Chapter 4
Macro Processors

Chapter 4: Macro Processors

- 4.1 Basic Macro Processors Functions
- 4.2 Machine-Independent Macro Processors Features
- 4.3 Macro Processors Design Options
- 4.4 Implementation Examples

Introduction to Macro Processors

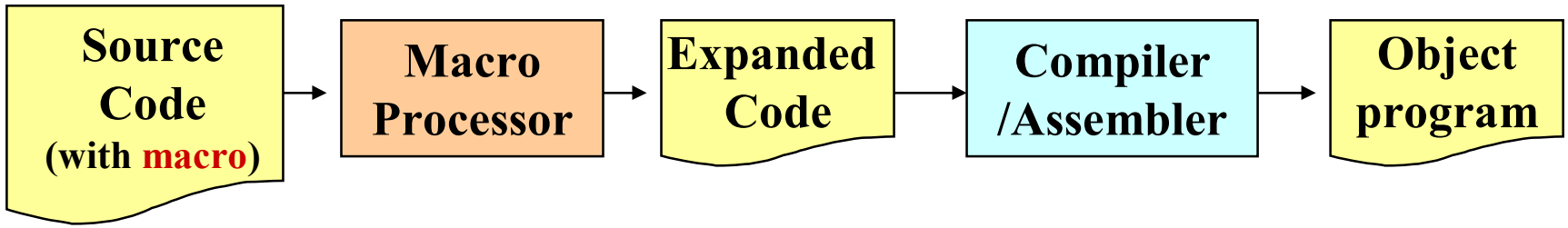
- A *macro instruction* (*macro*) is a notational convenience for the programmer.
  - Allow the programmer to write a shorthand version of a program
- A *macro* represents a commonly used group of statements in the source programming language.
- *Expanding* the macros
  - The macro processor replaces each macro instruction with the corresponding group of source language statements.

Introduction to Macro Processors (Cont.)

- A macro processor
  - Essentially involve the substitution of one group of characters or lines for another.
  - Normally, it performs no analysis of the text it handles.
  - It doesn't concern the meaning of the involved statements during macro expansion
- The design of a macro processor generally is machine independent.

Introduction to Macro Processors (Cont.)

- Three examples of actual macro processors:
  - A macro processor designed for use by assembler language programmers
  - Used with a high-level programming language
  - General-purpose macro processor, which is not tied to any particular language



Introduction to Macro Processors (Cont.)

- C uses a macro preprocessor to support language extensions, such as named constants, expressions, and file inclusion.

```
#define max(a,b)  ((a<b)?(a):(b))
#define MACBUF     4
#include <stdio.h>
```

4.1 Basic Macro Processors Functions

- *Macro processor* should processes the
  - **Macro definitions**
    - Define macro name, group of instructions
  - **Macro invocation (macro calls)**
    - A body is simply copied or substituted at the point of call
  - Expansion with substitution of parameters
    - ***Arguments*** are textually substituted for the ***parameters***
    - The resulting procedure body is textually substituted for the call

Macro Definition

- 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
- label op operands

```
name  MACRO  parameters
        :
      body
        :
      MEND
```

- Parameters: the entries in the operand field identify the parameters of the macro instruction
  - We require each parameter begins with '&'
- Body: the statements that will be generated as the expansion of the macro.
- Prototype for the macro:
  - The *macro name* and *parameters* define a pattern or *prototype* for the macro instructions used by the programmer

Fig 4.1: Macro Definition

```
 5      COPY      START   0                   COPY FILE FROM INPUT TO OUTPUT
10      RDBUFF    MACRO   &INDEV,&BUFADR,&RECLTH
15      .
20      .         MACRO TO READ RECORD INTO BUFFER
25      .
30                CLEAR   X                   CLEAR LOOP COUNTER
35                CLEAR   A
40                CLEAR   S
45               +LDT     #4096               SET MAXIMUM RECORD LENGTH
50                TD      =X'&INDEV'          TEST INPUT DEVICE
55                JEQ     *-3                 LOOP UNTIL READY
60                RD      =X'&INDEV'          READ CHARACTER INTO REG A
65                COMPR   A,S                 TEST FOR END OF RECORD
70                JEQ     *+11                EXIT LOOP IF EOR
75                STCH    &BUFADR,X           STORE CHARACTER IN BUFFER
80                TIXR    T                   LOOP UNLESS MAXIMUM LENGTH
85                JLT     *-19                  HAS BEEN REACHED
90                STX     &RECLTH             SAVE RECORD LENGTH
95                MEND
```

•**Macro definition**

Macro body contains no label

Fig 4.1: Macro Definition (Cont.)

•**Macro definition**

```
100     WRBUFF    MACRO    &OUTDEV,&BUFADR,&RECLTH
105     .
110     .         MACRO TO WRITE RECORD FROM BUFFER
115     .
120               CLEAR    X              CLEAR LOOP COUNTER
125               LDT      &RECLTH
130               LDCH     &BUFADR,X      GET CHARACTER FROM BUFFER
135               TD       =X'&OUTDEV'    TEST OUTPUT DEVICE
140               JEQ      *-3            LOOP UNTIL READY
145               WD       =X'&OUTDEV'    WRITE CHARACTER
150               TIXR     T              LOOP UNTIL ALL CHARACTERS
155               JLT      *-14             HAVE BEEN WRITTEN
160               MEND
```

Macro body contains no label

Macro Invocation

- A ***macro invocation statement*** (a ***macro call***) gives the **name** of the macro instruction being invoked and the **arguments** in expanding the macro.
- Macro Invocation vs. Subroutine Call.
  - Statements of the macro body are expanded each time the macro is invoked.
  - Statements of the subroutine appear only one, regardless of how many times the subroutine is called.
  - Macro invocation is more efficient than subroutine call, however, the code size is larger

Fig 4.1: Macro Invocation

•**Macro invocation**

```
165         .
170         .       MAIN PROGRAM
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
```

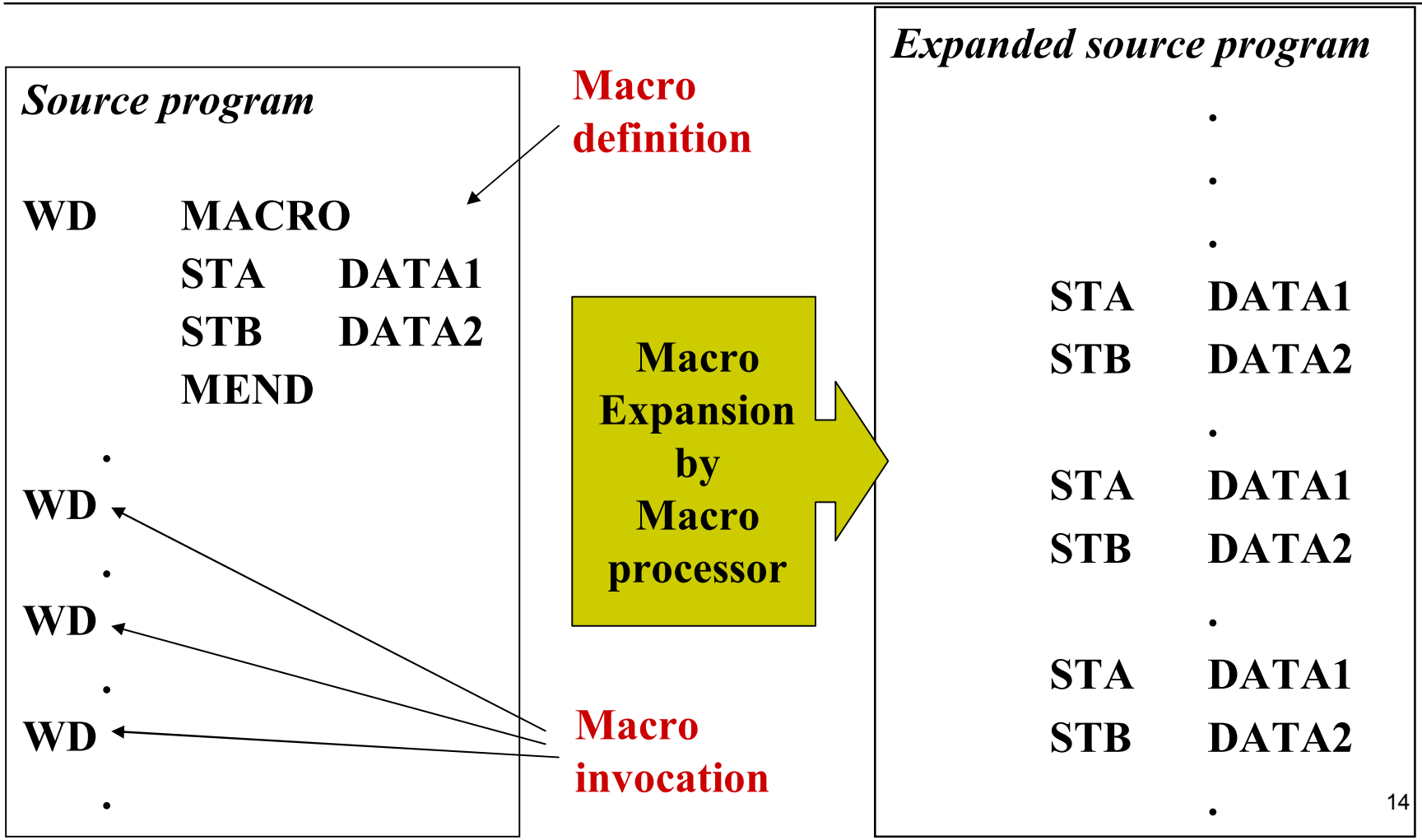
Figure 4.1 Use of macros in a SIC/XE program.

Macro Expansion

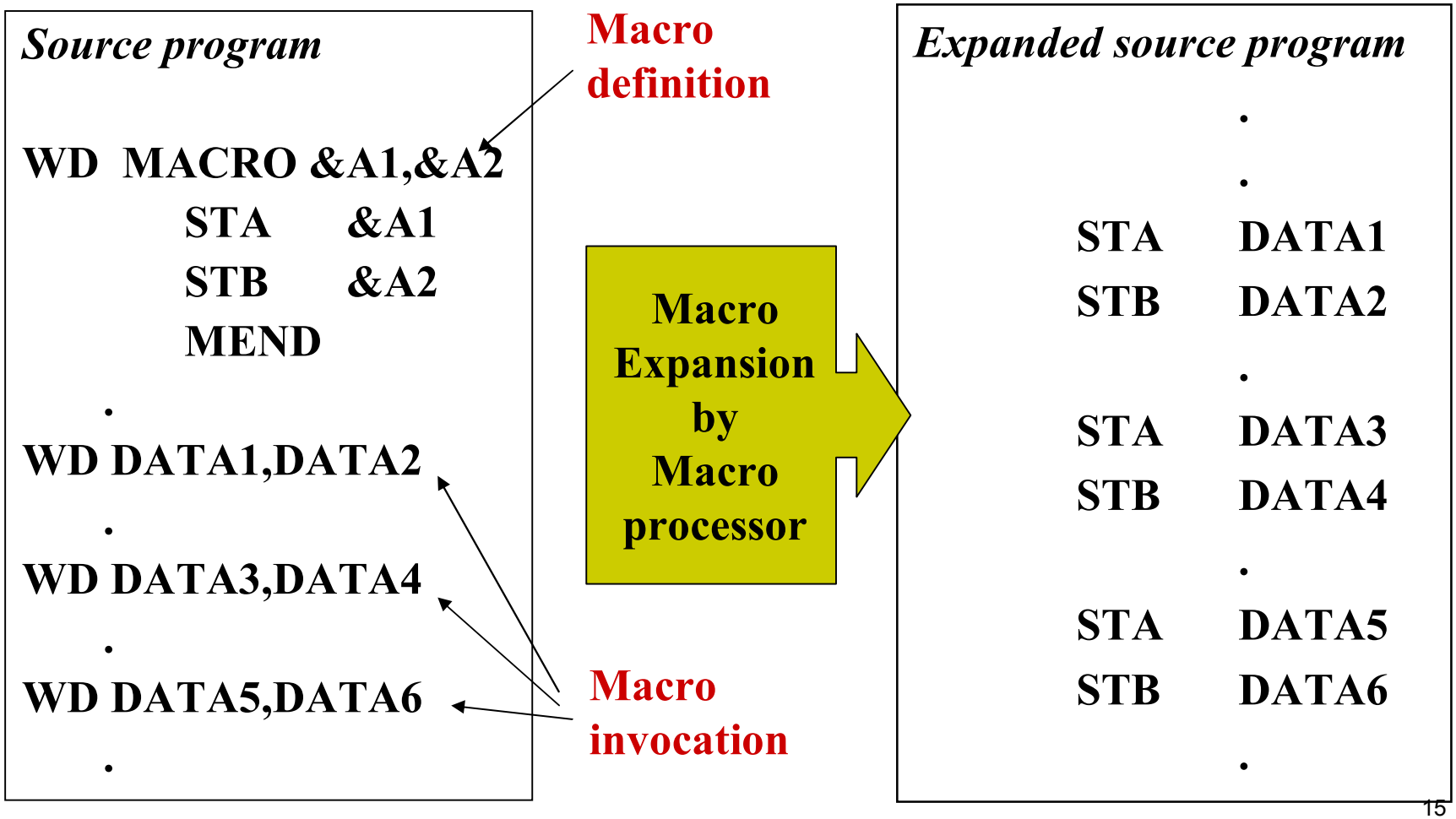
- Each macro invocation statement will be expanded into the statements that form the **body** of the macro.

- Arguments from the macro invocation are substituted for the parameters in the macro prototype.
  - The arguments and parameters are associated with one another according to their **positions.**
    - The first argument in the macro invocation corresponds to the first parameter in the macro prototype, etc.

Macro Expansion



Macro Expansion with Parameters Substitution



Program From Fig. 4.1 with Macros Expanded (fig. 4.2)

- **Macro expansion**

```
  5     COPY      START   0                 COPY FILE FROM INPUT TO OUTPUT
180     FIRST     STL     RETADR            SAVE RETURN ADDRESS
190     .CLOOP    RDBUFF  F1,BUFFER,LENGTH  READ RECORD INTO BUFFER
190a    CLOOP     CLEAR   X                 CLEAR LOOP COUNTER
190b              CLEAR   A
190c              CLEAR   S
190d             +LDT     #4096             SET MAXIMUM RECORD LENGTH
190e              TD      =X'F1'            TEST INPUT DEVICE
190f              JEQ      *-3              LOOP UNTIL READY
190g              RD      =X'F1'            READ CHARACTER INTO REG A
190h              COMPR    A,S              TEST FOR END OF RECORD
190i              JEQ      *+11             EXIT LOOP IF EOR
190j              STCH    BUFFER,X          STORE CHARACTER IN BUFFER
190k              TIXR     T                LOOP UNLESS MAXIMUM LENGTH
1901              JLT     *-19                HAS BEEN REACHED
190m              STX     LENGTH            SAVE RECORD LENGTH
```

Program From Fig. 4.1 with Macros Expanded (fig. 4.2)(Cont.)

•**Macro expansion**

```
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
210a        CLEAR    X                   CLEAR LOOP COUNTER
210b        LDT      LENGTH
210c        LDCH     BUFFER,X            GET CHARACTER FROM BUFFER
210d        TD       =X'05'              TEST OUTPUT DEVICE
210e        JEQ      *-3                 LOOP UNTIL READY
210f        WD       =X'05'              WRITE CHARACTER
210g        TIXR     T                   LOOP UNTIL ALL CHARACTERS
210h        JLT      *-14                  HAVE BEEN WRITTEN
```

Program From Fig. 4.1 with Macros Expanded (fig. 4.2)(Cont.)

- **Macro expansion**

```
215                     C       CLOOP                   LOOP
220     .ENDFIL         WRBUFF  05,EOF,THREE            INSERT EOF MARKER
220a    ENDFIL          CLEAR   X                       CLEAR LOOP COUNTER
220b                    LDT     THREE
220c                    LDCH    EOF,X                   GET CHARACTER FROM BUFFER
220d                    TD      =X'05'                  TEST OUTPUT DEVICE
220e                    JEQ     *-3                     LOOP UNTIL READY
220f                    WD      =X'05'                  WRITE CHARACTER
220g                    TIXR    T                       LOOP UNTIL ALL CHARACTERS
220h                    JLT     *-14                      HAVE BEEN WRITTEN
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
```

Figure 4.2 Program from Fig. 4.1 with macros expanded.

No Label in the Body of Macro

- 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:
  - Simply not to use labels in the body of macro.
  - Explicitly use PC-relative addressing instead.
    - For example, in RDBUFF and WRBUFF macros,

      JEQ * +11

      JLT *-14
    - It is inconvenient and error-prone.
  - Other better solution?
    - Mentioned in Section 4.2.2.

4.1.2 Macro Processors Algorithm and Data Structures

- Two-pass macro processor

- One-pass macro processor

Two-pass macro processor

- Two-pass macro processor
  - Pass1: process all *macro definitions*
  - Pass2: expand all *macro invocation* statements
- Problem
  - Does not allow *nested macro definitions*
  - Nested macro definitions
    - The body of a macro contains definitions of other macros
  - Because all macros would *have to be defined during the first pass* before any macro invocations were expanded
- Solution
  - One-pass macro processor

Nested Macros Definition

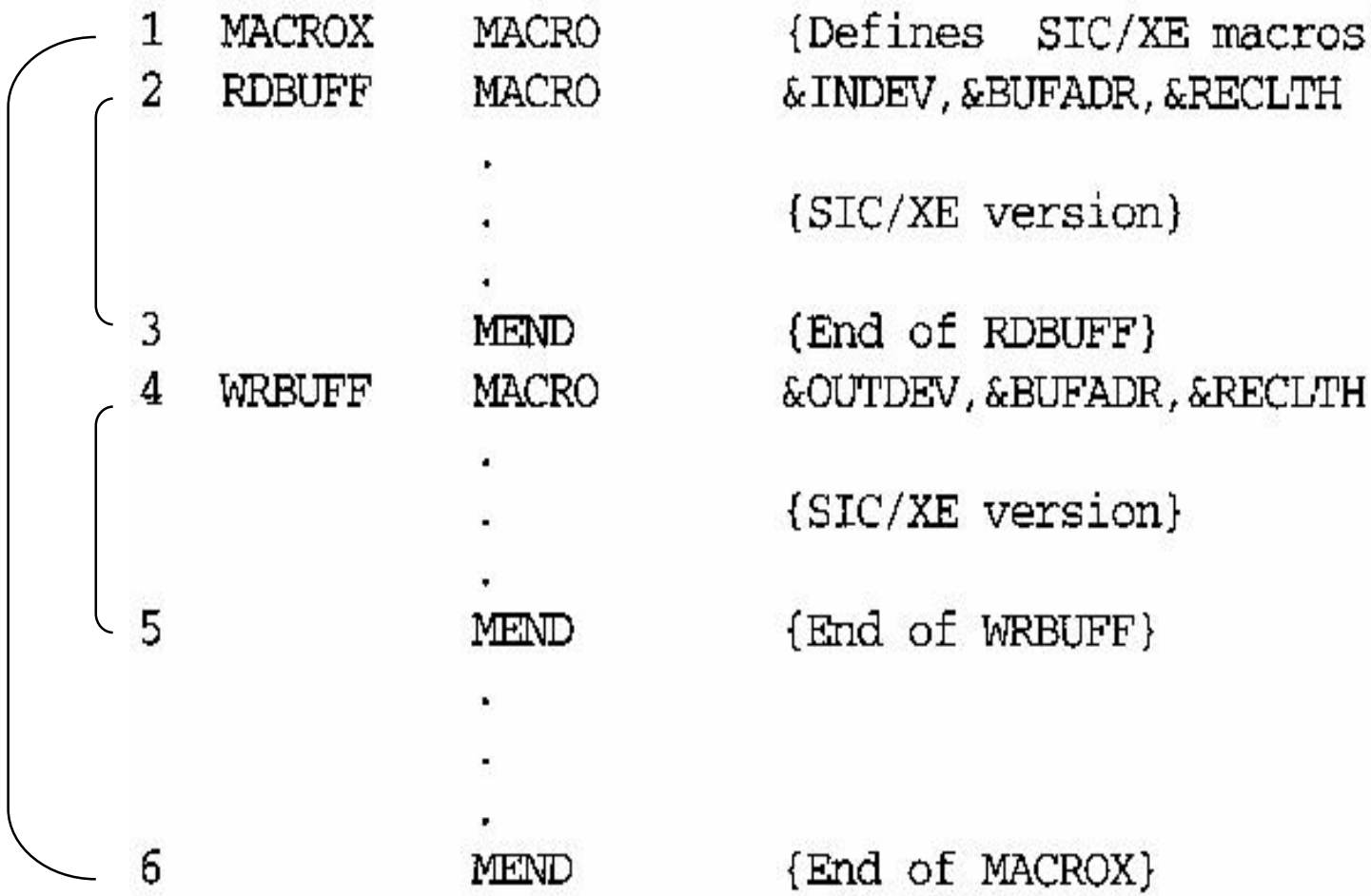
- MACROS (for SIC)
  - contains the definitions of RDBUFF and WRBUFF written in SIC instructions.
- MACROX (for SIC/XE)
  - contains the definitions of RDBUFF and WRBUFF written in SIC/XE instructions.
- Example 4.3

Macro Definition within a Macro Body (Figure 4.3(a))

```
1   MACROS    MACRO     {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}
```

(a)

Macro Definition within a Macro Body (Figure 4.3(b))



```
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}
```

Nested Macros Definition (Cont.)

- 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.

- Defining MACROX **does not** define RDBUFF and WRBUFF.
  - These definitions are processed only when an invocation of MACROX is expanded.

One-pass macro processor

- One-pass macro processor
  - *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

Three Main Data Structures

- **DEFTAB**
  - A ***definition table*** used to *store macro definition* including
    - macro prototype
    - macro body
  - Comment lines are omitted.
  - *Positional notation* has been used for the parameters for efficiency in substituting arguments.
    - E.g. the first parameter &INDEV has been converted to ?1 (indicating the first parameter in the prototype)
- **NAMTAB**
  - A ***name table*** used to *store the macro names*
  - Serves as an index to DEFTAB
    - Pointers to the beginning and the end of the macro definition
- **ARGTAB**
  - A ***argument table*** used to store the arguments used in the expansion of macro invocation
  - As the macro is expanded, arguments are substituted for the corresponding parameters in the macro body.

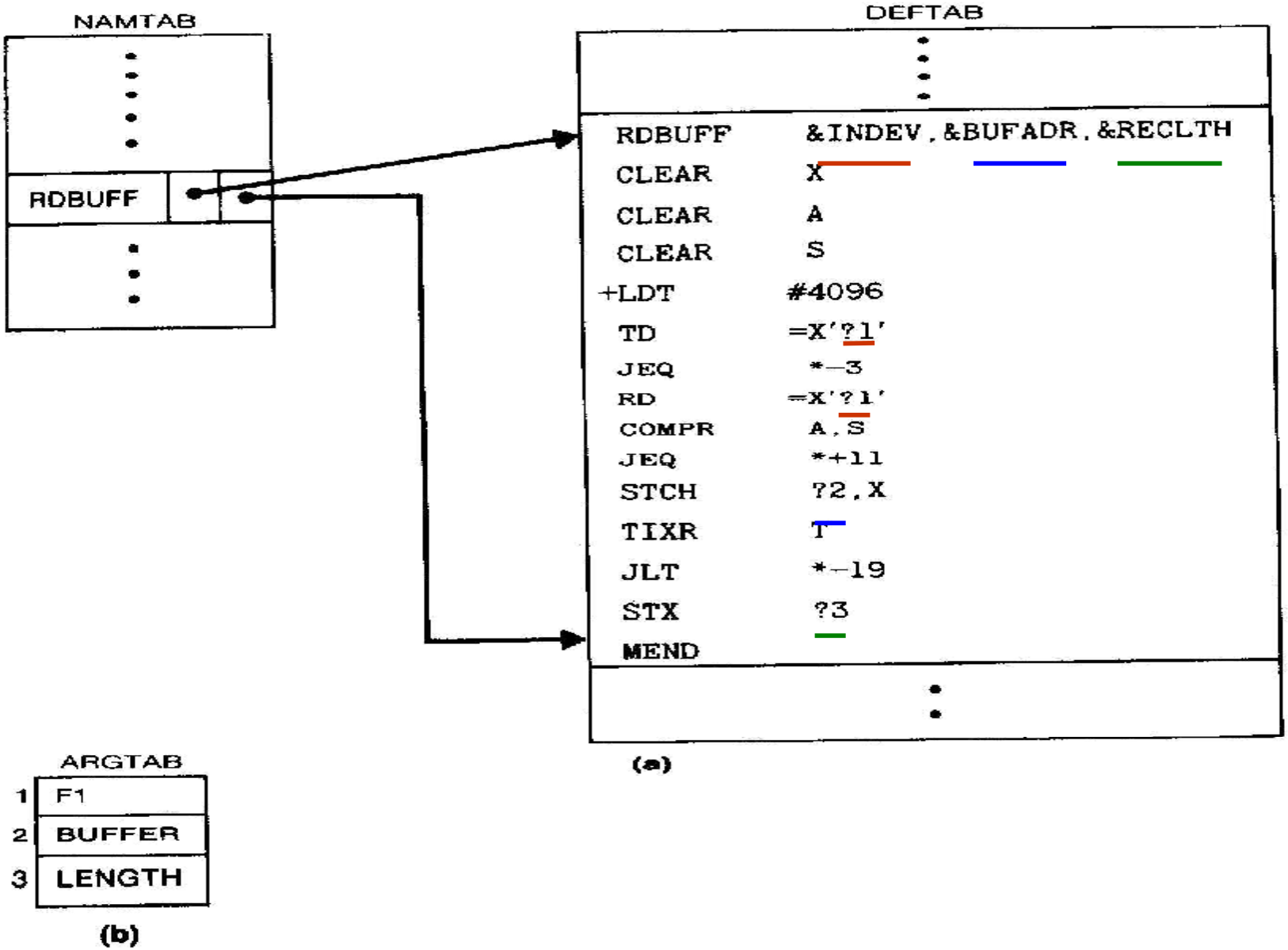
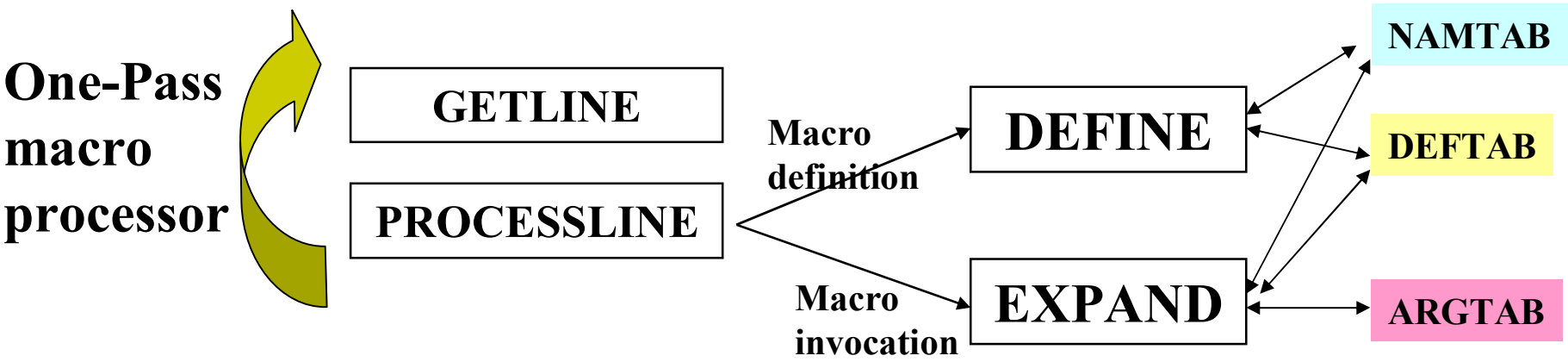


Figure 4.4 Contents of macro processor tables for the program in Fig. 4.1: (a) entries in NAMTAB and DEFTAB defining macro RDBUFF, (b) entries in ARGTAB for invocation of RDBUFF on line 190.

One-Pass Macro Processor

- Procedures
  - Macro definition: DEFINE
  - Macro invocation: EXPAND



```
begin {macro processor}
    EXPANDING := FALSE
    while OPCODE ≠ 'END' do
        begin
            GETLINE
            PROCESSLINE
        end {while}
end {macro processor}


procedure PROCESSLINE
    begin
        search NAMTAB for OPCODE
        if found then
            EXPAND
        else if OPCODE = 'MACRO' then
            DEFINE
        else write source line to expanded file
    end {PROCESSLINE}
```

Figure 4.5 Algorithm for a one-pass macro processor.

One-Pass Macro Processor Allows Nested Macro Definition

- Sub-procedure DEFINE should handle the nested macro definition
  - Maintains a counter named **LEVEL**
  - Each time a MACRO directive is read, the value of LEVEL is increased by 1
  - Each time an MEND directive is read, the value of LEVEL is decreased by 1

Algorithm for one-pass macro processor (Fig. 4.5)

```
procedure DEFINE
    begin
        enter macro name into NAMTAB
        enter macro prototype into DEFTAB
        LEVEL  := 1
        while LEVEL > 0 do
            begin
                GETLINE
                if this is not a comment line then
                    begin
                        substitute positional notation for parameters
                        enter line into DEFTAB
                        if OPCODE = 'MACRO' then
                            LEVEL := LEVEL + 1
                        else if OPCODE = 'MEND' then
                            LEVEL  := LEVEL - 1
                    end {if not comment}
            end {while}
        store in NAMTAB pointers to beginning and end of definition
    end {DEFINE}
```

```
procedure EXPAND
    begin
        EXPANDING  := TRUE
        get first line of macro definition {prototype} from DEFTAB
        set up arguments from macro invocation in ARGTAB
        write 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}
```

Figure 4.5 (*cont'd*)