Writing Macros

This lecture will focus on writing **macros**, and use stack handling as an example of macro use.

Macros differ from standard subroutines and functions.

Functions and subroutines represent separate blocks of code to which control can be transferred. Linkage is achieved by management of a **return address**, which is managed in various ways.

A macro represents code that is automatically generated by the assembler and inserted into the source code.

Macros are less efficient in terms of code space; each invocation of the macro will generate a copy of the code.

Macros are more efficient in terms of run time;
they lack the overhead associated with subroutine call and return.

Before discussing macros, let’s discuss an application.

Dynamic Memory: Stacks and Heaps

The first thing we note is that the IBM 370 supports neither in native mode.

A **stack** is a LIFO (Last–In / First–Out) data structure with three basic

operations:	PUSH	places an item onto the stack,
	POP	removes an item from the stack
	INIT	initializes the stack.

A heap is a dynamic structure used by a RTS (Run–Time System) to allocate memory in response to object creators, such as New.

A modern RTS will allocate an area of memory for use by both the stack and the heap. By convention in system design:

The stack starts at high memory addresses and moves toward lower addresses.

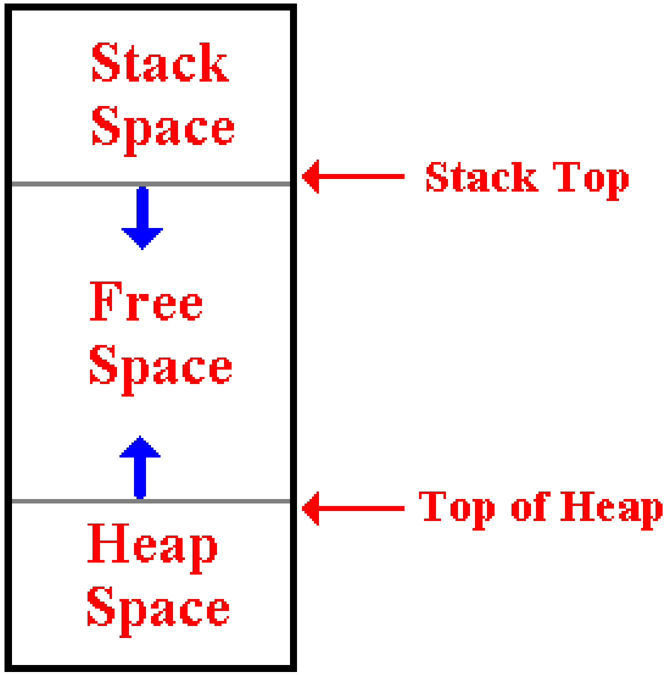
The heap starts at low memory addresses and moves toward higher addresses.

NOTE: IBM has macros called “PUSH” and “POP”, associated with handling print output. We must pick other names for our stack macros.

Division of the Dynamic Memory Space

This shows how the available space is divided between the stack and the heap.

There is no fixed allocation to either, just a limit on the total space used.



A stack is often managed using a stack pointer, SP, that locates its top.

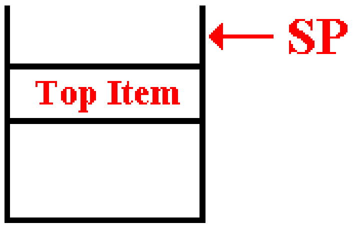
Our Stack Implementation

Our goal in this lecture is to examine the basic stack structure, and its implementation using macros.

Our implementation will use a fixed–size array to hold the stack. The stack will grow towards higher addresses.

The stack pointer will point to the location into which the next item will be pushed.

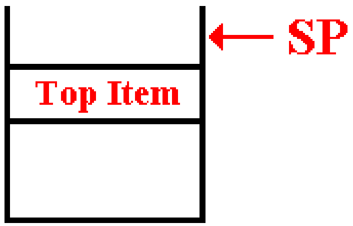
PUSH



STACK[SP] = ITEM

SP = SP + 1 // Moves toward higher addresses

POP



SP = SP – 1

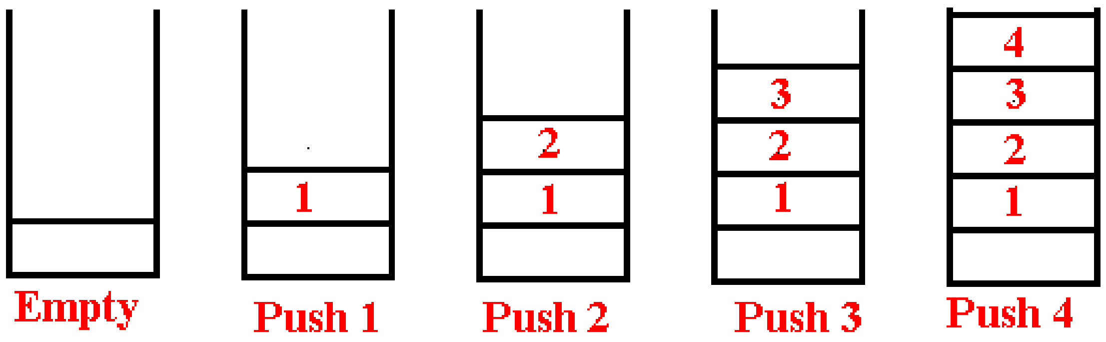
ITEM = STACK[SP]

This non–standard approach is easier for me to code.

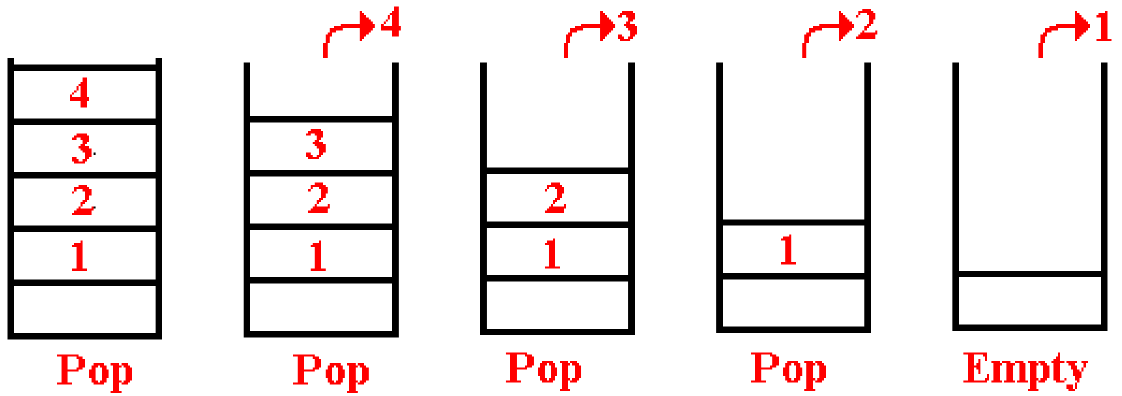
A Stack Example

Here we push four integers, one after the other. We then pop the values.

Push onto the stack



Pop from the stack: note the order is reversed.



Our Stack Implementation: Macro or Subroutine?

We have a choice of implementation method to use for our stack handler.

I have chosen to use an approach using macros for two reasons.

1. I wanted to discuss macros.
2. I wanted to use a stack to illustrate the subroutine call mechanism. That makes it difficult to use a subroutine for the stack.

We shall write three macros for the stack.

STKINIT	This is a macro without parameters. It will initialize the stack count; hence, the stack pointer.
STKPUSH	This is a macro with a single parameter. It pushes the 32–bit contents of a register onto the stack.
STKPOP	This is a macro with a single parameter. It pops the contents of the stack top into a 32–bit register.

AGAIN: These names are chosen to avoid name conflicts with existing macros.

Mechanics of Writing Macros

The MACRO definitions should occur very early in the program text.

Only comments and assembler control directives may precede a MACRO definition. This commonly includes the PRINT directive.

A MACRO begins with the key word MACRO, includes a prototype and a macro body, and ends with the trailer keyword MEND.

Parameters to a MACRO are prefixed by the ampersand "&".

Here is an example.

Header	**`MACRO`**
Prototype	**`DIVID &QUOT,&DIVIDEND,&DIVISOR`**
Model Statements	**`ZAP   &QOUT,&DIVIDEND`** **`DP    &QUOT,&DIVISOR`**
Trailer	**`MEND`**

Note that the header and trailer must appear as is. Each of the terms **"MACRO"** and **"MEND"** begin in column 10. Nothing else is allowed on either line.

Example of Macro Expansion

In assembly language, a macro is a single statement that causes the assembler to emit a sequence of other statements specified by the macro definition.

Consider the above example, with prototype

DIVID &QUOT,&DIVIDEND,&DIVISOR.

The macro body is

```
ZAP   &QOUT,&DIVIDEND
DP    &QUOT,&DIVISOR
```

Here is an example of the macro expansion. We assume that the labels used as “parameters” have been properly defined by DS or DC statements.

```
         DIVID MPG,MILES,GALS   MACRO INSTRUCTION
+        ZAP   MPG,MILES        ITS EXPANSION
+        DP    MPG,GALS
```

Symbolic Parameters

The macro prototype contains a list of symbolic parameters.

Each symbolic parameter is written as follows:

1. The name begins with an ampersand (&).
2. The ampersand is followed by one to seven alphanumeric characters, the first of which must be a letter.
3. Put another way, the first character of the name must be a "&" and the second character of the name must be a letter.

Note that this "seven character" rule limits the total length of the symbolic parameter to eight characters: the "&" and the 1 – 7 others.

According to the IBM HLASM reference manual, "Symbolic parameters have a local scope; that is, the name and value they are assigned only applies to the macro definition in which they have been declared".

Page 251, High Level Assembler for z/OS & z/VM & z/VSE Language Reference Manual, Release 6 (July 2008), SC26–4940–05

A Potential Problem with Macros.

It might appear that a macro invocation cannot be the target of a branch instruction. Here is some of my early code.

I had defined a macro, **STKPOP**, in the proper place. It was used by a routine, called **DOFACT**, to be discussed later.

I tried the following code:

```
         B DOFACT             CALL THE FACTORIAL CODE
```

Here is the branch target.

```
DOFACT   STKPOP 4             POP THE ARGUMENT INTO R4
         STKPOP 8             POP THE RETURN ADDRESS
         BR 8                 BRANCH TO RETURN ADDRESS
```

That did not assemble. The complaint was that the symbol DOFACT was not defined. What happened? The label was clearly there in the source code.

Here is What Happened.

Consider the following expansion from a macro call. It has been edited for clarity.

```
0000BA    4840 C4AE     134 A92POP    LH   4,STKCOUNT
0000BE    4940 C5B4     135           CH   4,=H'0'
0000C2    47D0 C0FE     136           BNP  A98DONE
                        137           STKPOP 4
0000C6    4830 C4AE     138+          LH   3,STKCOUNT
0000CA    4B30 C5B2     139+          SH   3,=H'1'
0000CE    4030 C4AE     140+          STH  3,STKCOUNT
0000D2    8B30 0002     141+          SLA  3,2
0000D6    4120 C4B2     142+          LA   2,THESTACK
0000DA    5843 2000     143+          L    4,0(3,2)
0000DE    The next instruction
```

Note that the STKPOP instruction on line 137 is not assigned an address.

The instruction on line 136 is at address C2 and has length 4. The next instruction will be at address C6. Only the expanded code is "real".

In other words, we note two facts:

1. The expansion code is what counts for code accuracy.
2. The label DOFACT does not "make it" into the expanded code.

The Solution to the Branch Target Problem

In order to solve the above problem, we need to focus on a more precise statement of the form of a macro definition. We must focus on the prototype and body.

The general form of a prototype statement is as follows.

Symbolic Name   Name of macro   Zero or more symbolic parameters

If the symbolic name is to be used, it has the form of a symbolic parameter.

If the symbolic name is to be used, it must be duplicated on the first line of the body.

Here is an example, using the DIVID macro.

```
         MACRO
&LABEL   DIVID &QUOT,&DIVIDEND,&DIVISOR
&LABEL   ZAP &QOUT,&DIVIDEND
         DP &QUOT,&DIVISOR
         MEND
```

Note that the symbolic parameter "**&LABEL**" is treated as any other such parameter.

Code Example to Illustrate the Solution

```
         MACRO
&LABEL   DIVID &QUOT,&DIVIDEND,&DIVISOR
&LABEL   ZAP &QOUT,&DIVIDEND
         DP &QUOT,&DIVISOR
         MEND

 B10DIV   DIVID X,Y,Z
+B10DIV   ZAP   X,Y
          DP    X,Z

 B20DIV   DIVID A,B,C
+B20DIV   ZAP   A,B
          DP    A,C
```

Note that each of the labels **B10DIV** and **B20DIV** now appears in the expanded code and can be used as a branch target address.

Concatenation: Building Operations

In a model statement, it is possible to concatenate two strings of characters.

Consider the macro prototype to load a register from one of several sources.
Note the use of the string "**&NAME**" to allow this to be a branch target.

```
         MACRO
&NAME    LOAD &REG,&TYPE,&ARG
&NAME    L&TYPE &REG,&ARG
         MEND
```

Consider a number of invocations.

LOAD R7,R,R6	becomes	**LR R7,R6**
LOAD R7,H,HW	becomes	**LH R7,HW**
LOAD R7,,FW	becomes	**L R7,FW**

Note here: the second argument is empty. The empty string is concatenated to **"F"**.

As soon as I can verify a few particulars, I shall extend the stack operations to push and pop contents of half–words and full–words.

Our Stack Data Structure

The stack is implemented as an array of full words, with two auxiliary counters.

There is a halfword that counts the number of items on the stack.

There is a halfword constant that gives the maximum stack capacity. This is not changed by the code.

There is the fixed–size array that holds the stack elements.

Here is the declaration of the stack.

```
STKCOUNT DC H’0’    NUMBER OF ITEMS STORED ON STACK
STKSIZE  DC H’64’   MAXIMUM STACK CAPACITY
THESTACK DC 64F’0’  THE STACK HOLDS 64 FULLWORDS
```

Note that the elements are full–words while the addresses are byte addresses.

The elements of the stack will be stored at the following addresses.

THESTACK, THESTACK + 4, THESTACK + 8, THESTACK + 12 up to a full word starting at THESTACK + 252.

Initialize the Stack

Here is the macro that initializes the stack.

```
*STKINIT
         MACRO
&L1      STKINIT
&L1      SR  4,4           CLEAR R4 – SUBTRACT FROM SELF
         STH 4,STKCOUNT    STORE AS THE STACK COUNT
         MEND
*
```

Note the standard trick of clearing a register by subtracting it from itself.

The register exists only for the purpose of placing a 0 into the stack count.

Following standard practice, the contents of the stack are not changed, because the elements of interest will be overwritten before they are used.

Note that this macro does not have any symbolic parameters.

PUSH: Placing Items Onto the Stack

Here is the macro STKPUSH

```
*STKPUSH
         MACRO
&L2      STKPUSH  &R
&L2      LH  3,STKCOUNT    GET THE CURRENT STACK SIZE
*                          SLA BY 2 TO MULTIPLY BY FOUR
         SLA 3,2           BYTE OFFSET OF INSERTION POINT
         LA  2,THESTACK    GET ADDRESS OF STACK START
         ST  &R,0(3,2)     STORE THE ITEM INTO THE STACK
         LH  3,STKCOUNT    GET THE (NOW) OLD STACK SIZE
         AH  3,=H'1'       INCREASE THE SIZE BY ONE
         STH 3,STKCOUNT    STORE THE NEW SIZE
         MEND
*
```

This macro has one symbolic parameter: **&R**. It is to be a register number.

When called as **STKPUSH 4**, the operative statement is changed by the assembler to **ST 4,0(3,2)** and executed as such at run time.

POP: Removing Items From the Stack

Here is the macro STKPOP

```
*STKPOP
         MACRO
&L3      STKPOP &R
&L3      LH  3,STKCOUNT   GET THE STACK COUNT
         SH  3,=H'1'      SUBTRACT 1 WORD OFFSET OF TOP
         STH 3,STKCOUNT   STORE AS NEW SIZE
         SLA 3,2          BYTE OFFSET OF STACK TOP
         LA  2,THESTACK   ADDRESS OF STACK BASE
         L   &R,0(3,2)    LOAD ITEM INTO THE REGISTER
         MEND
*
```

Again, this macro has one symbolic parameter: **&R**. Again, a register number.

When called as **STKPOP 6**, this is assembled with the last statement as

L   6,0(3,2).

NOTE: When invoked as **STKPOP MYDOG**, this will assemble as **L MYDOG,0(3,2)**; the assembler takes anything.

Using the Macros

Here is the part of the unexpanded source code that uses the macros.

```
STARTUP  OPEN (FILEIN,(INPUT))    OPEN THE STANDARD INPUT
         OPEN (PRINTER,(OUTPUT))  OPEN THE STANDARD OUTPUT
         PUT PRINTER,PRHEAD       PRINT HEADER
         STKINIT                  INITIALIZE THE STACK
         GET FILEIN,RECORDIN      GET THE FIRST RECORD, IF THERE
*
*  READ AND PROCESS LOOP
*
A10LOOP  MVC DATAPR,RECORDIN      MOVE INPUT RECORD
         PUT PRINTER,PRINT        PRINT THE RECORD
         PACK PACKIN,FIELD01      CONVERT DIGITS INPUT TO PACKED
         CVB R4,PACKIN            CONVERT THE NUMBER TO BINARY
         STKPUSH 4                PUSH THE NUMBER ONTO THE STACK
         GET FILEIN,RECORDIN      GET THE NEXT RECORD
         B A10LOOP                GO BACK AND PROCESS
*
```

Here, it is obvious that I have retained register R4 for communicating results with macros and subroutines. That is an arbitrary choice.

Using the Macros (Page 2)

Here is the unexpanded source code that uses the stack pop.

```
*   END OF INPUT PROCESSING
*
A90END   CLOSE FILEIN
         PUT PRINTER,ENDNOTE      ANNOUNCE THE END OF INPUT DATA
A92POP   LH  4,STKCOUNT           GET THE STACK COUNT
         CH  4,=H’0’              IS THE COUNT POSITIVE?
         BNP A98DONE              NO, WE ARE DONE
         STKPOP 4                 GET NEXT NUMBER INTO R4
         MVC PRINT,BLANKS         CLEAR THE OUTPUT BUFFER
         BAL 8,NUMOUT             PRODUCE THE FORMATTED SUM
         MVC DATAPR,THENUM        AND COPY TO THE PRINT AREA
         PUT PRINTER,PRINT        PRINT THE RESULT
         B   A92POP               GO AND GET ANOTHER OUTPUT
A98DONE  CLOSE PRINTER
```

Expansion of the Stack Pop

Here is the expanded code, edited from the assembler listing.

```
136 A92POP   LH  4,STKCOUNT
137          CH  4,=H'0'
138          BNP A98DONE
139          STKPOP 4
140+         LH  3,STKCOUNT
141+         CH  3,=H'0'
142+         SH  3,=H'1'
143+         STH 3,STKCOUNT
144+         SLA 3,2
145+         LA  2,THESTACK
146+         L   4,0(3,2)
147          MVC PRINT,BLANKS
148          BAL 8,NUMOUT
149          MVC DATAPR,THENUM
150          PUT PRINTER,PRINT
151 *
```

Note: There is no RETURN statement or the like.
The code is inserted in line.

A Problem with the Macros

There is a problem with each of the macros STKPUSH and STKPOP.

We show it for STKPOP, because it is easier to see in this macro.

Suppose we have code with the following two macro calls,
one immediately following the other.

```
      STKINIT
      STKPOP  6      NOTE: WE HAVE NOT PUSHED AN ITEM
```

The macro STKINIT will set the value at location STKCOUNT to 0.

Now look at the code in the expansion of macro STKPOP.

```
139           STKPOP 4
140+          LH  3,STKCOUNT
141+          CH  3,=H'0'
142+          SH  3,=H'1'
143+          STH 3,STKCOUNT
```

STKCOUNT will be set to –1, and the pop will reference the full word just before the stack. This is the pair STKCOUNT, STKSIZE: an error.

Avoiding the Problem: A Flawed Solution

The obvious solution is to test the value of STKCOUNT and avoid popping a value if the stack is empty.

Here is some code that appears to do just that.

```
*STKPOP
         MACRO
         STKPOP &R
         LH  3,STKCOUNT    GET THE STACK SIZE
         CH  3,=H'0'
         BNP NOPOP
         SH  3,=H'1'       SUBTRACT 1 WORD OFFSET OF LAST
         STH 3,STKCOUNT    WORD AND STORE AS NEW SIZE
         SLA 3,2           BYTE OFFSET OF STACK TOP
         LA  2,THESTACK    ADDRESS OF STACK START
         L   &R,0(3,2)     LOAD ITEM INTO R4
NOPOP    NOP               A DO NOTHING TARGET FOR BNP
         MEND
*
```

If the macro is written this way, the code will assemble and run correctly.

What Is the Flaw?

The macro definition given above works ONLY because the macro is invoked only one time. If the macro is invoked twice, trouble appears.

In this modification of running code, the macro is called twice in a row.

```
A90END   CLOSE FILEIN              NO MORE INPUT TO PROCESS
         PUT PRINTER,ENDNOTE       NOTE THE END OF DATA INPUT
A92POP   LH  4,STKCOUNT            GET THE STACK COUNT
         CH  4,=H'0'               IS IT POSITIVE
         BNP A98DONE               NO - WE ARE DONE HERE
         STKPOP 4                  GET NEXT NUMBER INTO R4
         STKPOP 5                  **** BAD CALL
         MVC PRINT,BLANKS          CLEAR THE OUTPUT AREA
         BAL 8,NUMOUT              PRODUCE THE FORMATTED SUM
         MVC DATAPR,THENUM         AND MOVE TO  PRINT AREA
         PUT PRINTER,PRINT         PRINT THE NUMBER
         B   A92POP                GO GET ANOTHER
A98DONE  CLOSE PRINTER
```

Listing for Double Use of the Macro

```
139           STKPOP 4
140+          LH   3,STKCOUNT
141+          CH   3,=H'0'
142+          BNP  NOPOP
143+          SH   3,=H'1'
144+          STH  3,STKCOUNT
145+          SLA  3,2
146+          LA   2,THESTACK
147+          L    4,0(3,2)
148+NOPOP     NOP
148           STKPOP 5
149+          LH   3,STKCOUNT
150+          CH   3,=H'0'
151+          BNP  NOPOP
152+          SH   3,=H'1'
153+          STH  3,STKCOUNT
154+          SLA  3,2
155+          LA   2,THESTACK
156+          L    4,0(3,2)
157+NOPOP     NOP
** ASMA043E Previously defined symbol - NOPOP
```

Avoiding the Problem: A Correct Solution

Here is a solution to the problem. It works, but it complex to write.

The solution is based on the current location operator, *****.
It is a jump to a relative address in bytes. One has to count carefully.

```
*STKPOP
         MACRO
         STKPOP &R
         LH  3,STKCOUNT           GET THE STACK SIZE
         SH  3,=H'1'              SUBTRACT 1 TO GET WORD OFFSET
*                                 OF THE TOP ITEM IN THE STACK
         CH  3,=H'0'              IS THE NEW SIZE NEGATIVE?
         BM   *+20           RX 4 YES, SO CANNOT POP AN ITEM
         STH 3,STKCOUNT      RX 4 WORD AND STORE AS NEW SIZE
         SLA 3,2             RS 4 BYTE OFFSET OF STACK TOP
         LA  2,THESTACK      RX 4 ADDRESS OF STACK START
         L   &R,0(3,2)       RX 4 LOAD ITEM INTO R4
         SLA 3,0                  A NO-OP TO SERVE AS A TARGET
         MEND
```

I am looking into other solutions, but I don’t think they exist if one is using a macro. Obviously, this can be done easily if one uses a subroutine.

Observations on the Solution

The complexity of the above instruction is based on the necessity of counting bytes in the object code, not instructions in the source code.

The above example is simple, because all instructions to be skipped have the same length. Let's look at this again.

```
CH  3,=H'0'            IS THE NEW SIZE NEGATIVE?
BM   *+20         A type RX instruction, length 4 bytes
STH 3,STKCOUNT    This instruction is at address *+4
SLA 3,2           A type RS instruction at address *+8
LA  2,THESTACK    This is at address *+12
L   &R,0(3,2)     Another 4-byte instruction at *+16
SLA 3,0           The branch target at address *+20
                  This address is offset 20 bytes from
                  that of the BM instruction.
```

Given the expected frequency of branch instructions, even within macros, there should be an easier way to handle a branch.

In the next lecture, we discuss that easier way.