Assembly Language for Intel-Based Computers, 4th Edition

Kip R. Irvine

Chapter 8:Advanced Procedures

Chapter Overview

- Local Variables
- Stack Parameters
- Stack Frames
- Recursion
- Creating Multimodule Programs

Local Directive

- A local variable is created, used, and destroyed within a single procedure
- The LOCAL directive declares a list of local variables
  - immediately follows the PROC directive
  - each variable is assigned a type
- Syntax:

  LOCAL *varlist*

Example:

```
MySub PROC
    LOCAL var1:BYTE, var2:WORD, var3:SDWORD
```

MASM-Generated Code (1 of 2)

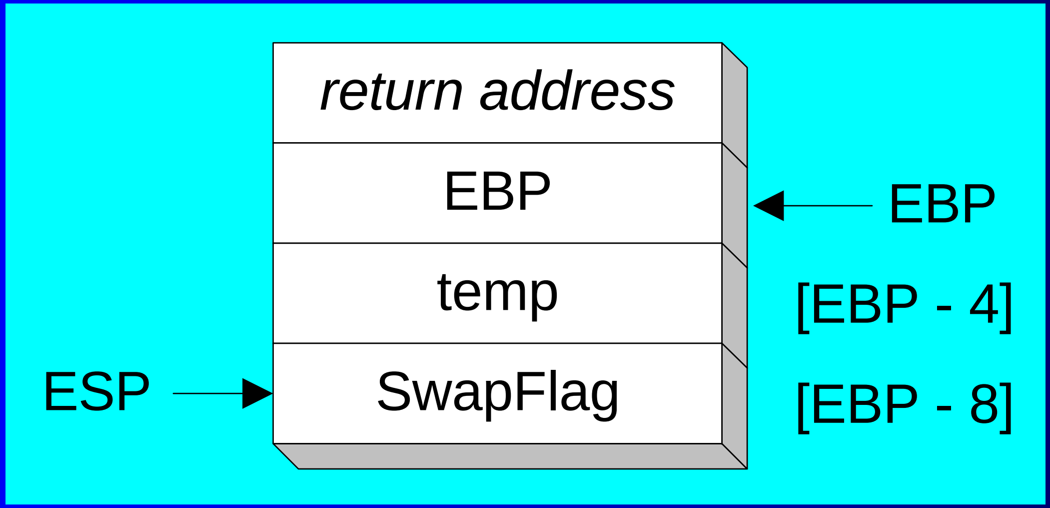
```
BubbleSort PROC
   LOCAL temp:DWORD, SwapFlag:BYTE
   . . .
   ret
BubbleSort ENDP
```

MASM generates the following code:

```
BubbleSort PROC
   push ebp
   mov  ebp,esp
   add  esp,0FFFFFFF8h        ; add -8 to ESP
   . . .
   mov  esp,ebp
   pop  ebp
   ret
BubbleSort ENDP
```

MASM-Generated Code (2 of 2)

Diagram of the stack frame for the BubbleSort procedure:



Stack Parameters

- Register vs. Stack Parameters
- INVOKE Directive
- PROC Directive
- PROTO Directive
- Passing by Value or by Reference
- Parameter Classifications
- Example: Exchanging Two Integers
- Trouble-Shooting Tips

Register vs. Stack Parameters

- Register parameters require dedicating a register to each parameter. Stack parameters are more convenient
- Imagine two possible ways of calling the DumpMem procedure. Clearly the second is easier:

```
pushad
mov esi,OFFSET array
mov ecx,LENGTHOF array
mov ebx,TYPE array
call DumpMem
popad
```

```
push OFFSET array
push LENGTHOF array
push TYPE array
call DumpMem
```

INVOKE Directive

- The INVOKE directive is a powerful replacement for Intel's CALL instruction that lets you pass multiple arguments.
- Syntax:

  INVOKE *procedureName* [, *argumentList*]

- *ArgumentList* is an optional comma-delimited list of procedure arguments
- Arguments can be:
  - immediate values and integer expressions
  - variable names
  - address and ADDR expressions
  - register names

INVOKE Examples

```
.data
byteVal BYTE 10
wordVal WORD 1000h
.code
    ; direct operands:
    INVOKE Sub1,byteVal,wordVal

    ; address of variable:
    INVOKE Sub2,ADDR byteVal

    ; register name, integer expression:
    INVOKE Sub3,eax,(10 * 20)

    ; address expression (indirect operand):
    INVOKE Sub4,[ebx]
```

ADDR Operator

- Returns a near or far pointer to a variable, depending on which memory model your program uses:
  - Small model: returns 16-bit offset
  - Large model: returns 32-bit segment/offset
  - Flat model: returns 32-bit offset
- Simple example:

```
.data
myWord WORD ?
.code
INVOKE mySub,ADDR myWord
```

PROC Directive

- The PROC directive declares a procedure with an optional list of named parameters.
- Syntax:

  label PROC paramList

- *paramList* is a list of parameters separated by commas. Each parameter has the following syntax:

  paramName:*type*

type must either be one of the standard ASM types (BYTE, SBYTE, WORD, etc.), or it can be a pointer to one of these types.

PROC Examples (1 of 3)

- The AddTwo procedure receives two integers and returns their sum in EAX.

```
AddTwo PROC,
    val1:DWORD, val2:DWORD

    mov eax,val1
    add eax,val2
    ret
AddTwo ENDP
```

PROC Examples (2 of 3)

FillArray receives a pointer to an array of bytes, a single byte fills value that will be copied to each element of the array, and the size of the array.

```
FillArray PROC,
    pArray:PTR BYTE, fillVal:BYTE
    arraySize:DWORD

    mov ecx,arraySize
    mov esi,pArray
    mov al,fillVal
L1: mov [esi],al
    inc esi
    loop L1
    ret
FillArray ENDP
```

PROC Examples (3 of 3)

```
Swap PROC,
   pValX:PTR DWORD,
   pValY:PTR DWORD
   . . .
Swap ENDP
```

```
ReadFile PROC,
   pBuffer:PTR BYTE
   LOCAL fileHandle:DWORD
   . . .
ReadFile ENDP
```

PROTO Directive

- Creates a procedure prototype
- Syntax:
  - *label* PROTO *paramList*
- Every procedure called by the INVOKE directive must have a prototype
- A complete procedure definition can also serve as its own prototype.

PROTO Directive

- Standard configuration: PROTO appears at top of the program listing, INVOKE appears in the code segment, and the procedure implementation occurs later in the program:

```
MySub PROTO             ; procedure prototype

.code
INVOKE MySub            ; procedure call


MySub PROC              ; procedure implementation
    .
    .
MySub ENDP
```

PROTO Example

- Prototype for the ArraySum procedure, showing its parameter list:

```
ArraySum PROTO,
    ptrArray:PTR DWORD,      ; points to the array
    szArray:DWORD            ; array size
```

Passing by Value

- When a procedure argument is passed by value, a copy of a 16-bit or 32-bit integer is pushed on the stack. Example:

```
.data
myData WORD 1000h
.code
main PROC
    INVOKE Sub1, myData
```

MASM generates the following code:

```
push myData
call Sub1
```

Passing by Reference

- When an argument is passed by reference, its address is pushed on the stack. Example:

```
.data
myData WORD 1000h
.code
main PROC
   INVOKE Sub1, ADDR myData
```

MASM generates the following code:

```
push OFFSET myData
call Sub1
```

Parameter Classifications

- An input parameter is data passed by a calling program to a procedure.
  - The called procedure is not expected to modify the corresponding parameter variable, and even if it does, the modification is confined to the procedure itself.
- An output parameter is created by passing a pointer to a variable when a procedure is called.
  - The procedure does not use any existing data from the variable, but it fills in a new value before it returns.
- An input-output parameter represents a value passed as input to a procedure, which the procedure may modify.
  - The same parameter is then able to return the changed data to the calling program.

Example: Exchanging Two Integers

The Swap procedure exchanges the values of two 32-bit integers. pValX and pValY do not change values, but the integers they point to are modified.

```
Swap PROC USES eax esi edi,
   pValX:PTR DWORD,         ; pointer to first integer
   pValY:PTR DWORD          ; pointer to second integer

   mov esi,pValX            ; get pointers
   mov edi,pValY
   mov eax,[esi]            ; get first integer
   xchg eax,[edi]           ; exchange with second
   mov [esi],eax            ; replace first integer
   ret
Swap ENDP
```

Trouble-Shooting Tips

- Save and restore registers when they are modified by a procedure.
  - Except a register that returns a function result
- When using INVOKE, be careful to pass a pointer to the correct data type.
  - For example, MASM cannot distinguish between a PTR DWORD argument and a PTR BYTE argument.
- Do not pass an immediate value to a procedure that expects a reference parameter.
  - Dereferencing its address will likely cause a general-protection fault.

Stack Frames

- Memory Models
- Language Specifiers
- Explicit Access to Stack Parameters
- Passing Arguments by Reference
- Creating Local Variables

Stack Frame

- Also known as an activation record
- Area of the stack set aside for a procedure's return address, passed parameters, saved registers, and local variables
- Created by the following steps:
  - Calling program pushes arguments on the stack and calls the procedure.
  - The called procedure pushes EBP on the stack, and sets EBP to ESP.
  - If local variables are needed, a constant is subtracted from ESP to make room on the stack.

Memory Models

- A program's memory model determines the number and sizes of code and data segments.
- Real-address mode supports tiny, small, medium, compact, large, and huge models.
- Protected mode supports only the flat model.

Small model: code < 64 KB, data (including stack) < 64 KB.
All offsets are 16 bits.

Flat model: single segment for code and data, up to 4 GB.
All offsets are 32 bits.

.MODEL Directive

- .MODEL directive specifies a program's memory model and model options (language-specifier).
- Syntax:

```
.MODEL memorymodel [,modeloptions]
```

- *memorymodel* can be one of the following:
  - tiny (a single segment, used by .com programs), small (one code segment and one data segment), medium (multiple code segments and a single data segment), compact (one code segment and multiple data segments), large (multiple code and data segments), huge (same as the large model, except that individual data item may be larger than a single segment), or flat (protected mode. Uses 32-bit offsets for code and data)

Language Specifiers

- *modeloptions* includes the language specifier:
  - procedure naming scheme
  - parameter passing conventions
- stdcall
  - procedure arguments pushed on stack in reverse order (right to left)
  - called procedure cleans up the stack

```
INVOKE AddTwo,5,6
```

```
push 6                    ; second argument
push 5                    ; first argument
call AddTwo
```

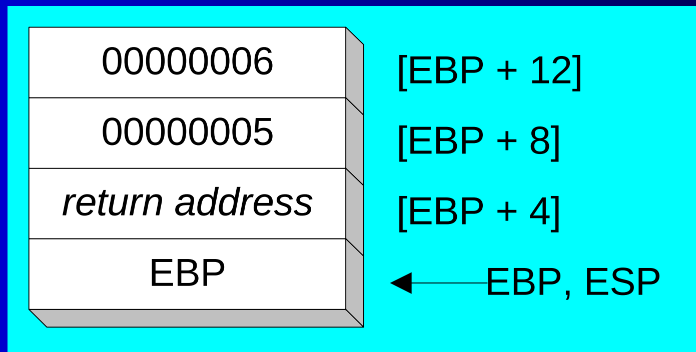
Explicit Access to Stack Parameters

- A procedure can explicitly access stack parameters using constant offsets from EBP.
  - Example: [ebp + 8]
- EBP is often called the base pointer or frame pointer because it holds the base address of the stack frame.
- EBP does not change value during the procedure.
- EBP must be restored to its original value when a procedure returns.

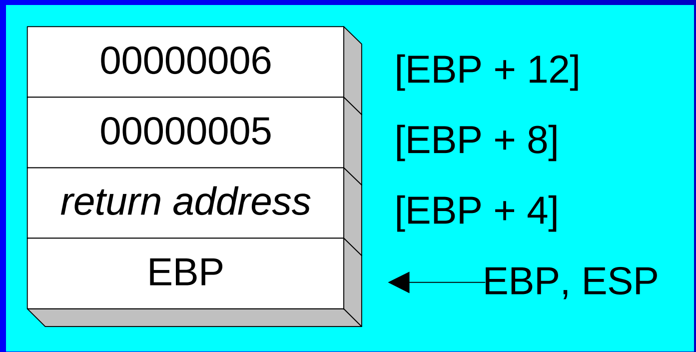
Stack Frame Example (1 of 2)

```
.data
sum DWORD ?
.code
    push 6                        ; second argument
    push 5                        ; first argument
    call AddTwo                   ; EAX = sum
    mov  sum,eax                  ; save sum
```

```
AddTwo PROC
    push ebp
    mov  ebp,esp
    .
    .
```



Stack Frame Example (2 of 2)




```
AddTwo PROC
   push ebp
   mov ebp,esp                ; base of stack frame
   mov eax,[ebp + 12]         ; second argument (6)
   add eax,[ebp + 8]          ; first argument (5)
   pop ebp
   ret 8                      ; clean up the stack
AddTwo ENDP                   ; EAX contains the sum
```

Your turn . . .

- Create a procedure named Difference that subtracts the first argument from the second one. Following is a sample call:

```
push 14                 ; first argument
push 30                 ; second argument
call Difference         ; EAX = 16
```

Passing Arguments by Reference (1 of 2)

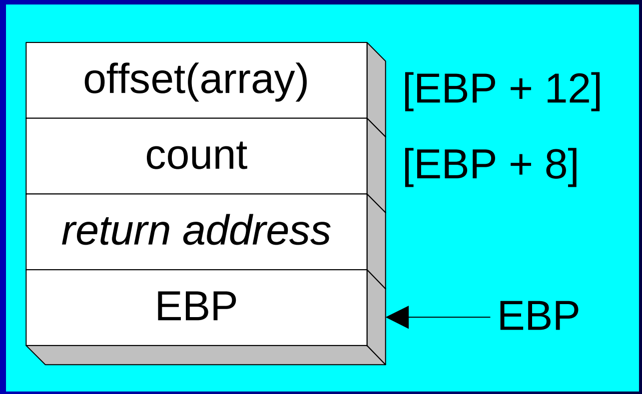
- The ArrayFill procedure fills an array with 16-bit random integers
- The calling program passes the address of the array, along with a count of the number of array elements:

```
.data
count = 100
array WORD count DUP(?)
.code
    push OFFSET array
    push COUNT
    call ArrayFill
```

Passing Arguments by Reference (2 of 2)

ArrayFill can reference an array without knowing the array's name:

```
ArrayFill PROC
    push ebp
    mov  ebp,esp
    pushad
    mov  esi,[ebp+12]
    mov  ecx,[ebp+8]
    .
    .
```



ESI points to the beginning of the array, so it's easy to use a loop to access each array element. View the complete program.

LEA Instruction

- The LEA instruction returns offsets of indirect operands.
  - OFFSET operator can only return constant assembly time offsets.
- LEA is required when obtaining the offset of a stack parameter or local variable. For example:

```
CopyString PROC,
   count:DWORD
   LOCAL temp[20]:BYTE

   mov edi,OFFSET count        ; invalid operand
   mov esi,OFFSET temp         ; invalid operand
   lea edi,count               ; ok
   lea esi,temp                ; ok
```

Creating Local Variables

- To explicitly create local variables, subtract their total size from ESP.
- The following example creates and initializes two 32-bit local variables (we'll call them locA and locB).

```
MySub PROC
    push ebp
    mov  ebp,esp
    sub  esp,8
    mov  [ebp-4],123456h          ; locA
    mov  [ebp-8],0                ; locB
    .
    .
```

ENTER and LEAVE Instructions

- ENTER instruction automatically creates a stack frame for a called procedure.
  - Push EBP on the stack
  - Set EBP to the base of the stack (mov ebp,esp)
  - Reserve space for local variables (sub esp,numbytes)
- ENTER localbytes,nestinglevel
- LEAVE instruction terminates the stack frame for a procedure.

```
MySub PROC
    enter 8,0
        .
        .
    leave
    ret
MySub ENDP
```

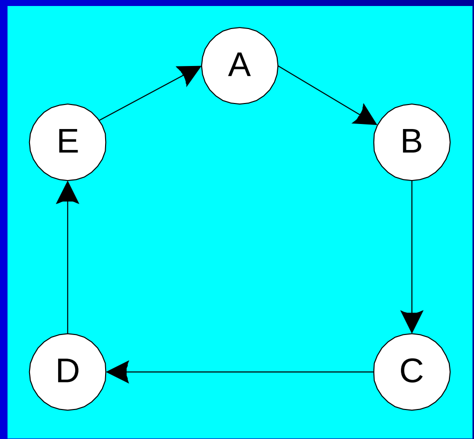
```
MySub PROC
    push ebp
    mov ebp,esp
    sub esp,8
        .
        .
    mov esp,ebp
    pop ebp
    ret
MySub ENDP
```

Recursion

- What is recursion?
- Recursively Calculating a Sum
- Calculating a Factorial

What is Recursion?

- The process created when . . .
  - A procedure calls itself
  - Procedure A calls procedure B, which in turn calls procedure A
- Using a graph in which each node is a procedure and each edge is a procedure call, recursion forms a cycle:



Recursively Calculating a Sum

The CalcSum procedure recursively calculates the sum of an array of integers. Receives: ECX = count. Returns: EAX = sum

```
CalcSum PROC
    cmp ecx,0               ; check counter value
    jz L2                   ; quit if zero
    add eax,ecx             ; otherwise, add to sum
    dec ecx                 ; decrement counter
    call CalcSum            ; recursive call
L2: ret
CalcSum ENDP
```

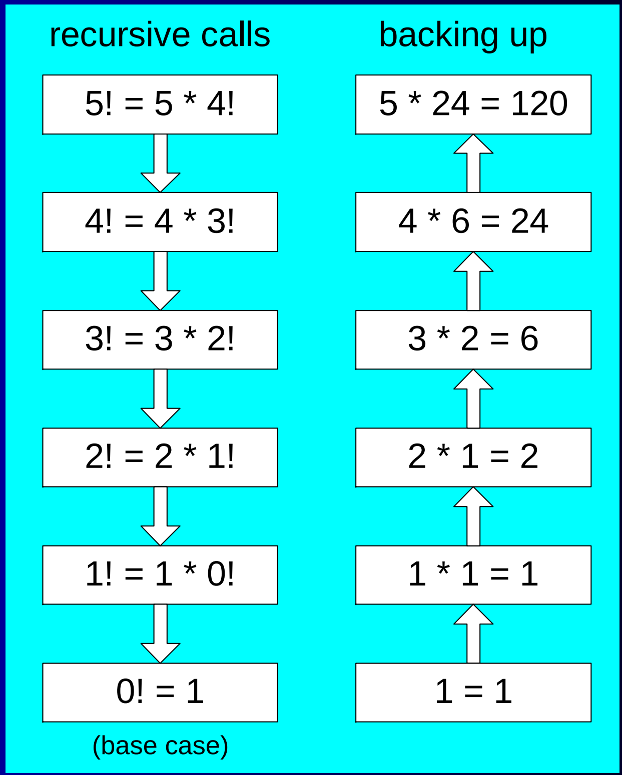
View the complete program

Calculating a Factorial (1 of 3)

This function calculates the factorial of integer *n*. A new value of *n* is saved in each stack frame:

```
int function factorial(int n)
{
    if(n == 0)
      return 1;
    else
      return n * factorial(n-1);
}
```

As each call instance returns, the product it returns is multiplied by the previous value of n.



Calculating a Factorial (2 of 3)

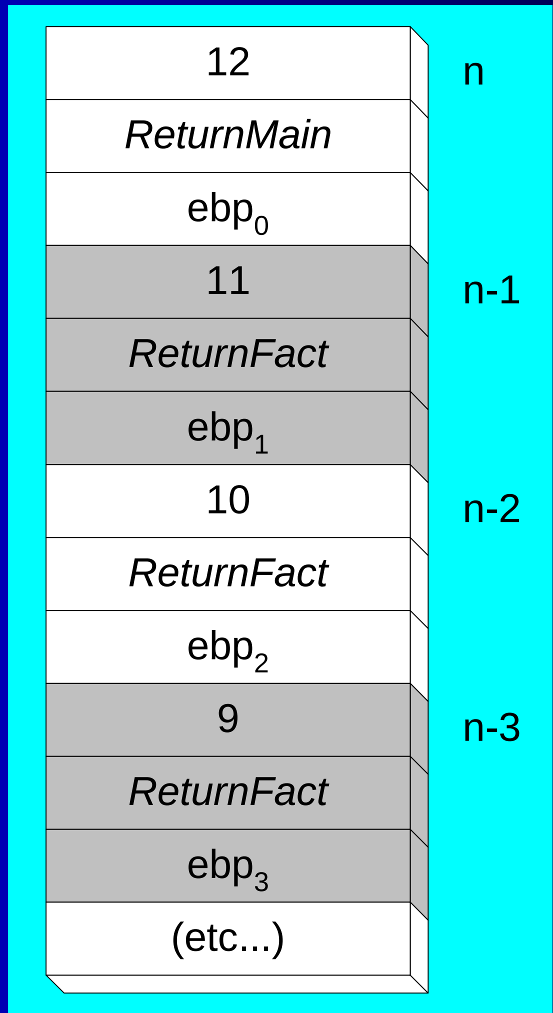
```
Factorial PROC
     push ebp
     mov  ebp,esp
     mov  eax,[ebp+8]              ; get n
     cmp  eax,0                    ; n < 0?
     ja   L1                       ; yes: continue
     mov  eax,1                    ; no: return 1
     jmp  L2

L1:  dec  eax
     push eax                      ; Factorial(n-1)
     call Factorial

; Instructions from this point on execute when each
; recursive call returns.

ReturnFact:
     mov  ebx,[ebp+8]              ; get n
     mul  ebx                      ; ax = ax * bx

L2:  pop  ebp                      ; return EAX
     ret  4                        ; clean up stack
Factorial ENDP
```

Calculating a Factorial (3 of 3)

Suppose we want to calculate 12!

This diagram shows the first few stack frames created by recursive calls to Factorial

Each recursive call uses 12 bytes of stack space.



Multimodule Programs

- A multimodule program is a program whose source code has been divided up into separate ASM files.
- Each ASM file (module) is assembled into a separate OBJ file.
- All OBJ files belonging to the same program are linked using the link utility into a single EXE file.

Advantages

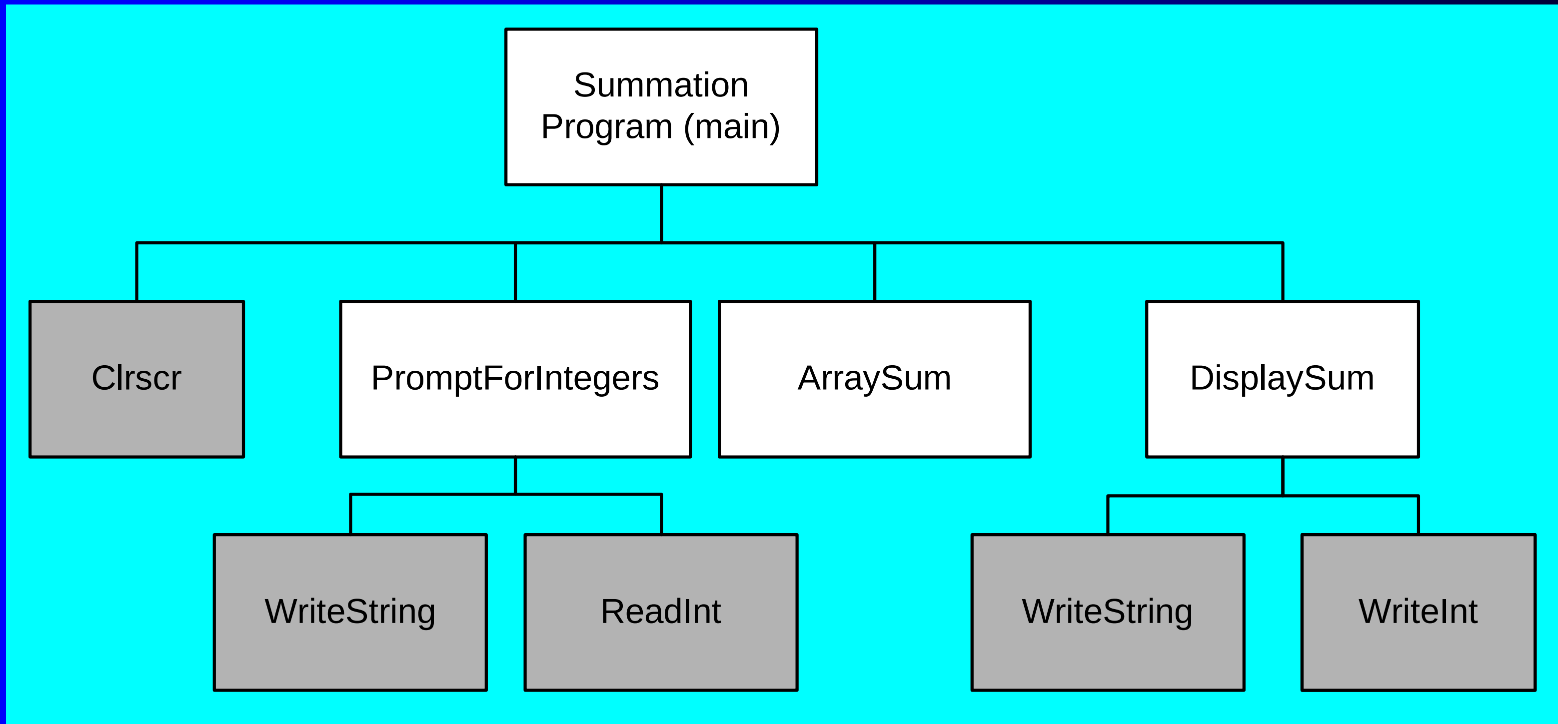
- Large programs are easier to write, maintain, and debug when divided into separate source code modules.
- When changing a line of code, only its enclosing module needs to be assembled again. Linking assembled modules requires little time.
- A module can be a container for logically related code and data (think object-oriented here...)
  - encapsulation: procedures and variables are automatically hidden in a module unless you declare them public

Creating a Multimodule Program

- Here are some basic steps to follow when creating a multimodule program:
  - Create the main module
  - Create a separate source code module for each procedure or set of related procedures
  - Create an include file that contains procedure prototypes for external procedures (ones that are called between modules)
  - Use the INCLUDE directive to make your procedure prototypes available to each module

Example: ArraySum Program

- Let's review the ArraySum program from Chapter 5.



Each of the four white rectangles will become a module.

Sample Program output

```
Enter a signed integer: -25

Enter a signed integer: 36

Enter a signed integer: 42

The sum of the integers is: +53
```

INCLUDE File

The sum.inc file contains prototypes for external functions that are not in the Irvine32 library:

```
INCLUDE Irvine32.inc

PromptForIntegers PROTO,
    ptrPrompt:PTR BYTE,         ; prompt string
    ptrArray:PTR DWORD,         ; points to the array
    arraySize:DWORD             ; size of the array

ArraySum PROTO,
    ptrArray:PTR DWORD,         ; points to the array
    count:DWORD                 ; size of the array

DisplaySum PROTO,
    ptrPrompt:PTR BYTE,         ; prompt string
    theSum:DWORD                ; sum of the array
```