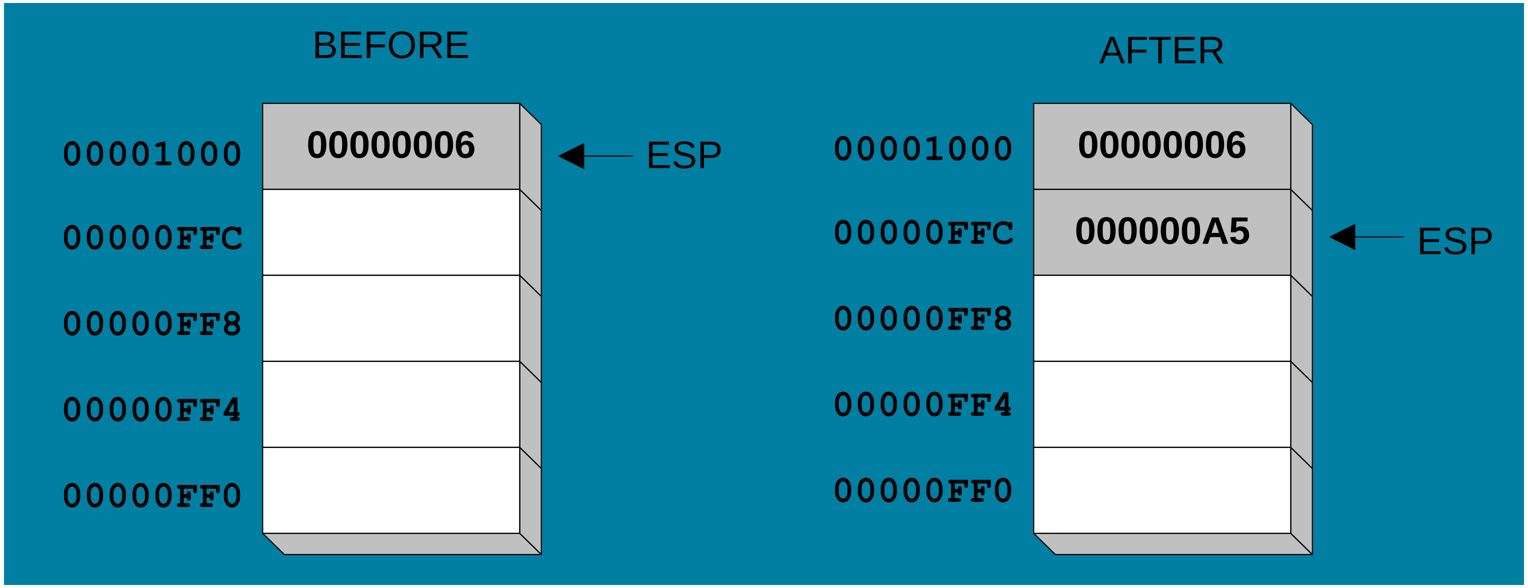
- Managed by the CPU, using two registers
  - SS (stack segment)
  - ESP (stack pointer) *



* SP in Real-address mode

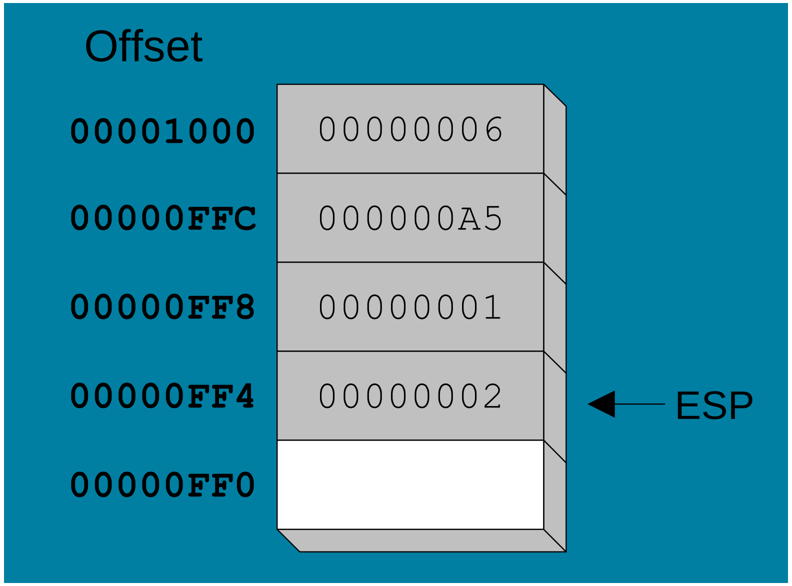
PUSH Operation (1 of 2)

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



PUSH Operation (2 of 2)

- Same stack after pushing two more integers:

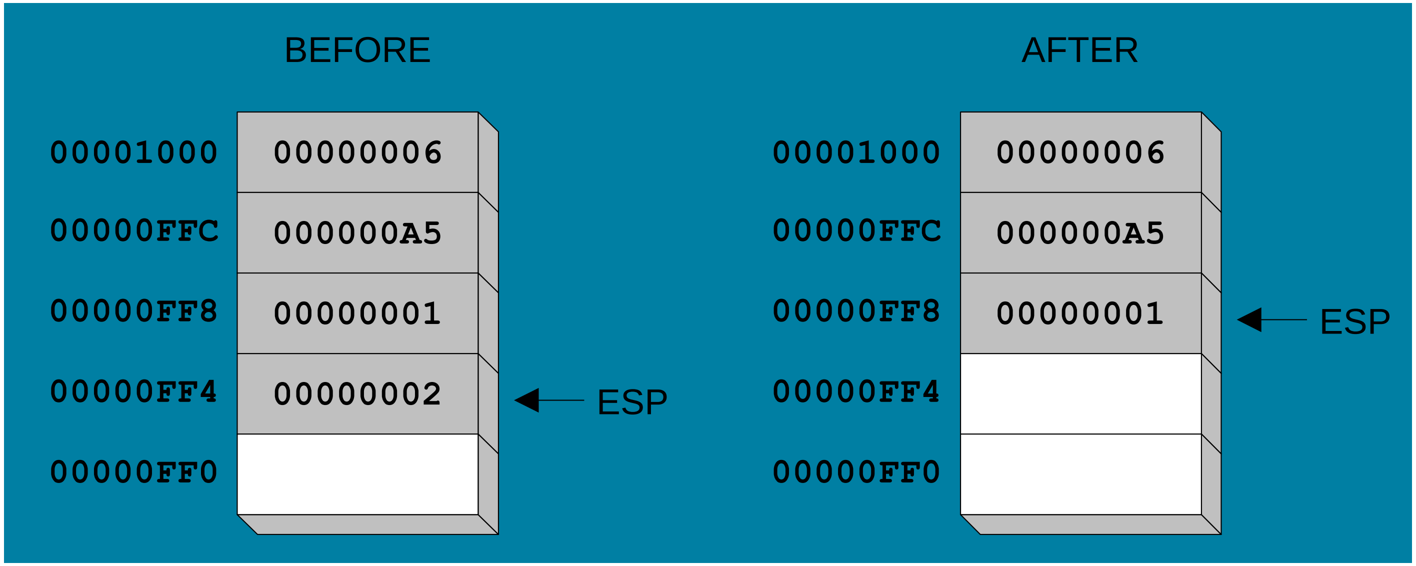


Offset		
00001000	00000006	
00000FFC	000000A5	
00000FF8	00000001	
00000FF4	00000002	← ESP
00000FF0		

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

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



BEFORE

00001000 00000006

00000FFC 000000A5

00000FF8 00000001

00000FF4 00000002 ← ESP

00000FF0

AFTER

00001000 00000006

00000FFC 000000A5

00000FF8 00000001 ← ESP

00000FF4

00000FF0

PUSH and POP Instructions

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

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
```

Example: Nested Loop

When creating a nested loop, 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
```

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.

Your Turn . . . (1 of 2)

- 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.

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

Your Turn . . . (2 of 2)

- 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

What's Next

- Stack Operations
- Defining and Using Procedures
- Linking to an External Library
- The Irvine32 Library
- 64-Bit Assembly Programming

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

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
```

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 satisfied, it will probably not produce the expected output.

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
```

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

CALL-RET Example (1 of 2)

0000025 is the offset of the instruction immediately following the CALL instruction

00000040 is the offset of the first instruction inside MySub

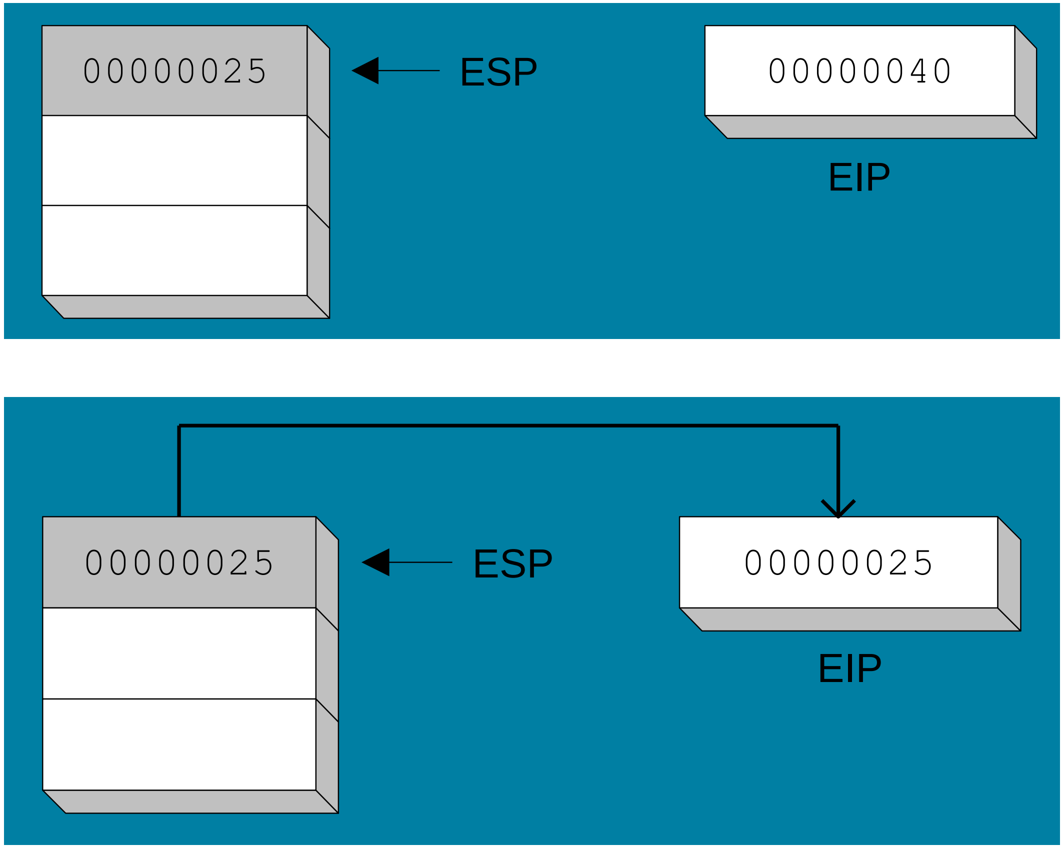
```
main PROC
     00000020 call MySub
     00000025 mov eax,ebx
     .
     .
main ENDP

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

CALL-RET Example (2 of 2)

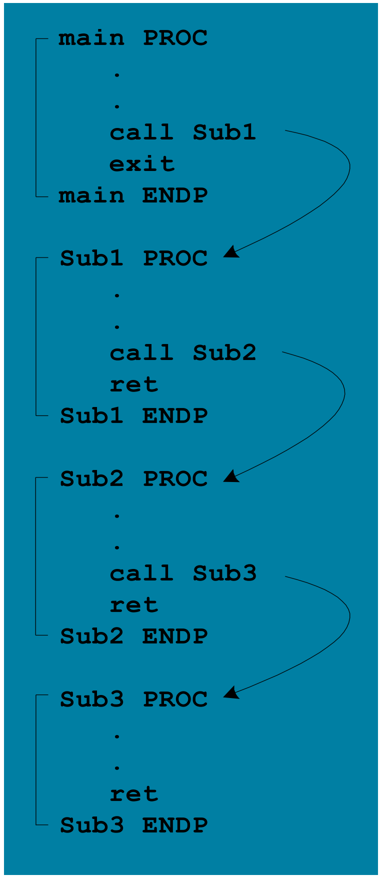
The CALL instruction pushes 00000025 onto the stack, and loads 00000040 into EIP

The RET instruction pops 00000025 from the stack into EIP



(stack shown before RET executes)

Nested Procedure Calls



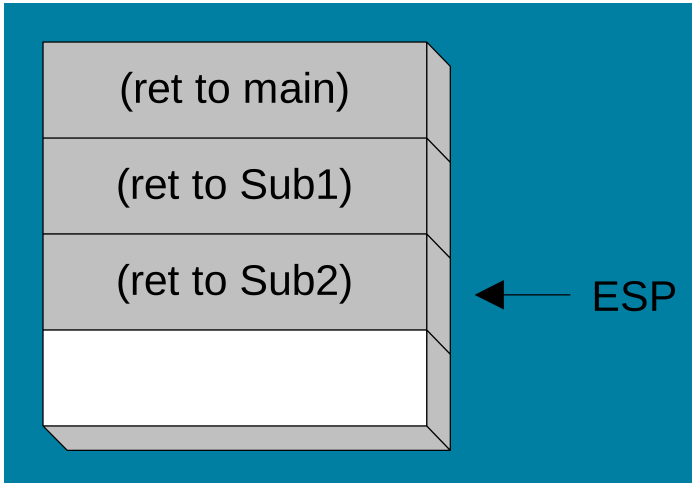
```
main PROC
    .
    .
    call Sub1
    exit
main ENDP

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:



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 label
        exit
main ENDP

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

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

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?

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
```

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 cyan:

```
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
```

What’s Next (1 of 3)

- Stack Operations
- Defining and Using Procedures
- Linking to an External Library
- The Irvine32 Library
- 64-Bit Assembly Programming

Linking to an External Library

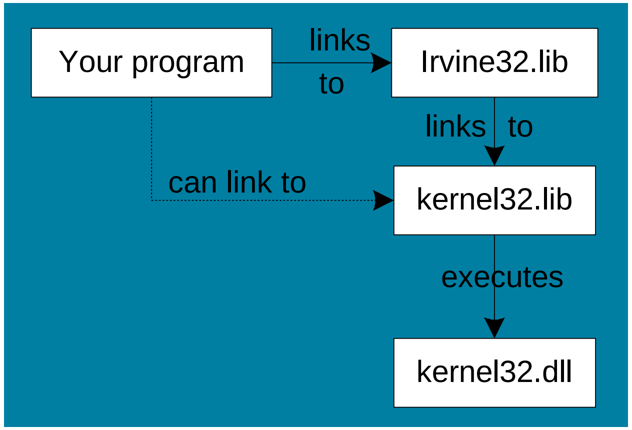
- What is a Link Library?
- How the Linker Works

What is a Link Library?

- 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

How The Linker Works

- 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)*



What’s Next (2 of 3)

- Stack Operations
- Defining and Using Procedures
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Calling Irvine32 Library Procedures

- Call each 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
```

Library Procedures - Overview (1 of 12)

CloseFile – Closes an open disk file

Clrscr – Clears console, locates cursor at upper left corner

Create OutputFile – Creates new disk file for writing in output mode

Crlf – Writes end of line sequence to standard output

Delay – Pauses program execution for *n* millisecond interval

Library Procedures - Overview (2 of 12)

DumpMem – Writes block of memory to standard output in hex

DumpRegs – Displays general-purpose registers and flags (hex)

GetCommandtail – Copies command-line args into array of bytes

GetDateTime – Gets the current date and time from the system

Library Procedures - Overview (3 of 12)

GetMaxXY – Gets number of cols, rows in console window buffer

GetMseconds – Returns milliseconds elapsed since midnight

Library Procedures - Overview (4 of 12)

GetTextColor – Returns active foreground and background text colors in the console window

Gotoxy – Locates cursor at row and column on the console

IsDigit – Sets Zero flag if AL contains ASCII code for decimal digit (0–9)

MsgBox, MsgBoxAsk – Display popup message boxes

OpenInputFile – Opens existing file for input

Library Procedures - Overview (5 of 12)

ParseDecimal32 – Converts unsigned integer string to binary

ParseInteger32 – Converts signed integer string to binary

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

Randomize – Seeds the random number generator

Library Procedures - Overview (6 of 12)

RandomRange – Generates a pseudorandom integer within a specified range

ReadChar – Reads a single character from standard input

Library Procedures - Overview (7 of 12)

ReadDec – Reads 32-bit unsigned decimal integer from keyboard

ReadFromFile – Reads input disk file into buffer

ReadHex – Reads 32-bit hexadecimal integer from keyboard

ReadInt – Reads 32-bit signed decimal integer from keyboard

ReadKey – Reads character from keyboard input buffer

Library Procedures - Overview (8 of 12)

ReadString – Reads string from stdin, terminated by [Enter]

SetTextColor – Sets foreground/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

Library Procedures - Overview (9 of 12)

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 message, waits for Enter key to be pressed

WriteBin – Writes unsigned 32-bit integer in ASCII binary format.

Library Procedures - Overview (10 of 12)

WriteBinB – Writes binary integer in byte, word, or doubleword format

WriteChar – Writes a single character to standard output

WriteDec – Writes unsigned 32-bit integer in decimal format

WriteHex – Writes an unsigned 32-bit integer in hexadecimal format

Library Procedures - Overview (11 of 12)

WriteHexB – Writes byte, word, or doubleword in hexadecimal format

WriteInt – Writes signed 32-bit integer 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.

Library Procedures - Overview (12 of 12)

WriteString – Writes null-terminated string to console window

WriteToFile – Writes buffer to output file

WriteWindowsMsg – Displays most recent error message generated by MS-Windows

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
```

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
```

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
```

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 0000 0010 0011
35
23
```

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.

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
```

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.

What’s Next (3 of 3)

- Stack Operations
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- The Irvine32 Library
- **64-Bit Assembly Programming**

64-Bit Assembly Programming

- The Irvine64 Library
- Calling 64-Bit Subroutines
- The x64 Calling Convention

The Irvine64 Library (1 of 3)

- Crlf: Writes an end-of-line sequence to the console.
- Random64: Generates a 64-bit pseudorandom integer.
- Randomize: Seeds the random number generator with a unique value.
- ReadInt64: Reads a 64-bit signed integer from the keyboard.
- ReadString: Reads a string from the keyboard.

The Irvine64 Library (2 of 3)

- Str_compare: Compares two strings in the same way as the CMP instruction.
- Str_copy: Copies a source string to a target location.
- Str_length: Returns the length of a null-terminated string in RAX.
- WriteInt64: Displays the contents in the RAX register as a 64-bit signed decimal integer.

The Irvine64 Library (3 of 3)

- WriteHex64: Displays the contents of the RAX register as a 64-bit hexadecimal integer.
- WriteHexB: Displays the contents of the RAX register as an 8-bit hexadecimal integer.
- WriteString: Displays a null-terminated ASCII string.

Calling 64-Bit Subroutines

- Place the first four parameters in registers
- Add PROTO directives at the top of your program
  - examples:

```
ExitProcess PROTO          ; located in the Windows API

WriteHex64 PROTO           ; located in the Irvine64 library
```

The x64 Calling Convention

- Must use this with the 64-bit Windows API
- CALl instruction subtracts 8 from RSP
- First four parameters must be placed in RCX, RDX, R8, and R9
- Caller must allocate at least 32 bytes of shadow space on the stack
- When calling a subroutine, the stack pointer must be aligned on a 16-byte boundary.

See the CallProc_64.asm example program.

Summary

- Procedure – named block of executable code
- Runtime stack – LIFO structure
  - holds return addresses, parameters, local variables
  - PUSH – add value to stack
  - POP – remove value from stack
- Use the Irvine32 library for all standard I/O and data conversion
  - Want to learn more? Study the library source code in the c:\Irvine\Examples\Lib32 folder

Extra

55 64 67 61 6E 67 65 6E

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