UNIT-IV: MACRO PROCESSOR

A Macro represents a commonly used group of statements in the source programming language.

- A macro instruction (macro) is a notational convenience for the programmer
  - It allows the programmer to write shorthand version of a program (module programming)
- The macro processor replaces each macro instruction with the corresponding group of source language statements (expanding)
  - Normally, it performs no analysis of the text it handles.
  - It does not concern the meaning of the involved statements during macro expansion.
- The design of a macro processor generally is machine independent!
- Two new assembler directives are used in macro definition
  - MACRO: identify the beginning of a macro definition
  - MEND: identify the end of a macro definition
- Prototype for the macro
  - Each parameter begins with ‘&’
    - name MACRO parameters:
      - body
      - MEND
  - Body: the statements that will be generated as the expansion of the macro.

4.1 Basic Macro Processor Functions:

- Macro Definition and Expansion
- Macro Processor Algorithms and Data structures

4.1.1 Macro Definition and Expansion:

The figure shows the MACRO expansion. The left block shows the MACRO definition and the right block shows the expanded macro replacing the MACRO call with its block of executable instruction.

M1 is a macro with two parameters D1 and D2. The MACRO stores the contents of register A in D1 and the contents of register B in D2. Later M1 is invoked with the parameters DATA1 and DATA2, Second time with DATA4 and DATA3. Every call of MACRO is expended with the executable statements.
The statement M1 DATA1, DATA2 is a macro invocation statements that gives the name of the macro instruction being invoked and the arguments (M1 and M2) to be used in expanding. A macro invocation is referred as a Macro Call or Invocation.

**Macro Expansion:**

The program with macros is supplied to the macro processor. Each macro invocation statement will be expanded into the statement s that form the body of the macro, with the arguments from the macro invocation substituted for the parameters in the macro prototype. During the expansion, the macro definition statements are deleted since they are no longer needed.

The arguments and the parameters are associated with one another according to their positions. The first argument in the macro matches with the first parameter in the macro prototype and so on.

After macro processing the expanded file can become the input for the Assembler. The Macro Invocation statement is considered as comments and the statement generated from expansion is treated exactly as though they had been written directly by the programmer.

The difference between Macros and Subroutines is that the statement s from the body of the Macro is expanded the number of times the macro invocation is encountered, whereas the statement of the subroutine appears only once no matter how many times the subroutine is called. Macro instructions will be written so that the body of the macro contains no labels.

- Problem of the label in the body of macro:
  - If the same macro is expanded multiple times at different places in the program …
  - There will be duplicate labels, which will be treated as errors by the assembler.

- Solutions:
Do not use labels in the body of macro.
Explicitly use PC-relative addressing instead.
- Ex, in RDBUFF and WRBUFF macros,
  - JEQ *+11
  - JLT *-14
- It is inconvenient and error-prone.

The following program shows the concept of Macro Invocation and Macro Expansion.

170 .
175 .
180 FIRST STL RETADR SAVE RETURN ADDRESS
190 CLOOP RDBUFF F1,BUFFER,LENGTH READ RECORD INTO BUFFER
195 LDA LENGTH TEST FOR END OF FILE
200 COMP #0
205 JEQ ENDFIL EXIT IF EOF FOUND
210 WRBUFF 05,BUFFER,LENGTH WRITE OUTPUT RECORD
215 J CLOOP LOOP
220 ENDFIL WRBUFF 05,EOF,THREE INSERT EOF MARKER
225 J @RETADR
230 EOF BYTE C’EOF’
235 THREE WORD 3
240 RETADR RESW 1
245 LENGTH RESW 1 LENGTH OF RECORD
250 BUFFER RESB 4096 4096-Byte BUFFER AREA
255 END FIRST
4.1.2 Macro Processor Algorithm and Data Structure:

Design can be done as two-pass or a one-pass macro. In case of two-pass assembler.

Two-pass macro processor
- You may design a two-pass macro processor
  - Pass 1:
    - Process all macro definitions
  - Pass 2:
    - Expand all macro invocation statements
- However, one-pass may be enough
  - Because all macros would have to be defined during the first pass before any macro invocations were expanded.
    - The definition of a macro must appear before any statements that invoke that macro.
- Moreover, the body of one macro can contain definitions of the other macro
- Consider the example of a Macro defining another Macro.
- In the example below, the body of the first Macro (MACROS) contains statement that define RDBUFF, WRBUFF and other macro instructions for SIC machine.
- The body of the second Macro (MACROX) defines the same macros for SIC/XE machine.
- A proper invocation would make the same program to perform macro invocation to run on either SIC or SIC/XEmachine.
MACROS for SIC machine

```plaintext
1 MACROS MACOR {Defines SIC standard version macros}
2 RDBUFF MACRO &INDEV,&BUFADR,&RECLTH
   .
   . {SIC standard version}
3 MEND {End of RDBUFF}
4 WRBUFF MACRO &OUTDEV,&BUFADR,&RECLTH
   .
   . {SIC standard version}
5 MEND {End of WRBUFF}
6 MEND {End of MACROS}
```

Fig 4.3(a)

MACROX for SIC/XE Machine

```plaintext
1 MACROX MACRO {Defines SIC/XE macros}
2 RDBUFF MACRO &INDEV,&BUFADR,&RECLTH
   .
   . {SIC/XE version}
3 MEND {End of RDBUFF}
4 WRBUFF MACRO &OUTDEV,&BUFADR,&RECLTH
   .
   . {SIC/XE version}
5 MEND {End of WRBUFF}
6 MEND {End of MACROX}
```

Fig 4.3(b)

- A program that is to be run on SIC system could invoke MACROS whereas a program to be run on SIC/XE can invoke MACROX.
- However, defining MACROS or MACROX does not define RDBUFF and WRBUFF.
- These definitions are processed only when an invocation of MACROS or MACROX is expanded.

**One-Pass Macro Processor:**
• A one-pass macro processor that alternate between *macro definition* and *macro expansion* in a recursive way is able to handle recursive macro definition.

• **Restriction**
  o The definition of a macro must appear in the source program before any statements that invoke that macro.
  o This restriction does not create any real inconvenience.

The design considered is for one-pass assembler. The data structures required are:

• **DEFTAB (Definition Table)**
  o Stores the macro definition including *macro prototype* and *macro body*
  o Comment lines are omitted.
  o References to the macro instruction parameters are converted to a positional notation for efficiency in substituting arguments.

• **NAMTAB (Name Table)**
  o Stores macro names
  o Serves as an index to DEFTAB
    • Pointers to the beginning and the end of the macro definition (DEFTAB)

• **ARGTAB (Argument Table)**
  o Stores the arguments according to their positions in the argument list.
  o As the macro is expanded the arguments from the Argument table are substituted for the corresponding parameters in the macro body.
  o The figure below shows the different data structures described and their relationship.

![Diagram](image_url)

**Fig 4.4**

The above figure shows the portion of the contents of the table during the processing of the program in page no. 3. In fig 4.4(a) definition of RDBUFF is stored in DEFTAB, with
an entry in NAMTAB having the pointers to the beginning and the end of the definition. The arguments referred by the instructions are denoted by their positional notations. For example,

\[
TD = X'1'
\]

The above instruction is to test the availability of the device whose number is given by the parameter \&INDEV. In the instruction this is replaced by its positional value \(1\).

Figure 4.4(b) shows the ARTAB as it would appear during expansion of the RDBUFF statement as given below:

\[
CLOOP RDBUFF F1, BUFFER, LENGTH
\]

For the invocation of the macro RDBUFF, the first parameter is \(F1\) (input device code), second is \(BUFFER\) (indicating the address where the characters read are stored), and the third is \(LENGTH\) (which indicates total length of the record to be read). When the \(?n\) notation is encountered in a line from DEFTAB, a simple indexing operation supplies the proper argument from ARGTAB.

The algorithm of the Macro processor is given below. This has the procedure DEFINE to make the entry of \textit{macro name} in the NAMTAB, \textit{Macro Prototype} in DEFTAB. EXPAND is called to set up the argument values in ARGTAB and expand a \textit{Macro Invocation} statement. Procedure GETLINE is called to get the next line to be processed either from the DEFTAB or from the file itself.

When a macro definition is encountered it is entered in the DEFTAB. The normal approach is to continue entering till MEND is encountered. If there is a program having a Macro defined within another Macro. While defining in the DEFTAB the very first MEND is taken as the end of the Macro definition. This does not complete the definition as there is another outer Macro which completes the definition of Macro as a whole. Therefore the DEFINE procedure keeps a counter variable LEVEL. Every time a Macro directive is encountered this counter is incremented by 1. The moment the innermost Macro ends indicated by the directive MEND it starts decreasing the value of the counter variable by one. The last MEND should make the counter value set to zero. So when LEVEL becomes zero, the MEND corresponds to the original MACRO directive.

Most macro processors allow the definitions of the commonly used instructions to appear in a standard system library, rather than in the source program. This makes the use of macros convenient; definitions are retrieved from the library as they are needed during macro processing.
Procedure GETLINE
If EXPANDING then
get the next line to be processed from DEFTAB
Else
read next line from input file

Procedure PROCESSLINE
• DEFINE
• EXPAND
• Output source line

Procedure EXPAND
Set up the argument values in ARGTABLE
Expand a macro invocation statement (like in MAIN procedure)
• Iterations of
  • GETLINE
  • PROCESSLINE

Procedure DEFINE
Make appropriate entries in DEFTAB and NAMTAB

Fig 4.5
Algorithms

\[ \text{begin} \{\text{macro processor}\} \]
\[ \text{EXPANDING} := \text{FALSE} \]
\[ \text{while} \ \text{_OPCODE} \neq \text{‘END’} \ \text{do} \]
\[ \text{begin} \]
\[ \text{GETLINE} \]
\[ \text{PROCESSLINE} \]
\[ \text{end} \{\text{while}\} \]
\[ \text{end} \{\text{macro processor}\} \]

\textbf{Procedure} \ PROCESSLINE
\[ \text{begin} \]
\[ \text{search MAMTAB for } \text{_OPCODE} \]
\[ \text{if found then} \]
\[ \text{EXPAND} \]
\[ \text{else if } \text{_OPCODE} = \text{‘MACRO’} \ \text{then} \]
\[ \text{DEFINE} \]
\[ \text{else} \ \text{write source line to expanded file} \]
\[ \text{end} \{\text{PROCCESSOR}\} \]

\textbf{Procedure} \ DEFINE
\[ \text{begin} \]
\[ \text{enter macro name into NAMTAB} \]
\[ \text{enter macro prototype into DEFTAB} \]
\[ \text{LEVEL} := 1 \]
\[ \text{while} \ \text{LEVEL} > 0 \ \text{do} \]
\[ \text{begin} \]
\[ \text{GETLINE} \]
\[ \text{if this is not a comment line then} \]
\[ \text{begin} \]
\[ \text{substitute positional notation for parameters} \]
\[ \text{enter line into DEFTAB} \]
\[ \text{if } \text{_OPCODE} = \text{‘MACRO’} \ \text{then} \]
\[ \text{LEVEL} := \text{LEVEL} + 1 \]
\[ \text{else if } \text{_OPCODE} = \text{‘MEND’} \ \text{then} \]
\[ \text{LEVEL} := \text{LEVEL} - 1 \]
\[ \text{end} \{\text{if not comment}\} \]
\[ \text{end} \{\text{while}\} \]
\[ \text{store in NAMTAB pointers to beginning and end of definition} \]
\[ \text{end} \{\text{DEFINE}\} \]
4.1.3 Comparison of Macro Processor Design

- **One-pass algorithm**
  - Every macro must be defined before it is called
  - One-pass processor can alternate between macro definition and macro expansion
  - Nested macro definitions are allowed but nested calls are not allowed.

- **Two-pass algorithm**
  - Pass1: Recognize macro definitions
  - Pass2: Recognize macro calls
  - Nested macro definitions are not allowed

**Procedure EXPAND**
begin
EXPANDING := TRUE
get first line of macro definition \{prototype\} from DEFTAB
set up arguments from macro invocation in ARGTAB
while macro invocation to expanded file as a comment
while not end of macro definition do
  begin
    GETLINE
    PROCESSLINE
  end {while}
EXPANDING := FALSE
end {EXPAND}

**Procedure GETLINE**
begin
  if EXPANDING then
    begin
      get next line of macro definition from DEFTAB
      substitute arguments from ARGTAB for positional notation
    end {if}
  else
    read next line from input file
  end {GETLINE}

Fig 4.6
4.1 Machine-independent Macro-Processor Features.

The design of macro processor doesn’t depend on the architecture of the machine. We will be studying some extended feature for this macro processor. These features are:

- Concatenation of Macro Parameters
- Generation of unique labels
- Conditional Macro Expansion
- Keyword Macro Parameters

4.2.1 Concatenation of unique labels:

Most macro processors allow parameters to be concatenated with other character strings. Suppose that a program contains a series of variables named by the symbols XA1, XA2, XA3,…, another series of variables named XB1, XB2, XB3,…, etc. If similar processing is to be performed on each series of labels, the programmer might put this as a macro instruction. The parameter to such a macro instruction could specify the series of variables to be operated on (A, B, etc.). The macro processor would use this parameter to construct the symbols required in the macro expansion (XA1, Xb1, etc.).

Suppose that the parameter to such a macro instruction is named &ID. The body of the macro definition might contain a statement like

\[ \text{LDA X}&ID1 \]

\[ \text{LDA X}&ID \rightarrow \]

\[ \text{LAD XA1} \]
\[ \text{ADD XA2} \]
\[ \text{STA XA3} \]

**Fig 4.7**

& is the starting character of the macro instruction; but the end of the parameter is not marked. So in the case of &ID1, the macro processor could deduce the meaning that was intended. If the macro definition contains contain &ID and &ID1 as parameters, the situation would be unavoidably ambiguous.

Most of the macro processors deal with this problem by providing a special concatenation operator. In the SIC macro language, this operator is the character →. Thus the statement LDA X&ID1 can be written as

\[ \text{LDA X}&ID \rightarrow \]
The above figure shows a macro definition that uses the concatenation operator as previously described. The statement SUM A and SUM BETA shows the invocation statements and the corresponding macro expansion.

### 4.2.2 Generation of Unique Labels

As discussed it is not possible to use labels for the instructions in the macro definition, since every expansion of macro would include the label repeatedly which is not allowed by the assembler. This in turn forces us to use relative addressing in the jump instructions. Instead we can use the technique of generating unique labels for every macro invocation and expansion. During macro expansion each $ will be replaced with $XX, where xx is a two-character alphanumeric counter of the number of macro instructions expansion.

For example,

XX = AA, AB, AC…

This allows 1296 macro expansions in a single program.
The following program shows the macro definition with labels to the instruction.

25    RDBUFF MACRO &INDEV, &BUFADR, &RECLTH
30        CLEAR X           CLEAR LOOP COUNTER
35        CLEAR A
40        CLEAR S
45      +LDT #4096          SET MAXIMUM RECORD LENGTH
50      $LOOP TD =X'&INDEV' TEST INPUT DEVICE
55        JEQ $LOOP           LOOP UNTIL READY
60        RD =X'&INDEV'      READ CHARACTER INTO REG A
65       COMPR A, S       TEST FOR END OF RECORD
70        JEQ $EXIT             EXIT LOOP IF EOR
75       STCH &BUFADR, X   STORE CHARACTER IN BUFFER
80       TIXR $LOOP           HAS BEEN REACHED
90      $EXIT STX &RECLTH   SAVE RECORD LENGTH
MEND

The following figure shows the macro invocation and expansion first time.

. RDBUFF F1, BUFFER, LENGTH

30        CLEAR X           CLEAR LOOP COUNTER
35        CLEAR A
40        CLEAR S
45      +LDT #4096          SET MAXIMUM RECORD LENGTH
50      $AALOOP TD =X'F1'        TEST INPUT DEVICE
55        JEQ $AALOOP       LOOP UNTIL READY
60        RD =X'F1'        READ CHARACTER INTO REG A
65       COMPR A, S       TEST FOR END OF RECORD
70        JEQ $AAEXIT           EXIT LOOP IF EOR
75       STCH BUFFER, X   STORE CHARACTER IN BUFFER
80       TIXR T           LOOP UNLESS MAXIMUM LENGTH
85       JLT $AALOOP       HAS BEEN REACHED
90      $AAEXIT STX LENGTH   SAVE RECORD LENGTH

If the macro is invoked second time the labels may be expanded as $SABLOOP $SABEXIT.
4.2.3 Conditional Macro Expansion

There are applications of macro processors that are not related to assemblers or assembler programming.

Conditional assembly depends on parameters provides

```assembly
MACRO &COND
    .......
    IF (&COND NE '')
       part I
    ELSE
       part II
    ENDIF
    .......
ENDM
```

Part I is expanded if condition part is true, otherwise part II is expanded. Compare operators: NE, EQ, LE, GT.

**Macro-Time Variables:**

Macro-time variables (often called as SET Symbol) can be used to store working values during the macro expansion. Any symbol that begins with symbol & and not a macro instruction parameter is considered as *macro-time variable*. All such variables are initialized to zero.

![Fig 4.9(a)](image-url)
Figure 4.5(a) gives the definition of the macro RDBUFF with the parameters &INDEV, &BUFADR, &RECLTH, &EOR, &MAXLTH. According to the above program if &EOR has any value, then &EORCK is set to 1 by using the directive SET, otherwise it retains its default value 0.

```
   .   RDBUFF F31 BUF, RECL, 04, 2048

30    CLEAR X          CLEAR LOOP COUNTER
35    CLEAR A
40    LDCH =x'04'     SET EOR CHARACTER
42    RMO A, S
47    +LDT #2048     SET MAXIMUM RECORD LENGTH
50    $AALOOP TD =X'F3' TEST INPUT DEVICE
55    JEQ $AALOOP LOOP UNTIL READY
60    RD =X'F3'      READ CHARACTER INTO REG A
65    COMPR A, S     TEST FOR END OF RECORD
70    JEQ $AAEXIT EXIT LOOP IF EOR
75    STCH BUF, X    STORE CHARACTER IN BUFFER
80    TDXR T         LOOP UNLESS MAXIMUM LENGTH
85    JLT $AALOOP HAS BEEN REACHED
90    $AAEXIT STX RECL SAVE RECORD LENGTH
```

Fig 4.9(b) Use of Macro-Time Variable with EOF being NOT NULL

```
   .   RDBUFF OE, BUFFER, LENGTH, 80

30    CLEAR X          CLEAR LOOP COUNTER
35    CLEAR A
47    +LDT #80        SET MAXIMUM RECORD LENGTH
50    $ABLOOP TD =X'0E' TEST INPUT DEVICE
55    JEQ $ABLOOP LOOP UNTIL READY
60    RD =X'0E'      READ CHARACTER IN REG A
75    STCH BUFFER, X STORE CHARACTER IN BUFFER
80    TDXR T         LOOP UNLESS MAXIMUM LENGTH
87    JLT $ABLOOP HAS BEEN REACHED
90    $ABEXIT STX LENGTH SAVE RECORD LENGTH
```

Fig 4.9(c) Use of Macro-Time conditional statement with EOF being NULL
The above programs show the expansion of Macro invocation statements with different values for the time variables. In figure 4.9(b) the &EOF value is NULL. When the macro invocation is done, IF statement is executed. If it is true EORCK is set to 1, otherwise normal execution of the other part of the program is continued.

The macro processor must maintain a symbol table that contains the value of all macro-time variables used. Entries in this table are modified when SET statements are processed. The table is used to look up the current value of the macro-time variable whenever it is required.

When an IF statement is encountered during the expansion of a macro, the specified Boolean expression is evaluated.

**If the value of this expression TRUE,**
- The macro processor continues to process lines from the DEFTAB until it encounters the ELSE or ENDIF statement.
- If an ELSE is found, macro processor skips lines in DEFTAB until the next ENDIF.
- Once it reaches ENDIF, it resumes expanding the macro in the usual way.

**If the value of the expression is FALSE,**
- The macro processor skips ahead in DEFTAB until it encounters next ELSE or ENDIF statement.
- The macro processor then resumes normal macro expansion.

The *macro-time* IF-ELSE-ENDIF structure provides a mechanism for either generating(once) or skipping selected statements in the macro body. There is another construct WHILE statement which specifies that the following line until the next ENDW
statement, are to be generated repeatedly as long as a particular condition is true. The testing of this condition, and the looping are done during the macro is under expansion. The example shown below shows the usage of Macro-Time Looping statement.

**WHILE-ENDW structure**

- When an WHILE statement is encountered during the expansion of a macro, the specified Boolean expression is evaluated.
- **TRUE**
  - The macro processor continues to process lines from DEFTAB until it encounters the next ENDW statement.
  - When ENDW is encountered, the macro processor returns to the preceding WHILE, re-evaluates the Boolean expression, and takes action based on the new value.
- **FALSE**
  - The macro processor skips ahead in DEFTAB until it finds the next ENDW statement and then resumes normal macro expansion.

```
25 RDBUFF MACRO &INDEV, &BUFADR, &RECLTH, &EOR
27 &EORCT SET %NITEMS(&EOR)↓ Macro processor function
30 CLEAR X CLEAR LOOP COUNTER
35 CLEAR A
45 +LDT #4096 SET MAX LENGTH = 4096
50 $LOOP TD =X'&INDEV' TEST INPUT DEVICE
55 JEQ $LOOP LOOP UNTIL READY
60 RD =X'&INDEV' READ CHARACTER INTO REG A
63 &CTR SET 1
64 WHILE (&CTR LE &EORCT)↓ List index
65 COMPR =X'0000&EOR[&CTR]'
70 JEQ $EXIT
71 &CTR SET &CTR+1
73 ENDW
75 STCH &BUFADR, X STORE CHARACTER IN BUFFER
80 TIXR T LOOP UNLESS MAXIMUM LENGTH
85 JL $LOOP HAS BEEN REACHED
90 $EXIT STX &RECLTH SAVE RECORTD LENGTH
100 NEND
```
All the macro instruction definitions used positional parameters. Parameters and arguments are matched according to their positions in the macro prototype and the macro invocation statement. The programmer needs to be careful while specifying the arguments. If an argument is to be omitted the macro invocation statement must contain a null argument mentioned with two commas.

Positional parameters are suitable for the macro invocation. But if the macro invocation has a large number of parameters, and if only a few of the values need to be used in a typical invocation, a different type of parameter specification is required (for example, in many cases most of the parameters may have default values, and the invocation may mention only the changes from the default values).

Ex: XXX MACRO &P1, &P2, …., &P20, ….
XXX A1, A2,,„„„„,,„„„„„„„„„„„„„„„A20,……

Null arguments

**Keyword parameters**
- Each argument value is written with a keyword that names the corresponding parameter.
- Arguments may appear in any order.
- Null arguments no longer need to be used.
- Ex: XXX P1=A1, P2=A2, P20=A20.
- It is easier to read and much less error-prone than the positional method.
RDBUFF MACRO &INDEV=F1, &BUFADR=, &RECLTH=, &EOR=04, &MAXLTH=4096

IF (&EOR NE '+')

&EORCK SET 1

ENDIF

CLEAR X CLEAR LOOP COUNTER

CLEAR A

IF (&EORCK EQ 1)

LDCH =X'&EOR'

SET EOR CHARACTER

RMO A, S

ENDIF

+LDT #MAXLTH SET MAXIMUM RECORD LENGTH

$LOOP TD =X'&INDEV' TEST INPUT DEVICE

JEQ $LOOP LOOP UNTIL READY

RD =X'&INDEV' READ CHARACTER INTO REG A

IF (&EORCK EQ 1)

COMPR A, S TEST FOR END OF RECORD

JEQ $EXIT EXIT LOOP IF EOR

ENDIF

STCH $BUFADR, X STORE CHARACTER IN BUFFER

TIXR T LOOP UNTIL MAXIMUM LENGTH

JLT $LOOP HAS BEEN REACHED

$EXIT STX &RECLTH SAVE RECORD LENGTH

MEND

RDBUFF BUFADR=BUFFER, RECLTH=LENGTH

CLEAR X CLEAR LOOP COUNTER

CLEAR A

LDCH =X'04' SET EOR CHARACTER

RMO A, S

+LDT #4096 SET MAXIMUM RECORD LENGTH

$ALOOP TD =X'F1' TEST INPUT DEVICE

JEQ $ALOOP LOOP UNTIL READY

RD =X'F1' READ CHARACTER INTO REG A

COMPR A, S TEST FOR END OF RECORD

JEQ $AAEXIT EXIT LOOP IF EOR

STCH BUFFER, X STORE CHARACTER IN BUFFER

TIXR T LOOP UNTIL MAXIMUM LENGTH

JLT $ALOOP HAS BEEN REACHED

$AAEXIT STX LENGTH SAVE RECORD LENGTH
4.3 Macro Processor Design Options

4.3.1 Recursive Macro Expansion

We have seen an example of the definition of one macro instruction by another. But we have not dealt with the invocation of one macro by another. The following example shows the invocation of one macro by another macro.
Problem of Recursive Expansion

- Previous macro processor design cannot handle such kind of recursive macro invocation and expansion
  - The procedure EXPAND would be called recursively, thus the invocation arguments in the ARGTAB will be overwritten. (P.201)
  - The Boolean variable EXPANDING would be set to FALSE when the “inner” macro expansion is finished, *i.e.*, the macro process would forget that it had been in the middle of expanding an “outer” macro.

- Solutions
  - Write the macro processor in a programming language that allows recursive calls, thus local variables will be retained.
  - If you are writing in a language without recursion support, use a stack to take care of pushing and popping local variables and return addresses.
The procedure EXPAND would be called when the macro was recognized. The arguments from the macro invocation would be entered into ARGTAB as follows:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>BUFFER</td>
</tr>
<tr>
<td>2</td>
<td>LENGTH</td>
</tr>
<tr>
<td>3</td>
<td>F1</td>
</tr>
<tr>
<td>4</td>
<td>(unused)</td>
</tr>
</tbody>
</table>

The Boolean variable EXPANDING would be set to TRUE, and expansion of the macro invocation statement would begin. The processing would proceed normally until statement invoking RDCHAR is processed. This time, ARGTAB would look like

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>F1</td>
</tr>
<tr>
<td>2</td>
<td>(Unused)</td>
</tr>
</tbody>
</table>

At the expansion, when the end of RDCHAR is recognized, EXPANDING would be set to FALSE. Thus the macro processor would ‘forget’ that it had been in the middle of expanding a macro when it encountered the RDCHAR statement. In addition, the arguments from the original macro invocation (RDBUFF) would be lost because the value in ARGTAB was overwritten with the arguments from the invocation of RDCHAR.

### 4.3.2 General-Purpose Macro Processors

- Macro processors that do not dependent on any particular programming language, but can be used with a variety of different languages
- **Pros**
  - Programmers do not need to learn many macro languages.
  - Although its development costs are somewhat greater than those for a language specific macro processor, this expense does not need to be repeated for each language, thus save substantial overall cost.
- **Cons**
  - Large number of details must be dealt with in a real programming language
    - Situations in which normal macro parameter substitution should not occur, e.g., comments.
    - Facilities for grouping together terms, expressions, or statements
    - Tokens, e.g., identifiers, constants, operators, keywords
    - Syntax had better be consistent with the source programming language
4.3.3 Macro Processing within Language Translators

- The macro processors we discussed are called “Preprocessors”.
  - Process macro definitions
  - Expand macro invocations
  - Produce an expanded version of the source program, which is then used as input to an assembler or compiler
- You may also combine the macro processing functions with the language translator:
  - Line-by-line macro processor
  - Integrated macro processor

4.3.4 Line-by-Line Macro Processor

- Used as a sort of input routine for the assembler or compiler
  - Read source program
  - Process macro definitions and expand macro invocations
  - Pass output lines to the assembler or compiler
- Benefits
  - Avoid making an extra pass over the source program.
  - Data structures required by the macro processor and the language translator can be combined (e.g., OPTAB and NAMTAB)
  - Utility subroutines can be used by both macro processor and the language translator.
    ▪ Scanning input lines
    ▪ Searching tables
    ▪ Data format conversion
  - It is easier to give diagnostic messages related to the source statements

4.3.5 Integrated Macro Processor

- An integrated macro processor can potentially make use of any information about the source program that is extracted by the language translator.
  - Ex (blanks are not significant in FORTRAN)
    ▪ DO 100 I = 1,20
      - a DO statement
    ▪ DO 100 I = 1
      - An assignment statement
      - DO100I: variable (blanks are not significant in FORTRAN)
- An integrated macro processor can support macro instructions that depend upon the context in which they occur.