Chapter 18: 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. There is an important definition that is key to understanding what a macro is and what it does.

Definition: A macro definition is a pattern for a **character–by–character textual substitution** without interpretation, and a macro invocation causes the assembler to effect that substitution exactly as written.

Dynamic Memory: Stacks and Heaps

Before discussing macros, let's discuss an application. The first thing to note in our discussion of dynamic memory, especially stacks and heaps, is that these features are not supported by our version of the System/370 assembler.

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

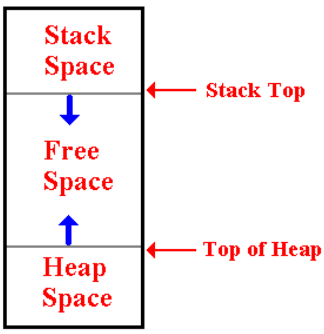
PUSH places an item onto the stack,
POP removes an item from the stack
INIT initializes the stack.

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:

1. The stack starts at high memory addresses and moves toward lower addresses.
2. The heap starts at low memory addresses and moves toward higher addresses.

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.



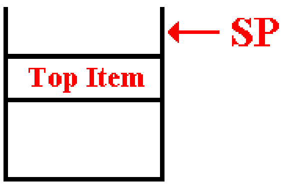
A stack is often managed using a stack pointer, SP, that locates its top.

Our Stack Implementation

The first caution in our implementation regards the selection of names for our macros. IBM has macros called “PUSH” and “POP”, associated with handling print output. We must pick other names for our stack macros. Our goal in this lecture is to examine the basic stack structure, and its implementation using macros.

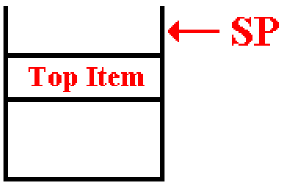
Our implementation will use a fixed–size array to hold the stack. The design will be atypical in that the stack will grow towards higher addresses. The stack pointer will point to the location into which the next item will be pushed. The two basic stack operations, as we implement them, are illustrated in the figures below.

PUSH



STACK[SP] = ITEM
SP = SP + 1 // Moves toward higher addresses

POP



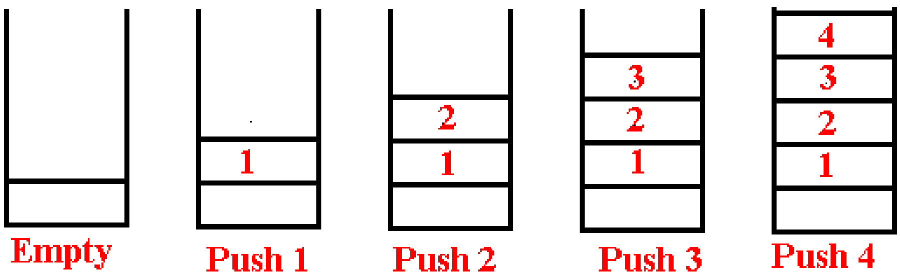
SP = SP – 1
ITEM = STACK[SP]

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

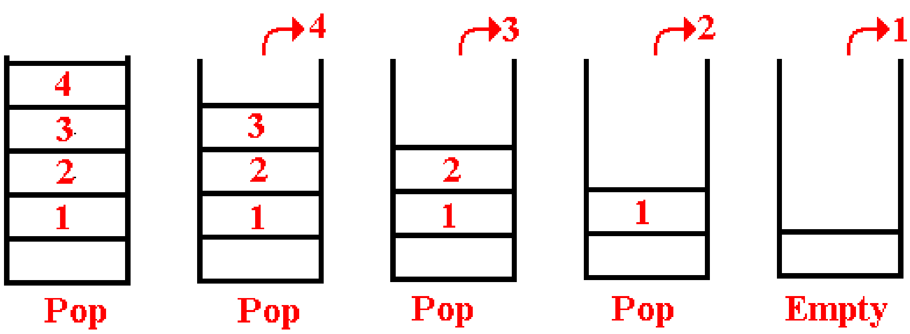
A Stack Example

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 and also 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 source code of the assembler program. 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 exactly as shown above. Each of the terms **“MACRO”** and **“MEND”** begin in column 10. Nothing else is allowed on either line.

The basic idea of a macro is to replace multiple copies of repeated code with a single macro invocation. Here, the savings are minimal, as we are replacing two lines of code with one line of code. Again, the reader is cautioned the some teaching examples are quite small.

With the above macro definition, based on packed decimal arithmetic, the idea is to replace the following two lines of code with the line that follows them.

Replace
```
ZAP X,Y
DP  X,Z
```

With
```
DIVID X,Y,Z
```

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
```

What Do We Mean by "Expansion"?

Consider the following code fragment, written to include a call to a macro.

```
   PACK   MILES,CARDIN+10(4)   COLUMNS 10 - 13
   PACK   GALS,CARDIN+14(3)    COLUMNS 14 – 16
   DIVID  MPG,MILES,GALS       INVOKE THE MACRO
   MVC    MPGPR,=X'40202020'   MOVE THE EDIT MASK
   ED     MPGPR,MPG            EDIT FOR PRINTING
```

Here is the code that is actually generated. I have inserted line numbers. Note that the macro invocation itself is not an executable instruction.

```
51   PACK   MILES,CARDIN+10(4)   COLUMNS 10 - 13
52   PACK   GALS,CARDIN+14(3)    COLUMNS 14 – 16
54   ZAP    MPG,MILES           ITS EXPANSION INTO
55   DP     MPG,GALS            TWO LINES OF CODE
56   MVC    MPGPR,=X'40202020'  MOVE THE EDIT MASK
57   ED     MPGPR,MPG           EDIT FOR PRINTING
```

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. The total length must be between 2 and 8 characters: first an "&", then a letter, then zero to six alphanumeric characters.
3. 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, R_17]

Keyword Macros
A standard invocation of the above macro might appear as follows:
```
         DIVID   MPG,MILES,GALS
```

In the above macro invocation, the arguments are passed by position. A macro invoked this way is called a **positional macro**. Another use, called a **keyword macro**, allows arguments to be passed in any order because each argument is tagged with an explicit symbolic parameter. Keyword macros also allow default values for each or all of the parameters.

The definition of a keyword macro differs from that of a positional macro only in the form of the prototype. Each symbolic parameter must be of the form **&PARAM=[DEFAULT]**. What this says is that the symbolic parameter is followed immediately by an "**=**", and is optionally followed by a default value. As a keyword macro, the above example can be written as:

Header	**MACRO**	
Prototype	**DIVID2**	**&QUOT=,&DIVIDEND=,&DIVISOR=**
Model Statements	**ZAP**	**&QOUT,&DIVIDEND**
	DP	**&QUOT,&DIVISOR**
Trailer	**MEND**	

Here are a number of equivalent invocations of this macro, written in the keyword style. Note that this definition has not listed any default values.
```
         DIVID2   &QUOT=MPG,&DIVIDEND=MILES,&DIVISOR=GALS
         DIVID2   &DIVIDEND=MILES,&DIVISOR=GALS,&QUOT=MPG
         DIVID2   &QUOT=MPG,&DIVISOR=GALS,&DIVIDEND=MILES
```

It is possible to use labels defined in the body of the program as default values.
```
         MACRO
         DIVID2  &QUOT=MPG,&DIVIDEND=,&DIVISOR=
         ZAP     &QOUT,&DIVIDEND
         DP      &QUOT,&DIVISOR
         MEND
```

With this definition, the two invocations are exactly equivalent.
```
         DIVID   MPG,MILES,GALS
         DIVID2  &DIVIDEND=MILES,&DIVISOR=GALS
```

The invocation of the macro DIVID2 will expand as follows:
```
         ZAP     MPG,MILES
         DP      MPG,GALS
```

It is interesting to note that a keyword macro cannot be invokes as if it were a positional macro. The student should consult the following listing to see what happens.

From the listing of the macro invocations, we can infer that the statement
```
    DIVID2 MPG,MILES,GALS
```
is treated as if there were no arguments present.

One may specify default constants in the keyword macro, being careful to observe the correct syntax. For example, one might be tempted to specify **&DIVISOR=10**, but the number by itself will name a register. The only way to do this would be set **&DIVISOR to =P'10'**, by using the construct required to pass literals to a keyword macro.

```
MACRO
DIVID3  &QUOT=MPG,&DIVIDEND=,&DIVISOR==P'10'
ZAP     &QOUT,&DIVIDEND
DP      &QUOT,&DIVISOR
MEND
```

The above usage is explained simply "If the value of a keyword operand is a literal, two equal signs must be specified." [R_17, page 300]. A more complete explanation of the above can be seen by considering the macro **DIVID2**. The student will note the shortening of the keywords in what follows, in an attempt to fit the listings on the page.

Here is the prototype **DIVID2 &QUOT=MPG,&DVD=,&DVS=**
Here is a correct invocation **DIVID2 QUOT=ARG1,DVD=ARG2,DVS==P'20'**

The key here is to remove the text fragments "**QUOT=**", "**DVD=**", and "**DVS=**", and see what remains. Let's do that. Consider QUOT=**ARG1,**DVD=**ARG2,**DVS=**=P'20'**
What remains is "**ARG1**", "**ARG2**", and "**=P'20'**", each of which is a correct argument. The third argument is a literal value for the packed decimal with value 20. Had we invoked the macro with the third argument as **DVS=P'20'**, the third argument would have been just "**P'20'**", which is meaningless to the assembler.

Sample Expansion Listings for Macros
Here is some assembly output from a program that I wrote to test these ideas.

```
*
*        MACRO DEFINITIONS
*
         MACRO
         DIVID &QUOT,&DVD,&DVS
         ZAP   &QUOT,&DVD
         DP    &QUOT,&DVS
         MEND
*
         MACRO
         DIVID2 &QUOT=,&DVD=,&DVS=
         ZAP    &QUOT,&DVD
         DP     &QUOT,&DVS
         MEND
*
         MACRO
         DIVID3 &QUOT=,&DVD=,&DVS==P'10'
         ZAP    &QUOT,&DVD
         DP     &QUOT,&DVS
         MEND
*
```

Here is the listing for the expansions of the macros. Note the use of a literal argument in lines 100 and 109. In the positional macro, the literal has a single equals sign, while in the keyword macro it has two equals signs.

Note the errors in the first expansion of **DIVID2**. Consider line 104 in particular. The macro definition indicates that the text “ZAP” is to be followed by a text string forthe first argument, followed by a comma, followed by a text string for the second argument. However, neither text string has been provided properly, so it attempts to generate the string “**ZAP ,** ”, which has no meaning.

```
                                 95 *         SOME MACRO INVOCATIONS
                                 96 *
                                 97           DIVID  ARG1,ARG2,ARG3
00004A F831 C0B2 C0B6 000B8 000BC  98+          ZAP   ARG1,ARG2
000050 FD31 C0B2 C0B8 000B8 000BE  99+          DP    ARG1,ARG3
                                100           DIVID  ARG1,ARG2,=P'30'
000056 F831 C0B2 C0B6 000B8 000BC 101+          ZAP   ARG1,ARG2
00005C FD31 C0B2 C322 000B8 00328 102+          DP    ARG1,=P'30'
                                103           DIVID2 ARG1,ARG2,ARG3
000062 0000 0000 0000 00000 00000 104+          ZAP     ,
** ASMA074E Illegal syntax in expression - ,
000068 0000 0000 0000 00000 00000 105+          DP      ,
** ASMA074E Illegal syntax in expression - ,
                                106           DIVID2 DVD=ARG2,DVS=ARG3,QUOT=ARG1
00006E F831 C0B2 C0B6 000B8 000BC 107+          ZAP    ARG1,ARG2
000074 FD31 C0B2 C0B8 000B8 000BE 108+          DP     ARG1,ARG3
                                109           DIVID2 DVD=ARG2,DVS==P'20',QUOT=ARG1
00007A F831 C0B2 C0B6 000B8 000BC 110+          ZAP    ARG1,ARG2
000080 FD31 C0B2 C324 000B8 0032A 111+          DP     ARG1,=P'20'
                                112           DIVID3 DVD=ARG2,QUOT=ARG1
000086 F831 C0B2 C0B6 000B8 000BC 113+          ZAP    ARG1,ARG2
00008C FD31 C0B2 C326 000B8 0032C 114+          DP     ARG1,=P'10'
                                115 *
```

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. As we shall see, DOFACT computes the factorial of a small integer, hence the name.

At the time, I was working with non–standard ways to invoke subroutines.
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. Where did the label go?

Here is What Happened.
Consider the following expansion from a macro call. It has been edited for clarity. At present, the reader should not worry about lines 134 – 136 of the listing, but just focus on line 137 (the macro invocation) and its expansion.

```
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 <u>not assigned an object code address</u>.

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”. Line 137 is basically a comment.

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.

In my early work on the subject I had concluded that a macro invocation could not also be a branch target. Then I did something almost radical, I actually read the relevant portion of the IBM Assembler Language Manual [R_17]. I found the solution.

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. In particular, it has local scope; thus the parameter has meaning only within the macro. The most important point is that the label, first seen in the prototype is repeated in the first model statement. It is that repetition that allows the label to be present in the expanded code.

Consider the prototype **&LABEL DIVID &QUOT,&DIVIDEND,&DIVISOR**
matched against the invocation **B10DIV DIVID X,Y,Z**

This forces the following substitutions in the model statements of the macro body.
&LABEL is replaced by **B10DIV**, **&QUOT** is replaced by **X**, etc. This positional replacement mimics that seen in arguments to functions as used in high–level languages.

Code Example to Illustrate the Solution

```
          MACRO
&LABEL    DIVID &QUOT,&DIVIDEND,&DIVISOR
&LABEL    ZAP &QOUT,&DIVIDEND
          DP &QUOT,&DIVISOR
          MEND
*
*         NOW THE MACRO INVOCATIONS AND EXPANSIONS
*
 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 that the second argument in the third example is empty. The empty string is concatenated to **“L”** to produce the single character **“L”**.

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’         THE NUMBER OF ITEMS STORED ON STACK
STKSIZE  DC H’64’        THE MAXIMUM STACK CAPACITY
THESTACK DC 64F’0’       THE STACK IS ACTUALLY AN ARRAY OF 64
                         FULLWORDS, REQUIRING 256 BYTES OF STORAGE.
```

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.

Needless to say, this last invocation will generate nonsense code if it assembles at all. If the code does assemble, it will likely generate a run time error. The only way in which this bit of doggerel (pardon the pun) would assemble is if the symbol **MYDOG** were equated (with EQU) to an integer that could be interpreted as a general purpose register.

Using the Macros

Here is the part of the unexpanded source code that uses the macros. Here, it is obvious that I have retained register R4 for communicating results with macros and subroutines. That is an arbitrary choice.

```
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
*
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
*
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 *
```

<u>**Note**</u>: 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. After line 143, the values will be.

```
STKCOUNT DC X‘FFFF’       MINUS ONE
STKSIZE  DC X‘0040’       HEXADECIMAL REPRESENTATION OF 64.
```

Register 6 would be loaded with **X‘FFFF0040’**, which is a negative number. A bit of arithmetic reveals this to be the negative of the number represented in hexadecimal as **X‘0000FFC0’** or as 65,472 in decimal.

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. Actually, it runs correctly due only to a quirk in the code. It is a general principle that erroneous code might run on occasion, but it will not run always.

We shall hold out for code that is correct in that it will always assemble, always run, and always produce the correct result.

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

Notice in the listing below that the first macro expansion produces no problems. It is the second expansion that gives rise to the assembler error. The symbol **NOPOP** has already been used when it is redefined in the second expansion. This is not allowed.

Note that this would not be a problem for a symbolic parameter, which has scope local to the particular expansion 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. The complexity in writing this is due to counting the bytes in each instruction beginning with the branch instruction and ending just before the branch target. It is easy to miscount.

```
*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               YES, SO CANNOT POP AN ITEM
         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
         SLA 3,0                 A NO-OP TO SERVE AS A TARGET
         MEND
```

Observations on the First 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          RX 4    A type RX instruction, length 4 bytes
 STH 3,STKCOUNT     RX 4    This instruction is at address   *+4
 SLA 3,2            RS 4    A type RS instruction at address *+8
 LA  2,THESTACK     RX 4    This is at address *+12
 L   &R,0(3,2)      RX 4    Another 4-byte instruction at *+16
 SLA 3,0                    The branch target at address *+20
```

The Preferred Solution

What we need is a way to generate a branch target that would be unique to each expansion of the macro. As should be expected, the System/370 assembler provides a method, which is based on concatenation of system variable symbols. We describe this process in two stages, first reviewing the idea of using concatenation to build symbols and operations. In our earlier discussion we used concatenation to build load operators for various types.

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

Consider a number of invocations, each of which constructs a load operator.

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

System Variable Symbols

The System/370 assembler provides a large number of special predefined symbols called **"system variable symbols"**. There are a number of these symbols. I mention three.

&SYSDATE The system date, in the 8 character form "**MM/DD/YY**".
Use in the form of a declaration of initialized storage, as in
TODAY DC C'&SYSDATE'

&SYSTIME The system time of day, in the five character form "**HH.MM**".
Also used in the form of a declaration, as in
NOW DC C'&SYSTIME'

&SYSNDX The macro expansion index. For the first macro expansion, the Assembler initializes **&SYSNDX** to the string **"0001"**. Each expansion of any macro invocation increases the value represented by 1, giving rise to the sequence **"0001"**, **"0002"**, **"0003"**, etc.

The **&SYSNDX** system variable symbol can prevent a macro from generating duplicate labels. The system symbol is concatenated to a leading character, which begins the label and must be unique within the macro definition. In what follows, we use the letter "**L**". Consider the following string, used as a label within the body of a macro definition.

```
L&SYSNDX L R4,STKSAV4
```

Note that the string "**L&SYSNDX**", as written, contains eight characters: the initial character "**L**" followed by the 7 character sequence "**&SYSNDX**". On expansion, this will be converted to labels such as "**L0001**", "**L0002**", etc. As the string "**&SYSNDX**" already takes seven characters, it is better to make the prefix a single letter, though multiple letters are allowed.

In actual fact, the requirement for the leading characters, to which the **&SYSNDX** is to be appended can be any sequence of one to four characters, provided only that the first character is a letter. Thus the following are valid, but they disrupt the flow of the listing.

```
A12&SYSNDX ...    This label might become A120003.
WXYZ&SYSNDX ...   This might become WXYZ0117.
```

A Simple Example of Label Generation

Consider the simple macro used for packed division in the previous lecture.
We adapt it to prevent division by zero.

```
         MACRO
&LABEL   DIVID &QUOT,&DIVIDEND,&DIVISOR
&LABEL   ZAP   &QOUT,&DIVIDEND
         CP    &DIVISOR,=P'0'  IS IT ZERO
         BNE   A&SYSNDX        NO, DIVISION IS OK
         ZAP   &QUOT,=P'0'     YES, SET QUOTIENT TO 0
         B     B&SYSNDX
A&SYSNDX DP    &QUOT,&DIVISOR
B&SYSNDX NOPR  R3              DO NOTHING
         MEND
```

Note that the format of the **NOPR** instruction requires a register number (here **R3**), even though the instruction does nothing.

Sample Expansion of the Macro
With the above definition, consider the following expansions.

```
 A10START DIVID X,Y,Z
+A10START ZAP   X,Y
+         CP    Z,=P‘0’      IS IT ZERO
+         BNE   A0001        NO, DIVISION IS OK
+         ZAP   X,=P‘0’      YES, SET QUOTIENT TO 0
+         B     B0001
+A0001    DP    X,Z
+B0001    NOPR  R3           DO NOTHING
 A20DOIT  DIVID A,B,C
+A20DOIT  ZAP   A,B
+         CP    C,=P‘0’      IS IT ZERO
+         BNE   A0002        NO, DIVISION IS OK
+         ZAP   X,=P‘0’      YES, SET QUOTIENT TO 0
+         B     B0002
+A0002    DP    A,C
+B0002    NOPR  R3           DO NOTHING
```

Note that each invocation has distinct labels. This removes the name clashes.

For the first expansion of the macro DIVID, the label **&SYSNDX** is replaced by the string **“0001”** and on the second expansion, the label is replaced by **“0002”**.

It is important to note that the **&SYSNDX** is incremented due to the expansion of any macro. Were there another macro expansion between the two invocations of the macro **DIVID**, the second invocation of that macro would be associated with the replacement of the label **&SYSNDX** by the string **“0003”**. The string **“0002”** would be associated with the intermediate macro expansion, assuming that it used the system symbol **&SYSNDX**.

The Preferred Solution Applied to STKPOP
Here is a revision of the code that will avoid the problem of duplicate labels.

```
*STKPOP
         MACRO
         STKPOP &R
         LH  3,STKCOUNT     GET THE STACK SIZE
         CH  3,=H'0'
         BNP L&SYSNDX
         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
L&SYSNDX NOP                A DO NOTHING TARGET FOR BNP
         MEND
*
```

STKPOP: Preferred Solution with Two Invocations

The following listing was produced when the revised macro definition above was implemented in the source code.

```
139          STKPOP 4
140+         LH   3,STKCOUNT
141+         CH   3,=H'0'
142+         BNP  L0001
143+         SH   3,=H'1'
144+         STH  3,STKCOUNT
145+         SLA  3,2
146+         LA   2,THESTACK
147+         L    4,0(3,2)
148+L0001    NOP
148          STKPOP 5
149+         LH   3,STKCOUNT
150+         CH   3,=H'0'
151+         BNP  L0002
152+         SH   3,=H'1'
153+         STH  3,STKCOUNT
154+         SLA  3,2
155+         LA   2,THESTACK
156+         L    4,0(3,2)
157+L0002    NOP
```

Pushing from Various Sources

We look first at the handling of our **STKPUSH**. The only restriction on the stack is that every value pushed be treated as a 32–bit fullword. As a result, a 16–bit halfword will be sign–extended to a 32–bit fullword before being pushed onto the stack. This is similar to the function of the **LH** instruction, which loads a register from a halfword.

The key instruction in the original **STKPUSH** macro is the following.

```
    ST   &R,0(3,2)      STORE THE ITEM INTO THE STACK
```

In this case, the item to be placed on the stack is found in the register indicated by the symbolic parameter **&R**.

The way to extend this instruction to all data types is as follows.

1. Select a register to be a fixed source for the word on the stack, and
2. Construct instructions to load that fixed register from the source.

What Shall Be Stored on the Stack?

At this point, we have a decision to make. What data types to store? The size restriction on the stack limits the simple choices to addresses and the contents of registers, halfwords, and fullwords. We must select a working register for the new macro. I select R4.

The “key code” becomes as follows.

Stacking an address	`LA R4,&ARG`	`Load address into R4.`
Stacking a halfword	`LH R4,&ARG`	`Load halfword into R4.`
Stacking a fullword	`L  R4,&ARG`	`Load fullword into R4.`
Stacking a register	`LR R4,&ARG`	`Load value from source register`

Passing the Type in a Macro Invocation

The solution adopted to the problem above is to pass the type in the macro call and use concatenation to build the load operator. Here is some code taken from a macro definition that has been run and tested.

First, we show the macro prototype.

```
&L2      STKPUSH &ARG,&TYP
```

Next we show the "key instruction" in the macro body.

```
         L&TYP R4,&ARG
```

Here are four typical invocations of the macro.

```
          STKPUSH R7,R      PUSH VALUE IN REGISTER.
          STKPUSH HHW,H     PUSH A HALFWORD VALUE.
          STKPUSH FFW,A     PUSH AN ADDRESS.
          STKPUSH FFW       PUSH A FULLWORD.
```

Note that the last invocation lacks a second argument. In the expansion, this causes **&TYP** to be set to **' '**, a blank; "**L&TYP**" becomes "**L** ".

The Macro Definition

Here is the definition for the macro at this stage of its development.

```
         MACRO
&L2      STKPUSH &ARG,&TYP
&L2      LH    R3,STKCOUNT
         SLA   R3,2
         LA    R2,THESTACK
         L&TYP R4,&ARG
         ST    R4,0(3,2)
         LH    R3,STKCOUNT
         AH    R3,=H'1'
         STH   3,STKCOUNT
         MEND
```

Again, the "**&L2**" allows the macro invocation to be a branch target. This is a practice that your author has decided to employ, even absent a present need to use any invocation of the macro as a branch target. This is a flexibility option only; one that is easy to implement.

At this point, the code fixes on general–purpose registers **R3** and **R4** for use. There is no particular logic to these choices; it is just that two registers had to be chosen. The point here is to focus on the construction of the operator using the concatenation **"L&TYP"**.

This macro will be invoked with four distinct values for the second parameter, **&TYP**. Again, the value is **""** for push fullword, **"H"** for push a sign–extended halfword, **"A"** for an address, and **"R"** for register. As always, there is insufficient error checking code. It is assumed that the macro will always be invoked with the correct type.

Some Invocations of this Macro

```
91          STKPUSH R7,R
92+         LH      R3,STKCOUNT
93+         SLA     R3,2
94+         LA      R2,THESTACK
95+         LR      R4,R7
96+         ST      R4,0(3,2)
97+         LH      R3,STKCOUNT
98+         AH      R3,=H'1'
99+         STH     3,STKCOUNT

100         STKPUSH HHW,H
101+        LH      R3,STKCOUNT
102+        SLA     R3,2
103+        LA      R2,THESTACK
104+        LH      R4,HHW
105+        ST      R4,0(3,2)
106+        LH      R3,STKCOUNT
107+        AH      R3,=H'1'
108+        STH     3,STKCOUNT
```

More Invocations of this Macro

```
109         STKPUSH FFW
110+        LH      R3,STKCOUNT
111+        SLA     R3,2
112+        LA      R2,THESTACK
113+        L       R4,FFW
114+        ST      R4,0(3,2)
115+        LH      R3,STKCOUNT
116+        AH      R3,=H'1'
117+        STH     3,STKCOUNT

118         STKPUSH FFW,A
119+        LH      R3,STKCOUNT
120+        SLA     R3,2
121+        LA      R2,THESTACK
122+        LA      R4,FFW
123+        ST      R4,0(3,2)
124+        LH      R3,STKCOUNT
125+        AH      R3,=H'1'
126+        STH     3,STKCOUNT
```

NOTE: The originals of the program listing are found at the end of the chapter.

Saving the Work Registers
As written, this macro has the side effect of changing the values of three registers: R2, R3, and R4. The value of R4 is preserved only if it is being pushed. We should write macros so that they operate without side effects. The only way to do this is to save and restore the values of the work registers. There are many ways to do this. The simplest is to alter the stack data structure. Here is the new version.

```
STKCOUNT DC H‘0’            NUMBER OF ITEMS STORED ON STACK
STKSIZE  DC H‘64’           MAXIMUM STACK CAPACITY
STKSAV2  DC F‘0’            SAVES CONTENTS OF R2
STKSAV3  DC F‘0’            SAVES CONTENTS OF R3
STKSAV4  DC F‘0’            SAVES CONTENTS OF R4
THESTACK DC 64F‘0’          THE STACK HOLDS 64 FULLWORDS
```

This new definition does not alter the **STKINIT** macro. It does affect the other two macros: **STKPOP** and **STKPUSH**. We illustrate the latter.

The First Revision of STKPUSH
Here is the revision that allows the work registers to be saved.

```
         MACRO
&L2      STKPUSH &ARG,&TYP
&L2      ST    R2,STKSAV2            THE ORDER OF SAVING
         ST    R3,STKSAV3            IS NOT IMPORTANT.
         ST    R4,STKSAV4
         LH    R3,STKCOUNT
         SLA   R3,2
         LA    R2,THESTACK
         L&TYP R4,&ARG
         ST    R4,0(3,2)
         LH    R3,STKCOUNT
         AH    R3,=H'1'
         STH   R3,STKCOUNT
         L     R4,STKSAV4            THE ORDER OF RESTORATION
         L     R3,STKSAV3            IS NOT IMPORTANT EITHER.
         L     R2,STKSAV2
         MEND
```

The Status of the Macros at This Point
There are a few issues to be addressed at this point.
The only macro that will not change is the initialization macro, **STKINIT**.

1. We have not yet dealt with generalizing the **STKPOP** macro.
2. We have not yet dealt with either the stack empty problem or that of the stack being full. Each has to be addressed.

Each of these issues requires some additional code. We now move towards the final versions of each of the macros.

The First Revision of STKINIT

Here is a revision of the STKINIT code that allows initialization of its size. This was done in order to show how to concatenate the symbolic parameter **&SIZE** as a prefix.

```
         MACRO
&L1      STKINIT &SIZE
&L1      ST R3,STKSAV3
         SR R3,R3
         STH R3,STKCOUNT
         L  R3,STKSAV3
         B  L&SYSNDX
STKCOUNT DC H'0'
STKSIZE  DC H'&SIZE'
STKSAV2  DC F'0'
STKSAV3  DC F'0'
STKSAV4  DC F'0'
THESTACK DC &SIZE.F'0'
L&SYSNDX SLA R3,0
         MEND
```

Note the **“.”** in the definition of **THESTACK** as **DC &SIZE.F'0'**. This concatenates the value of the symbolic parameter with “**F‘0’**”, as in “**128F‘0’**”

The Second Revision of STKPUSH

Here is the final version of the macro for pushing onto the stack.

```
         MACRO
&L2      STKPUSH &ARG,&TYP
&L2      ST    R3,STKSAV3
         LH    R3,STKCOUNT      GET COUNT OF ITEMS ON THE STACK
         CH    R3,STKSIZE       IS THE STACK FULL?
         BNL   Z&SYSNDX         YES, DO NOT ADD ANOTHER.
         ST    R4,STKSAV4       NO, WE CAN PUSH ANOTHER ITEM.
         ST    R2,STKSAV2       START BY SAVING THE OTHER 2 REGISTERS
         SLA   R3,2             MULTIPLY THE INDEX BY 4.
         LA    R2,THESTACK
         L&TYP R4,&ARG          FORM THE ADDRESS
         ST    R4,0(3,2)        STORE THE ITEM
         LH    R3,STKCOUNT      GET THE OLD COUNT OF ITEMS
         AH    R3,=H'1'         INCREMENT THE COUNT BY 1
         STH   R3,STKCOUNT      STORE THE CURRENT COUNT
         L     R4,STKSAV4       RESTORE THE REGISTERS.
         L     R2,STKSAV2
Z&SYSNDX L     R3,STKSAV3
         MEND
```

Conditional Assembly

Consider the problem of generalizing **STKPOP**. We shall want to pop the following from the stack: register values, halfwords, and fullwords. The type for the argument refers to the destination; an address can be popped into either a register or fullword. In order to see the problem for **STKPOP**, consider the "key instruction".

Halfword:	**STH R4,&ARG**
Fullword:	**ST R4,&ARG**
Register:	**LR &ARG,R4 No STR for store register.**

We could write a **STR** macro, but I want to use another solution. We have already seen how concatenation can be used to construct different instructions in a macro expansion. We now investigate conditional assembly, in which the expansion of a macro can lead to a number of distinct code sequences.

Conditional assembly permits the testing of attributes such as data format, data value, or field length, and to use the results of such testing to generate source code that is specific to the case in question. This chapter will focus on five specific conditional assembly instructions.

AGO	an unconditional branch
AIF	a conditional branch. This means "Ask If".
ANOP	A NOP that can be the branch target for either **AGO** or **AIF**.
MNOTE	print a programmer defined message at assembly time
MEXIT	exit the macro definition.

Attributes for Use by Conditional Assembly

The assembler can generate code specified by certain attributes of the arguments to the macro definition at the time it is expanded. There are six types of attributes that can be associated with a parameter. Here are three if the more useful attributes.

L'	Length	The length of the symbolic parameter
I'	Integer	The integer attribute of a fixed–point, floating–point, or packed decimal number.
T'	Type	The type of the parameter, as specified by the DC or DS declaration with which it is defined.

Some types for the T' attribute are as follows.

A	Address	H	Halfword
B	Binary	I	Instruction
C	Character	P	Packed Decimal
F	Fullword	X	Hexadecimal

The Sequence Symbol

Conditional assembly is built on the ability to generate conditional branching in the code generation process. In this, it is not that branch assembler language statements are used, but that entire segments of code will not even be assembled.

The assembler uses sequence symbols, denoted by the "." (period) prefix. More on this later.

The Ask If (AIF) Instruction
The **AIF** instruction has two parts.

1. A logical expression in parentheses, and
2. A sequence symbol immediately following, which serves as the branch target.

The **AIF** logical expression may use the following relational operators, which are quite similar to those seen in early versions of the FORTRAN language.

EQ	Equal To	**NE**	Not Equal To
LT	Less Than	**GE**	Greater Than or Equal To
GT	Greater Than	**LE**	Less Than or Equal To

If the type of **&AMT** is packed, go to **.B23PACK**
```
AIF(T'&AMT EQ 'P').B23PACK
```

If the type of **&LINK** is not an instruction, go to **.R30ERROR**
```
AIF(T'&LINK NE 'I').R30ERROR
```

Here, each of **.B23PACK** and **.R30ERROR** are sequence symbols.

Testing the Value of a Symbolic Parameter
What we want for the STKPOP instruction is a conditional assembly based on the value of the second parameter. The prototype for the macro will be something like
```
&L1       STKPOP &ARG,&TYP
```

What we want to issue is an **AIF** statement such as
```
AIF (&TYP EQ 'R').ISREG
```

There is a well–known peculiarity in any assembler language, not just in the IBM Assembler, that disallows this straightforward construct.

We must put the symbolic parameter in single quotes. The statement is thus:
```
AIF ('&TYP' EQ 'R').ISREG
```

If **&TYP** is the character R, the logical expression becomes **('R' EQ 'R')**, which immediately evaluates to True, and the branch is taken. [Page 384, R_17]

Targets for Use by Conditional Assembly
Each of the **AGO** and **AIF** instructions is a branch instruction that takes effect at assembly time. Neither persists into the assembly source code. It should be expected that the targets for either of these conditional assembly branch instructions should be of a distinct type. The targets for these are called **sequence symbols**.

The format of a sequence symbol is as follows. A **sequence symbol** begins with a period (.) followed by one to seven letters or digits, the first of which must be a letter.
Unlike the symbols created by use of the **&SYSNDX** system symbol, sequence symbols do not persist into assembly time, and thus cannot generate a name conflict for the assembler.

A Sample of Conditional Assembly

Here is the DIVID macro, with conditional assembly instructions to insure that it is expanded only for parameters that are packed decimal.

```
         MACRO
&LABEL   DIVID &QUOT,&DIVIDEND,&DIVISOR
         AIF   (T’&QUOT NE ‘P’).NOTPACK
         AIF   (T’&DIVIDEND NE T’&QUOT).NOTPACK
         AIF   (T’&DIVISOR NE T’&QUOT).NOTPACK
         AGO   .DOIT
.NOTPAK  MNOTE  ‘ONE PARAMETER IS NOT PACKED DECIMAL’
         MEXIT
.DOIT    ANOP
&LABEL   ZAP   &QOUT,&DIVIDEND
         CP    &DIVISOR,=P‘0’  IS IT ZERO
         BNE   A&SYSNDX        NO, DIVISION IS OK
         ZAP   &QUOT,=P‘0’     YES, SET QUOTIENT TO 0
         B     B&SYSNDX
A&SYSNDX DP    &QUOT,&DIVISOR
B&SYSNDX NOPR  R3              DO NOTHING
         MEND
```

Some Examples of the Conditional Assembly Divide Macro

In the following, assume that each of **X**, **Y**, and **Z** is defined by a DC statement as packed decimal, but that **A**, **B**, and **C** are defined as halfwords. Here are some possible expansions.

```
 F10DOIT  DIVID X,Y,Z
+F10DOIT  ZAP   X,Y
+         CP    Z,=P‘0’         IS IT ZERO
+         BNE   A0032           NO, DIVISION IS OK
+         ZAP   X,=P‘0’         YES, SET QUOTIENT TO 0
+         B     B0032
+A0032    DP    X,Z
+B0032    NOPR  R3              DO NOTHING
 F25NODO  DIVID A,B,C
+ONE PARAMETER IS NOT PACKED DECIMAL
```

The Original Definition of Macro STKPOP

We now begin our redefinition of the **STKPOP** macro.

We begin with the original definition, which popped a value into a register.

```
*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. We want to expand this definition in a number of ways. We begin by introducing the type **&TYP**.
At this point, it will become necessary to have another work register.

Mechanics of the Revised STKPOP
The new design will use register R4 to transfer the value at the top of the stack.

The new prototype will be as follows.
```
&L3      STKPOP &ARG,&TYP
```

Each type of instruction will include the following as the first statement in the "key code" – that which actually places the value into the destination.
```
         L   R4,0(3,2)    LOAD ITEM INTO REGISTER R4.
```

The second statement of the "key code" depends on the type of the destination.
```
&TYP == H        STH R4,&ARG
&TYP == F        ST  R4,&ARG
&TYP == A        ST  R4,&ARG  (SAME AS FULLWORD)
&TYP == R        LR &ARG,R4   COPY R4 INTO REGISTER
```

Here is the key code section, with the conditional assembly.
The first statement is common to all types.
```
         L   R4,0(3,2)    LOAD ITEM INTO REGISTER R4.
         AIF ('&TYPE' EQ 'R').ISREG
         ST&TYP R4,&ARG
         AGO .CONT
.ISREG   LR &ARG,R4
.CONT    The next statement.
```

STKPOP: Revision 2
Here I am going to add some code to save and restore the work registers.
```
         MACRO
&L3      STKPOP &ARG,&TYP
&L3      ST  R2,STKSAV2
         ST  R3,STKSAV3
         ST  R4,STKSAV4
         LH  R3,STKCOUNT   GET THE STACK COUNT
         SH  R3,=H'1'      SUBTRACT 1 WORD OFFSET OF TOP
         STH R3,STKCOUNT   STORE AS NEW SIZE
         SLA R3,2          BYTE OFFSET OF STACK TOP
         LA  R2,THESTACK   ADDRESS OF STACK BASE
         L   R4,0(3,2)    LOAD ITEM INTO REGISTER R4.
         AIF ('&TYPE' EQ 'R').ISREG
         ST&TYP R4,&ARG
         AGO .CONT
.ISREG   LR &ARG,R4
.CONT    L   R4,STKSAV4
         L   R3,STKSAV3
         L   R2,STKSAV2
         MEND
```

STKPOP: The Complete Version

```
         MACRO
&L3      STKPOP &ARG,&TYP
&L3      ST   R3,STKSAV3
         LH   R3,STKCOUNT   GET THE STACK COUNT
         CH   R3,=H'0'      IS THE COUNT POSITIVE
         BNH  Z&SYSNDX      NO, WE CANNOT POP.
         SH   R3,=H'1'      SUBTRACT 1 WORD OFFSET OF TOP
         STH  R3,STKCOUNT   STORE AS NEW SIZE
         SLA  R3,2          BYTE OFFSET OF STACK TOP
         ST   R2,STKSAV2    SAVE REGISTER R2
         ST   R4,STKSAV4    SAVE REGISTER R4
         LA   R2,THESTACK   ADDRESS OF STACK BASE
         L    R4,0(3,2)    LOAD ITEM INTO REGISTER R4.
         AIF  ('&TYPE' EQ 'R').ISREG
         ST&TYP R4,&ARG
         AGO  .CONT
.ISREG   LR &ARG,R4
.CONT    L    R4,STKSAV4
         L    R2,STKSAV2
Z&SYSNDX L    R3,STKSAV3
         MEND
```

Original Code for the Macro Expansions

```
                                          33 *        MACRO DEFINITIONS
                                          34 *
                                          35          MACRO
                                          36 &L2      STKPUSH &ARG,&TYP
                                          37 &L2      LH     R3,STKCOUNT
                                          38          SLA    R3,2
                                          39          LA     R2,THESTACK
                                          40          L&TYP  R4,&ARG
                                          41          ST     R4,0(3,2)
                                          42          LH     R3,STKCOUNT
                                          43          AH     R3,=H'1'
                                          44          STH    3,STKCOUNT
                                          45          MEND
                                          46 *
                                          89 *        SOME MACRO INVOCATIONS
                                          90 *
                                          91          STKPUSH R7,R
00004A 4830 C0C6                 000CC    92+         LH     R3,STKCOUNT
00004E 8B30 0002                 00002    93+         SLA    R3,2
000052 4120 C0CA                 000D0    94+         LA     R2,THESTACK
000056 1847                               95+         LR     R4,R7
000058 5043 2000                 00000    96+         ST     R4,0(3,2)
00005C 4830 C0C6                 000CC    97+         LH     R3,STKCOUNT
000060 4A30 C43A                 00440    98+         AH     R3,=H'1'
000064 4030 C0C6                 000CC    99+         STH    3,STKCOUNT
                                         100          STKPUSH HHW,H
000068 4830 C0C6                 000CC   101+         LH     R3,STKCOUNT
00006C 8B30 0002                 00002   102+         SLA    R3,2
000070 4120 C0CA                 000D0   103+         LA     R2,THESTACK
000074 4840 C1CE                 001D4   104+         LH     R4,HHW
000078 5043 2000                 00000   105+         ST     R4,0(3,2)
00007C 4830 C0C6                 000CC   106+         LH     R3,STKCOUNT
000080 4A30 C43A                 00440   107+         AH     R3,=H'1'
000084 4030 C0C6                 000CC   108+         STH    3,STKCOUNT
                                         109          STKPUSH FFW
000088 4830 C0C6                 000CC   110+         LH     R3,STKCOUNT
00008C 8B30 0002                 00002   111+         SLA    R3,2
000090 4120 C0CA                 000D0   112+         LA     R2,THESTACK
000094 5840 C1CA                 001D0   113+         L      R4,FFW
000098 5043 2000                 00000   114+         ST     R4,0(3,2)
00009C 4830 C0C6                 000CC   115+         LH     R3,STKCOUNT
0000A0 4A30 C43A                 00440   116+         AH     R3,=H'1'
0000A4 4030 C0C6                 000CC   117+         STH    3,STKCOUNT
                                         118          STKPUSH FFW,A
0000A8 4830 C0E6                 000EC   119+         LH     R3,STKCOUNT
0000AC 8B30 0002                 00002   120+         SLA    R3,2
0000B0 4120 C0EA                 000F0   121+         LA     R2,THESTACK
0000B4 4140 C1EA                 001F0   122+         LA     R4,FFW
0000B8 5043 2000                 00000   123+         ST     R4,0(3,2)
0000BC 4830 C0E6                 000EC   124+         LH     R3,STKCOUNT
0000C0 4A30 C45A                 00460   125+         AH     R3,=H'1'
0000C4 4030 C0E6                 000EC   126+         STH    3,STKCOUNT
                                         127 *
                                         136 **********************************
```

Revised Code for the Macros

The next few pages show the listing of the final forms of the macros, as actually coded and tested. These are followed by listings of the expanded macros.

```
*
         MACRO
&L1      STKINIT
&L1      ST R3,STKSAV3
         SR R3,R3
         STH R3,STKCOUNT             CLEAR THE COUNT
         L  R3,STKSAV3
         MEND
*

         MACRO
&L2      STKPUSH &ARG,&TYP
&L2      ST    R3,STKSAV3           SAVE REGISTER R3
         LH    R3,STKCOUNT          GET THE CURRENT SIZE
         CH    R3,STKSIZE           IS THE STACK FULL?
         BNL   Z&SYSNDX             YES, DO NOT PUSH
         ST    R4,STKSAV4           OK, SAVE R2 AND R4
         ST    R2,STKSAV2
         SLA   R3,2                 MULTIPLY BY FOUR
         LA    R2,THESTACK          ADDRESS OF STACK START
         L&TYP R4,&ARG              LOAD R4 WITH VALUE
         ST    R4,0(3,2)            STORE INTO THE STACK
         LH    R3,STKCOUNT
         AH    R3,=H'1'
         STH   3,STKCOUNT
         L     R4,STKSAV4
         L     R2,STKSAV2
Z&SYSNDX L     R3,STKSAV3
         MEND
*
*
```

```
        MACRO
&L3     STKPOP &ARG,&TYP
&L3     ST    R3,STKSAV3
        LH    R3,STKCOUNT      GET THE STACK COUNT
        CH    R3,=H'0'         IS THE COUNT POSITIVE?
        BNH   Z&SYSNDX         NO, WE CANNOT POP
        SH    R3,=H'1'         SUBTRACT 1 WORD OFFSET
        STH   R3,STKCOUNT      STORE THE NEW SIZE
        SLA   R3,2             BYTE OFFSET OF STACK TOP
        ST    R2,STKSAV2       SAVE REGISTER R2
        ST    R4,STKSAV4       SAVE REGISTER R4
        LA    R2,THESTACK      ADDRESS OF STACK BASE
        L     R4,0(3,2)        LOAD ITEM INTO R4
        AIF   ('&TYP' EQ 'R').ISREG
        ST&TYP R4,&ARG
        AGO .CONT
.ISREG  LR &ARG,R4
.CONT   L   R4,STKSAV4
        L   R2,STKSAV2
Z&SYSNDX L   R3,STKSAV3
        MEND
*
```

Revised Code for the Macro STKINIT
Here is an expansion of the newer definition of STKINIT, which allows the stack size to be specified.

```
                                 138          STKINIT 128
00004A 5030 C05E         00064   139+         ST R3,STKSAV3
00004E 1B33                      140+         SR R3,R3
000050 4030 C056         0005C   141+         STH R3,STKCOUNT
000054 5830 C05E         00064   142+         L  R3,STKSAV3
000058 47F0 C266         0026C   143+         B  L0009
00005C 0000                      144+STKCOUNT DC H'0'
00005E 0080                      145+STKSIZE  DC H'128'
000060 00000000                  146+STKSAV2  DC F'0'
000064 00000000                  147+STKSAV3  DC F'0'
000068 00000000                  148+STKSAV4  DC F'0'
```

Revised Code for the Macro Expansions

```
                                  128 *         SOME MACRO INVOCATIONS
                                  129 *
                                  130           STKINIT
00004A 5030 C22E           00234  131+          ST  R3,STKSAV3
00004E 1B33                       132+          SR  R3,R3
000050 4030 C226           0022C  133+          STH R3,STKCOUNT
000054 5830 C22E           00234  134+          L   R3,STKSAV3
                                  135 *
```

*   **Stack Push with a Register as an Argument**

```
                                  136           STKPUSH R7,R
000058 5030 C22E           00234  137+          ST     R3,STKSAV3
00005C 4830 C226           0022C  138+          LH     R3,STKCOUNT
000060 4930 C228           0022E  139+          CH     R3,STKSIZE
000064 47B0 C08C           00092  140+          BNL    Z0010
000068 5040 C232           00238  141+          ST     R4,STKSAV4
00006C 5020 C22A           00230  142+          ST     R2,STKSAV2
000070 8B30 0002           00002  143+          SLA    R3,2
000074 4120 C236           0023C  144+          LA     R2,THESTACK
000078 1847                       145+          LR     R4,R7
00007A 5043 2000           00000  146+          ST     R4,0(3,2)
00007E 4830 C226           0022C  147+          LH     R3,STKCOUNT
000082 4A30 C5A2           005A8  148+          AH     R3,=H'1'
000086 4030 C226           0022C  149+          STH    3,STKCOUNT
00008A 5840 C232           00238  150+          L      R4,STKSAV4
00008E 5820 C22A           00230  151+          L      R2,STKSAV2
000092 5830 C22E           00234  152+Z0010     L      R3,STKSAV3
```

*   **Stack Push with a Halfword as an Argument**

```
                                  153           STKPUSH HHW,H
000096 5030 C22E           00234  154+          ST     R3,STKSAV3
00009A 4830 C226           0022C  155+          LH     R3,STKCOUNT
00009E 4930 C228           0022E  156+          CH     R3,STKSIZE
0000A2 47B0 C0CC           000D2  157+          BNL    Z0011
0000A6 5040 C232           00238  158+          ST     R4,STKSAV4
0000AA 5020 C22A           00230  159+          ST     R2,STKSAV2
0000AE 8B30 0002           00002  160+          SLA    R3,2
0000B2 4120 C236           0023C  161+          LA     R2,THESTACK
0000B6 4840 C33A           00340  162+          LH     R4,HHW
0000BA 5043 2000           00000  163+          ST     R4,0(3,2)
0000BE 4830 C226           0022C  164+          LH     R3,STKCOUNT
0000C2 4A30 C5A2           005A8  165+          AH     R3,=H'1'
0000C6 4030 C226           0022C  166+          STH    3,STKCOUNT
0000CA 5840 C232           00238  167+          L      R4,STKSAV4
0000CE 5820 C22A           00230  168+          L      R2,STKSAV2
0000D2 5830 C22E           00234  169+Z0011     L      R3,STKSAV3
```

***   Stack Push with a Fullword as an Argument**

```
                                    170          STKPUSH FFW
0000D6 5030 C22E           00234    171+         ST     R3,STKSAV3
0000DA 4830 C226           0022C    172+         LH     R3,STKCOUNT
0000DE 4930 C228           0022E    173+         CH     R3,STKSIZE
0000E2 47B0 C10C           00112    174+         BNL    Z0012
0000E6 5040 C232           00238    175+         ST     R4,STKSAV4
0000EA 5020 C22A           00230    176+         ST     R2,STKSAV2
0000EE 8B30 0002           00002    177+         SLA    R3,2
0000F2 4120 C236           0023C    178+         LA     R2,THESTACK
0000F6 5840 C336           0033C    179+         L      R4,FFW
0000FA 5043 2000           00000    180+         ST     R4,0(3,2)
0000FE 4830 C226           0022C    181+         LH     R3,STKCOUNT
000102 4A30 C5A2           005A8    182+         AH     R3,=H'1'
000106 4030 C226           0022C    183+         STH    3,STKCOUNT
00010A 5840 C232           00238    184+         L      R4,STKSAV4
00010E 5820 C22A           00230    185+         L      R2,STKSAV2
000112 5830 C22E           00234    186+Z0012    L      R3,STKSAV3
```

***   Stack Push with an Address as an Argument**

```
                                    187          STKPUSH FFW,A
000116 5030 C22E           00234    188+         ST     R3,STKSAV3
00011A 4830 C226           0022C    189+         LH     R3,STKCOUNT
00011E 4930 C228           0022E    190+         CH     R3,STKSIZE
000122 47B0 C14C           00152    191+         BNL    Z0013
000126 5040 C232           00238    192+         ST     R4,STKSAV4
00012A 5020 C22A           00230    193+         ST     R2,STKSAV2
00012E 8B30 0002           00002    194+         SLA    R3,2
000132 4120 C236           0023C    195+         LA     R2,THESTACK
000136 4140 C336           0033C    196+         LA     R4,FFW
00013A 5043 2000           00000    197+         ST     R4,0(3,2)
00013E 4830 C226           0022C    198+         LH     R3,STKCOUNT
000142 4A30 C5A2           005A8    199+         AH     R3,=H'1'
000146 4030 C226           0022C    200+         STH    3,STKCOUNT
00014A 5840 C232           00238    201+         L      R4,STKSAV4
00014E 5820 C22A           00230    202+         L      R2,STKSAV2
000152 5830 C22E           00234    203+Z0013    L      R3,STKSAV3
                                    204 *
```

***   Stack Pop with a Register as an Argument**

```
                                    205          STKPOP  R8,R
000156 5030 C22E           00234    206+         ST     R3,STKSAV3
00015A 4830 C226           0022C    207+         LH     R3,STKCOUNT
00015E 4930 C5A4           005AA    208+         CH     R3,=H'0'
000162 47D0 C186           0018C    209+         BNH    Z0014
000166 4B30 C5A2           005A8    210+         SH     R3,=H'1'
00016A 4030 C226           0022C    211+         STH    R3,STKCOUNT
00016E 8B30 0002           00002    212+         SLA    R3,2
000172 5020 C22A           00230    213+         ST     R2,STKSAV2
000176 5040 C232           00238    214+         ST     R4,STKSAV4
00017A 4120 C236           0023C    215+         LA     R2,THESTACK
00017E 5843 2000           00000    216+         L      R4,0(3,2)
000182 1884                         217+         LR R8,R4
000184 5840 C232           00238    218+         L    R4,STKSAV4
000188 5820 C22A           00230    219+         L    R2,STKSAV2
00018C 5830 C22E           00234    220+Z0014    L    R3,STKSAV3
```

```
*       Stack Pop with a Fullword as an Argument
                                          221          STKPOP   FFW
000190 5030 C22E               00234     222+          ST      R3,STKSAV3
000194 4830 C226               0022C     223+          LH      R3,STKCOUNT
000198 4930 C5A4               005AA     224+          CH      R3,=H'0'
00019C 47D0 C1C2               001C8     225+          BNH     Z0015
0001A0 4B30 C5A2               005A8     226+          SH      R3,=H'1'
0001A4 4030 C226               0022C     227+          STH     R3,STKCOUNT
0001A8 8B30 0002               00002     228+          SLA     R3,2
0001AC 5020 C22A               00230     229+          ST      R2,STKSAV2
0001B0 5040 C232               00238     230+          ST      R4,STKSAV4
0001B4 4120 C236               0023C     231+          LA      R2,THESTACK
0001B8 5843 2000               00000     232+          L       R4,0(3,2)
0001BC 5040 C336               0033C     233+          ST       R4,FFW
0001C0 5840 C232               00238     234+          L     R4,STKSAV4
0001C4 5820 C22A               00230     235+          L     R2,STKSAV2
0001C8 5830 C22E               00234     236+Z0015     L     R3,STKSAV3

*       Stack Pop with a Halfword as an Argument
                                          237          STKPOP   HHW,H
0001CC 5030 C22E               00234     238+          ST      R3,STKSAV3
0001D0 4830 C226               0022C     239+          LH      R3,STKCOUNT
0001D4 4930 C5A4               005AA     240+          CH      R3,=H'0'
0001D8 47D0 C1FE               00204     241+          BNH     Z0016
0001DC 4B30 C5A2               005A8     242+          SH      R3,=H'1'
0001E0 4030 C226               0022C     243+          STH     R3,STKCOUNT
0001E4 8B30 0002               00002     244+          SLA     R3,2
0001E8 5020 C22A               00230     245+          ST      R2,STKSAV2
0001EC 5040 C232               00238     246+          ST      R4,STKSAV4
0001F0 4120 C236               0023C     247+          LA      R2,THESTACK
0001F4 5843 2000               00000     248+          L       R4,0(3,2)
0001F8 4040 C33A               00340     249+          STH      R4,HHW
0001FC 5840 C232               00238     250+          L     R4,STKSAV4
000200 5820 C22A               00230     251+          L     R2,STKSAV2
000204 5830 C22E               00234     252+Z0016     L     R3,STKSAV3
                                          253 *
00006C 0000000000000000                  149+THESTACK DC 128F'0'
00026C 8B30 0000               00000     150+L0009     SLA R3,0
```