CS2304 – SYSTEM SOFTWARE

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UNIT I

INTRODUCTION TO SYSTEM SOFTWARE AND MACHINE STRUCTURE

1.1 SYSTEM SOFTWARE

- System software consists of a variety of programs that support the operation of a computer.
- It is a set of programs to perform a variety of system functions as file editing, resource management, I/O management and storage management.
- The characteristic in which system software differs from application software is machine dependency.
- An application program is primarily concerned with the solution of some problem, using the computer as a tool.
- System programs on the other hand are intended to support the operation and use of the computer itself, rather than any particular application.
- For this reason, they are usually related to the architecture of the machine on which they are run.
- For example, assemblers translate mnemonic instructions into machine code. The instruction formats, addressing modes are of direct concern in assembler design.
- There are some aspects of system software that do not directly depend upon the type of computing system being supported. These are known as machine-independent features.
- For example, the general design and logic of an assembler is basically the same on most computers.

TYPES OF SYSTEM SOFTWARE:

1. Operating system
2. Language translators
    a. Compilers
    b. Interpreters
    c. Assemblers
    d. Preprocessors
3. Loaders
4. Linkers
5. Macro processors

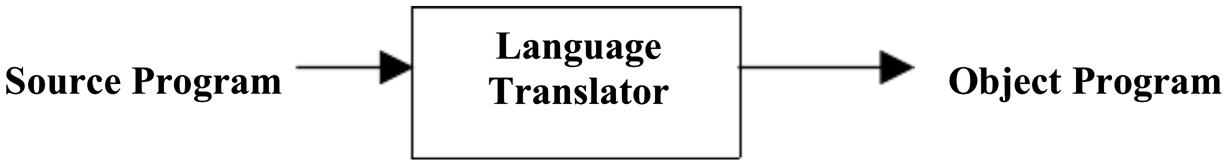
OPERATING SYSTEM

- It is the most important system program that act as an interface between the users and the system. It makes the computer easier to use.

- It provides an interface that is more user-friendly than the underlying hardware.
- The functions of OS are:
    1. Process management
    2. Memory management
    3. Resource management
    4. I/O operations
    5. Data management
    6. Providing security to user's job.

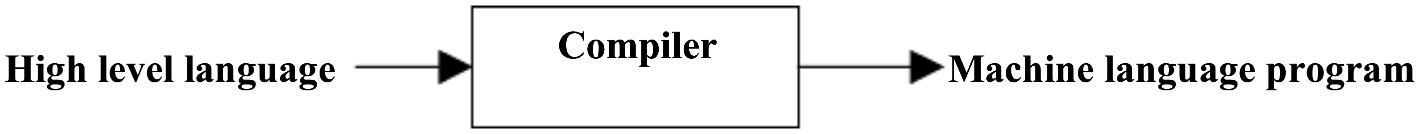
LANGUAGE TRANSLATORS

It is the program that takes an input program in one language and produces an output in another language.



Compilers

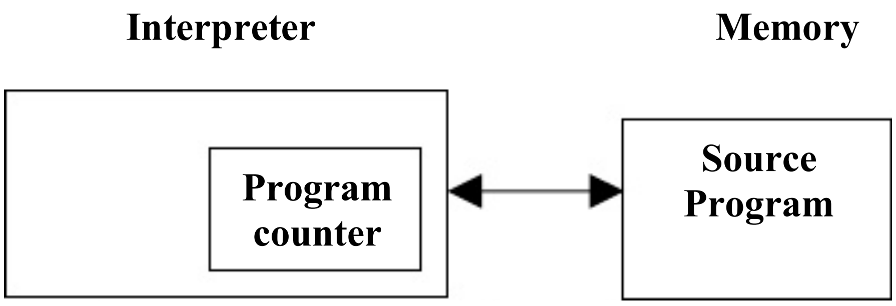
- A compiler is a language program that translates programs written in any high-level language into its equivalent machine language program.
- It bridges the semantic gap between a programming language domain and the execution domain.
- Two aspects of compilation are:
    - Generate code to increment meaning of a source program in the execution domain.
    - Provide diagnostics for violation of programming language, semantics in a source program.
- The program instructions are taken as a whole.



Interpreters:

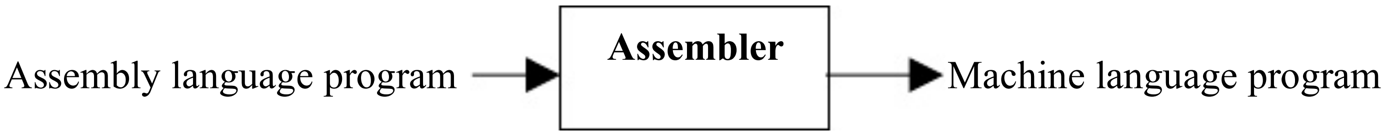
- It is a translator program that translates a statement of high-level language to machine language and executes it immediately. The program instructions are taken line by line.
- The interpreter reads the source program and stores it in memory.

- During interpretation, it takes a source statement, determines its meaning and performs actions which increments it. This includes computational and I/O actions.
- Program counter (PC) indicates which statement of the source program is to be interpreted next. This statement would be subjected to the interpretation cycle.
- The interpretation cycle consists of the following steps:
    - Fetch the statement.
    - Analyze the statement and determine its meaning.
    - Execute the meaning of the statement.
- The following are the characteristics of interpretation:
    - The source program is retained in the source form itself, no target program exists.
    - A statement is analyzed during the interpretation.



Assemblers:

- Programmers found it difficult to write or red programs in machine language. In a quest for a convenient language, they began to use a mnemonic (symbol) for each machine instructions which would subsequently be translated into machine language.
- Such a mnemonic language is called Assembly language.
- Programs known as Assemblers are written to automate the translation of assembly language into machine language.



- Fundamental functions:
    1. Translating mnemonic operation codes to their machine language equivalents.
    2. Assigning machine addresses to symbolic tables used by the programmers.

1.2 THE SIMPLIFIED INSTRUCTIONAL COMPUTER (SIC):

It is similar to a typical microcomputer. It comes in two versions:

- The standard model
- XE version

SIC Machine Structure:

Memory:

- It consists of bytes(8 bits) ,words (24 bits which are consecutive 3 bytes) addressed by the location of their lowest numbered byte.
- There are totally 32,768 bytes in memory.

Registers:

There are 5 registers namely

1. Accumulator (A)
2. Index Register(X)
3. Linkage Register(L)
4. Program Counter(PC)
5. Status Word(SW).

- Accumulator is a special purpose register used for arithmetic operations.
- Index register is used for addressing.
- Linkage register stores the return address of the jump of subroutine instructions (JSUB).
- Program counter contains the address of the current instructions being executed.
- Status word contains a variety of information including the condition code.

Data formats:

- Integers are stored as 24-bit binary numbers: 2's complement representation is used for negative values characters are stored using their 8 bit ASCII codes.
- They do not support floating – point data items.

Instruction formats:

All machine instructions are of 24-bits wide

Opcode (8)	**X (1)**	**Address (15)**

- X-flag bit that is used to indicate indexed-addressing mode.

Addressing modes:

- Two types of addressing are available namely,
    1. Direct addressing mode
    2. Indexed addressing mode or indirect addressing mode

Mode	Indication	Target Address calculation
Direct	X=0	TA=Address
Indexed	X=1	TA=Address + (X)

- Where(x) represents the contents of the index register(x)

Instruction set:

It includes instructions like:

1. Data movement instruction
   Ex: LDA, LDX, STA, STX.

2. Arithmetic operating instructions
   Ex: ADD, SUB, MUL, DIB.
   This involves register A and a word in memory, with the result being left in the register.

3. Branching instructions
   Ex: JLT, JEQ, TGT.

4. Subroutine linkage instructions
   Ex: JSUB, RSUB.

Input and Output:

- I/O is performed by transferring one byte at a time to or from the rightmost 8 bits of register A.
- Each device is assigned a unique 8-bit code.
- There are 3 I/O instructions,
  1) The Test Device (TD) instructions tests whether the addressed device is ready to send or receive a byte of data.
  2) A program must wait until the device is ready, and then execute a Read Data (RD) or Write Data (WD).
  3) The sequence must be repeated for each byte of data to be read or written.

1.3 SIC/XE ARCHITECTURE & SYSTEM SPECIFICATION

Memory:

- 1 word = 24 bits (3 8-bit bytes)
- Total (SIC/XE) = 2^{20} (1,048,576) bytes (1Mbyte)

Registers:

- 10 x 24 bit registers

MNEMONIC	Register	Purpose
A	0	Accumulator
X	1	Index register
L	2	Linkage register (JSUB/RSUB)
B	3	Base register
S	4	General register
T	5	General register
F	6	Floating Point Accumulator (48 bits)
PC	8	Program Counter (PC)
SW	9	Status Word (includes Condition Code, CC)

Data Format:

- Integers are stored in 24 bit, 2's complement format
- Characters are stored in 8-bit ASCII format
- Floating point is stored in 48 bit signed-exponent-fraction format:

s	exponent {11}	fraction {36}

- The fraction is represented as a 36 bit number and has value between 0 and 1.
- The exponent is represented as a 11 bit unsigned binary number between 0 and 2047.
- The sign of the floating point number is indicated by s : 0=positive, 1=negative.
- Therefore, the absolute floating point number value is: $f*2^{(e-1024)}$

Instruction Format:

- There are 4 different instruction formats available:

Format 1 (1 byte):

op {8}

Format 2 (2 bytes):

op {8}	r1 {4}	r2 {4}

Format 3 (3 bytes):

op {6}	n	i	x	b	p	e	displacement {12}

Format 4 (4 bytes):

op {6}	n	i	x	b	p	e	address {20}

Formats 3 & 4 introduce addressing mode flag bits:

- n=0 & i=1
  Immediate addressing - TA is used as an operand value (no memory reference)
- n=1 & i=0
  Indirect addressing - word at TA (in memory) is fetched & used as an address to fetch the operand from
- n=0 & i=0
  Simple addressing TA is the location of the operand
- n=1 & i=1
  Simple addressing same as n=0 & i=0

Flag x:

x=1 Indexed addressing add contents of X register to TA calculation

Flag b & p (Format 3 only):

- b=0 & p=0
  Direct addressing displacement/address field containsTA (Format 4 always uses direct addressing)
- b=0 & p=1
  PC relative addressing - TA=(PC)+disp (-2048<=disp<=2047)*
- b=1 & p=0
  Base relative addressing - TA=(B)+disp (0<=disp<=4095)**

Flag e:

e=0 use Format 3
e=1 use Format 4

Instructions:

SIC provides 26 instructions, SIC/XE provides an additional 33 instructions (59 total)

SIC/XE has 9 categories of instructions:

- Load/store registers (LDA, LDX, LDCH, STA, STX, STCH, etc.)
- integer arithmetic operations (ADD, SUB, MUL, DIV) these will use register A and a word in memory, results are placed into register A
- compare (COMP) compares contents of register A with a word in memory and sets CC (Condition Code) to <, >, or =
- conditional jumps (JLT, JEQ, JGT) - jumps according to setting of CC
- subroutine linkage (JSUB, RSUB) - jumps into/returns from subroutine using register L
- input & output control (RD, WD, TD) - see next section
- floating point arithmetic operations (ADDF, SUBF, MULF, DIVF)
- register manipulation, operands-from-registers, and register-to-register arithmetics (RMO, RSUB, COMPR, SHIFTR, SHIFTL, ADDR, SUBR, MULR, DIVR, etc)

Input and Output (I/O):

- 2^8 (256) I/O devices may be attached, each has its own unique 8-bit address
- 1 byte of data will be transferred to/from the rightmost 8 bits of register A

Three I/O instructions are provided:

- RD Read Data from I/O device into A
- WD Write data to I/O device from A
- TD Test Device determines if addressed I/O device is ready to send/receive a byte of data. The CC (Condition Code) gets set with results from this test:
  < device is ready to send/receive
  = device isn't ready

SIC/XE Has capability for programmed I/O (I/O device may input/output data while CPU does other work) - 3 additional instructions are provided:

- SIO Start I/O
- HIO Halt I/O
- TIO Test I/O

1.4 SIC, SIC/XE ADDRESSING MODES

Addressing Type	**Flag Bits**						**Notation**	**Calculation of Target Address**	**Operand**	**Notes**
	n	**i**	**x**	**b**	**p**	**e**				

Simple	1	1	0	0	0	0	op c	disp	(TA)	Direct-addressing Instruction
	1	1	0	0	0	1	+op m	addr	(TA)	Format 4 & Direct-addressing Instruction
	1	1	0	0	1	0	op m	(PC) + disp	(TA)	Assembler selects either base-relative or program-counter relative mode
	1	1	0	1	0	0	op m	(B) + disp	(TA)	Assembler selects either base-relative or program-counter relative mode
	1	1	1	0	0	0	op c,X	disp + (X)	(TA)	Direct-addressing Instruction
	1	1	1	0	0	1	+op m,X	addr + (X)	(TA)	Format 4 & Direct-addressing Instruction
	1	1	1	0	1	0	op m,X	(PC) + disp + (X)	(TA)	Assembler selects either base-relative or program-counter relative mode
	1	1	1	1	0	0	op m,X	(B) + disp + (X)	(TA)	Assembler selects either base-relative or program-counter relative mode
	0	0	0	-	-	-	op m	b/p/e/disp	(TA)	Direct-addressing Instruction; SIC compatible format.
	0	0	1	-	-	-	op m,X	b/p/e/disp + (X)	(TA)	Direct-addressing Instruction; SIC compatible format.
Indirect	1	0	0	0	0	0	op @c	disp	((TA))	Direct-addressing Instruction
	1	0	0	0	0	1	+op @m	addr	((TA))	Format 4 & Direct-addressing Instruction
	1	0	0	0	1	0	op @m	(PC) + disp	((TA))	Assembler selects either base-relative or program-counter relative mode
	1	0	0	1	0	0	op @m	(B) + disp	((TA))	Assembler selects

										either base-relative or program-counter relative mode
Immediate	0	1	0	0	0	0	op #c	disp	TA	Direct-addressing Instruction
	0	1	0	0	0	1	op #m	addr	TA	Format 4 & Direct-addressing Instruction
	0	1	0	0	1	0	op #m	(PC) + disp	TA	Assembler selects either base-relative or program-counter relative mode
	0	1	0	1	0	0	op #m	(B) + disp	TA	Assembler selects either base-relative or program-counter relative mode

UNIT II

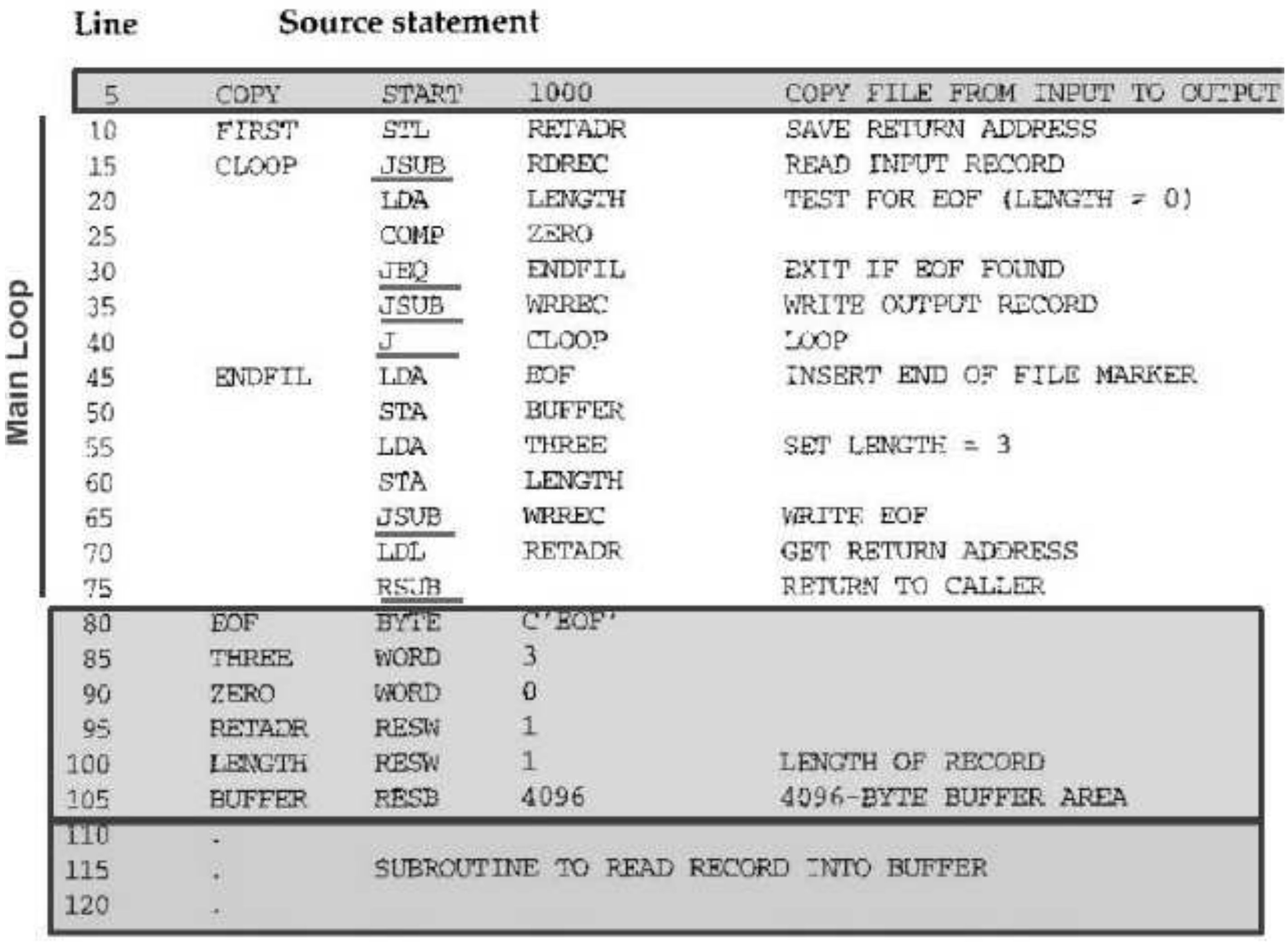
ASSEMBLERS

2.1. BASIC ASSEMBLER FUNCTIONS

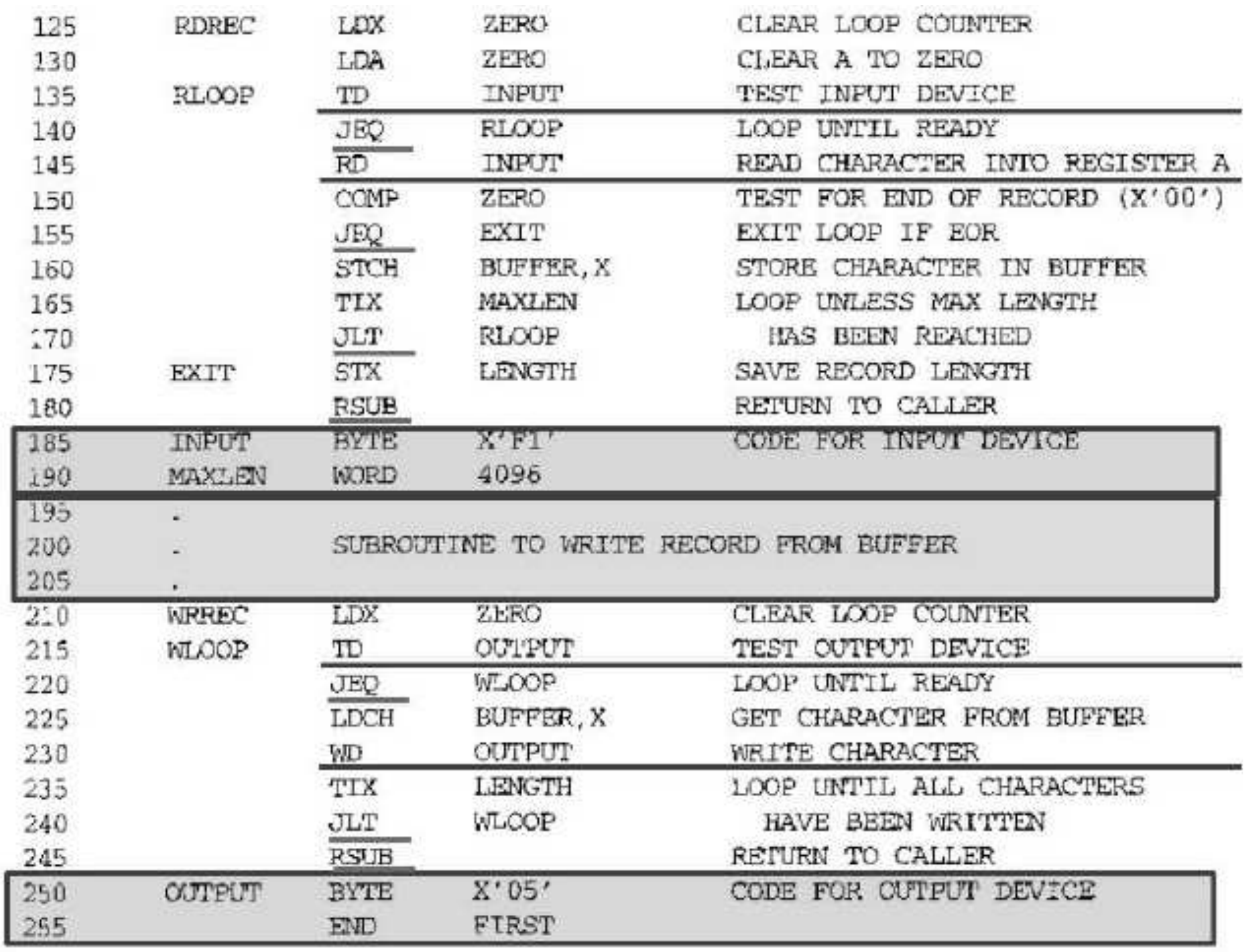
Fundamental functions of an assembler:

- Translating mnemonic operation codes to their machine language equivalents.
- Assigning machine addresses to symbolic labels used by the programmer.

Figure 2.1: Assembler language program for basic SIC version



```
Line        Source statement

  5    COPY      START   1000       COPY FILE FROM INPUT TO OUTPUT
 10    FIRST     STL     RETADR     SAVE RETURN ADDRESS
 15    CLOOP     JSUB    RDREC      READ INPUT RECORD
 20              LDA     LENGTH     TEST FOR EOF (LENGTH = 0)
 25              COMP    ZERO
 30              JEQ     ENDFIL     EXIT IF EOF FOUND
 35              JSUB    WRREC      WRITE OUTPUT RECORD
 40              J       CLOOP      LOOP
 45    ENDFIL    LDA     EOF        INSERT END OF FILE MARKER
 50              STA     BUFFER
 55              LDA     THREE      SET LENGTH = 3
 60              STA     LENGTH
 65              JSUB    WRREC      WRITE EOF
 70              LDL     RETADR     GET RETURN ADDRESS
 75              RSUB               RETURN TO CALLER
 80    EOF       BYTE    C'EOF'
 85    THREE     WORD    3
 90    ZERO      WORD    0
 95    RETADR    RESW    1
100    LENGTH    RESW    1          LENGTH OF RECORD
105    BUFFER    RESB    4096       4096-BYTE BUFFER AREA
110    .
115    .         SUBROUTINE TO READ RECORD INTO BUFFER
120    .
```



```
RDREC    LDX    ZERO         CLEAR LOOP COUNTER
         LDA    ZERO         CLEAR A TO ZERO
RLOOP    TD     INPUT        TEST INPUT DEVICE
         JEQ    RLOOP        LOOP UNTIL READY
         RD     INPUT        READ CHARACTER INTO REGISTER A
         COMP   ZERO         TEST FOR END OF RECORD (X'00')
         JEQ    EXIT         EXIT LOOP IF EOR
         STCH   BUFFER,X     STORE CHARACTER IN BUFFER
         TIX    MAXLEN       LOOP UNLESS MAX LENGTH
         JLT    RLOOP          HAS BEEN REACHED
EXIT     STX    LENGTH       SAVE RECORD LENGTH
         RSUB                RETURN TO CALLER
INPUT    BYTE   X'F1'        CODE FOR INPUT DEVICE
MAXLEN   WORD   4096
.
.        SUBROUTINE TO WRITE RECORD FROM BUFFER
.
WRREC    LDX    ZERO         CLEAR LOOP COUNTER
WLOOP    TD     OUTPUT       TEST OUTPUT DEVICE
         JEQ    WLOOP        LOOP UNTIL READY
         LDCH   BUFFER,X     GET CHARACTER FROM BUFFER
         WD     OUTPUT       WRITE CHARACTER
         TIX    LENGTH       LOOP UNTIL ALL CHARACTERS
         JLT    WLOOP          HAVE BEEN WRITTEN
         RSUB                RETURN TO CALLER
OUTPUT   BYTE   X'05'        CODE FOR OUTPUT DEVICE
         END    FIRST
```

Indexed addressing is indicated by adding the modifier “ X” following the operand. Lines beginning with “.” contain comments only.

The following assembler directives are used:

- **START:** Specify name and starting address for the program.
- **END :** Indicate the end of the source program and specify the first executable instruction in the program.
- **BYTE:** Generate character or hexadecimal constant, occupying as many bytes as needed to represent the constant.
- **WORD:** Generate one- word integer constant.
- **RESB:** Reserve the indicated number of bytes for a data area.
- **RESW:** Reserve the indicated number of words for a data area.

The program contains a main routine that reads records from an input device(code F1) and copies them to an output device(code 05).

The main routine calls subroutines:

- **RDREC** – To read a record into a buffer.

- **WRREC** – To write the record from the buffer to the output device.

The end of each record is marked with a null character (hexadecimal 00).

2.1.1. A Simple SIC Assembler

The translation of source program to object code requires the following functions:

1. Convert mnemonic operation codes to their machine language equivalents. Eg: Translate STL to 14 (line 10).
2. Convert symbolic operands to their equivalent machine addresses. Eg:Translate RETADR to 1033 (line 10).
3. Build the machine instructions in the proper format.
4. Convert the data constants specified in the source program into their internal machine representations. Eg: Translate EOF to 454F46(line 80).
5. Write the object program and the assembly listing.

All fuctions except function 2 can be established by sequential processing of source program one line at a time.

Consider the statement

```
10      1000            FIRST           STL             RETADR              141033
```

This instruction contains a **forward reference** (i.e.) a reference to a label (RETADR) that is defined later in the program. It is unable to process this line because the address that will be assigned to RETADR is not known. Hence most assemblers make two passes over the source program where the second pass does the actual translation.

The assembler must also process statements called **assembler directives or pseudo instructions** which are not translated into machine instructions. Instead they provide instructions to the assembler itself.
Examples: RESB and RESW instruct the assembler to reserve memory locations without generating data values.

The assembler must write the generated object code onto some output device. This object program will later be loaded into memory for execution.

Object program format contains three types of records:

- **Header record**: Contains the program name, starting address and length.
- **Text record**: Contains the machine code and data of the program.
- **End record**: Marks the end of the object program and specifies the address in the program where execution is to begin.

Record format is as follows:

Header record:

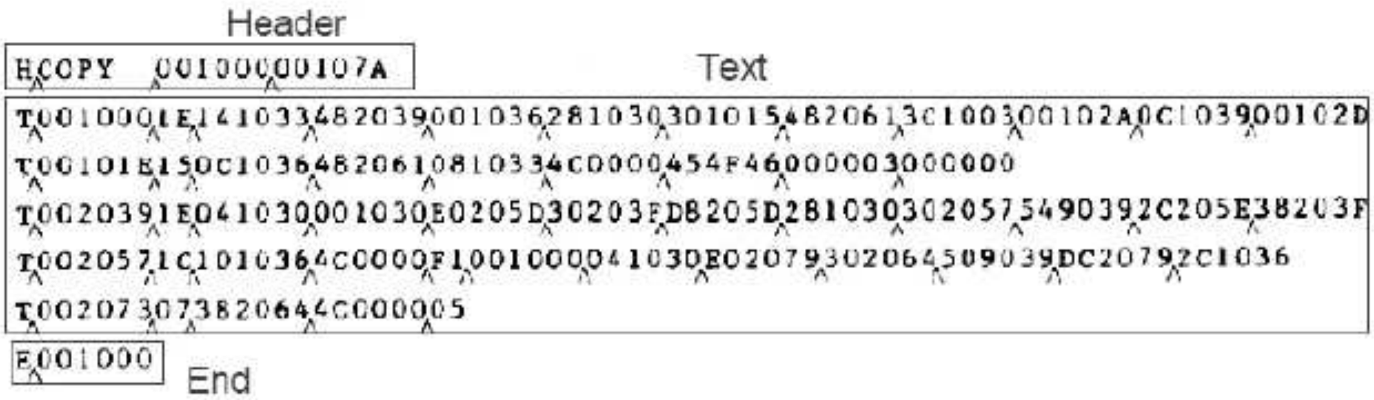
Col. 1	H
Col.2-7	Program name
Col.8-13	Starting address of object program
Col.14-19	Length of object program in bytes

Text record:

Col.1	T
Col.2-7	Starting address for object code in this record
Col.8-9	Length of object code in this record in bytes
Col 10-69	Object code, represented in hexadecimal (2 columns per byte of object code)

End record:

Col.1	E
Col.2-7	Address of first executable instruction in object program.


Header
Text
End

```
H^COPY  ^001000^00107A
T^001000^1E^141033^482039^001036^281030^301015^482061^3C1003^00102A^0C1039^00102D
T^00101E^15^0C1036^482061^081033^4C0000^454F46^000003^000000
T^002039^1E^041030^001030^E0205D^30203F^D8205D^281030^302057^549039^2C205E^38203F
T^002057^1C^101036^4C0000^F1^001000^041030^E02079^302064^509039^DC2079^2C1036
T^002073^07^382064^4C0000^05
E^001000
```

Figure 2.3 Object program corresponding to Fig. 2.2.

Functions of the two passes of assembler:

Pass 1 (Define symbols)

1. Assign addresses to all statements in the program.
2. Save the addresses assigned to all labels for use in Pass 2.
3. Perform some processing of assembler directives.

Pass 2 (Assemble instructions and generate object programs)

1. Assemble instructions (translating operation codes and looking up addresses).
2. Generate data values defined by BYTE,WORD etc.
3. Perform processing of assembler directives not done in Pass 1.
4. Write the object program and the assembly listing.

2.1.2. Assembler Algorithm and Data Structures

Assembler uses two major internal data structures:

1. **Operation Code Table (OPTAB) :** Used to lookup mnemonic operation codes and translate them into their machine language equivalents.
2. **Symbol Table (SYMTAB) :** Used to store values(Addresses) assigned to labels.

Location Counter (LOCCTR) :

- Variable used to help in the assignment of addresses.
- It is initialized to the beginning address specified in the START statement.
- After each source statement is processed, the length of the assembled instruction or data area is added to LOCCTR.
- Whenever a label is reached in the source program, the current value of LOCCTR gives the address to be associated with that label.

Operation Code Table (OPTAB) :

- Contains the mnemonic operation and its machine language equivalent.
- Also contains information about instruction format and length.
- In Pass 1, OPTAB is used to lookup and validate operation codes in the source program.
- In Pass 2, it is used to translate the operation codes to machine language program.
- During Pass 2, the information in OPTAB tells which instruction format to use in assembling the instruction and any peculiarities of the object code instruction.

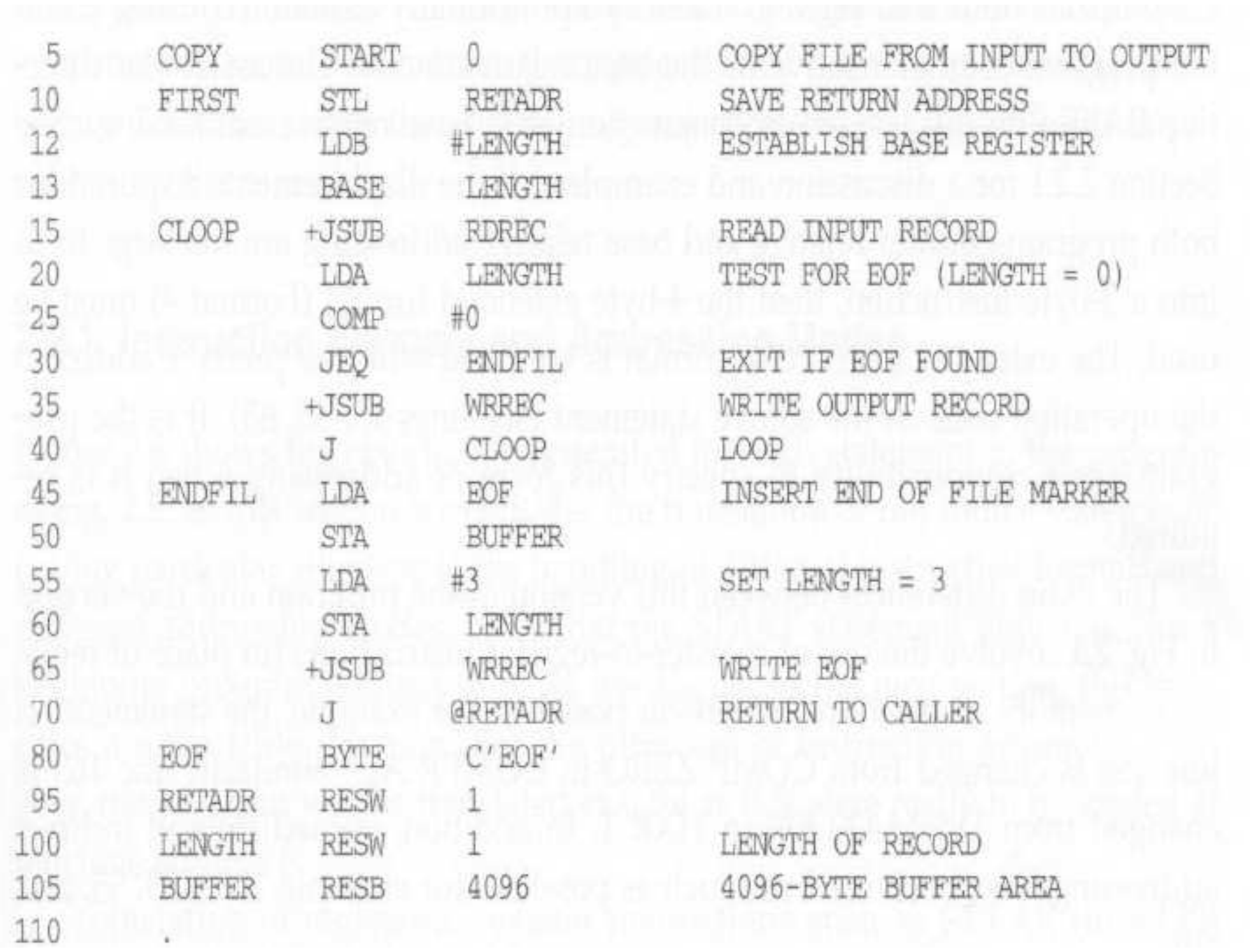
Symbol Table (SYMTAB) :

- Includes the name and value for each label in the source program and flags to indicate error conditions.
- During Pass 1 of the assembler, labels are entered into SYMTAB as they are encountered in the source program along with their assigned addresses.
- During Pass 2, symbols used as operands are looked up in SYMTAB to obtain the addresses to be inserted in the assembled instructions.

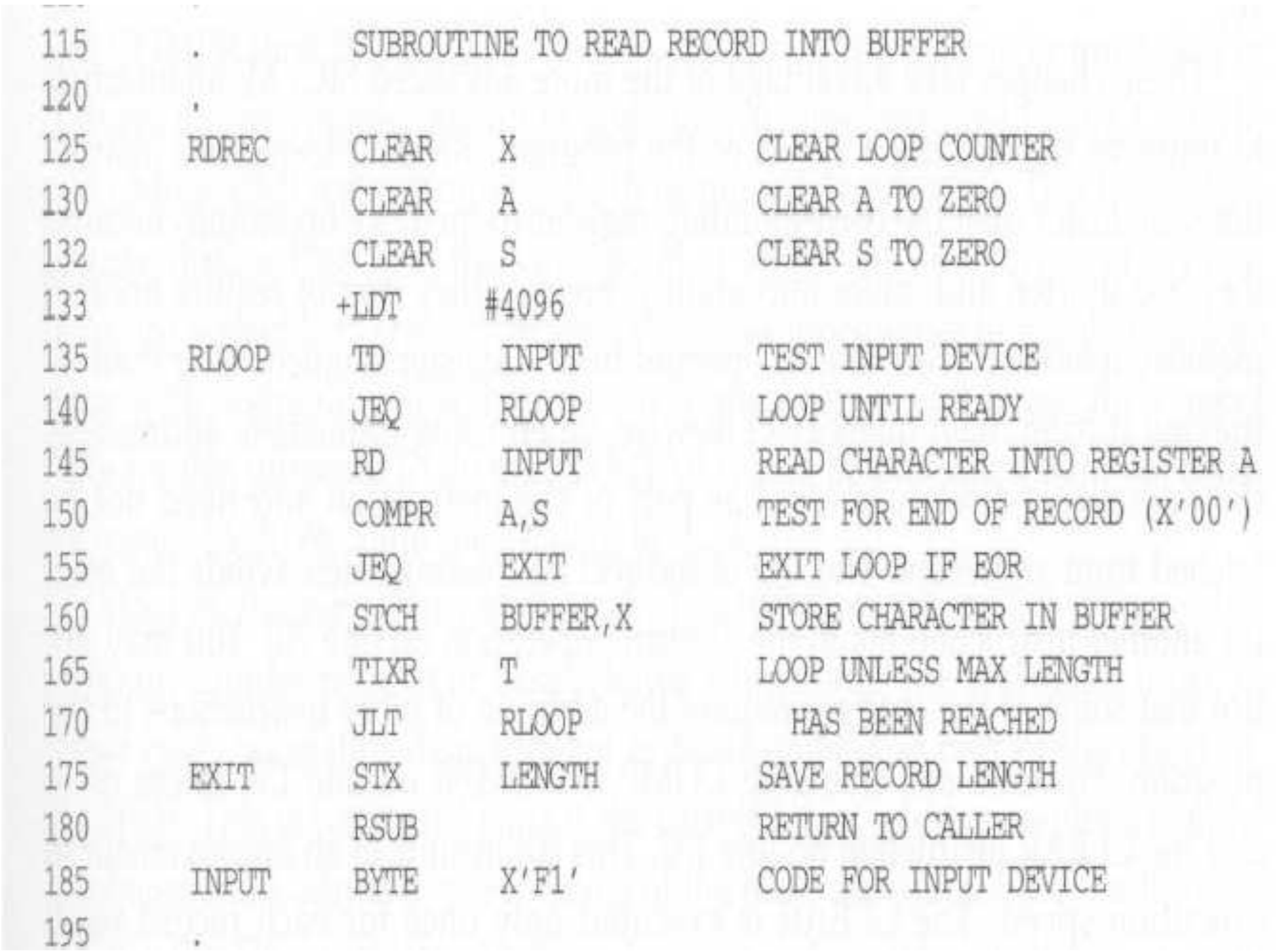
Pass 1 usually writes an intermediate file that contains each source statement together with its assigned address, error indicators. This file is used as the input to Pass 2. This copy of the source program can also be used to retain the results of certain operations that may be performed during Pass 1 such as scanning the operand field for symbols and addressing flags, so these need not be performed again during Pass 2.

2.2. MACHINE DEPENDENT ASSEMBLER FEATURES

Consider the design and implementation of an assembler for SIC/XE version.



```
  5   COPY     START   0          COPY FILE FROM INPUT TO OUTPUT
 10   FIRST    STL     RETADR     SAVE RETURN ADDRESS
 12            LDB    #LENGTH     ESTABLISH BASE REGISTER
 13            BASE    LENGTH
 15   CLOOP   +JSUB    RDREC      READ INPUT RECORD
 20            LDA     LENGTH     TEST FOR EOF (LENGTH = 0)
 25            COMP   #0
 30            JEQ     ENDFIL     EXIT IF EOF FOUND
 35           +JSUB    WRREC      WRITE OUTPUT RECORD
 40            J       CLOOP      LOOP
 45   ENDFIL   LDA     EOF        INSERT END OF FILE MARKER
 50            STA     BUFFER
 55            LDA    #3          SET LENGTH = 3
 60            STA     LENGTH
 65           +JSUB    WRREC      WRITE EOF
 70            J      @RETADR     RETURN TO CALLER
 80   EOF      BYTE    C'EOF'
 95   RETADR   RESW    1
100   LENGTH   RESW    1          LENGTH OF RECORD
105   BUFFER   RESB    4096       4096-BYTE BUFFER AREA
110   .
```



```
115   .        SUBROUTINE TO READ RECORD INTO BUFFER
120   .
125   RDREC    CLEAR    X           CLEAR LOOP COUNTER
130            CLEAR    A           CLEAR A TO ZERO
132            CLEAR    S           CLEAR S TO ZERO
133           +LDT      #4096
135   RLOOP    TD       INPUT       TEST INPUT DEVICE
140            JEQ      RLOOP       LOOP UNTIL READY
145            RD       INPUT       READ CHARACTER INTO REGISTER A
150            COMPR    A,S         TEST FOR END OF RECORD (X'00')
155            JEQ      EXIT        EXIT LOOP IF EOR
160            STCH     BUFFER,X    STORE CHARACTER IN BUFFER
165            TIXR     T           LOOP UNLESS MAX LENGTH
170            JLT      RLOOP         HAS BEEN REACHED
175   EXIT     STX      LENGTH      SAVE RECORD LENGTH
180            RSUB                 RETURN TO CALLER
185   INPUT    BYTE     X'F1'       CODE FOR INPUT DEVICE
195   .
```

Indirect addressing is indicated by adding the prefix @ to the operand (line70). Immediate operands are denoted with the prefix # (lines 25, 55,133). Instructions that refer to memory are normally assembled using either the program counter relative or base counter relative mode.

The assembler directive BASE (line 13) is used in conjunction with base relative addressing. The four byte extended instruction format is specified with the prefix + added to the operation code in the source statement.

Register-to-register instructions are used wherever possible. For example the statement on line 150 is changed from COMP ZERO to COMPR A,S. Immediate and indirect addressing have also been used as much as possible.

Register-to-register instructions are faster than the corresponding register-to-memory operations because they are shorter and do not require another memory reference.
While using immediate addressing, the operand is already present as part of the instruction and need not be fetched from anywhere. The use of indirect addressing often avoids the need for another instruction.

2.2.1 Instruction Formats and Addressing Modes

- SIC/XE
    - PC-relative or Base-relative addressing: op m
    - Indirect addressing: op @m
    - Immediate addressing: op #c
    - Extended format: +op m
    - Index addressing: op m,x
    - register-to-register instructions
    - larger memory -> multi-programming (program allocation)

Translation

- Register translation
    - register name (A, X, L, B, S, T, F, PC, SW) and their values (0,1, 2, 3, 4, 5, 6, 8, 9)
    - preloaded in SYMTAB
- Address translation
    - Most register-memory instructions use program counter relative or base relative addressing
    - Format 3: 12-bit address field
        - base-relative: 0~4095
        - pc-relative: -2048~2047
    - Format 4: 20-bit address field

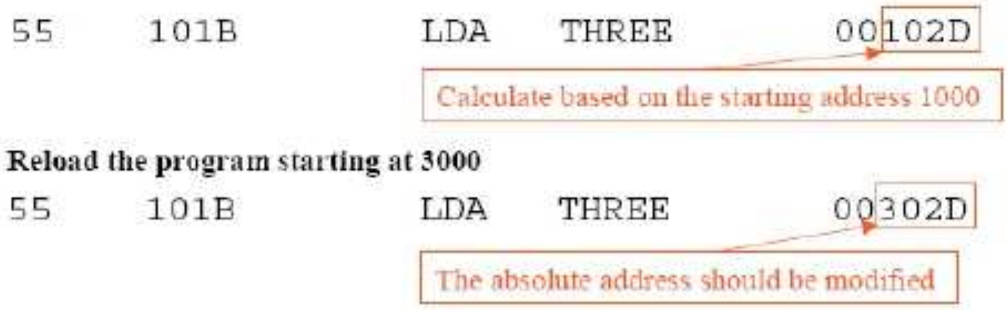
2.2.2 Program Relocation

The need for program relocation

- It is desirable to load and run several programs at the same time.
- The system must be able to load programs into memory wherever there is room.
- The exact starting address of the program is not known until load time.

Absolute Program

- Program with starting address specified at assembly time
- The address may be invalid if the program is loaded into somewhere else.
- Example:



```
55      101B            LDA     THREE           00102D
```

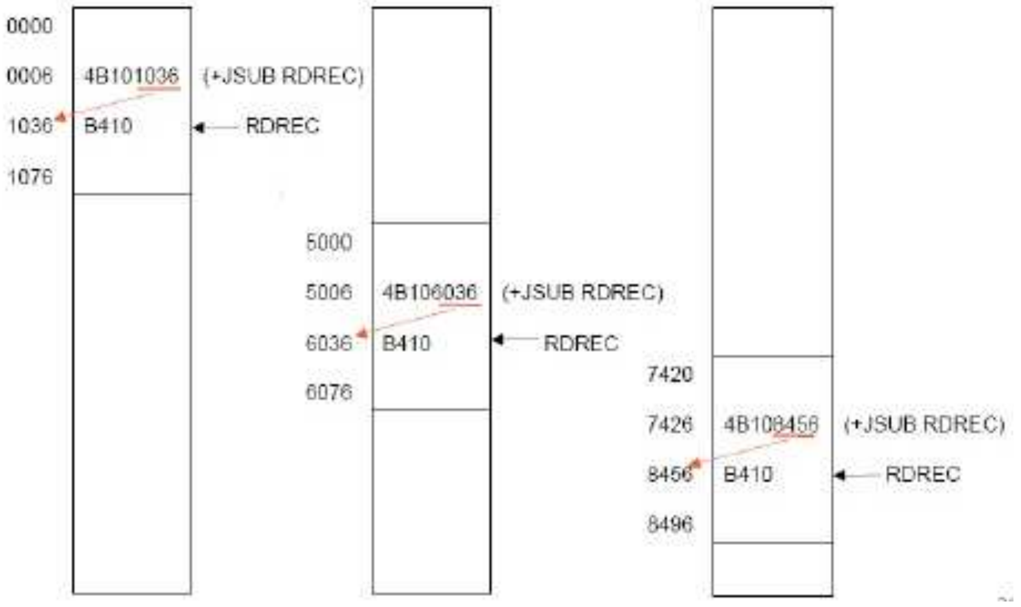
Calculate based on the starting address 1000

Reload the program starting at 3000

```
55      101B            LDA     THREE           00302D
```

The absolute address should be modified

Example: Program Relocation



- The only parts of the program that require modification at load time are those that specify direct addresses.
- The rest of the instructions need not be modified.
    - Not a memory address (immediate addressing)
    - PC-relative, Base-relative
- From the object program, it is not possible to distinguish the address and constant.
    - The assembler must keep some information to tell the loader.
    - The object program that contains the modification record is called a relocatable program.

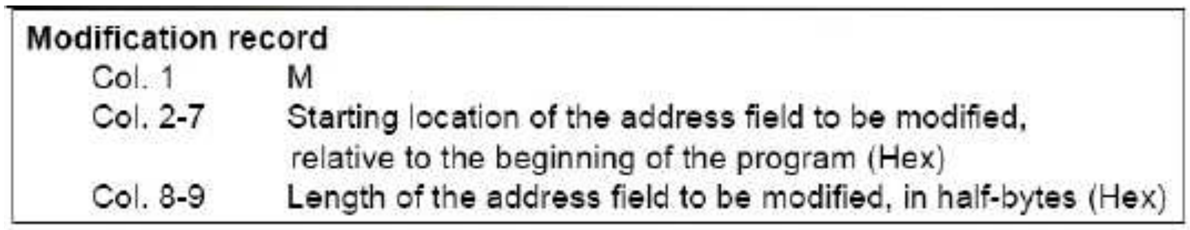
The way to solve the relocation problem

- For an address label, its address is assigned relative to the start of the program(START 0)
- Produce a Modification record to store the starting location and the length of the address
- field to be modified.

- The command for the loader must also be a part of the object program.

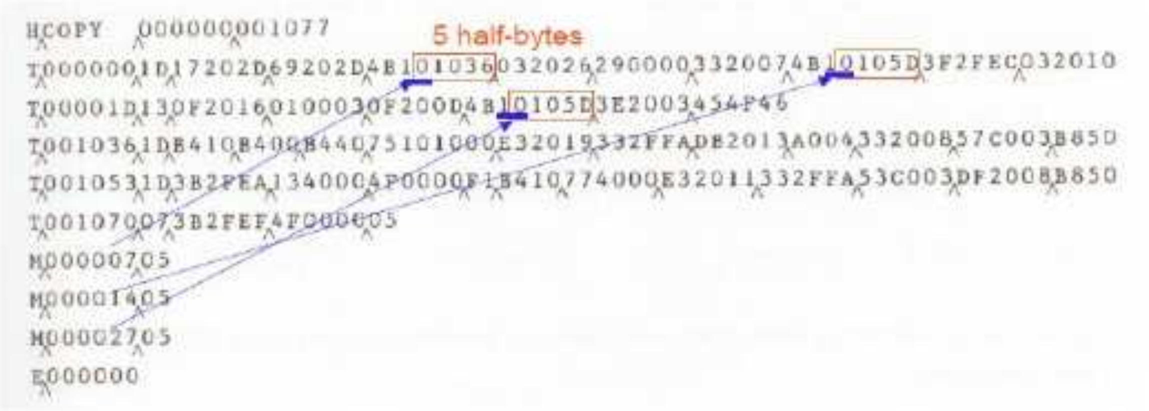
Modification record

- One modification record for each address to be modified
- The length is stored in half-bytes (4 bits)
- The starting location is the location of the byte containing the leftmost bits of the address field to be modified.
- If the field contains an odd number of half-bytes, the starting location begins in the middle of the first byte.



Modification record	
Col. 1	M
Col. 2-7	Starting location of the address field to be modified, relative to the beginning of the program (Hex)
Col. 8-9	Length of the address field to be modified, in half-bytes (Hex)

Relocatable Object Program



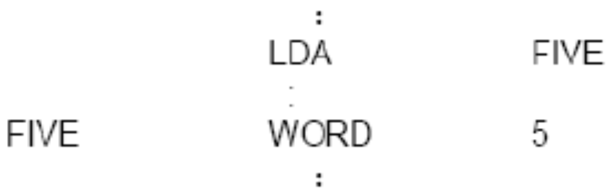
```
H^COPY  ^000000^001077
T^000000^1D^17202D^69202D^4B101036^032026^290000^332007^4B10105D^3F2FEC^032010
T^00001D^13^0F2016^010003^0F200D^4B10105D^3E2003^454F46
T^001036^1D^B410^B400^B440^75101000^E32019^332FFA^DB2013^A004^332008^57C003^B850
T^001053^1D^3B2FEA^134000^4F0000^F1^B410^774000^E32011^332FFA^53C003^DF2008^B850
T^001070^07^3B2FEF^4F0000^05
M^000007^05
M^000014^05
M^000027^05
E^000000
```

2.3. MACHINE INDEPENDENT ASSEMBLER FEATURES

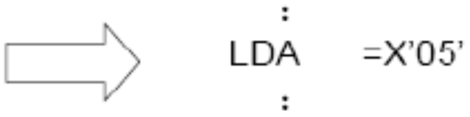
2.3.1 Literals

- The programmer writes the value of a constant operand as a part of the instruction that uses it. This avoids having to define the constant elsewhere in the program and make a label for it.
- Such an operand is called a Literal because the value is literally in the instruction.

- Consider the following example



```
              :
             LDA          FIVE
              .
FIVE         WORD         5
              :
```

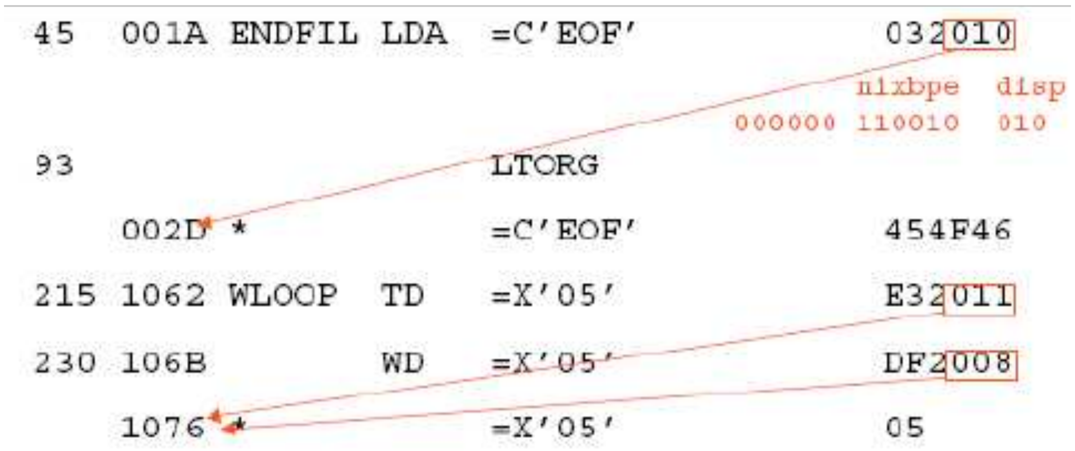


```
          :
         LDA    =X'05'
          :
```

- It is convenient to write the value of a constant operand as a part of instruction.

- A literal is identified with the prefix =, followed by a specification of the literal value.

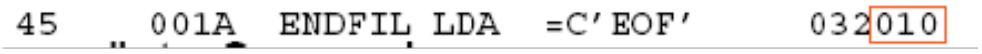
- Example:



```
45   001A ENDFIL LDA  =C'EOF'          032010
                                nixbpe  disp
                         000000 110010  010
93                        LTORG
     002D *               =C'EOF'          454F46
215  1062 WLOOP  TD   =X'05'               E32011
230  106B        WD   =X'05'               DF2008
     1076 *               =X'05'           05
```

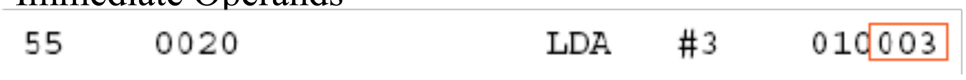
Literals vs. Immediate Operands

- Literals
  The assembler generates the specified value as a constant at some other memory location.



```
45     001A  ENDFIL LDA   =C'EOF'      032010
```

- Immediate Operands



```
55     0020                 LDA    #3     010003
```

The operand value is assembled as part of the machine instruction

- We can have literals in SIC, but immediate operand is only valid in SIC/XE.

Literal Pools

- Normally literals are placed into a pool at the end of the program
- In some cases, it is desirable to place literals into a pool at some other location in the object program
- Assembler directive LTORG
    - When the assembler encounters a LTORG statement, it generates a *literal pool* (containing all literal operands used since previous LTORG)
- Reason: keep the literal operand close to the instruction
    - Otherwise PC-relative addressing may not be allowed

Duplicate literals

- The same literal used more than once in the program
    - Only one copy of the specified value needs to be stored
    - For example, =X’05’
- Inorder to recognize the duplicate literals
    - Compare the character strings defining them
        - Easier to implement, but has potential problem
        - e.g. =X’05’
    - Compare the generated data value
        - Better, but will increase the complexity of the
        - assembler
        - e.g. **=C’EOF’** and **=X’454F46’**

Problem of duplicate-literal recognition

- ‘*’ denotes a literal refer to the current value of program counter
    - BUFEND EQU *
- There may be some literals that have the same name, but different values
    - BASE *
    - LDB =* (#LENGTH)
- The literal =* repeatedly used in the program has the same name, but different values
- The literal “=*” represents an “address” in the program, so the assembler must generate the appropriate “Modification records”.

Literal table - LITTAB

- Content
    - Literal name
    - Operand value and length
    - Address
- LITTAB is often organized as a hash table, using the literal name or value as the key.

Implementation of Literals

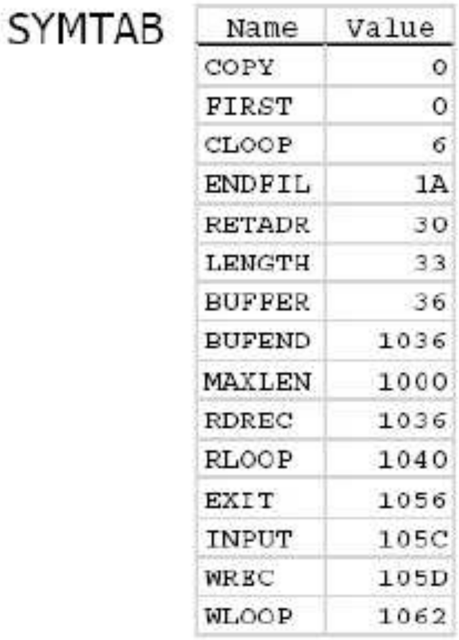
Pass 1

- Build LITTAB with literal name, operand value and length, leaving the address unassigned
- When LTORG or END statement is encountered, assign an address to each literal not yet assigned an address
    - updated to reflect the number of bytes occupied by each literal

Pass 2

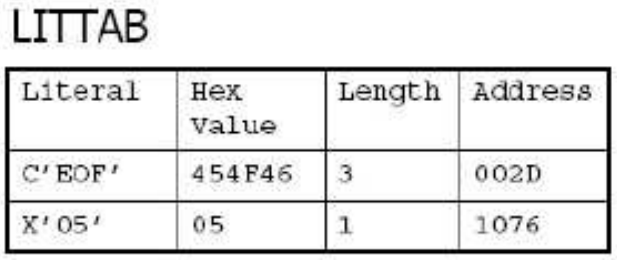
- Search LITTAB for each literal operand encountered
- Generate data values using BYTE or WORD statements
- Generate Modification record for literals that represent an address in the program

SYMTAB & LITTAB



SYMTAB

Name	Value
COPY	0
FIRST	0
CLOOP	6
ENDFIL	1A
RETADR	30
LENGTH	33
BUFFER	36
BUFEND	1036
MAXLEN	1000
RDREC	1036
RLOOP	1040
EXIT	1056
INPUT	105C
WREC	105D
WLOOP	1062



LITTAB

Literal	Hex Value	Length	Address
C'EOF'	454F46	3	002D
X'05'	05	1	1076

2.3.2 Symbol-Defining Statements

- Most assemblers provide an assembler directive that allows the programmer to define symbols and specify their values.

Assembler directive used is **EQU.**

- Syntax: symbol EQU value
- Used to improve the program readability, avoid using magic numbers, make it easier to find and change constant values
- Replace +LDT #4096 with

```
MAXLEN      EQU   4096
+LDT              #MAXLEN
```

- Define mnemonic names for registers.

```
A       EQU   0       RMO A,X
X       EQU   1
```

- Expression is allowed

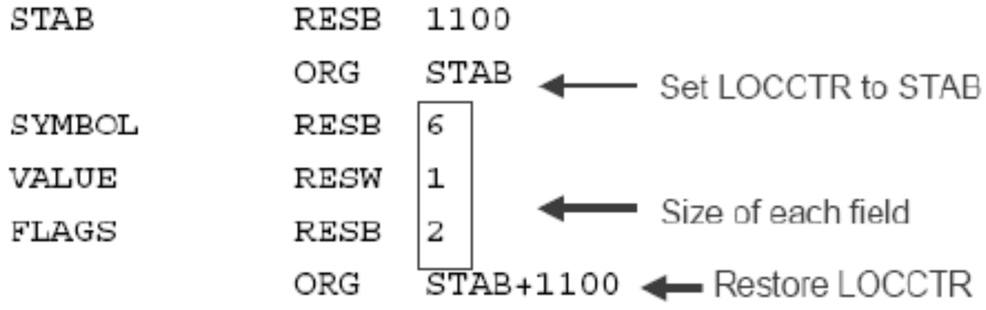
```
MAXLEN      EQU   BUFEND-BUFFER
```

Assembler directive ORG

- Allow the assembler to reset the PC to values
  - Syntax: ORG value
- When ORG is encountered, the assembler resets its LOCCTR to the specified value.
- ORG will affect the values of all labels defined until the next ORG.
- If the previous value of LOCCTR can be automatically remembered, we can return to the normal use of LOCCTR by simply writing
  - ORG

Example: using ORG

- If ORG statements are used



```
STAB        RESB   1100
            ORG    STAB
SYMBOL      RESB   6
VALUE       RESW   1
FLAGS       RESB   2
            ORG    STAB+1100
```

Set LOCCTR to STAB

Size of each field

Restore LOCCTR

- We can fetch the VALUE field by
  - LDA VALUE,X
  - X = 0, 11, 22, … for each entry

Forward-Reference Problem

- Forward reference is not allowed for either EQU or ORG.
- All terms in the value field must have been defined previously in the program.
- The reason is that all symbols must have been defined during Pass 1 in a two-pass assembler.
- Allowed:

  ```
  ALPHA       RESW        1
  BETA        EQU         ALPHA
  ```

- Not Allowed:

  ```
  BETA        EQU         ALPHA
  ALPHA       RESW        1
  ```

2.3.3 Expressions

- The assemblers allow “the use of expressions as operand”
- The assembler evaluates the expressions and produces a single operand address or value.
- Expressions consist of

  Operator
    - +,-,*,/ (division is usually defined to produce an integer result)

  Individual terms
    - Constants
    - User-defined symbols
    - Special terms, e.g., *, the current value of LOCCTR
- Examples

  ```
  MAXLEN      EQU         BUFEND-BUFFER
   STAB       RESB        (6+3+2)*MAXENTRIES
  ```

Relocation Problem in Expressions

- Values of terms can be
  - Absolute (independent of program location)
    - constants
  - Relative (to the beginning of the program)
    - Address labels
    - * (value of LOCCTR)
- Expressions can be
  - Absolute
    - Only absolute terms.
    - MAXLEN EQU 1000
  - Relative terms in pairs with opposite signs for each pair.

    ```
    MAXLEN      EQU         BUFEND-BUFFER
    ```
  - Relative

All the relative terms except one can be paired as described in “absolute”. The remaining unpaired relative term must have a positive sign.

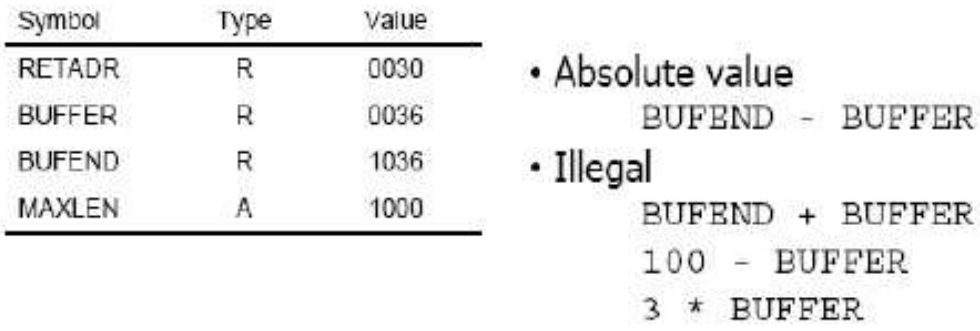
```
STAB            EQU             OPTAB + (BUFEND – BUFFER)
```

Restriction of Relative Expressions

- No relative terms may enter into a multiplication or division operation
  - o 3 * BUFFER
- Expressions that do not meet the conditions of either “absolute” or “relative” should be flagged as errors.
  - o BUFEND + BUFFER
  - o 100 – BUFFER

Handling Relative Symbols in SYMTAB

- To determine the type of an expression, we must keep track of the types of all symbols defined in the program.
- We need a “flag” in the SYMTAB for indication.



Symbol	Type	Value
RETADR	R	0030
BUFFER	R	0036
BUFEND	R	1036
MAXLEN	A	1000

- Absolute value

```
BUFEND - BUFFER
```

- Illegal

```
BUFEND + BUFFER
100 - BUFFER
3 * BUFFER
```

2.3.4 Program Blocks

- Allow the generated machine instructions and data to appear in the object program in a different order
- Separating blocks for storing code, data, stack, and larger data block
- Program blocks versus. Control sections
  - o Program blocks
    - ▪ Segments of code that are rearranged within a single object program unit.
  - o Control sections
    - ▪ Segments of code that are translated into independent object program units.

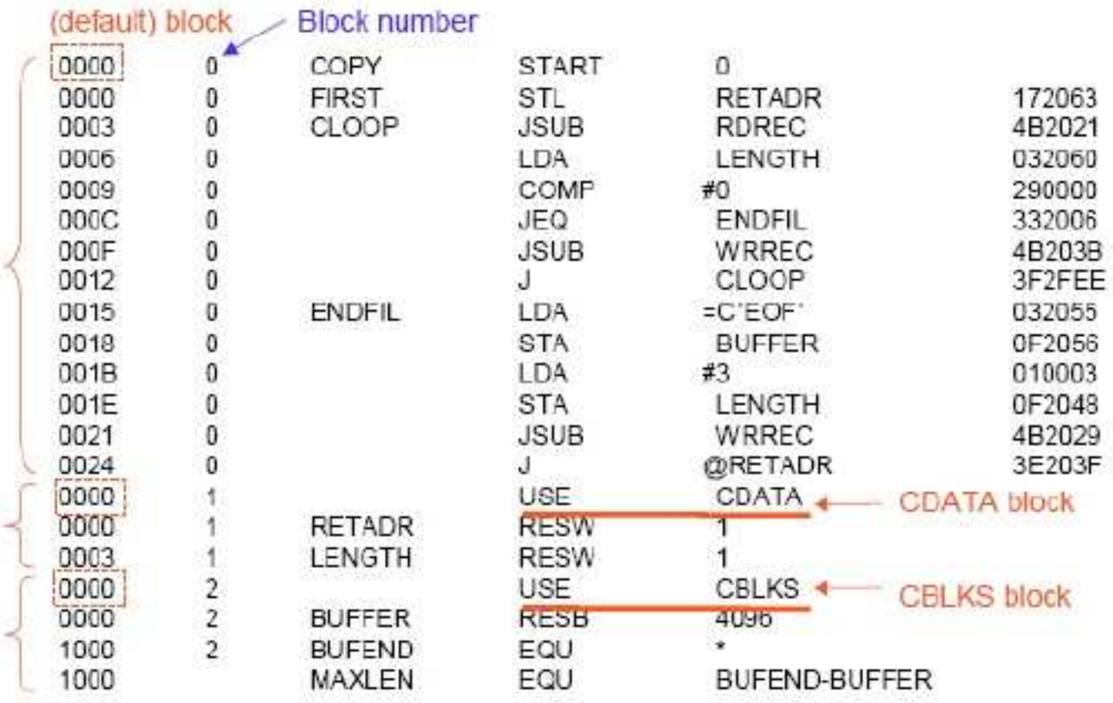
- Assembler rearranges these segments to gather together the pieces of each block and assign address.
- Separate the program into blocks in a particular order

- Large buffer area is moved to the end of the object program
- Program readability is better if data areas are placed in the source program close to the statements that reference them.

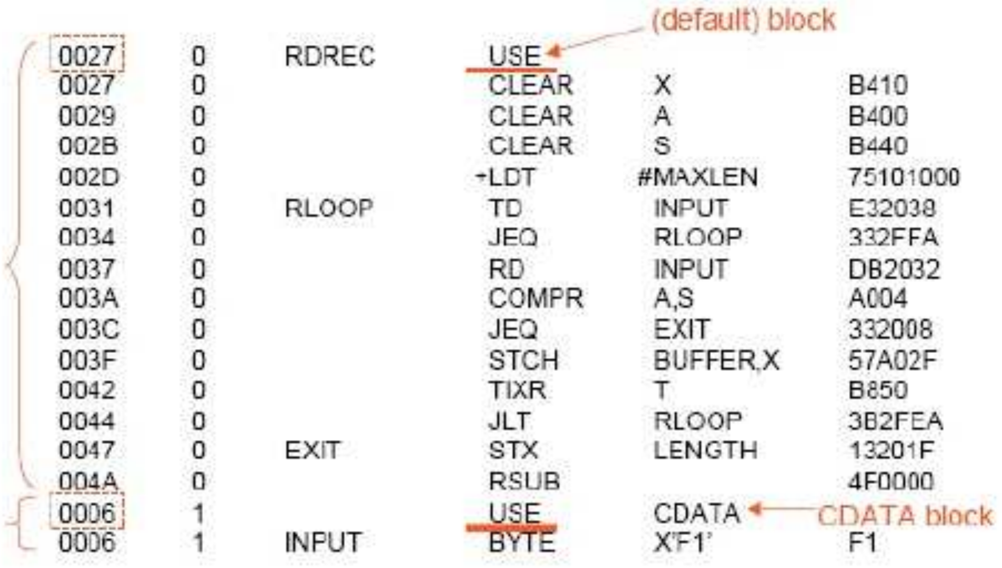
Assembler directive: USE

- USE [blockname]
- At the beginning, statements are assumed to be part of the unnamed (default) block
- If no USE statements are included, the entire program belongs to this single block
- Each program block may actually contain several separate segments of the source program

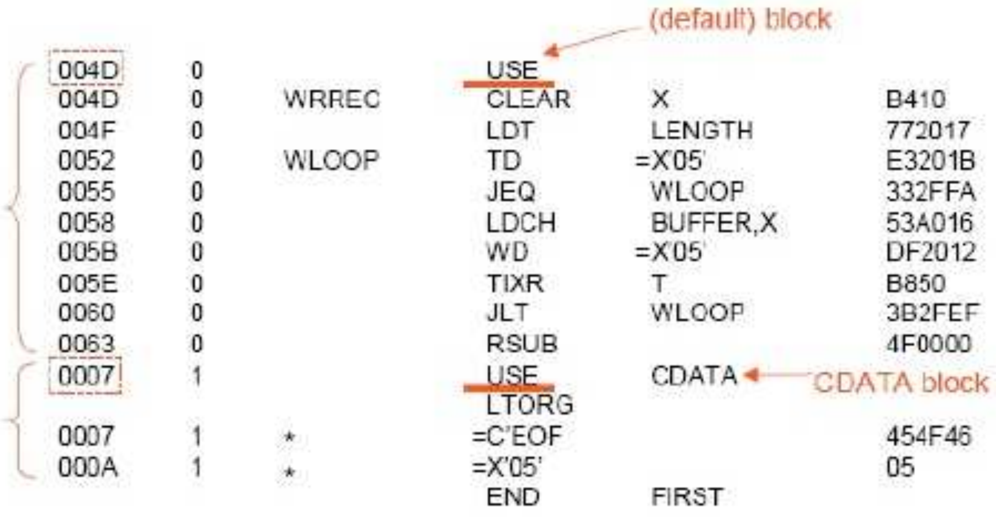
Example


(default) block
Block number
CDATA block
CBLKS block

```
0000    0    COPY      START    0
0000    0    FIRST     STL      RETADR          172063
0003    0    CLOOP     JSUB     RDREC           4B2021
0006    0              LDA      LENGTH          032060
0009    0              COMP    #0               290000
000C    0              JEQ      ENDFIL          332006
000F    0              JSUB     WRREC           4B203B
0012    0              J        CLOOP           3F2FEE
0015    0    ENDFIL    LDA     =C'EOF'          032055
0018    0              STA      BUFFER          0F2056
001B    0              LDA     #3               010003
001E    0              STA      LENGTH          0F2048
0021    0              JSUB     WRREC           4B2029
0024    0              J       @RETADR          3E203F
0000    1              USE      CDATA
0000    1    RETADR    RESW     1
0003    1    LENGTH    RESW     1
0000    2              USE      CBLKS
0000    2    BUFFER    RESB     4096
1000    2    BUFEND    EQU      *
1000         MAXLEN    EQU      BUFEND-BUFFER
```



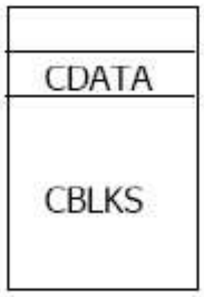
```
0027   0   RDREC    USE
0027   0            CLEAR    X            B410
0029   0            CLEAR    A            B400
002B   0            CLEAR    S            B440
002D   0           +LDT     #MAXLEN       75101000
0031   0   RLOOP    TD       INPUT        E32038
0034   0            JEQ      RLOOP        332FFA
0037   0            RD       INPUT        DB2032
003A   0            COMPR    A,S          A004
003C   0            JEQ      EXIT         332008
003F   0            STCH     BUFFER,X     57A02F
0042   0            TIXR     T            B850
0044   0            JLT      RLOOP        3B2FEA
0047   0   EXIT     STX      LENGTH       13201F
004A   0            RSUB                  4F0000
0006   1            USE      CDATA
0006   1   INPUT    BYTE     X'F1'        F1
```



```
004D   0            USE
004D   0   WRREC    CLEAR    X            B410
004F   0            LDT      LENGTH       772017
0052   0   WLOOP    TD      =X'05'        E3201B
0055   0            JEQ      WLOOP        332FFA
0058   0            LDCH     BUFFER,X     53A016
005B   0            WD      =X'05'        DF2012
005E   0            TIXR     T            B850
0060   0            JLT      WLOOP        3B2FEF
0063   0            RSUB                  4F0000
0007   1            USE      CDATA
                    LTORG
0007   1   *       =C'EOF                 454F46
000A   1   *       =X'05'                 05
                    END      FIRST
```

Three blocks are used

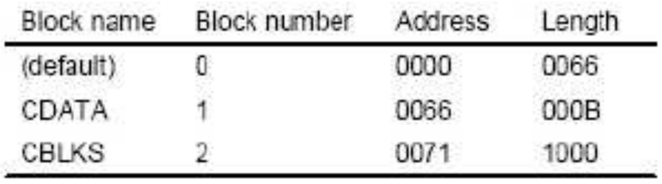
- default: executable instructions.
- CDATA: all data areas that are less in length.
- CBLKS: all data areas that consists of larger blocks of memory.



Rearrange Codes into Program Blocks

Pass 1

- A separate location counter for each program block
  - Save and restore LOCCTR when switching between blocks
  - At the beginning of a block, LOCCTR is set to 0.
- Assign each label an address relative to the start of the block
- Store the block name or number in the SYMTAB along with the assigned relative address of the label
- Indicate the block length as the latest value of LOCCTR for each block at the end of Pass1
- Assign to each block a starting address in the object program by concatenating the program blocks in a particular order

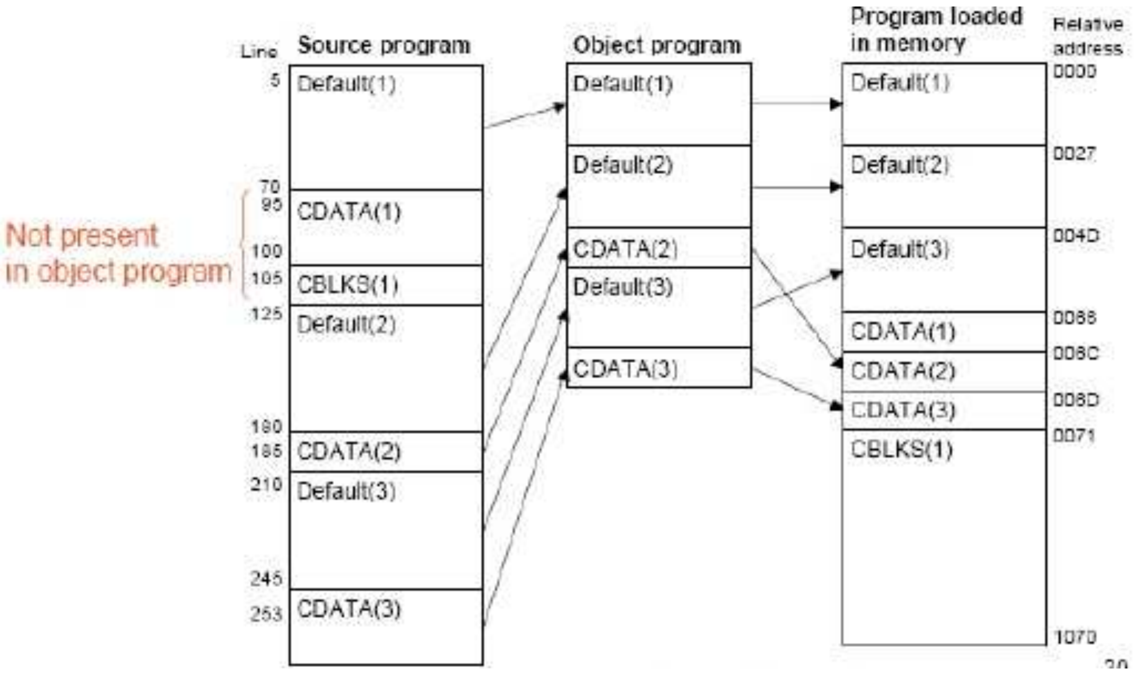


Block name	Block number	Address	Length
(default)	0	0000	0066
CDATA	1	0066	000B
CBLKS	2	0071	1000

Pass 2

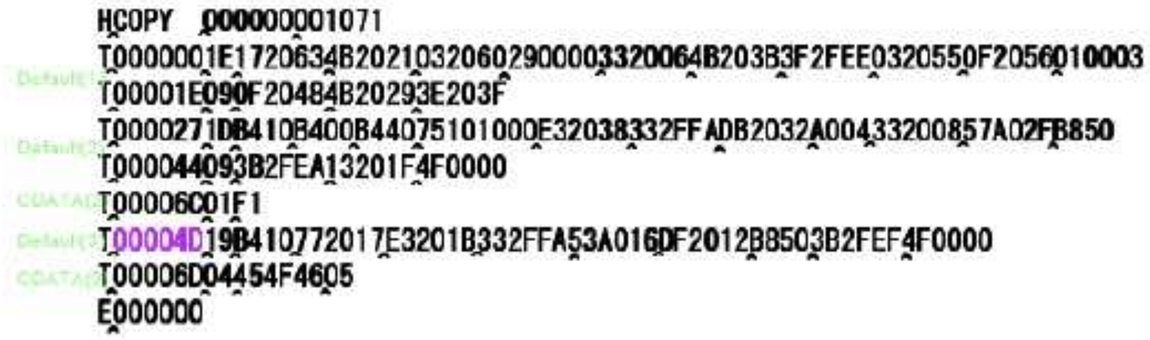
- Calculate the address for each symbol relative to the start of the object program by adding
  - The location of the symbol relative to the start of its block
  - The starting address of this block

Program Blocks Loaded in Memory



Object Program

- It is not necessary to physically rearrange the generated code in the object program
- The assembler just simply inserts the proper load address in each Text record.
- The loader will load these codes into correct place



```
HCOPY  000000001071
T0000001E1720634B20210320602900003320064B203B3F2FEE0320550F2056010003
T00001E090F20484B20293E203F
T0000271DB410B400B44075101000E32038332FFADB2032A00433200857A02FB850
T000044093B2FEA13201F4F0000
T00006C01F1
T00004D19B410772017E3201B332FFA53A016DF2012B8503B2FEF4F0000
T00006D04454F4605
E000000
```

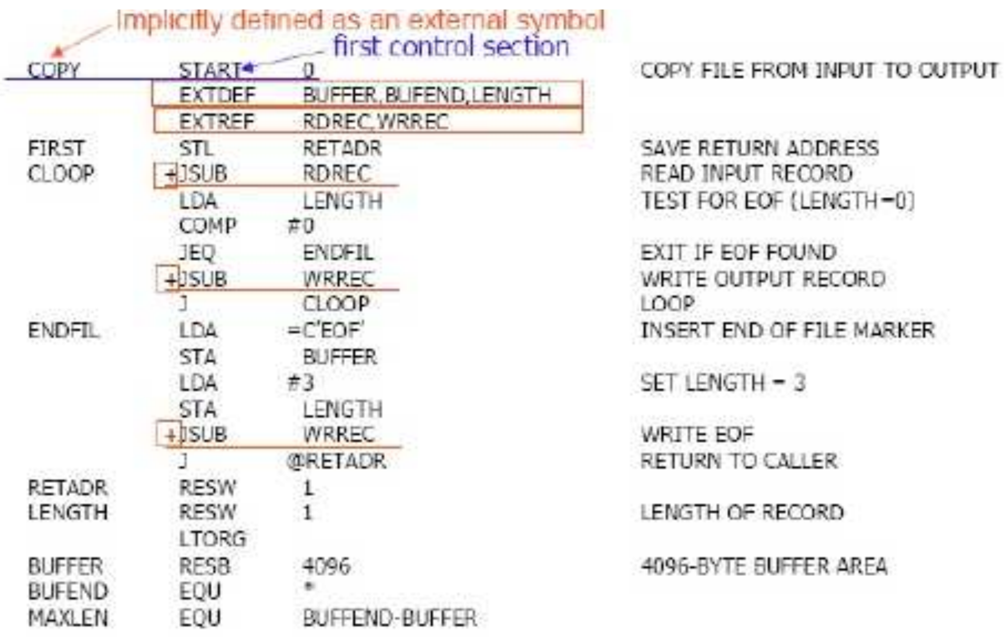
2.3.5 Control Sections and Program Linking

Control sections

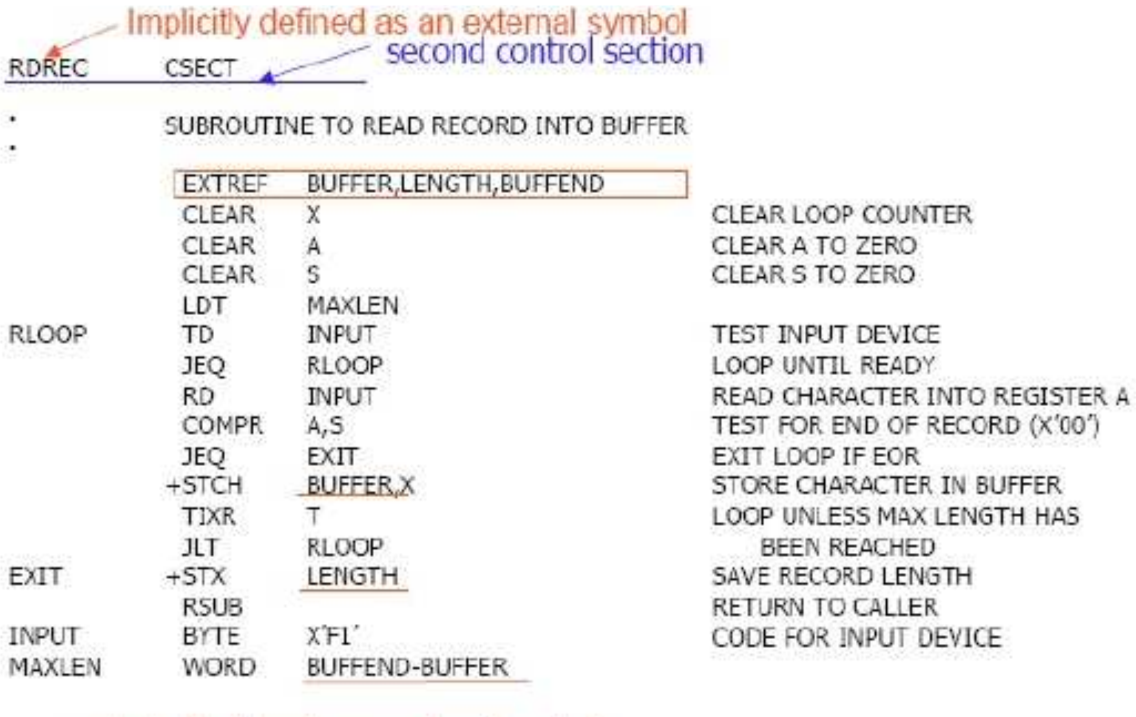
- can be loaded and relocated independently of the other
- are most often used for subroutines or other logical subdivisions of a program
- the programmer can assemble, load, and manipulate each of these control sections separately
- because of this, there should be some means for linking control sections together
- assembler directive: CSECT
  secname CSECT
- separate location counter for each control section

External Definition and Reference

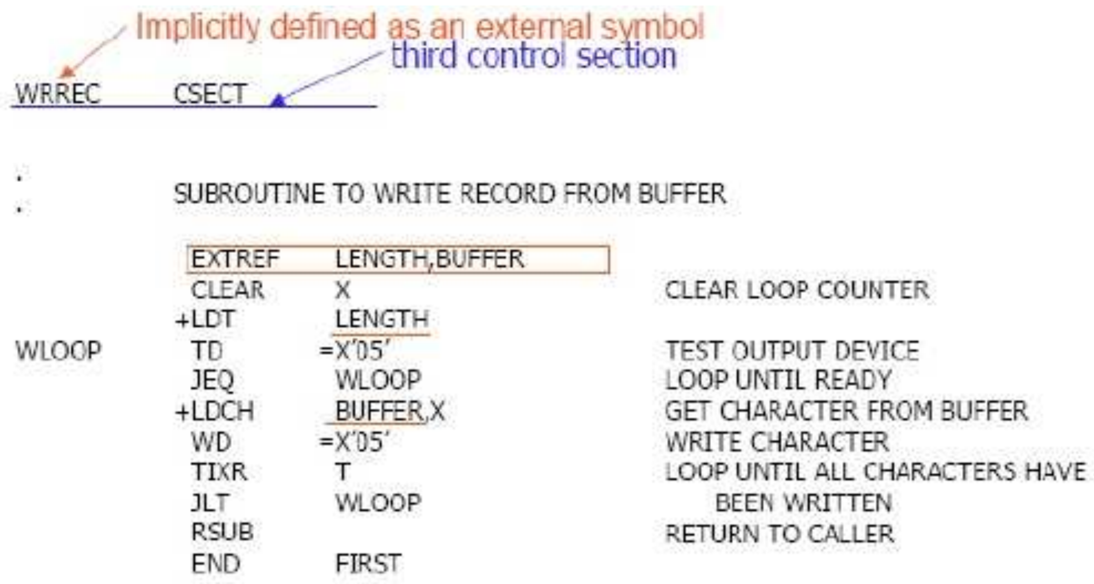
- Instructions in one control section may need to refer to instructions or data located in another section
- External definition
  - EXTDEF name [, name]
  - EXTDEF names symbols that are defined in this control section and may be used by other sections
  - Ex: EXTDEF BUFFER, BUFEND, LENGTH
- External reference
  - EXTREF name [,name]
  - EXTREF names symbols that are used in this control section and are defined elsewhere
  - Ex: EXTREF RDREC, WRREC
- To reference an external symbol, extended format instruction is needed.



```
COPY      START     0               COPY FILE FROM INPUT TO OUTPUT
          EXTDEF    BUFFER,BUFEND,LENGTH
          EXTREF    RDREC,WRREC
FIRST     STL       RETADR          SAVE RETURN ADDRESS
CLOOP     +JSUB     RDREC           READ INPUT RECORD
          LDA       LENGTH          TEST FOR EOF (LENGTH=0)
          COMP     #0
          JEQ       ENDFIL          EXIT IF EOF FOUND
          +JSUB     WRREC           WRITE OUTPUT RECORD
          J         CLOOP           LOOP
ENDFIL    LDA      =C'EOF'          INSERT END OF FILE MARKER
          STA       BUFFER
          LDA      #3               SET LENGTH = 3
          STA       LENGTH
          +JSUB     WRREC           WRITE EOF
          J        @RETADR          RETURN TO CALLER
RETADR    RESW      1
LENGTH    RESW      1               LENGTH OF RECORD
          LTORG
BUFFER    RESB      4096            4096-BYTE BUFFER AREA
BUFEND    EQU       *
MAXLEN    EQU       BUFFEND-BUFFER
```



```
RDREC     CSECT
.
.         SUBROUTINE TO READ RECORD INTO BUFFER
          EXTREF    BUFFER,LENGTH,BUFFEND
          CLEAR     X               CLEAR LOOP COUNTER
          CLEAR     A               CLEAR A TO ZERO
          CLEAR     S               CLEAR S TO ZERO
          LDT       MAXLEN
RLOOP     TD        INPUT           TEST INPUT DEVICE
          JEQ       RLOOP           LOOP UNTIL READY
          RD        INPUT           READ CHARACTER INTO REGISTER A
          COMPR     A,S             TEST FOR END OF RECORD (X'00')
          JEQ       EXIT            EXIT LOOP IF EOR
         +STCH      BUFFER,X        STORE CHARACTER IN BUFFER
          TIXR      T               LOOP UNLESS MAX LENGTH HAS
          JLT       RLOOP              BEEN REACHED
EXIT     +STX       LENGTH          SAVE RECORD LENGTH
          RSUB                      RETURN TO CALLER
INPUT     BYTE      X'F1'           CODE FOR INPUT DEVICE
MAXLEN    WORD      BUFFEND-BUFFER
```



Implicitly defined as an external symbol

third control section

```
WRREC      CSECT
.
.          SUBROUTINE TO WRITE RECORD FROM BUFFER

            EXTREF    LENGTH,BUFFER
            CLEAR     X                      CLEAR LOOP COUNTER
           +LDT       LENGTH
WLOOP       TD       =X'05'                  TEST OUTPUT DEVICE
            JEQ       WLOOP                  LOOP UNTIL READY
           +LDCH      BUFFER,X               GET CHARACTER FROM BUFFER
            WD       =X'05'                  WRITE CHARACTER
            TIXR      T                      LOOP UNTIL ALL CHARACTERS HAVE
            JLT       WLOOP                     BEEN WRITTEN
            RSUB                             RETURN TO CALLER
            END       FIRST
```

External Reference Handling

Case 1

- 15 0003 CLOOP +JSUB RDREC 4B100000
- The operand RDREC is an external reference.
- The assembler
  - Has no idea where RDREC is
  - Inserts an address of zero
  - Can only use extended format to provide enough room (that is, relative addressing for external reference is invalid)
- The assembler generates information for each external reference that will allow the loader to perform the required linking.

Case 2

- 190 0028 MAXLEN WORD BUFEND-BUFFER 000000
- There are two external references in the expression, BUFEND and BUFFER.
- The assembler
  - inserts a value of zero
  - passes information to the loader
    - Add to this data area the address of BUFEND
    - Subtract from this data area the address of BUFFER

Case 3

- On line 107, BUFEND and BUFFER are defined in the same control section and the expression can be calculated immediately.
- 107 1000 MAXLEN EQU BUFEND-BUFFER

Records for Object Program

- The assembler must include information in the object program that will cause the loader to insert proper values where they are required.

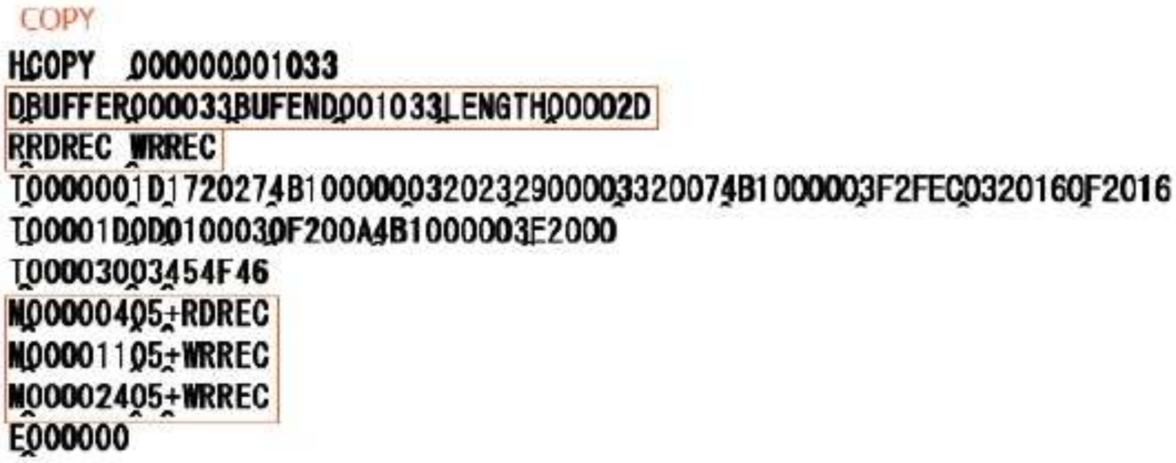
- Define record (EXTDEF)
  Col. 1 D
  Col. 2-7 Name of external symbol defined in this control section
  Col. 8-13 Relative address within this control section (hexadeccimal)
  Col.14-73 Repeat information in Col. 2-13 for other external symbols

- Refer record (EXTREF)
  Col. 1 R
  Col. 2-7 Name of external symbol referred to in this control section
  Col. 8-73 Name of other external reference symbols

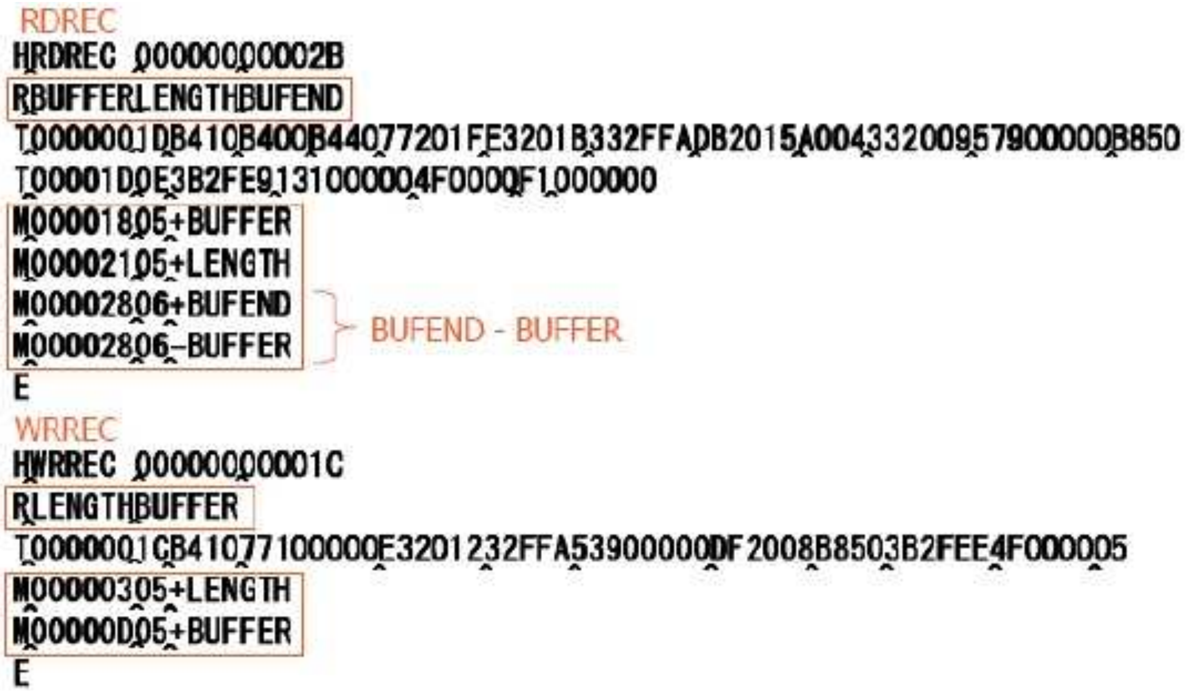
- Modification record
  Col. 1 M
  Col. 2-7 Starting address of the field to be modified (hexiadecimal)
  Col. 8-9 Length of the field to be modified, in half-bytes (hexadeccimal)
  Col.11-16 External symbol whose value is to be added to or subtracted from the indicated field

- Control section name is automatically an external symbol, i.e. it is available for use in Modification records.

Object Program



```
COPY
H^COPY  ^000000^001033
D^BUFFER^000033^BUFEND^001033^LENGTH^00002D
R^RDREC ^WRREC
T^000000^1D^172027^4B100000^032023^290000^332007^4B100000^3F2FEC^032016^0F2016
T^00001D^0D^010003^0F200A^4B100000^3E2000
T^000030^03^454F46
M^000004^05^+RDREC
M^000011^05^+WRREC
M^000024^05^+WRREC
E^000000
```



```
RDREC
H^RDREC ^000000^00002B
R^BUFFER^LENGTH^BUFEND
T^000000^1D^B410^B400^B440^77201F^E3201B^332FFA^DB2015^A004^332009^57900000^B850
T^00001D^0E^3B2FE9^13100000^4F0000^F1^000000
M^000018^05^+BUFFER
M^000021^05^+LENGTH
M^000028^06^+BUFEND
M^000028^06^-BUFFER      BUFEND - BUFFER
E
WRREC
H^WRREC ^000000^00001C
R^LENGTH^BUFFER
T^000000^1C^B410^77100000^E32012^332FFA^53900000^DF2008^B850^3B2FEE^4F000005
M^000003^05^+LENGTH
M^00000D^05^+BUFFER
E
```

Expressions in Multiple Control Sections

- Extended restriction
  - Both terms in each pair of an expression must be within the same control section
  - Legal: BUFEND-BUFFER
  - Illegal: RDREC-COPY
- How to enforce this restriction
  - When an expression involves external references, the assembler cannot determine whether or not the expression is legal.
  - The assembler evaluates all of the terms it can, combines these to form an initial expression value, and generates Modification records.
  - The loader checks the expression for errors and finishes the evaluation.

2.4. ASSEMBLER DESIGN

The assembler design deals with

- Two-pass assembler with overlay structure
- One-pass assemblers
- Multi-pass assemblers

2.4.1 One-pass assembler

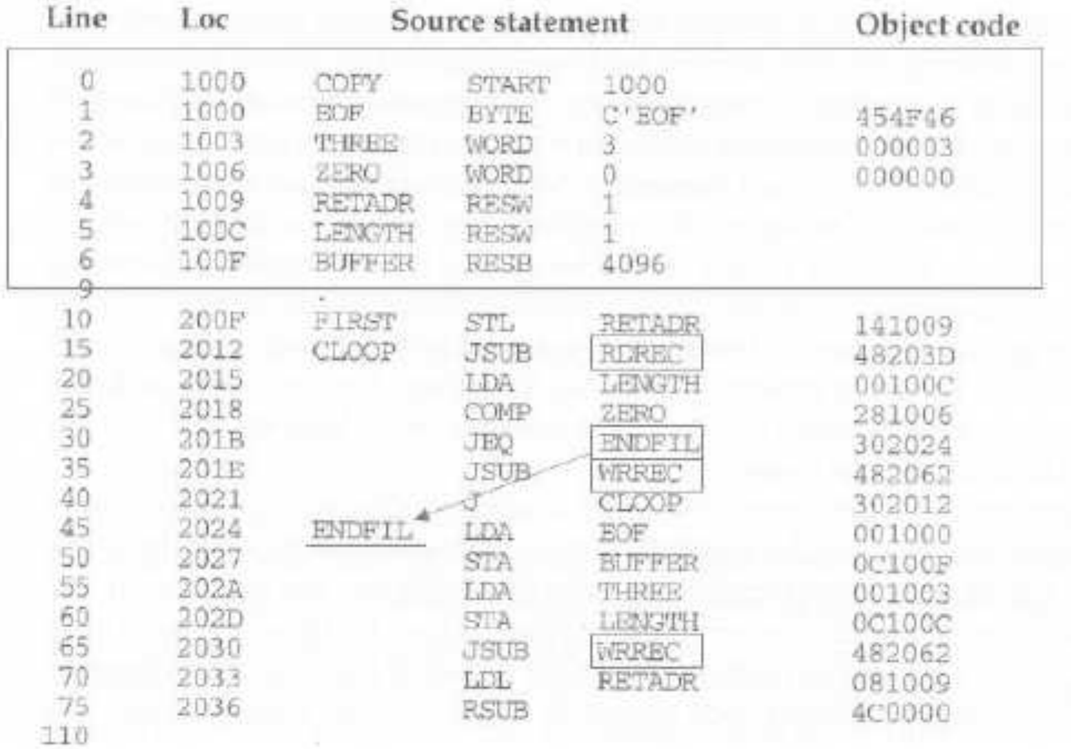
Load-and-Go Assembler

- Load-and-go assembler generates their object code in memory for immediate execution.
- No object program is written out, no loader is needed.
- It is useful in a system with frequent program development and testing
- The efficiency of the assembly process is an important consideration.
- Programs are re-assembled nearly every time they are run; efficiency of the assembly process is an important consideration.

One-Pass Assemblers

- Scenario for one-pass assemblers
  - Generate their object code in memory for immediate execution – *load-and-go* assembler
  - External storage for the intermediate file between two passes is slow or is inconvenient to use
- Main problem - Forward references
  - Data items
  - Labels on instructions
- Solution
  - Require that all areas be defined before they are referenced.
  - It is possible, although inconvenient, to do so for data items.
  - Forward jump to instruction items cannot be easily eliminated.
    - Insert (label, *address_to_be_modified*) to SYMTAB
    - Usually, *address_to_be_modified* is stored in a linked-list

Sample program for a one-pass assembler



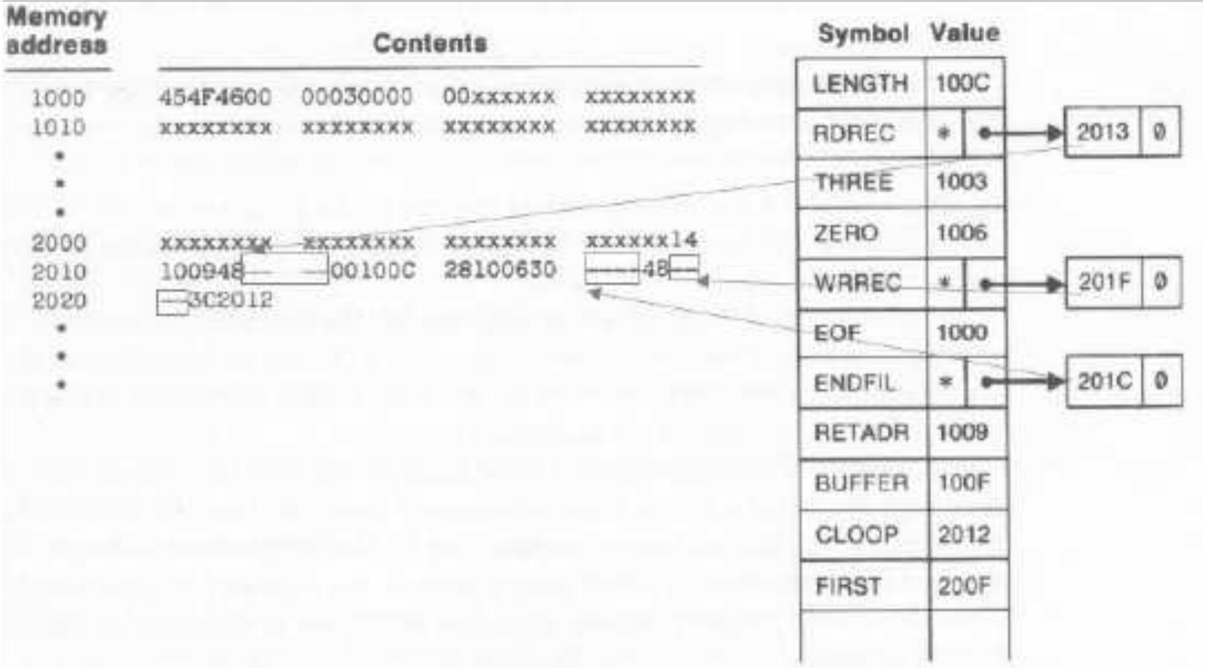
```
Line   Loc        Source statement              Object code

  0    1000   COPY     START   1000
  1    1000   EOF      BYTE    C'EOF'           454F46
  2    1003   THREE    WORD    3                000003
  3    1006   ZERO     WORD    0                000000
  4    1009   RETADR   RESW    1
  5    100C   LENGTH   RESW    1
  6    100F   BUFFER   RESB    4096
  9           .
 10    200F   FIRST    STL     RETADR           141009
 15    2012   CLOOP    JSUB    RDREC            48203D
 20    2015            LDA     LENGTH           00100C
 25    2018            COMP    ZERO             281006
 30    201B            JEQ     ENDFIL           302024
 35    201E            JSUB    WRREC            482062
 40    2021            J       CLOOP            302012
 45    2024   ENDFIL   LDA     EOF              001000
 50    2027            STA     BUFFER           0C100F
 55    202A            LDA     THREE            001003
 60    202D            STA     LENGTH           0C100C
 65    2030            JSUB    WRREC            482062
 70    2033            LDL     RETADR           081009
 75    2036            RSUB                     4C0000
110
```

Forward Reference in One-pass Assembler

- Omits the operand address if the symbol has not yet been defined.
- Enters this undefined symbol into SYMTAB and indicates that it is undefined.
- Adds the address of this operand address to a list of forward references associated with the SYMTAB entry.
- When the definition for the symbol is encountered, scans the reference list and inserts the address.
- At the end of the program, reports the error if there are still SYMTAB entries indicated undefined symbols.
- For Load-and-Go assembler
    - Search SYMTAB for the symbol named in the END statement and jumps to this location to begin execution if there is no error.

Object Code in Memory and SYMTAB

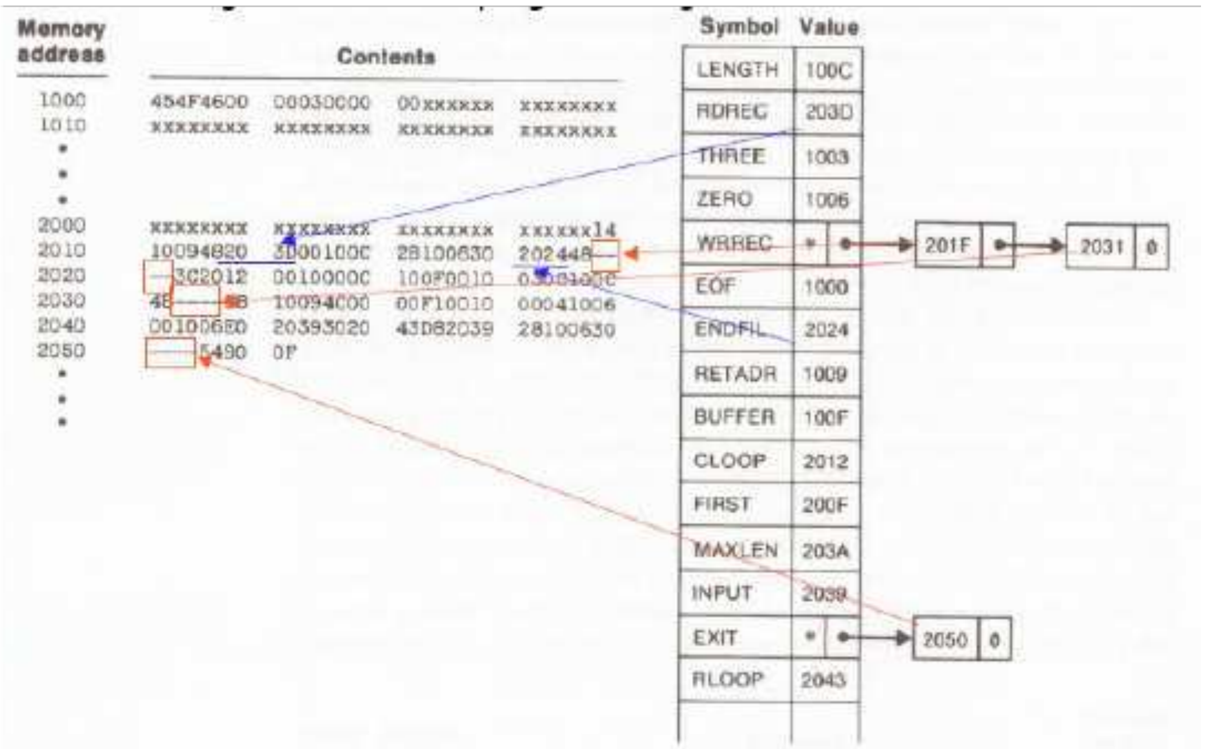
After scanning line 40 of the above program



```
Memory
address          Contents

1000     454F4600  00030000  00xxxxxx  xxxxxxxx
1010     xxxxxxxx  xxxxxxxx  xxxxxxxx  xxxxxxxx
  •
  •
  •
2000     xxxxxxxx  xxxxxxxx  xxxxxxxx  xxxxxx14
2010     100948----      ----00100C  28100630  ------48----
2020     ----3C2012
  •
  •
  •
```

Symbol	Value
LENGTH	100C
RDREC	*
THREE	1003
ZERO	1006
WRREC	*
EOF	1000
ENDFIL	*
RETADR	1009
BUFFER	100F
CLOOP	2012
FIRST	200F

After scanning line 160 of the above program



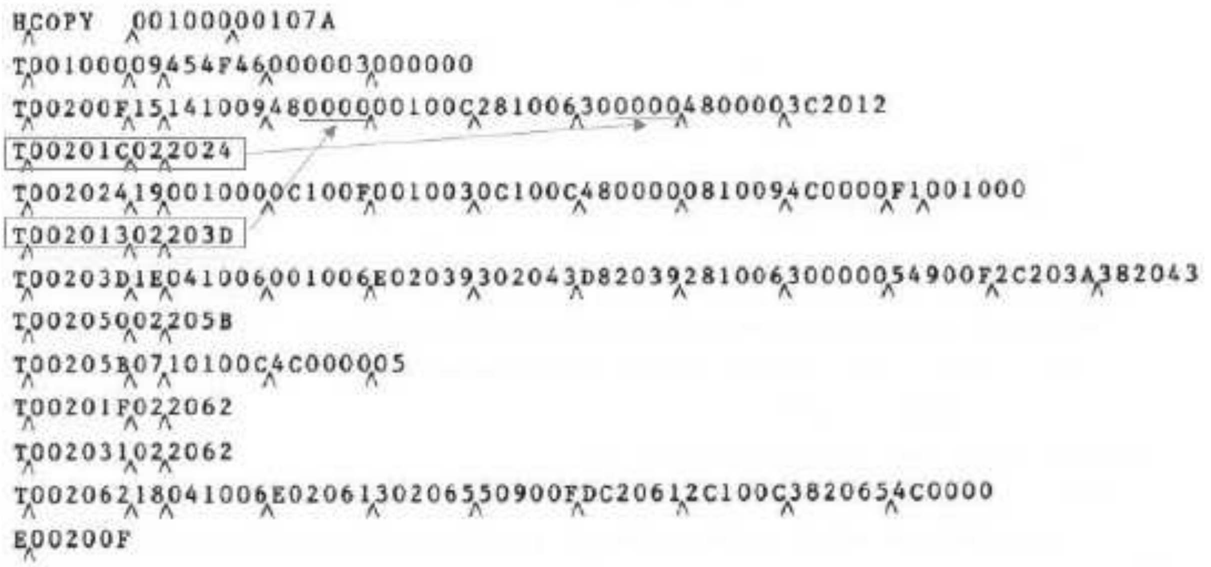
```
Memory
address          Contents

1000     454F4600  00030000  00xxxxxx  xxxxxxxx
1010     xxxxxxxx  xxxxxxxx  xxxxxxxx  xxxxxxxx
  •
  •
  •
2000     xxxxxxxx  xxxxxxxx  xxxxxxxx  xxxxxx14
2010     10094820  3D00100C  28100630  202448----
2020     ----3C2012  0010000C  100F0010  0300100C
2030     48------08  10094C00  00F10010  00041006
2040     001006E0  20393020  43D82039  28100630
2050     ------5490  0F
  •
  •
  •
```

Symbol	Value
LENGTH	100C
RDREC	203D
THREE	1003
ZERO	1006
WRREC	*
EOF	1000
ENDFIL	2024
RETADR	1009
BUFFER	100F
CLOOP	2012
FIRST	200F
MAXLEN	203A
INPUT	2039
EXIT	*
RLOOP	2043

If One-Pass Assemblers need to produce object codes

- If the operand contains an undefined symbol, use 0 as the address and write the Text record to the object program.
- Forward references are entered into lists as in the load-and-go assembler.
- When the definition of a symbol is encountered, the assembler generates another Text record with the correct operand address of each entry in the reference list.
- When loaded, the incorrect address 0 will be updated by the latter Text record containing the symbol definition.

Object code generated by one-pass assembler

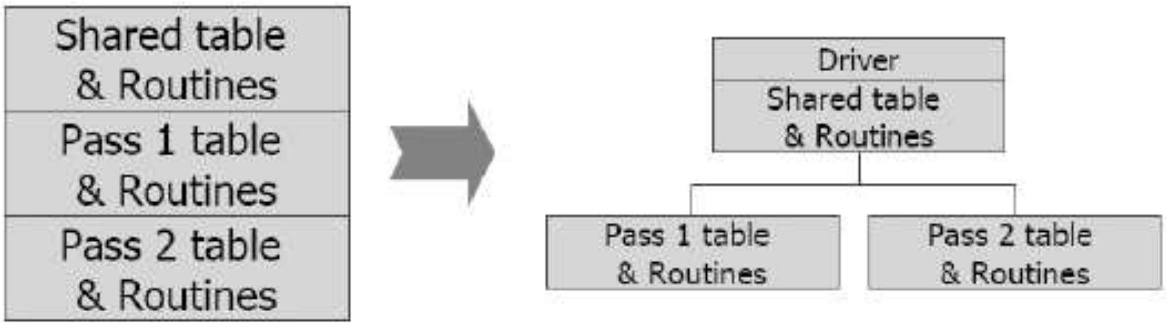


```
HCOPY  00100000107A
T00100009454F46000003000000
T00200F15141009480000000100C281006300000480000 3C2012
T00201C022024
T002024190010000C100F0010030C100C48000008100 94C0000F1001000
T00201302203D
T00203D1E041006001006E02039302043D82039281006300000 54900F2C203A382043
T00205002205B
T00205B0710100C4C000005
T00201F022062
T002031022062
T00206218041006E02061302065 50900FDC20612C100C3820654C0000
E00200F
```

2.4.2 Two-pass assembler with overlay structure

- Most assemblers divide the processing of the source program into two passes.
- The internal tables and subroutines that are used only during Pass 1 are no longer needed after the first pass is completed.
- The routines and tables for Pass 1 and Pass 2 are never required at the same time.
- There are certain tables (SYMTAB) and certain processing subroutines (searching SYMTAB) that are used by both passes.
- Since Pass 1 and Pass 2 segments are never needed at the same time, they can occupy the same locations in memory during execution of the assembler.
- Initially the Root and Pass 1 segments are loaded into memory.
- The assembler then makes the first pass over the program being assembled.
- At the end of the Pass1, the Pass 2 segment is loaded, replacing the Pass 1 segment.
- The assembler then makes its second pass of the source program and terminates.

- The assembler needs much less memory to run in this way than it would be if both Pass 1 and Pass 2 were loaded at the same time.
- A program that is designed to execute in this way is called an Overlay program because some of its segments overlay others during execution.



2.4.3 Multi-Pass Assemblers

- For a two pass assembler, forward references in symbol definition are not allowed:

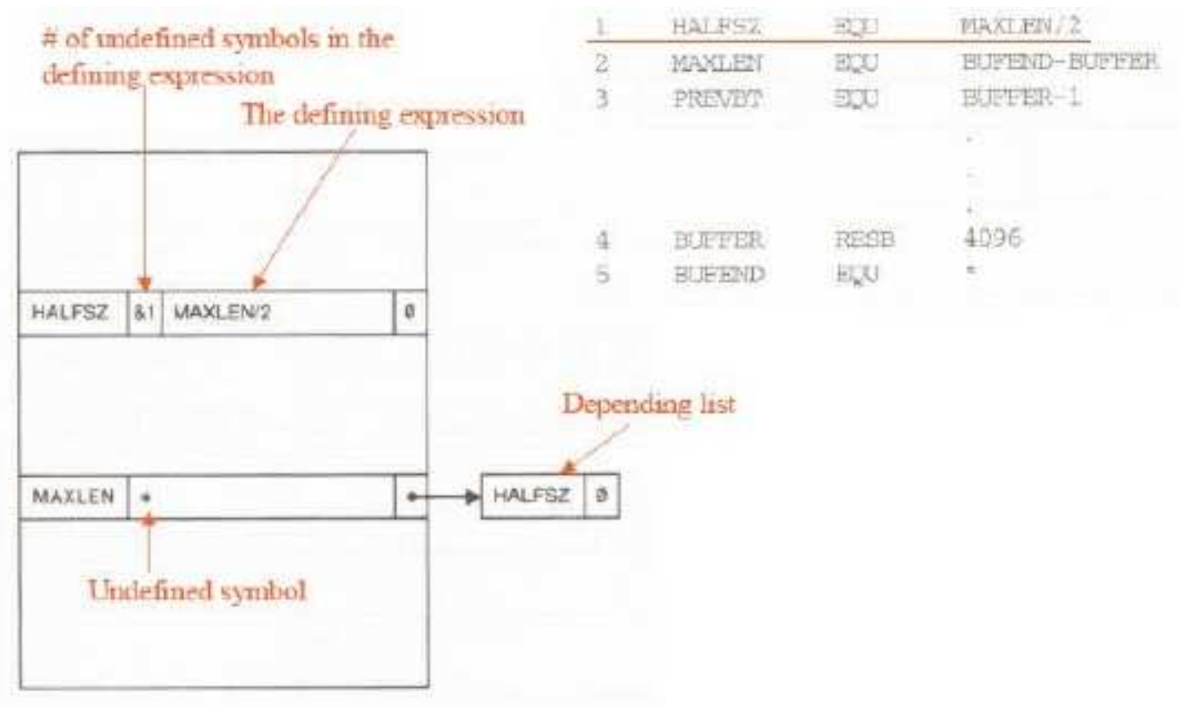
```
ALPHA           EQU            BETA
BETA            EQU            DELTA
DELTA           RESW           1
```

- The symbol BETA cannot be assigned a value when it is encountered during Pass 1 because DELTA has not yet been defined.
- Hence ALPHA cannot be evaluated during Pass 2.
- Symbol definition must be completed in pass 1.
- Prohibiting forward references in symbol definition is not a serious inconvenience.
- Forward references tend to create difficulty for a person reading the program.
- The general solution for forward references is a multi-pass assembler that can make as many passes as are needed to process the definitions of symbols.
- It is not necessary for such an assembler to make more than 2 passes over the entire program.
- The portions of the program that involve forward references in symbol definition are saved during Pass 1.
- Additional passes through these stored definitions are made as the assembly progresses.
- This process is followed by a normal Pass 2.

Implementation

- For a forward reference in symbol definition, we store in the SYMTAB:
  - The symbol name
  - The defining expression
  - The number of undefined symbols in the defining expression
- The undefined symbol (marked with a flag *) associated with a list of symbols depend on this undefined symbol.
- When a symbol is defined, we can recursively evaluate the symbol expressions depending on the newly defined symbol.

Example of Multi-pass assembler



```
1   HALFSZ   EQU    MAXLEN/2
2   MAXLEN   EQU    BUFEND-BUFFER
3   PREVBT   EQU    BUFFER-1
                    .
                    .
                    .
4   BUFFER   RESB   4096
5   BUFEND   EQU    *
```

Consider the symbol table entries from Pass 1 processing of the statement.

HALFS2 EQU MAXLEN/2

- Since MAXLEN has not yet been defined, no value for HALFS2 can be computed.
- The defining expression for HALFS2 is stored in the symbol table in place of its value.
- The entry &1 indicates that 1 symbol in the defining expression undefined.
- SYMTAB simply contain a pointer to the defining expression.

- The symbol MAXLEN is also entered in the symbol table, with the flag * identifying it as undefined.
- Associated with this entry is a list of the symbols whose values depend on MAXLEN.

UNIT III

LOADERS AND LINKERS

INTRODUCTION

- Loader is a system program that performs the loading function.
- Many loaders also support relocation and linking.
- Some systems have a linker (linkage editor) to perform the linking operations and a separate loader to handle relocation and loading.
- One system loader or linker can be used regardless of the original source programming language.
- Loading → Brings the object program into memory for execution.
- Relocation → Modifies the object program so that it can be loaded at an address different from the location originally specified.
- Linking → Combines two or more separate object programs and supplies the information needed to allow references between them.

3.1 BASIC LOADER FUNCTIONS

Fundamental functions of a loader:

1. Bringing an object program into memory.
2. Starting its execution.

3.1.1 Design of an Absolute Loader

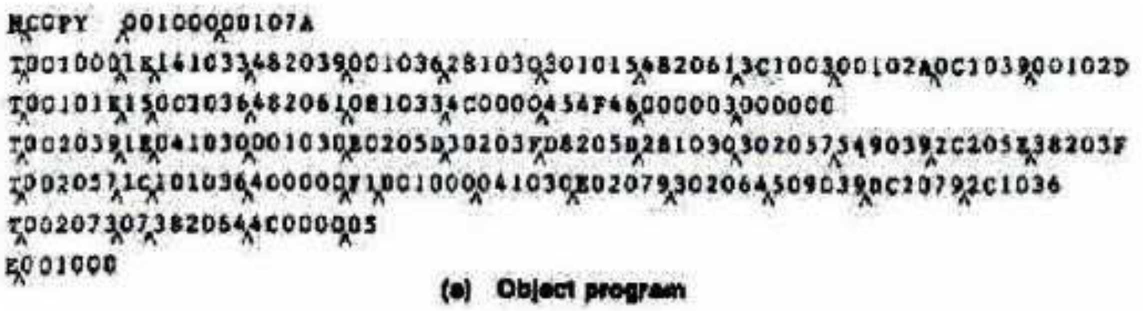
For a simple absolute loader, all functions are accomplished in a single pass as follows:

1) The Header record of object programs is checked to verify that the correct program has been presented for loading.

2) As each Text record is read, the object code it contains is moved to the indicated address in memory.

3) When the End record is encountered, the loader jumps to the specified address to begin execution of the loaded program.

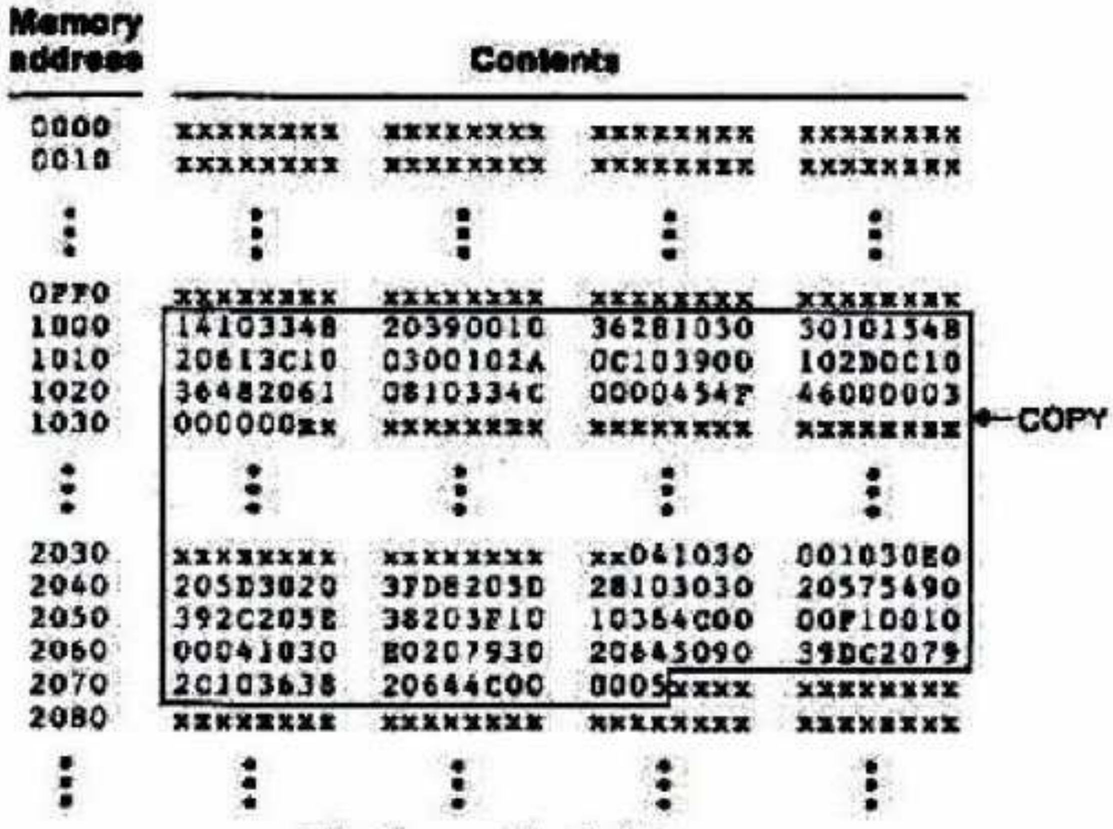
An example object program is shown in Fig (a).



```
H^COPY  ^001000^00107A
T^001000^1E^141033^482039^001036^281030^301015^482061^3C1003^00102A^0C1039^00102D
T^00101E^15^0C1036^482061^081033^4C0000^454F46^000003^000000
T^002039^1E^041030^001030^E0205D^30203F^D8205D^281030^302057^549039^2C205E^38203F
T^002057^1C^101036^4C0000^F1^001000^041030^E02079^302064^509039^DC2079^2C1036
T^002073^07^382064^4C0000^05
E^001000
```

(a) Object program

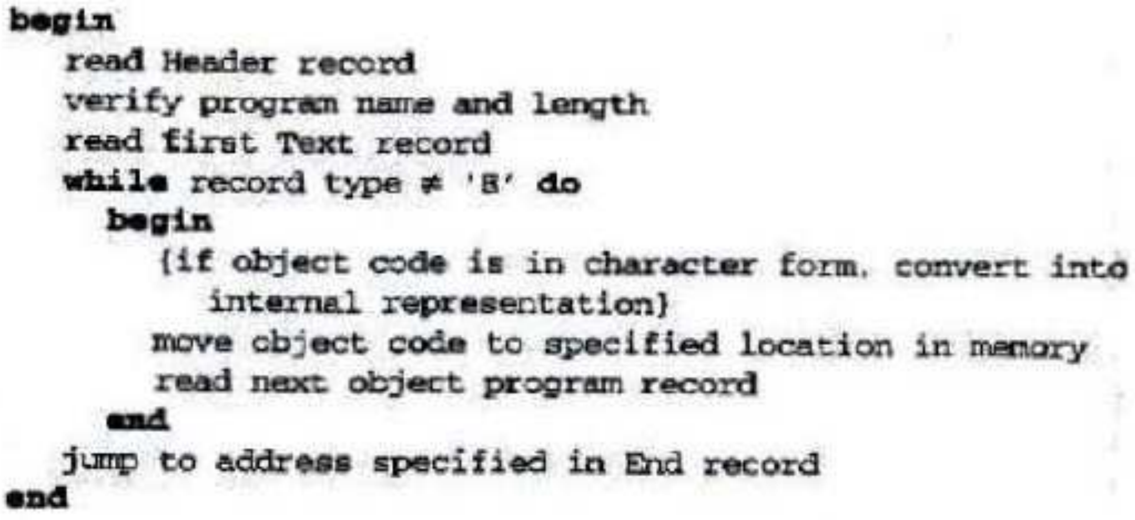
Fig (b) shows a representation of the program from Fig (a) after loading.



```
Memory
address                          Contents

 0000      xxxxxxxx   xxxxxxxx   xxxxxxxx   xxxxxxxx
 0010      xxxxxxxx   xxxxxxxx   xxxxxxxx   xxxxxxxx
   :           :          :          :          :
 0FF0      xxxxxxxx   xxxxxxxx   xxxxxxxx   xxxxxxxx
 1000      14103348   20390010   36281030   30101548
 1010      20613C10   0300102A   0C103900   102D0C10
 1020      36482061   0810334C   0000454F   46000003
 1030      000000xx   xxxxxxxx   xxxxxxxx   xxxxxxxx  ←COPY
   :           :          :          :          :
 2030      xxxxxxxx   xxxxxxxx   xx041030   001030E0
 2040      205D3020   3FD8205D   28103030   20575490
 2050      392C205E   38203F10   10364C00   00F10010
 2060      00041030   E0207930   20645090   39DC2079
 2070      2C103638   20644C00   0005xxxx   xxxxxxxx
 2080      xxxxxxxx   xxxxxxxx   xxxxxxxx   xxxxxxxx
   :           :          :          :          :
```

(b) Program loaded in memory

Algorithm for Absolute Loader



```
begin
   read Header record
   verify program name and length
   read first Text record
   while record type $\neq$ 'E' do
     begin
        {if object code is in character form, convert into
           internal representation}
        move object code to specified location in memory
        read next object program record
     end
   jump to address specified in End record
end
```

- It is very important to realize that in Fig (a), each printed character represents one byte of the object program record.
- In Fig (b), on the other hand, each printed character represents one hexadecimal digit in memory (a half-byte).
- Therefore, to save space and execution time of loaders, most machines store object programs in a **binary form**, with each byte of object code stored as a single byte in the object program.
- In this type of representation a byte may contain any binary value.

3.1.2 A Simple Bootstrap Loader

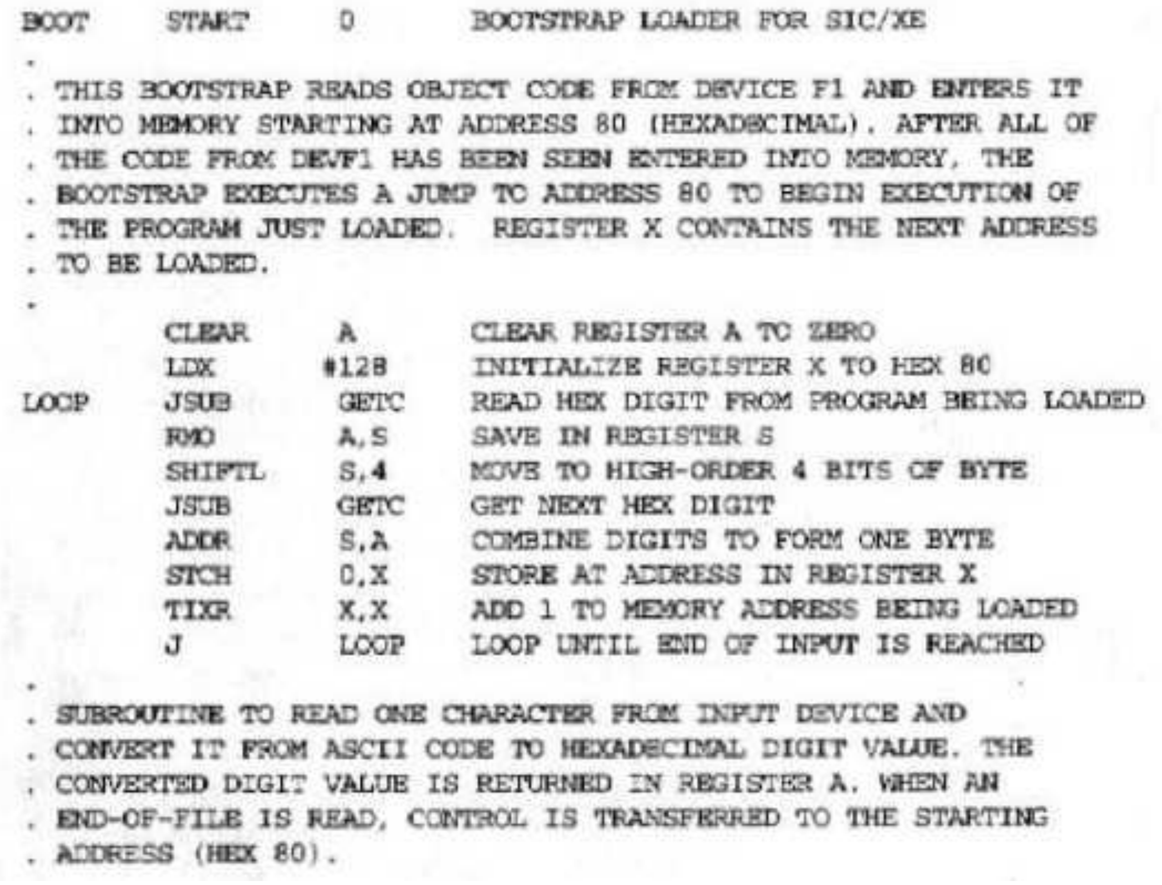
When a computer is first turned on or restarted, a special type of absolute loader, called a **bootstrap loader**, is executed. This bootstrap loads the first program to be run by the computer – usually an operating system.

Working of a simple Bootstrap loader

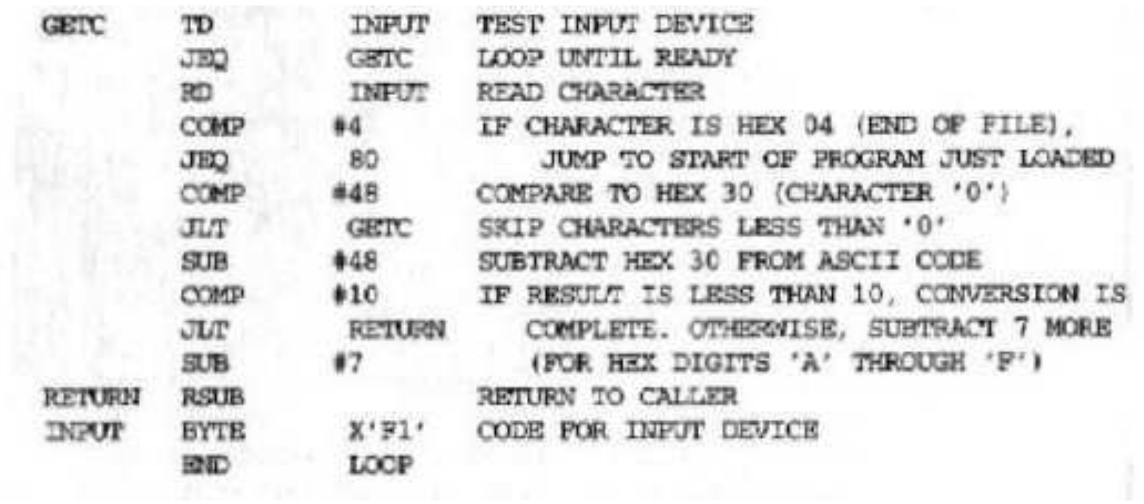
- The bootstrap begins at address 0 in the memory of the machine.
- It loads the operating system at address 80.
- Each byte of object code to be loaded is represented on device F1 as *two hexadecimal digits* just as it is in a Text record of a SIC object program.

- The object code from device F1 is always loaded into consecutive bytes of memory, starting at address 80. The main loop of the bootstrap keeps the address of the next memory location to be loaded in register X.
- After all of the object code from device F1 has been loaded, the bootstrap jumps to address 80, which begins the execution of the program that was loaded.
- Much of the work of the bootstrap loader is performed by the subroutine GETC.
- GETC is used to read and convert a pair of characters from device F1 representing 1 byte of object code to be loaded. For example, two bytes = C "D8"→ '4438'H converting to one byte 'D8'H.
- The resulting byte is stored at the address currently in register X, using STCH instruction that refers to location 0 using indexed addressing.
- The TIXR instruction is then used to add 1 to the value in X.

Source code for bootstrap loader



```
BOOT    START   0       BOOTSTRAP LOADER FOR SIC/XE
.
. THIS BOOTSTRAP READS OBJECT CODE FROM DEVICE F1 AND ENTERS IT
. INTO MEMORY STARTING AT ADDRESS 80 (HEXADECIMAL). AFTER ALL OF
. THE CODE FROM DEVF1 HAS BEEN SEEN ENTERED INTO MEMORY, THE
. BOOTSTRAP EXECUTES A JUMP TO ADDRESS 80 TO BEGIN EXECUTION OF
. THE PROGRAM JUST LOADED.  REGISTER X CONTAINS THE NEXT ADDRESS
. TO BE LOADED.
.
        CLEAR   A       CLEAR REGISTER A TO ZERO
        LDX     #128    INITIALIZE REGISTER X TO HEX 80
LOOP    JSUB    GETC    READ HEX DIGIT FROM PROGRAM BEING LOADED
        RMO     A,S     SAVE IN REGISTER S
        SHIFTL  S,4     MOVE TO HIGH-ORDER 4 BITS OF BYTE
        JSUB    GETC    GET NEXT HEX DIGIT
        ADDR    S,A     COMBINE DIGITS TO FORM ONE BYTE
        STCH    0,X     STORE AT ADDRESS IN REGISTER X
        TIXR    X,X     ADD 1 TO MEMORY ADDRESS BEING LOADED
        J       LOOP    LOOP UNTIL END OF INPUT IS REACHED
.
. SUBROUTINE TO READ ONE CHARACTER FROM INPUT DEVICE AND
. CONVERT IT FROM ASCII CODE TO HEXADECIMAL DIGIT VALUE. THE
. CONVERTED DIGIT VALUE IS RETURNED IN REGISTER A. WHEN AN
. END-OF-FILE IS READ, CONTROL IS TRANSFERRED TO THE STARTING
. ADDRESS (HEX 80).
```



```
GETC    TD      INPUT   TEST INPUT DEVICE
        JEQ     GETC    LOOP UNTIL READY
        RD      INPUT   READ CHARACTER
        COMP    #4      IF CHARACTER IS HEX 04 (END OF FILE),
        JEQ     80         JUMP TO START OF PROGRAM JUST LOADED
        COMP    #48     COMPARE TO HEX 30 (CHARACTER '0')
        JLT     GETC    SKIP CHARACTERS LESS THAN '0'
        SUB     #48     SUBTRACT HEX 30 FROM ASCII CODE
        COMP    #10     IF RESULT IS LESS THAN 10, CONVERSION IS
        JLT     RETURN    COMPLETE. OTHERWISE, SUBTRACT 7 MORE
        SUB     #7        (FOR HEX DIGITS 'A' THROUGH 'F')
RETURN  RSUB            RETURN TO CALLER
INPUT   BYTE    X'F1'   CODE FOR INPUT DEVICE
        END     LOOP
```

3.2 MACHINE-DEPENDENT LOADER FEATURES

- The absolute loader has several potential disadvantages. One of the most obvious is the need for the programmer to specify the actual address at which it will be loaded into memory.
- On a simple computer with a small memory the actual address at which the program will be loaded can be specified easily.
- On a larger and more advanced machine, we often like to run several independent programs together, sharing memory between them. We do not know in advance where a program will be loaded. Hence we write relocatable programs instead of absolute ones.
- Writing absolute programs also makes it difficult to use subroutine libraries efficiently. This could not be done effectively if all of the subroutines had pre-assigned absolute addresses.
- The need for *program relocation* is an indirect consequence of the change to larger and more powerful computers. The way relocation is implemented in a loader is also dependent upon machine characteristics.
- Loaders that allow for program relocation are called relocating loaders or relative loaders.

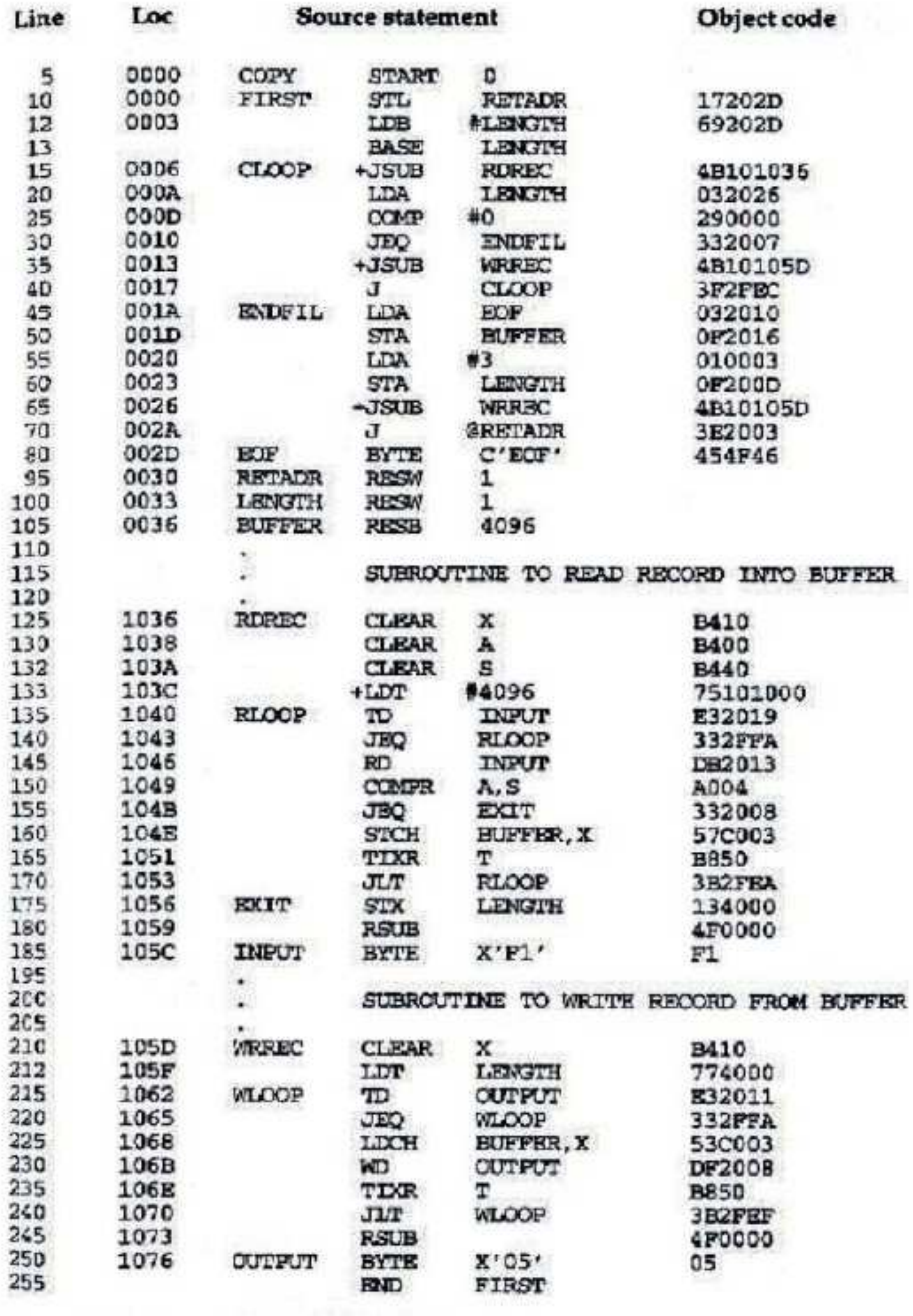
3.2.1 Relocation

Two methods for specifying relocation as part of the object program:

<u>The first method:</u>

- A Modification is used to describe each part of the object code that must be changed when the program is relocated.

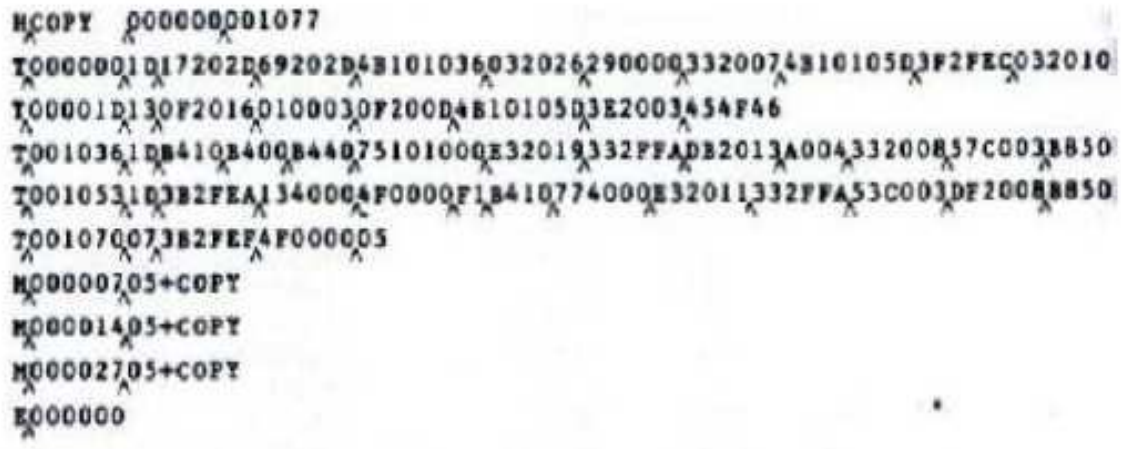
Fig(1) :Consider the program



```
Line   Loc        Source statement                   Object code

  5    0000   COPY     START    0
 10    0000   FIRST    STL      RETADR               17202D
 12    0003            LDB      #LENGTH              69202D
 13                    BASE     LENGTH
 15    0006   CLOOP    +JSUB    RDREC                4B101036
 20    000A            LDA      LENGTH               032026
 25    000D            COMP     #0                   290000
 30    0010            JEQ      ENDFIL               332007
 35    0013            +JSUB    WRREC                4B10105D
 40    0017            J        CLOOP                3F2FEC
 45    001A   ENDFIL   LDA      EOF                  032010
 50    001D            STA      BUFFER               0F2016
 55    0020            LDA      #3                   010003
 60    0023            STA      LENGTH               0F200D
 65    0026            +JSUB    WRREC                4B10105D
 70    002A            J        @RETADR              3E2003
 80    002D   EOF      BYTE     C'EOF'               454F46
 95    0030   RETADR   RESW     1
100    0033   LENGTH   RESW     1
105    0036   BUFFER   RESB     4096
110           .
115           .        SUBROUTINE TO READ RECORD INTO BUFFER
120           .
125    1036   RDREC    CLEAR    X                    B410
130    1038            CLEAR    A                    B400
132    103A            CLEAR    S                    B440
133    103C            +LDT     #4096                75101000
135    1040   RLOOP    TD       INPUT                E32019
140    1043            JEQ      RLOOP                332FFA
145    1046            RD       INPUT                DB2013
150    1049            COMPR    A,S                  A004
155    104B            JEQ      EXIT                 332008
160    104E            STCH     BUFFER,X             57C003
165    1051            TIXR     T                    B850
170    1053            JLT      RLOOP                3B2FEA
175    1056   EXIT     STX      LENGTH               134000
180    1059            RSUB                          4F0000
185    105C   INPUT    BYTE     X'F1'                F1
195           .
200           .        SUBROUTINE TO WRITE RECORD FROM BUFFER
205           .
210    105D   WRREC    CLEAR    X                    B410
212    105F            LDT      LENGTH               774000
215    1062   WLOOP    TD       OUTPUT               E32011
220    1065            JEQ      WLOOP                332FFA
225    1068            LDCH     BUFFER,X             53C003
230    106B            WD       OUTPUT               DF2008
235    106E            TIXR     T                    B850
240    1070            JLT      WLOOP                3B2FEF
245    1073            RSUB                          4F0000
250    1076   OUTPUT   BYTE     X'05'                05
255                    END      FIRST
```

- Most of the instructions in this program use relative or immediate addressing.
- The only portions of the assembled program that contain actual addresses are the extended format instructions on lines 15, 35, and 65. Thus these are the only items whose values are affected by relocation.

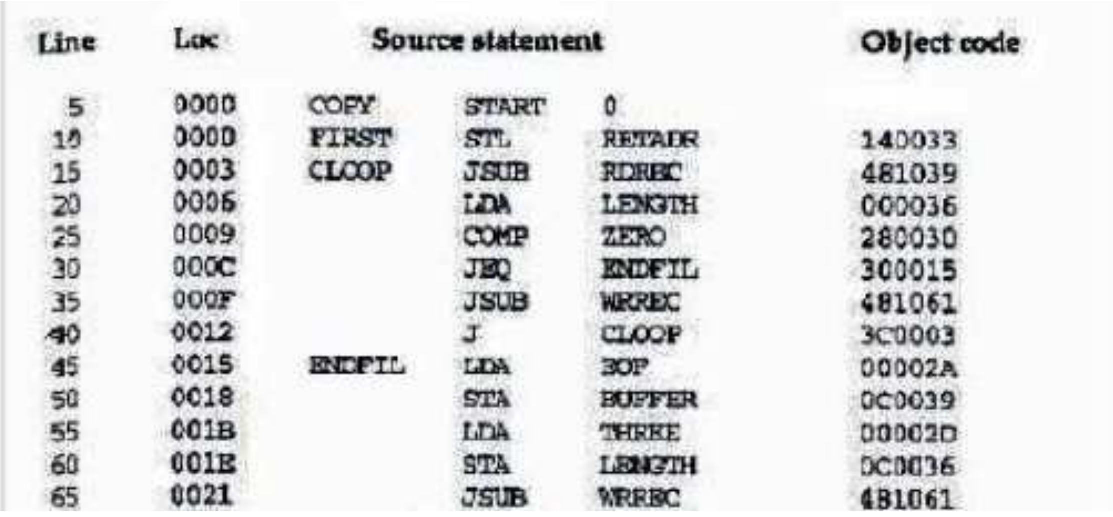
Object program



```
H^COPY  ^000000^001077
T^000000^1D^17202D^69202D^4B101036^032026^290000^332007^4B10105D^3F2FEC^032010
T^00001D^13^0F2016^010003^0F200D^4B10105D^3E2003^454F46
T^001036^1D^B410^B400^B440^75101000^E32019^332FFA^DB2013^A004^332008^57C003^B850
T^001053^1D^3B2FEA^134000^4F0000^F1^B410^774000^E32011^332FFA^53C003^DF2008^B850
T^001070^07^3B2FEF^4F0000^05
M^000007^05+COPY
M^000014^05+COPY
M^000027^05+COPY
E^000000
```

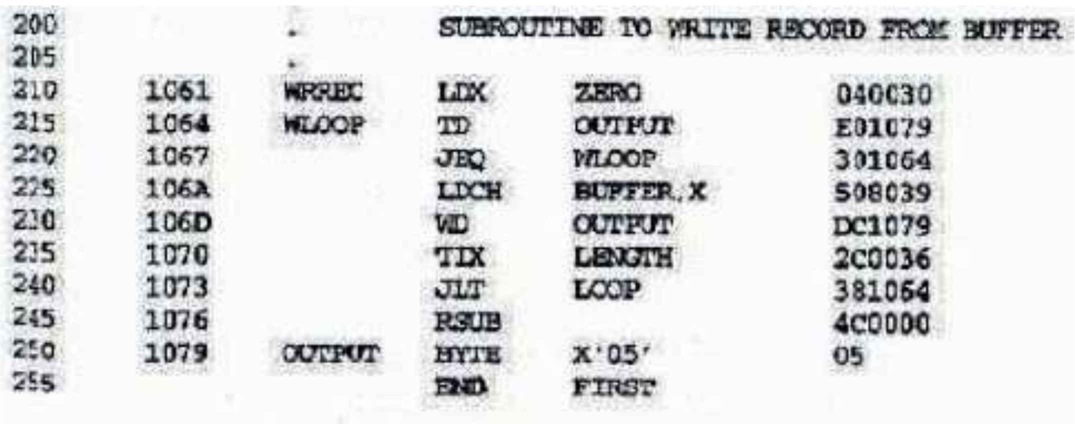
- Each Modification record specifies the starting address and length of the field whose value is to be altered.
- It then describes the modification to be performed.
- In this example, all modifications add the value of the symbol COPY, which represents the starting address of the program.

Fig(2) :Consider a Relocatable program for a Standard SIC machine



Line	Loc	Source statement			Object code
5	0000	COPY	START	0	
10	0000	FIRST	STL	RETADR	140033
15	0003	CLOOP	JSUB	RDREC	481039
20	0006		LDA	LENGTH	000036
25	0009		COMP	ZERO	280030
30	000C		JEQ	ENDFIL	300015
35	000F		JSUB	WRREC	481061
40	0012		J	CLOOP	3C0003
45	0015	ENDFIL	LDA	EOF	00002A
50	0018		STA	BUFFER	0C0039
55	001B		LDA	THREE	00002D
60	001E		STA	LENGTH	0C0036
65	0021		JSUB	WRREC	481061

```
                                    .
                                    .
                                    .
```



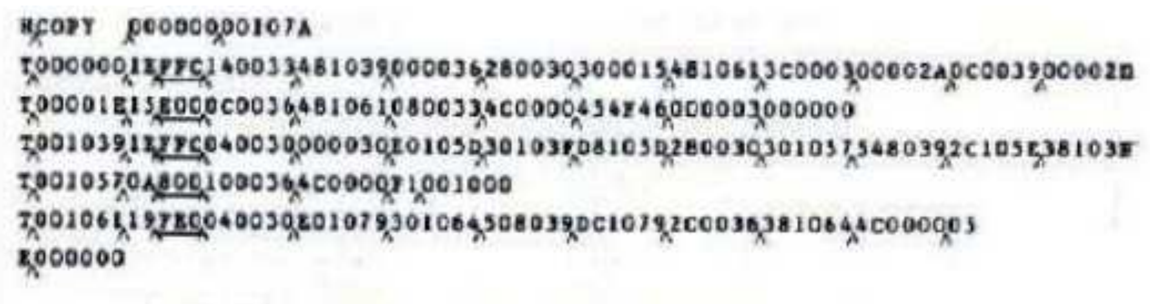
```
200            .        SUBROUTINE TO WRITE RECORD FROM BUFFER
205            .
210    1061    WRREC    LDX       ZERO             040030
215    1064    WLOOP    TD        OUTPUT           E01079
220    1067             JEQ       WLOOP            301064
225    106A             LDCH      BUFFER,X         508039
230    106D             WD        OUTPUT           DC1079
235    1070             TIX       LENGTH           2C0036
240    1073             JLT       LOOP             381064
245    1076             RSUB                       4C0000
250    1079    OUTPUT   BYTE      X'05'            05
255                     END       FIRST
```

- The Modification record is not well suited for use with all machine architectures.Consider, for example, the program in Fig (2) .This is a relocatable program written for standard version for SIC.
- The important difference between this example and the one in Fig (1) is that the standard SIC machine does not use relative addressing.
- In this program the addresses in all the instructions except RSUB must modified when the program is relocated. This would require 31 Modification records, which results in an object program more than twice as large as the one in Fig (1).

The second method:

- There are no Modification records.
- The Text records are the same as before except that there is a *relocation bit* associated with each word of object code.
- Since all SIC instructions occupy one word, this means that there is one relocation bit for each possible instruction.

Fig (3): Object program with relocation by bit mask



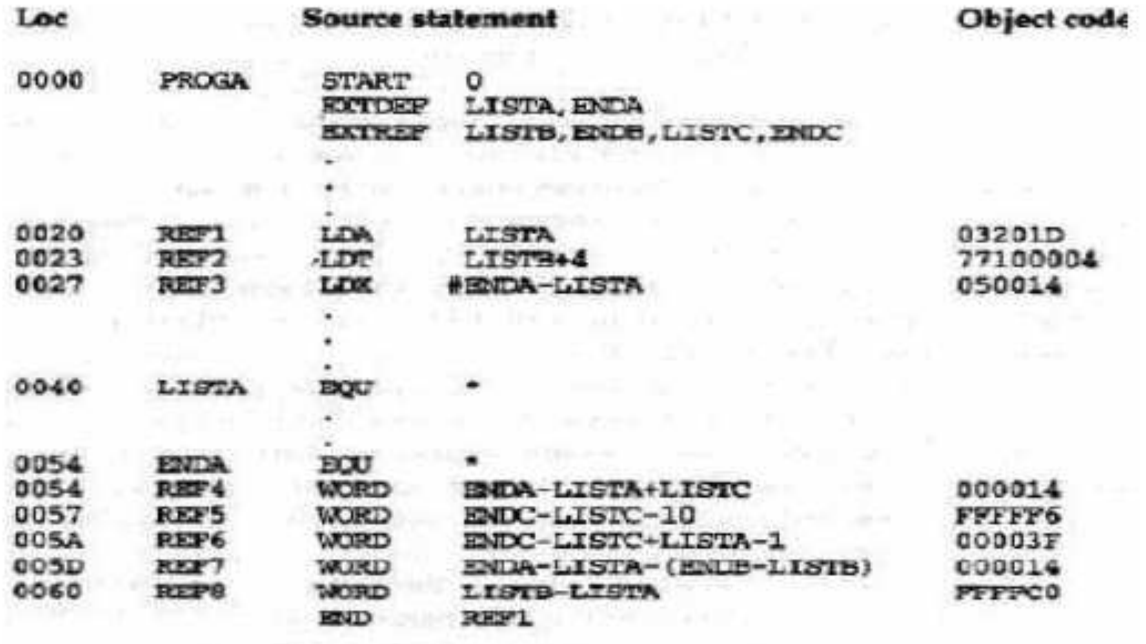
```
HCOPY  00000000107A
T0000001EFFC140033481039000036280030300015481061 3C000300002A0C003900002D
T00001E15E000C00364810610800334C0000454F46000003000000
T0010391EFFC040030000030E0105D30103FD8105D280030301057548039 2C105E38103F
T0010570A8001000364C0000F1001000
T00106119FE0040030E01079301064508039DC10792C0036381064 4C000005
E000000
```

- The relocation bits are gathered together into a **bit mask** following the length indicator in each Text record. In Fig (3) this mask is represented (in character form) as three hexadecimal digits.
- If the relocation bit corresponding to a word of object code is set to **1**, the program's starting address is to be added to this word when the program is relocated. A bit value of **0** indicates that no modification is necessary.
- If a Text record contains fewer than 12 words of object code, the bits corresponding to unused words are set to 0.
- For example, the bit mask FFC (representing the bit string 111111111100) in the first Text record specifies that all 10 words of object code are to be modified during relocation.
- **Example:** Note that the LDX instruction on line 210 (Fig (2)) begins a new Text record. If it were placed in the preceding Text record, it would not be properly aligned to correspond to a relocation bit because of the 1-byte data value generated from line 185.

3.2.2 Program Linking

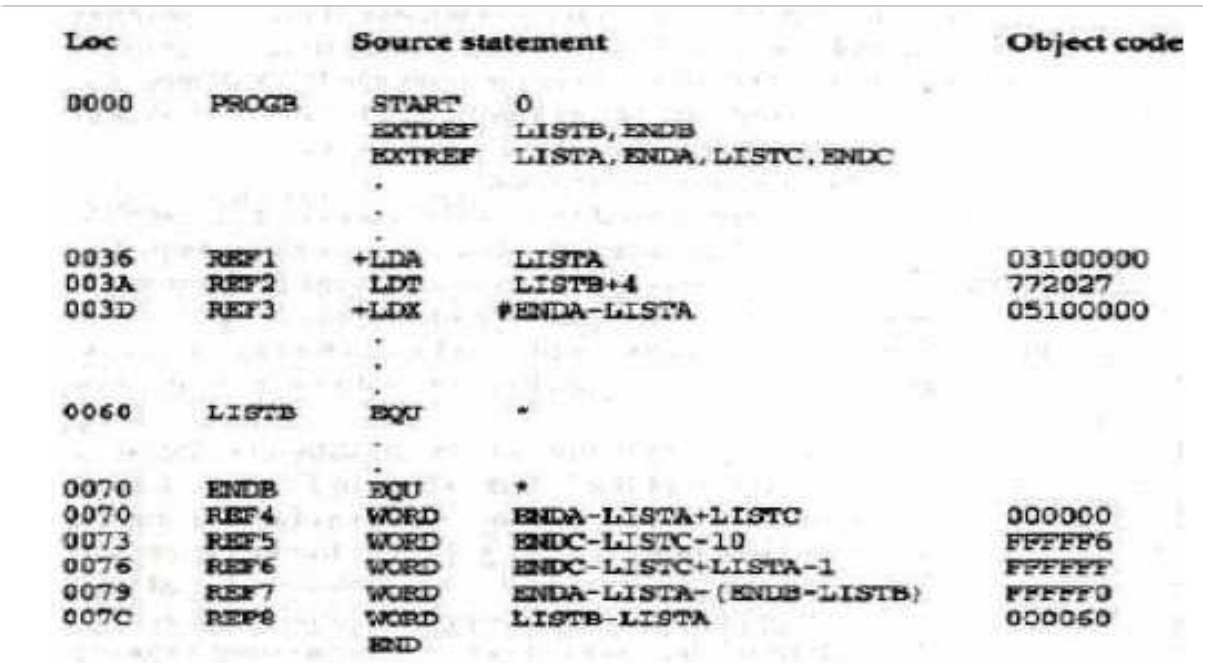
Consider the three (separately assembled) programs in the figure, each of which consists of a single control section.

Program 1 (PROGA):



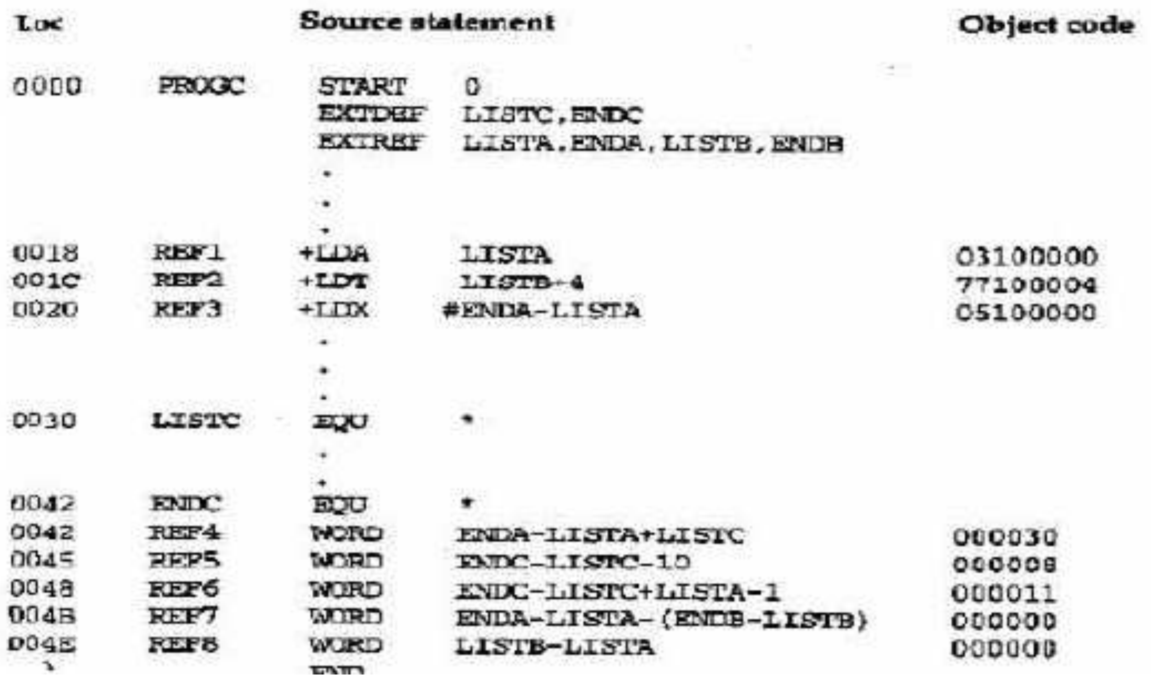
```
Loc              Source statement                        Object code

0000    PROGA    START   0
                 EXTDEF  LISTA,ENDA
                 EXTREF  LISTB,ENDB,LISTC,ENDC
                 .
                 .
                 .
0020    REF1     LDA     LISTA                           03201D
0023    REF2     +LDT    LISTB+4                         77100004
0027    REF3     LDX    #ENDA-LISTA                      050014
                 .
                 .
                 .
0040    LISTA    EQU     *
                 .
                 .
0054    ENDA     EQU     *
0054    REF4     WORD    ENDA-LISTA+LISTC                000014
0057    REF5     WORD    ENDC-LISTC-10                   FFFFF6
005A    REF6     WORD    ENDC-LISTC+LISTA-1              00003F
005D    REF7     WORD    ENDA-LISTA-(ENDB-LISTB)         000014
0060    REF8     WORD    LISTB-LISTA                     FFFFC0
                 END     REF1
```

Program 2 (PROGB):



```
Loc              Source statement                        Object code

0000    PROGB    START   0
                 EXTDEF  LISTB,ENDB
                 EXTREF  LISTA,ENDA,LISTC,ENDC
                 .
                 .
                 .
0036    REF1     +LDA    LISTA                           03100000
003A    REF2     LDT     LISTB+4                         772027
003D    REF3     +LDX   #ENDA-LISTA                      05100000
                 .
                 .
                 .
0060    LISTB    EQU     *
                 .
                 .
0070    ENDB     EQU     *
0070    REF4     WORD    ENDA-LISTA+LISTC                000000
0073    REF5     WORD    ENDC-LISTC-10                   FFFFF6
0076    REF6     WORD    ENDC-LISTC+LISTA-1              FFFFFF
0079    REF7     WORD    ENDA-LISTA-(ENDB-LISTB)         FFFFF0
007C    REF8     WORD    LISTB-LISTA                     000060
                 END
```

Program 3 (PROGC):



```
Loc                Source statement                              Object code

0000    PROGC     START    0
                  EXTDEF   LISTC,ENDC
                  EXTREF   LISTA,ENDA,LISTB,ENDB
                    .
                    .
                    .
0018    REF1     +LDA      LISTA                                 03100000
001C    REF2     +LDT      LISTB+4                               77100004
0020    REF3     +LDX     #ENDA-LISTA                            05100000
                    .
                    .
                    .
0030    LISTC     EQU      *
                    .
                    .
0042    ENDC      EQU      *
0042    REF4      WORD     ENDA-LISTA+LISTC                      000030
0045    REF5      WORD     ENDC-LISTC-10                         000008
0048    REF6      WORD     ENDC-LISTC+LISTA-1                    000011
004B    REF7      WORD     ENDA-LISTA-(ENDB-LISTB)               000000
004E    REF8      WORD     LISTB-LISTA                           000000
                  END
```

Consider first the reference marked REF1.

For the first program (PROGA),

- REF1 is simply a reference to a label within the program.
- It is assembled in the usual way as a PC relative instruction.
- No modification for relocation or linking is necessary.

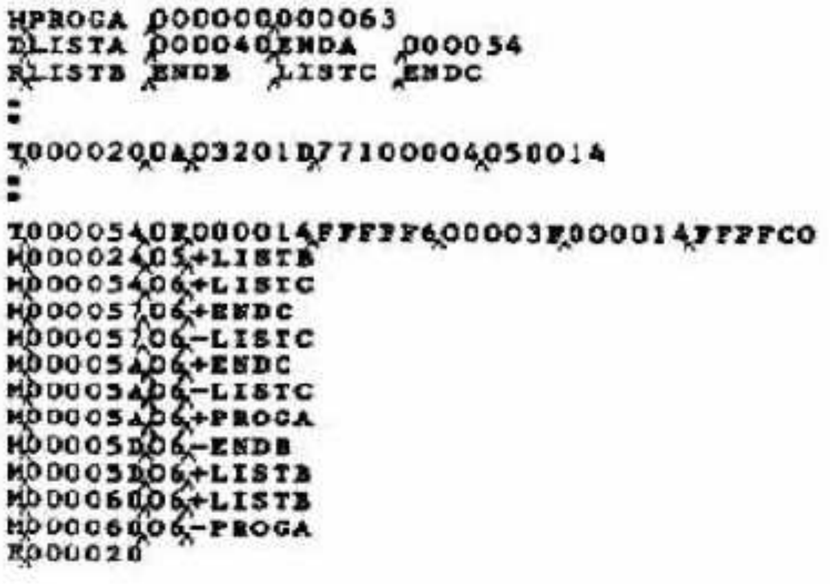
In PROGB, the same operand refers to an external symbol.

- The assembler uses an extended-format instruction with address field set to 00000.
- The object program for PROGB contains a Modification record instructing the loader to add *the value of the symbol LISTA* to *this address field* when the program is linked.

For PROGC, REF1 is handled in exactly the same way.

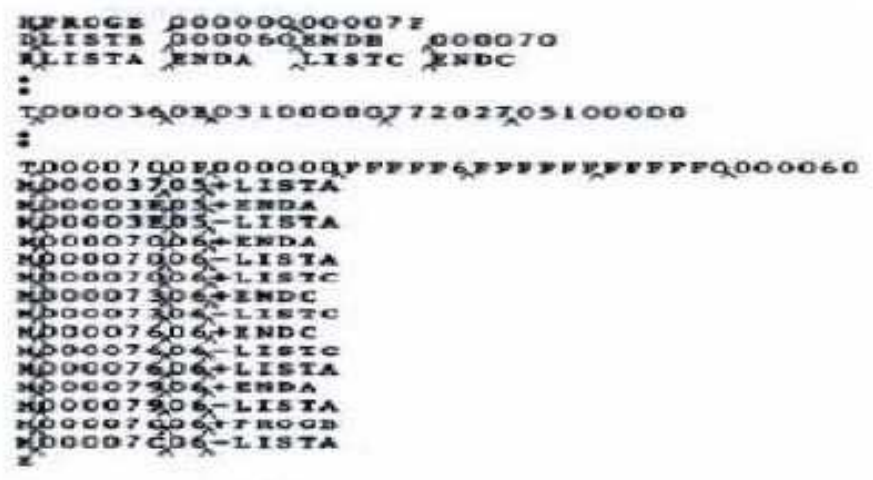
Corresponding object programs

PROGA:



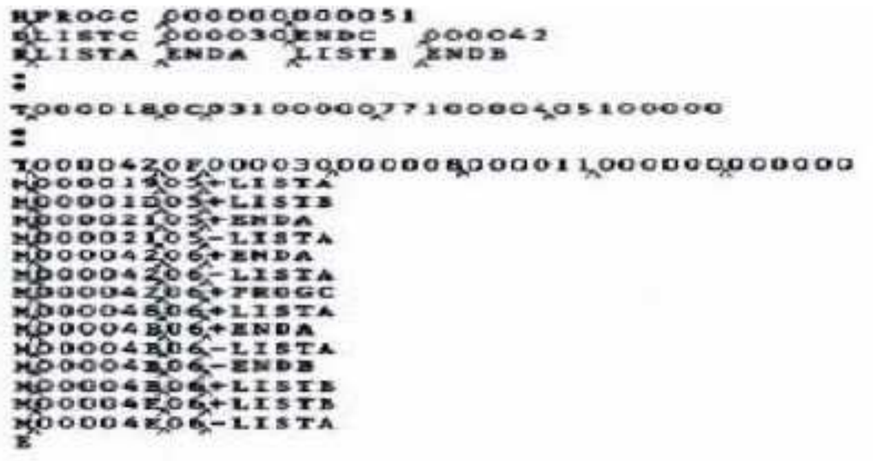
```
HPROGA 000000000063
DLISTA 000040ENDA  000054
RLISTB ENDB  LISTC ENDC
.
.
T0000200A03201D77100004050014
.
.
T0000540F000014FFFFF600003F000014FFFFC0
M00002405+LISTB
M00005406+LISTC
M00005706+ENDC
M00005706-LISTC
M00005A06+ENDC
M00005A06-LISTC
M00005A06+PROGA
M00005D06-ENDB
M00005D06+LISTB
M00006006+LISTB
M00006006-PROGA
E000020
```

PROGB:



```
HPROGB 00000000007F
DLISTB 000060ENDB  000070
RLISTA ENDA  LISTC ENDC
.
T0000360B0310000077202705100000
.
T0000700F000000FFFFF6FFFFFFFFFFF0000060
M00003705+LISTA
M00003E05+ENDA
M00003E05-LISTA
M00007006+ENDA
M00007006-LISTA
M00007006+LISTC
M00007306+ENDC
M00007306-LISTC
M00007606+ENDC
M00007606-LISTC
M00007606+LISTA
M00007906+ENDA
M00007906-LISTA
M00007C06+PROGB
M00007C06-LISTA
E
```

PROGC:



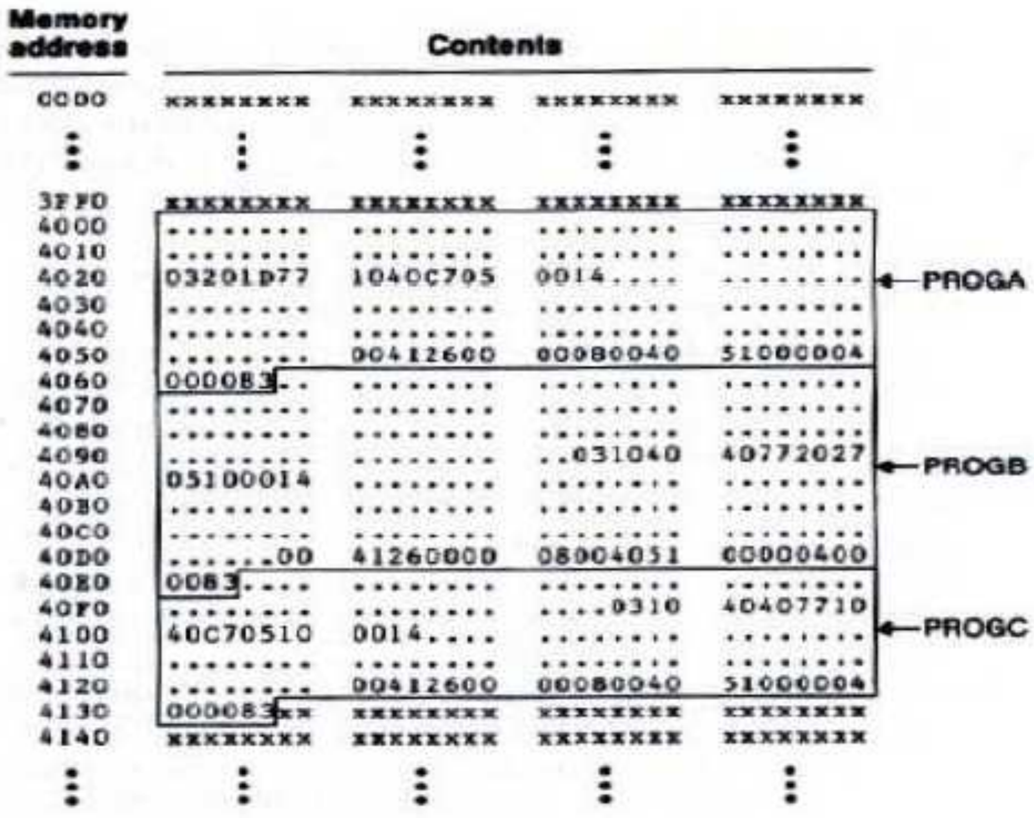
```
HPROGC ^000000^000051
DLISTC ^000030^ENDC  ^000042
RLISTA ^ENDA  ^LISTB ^ENDB
:
T^000018^0C^031000000^77100004^05100000
:
T^000042^0F^000030^000008^000011^000000^000000
M^000019^05^+LISTA
M^00001D^05^+LISTB
M^000021^05^+ENDA
M^000021^05^-LISTA
M^000042^06^+ENDA
M^000042^06^-LISTA
M^000042^06^+PROGC
M^000048^06^+LISTA
M^00004B^06^+ENDA
M^00004B^06^-LISTA
M^00004B^06^-ENDB
M^00004B^06^+LISTB
M^00004E^06^+LISTB
M^00004E^06^-LISTA
E
```

- The reference marked REF2 is processed in a similar manner.

- REF3 is an immediate operand whose value is to be the difference between ENDA and LISTA (that is, the length of the list in bytes).
- In PROGA, the assembler has all of the information necessary to compute this value. During the assembly of PROGB (and PROGC), the values of the labels are unknown.
- In these programs, the expression must be assembled as an external reference (*with two Modification records*) even though the final result will be an absolute value independent of the locations at which the programs are loaded.

- **Consider REF4.**
- The assembler for PROGA can evaluate all of the expression in REF4 except for the value of LISTC. This results in an initial value of ‘000014’H and one Modification record.
- The same expression in PROGB contains no terms that can be evaluated by the assembler. The object code therefore contains an initial value of 000000 and *three* Modification records.
- For PROGC, the assembler can supply the value of LISTC relative to the beginning of the program (but not the actual address, which is not known until the program is loaded).
- The initial value of this data word contains the relative address of LISTC (‘000030’H). Modification records instruct the loader to add the beginning address of the program (i.e., the value of PROGC), to add the value of ENDA, and to subtract the value of LISTA.

Fig (4): The three programs as they might appear in memory after loading and linking.

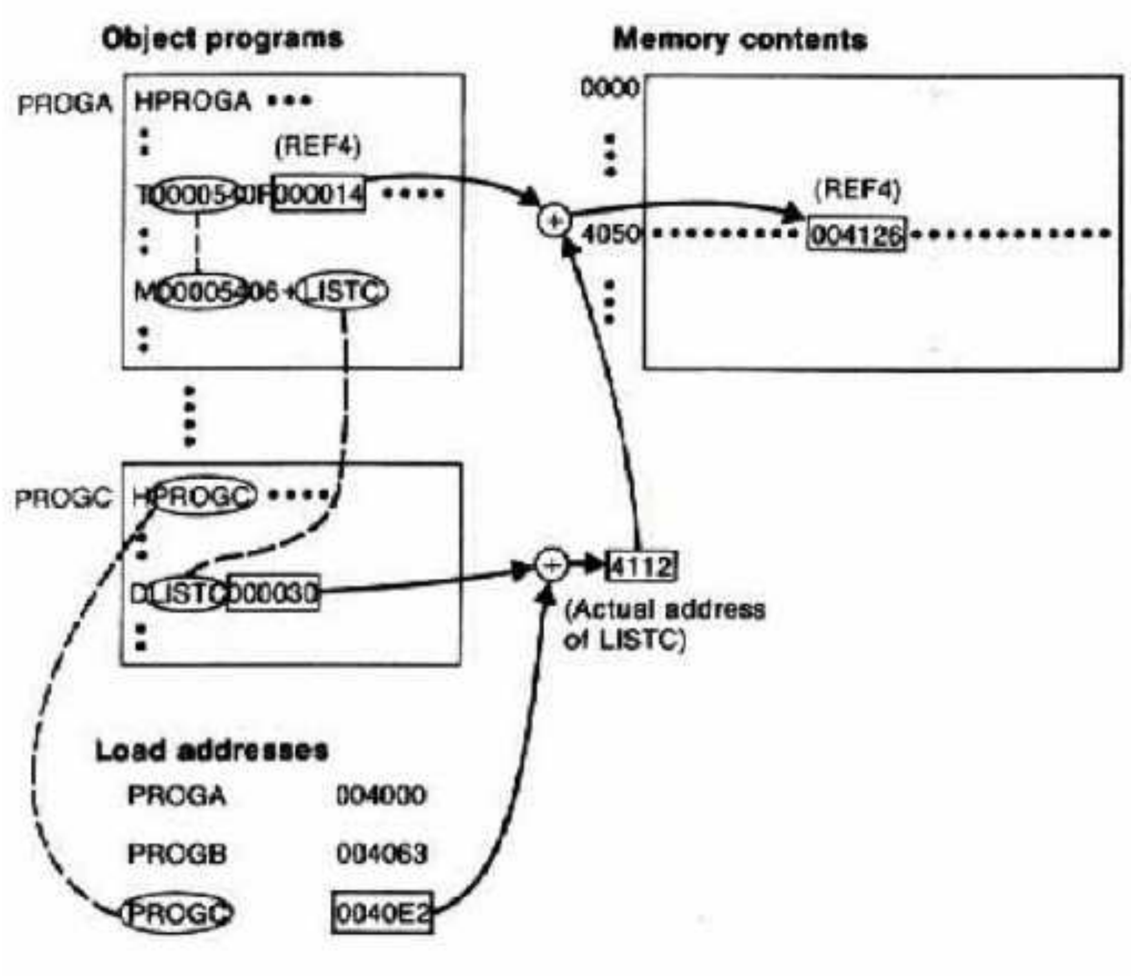


```
Memory
address                      Contents

0000    xxxxxxxx  xxxxxxxx  xxxxxxxx  xxxxxxxx
  :        :         :         :         :
3FF0    xxxxxxxx  xxxxxxxx  xxxxxxxx  xxxxxxxx
4000    ........  ........  ........  ........
4010    ........  ........  ........  ........
4020    03201D77  1040C705  0014....  ........  <-PROGA
4030    ........  ........  ........  ........
4040    ........  ........  ........  ........
4050    ........  00412600  00080040  51000004
4060    000083..  ........  ........  ........
4070    ........  ........  ........  ........
4080    ........  ........  ........  ........
4090    ........  ........  ..031040  40772027  <-PROGB
40A0    05100014  ........  ........  ........
40B0    ........  ........  ........  ........
40C0    ........  ........  ........  ........
40D0    ......00  41260000  08004051  00000400
40E0    0083....  ........  ........  ........
40F0    ........  ........  ....0310  40407710
4100    40C70510  0014....  ........  ........  <-PROGC
4110    ........  ........  ........  ........
4120    ........  00412600  00080040  51000004
4130    000083xx  xxxxxxxx  xxxxxxxx  xxxxxxxx
4140    xxxxxxxx  xxxxxxxx  xxxxxxxx  xxxxxxxx
  :        :         :         :         :
```

PROGA has been loaded starting at address 4000, with PROGB and PROGC immediately following.

For example, the value for reference REF4 in PROGA is located at address 4054 (the beginning address of PROGA plus 0054).

Fig (5): Relocation and linking operations performed on REF4 in PROGA



The initial value (from the Text record) is 000014. To this is added the address assigned to LISTC, which 4112 (the beginning address of PROGC plus 30).

3.2.3 Algorithm and Data Structures for a Linking Loader

- The algorithm for a *linking loader* is considerably more complicated than the *absolute loader* algorithm.
- A linking loader usually makes *two passes* over its input, just as an assembler does. In terms of general function, the two passes of a linking loader are quite similar to the two passes of an assembler:
- Pass 1 assigns addresses to all external symbols.
- Pass 2 performs the actual loading, relocation, and linking.
- The main data structure needed for our linking loader is an *external symbol table* **ESTAB.**

  (1) This table, which is analogous to SYMTAB in our assembler algorithm, is used to store the *name* and *address* of each external symbol in the set of control sections being loaded.

(2) A *hashed organization* is typically used for this table.

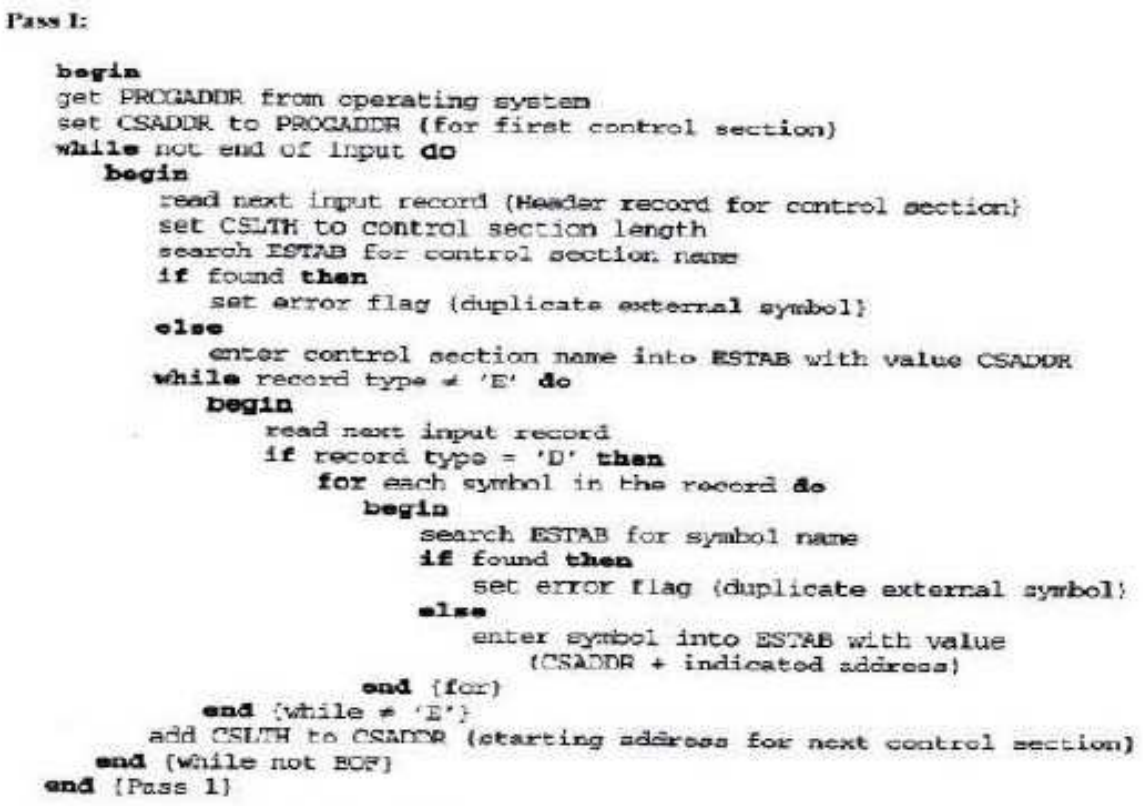
- Two other important variables are **PROGADDR (program load address)** and **CSADDR (control section address).**

  (1) PROGADDR is *the beginning address in memory* where the linked program is to be loaded. Its value is supplied to the loader by the OS.
  (2) CSADDR contains *the starting address* assigned to the control section currently being scanned by the loader. This value is added to all relative addresses within the control section to convert them to actual addresses.

3.2.3.1 PASS 1

- During Pass 1, the loader is concerned only with Header and Define record types in the control sections.

Algorithm for Pass 1 of a Linking loader



```
Pass 1:

  begin
  get PROGADDR from operating system
  set CSADDR to PROGADDR (for first control section)
  while not end of input do
     begin
        read next input record (Header record for control section}
        set CSLTH to control section length
        search ESTAB for control section name
        if found then
           set error flag (duplicate external symbol}
        else
           enter control section name into ESTAB with value CSADDR
        while record type ≠ 'E' do
           begin
              read next input record
              if record type = 'D' then
                 for each symbol in the record do
                    begin
                       search ESTAB for symbol name
                       if found then
                          set error flag (duplicate external symbol}
                       else
                          enter symbol into ESTAB with value
                             (CSADDR + indicated address)
                    end {for)
           end {while ≠ 'E'}
        add CSLTH to CSADDR (starting address for next control section)
     end {while not EOF}
  end {Pass 1}
```

1) The beginning load address for the linked program (PROGADDR) is obtained from the OS. This becomes the starting address (CSADDR) for the first control section in the input sequence.
2) The control section name from Header record is entered into ESTAB, with value given by CSADDR. All **external symbols** appearing in the Define record for the control

section are also entered into ESTAB. Their addresses are obtained by adding the value specified in the Define record to CSADDR.
3) When the End record is read, the control section length CSLTH (which was saved from the End record) is added to CSADDR. This calculation gives the starting address for the next control section in sequence.

- At the end of Pass 1, ESTAB contains all external symbols defined in the set of control sections together with the address assigned to each.

- Many loaders include as an option the ability to print a **load map** that shows these symbols and their addresses.

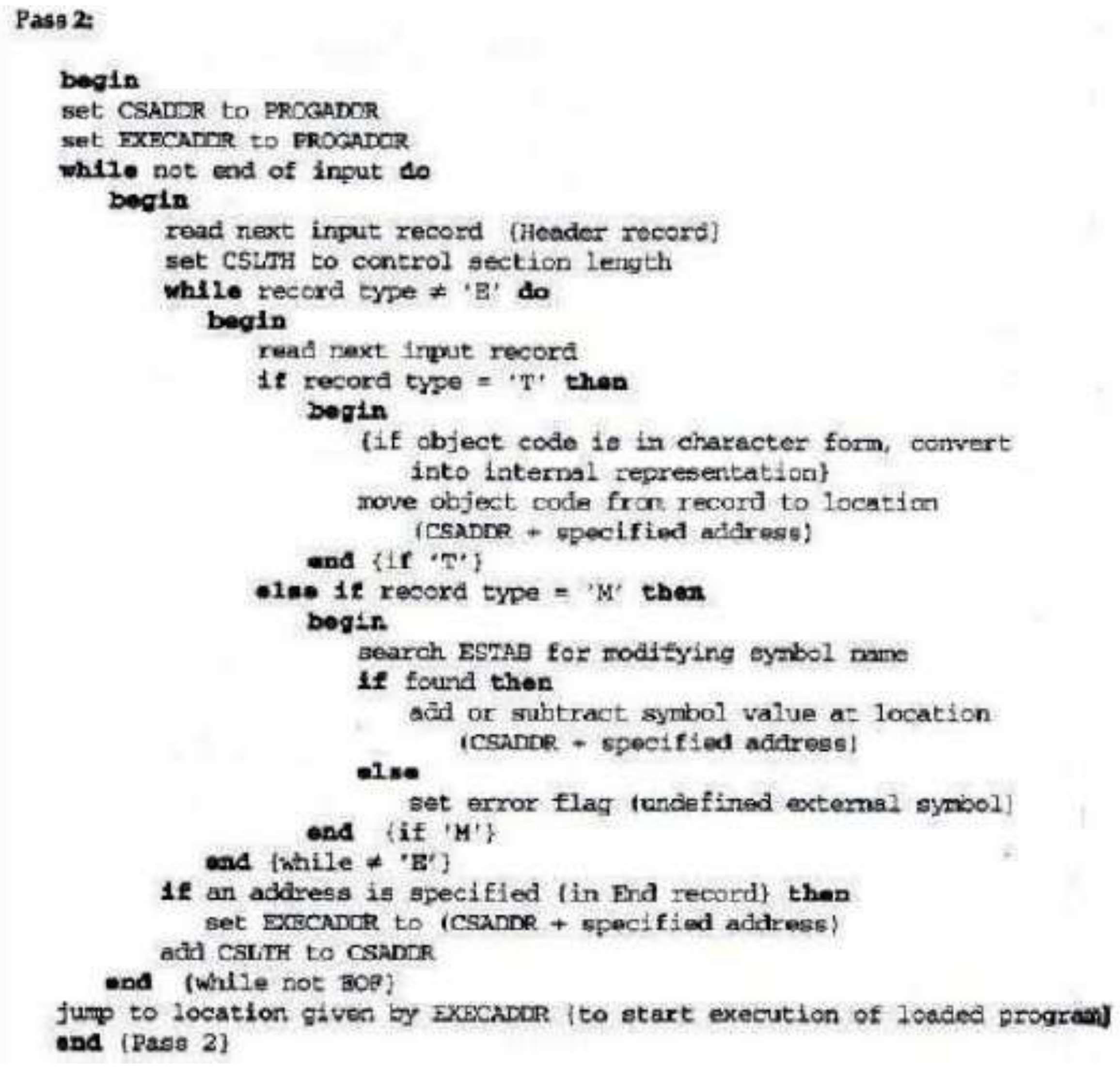
3.2.3.2 PASS 2

- Pass 2 performs the actual *loading*, *relocation*, and *linking* of the program.

Algorithm for Pass 2 of a Linking loader

1) As each Text record is read, the object code is moved to the specified address (plus the current value of CSADDR).
2) When a Modification record is encountered, the symbol whose value is to be used for modification is looked up in ESTAB.
3) This value is then added to or subtracted from the indicated location in memory.
4) The last step performed by the loader is usually the transferring of control to the loaded program to begin execution.

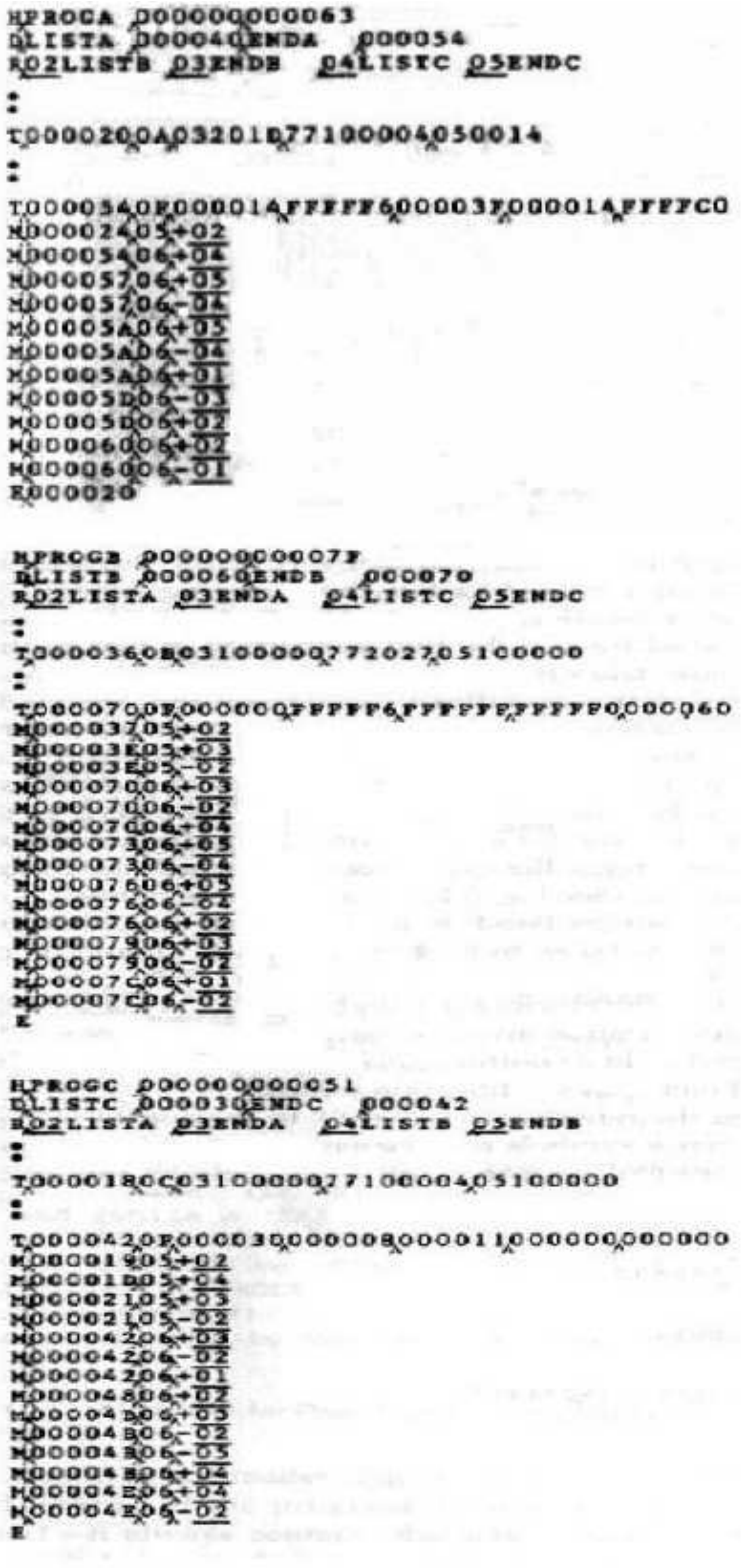
- The End record for each control section may contain the address of the first instruction in that control section to be executed. Our loader takes this as the transfer point to begin execution. If more than one control section specifies a transfer address, the loader arbitrarily uses the last one encountered.
- If no control section contains a transfer address, the loader uses the beginning of the linked program (i.e., PROGADDR) as the transfer point.
- Normally, a transfer address would be placed in the End record for a main program, but not for a subroutine.



```
Pass 2:

    begin
    set CSADDR to PROGADDR
    set EXECADDR to PROGADDR
    while not end of input do
        begin
            read next input record {Header record}
            set CSLTH to control section length
            while record type ≠ 'E' do
                begin
                    read next input record
                    if record type = 'T' then
                        begin
                            {if object code is in character form, convert
                                into internal representation}
                            move object code from record to location
                                (CSADDR + specified address)
                        end {if 'T'}
                    else if record type = 'M' then
                        begin
                            search ESTAB for modifying symbol name
                            if found then
                                add or subtract symbol value at location
                                    (CSADDR + specified address)
                            else
                                set error flag (undefined external symbol)
                        end {if 'M'}
                end {while ≠ 'E'}
            if an address is specified {in End record} then
                set EXECADDR to (CSADDR + specified address)
            add CSLTH to CSADDR
        end {while not EOF}
    jump to location given by EXECADDR {to start execution of loaded program}
    end {Pass 2}
```

This algorithm can be made more efficient. Assign a reference number, which is used (instead of the symbol name) in Modification records, to each external symbol referred to in a control section. Suppose we always assign the reference number 01 to the control section name.

Fig (6): Object programs using reference numbers for code modification



```
HPROGA 000000000063
DLISTA 000040ENDA  000054
R02LISTB 03ENDB  04LISTC 05ENDC
:
T0000200A03201D77100004050014
:
T0000540F000014FFFFF600003F000014FFFFC0
M00002405+02
M00005406+04
M00005706+05
M00005706-04
M00005A06+05
M00005A06-04
M00005A06+01
M00005D06-03
M00005D06+02
M00006006+02
M00006006-01
E000020

HPROGB 00000000007F
DLISTB 000060ENDB  000070
R02LISTA 03ENDA  04LISTC 05ENDC
:
T0000360B0310000077202705100000
:
T0000700F000000FFFFF6FFFFFFFFFFF0000060
M00003705+02
M00003E05+03
M00003E05-02
M00007006+03
M00007006-02
M00007006+04
M00007306+05
M00007306-04
M00007606+05
M00007606-04
M00007606+02
M00007906+03
M00007906-02
M00007C06+01
M00007C06-02
E

HPROGC 000000000051
DLISTC 000030ENDC  000042
R02LISTA 03ENDA  04LISTB 05ENDB
:
T0000180C031000007710000405100000
:
T0000420F000030000008000011000000000000
M00001905+02
M00001D05+04
M00002105+03
M00002105-02
M00004206+03
M00004206-02
M00004206+01
M00004806+02
M00004B06+03
M00004B06-02
M00004B06-05
M00004B06+04
M00004E06+04
M00004E06-02
E
```

3.3 MACHINE-INDEPENDENT LOADER FEATURES

- Loading and linking are often thought of as OS service functions. Therefore, most loaders include fewer different features than are found in a typical assembler.
- They include the use of an automatic library search process for handling external reference and some common options that can be selected at the time of loading and linking.

3.3.1 Automatic Library Search

- Many linking loaders can automatically incorporate routines from a subprogram library into the program being loaded.
- Linking loaders that support *automatic library search* must keep track of external symbols that are referred to, but not defined, in the primary input to the loader.
- At the end of Pass 1, the symbols in ESTAB that remain undefined represent unresolved external references.
- The loader searches the library or libraries specified for routines that contain the definitions of these symbols, and processes the subroutines found by this search exactly as if they had been part of the primary input stream.
- The subroutines fetched from a library in this way may themselves contain external references. It is therefore necessary to repeat the library search process until all references are resolved.
- If unresolved external references remain after the library search is completed, these must be treated as errors.

3.3.2 Loader Options

- Many loaders allow the user to specify options that modify the standard processing

- **Typical loader option 1:** Allows the selection of alternative sources of input.

  Ex : INCLUDE program-name (library-name) might direct the loader to read the designated object program from a library and treat it as if it were part of the primary loader input.

- **Loader option 2:** Allows the user to delete external symbols or entire control sections.

  Ex : DELETE csect-name might instruct the loader to delete the named control section(s) from the set of programs being loaded.

  CHANGE name1, name2 might cause the external symbol name1 to be changed to name2 wherever it appears in the object programs.

- **Loader option 3:** Involves the automatic inclusion of library routines to satisfy external references.

  Ex. : LIBRARY MYLIB
  Such user-specified libraries are normally searched before the standard system libraries. This allows the user to use special versions of the standard routines.

  NOCALL STDDEV, PLOT, CORREL

- To instruct the loader that these external references are to remain unresolved. This avoids the overhead of loading and linking the unneeded routines, and saves the memory space that would otherwise be required.

3.4 LOADER DESIGN OPTIONS

- Linking loaders perform all linking and relocation at load time.
- There are two alternatives:
  1. **Linkage editors**, which perform linking prior to load time.
  2. **Dynamic linking**, in which the linking function is performed at execution time.
- Precondition: The source program is first assembled or compiled, producing an object program.
- A **linking loader** performs all linking and relocation operations, including automatic library search if specified, and loads the linked program directly into memory for execution.
- A **linkage editor** produces a linked version of the program (load module or executable image), which is written to a file or library for later execution.

3.4.1 Linkage Editors

- The linkage editor performs relocation of all control sections relative to the start of the linked program. Thus, all items that need to be modified at load time have values that are relative to the start of the linked program.
- This means that the loading can be accomplished in one pass with no external symbol table required.
- If a program is to be executed many times without being reassembled, the use of a linkage editor substantially reduces the overhead required.

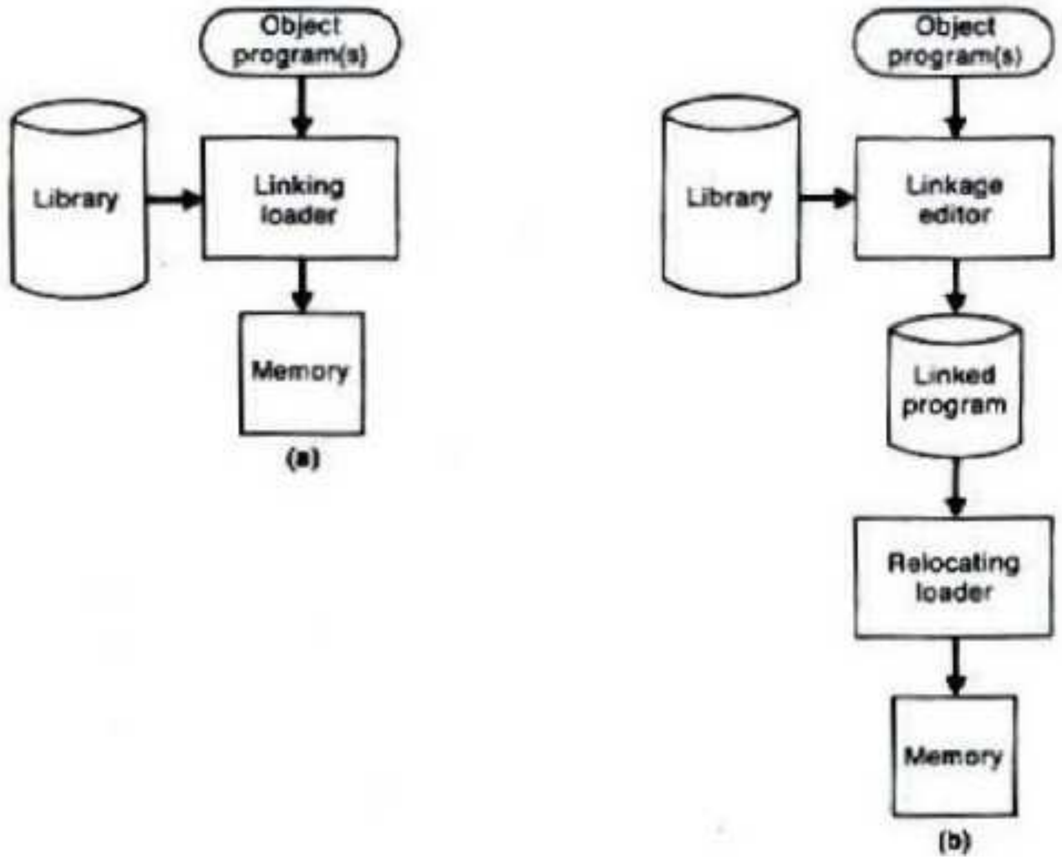
- Linkage editors can perform many useful functions besides simply preparing an object program for execution. Ex., a typical sequence of linkage editor commands used:

```
INCLUDE PLANNER (PROGLIB)
```

DELETE PROJECT **{delete from existing PLANNER}**
INCLUDE PROJECT (NEWLIB) **{include new version}**
REPLACE PLANNER (PROGLIB)

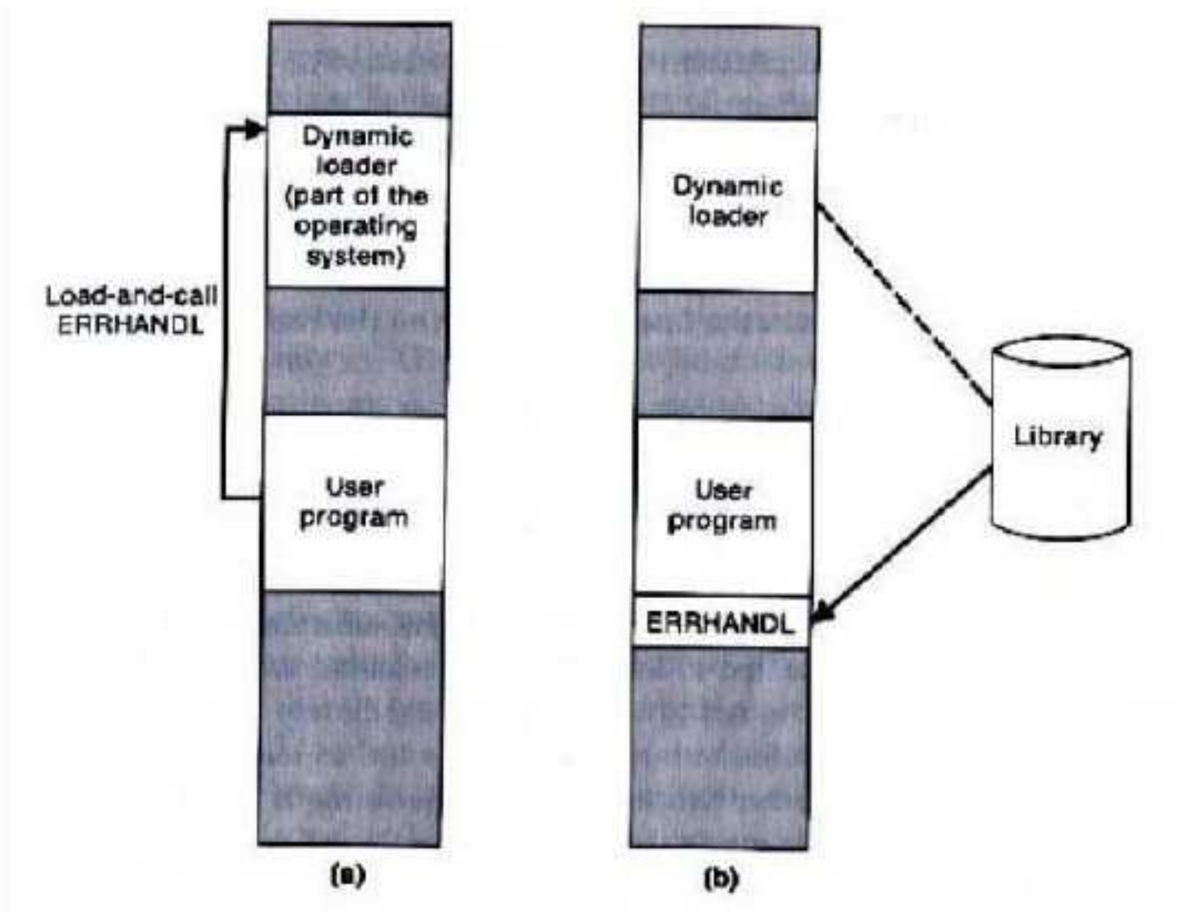
- Linkage editors can also be used to build packages of subroutines or other control sections that are generally used together. This can be useful when dealing with subroutine libraries that support high-level programming languages.
- Linkage editors often include a variety of other options and commands like those discussed for linking loaders. Compared to linking loaders, linkage editors in general tend to offer more flexibility and control.

Fig (7): Processing of an object program using (a) Linking loader and (b) Linkage editor



3.4.2 Dynamic Linking

- Linkage editors perform linking operations before the program is loaded for execution.
- Linking loaders perform these same operations at load time.
- Dynamic linking, dynamic loading, or load on call postpones the linking function until execution time: a subroutine is loaded and linked to the rest of the program when it is first called.
- Dynamic linking is often used to allow several executing programs to share one copy of a subroutine or library, ex. run-time support routines for a high-level language like C.
- With a program that allows its user to interactively call any of the subroutines of a large mathematical and statistical library, all of the library subroutines could potentially be needed, but only a few will actually be used in any one execution.
- Dynamic linking can avoid the necessity of loading the entire library for each execution except those necessary subroutines.



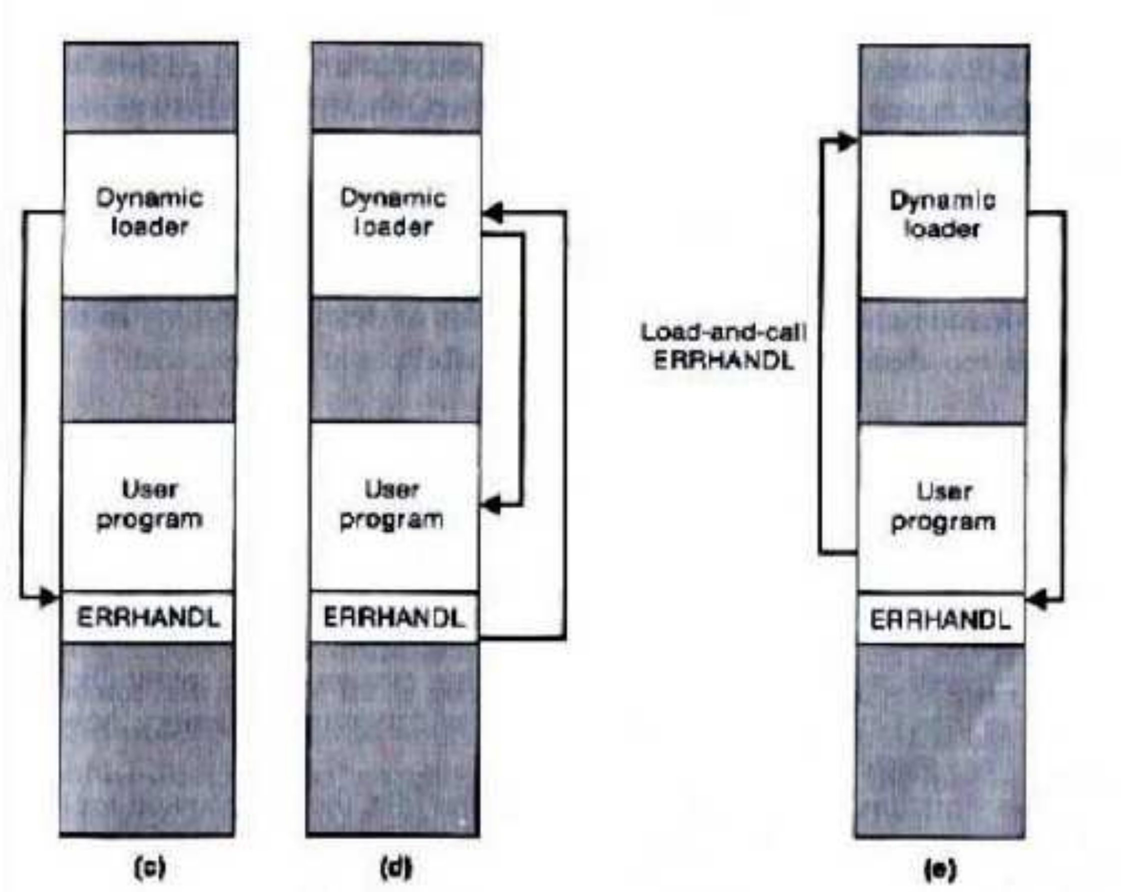


Fig (a): Instead of executing a JSUB instruction referring to an external symbol, the program makes a load-and-call service request to OS. The parameter of this request is the symbolic name of the routine to be called.

Fig (b): OS examines its internal tables to determine whether or not the routine is already loaded. If necessary, the routine is loaded from the specified user or system libraries.

Fig (c): Control is then passed from OS to the routine being called

Fig (d): When the called subroutine completes it processing, it returns to its caller (i.e., OS). OS then returns control to the program that issued the request.

Fig (e): If a subroutine is still in memory, a second call to it may not require another load operation. Control may simply be passed from the dynamic loader to the called routine.

3.4.3 Bootstrap Loaders

- With the machine empty and idle there is no need for program relocation.
- We can specify the absolute address for whatever program is first loaded and this will be the OS, which occupies a predefined location in memory.
- We need some means of accomplishing the functions of an absolute loader.
  1. To have the operator enter into memory the object code for an absolute loader, using switches on the computer console.
  2. To have the absolute loader program permanently resident in a ROM.
  3. To have a built –in hardware function that reads a fixed –length record from some device into memory at a fixed location.

- When some hardware signal occurs, the machine begins to execute this ROM program.
- On some computers, the program is executed directly in the ROM: on others, the program is copied from ROM to main memory and executed there.
- The particular device to be used can often be selected via console switches.
- After the read operation is complete, control is automatically transferred to the address in memory where the record was stored, which contains machine where the record was stored, which contains machine instructions that load the absolute program that follow.
- If the loading process requires more instructions that can be read in a single record, this first record causes the reading of others, and these in turn can cause the reading of still more records – boots trap.
- The first record is generally referred to as bootstrap loader:
- Such a loader is added to the beginning of all object programs that are to be loaded into an empty and idle system.
- This includes the OS itself and all stand-alone programs that are to be run without an OS.

UNIT IV

MACROPROCESSORS

INTRODUCTION

Macro Instructions

- A macro instruction (macro)
  - It is simply a notational convenience for the programmer to write a shorthand version of a program.
  - It represents a commonly used group of statements in the source program.
  - It is replaced by the macro processor with the corresponding group of source language statements. This operation is called "expanding the macro"
- For example:
  - Suppose it is necessary to save the contents of all registers before calling a subroutine.
  - This requires a sequence of instructions.
  - We can define and use a macro, SAVEREGS, to represent this sequence of instructions.

Macro Processor

- A macro processor
  - Its functions 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.
- Therefore, the design of a macro processor generally is machine independent.
- Macro processors are used in
  - assembly language
  - high-level programming languages, e.g., C or C++
  - OS command languages
  - general purpose

Format of macro definition

A macro can be defined as follows

MACRO - MACRO pseudo-op shows start of macro definition.
Name [List of Parameters] – Macro name with a list of formal parameters.

```
…….
…….
…….          -     Sequence of assembly language instructions.

MEND          -     MEND (MACRO-END) Pseudo shows the end of macro definition.
```

Example:

```
MACRO
        SUM X,Y
        LDA X
        MOV BX,X
        LDA Y
        ADD BX
MEND
```

4.1 BASIC MACROPROCESSOR FUNCTIONS

The fundamental functions common to all macro processors are:

1. Macro Definition
2. Macro Invocation
3. Macro Expansion

Macro Definition and Expansion

- 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 '&'

```
label      op       operands
name     MACRO    parameters
            :
           body
            :
          MEND
```

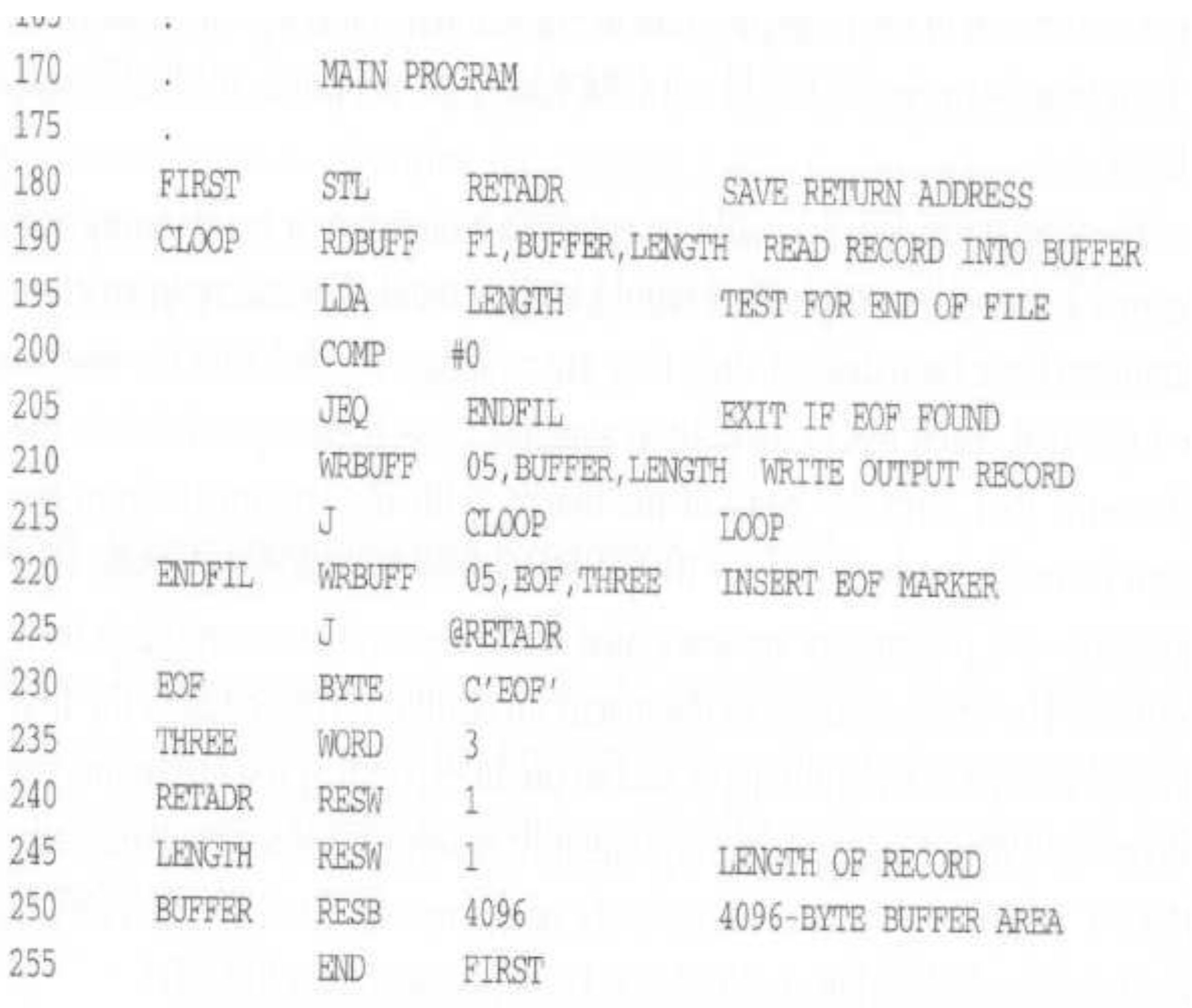
- Body: The statements that will be generated as the expansion of the macro.

```
COPY      START   0                 COPY FILE FROM INPUT TO OUTPUT
RDBUFF    MACRO   &INDEV,&BUFADR,&RECLTH
.
.         MACRO TO READ RECORD INTO BUFFER
.
          CLEAR   X                 CLEAR LOOP COUNTER
          CLEAR   A
          CLEAR   S
         +LDT     #4096             SET MAXIMUM RECORD LENGTH
          TD      =X'&INDEV'        TEST INPUT DEVICE
          JEQ     *-3               LOOP UNTIL READY
          RD      =X'&INDEV'        READ CHARACTER INTO REG A
          COMPR   A,S               TEST FOR END OF RECORD
          JEQ     *+11              EXIT LOOP IF EOR
          STCH    &BUFADR,X         STORE CHARACTER IN BUFFER
          TIXR    T                 LOOP UNLESS MAXIMUM LENGTH
          JLT     *-19                HAS BEEN REACHED
          STX     &RECLTH           SAVE RECORD LENGTH
          MEND
WRBUFF    MACRO   &OUTDEV,&BUFADR,&RECLTH
.
.         MACRO TO WRITE RECORD FROM BUFFER
.
          CLEAR   X                 CLEAR LOOP COUNTER
          LDT     &RECLTH
          LDCH    &BUFADR,X         GET CHARACTER FROM BUFFER
          TD      =X'&OUTDEV'       TEST OUTPUT DEVICE
          JEQ     *-3               LOOP UNTIL READY
          WD      =X'&OUTDEV'       WRITE CHARACTER
          TIXR    T                 LOOP UNTIL ALL CHARACTERS
          JLT     *-14                HAVE BEEN WRITTEN
          MEND
.
```

- It shows an example of a SIC/XE program using macro Instructions.
- This program defines and uses two macro instructions, RDBUFF and WRDUFF .
- The functions and logic of RDBUFF macro are similar to those of the RDBUFF subroutine.
- The WRBUFF macro is similar to WRREC subroutine.
- Two Assembler directives (MACRO and MEND) are used in macro definitions.
- The first MACRO statement identifies the beginning of macro definition.
- The Symbol in the label field (RDBUFF) is the name of macro, and entries in the operand field identify the parameters of macro instruction.
- In our macro language, each parameter begins with character &, which facilitates the substitution of parameters during macro expansion.
- The macro name and parameters define the pattern or prototype for the macro instruction used by the programmer. The macro instruction definition has been deleted since they have been no longer needed after macros are expanded.
- Each macro invocation statement has been expanded into the statements that form the body of the macro, with the arguments from macro invocation substituted for the parameters in macro prototype.
- The arguments and parameters are associated with one another according to their positions.

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.
- The processes of macro invocation and subroutine call are quite different.
    - 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.
- The macro invocation statements treated as comments and the statements generated from macro expansion will be assembled as though they had been written by the programmer.

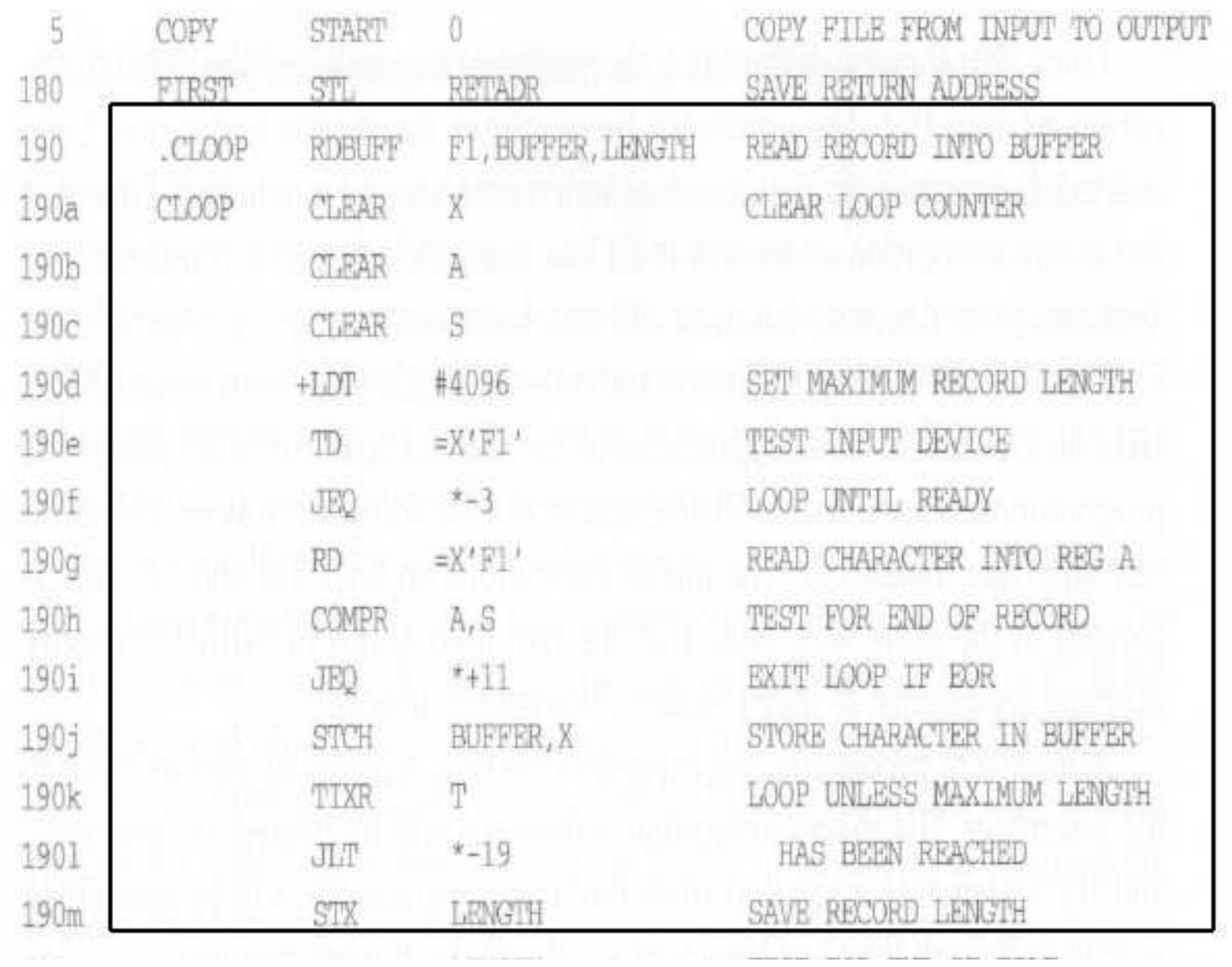


```
165    .
170    .        MAIN PROGRAM
175    .
180    FIRST    STL      RETADR            SAVE RETURN ADDRESS
190    CLOOP    RDBUFF   F1,BUFFER,LENGTH  READ RECORD INTO BUFFER
195             LDA      LENGTH            TEST FOR END OF FILE
200             COMP    #0
205             JEQ      ENDFIL            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
```

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.
- Comment lines within the macro body have been deleted, but comments on individual statements have been retained.
- Macro invocation statement itself has been included as a comment line.

Example of a macro expansion



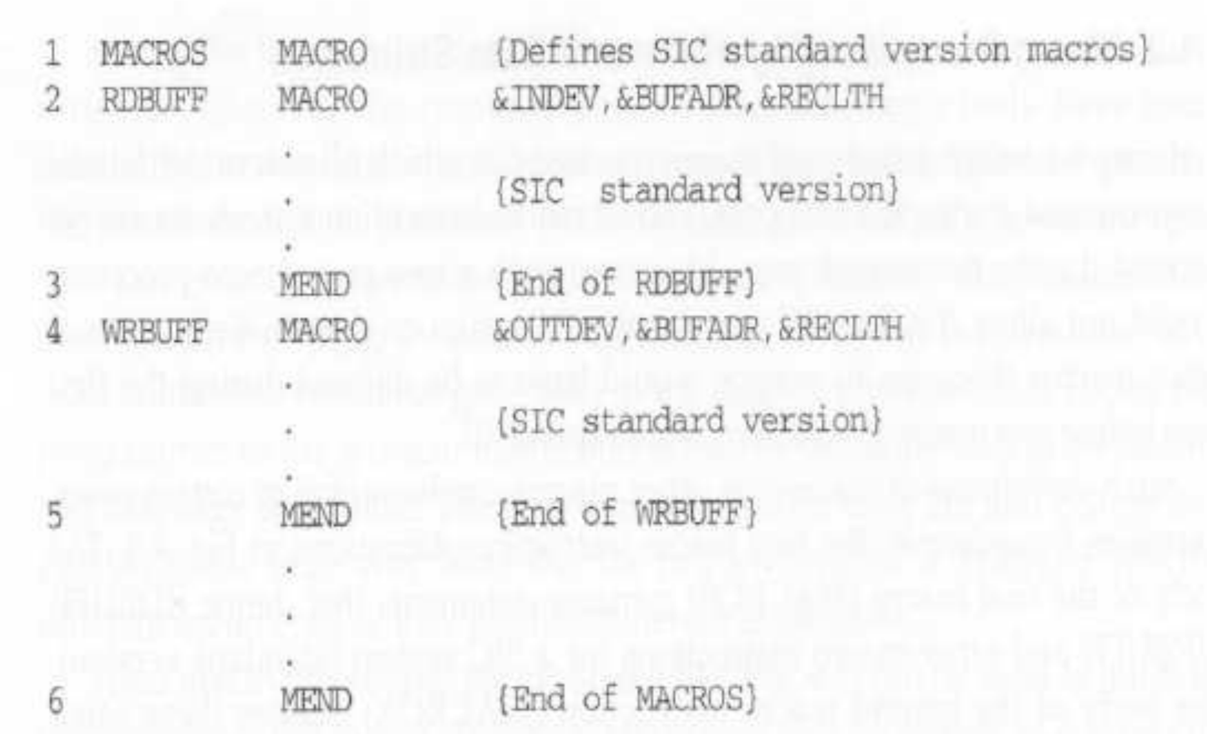
```
5      COPY     START   0                   COPY FILE FROM INPUT TO OUTPUT
180    FIRST    STL     RETADR              SAVE RETURN ADDRESS
190    .CLOOP   RDBUFF  F1,BUFFER,LENGTH    READ RECORD INTO BUFFER
190a   CLOOP    CLEAR   X                   CLEAR LOOP COUNTER
190b            CLEAR   A
190c            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
190l            JLT     *-19                  HAS BEEN REACHED
190m            STX     LENGTH              SAVE RECORD LENGTH
```

- In expanding the macro invocation on line 190, the argument F1 is substituted for the parameter and INDEV wherever it occurs in the body of the macro.
- Similarly BUFFER is substituted for BUFADR and LENGTH is substituted for RECLTH.
- Lines 190a through 190m show the complete expansion of the macro invocation on line 190.
- The label on the macro invocation statement CLOOP has been retained as a label on the first statement generated in the macro expansion.
- This allows the programmer to use a macro instruction in exactly the same way as an assembler language mnemonic.
- After macro processing the expanded file can be used as input to assembler.
- The macro invocation statement will be treated as comments and the statements generated from the macro expansions will be assembled exactly as though they had been written directly by the programmer.

4.1.1 Macro Processor Algorithm and Data Structures

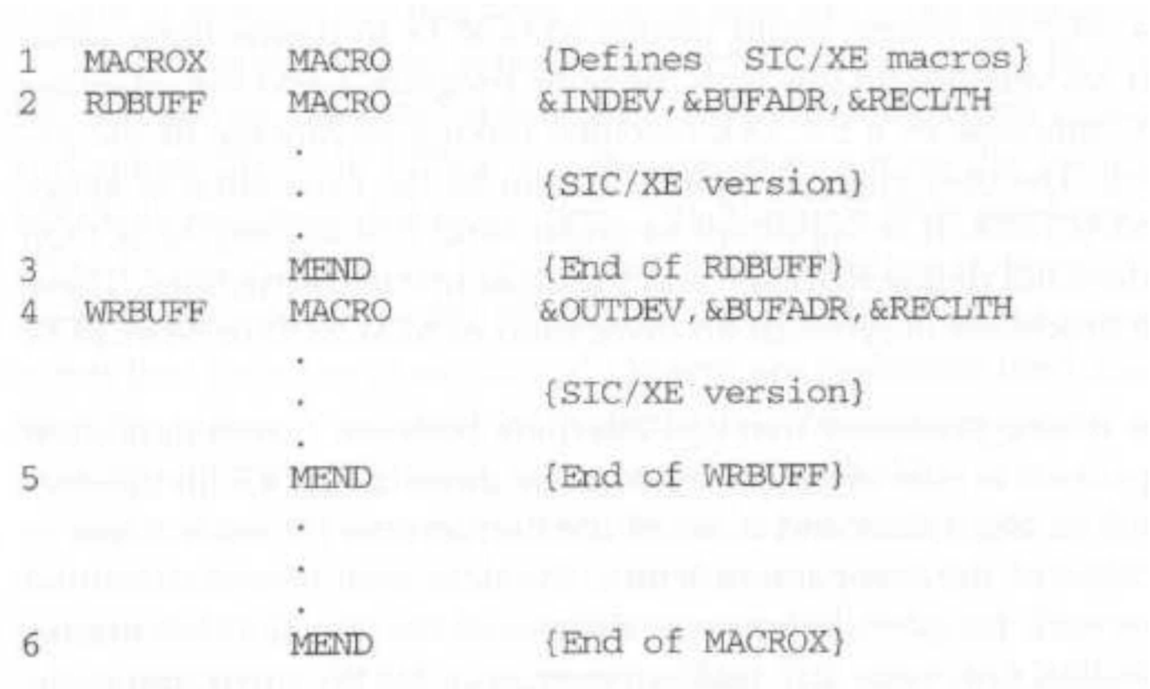
- It is easy to design a two-pass macro processor in which all macro definitions are processed during the first pass ,and all macro invocation statements are expanded during second pass
- Such a two pass macro processor would not allow the body of one macro instruction to contain definitions of other macros.

Example 1:



```
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}
```

Example 2:



```
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}
```

- Defining MACROS or MACROX does not define RDBUFF and the other macro instructions. These definitions are processed only when an invocation of MACROS or MACROX is expanded.
- A one pass macroprocessor that can alternate between macro definition and macro expansion is able to handle macros like these.
- There are 3 main data structures involved in our macro processor.

Definition table (DEFTAB)

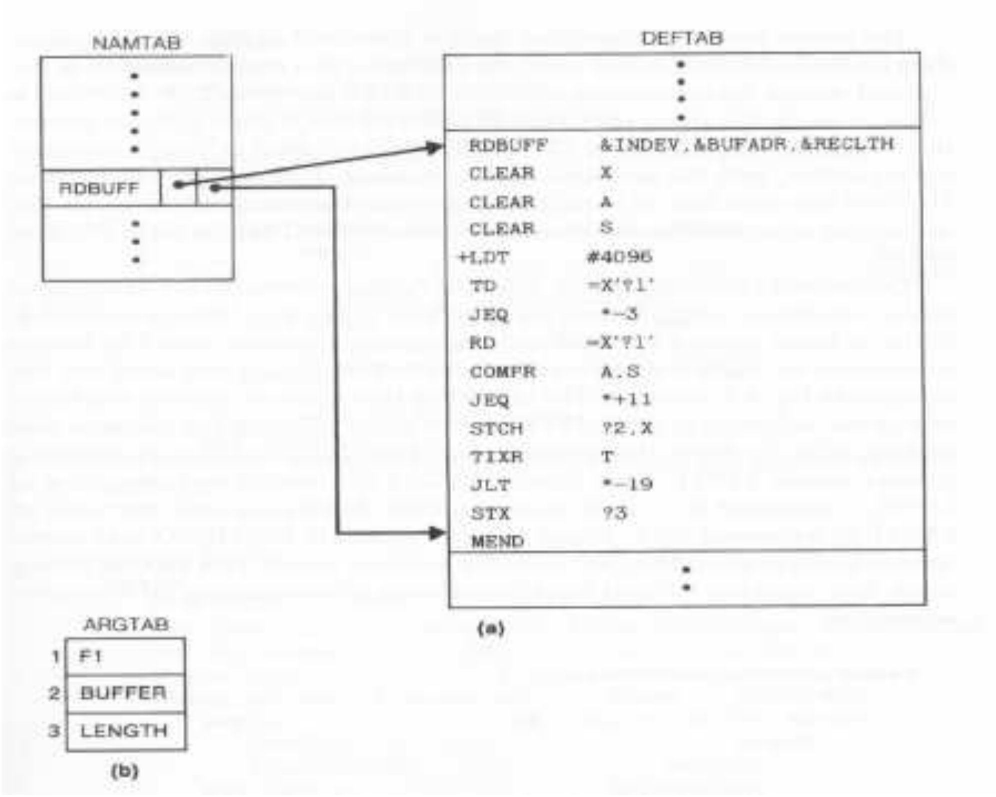
1. The macro definition themselves are stored in definition table (DEFTAB), which contains the macro prototype and statements that make up the macro body.
2. Comment lines from macro definition are not entered into DEFTAB because they will not be a part of macro expansion.

Name table (NAMTAB)

1. References to macro instruction parameters are converted to a positional entered into NAMTAB, which serves the index to DEFTAB.
2. For each macro instruction defined, NAMTAB contains pointers to beginning and end of definition in DEFTAB.

Argument table (ARGTAB)

1. The third Data Structure in an argument table (ARGTAB), which is used during expansion of macro invocations.
2. When macro invocation statements are recognized, the arguments are stored in ARGTAB according to their position in argument list.
3. As the macro is expanded, arguments from ARGTAB are substituted for the corresponding parameters in the macro body.



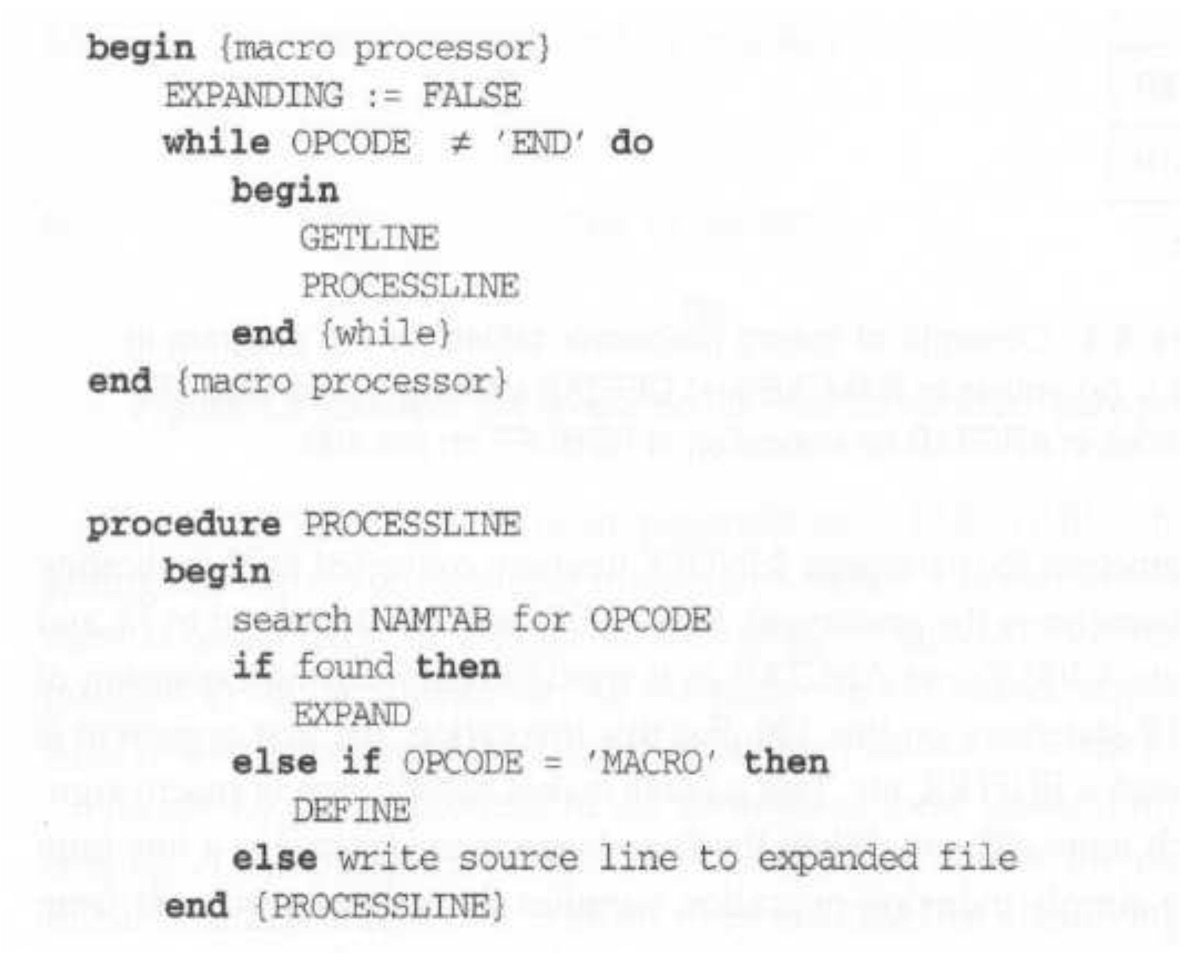
```
RDBUFF    &INDEV,&BUFADR,&RECLTH
CLEAR     X
CLEAR     A
CLEAR     S
+LDT     #4096
TD       =X'?1'
JEQ       *-3
RD       =X'?1'
COMPR     A,S
JEQ       *+11
STCH      ?2,X
TIXR      T
JLT       *-19
STX       ?3
MEND
```

1	F1
2	BUFFER
3	LENGTH

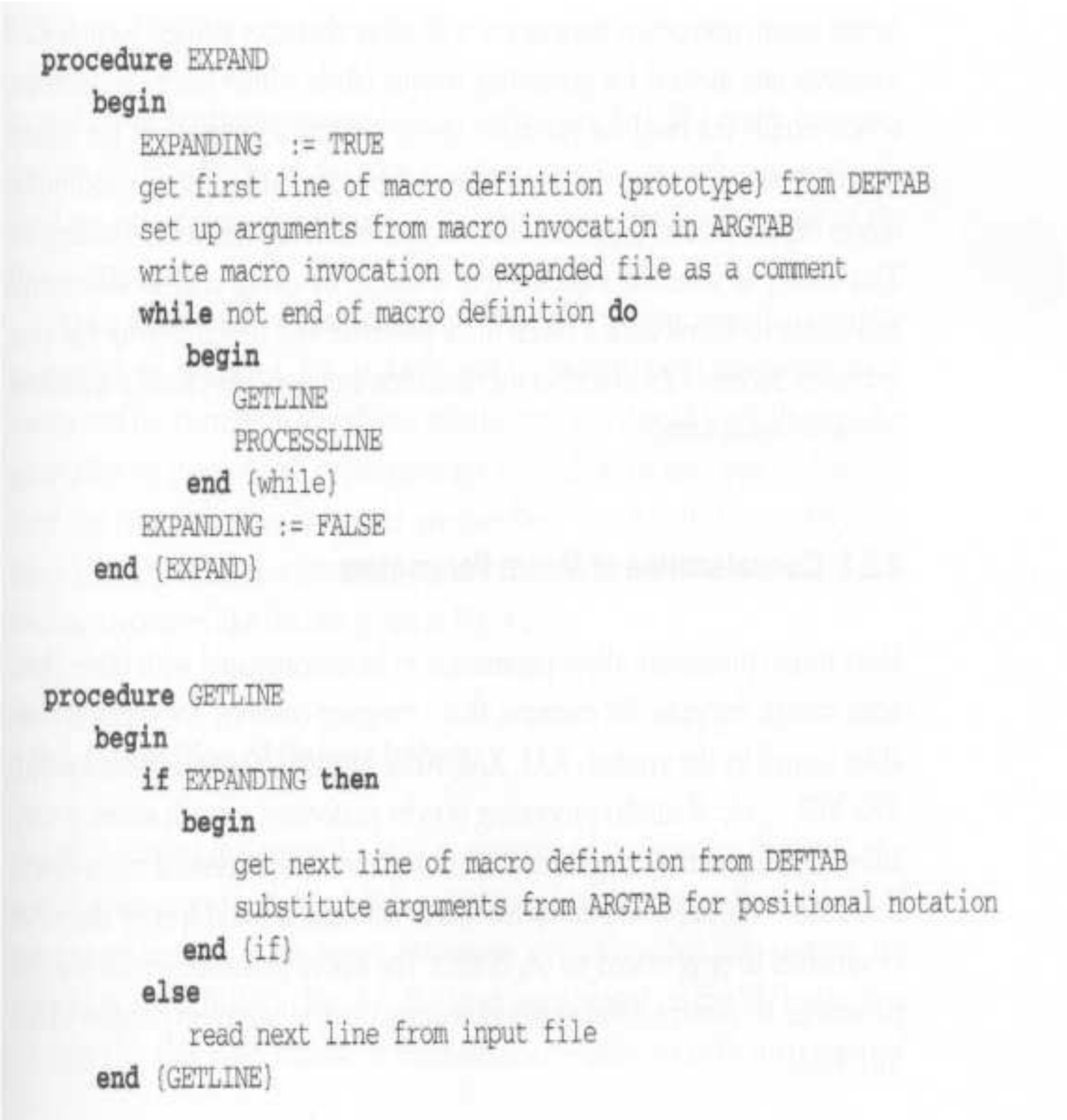
- The position notation is used for the parameters. The parameter &INDEV has been converted to ?1, &BUFADR has been converted to ?2.
- When the ?n notation is recognized in a line from DEFTAB, a simple indexing operation supplies the property argument from ARGTAB.

Algorithm:

- The procedure DEFINE, which is called when the beginning of a macro definition is recognized, makes the appropriate entries in DEFTAB and NAMTAB.
- EXPAND is called to set up the argument values in ARGTAB and expand a macro invocation statement.
- The procedure GETLINE gets the next line to be processed
- This line may come from DEFTAB or from the input file, depending upon whether the Boolean variable EXPANDING is set to TRUE or FALSE.



```
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}
```



```
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)*

4.2 MACHINE INDEPENDENT MACRO PROCESSOR FEATURES

Machine independent macro processor features are extended features that are not directly related to architecture of computer for which the macro processor is written.

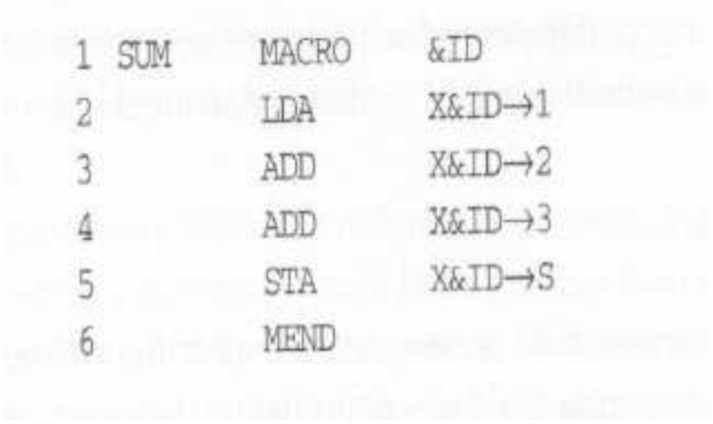
4.2.1 Concatenation of Macro Parameter

- Most Macro Processor allows parameters to be concatenated with other character strings.
- A program contains a set of series of variables:
    - XA1, XA2, XA3,…

        - ▪ XB1, XB2, XB3,…
- If similar processing is to be performed on each series of variables, the programmer might want to incorporate this processing into a macro instructuion.
- The parameter to such a macro instruction could specify the series of variables to be operated on (A, B, C …).
- The macro processor constructs the symbols by concatenating X, (A, B, …), and (1,2,3,…) in the macro expansion.

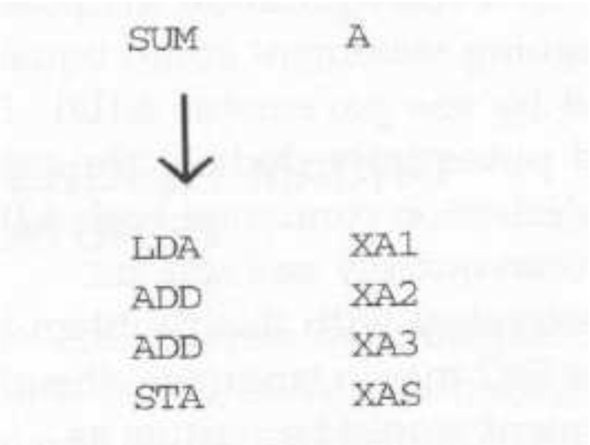
- Suppose such parameter is named &ID, the macro body may contain a statement: LDA X&ID1, in which &ID is concatenated after the string “X” and before the string “1”.
  ◊ LDA XA1 (&ID=A)
  ◊ LDA XB1 (&ID=B)
- Ambiguity problem:
  E.g., X&ID1 may mean
  “X” + &ID + “1”
  “X” + &ID1
  This problem occurs because the end of the parameter is not marked.
- Solution to this ambiguity problem:
  Use a special concatenation operator “→” to specify the end of the parameter
  LDA X&ID →1
  So that the end of parameter &ID is clearly identified.

Macro definition



```
SUM   MACRO   &ID
      LDA     X&ID→1
      ADD     X&ID→2
      ADD     X&ID→3
      STA     X&ID→S
      MEND
```

Macro invocation statements



```
SUM     A
   ↓
LDA     XA1
ADD     XA2
ADD     XA3
STA     XAS
```

- The macroprocessor deletes all occurrences of the concatenation operator immediately after performing parameter substitution, so the character → will not appear in the macro expansion.

4.2.2 Generation of Unique Labels

- Labels in the macro body may cause "duplicate labels" problem if the macro is invocated and expanded multiple times.
- Use of relative addressing at the source statement level is very inconvenient, error-prone, and difficult to read.
- It is highly desirable to

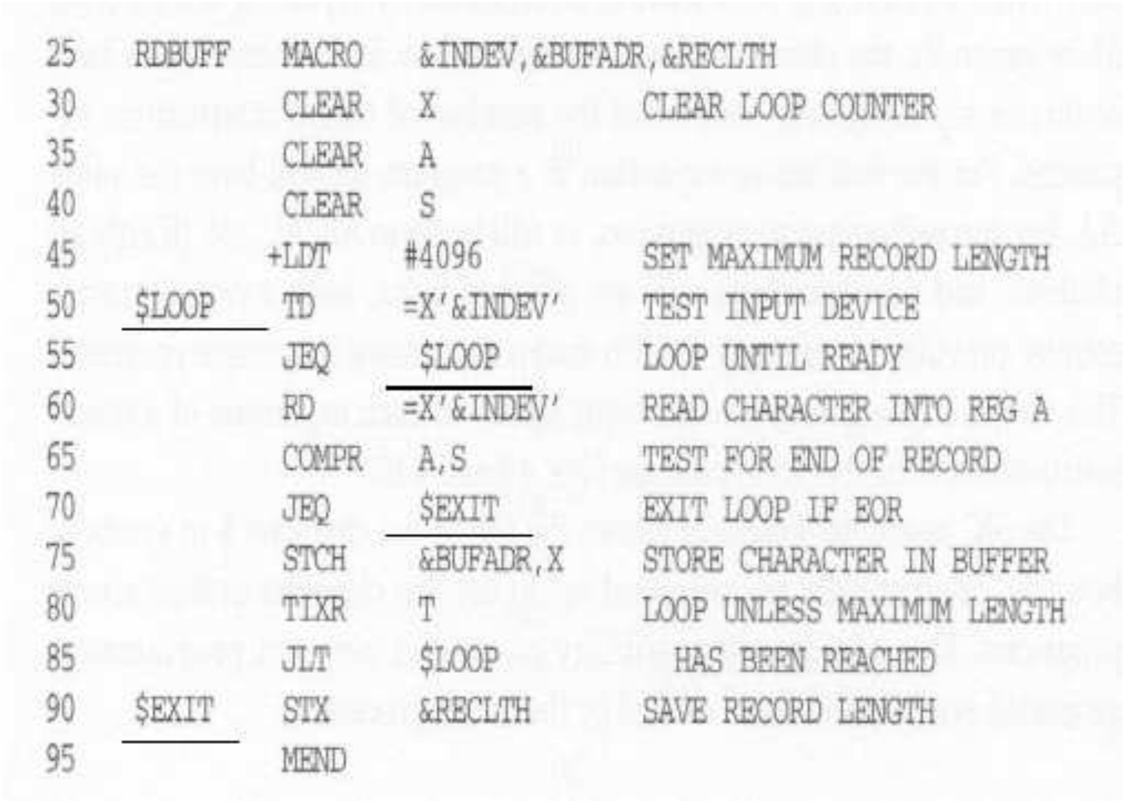
1. Let the programmer use label in the macro body
    - Labels used within the macro body begin with $.
2. Let the macro processor generate unique labels for each macro invocation and expansion.
    - During macro expansion, the $ will be replaced with $xx, where xx is a two-character alphanumeric counter of the number of macro instructions expanded.
    - XX=AA, AB, AC …….

`Consider the definition of WRBUFF

```
5      COPY        START      0
         :
         :
135    TD                     =X '&OUTDEV'
         :
140    JEQ                    *-3
         :
155    JLT                    *-14
         :
255    END                    FIRST
```

- If a label was placed on the TD instruction on line 135, this label would be defined twice, once for each invocation of WRBUFF.
- This duplicate definition would prevent correct assembly of the resulting expanded program.
- The jump instructions on line 140 and 155 are written using the re4lative operands *-3 and *-14, because it is not possible to place a label on line 135 of the macro definition.
- This relative addressing may be acceptable for short jumps such as " JEQ *-3"
- For longer jumps spanning several instructions, such notation is very inconvenient, error-prone and difficult to read.
- Many macroprocessors avoid these problems by allowing the creation of special types of labels within macro instructions.

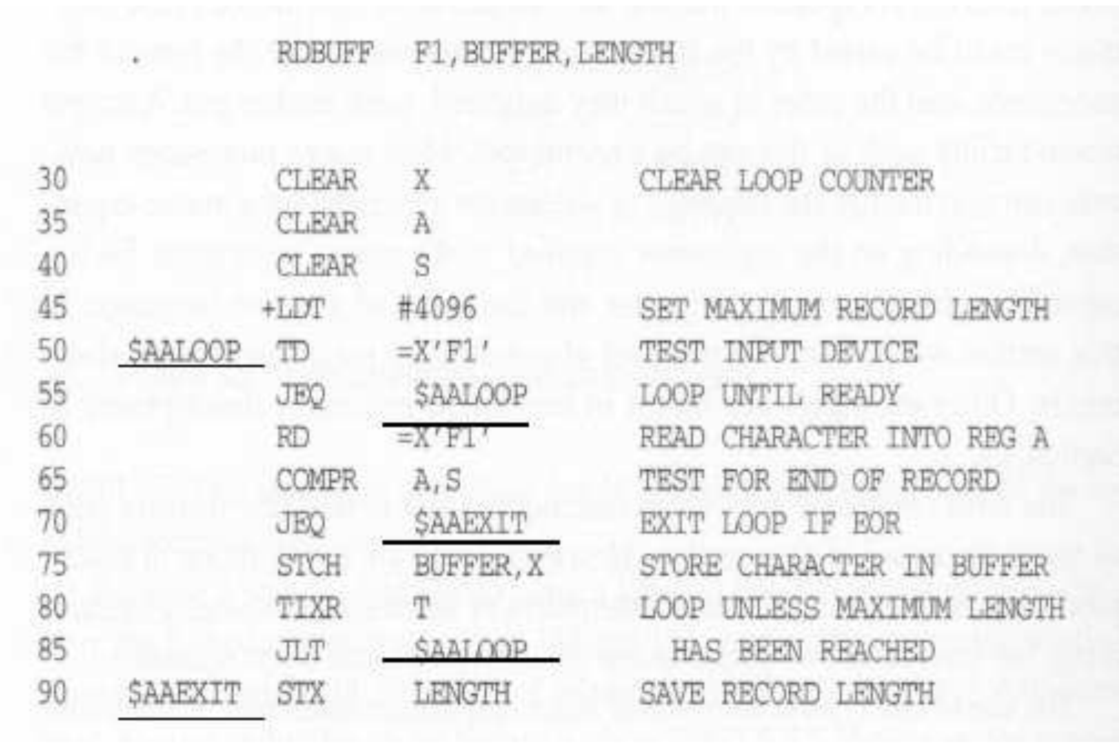
RDBUFF definition



```
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    T              LOOP UNLESS MAXIMUM LENGTH
85            JLT     $LOOP            HAS BEEN REACHED
90   $EXIT    STX     &RECLTH        SAVE RECORD LENGTH
95            MEND
```

- Labels within the macro body begin with the special character $.

Macro expansion



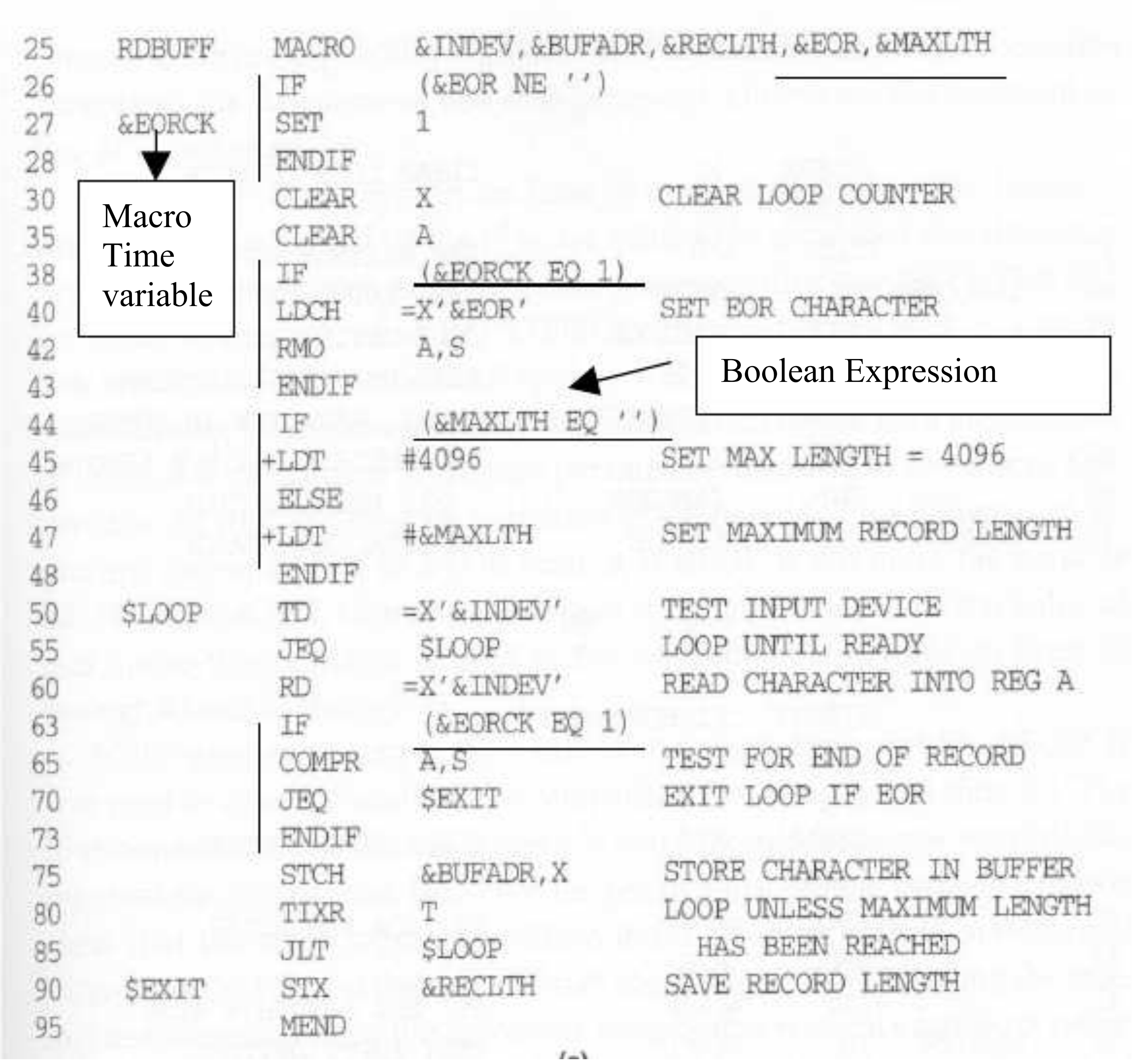
```
       .        RDBUFF   F1,BUFFER,LENGTH

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
```

- Unique labels are generated within macro expansion.
- Each symbol beginning with $ has been modified by replacing $ with $AA.
- The character $ will be replaced by $xx, where xx is a two-character alphanumeric counter of the number of macro instructions expanded.
- For the first macro expansion in a program, xx will have the value AA. For succeeding macro expansions, xx will be set to AB, AC etc.

4.2.3 Conditional Macro Expansion

- Arguments in macro invocation can be used to:
  - Substitute the parameters in the macro body without changing the sequence of statements expanded.
  - Modify the sequence of statements for **conditional macro expansion** (or conditional assembly when related to assembler).
    - This capability adds greatly to the power and flexibility of a macro language.

Consider the example



```
RDBUFF   MACRO   &INDEV,&BUFADR,&RECLTH,&EOR,&MAXLTH
         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
         IF      (&MAXLTH EQ '')
        +LDT     #4096             SET MAX LENGTH = 4096
         ELSE
        +LDT     #&MAXLTH          SET MAXIMUM RECORD LENGTH
         ENDIF
$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 UNLESS MAXIMUM LENGTH
         JLT     $LOOP               HAS BEEN REACHED
$EXIT    STX     &RECLTH           SAVE RECORD LENGTH
         MEND
```

- Two additional parameters used in the example of conditional macro expansion
  - &EOR: specifies a hexadecimal character code that marks the end of a record
  - &MAXLTH: specifies the maximum length of a record

- Macro-time variable (SET symbol)
  - can be used to
    - store working values during the macro expansion
    - store the evaluation result of Boolean expression
    - control the macro-time conditional structures
  - begins with "&" and that is not a macro instruction parameter
  - be initialized to a value of 0
  - be set by a macro processor directive, SET

- Macro-time conditional structure
  - IF-ELSE-ENDIF
  - WHILE-ENDW

4.2.3.1 Implementation of Conditional Macro Expansion (IF-ELSE-ENDIF Structure)

- A symbol table is maintained by the macroprocessor.
    - This table contains the values of all macro-time variables used.
    - Entries in this table are made or modified when SET statements are processed.
    - This table is used to look up the current value of a macro-time variable whenever it is required.
- The testing of the condition and looping are done while the macro is being expanded.
- When an IF statement is encountered during the expansion of a macro, the specified Boolean expression is evaluated. If value is
    - TRUE
        - The macro processor continues to process lines from DEFTAB until it encounters the next ELSE or ENDIF statement.
        - If ELSE is encountered, then skips to ENDIF
    - FALSE
        - The macro processor skips ahead in DEFTAB until it finds the next ELSE or ENDLF statement.

4.2.3.2 Implementation of Conditional Macro Expansion (WHILE-ENDW Structure)

- When an WHILE statement is encountered during the expansion of a macro, the specified Boolean expression is evaluated. If value is
    - 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 again.
    - FALSE
        - The macro processor skips ahead in DEFTAB until it finds the next ENDW statement and then resumes normal macro expansion.

4.2.4 Keyword Macro Parameters

- **Positional parameters**
  - Parameters and arguments are associated according to their positions in the macro prototype and invocation. The programmer must specify the arguments in proper order.
  - If an argument is to be omitted, a null argument should be used to maintain the proper order in macro invocation statement.
  - For example: Suppose a macro instruction GENER has 10 possible parameters, but in a particular invocation of the macro only the 3rd and 9th parameters are to be specified.
  - The statement is GENER „DIRECT,,,,,,3.
  - It is not suitable if a macro has a large number of parameters, and only a few of these are given values in a typical invocation.

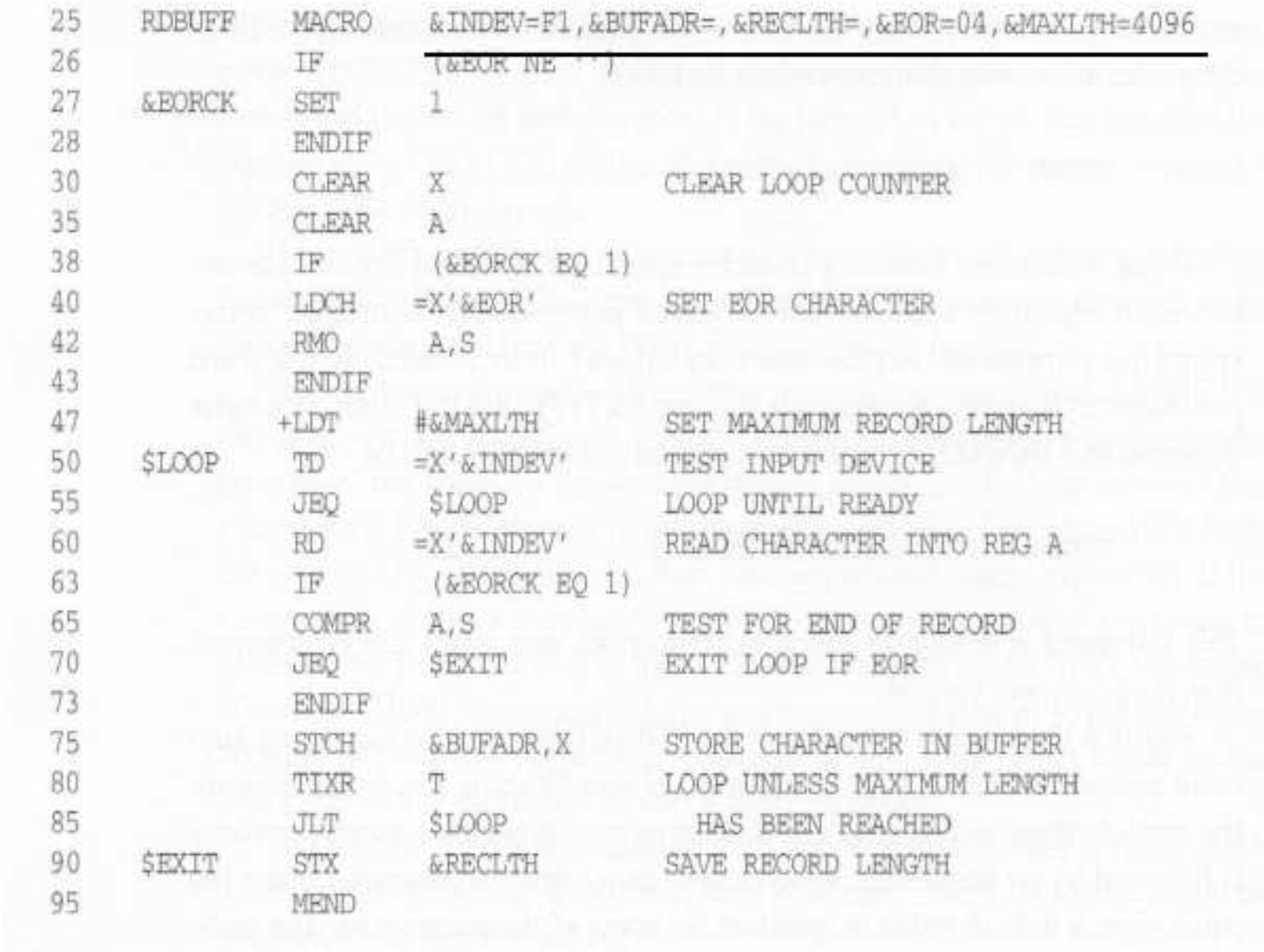
- **Keyword parameters**
  - Each argument value is written with a keyword that names the corresponding parameter.
  - Arguments may appear in any order.
  - Null arguments no longer need to be used.
  - If the 3rd parameter is named &TYPE and 9th parameter is named &CHANNEL, the macro invocation would be

    GENER TYPE=DIRECT,CHANNEL=3.

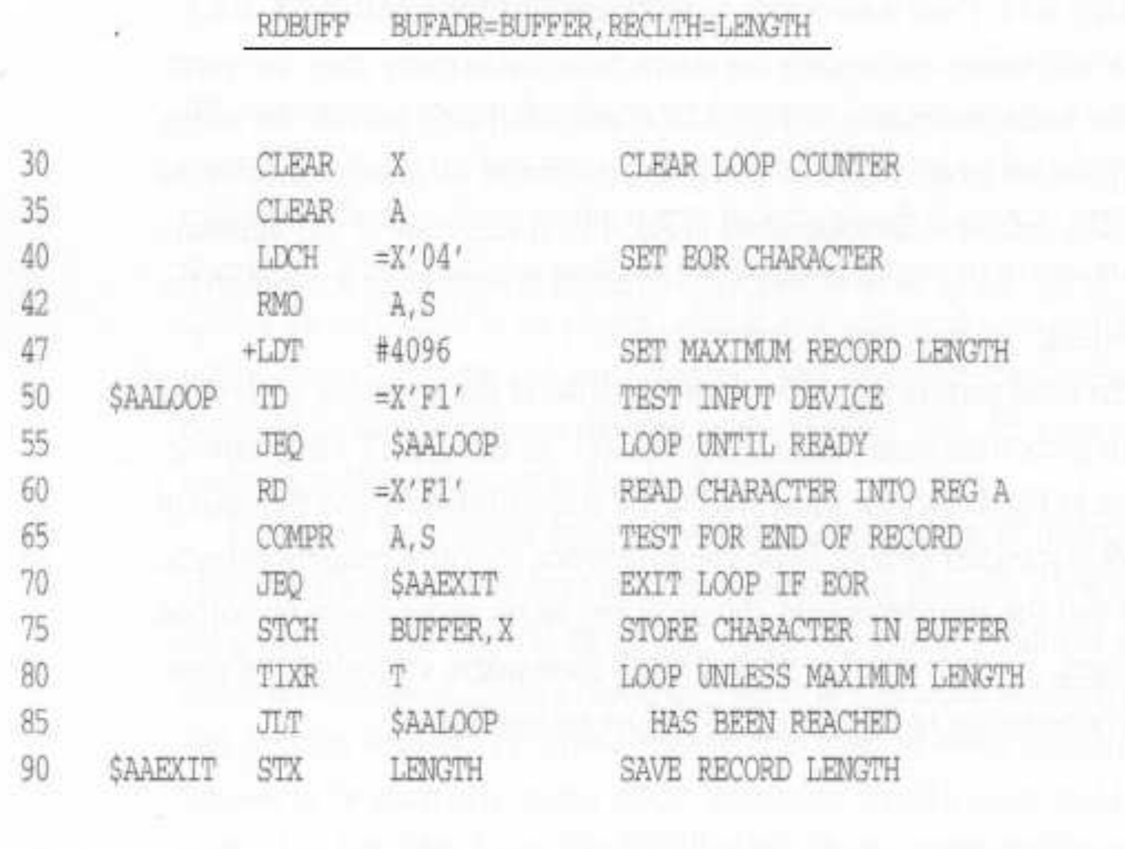
  - It is easier to read and much less error-prone than the positional method.

Consider the example

- Here each parameter name is followed by equal sign, which identifies a keyword parameter and a default value is specified for some of the parameters.



```
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 UNLESS MAXIMUM LENGTH
          JLT       $LOOP              HAS BEEN REACHED
$EXIT     STX       &RECLTH          SAVE RECORD LENGTH
          MEND
```

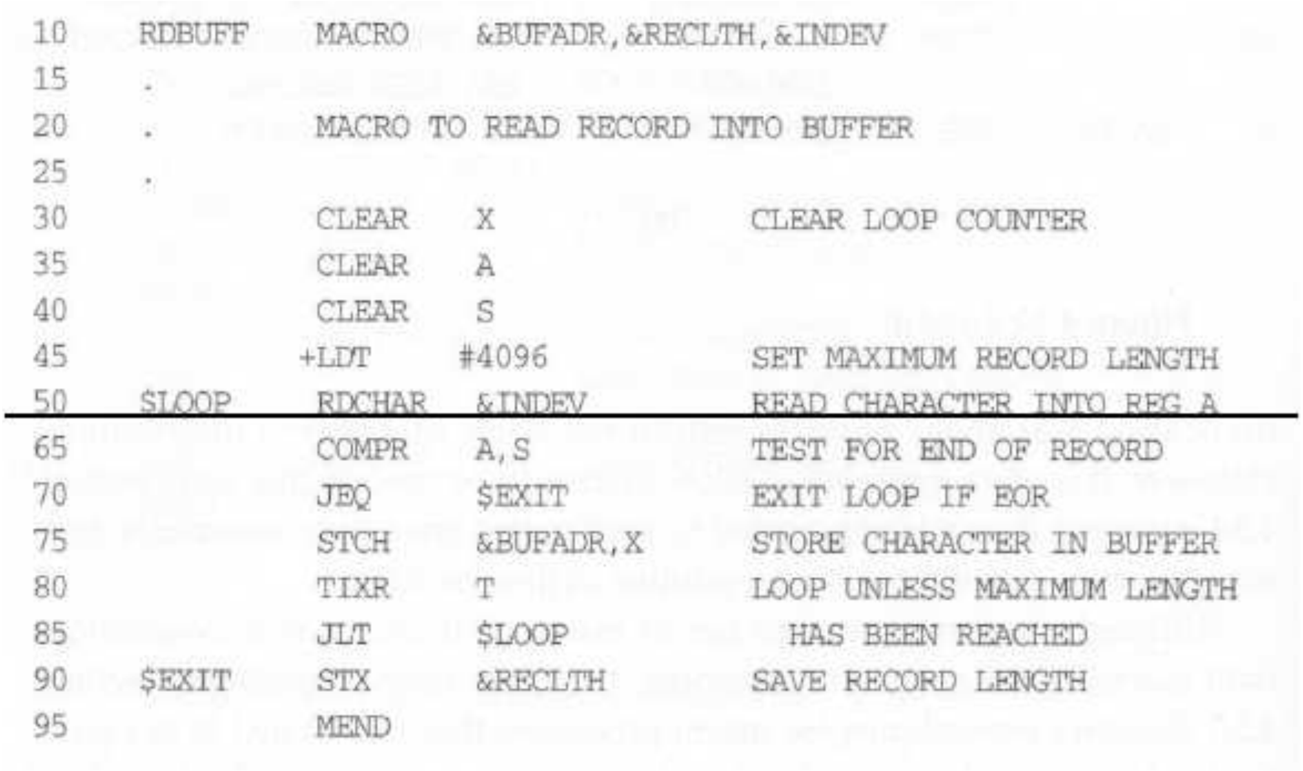


```
.         RDBUFF    BUFADR=BUFFER,RECLTH=LENGTH

          CLEAR     X                CLEAR LOOP COUNTER
          CLEAR     A
          LDCH     =X'04'            SET EOR CHARACTER
          RMO       A,S
         +LDT      #4096             SET MAXIMUM RECORD LENGTH
$AALOOP   TD       =X'F1'            TEST INPUT DEVICE
          JEQ       $AALOOP          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 UNLESS MAXIMUM LENGTH
          JLT       $AALOOP            HAS BEEN REACHED
$AAEXIT   STX       LENGTH           SAVE RECORD LENGTH
```

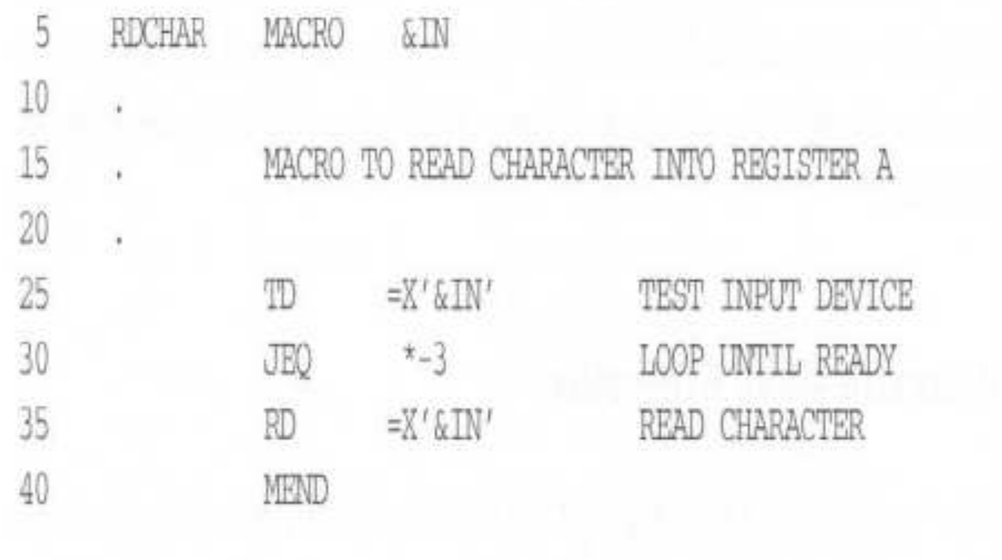
Here the value if &INDEV is specified as F3 and the value of &EOR is specified as null.

4.3. MACROPROCESSOR DESIGN OPTIONS

4.3.1 Recursive Macro Expansion



```
10   RDBUFF   MACRO   &BUFADR,&RECLTH,&INDEV
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   $LOOP    RDCHAR  &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    T              LOOP UNLESS MAXIMUM LENGTH
85            JLT     $LOOP            HAS BEEN REACHED
90   $EXIT    STX     &RECLTH        SAVE RECORD LENGTH
95            MEND
```



```
 5   RDCHAR   MACRO   &IN
10   .
15   .        MACRO TO READ CHARACTER INTO REGISTER A
20   .
25            TD      =X'&IN'        TEST INPUT DEVICE
30            JEQ      *-3           LOOP UNTIL READY
35            RD      =X'&IN'        READ CHARACTER
40            MEND
```

- RDCHAR:
    - read one character from a specified device into register A
    - should be defined beforehand (i.e., before RDBUFF)

Implementation of Recursive Macro Expansion

- Previous macro processor design cannot handle such kind of recursive macro invocation and expansion, e.g., RDBUFF BUFFER, LENGTH, F1
- Reasons:
    1) The procedure EXPAND would be called recursively, thus the invocation arguments in the ARGTAB will be overwritten.
    2) The Boolean variable EXPANDING would be set to FALSE when the "inner" macro expansion is finished, that is, the macro process would forget that it had been in the middle of expanding an "outer" macro.
    3) A similar problem would occur with PROCESSLINE since this procedure too would be called recursively.
- Solutions:
    1) Write the macro processor in a programming language that allows recursive calls, thus local variables will be retained.
    2) Use a stack to take care of pushing and popping local variables and return addresses.
- Another problem: can a macro invoke itself recursively?

4.3.2 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.
- Because of the one-pass structure, the definition of a macro must appear in the source program before any statements that invoke that macro.

Handling Recursive Macro Definition

- In DEFINE procedure
    - When a macro definition is being entered into DEFTAB, the normal approach is to continue until an MEND directive is reached.
    - This would not work for recursive macro definition because the first MEND encountered in the inner macro will terminate the whole macro definition process.
    - To solve this problem, a counter LEVEL is used to keep track of the level of macro definitions.
        - Increase LEVEL by 1 each time a MACRO directive is read.
        - Decrease LEVEL by 1 each time a MEND directive is read.
        - A MEND can terminate the whole macro definition process only when LEVEL reaches 0.

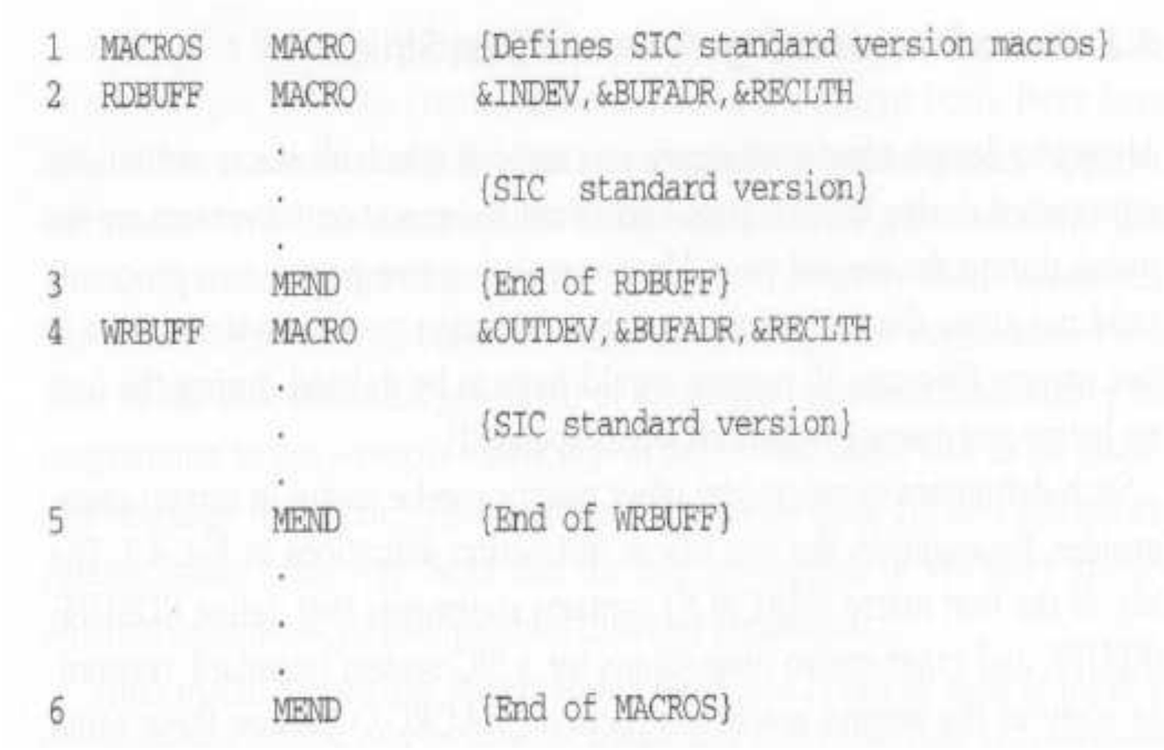
        - This process is very much like matching left and right parentheses when scanning an arithmetic expression.

4.3.3 Two-Pass Macro Processor

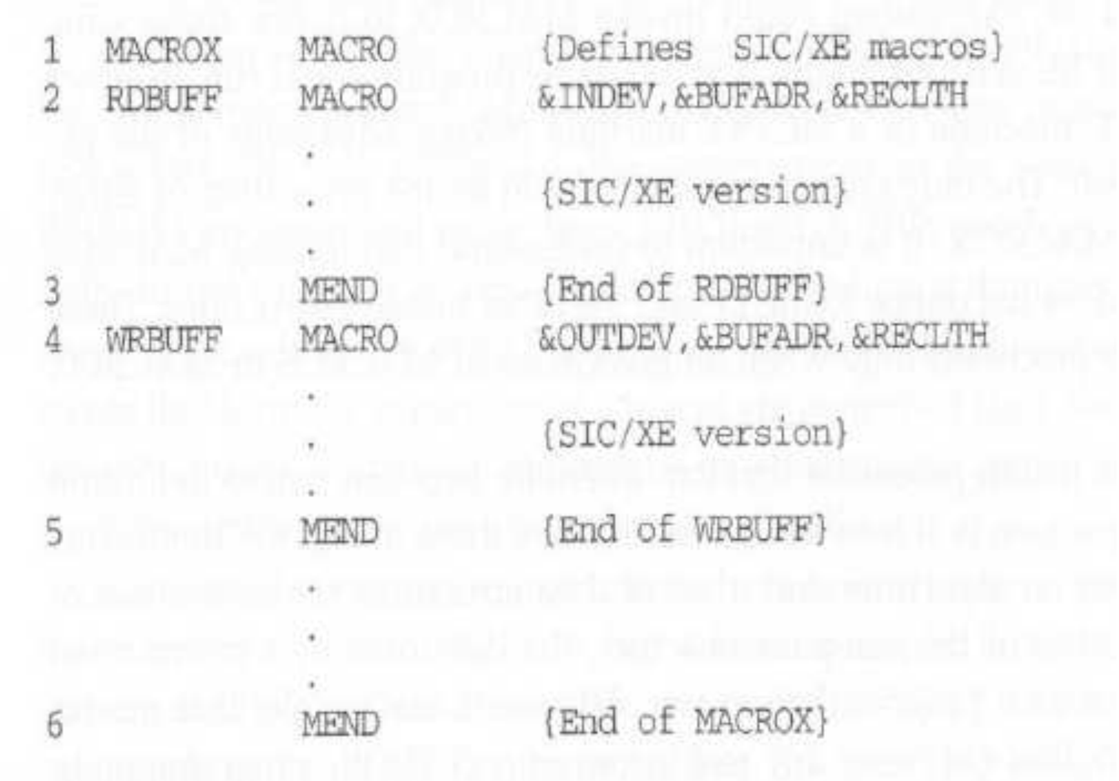
- Two-pass macro processor
    - Pass 1:
        - Process macro definition
    - Pass 2:
        - Expand all macro invocation statements
- Problem
    - This kind of macro processor cannot allow recursive macro definition, that is, the body of a macro contains definitions of other macros (because all macros would have to be defined during the first pass before any macro invocations were expanded).

Example of Recursive Macro 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.
- 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 MACROS or MACROX does not define RDBUFF and WRBUFF. These definitions are processed only when an invocation of MACROS or MACROX is expanded.



```
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}
```



```
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}
```

4.3.4 General-Purpose Macro Processors

Goal

- Macro processors that do not dependent on any particular programming language, but can be used with a variety of different languages.

Advantages

- 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.

Disadvantages

- 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

4.3.5 Macro Processing within Language Translators

Macro processors can be

1) **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.
2) **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.
3) **Integrated macro processor**

4.3.5.1 Line-by-Line Macro Processor

Benefits

- It avoids 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.

4.3.5.2 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.
- As an example in FORTRAN
  DO 100 I = 1,20
    - a DO statement:
      - DO: keyword
      - 100: statement number
      - I: variable name

  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.

Drawbacks of Line-by-line or Integrated Macro Processor

- They must be specially designed and written to work with a particular implementation of an assembler or compiler.
- The cost of macro processor development is added to the costs of the language translator, which results in a more expensive software.
- The assembler or compiler will be considerably larger and more complex.

UNIT V

TEXT- EDITORS

OVERVIEW OF THE EDITING PROCESS.

An interactive editor is a computer program that allows a user to create and revise a target document. The term document includes objects such as computer programs, texts, equations, tables, diagrams, line art and photographs-anything that one might find on a printed page. Text editor is one in which the primary elements being edited are character strings of the target text. The document editing process is an interactive user-computer dialogue designed to accomplish four tasks:

1) Select the part of the target document to be viewed and manipulated
2) Determine how to format this view on-line and how to display it.
3) Specify and execute operations that modify the target document.
4) Update the view appropriately.

Traveling – Selection of the part of the document to be viewed and edited. It involves first **traveling** through the document to locate the area of interest such as "next screenful", "bottom",and "find pattern". Traveling specifies where the area of interest is;

Filtering - The selection of what is to be viewed and manipulated is controlled by filtering. Filtering extracts the relevant subset of the target document at the point of interest such as next screenful of text or next statement.

Formatting: Formatting determines how the result of filtering will be seen as a visible representation (the view) on a display screen or other device.

Editing: In the actual editing phase, the target document is created or altered with a set of operations such as insert, delete, replace, move or copy.

Manuscript oriented editors operate on elements such as single characters, words, lines, sentences and paragraphs; **Program-oriented editors** operates on elements such as identifiers, keywords and statements

THE USER-INTERFACE OF AN EDITOR.

The user of an interactive editor is presented with a conceptual model of the editing system. The model is an abstract framework on which the editor and the world on which the operations are based. The **line editors** simulated the world of the keypunch they allowed operations on numbered sequence of 80-character card image lines.

The **Screen-editors** define a world in which a document is represented as a quarter-plane of text lines, unbounded both down and to the right. The user sees, through a cutout, only a rectangular subset of this plane on a multi line display terminal. The cutout can be moved left or right, and up or down, to display other portions of the document. The user interface is also concerned with the input devices, the output devices, and the interaction language of the system.

INPUT DEVICES: The input devices are used to enter elements of text being edited, to enter commands, and to designate editable elements. Input devices are categorized as: 1) Text devices 2) Button devices 3) Locator devices

1) Text or string devices are typically typewriter like keyboards on which user presses and release keys, sending unique code for each key. Virtually all computer key boards are of the QWERTY type.

2) Button or Choice devices generate an interrupt or set a system flag, usually causing an invocation of an associated application program. Also special function keys are also available on the key board. Alternatively, buttons can be simulated in software by displaying text strings or symbols on the screen. The user chooses a string or symbol instead of pressing a button.

3) Locator devices: They are two-dimensional analog-to-digital converters that position a cursor symbol on the screen by observing the user‟s movement of the device. The most common such devices are the **mouse** and the **tablet.**

The Data Tablet is a flat, rectangular, electromagnetically sensitive panel. Either the ballpoint pen like stylus or a puck, a small device similar to a mouse is moved over the surface. The tablet returns to a system program the co-ordinates of the position on the data tablet at which the stylus or puck is currently located. The program can then map these data-tablet coordinates to screen coordinates and move the cursor to the corresponding screen position. Text devices with arrow (Cursor) keys can be used to simulate locator devices. Each of these keys shows an arrow that point up, down, left or right. Pressing an arrow key typically generates an appropriate character sequence; the program interprets this sequence and moves the cursor in the direction of the arrow on the key pressed.

VOICE-INPUT DEVICES: which translate spoken words to their textual equivalents, may prove to be the text input devices of the future. Voice recognizers are currently available for command input on some systems.

OUTPUT DEVICES The output devices let the user view the elements being edited and the result of the editing operations.

- The first output devices were **teletypewriters** and other character-printing terminals that generated output on paper.
- Next "**glass teletypes**" based on Cathode Ray Tube (CRT) technology which uses CRT screen essentially to simulate the hard-copy teletypewriter.
- Today‟s **advanced CRT terminals** use hardware assistance for such features as moving the cursor, inserting and deleting characters and lines, and scrolling lines and pages.
- The modern **professional workstations** are based on personal computers with high resolution displays; support multiple proportionally spaced character fonts to produce realistic facsimiles of hard copy documents.

INTERACTION LANGUAGE:

The interaction language of the text editor is generally one of several common types.

The typing oriented or text command-oriented method It is the oldest of the major editing interfaces. The user communicates with the editor by typing text strings both for command names and for operands. These strings are sent to the editor and are usually echoed to the output device. Typed specification often requires the user to remember the exact form of all commands, or at least their abbreviations. If the command language is complex, the user must continually refer to a manual or an on-line Help function. The typing required can be time consuming for in-experienced users.

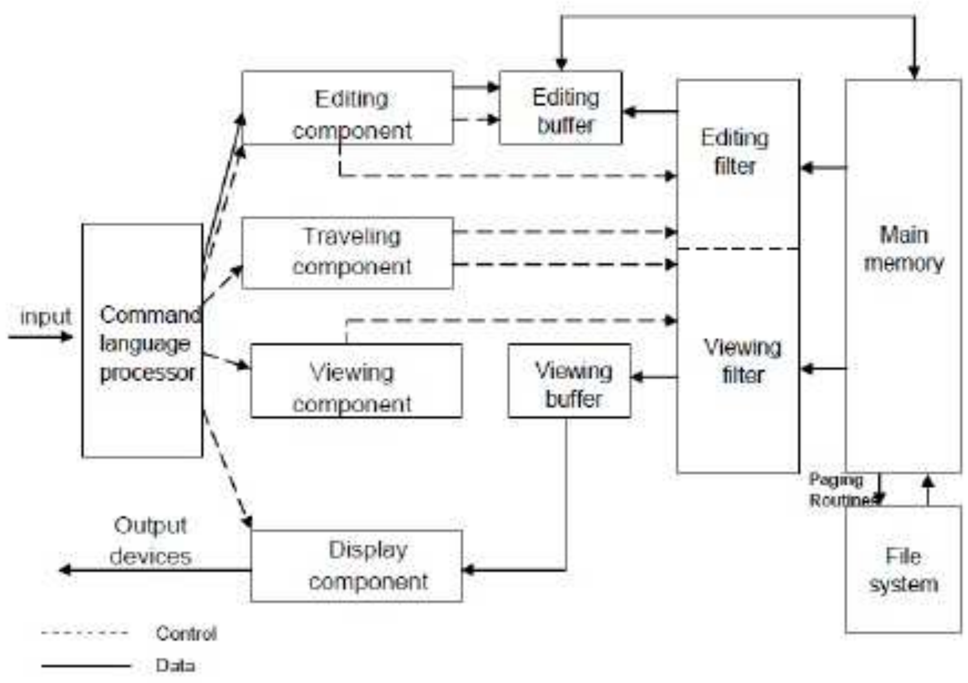
Function key interfaces: Each command is associated with marked key on the key board. This eliminates much typing. E.g.: Insert key, Shift key, Control key

Disadvantages:

Have too many unique keys
Multiple key stroke commands

Menu oriented interface A menu is a multiple choice set of text strings or icons which are graphical symbols that represent objects or operations. The user can perform actions by selecting items for the menus. The editor prompts the user with a menu. One problem with menu oriented system can arise when there are many possible actions and several choices are required to complete an action. The display area of the menu is rather limited

EDITOR STRUCTURE



Most Text editors have a structure similar to that shown above.

The command Language Processor It accepts input from the user‟s input devices, and analyzes the tokens and syntactic structure of the commands. It functions much like the lexical and syntactic phases of a compiler. The command language processor may invoke the semantic routines directly. In a text editor, these semantic routines perform functions such as editing and viewing. The semantic routines involve traveling, editing, viewing and display functions. Editing operations are always specified by the user and display operations are specified implicitly by the other three categories of operations. Traveling and viewing operations may be invoked either explicitly by the user or implicitly by the editing operations

Editing Component

In editing a document, the start of the area to be edited is determined by the **current editing pointer** maintained by the editing component, which is the collection of modules dealing with editing tasks. The current editing pointer can be set or reset explicitly by the user using travelling commands, such as next paragraph and next screen, or implicitly as a side effect of the previous editing operation such as delete paragraph.

Traveling Component

The traveling component of the editor actually performs the setting of the current editing and viewing pointers, and thus determines the point at which the viewing and /or editing filtering begins.

Viewing Component

The start of the area to be viewed is determined by the current viewing pointer. This pointer is maintained by the viewing component of the editor, which is a collection of modules responsible for determining the next view. The current viewing pointer can be set or reset explicitly by the user or implicitly by system as a result of previous editing operation. The viewing component formulates an ideal view, often expressed in a device independent intermediate representation. This view may be a very simple one consisting of a window ‟s worth of text arranged so that lines are not broken in the middle of the words.

Display Component

It takes the idealized view from the viewing component and maps it to a physical output device in the most efficient manner. The display component produces a display by mapping the buffer to a rectangular subset of the screen, usually a window

Editing Filter

Filtering consists of the selection of contiguous characters beginning at the current point. The editing filter filters the document to generate a new editing buffer based on the current editing pointer as well as on the editing filter parameters

Editing Buffer

It contains the subset of the document filtered by the editing filter based on the editing pointer and editing filter parameters

Viewing Filter

When the display needs to be updated, the viewing component invokes the viewing filter. This component filters the document to generate a new viewing buffer based on the current viewing pointer as well as on the viewing filter parameters.

Viewing Buffer

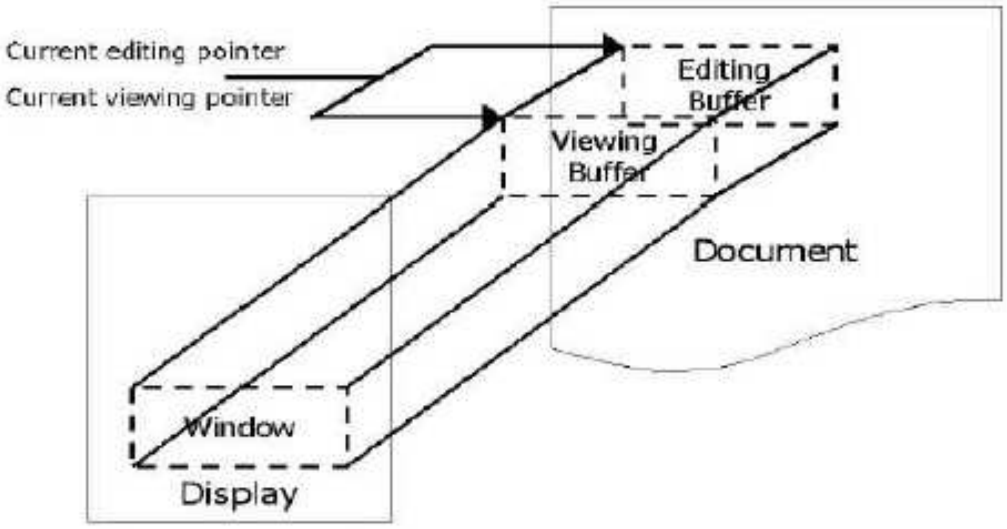
It contains the subset of the document filtered by the viewing filter based on the viewing pointer and viewing filter parameters. E.g. The user of a certain editor might travel to line 75,and after viewing it, decide to change all occurrences of "ugly duckling" to "swan" in lines 1 through 50 of the file by using a change command such as

[1,50] c/ugly duckling/swan/

As a part of the editing command there is implicit travel to the first line of the file. Lines 1 through 50 are then filtered from the document to become the editing buffer. Successive substitutions take place in this editing buffer without corresponding updates of the view

In *Line editors*, the viewing buffer may contain the current line; in *screen editors*, this buffer may contain rectangular cut out of the quarter-plane of text. This viewing buffer is then passed to the display component of the editor, which produces a display by mapping the buffer to a rectangular subset of the screen, usually called a *window.*

The editing and viewing buffers, while independent, can be related in many ways. In a simplest case, they are identical: the user edits the material directly on the screen. On the other hand, the editing and viewing buffers may be completely disjoint.



Simple relationship between editing and viewing buffers

Windows typically cover the entire screen or rectangular portion of it. Mapping viewing buffers to windows that cover only part of the screen is especially useful for editors on modern graphics based workstations. Such systems can support multiple windows, simultaneously showing different portions of the same file or portions of different file.

This approach allows the user to perform inter-file editing operations much more effectively than with a system only a single window.

The mapping of the viewing buffer to a window is accomplished by two components of the system.

(i) First, the viewing component formulates an ideal view often expressed in a device **independent intermediate representation**. This view may be a very simple one consisting of a windows worth of text arranged so that lines are not broken in the middle of words. At the other extreme, the idealized view may be a facsimile of a page of fully formatted and typeset text with equations, tables and figures.

(ii) Second the display component takes these idealized views from the viewing component and maps it to a physical output device the most efficient manner possible.

The components of the editor deal with a user document on two levels:

(i) In main memory and

(ii) In the disk file system.

Loading an entire document into main memory may be infeasible. However if only part of a document is loaded and if many user specified operations require a disk read by the editor to locate the affected portions, editing might be unacceptably slow. In some systems this problem is solved by the mapping the entire file into **virtual memory** and letting the operating system perform efficient demand paging.

An alternative is to provide is the editor paging routines which read one or more logical portions of a document into memory as needed. Such portions are often termed **pages**, although there is usually no relationship between these pages and the hard copy document pages or virtual memory pages. These pages remain resident in main memory until a user operation requires that another portion of the document be loaded.

Editors function in three basic types of computing environment:

(i) **Time-sharing environment**

(ii) **Stand-alone environment and**

(iii) **Distributed environment**.

Each type of environment imposes some constraint on the design of an editor. The Time –Sharing Environment The time sharing editor must function swiftly within the context of the load on the computer‟s processor, central memory and I/O devices.

The Stand alone Environment The editor on a stand-alone system must have access to the functions that the time sharing editors obtain from its host operating system. This may be provided in pare by a small local operating system or they may be built into the editor itself if the stand alone system is dedicated to editing. Distributed Environment The editor operating in a distributed resource sharing local network must, like a standalone editor, run independently on each user‟s machine and must, like a time sharing editor, content for shared resources such as files.

INTERACTIVE DEBUGGING SYSTEMS

An interactive debugging system provides programmers with facilities that aid in testing and debugging of programs interactively.

DEBUGGING FUNCTIONS AND CAPABILITIES

Execution sequencing: It is the observation and control of the flow of program execution. For example, the program may be halted after a fixed number of instructions are executed.

Breakpoints – The programmer may define break points which cause execution to be suspended, when a specified point in the program is reached. After execution is suspended, the debugging command is used to analyze the progress of the program and to diagnose errors detected. Execution of the program can then be removed.

Conditional Expressions – Programmers can define some conditional expressions, evaluated during the debugging session, program execution is suspended, when conditions are met, analysis is made, later execution is resumed

Gaits- Given a good graphical representation of program progress may even be useful in running the program in various speeds called gaits. A Debugging system should also provide functions such as tracing and traceback. Tracing can be used to track the flow of execution logic and data modifications. The control flow can be traced at different levels of detail – procedure, branch, individual instruction, and so on…

Traceback can show the path by which the current statement in the program was reached. It can also show which statements have modified a given variable or parameter. The statements are displayed rather than as hexadecimal displacements. Program-display Capabilities It is also important for a debugging system to have good program display capabilities. It must be possible to display the program being debugged, complete with statement numbers. Multilingual Capability A debugging system should consider the language in which the program being debugged is written. Most user environments and many applications systems involve the use of different programming languages. A single debugging tool should be available to multilingual situations.

Context Effects

The context being used has many different effects on the debugging interaction. For example. The statements are different depending on the language

COBOL - MOVE 6.5 TO X
FORTRAN - X = 6.5

Likewise conditional statements should use the notation of the source language

COBOL - IF A NOT EQUAL TO B
FORTRAN - IF (A .NE. B)

Similar differences exist with respect to the form of statement labels, keywords and so on.

Display of source code

The language translator may provide the source code or source listing tagged in some standard way so that the debugger has a uniform method of navigating about it.

Optimization:

It is also important that a debugging system be able to deal with optimized code. Many optimizations involve the rearrangement of segments of code in the program

For eg. - invariant expressions can be removed from loop - separate loops can be combined into a single loop - redundant expression may be eliminated - elimination of unnecessary branch instructions The debugging of optimized code requires a substantial amount of cooperation from the optimizing compiler.

Relationship with Other Parts of the System

An interactive debugger must be related to other parts of the system in many different ways. Availability Interactive debugger must appear to be a part of the run-time environment and an integral part of the system. When an error is discovered, immediate debugging must be possible because it may be difficult or impossible to reproduce the program failure in some other environment or at some other times. Consistency with security and integrity components User need to be able to debug in a production environment. When an application fails during a production run, work dependent on that application stops. Since the production environment is often quite different from the test environment, many program failures cannot be repeated outside the production environment. Debugger must also exist in a way that is consistent with the security and integrity components of the system. Use of debugger must be subjected to the normal authorization mechanism and must leave the usual audit trails. Someone (unauthorized user) must not access any data or code. It must not be possible to use the debuggers to interface with any aspect of system integrity. Coordination with existing and future systems The debugger must co-ordinate its activities with those of existing and future language compilers and interpreters. It is assumed that debugging facilities in existing language will continue to exist and be maintained. The requirement of cross-language debugger assumes that such a facility would be installed as an alternative to the individual language debuggers.

USER- INTERFACE CRITERIA

The interactive debugging system should be user friendly. The facilities of debugging system should be organized into few basic categories of functions which should closely reflect common user tasks.

Full – screen displays and windowing systems

- The user interaction should make use of full-screen display and windowing systems. The advantage of such interface is that the information can be should displayed and changed easily and quickly.

Menus:

- With menus and full screen editors, the user has far less information to enter and remember
- It should be possible to go directly to the menus without having to retrace an entire hierarchy.
- When a full-screen terminal device is not available, user should have an equivalent action in a linear debugging language by providing commands.

Command language:

- The command language should have a clear, logical, simple syntax. Parameters names should be consistent across set of commands