# FRANCIS XAVIER ENGINEERING COLLEGE

# DEPARTMENT OF COMPUTER SCIENCE AND ENGINEERING

# CS2304

# SYSTEM SOFTWARE NOTES

## CS2304 – SYSTEM SOFTWARE

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**TEXT BOOK**

1. Leland L. Beck, "System Software – An Introduction to Systems Programming", 3rd Edition, Pearson Education Asia, 2006.

**REFERENCES**

1. D. M. Dhamdhere, "Systems Programming and Operating Systems", Second Revised Edition, Tata McGraw-Hill, 2000.
2. John J. Donovan "Systems Programming", Tata McGraw-Hill Edition, 2000.

## UNIT I

## INTRODUCTION

### 1.1 SYSTEM SOFTWARE AND MACHINE ARCHITECTURE

- 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

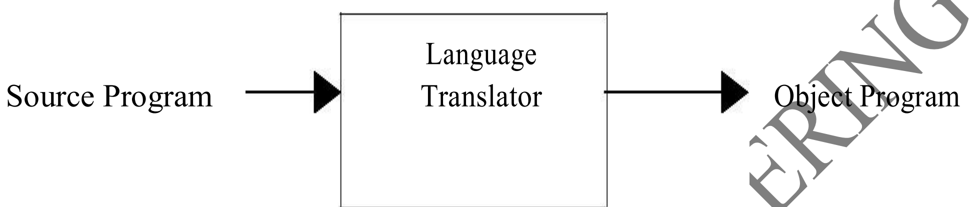
**OPERATING SYSTEM**

- 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.




**<u>Compilers</u>**

- A compiler is a language program that translates programs written in any high-level language into its equivalent machine language program.

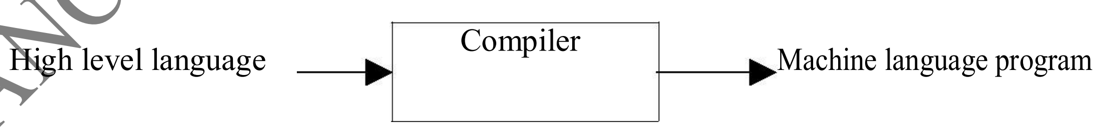
- It bridges the semantic gap between a programming language domain and the execution domain.

- 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.




**<u>Interpreters:</u>**

- 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.

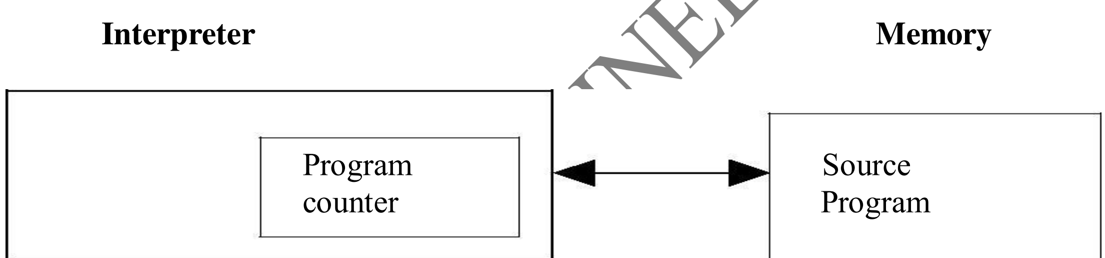
- During interpretation, it takes a source statement, determines its meaning and performs actions which increments it. This includes computational and I/O actions.
- Program counter (PC) indicates which statement of the source program is to be interpreted next. This statement would be subjected to the 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.

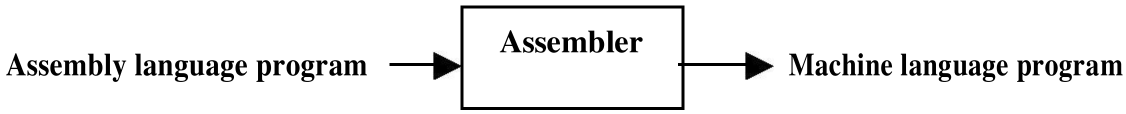



**Assemblers:**

- 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 instructions Ex: LDA, LDX, STA, STX.
2. Arithmetic operating instruction 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 programming:**

- 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
  3) Data (RD) or Write Data (WD).
  4) The sequence must be repeated for each byte of data to be read or written.

## 1.3 SIC/XE ARCHITECTURE :

**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

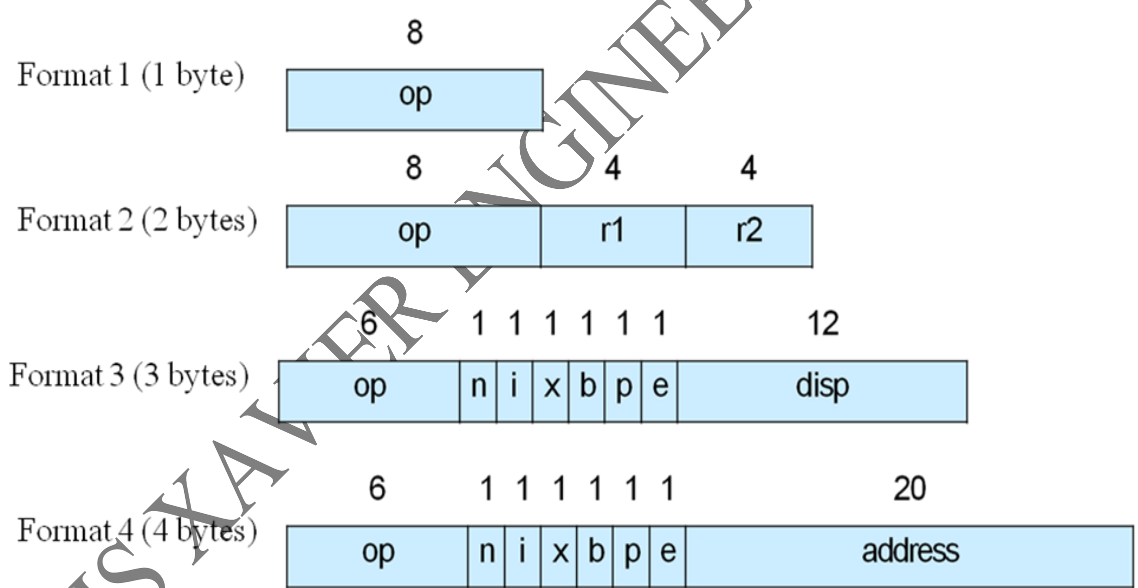
- Floating point is stored in 48 bit signed-exponent-fraction format:

| 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:




<u>Formats 3 & 4 introduce addressing mode flag bits:</u>

- 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

<u>Flag x:</u>

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

calculation

<u>Flag b & p (Format 3 only):</u>

- 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)**

<u>Flag e:</u>

e=0 use

Format 3

e=1 use

Format 4

**Instruction set:**

- Load and store the new registers: LDB, STB, etc.
- Floating-point arithmetic operations: ADDF, SUBF, MULF, DIVF
- Register move: RMO
- Register-to-register arithmetic operations : ADDR, SUBR, MULR, DIVR
- Supervisor call: SVC

(RMO, RSUB, COMPR, SHIFTR, SHIFTL, ADDR, SUBR, MULR, DIVR, etc)

**Input and Output (I/O) programming:**

- $2^8$ (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

**Addressing modes of SIC/XE**

- **Base Relative Addressing Mode**

| opcode | n | i | x | b | p | e | disp |
|---|---|---|---|---|---|---|---|
| opcode | | | | 1 | 0 | | disp |

b=1, p=0, TA=(B)+disp (0≤disp ≤4095)

- **Program-Counter Relative Addressing Mode**

| opcode | n | i | x | b | p | e | disp |
|---|---|---|---|---|---|---|---|
| opcode | | | | 0 | 1 | | disp |

b=0, p=1, TA=(PC)+disp (-2048≤disp ≤2047)

- **Direct Addressing Mode**

| opcode | n | i | x | b | p | e | disp |
|---|---|---|---|---|---|---|---|
| **opcode** | | | | **0** | **0** | | **disp** |

b=0, p=0, TA=disp (0≤disp ≤4095)

| | n | i | x | b | p | e | |
|---|---|---|---|---|---|---|---|
| **opcode** | | | **1** | **0** | **0** | | **disp** |

b=0, p=0, TA=(X)+disp (with index addressing mode)

- **Immediate Addressing Mode**

| | n | i | x | b | p | e | |
|---|---|---|---|---|---|---|---|
| **opcode** | **0** | **1** | **0** | | | | **disp** |

n=0, i=1, x=0, operand=disp

- **Indirect Addressing Mode**

| | n | i | x | b | p | e | |
|---|---|---|---|---|---|---|---|
| **opcode** | **1** | **0** | **0** | | | | **disp** |

n=1, i=0, x=0, TA=(disp)

- **Simple Addressing Mode**

| | n | i | x | b | p | e | |
|---|---|---|---|---|---|---|---|
| **opcode** | **0** | **0** | | | | | **disp** |

i=0, n=0, TA=bpe+disp (SIC standard)

opcode+n+i = SIC standard opcode (8-bit)

| | n | i | x | b | p | e | |
|---|---|---|---|---|---|---|---|
| **opcode** | **1** | **1** | | | | | **disp** |

**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**

Source statement

```
COPY     START   1000      COPY FILE FROM INPUT TO OUTPUT
FIRST    STL     RETADR    SAVE RETURN ADDRESS
CLOOP    JSUB    RDREC     READ INPUT RECORD
         LDA     LENGTH    TEST FOR EOF (LENGTH = 0)
         COMP    ZERO
         JEQ     ENDFIL    EXIT IF EOF FOUND
         JSUB    WRREC     WRITE OUTPUT RECORD
         J       CLOOP     LOOP
ENDFIL   LDA     EOF       INSERT END OF FILE MARKER
         STA     BUFFER
         LDA     THREE     SET LENGTH = 3
         STA     LENGTH
         JSUB    WRREC     WRITE EOF
         LDL     RETADR    GET RETURN ADDRESS
         RSUB              RETURN TO CALLER
EOF      BYTE    C'EOF'
THREE    WORD    3
ZERO     WORD    0
RETADR   RESW    1
LENGTH   RESW    1         LENGTH OF RECORD
BUFFER   RESB    4096      4096-BYTE BUFFER AREA
.
.        SUBROUTINE TO READ RECORD INTO BUFFER
.
```

Main Loop

```
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. |

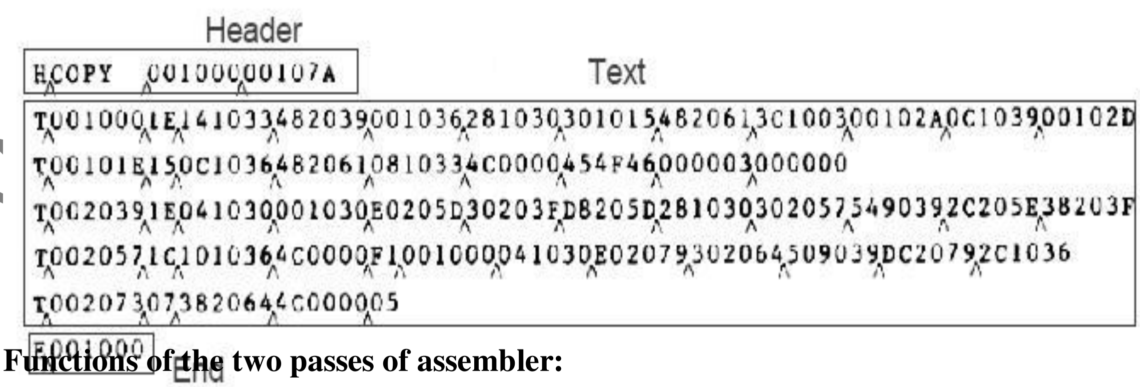


Figure 2.3 Object program corresponding to Fig. 2.2.

**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.

```
COPY     START   0         COPY FILE FROM INPUT TO OUTPUT
FIRST    STL     RETADR    SAVE RETURN ADDRESS
         LDB     #LENGTH   ESTABLISH BASE REGISTER
         BASE    LENGTH
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     EOF       INSERT END OF FILE MARKER
         STA     BUFFER
         LDA     #3        SET LENGTH = 3
         STA     LENGTH
        +JSUB    WRREC     WRITE EOF
         J       @RETADR   RETURN TO CALLER
EOF      BYTE    C'EOF'
RETADR   RESW    1
LENGTH   RESW    1         LENGTH OF RECORD
BUFFER   RESB    4096      4096-BYTE BUFFER AREA
.
```

```
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

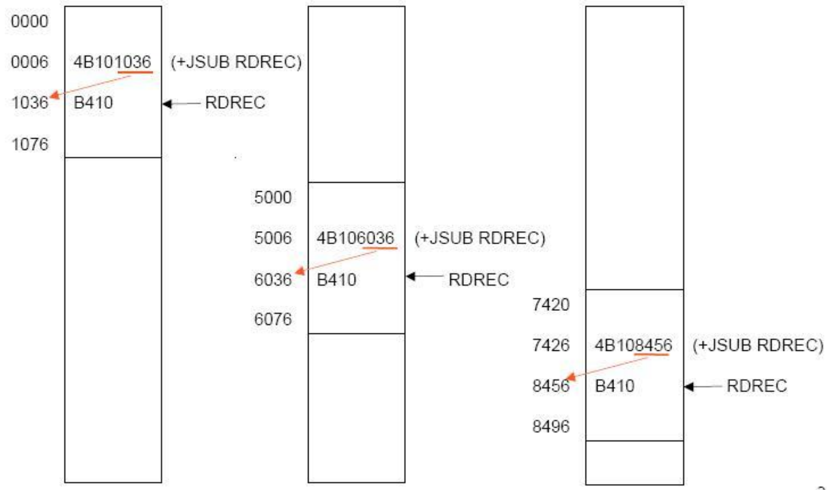
The need for program relocation

- 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:

**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.

  - o Not a memory address (immediate addressing)

  - o PC-relative, Base-relative

- From the object program, it is not possible to distinguish the address and constant.

  - o The assembler must keep some information to tell the loader.
  - o 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**

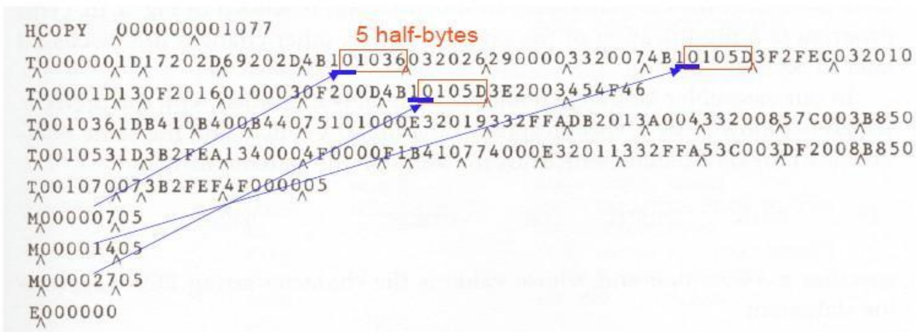
- One modification record for each address to be modified

- 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**




## 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 o BUFEND EQU *
- There may be some literals that have the same name, but different values o BASE *
  - o 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

- o Literal name
- o Operand value and length
- o 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
  - o 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
    - o 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
    - o ORG

**Example: using ORG**

- If ORG statements are used

```
STAB        RESB   1100
            ORG    STAB        <--- Set LOCCTR to STAB
SYMBOL      RESB   6
VALUE       RESW   1           <--- Size of each field
FLAGS       RESB   2
            ORG    STAB+1100   <--- 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
  - o +,-,*,/ (division is usually defined to produce an integer result) Individual terms
  - o Constants
  - o User-defined symbols
  - o 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
  - o Absolute (independent of program location) constants
  - o Relative (to the beginning of the program) Address labels
    * (value of LOCCTR)

- Expressions can be
  - Absolute
    - o Only absolute terms.
    - o 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.

- BUFEND + BUFFER
- 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

  - Program blocks

    - Segments of code that are rearranged within a single object program unit.
  - 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

| | | | | | |
|---|---|---|---|---|---|
| 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 | CDATA block |
| 0000 | 1 | RETADR | RESW | 1 | |
| 0003 | 1 | LENGTH | RESW | 1 | |
| 0000 | 2 | | USE | CBLKS | CBLKS block |
| 0000 | 2 | BUFFER | RESB | 4096 | |
| 1000 | 2 | BUFEND | EQU | * | |
| 1000 | | MAXLEN | EQU | BUFEND-BUFFER | |

(default) block

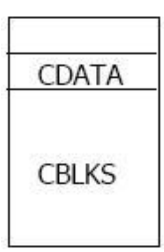
| | | | | | |
|---|---|---|---|---|---|
| 0027 | 0 | RDREC | USE | | |
| 0027 | 0 | | CLEAR | X | B410 |
| 0029 | 0 | | CLEAR | A | B400 |
| 002B | 0 | | CLEAR | S | B440 |
| 002D | 0 | | +LDT | #MAXLEN | 75101000 |
| 0031 | 0 | RLOOP | TD | INPUT | E32038 |
| 0034 | 0 | | JEQ | RLOOP | 332FFA |
| 0037 | 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 | CDATA block |
| 0006 | 1 | INPUT | BYTE | X'F1' | F1 |

(default) block

| | | | | | |
|---|---|---|---|---|---|
| 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 | CDATA block |
| | | | 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

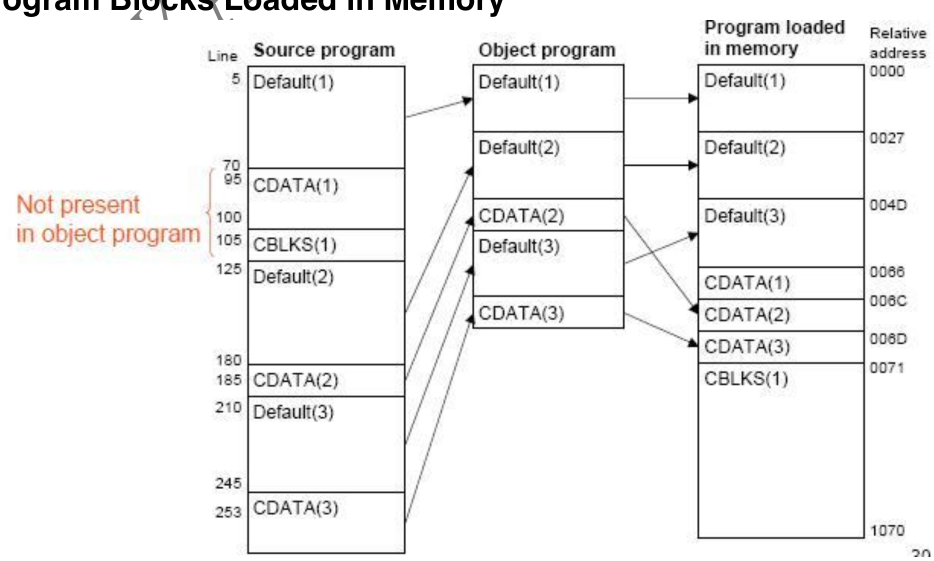
- A separate location counter for each program block
    - o Save and restore LOCCTR when switching between blocks
    - o At the beginning of a block, LOCCTR is set to 0.
- Assign each label an address relative to the start of the block
- Store the block name or number in the SYMTAB along with the assigned 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
    - o The location of the symbol relative to the start of its block
    - o 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
  - o EXTREF name [,name]
  - o EXTREF names symbols that are used in this control section and are defined elsewhere
  - o Ex: EXTREF RDREC, WRREC

- To reference an external symbol, extended format instruction is needed.

Implicitly defined as an external symbol

first control section

```
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
```

Implicitly defined as an external symbol

second control section

```
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
    - o Has no idea where RDREC is
    - o Inserts an address of zero
    - o 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
    - o inserts a value of zero
    - o 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
HCOPY  000000001033
DBUFFER000033BUFEND001033LENGTH00002D
RRDREC WRREC
T0000001D1720274B1000000320232900003320074B1000003F2FEC0320160F2016
T00001D0D0100030F200A4B1000003E2000
T00003003454F46
M00000405+RDREC
M00001105+WRREC
M00002405+WRREC
E000000
```

```
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^4F0000^05
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 ONE PASS ASSEMBLERS AND 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
  - o Generate their object code in memory for immediate execution – *load-and-go* assembler
  - o External storage for the intermediate file between two passes is slow or is inconvenient to use

- Main problem - Forward references
  - o Data items
  - o Labels on instructions

- Solution
  - o Require that all areas be defined before they are referenced.
  - o It is possible, although inconvenient, to do so for data items.
  - o Forward jump to instruction items cannot be easily eliminated.
  - o 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 |

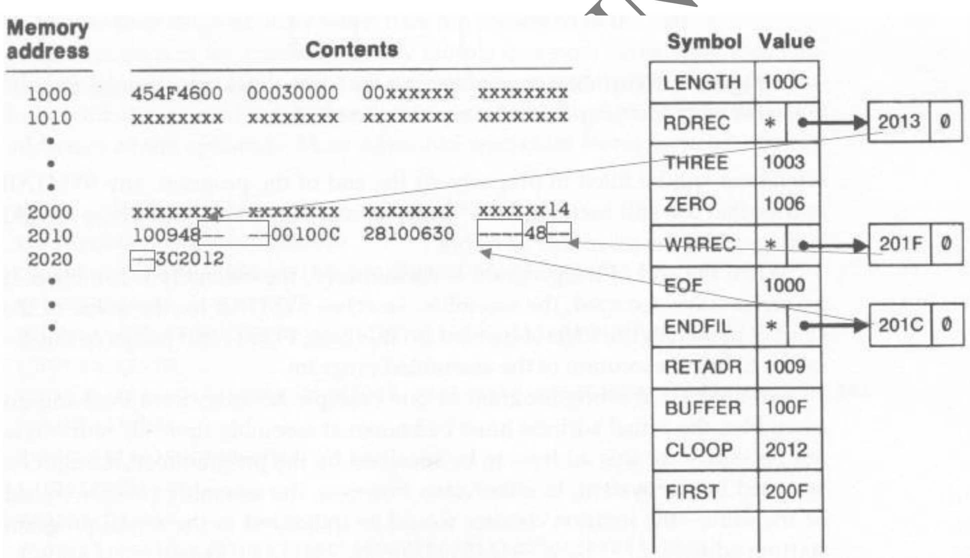
### Forward Reference in One-pass Assembler

- Omits the operand address if the symbol has not yet been defined.

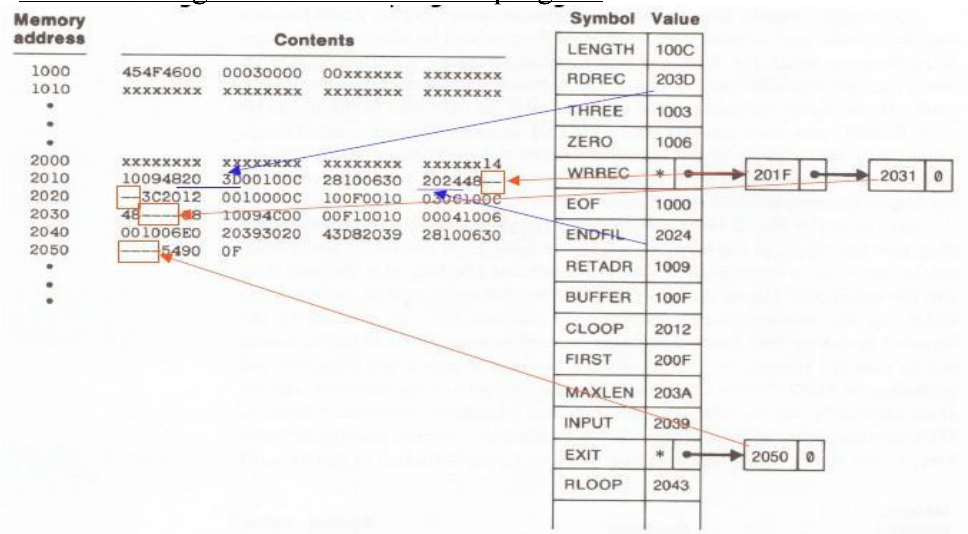
- Enters this undefined symbol into SYMTAB and indicates that it is undefined.
- Adds the address of this operand address to a list of forward references associated with the SYMTAB entry.
- When the definition for the symbol is encountered, scans the reference list and inserts the address.
- At the end 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**

<u>After scanning line 40 of the above program</u>



After scanning line 160 of the above program




**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**

```
H^COPY  ^001000^00107A
T^001000^09^454F46^000003^000000
T^00200F^15^141009^480000^00100C^281006^300000^480000^3C2012
T^00201C^02^2024
T^002024^19^001000^0C100F^001003^0C100C^480000^081009^4C0000^F1^001000
T^002013^02^203D
T^00203D^1E^041006^001006^E02039^302043^D82039^281006^300000^5490^0F^2C203A^382043
T^002050^02^205B
T^00205B^07^10100C^4C0000^05
T^00201F^02^2062
T^002031^02^2062
T^002062^18^041006^E02061^302065^50900F^DC2061^2C100C^382065^4C0000
E^00200F
```

### 2.4.2 MULTI-PASS ASSEMBLERS

**Multi Pass Assembler:**

- If we use a two-pass assembler, the following symbol definition cannot be allowed.

| | | |
|---|---|---|
| **ALPHA** | **EQU** | **BETA** |
| **BETA** | **EQU** | **DELTA** |
| **DELTA** | **RESW1** | |

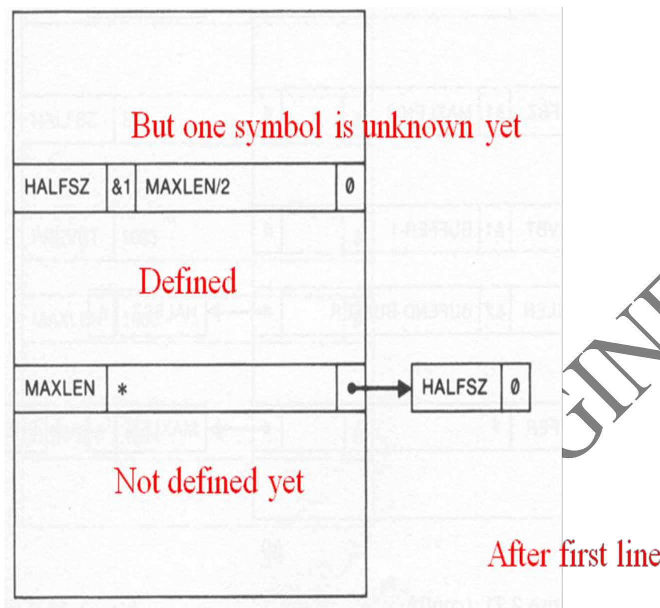
- This is because ALPHA and BETA cannot be defined in pass 1. Actually, if we allow multi-pass processing, DELTA is defined in pass 1, BETA is defined in pass 2, and ALPHA is defined in pass 3, and the above definitions can be allowed.
- This is the motivation for using a multi-pass assembler.
- It is unnecessary for a multi-pass assembler to make more than two passes over the entire program.
- Instead, only the parts of the program involving forward references need to be processed in multiple passes.
- The method presented here can be used to process any kind of forward references.

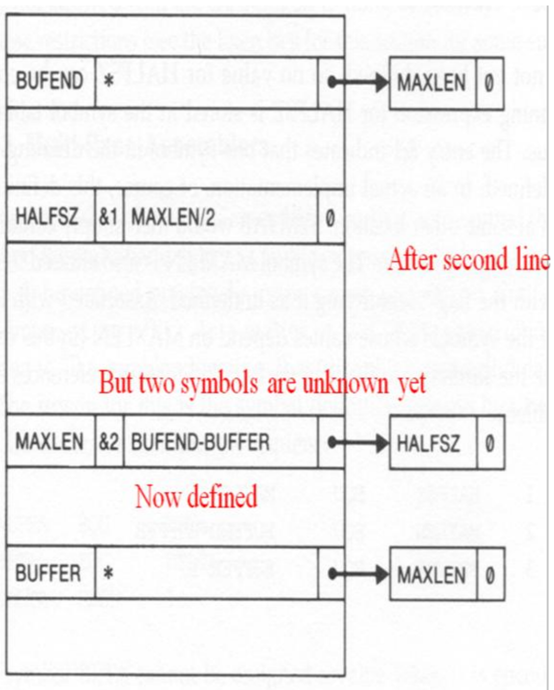
**Multi-Pass Assembler Implementation:**

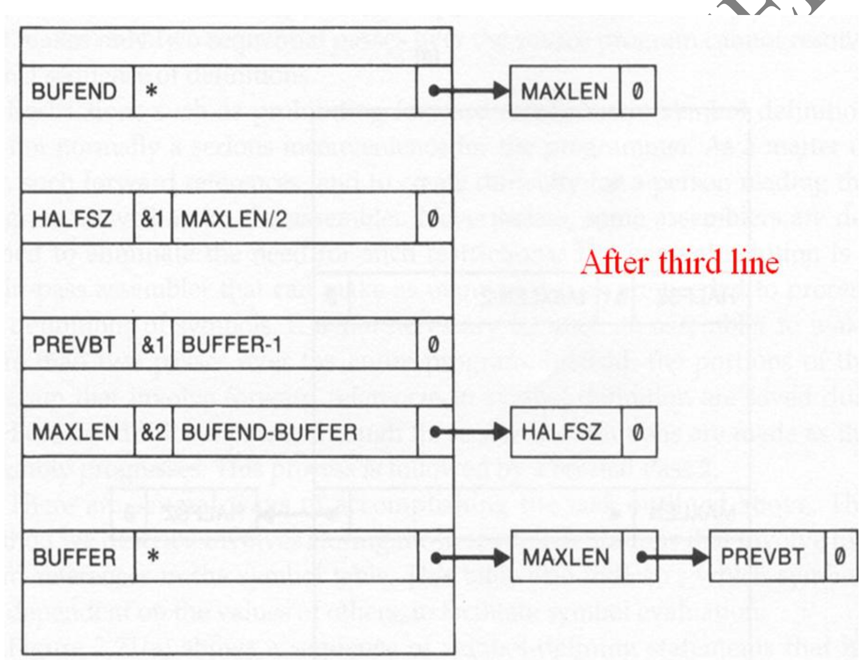
- Use a symbol table to store symbols that are not totally defined yet.
- For a undefined symbol, in its entry,
  - We store the names and the number of undefined symbols which contribute to the calculation of its value.
  - We also keep a list of symbols whose values depend on the defined value of this symbol.
- When a symbol becomes defined, we use its value to reevaluate the values of all of the symbols that are kept in this list.
- The above step is performed recursively.

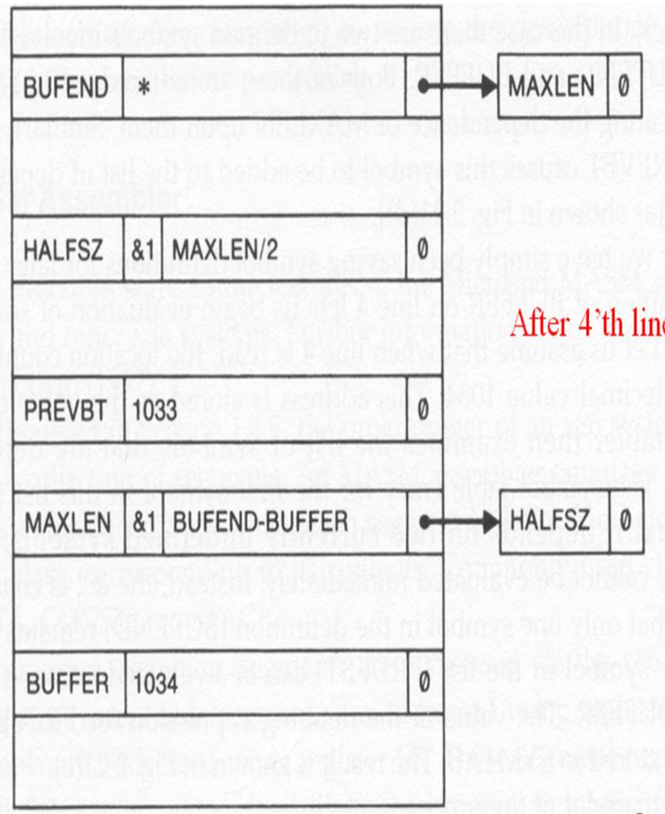
**Forward Reference Example:**

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

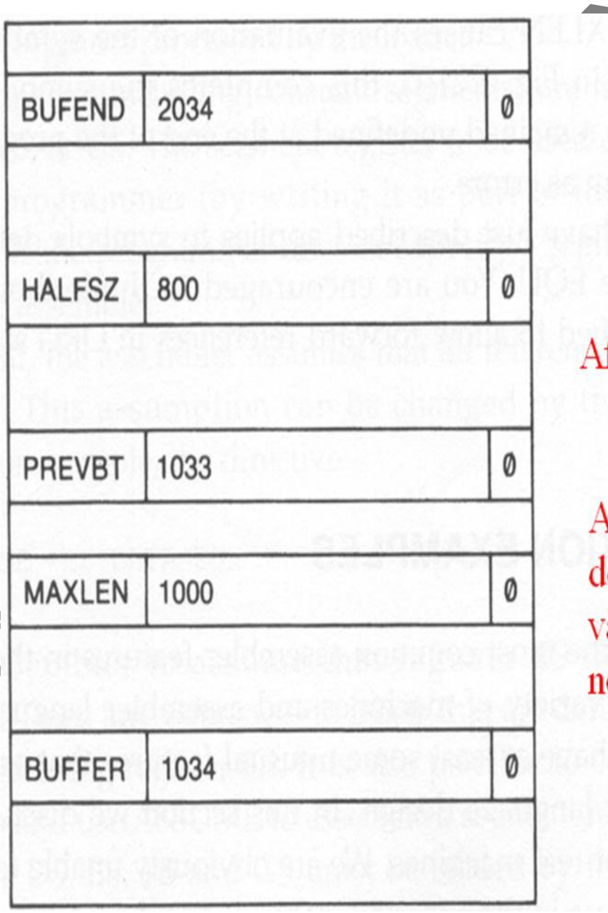



BUFEND * MAXLEN 0
HALFSZ &1 MAXLEN/2 0
After second line
But two symbols are unknown yet
MAXLEN &2 BUFEND-BUFFER HALFSZ 0
Now defined
BUFFER * MAXLEN 0


BUFEND * MAXLEN 0
HALFSZ &1 MAXLEN/2 0
After third line
PREVBT &1 BUFFER-1 0
MAXLEN &2 BUFEND-BUFFER HALFSZ 0
BUFFER * MAXLEN PREVBT 0




After 4'th line




After 5'th line

All symbols are defined and their values are known now.

**2.5 IMPLEMENTATION EXAMPLE MASM ASSEMBLER.**

- A collection of segments.
  - Each segment belongs to a specific class
    - Common classes: CODE, DATA, CONST, STACK
  - Segments are addressed by segment registers:
    - Segment registers are automatically set by loader.
    - CODE: CS,
      - is set to the segment containing the starting label specified in the END statement.
    - STACK: SS
      - Is set to the last stack segment processed by the loader.
    - DATA: DS, ES,FS,GS
      - Can be specified by programmers in their programs.
      - Otherwise, one of them is selected by assembler.
      - DS is the data segment register by default
        - » Can be changed and set by: ASSUME ES:DATASEG2
        - » Any reference to the labels defined in DATASEG2 will be assembled based on ES
      - Must be loaded by program before they can be used.
        - » MOV AX,DATASEG2
        - » MOV ES, AX
      - ASSUME is somewhat similar with BASE in SIC, programmer must provide instructions to load the value to registers.
    - Collect several segments into a group and use ASSUME to link a register with the group.
    - Parts of a segment can be separated and assembler arranges them together, like program blocks in SIC/XE
- JMP is a main specific issue:
  - Near JMP: 2 to 3 bytes, same segment, using current CS

- Far JMP: 5 bytes, different segment, using a different segment register, as the instruction prefix.
- Forward JMP: e.g., JMP TARGET,
  - Assembler does not know whether it is a near jump or far jump, so not sure how many bytes to reserve for the instruction.
  - By default, assembler assumes a forward jump is near jump. Otherwise,
  - JMP FAR PTR TARGET , indicate a jump to a different segment
    - Without FAR PTR, error will occur.
    - Similar to SIC/EX extended format instructions.
  - JMP SHORT TARGET, indicate a within-128 offset jump.

- Other situations that the length of an instruction depends on operands. So more complicate than SIC/EX
  - Must analyze operands, in addition to opcode
  - Opcode table is more complex.
- References between segments that are assembled together can be processed by assembler
- Otherwise, it must be processed by loader.
  - PUBLIC is similar to EXTDEF
  - EXTRN is similar to EXTREF
- Object programs from MASM can have different formats.
- MASM can also generate an instruction timing list.

## 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 ≠ '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**

- When a computer is first turned on or restarted, a special type of absolute loader must be executed (stored in ROM on a PC).
- The bootstrap loader loads the first program to be run by the computer – usually the operating system, from the boot disk (e.g., a hard disk or a floppy disk)
- It then jumps to the just loaded program to execute it.
- Normally, the just loaded program is very small (e.g., a disk sector's size, 512 bytes) and is a loader itself.

- The just loaded loader will continue to load another larger loader and jump to it.
- This process repeats another entire large operating system is loaded.
- The algorithm for the bootstrap loader is as follows

Begin

X=0x80 (the address of the next memory location to be loaded

Loop

A←GETC (and convert it from the ASCII character code to the value of the hexadecimal digit)

save the value in the high-order 4 bits of S

A←GETC

combine the value to form one byte A← (A+S)

store the value (in A) to the address in register X

X←X+1

End

- It uses a subroutine GETC, which is

GETC A←read one character

if A=0x04 then jump to 0x80

if A<48 then GETC

A ← A-48 (0x30)

if A<10 then return

A ←A-7 return

**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**

```
Loc     Source statement                      Object code

0000    COPY     START    0
0000    FIRST    STL      RETADR              17202D
0003             LDB      #LENGTH             69202D
                 BASE     LENGTH
0006    CLOOP    +JSUB    RDREC               4B101036
000A             LDA      LENGTH              032026
000D             COMP     #0                  290000
0010             JEQ      ENDFIL              332007
0013             +JSUB    WRREC               4B10105D
0017             J        CLOOP               3F2FEC
001A    ENDFIL   LDA      EOF                 032010
001D             STA      BUFFER              0F2016
0020             LDA      #3                  010003
0023             STA      LENGTH              0F200D
0026             +JSUB    WRREC               4B10105D
002A             J        @RETADR             3E2003
002D    EOF      BYTE     C'EOF'              454F46
0030    RETADR   RESW     1
0033    LENGTH   RESW     1
0036    BUFFER   RESB     4096
        .
        .        SUBROUTINE TO READ RECORD INTO BUFFER
        .
1036    RDREC    CLEAR    X                   B410
1038             CLEAR    A                   B400
103A             CLEAR    S                   B440
103C             +LDT     #4096               75101000
1040    RLOOP    TD       INPUT               E32019
1043             JEQ      RLOOP               332FFA
1046             RD       INPUT               DB2013
1049             COMPR    A,S                 A004
104B             JEQ      EXIT                332008
104E             STCH     BUFFER,X            57C003
1051             TIXR     T                   B850
1053             JLT      RLOOP               3B2FEA
1056    EXIT     STX      LENGTH              134000
1059             RSUB                         4F0000
105C    INPUT    BYTE     X'F1'               F1
        .
        .        SUBROUTINE TO WRITE RECORD FROM BUFFER
        .
105D    WRREC    CLEAR    X                   B410
105F             LDT      LENGTH              774000
1062    WLOOP    TD       OUTPUT              E32011
1065             JEQ      WLOOP               332FFA
1068             LDCH     BUFFER,X            53C003
106B             WD       OUTPUT              DF2008
106E             TIXR     T                   B850
1070             JLT      WLOOP               3B2FEF
1073             RSUB                         4F0000
1076    OUTPUT   BYTE     X'05'               05
                 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 |

| | | | | |
|---|---|---|---|---|
| | . | SUBROUTINE TO WRITE RECORD FROM BUFFER | | |
| | . | | | |
| 1061 | WRREC | LDX | ZERO | 040030 |
| 1064 | WLOOP | TD | OUTPUT | E01079 |
| 1067 | | JEQ | WLOOP | 301064 |
| 106A | | LDCH | BUFFER,X | 508039 |
| 106D | | WD | OUTPUT | DC1079 |
| 1070 | | TIX | LENGTH | 2C0036 |
| 1073 | | JLT | LOOP | 381064 |
| 1076 | | RSUB | | 4C0000 |
| 1079 | OUTPUT | BYTE | X'05' | 05 |
| | | 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**

```
H^COPY ^000000^00107A
T^000000^1E^FFC^140033^481039^000036^280030^300015^481061^3C0003^00002A^0C0039^00002D
T^00001E^15^E00^0C0036^481061^080033^4C0000^454F46^000003^000000
T^001039^1E^FFC^040030^000030^E0105D^30103F^D8105D^280030^301057^548039^2C105E^38103F
T^001057^0A^800^100036^4C0000^F1^001000
T^001061^19^FE0^040030^E01079^301064^508039^DC1079^2C0036^381064^4C0000^05
E^000000
```

- 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:**

```
H^PROGA ^000000^000063
D^LISTA ^000040^ENDA  ^000054
R^LISTB ^ENDB  ^LISTC ^ENDC
.
T^000020^0A^03201D^77100004^050014
.
T^000054^0F^000014^FFFFF6^00003F^000014^FFFFC0
M^000024^05^+LISTB
M^000054^06^+LISTC
M^000057^06^+ENDC
M^000057^06^-LISTC
M^00005A^06^+ENDC
M^00005A^06^-LISTC
M^00005A^06^+PROGA
M^00005D^06^-ENDB
M^00005D^06^+LISTB
M^000060^06^+LISTB
M^000060^06^-PROGA
E^000020
```

**PROGB:**

```
HPROGB 00000000007F
DLISTB 000060ENDB  000070
RLISTA ENDA  LISTC ENDC
:
T0000360B03100000772027051000000
:
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 000000000051
DLISTC 000030ENDC  000042
RLISTA ENDA  LISTB ENDB
:
T0000180C031000007710000405100000
:
T0000420F000030000008000011000000000000
M00001905+LISTA
M00001D05+LISTB
M00002105+ENDA
M00002105-LISTA
M00004206+ENDA
M00004206-LISTA
M00004206+PROGC
M00004806+LISTA
M00004B06+ENDA
M00004B06-LISTA
M00004B06-ENDB
M00004B06+LISTB
M00004E06+LISTB
M00004E06-LISTA
E
```

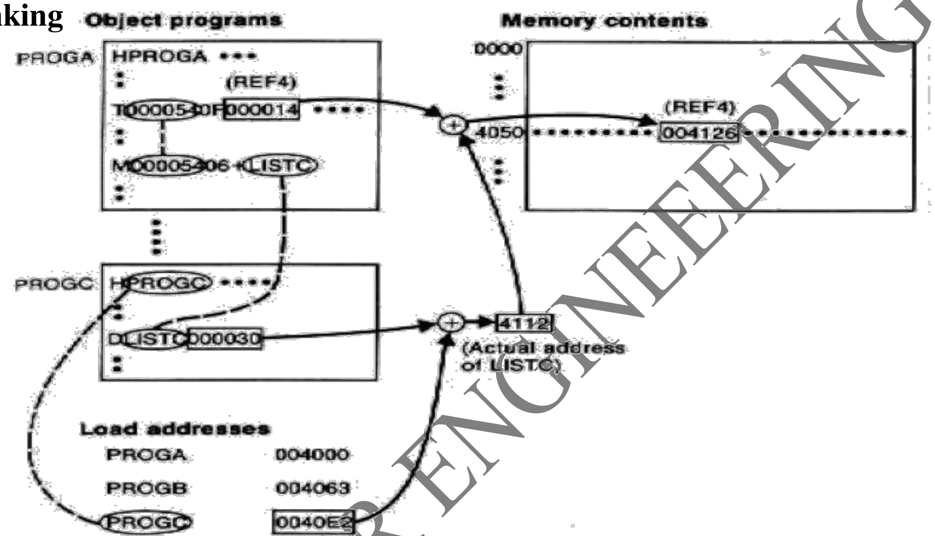
- The reference marked REF2 is processed in a similar manner.
- REF3 is an immediate operand whose value is to be the difference between ENDA and LISTA (that is, the length of the list in bytes).
- In PROGA, the assembler has all of the information necessary to compute this value. During the assembly 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 | ← PROGC |
| 4100 | 40C70510 | 0014.... | ........ | ........ | |
| 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.**
- 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.
- 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}
```

```
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
```

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

- 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.

## 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.

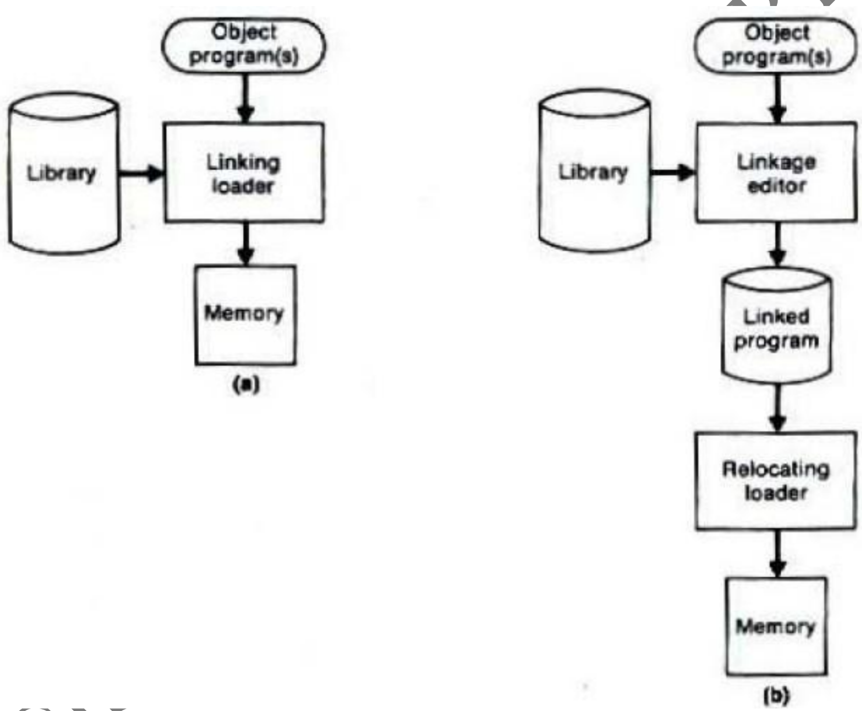
- Linkage editors can perform many useful functions besides simply preparing an object program for execution. Ex., a typical sequence of linkage editor commands used:

```
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.

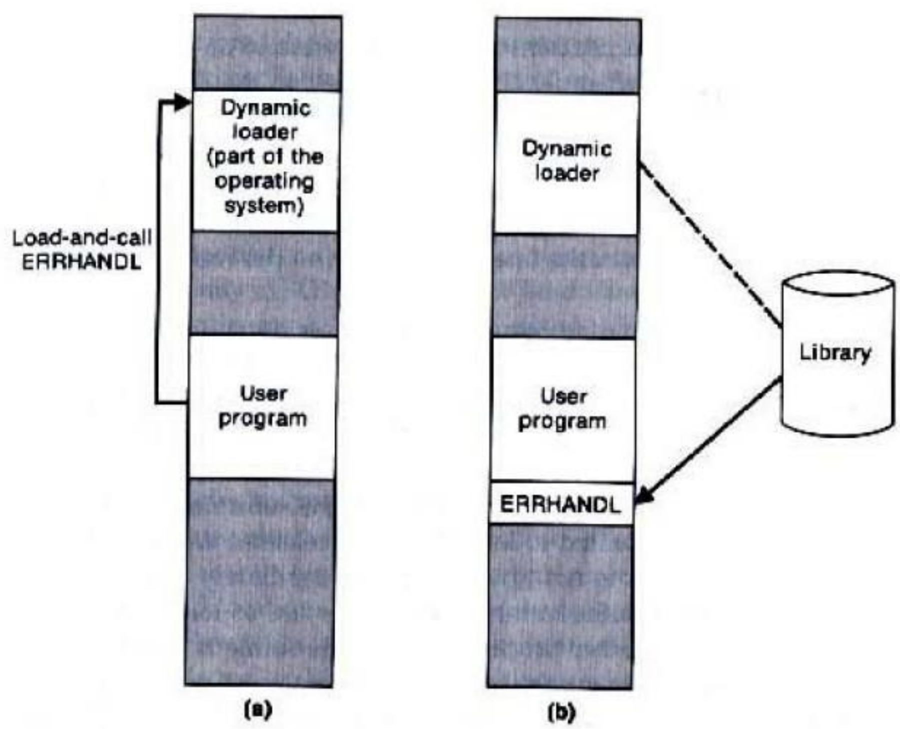
- Linkage editors often include a variety of other options and commands like those discussed for linking loaders. Compared to linking loaders, linkage editors in general tend to offer more flexibility and control.

**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.



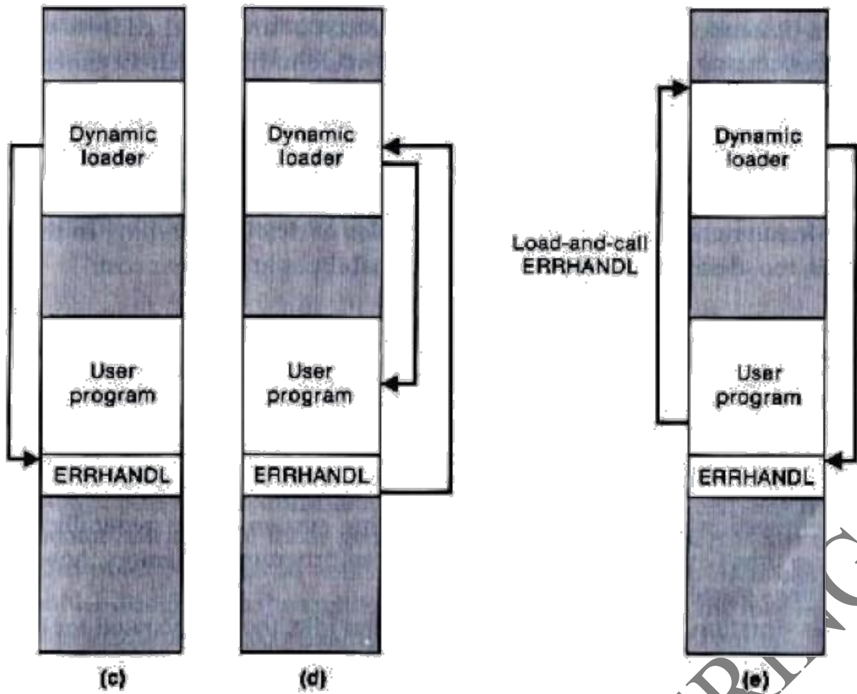



**Fig (a):** Instead of executing a JSUB instruction referring to an external symbol, the program makes a load-and-call service request to OS. The parameter of this request is the symbolic name of the routine to be called.

**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.

### 3.5 IMPLEMENTATION EXAMPLE-MSDOS LINKER

**MS-DOS Linker** This explains some of the features of Microsoft MS-DOS linker, which is a linker for Pentium and other x86 systems. Most MS-DOS compilers and assemblers (MASM) produce object modules, and they are stored in .OBJ files. MS-DOS LINK is a linkage editor that combines one or more object modules to produce a complete executable program - .EXE file; this file is later executed for results.

The following table illustrates the typical MS-DOS object module

» THEADER similar to Header record in SIC/XE

» MODEND similar to End record in SIC/XE

» TYPDEF data type

» PUBDEF similar to Define record in SIC/XE

- » EXTDEF similar to Reference record in SIC/XE
- » LNAMES contain a list of segments and class names
- » SEGDEF segment define
- » GRPDEF specify how segments are grouped
- » LEDATA similar to Text Record in SIC/XE
- » LIDATA specify repeated instructions
- » FIXUPP similar to Modification record in SIC/XE

THEADR specifies the name of the object module. MODEND specifies the end of the module. PUBDEF contains list of the external symbols (called public names). EXTDEF contains list of external symbols referred in this module, but defined elsewhere. TYPDEF the data types are defined here. SEGDEF describes segments in the object module ( includes name, length, and alignment). GRPDEF includes how segments are combined into groups. LNAMES contains all segment and class names. LEDATA contains translated instructions and data. LIDATA has above in repeating pattern. Finally, FIXUPP is used to resolve external references.

Suppose that the SIC assembler language is changed to include a new form of the RESB statement, such as

**RESB n'c'**

which reserves n bytes of memory and initializes all of these bytes to the character 'c'. For example

**BUFFER RESB 4096' '**

This feature could be implemented by simply generating the required number of bytes in Text records. However, this could lead to a large increase in the size of the object program.

**Pass 1**

- » compute a starting address for each segment in the program
  - – segment from different object modules that have the same segment name and class are combined
  - – segments with the same class, but different names are concatenated

– a segment's starting address is updated as these combinations and concatenations are performed

**Pass 2**

- » extract the translated instructions from the object modules
- » build an image of the executable program in memory
- » write it to the executable (.EXE) file

## 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

### 4.1.1 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:
  - o 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.
  - o Statements of the macro body are expanded each time the macro is invoked.
  - o 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.

```
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
```

```
        .
        .       MAIN PROGRAM
        .
FIRST   STL     RETADR            SAVE RETURN ADDRESS
CLOOP   RDBUFF  F1,BUFFER,LENGTH  READ RECORD INTO BUFFER
        LDA     LENGTH            TEST FOR END OF FILE
        COMP    #0
        JEQ     ENDFIL            EXIT IF EOF FOUND
        WRBUFF  05,BUFFER,LENGTH  WRITE OUTPUT RECORD
        J       CLOOP             LOOP
ENDFIL  WRBUFF  05,EOF,THREE      INSERT EOF MARKER
        J       @RETADR
EOF     BYTE    C'EOF'
THREE   WORD    3
RETADR  RESW    1
LENGTH  RESW    1                 LENGTH OF RECORD
BUFFER  RESB    4096              4096-BYTE BUFFER AREA
        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.
  - o 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.

<u>Example of a macro expansion</u>

- 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.

### 4.1.2 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.

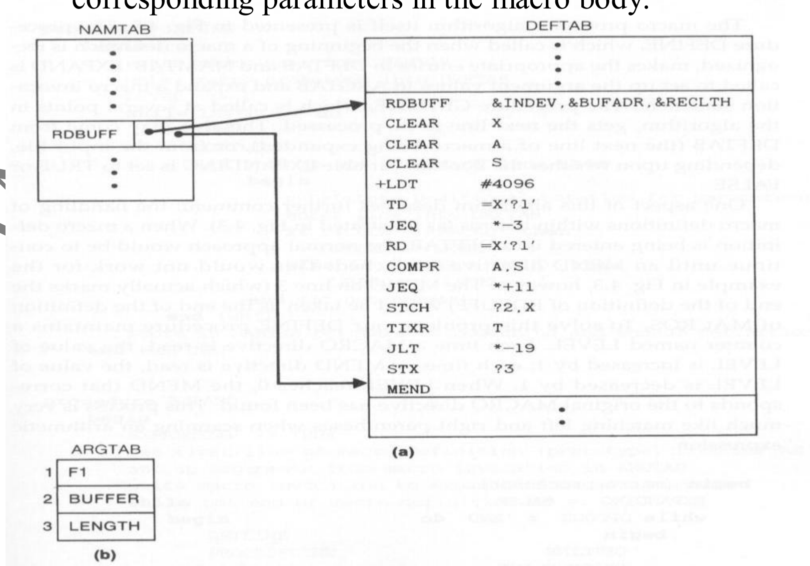
2. For each macro instruction defined, NAMTAB contains pointers to beginning and end of definition in DEFTAB.

**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.



- 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.

```
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,…
  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
- Let the programmer use label in the macro body
- Labels used within the macro body begin with $.
- 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**

```
RDBUFF  MACRO   &INDEV,&BUFADR,&RECLTH
        CLEAR   X               CLEAR LOOP COUNTER
        CLEAR   A
        CLEAR   S
       +LDT     #4096           SET MAXIMUM RECORD LENGTH
$LOOP   TD      =X'&INDEV'      TEST INPUT DEVICE
        JEQ     $LOOP           LOOP UNTIL READY
        RD      =X'&INDEV'      READ CHARACTER INTO REG A
        COMPR   A,S             TEST FOR END OF RECORD
        JEQ     $EXIT           EXIT LOOP IF EOR
        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
```

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

**Macro expansion**

```
.               RDBUFF   F1,BUFFER,LENGTH

                CLEAR    X              CLEAR LOOP COUNTER
                CLEAR    A
                CLEAR    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
```

- 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:
  - o Substitute the parameters in the macro body without changing the sequence of statements expanded.
  - o 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.

```
25  RDBUFF   MACRO   &INDEV=F1,&BUFADR=,&RECLTH=,&EOR=04,&MAXLTH=4096
26           IF      (&EOR NE '')
27  &EORCK   SET     1
28           ENDIF
30           CLEAR   X               CLEAR LOOP COUNTER
35           CLEAR   A
38           IF      (&EORCK EQ 1)
40           LDCH    =X'&EOR'        SET EOR CHARACTER
42           RMO     A,S
43           ENDIF
47          +LDT     #&MAXLTH        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
63           IF      (&EORCK EQ 1)
65           COMPR   A,S             TEST FOR END OF RECORD
70           JEQ     $EXIT           EXIT LOOP IF EOR
73           ENDIF
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
```

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

```
30             CLEAR   X             CLEAR LOOP COUNTER
35             CLEAR   A
40             LDCH    =X'04'        SET EOR CHARACTER
42             RMO     A,S
47            +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
```

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

**Macro within macro**

It allows the definition of macro statements inside the assembly language program or macro.

## 4.3. MACROPROCESSOR DESIGN OPTIONS

### 4.3.1 Recursive Macro Expansion

```
RDBUFF  MACRO   &BUFADR,&RECLTH,&INDEV
.
.       MACRO TO READ RECORD INTO BUFFER
.
        CLEAR   X           CLEAR LOOP COUNTER
        CLEAR   A
        CLEAR   S
       +LDT     #4096       SET MAXIMUM RECORD LENGTH
$LOOP   RDCHAR  &INDEV      READ CHARACTER INTO REG A
        COMPR   A,S         TEST FOR END OF RECORD
        JEQ     $EXIT       EXIT LOOP IF EOR
        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
```

```
RDCHAR  MACRO   &IN
.
.       MACRO TO READ CHARACTER INTO REGISTER A
.
        TD      =X'&IN'     TEST INPUT DEVICE
        JEQ      *-3        LOOP UNTIL READY
        RD      =X'&IN'     READ CHARACTER
        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:
    - The procedure EXPAND would be called recursively, thus the invocation arguments in the ARGTAB will be overwritten.
    - 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.
    - A similar problem would occur with PROCESSLINE since this procedure too would be called recursively.
- Solutions:
    - Write the macro processor in a programming language that allows recursive calls, thus local variables will be retained.
    - 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**

o Process macrodefinitions.
o Expandmacroinvocations.
o 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**

o Used as a sort of input routine for the assembler or compiler. o Read source program.
o Process macro definitions and expand macro invocations. o 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.
    - o Scanning input lines
    - o Searching tables
    - o 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.

## 4.4 IMPLEMENTATION EXAMPLE

### 4.4.1 MASM Macro Processor

- Conditional assembly statements
- MASM macro
- Conditional statements

### 4.4.2 ANSI C Macro language

- Macro definitions with parenthesis
- Nested macro invocation.
- Macro expansion with parenthesis
- Conditional compilation statements

## TUTORIAL – I:

**Topic: SIC, SIC / XE: Data Movement Operation**

1. **Write a sequence of instructions to store the data value 8 in the memory location ALPHA (for SIC and SIC/XE)**

**SIC:**

```
        LDA     EIGHT
        STA     ALPHA
        …..
ALPHA           RESW    1
EIGHT           WORD    8
```

**SIC/XE:**

```
        LDA     #8
        STA     ALPHA
        …..
        ALPHA   RESW    1
```

2. **Write a sequence of instructions to store the character "A" in the memory location BETA (for SIC and SIC/XE)**

**SIC:**

```
        LDCH    CHAR A
        STCH    BETA
        …..
CHARA   BYTE    'A'
BETA    RESB    1
```

**SIC/XE:**

```
        LDA     #65
        STCH    BETA
        …..
BETA    RESB    1
```

3. **Write a sequence of instructions to store the data value 2 and character X in the memory location (for SIC and SIC/XE)**

**SIC:**

```
        LDA     TWO      Load 2 into A
        STA     ALPHA    Store in ALPHA
        LDCH    CHARX    Load character 'X' into A
        STCH    C1       Store in C1
        .
        .
ALPHA   RESW    1        one word variable
TWO     WORD    2        one word constant
CHARX   BYTE    'X'      one byte constant
C1      RESB    1        one byte variable
```

**SIC/XE**

```
        LDA     #2       Load 2into A
        STA     ALPHA    Store in ALPHA
        LDCH    #88      Load character 'X' into A
        STCH    C1       Store in C1
        .
        .
ALPHA   RESW    1        one word variable
C1      RESB    1        one byte variable
```

## TUTORIAL – II:

**Topic: SIC , SIC / XE : Arithmetic operation**

1. **Write a sequence of instructions for SIC to ALPHA equal to the product of BETA and GAMMA. Assume that ALPHA, BETA and GAMMA are defined as one word**

   **Assembly Code:**

```
LDA     BETA
MUL     GAMMA
STA     ALPHA
….

ALPHA   RESW 1
BETA    RESW 1
GAMMA   RESW 1
```

2. **Write a sequence of instructions for SIC/XE to set ALPHA equal to 4 * BETA – 9. Assume that ALPHA and BETA are defined as one word. Use immediate addressing for the constants.**

   **Assembly Code**

```
LDA     BETA
LDS     #4
MULR    S,A
SUB     #9
STA     ALPHA
…..

ALPHA   RESW 1
BETA    RESW 1
```

3. **Write a sequence of instructions for SIC to set ALPHA equal to the integer portion of BETA ÷ GAMMA. Assume that ALPHA and BETA are defined as one word.**

**Assembly Code:**

```
LDA       BETA
DIV       GAMMA
STA       ALPHA
….
ALPHA     RESW    1
BETA      RESW    1
GAMMA  RESW    1
```

4. **Write a sequence of instructions for SIC/XE to divide BETA by GAMMA, setting ALPHA to the integer portion of the quotient and DELTA to the remainder. Use register-to-register instructions to make the calculation as efficient as possible.**

**Assembly Code:**

```
LDA       BETA
LDS       GAMMA
DIVR      S, A
STA       ALPHA
MULR      S, A
LDS       BETA
SUBR      A, S
STS       DELTA
:
:
ALPHA     RESW    1
BETA      RESW    1
GAMMA     RESW    1
DELTA     RESW    1
```

## TUTORIAL – III:

**Topic: SIC Looping, Indexing**

1. **Suppose that ALPHA is an array of 100 words, which is defined as 100 words. Write a sequence of instructions for SIC to set all 100 elements of the array to 0.**

**Assembly Code:**

```
            LDA     ZERO
            STA     INDEX
LOOP        LDX     INDEX
            LDA     ZERO
            STA     ALPHA, X
            LDA     INDEX
            ADD     THREE
            STA     INDEX
            COMP    K300
            TIX     TWENTY
            JLT     LOOP
            ….
INDEX       RESW    1
ALPHA       RESW    100
….
ZERO        WORD    0
K300        WORD    100
THREE       WORD    3
```

2. **Write SIC instructions to swap the values of ALPHA and BETA.**

**Assembly Code:**

```
        LDA     ALPHA
        STA     GAMMA
        LDA     BETA
        STA     ALPHA
        LDA     GAMMA
        STA     BETA
        ….
ALPHA   RESW    1
BETA RESW    1
GAMMA   RESW    1
```

## TUTORIAL – IV:

**Topic: SIC / XE Looping**

1. **Write a sequence of instructions for SIC/XE to clear a 20-byte string to all blanks.**

   **Assembly Code:**

```
LDX       ZERO
LOOP      LDCH BLANK
STCH      STR1,X
TIX       TWENTY
JLT       LOOP
:
:
STR1           RESW      20
BLANK          BYTE      C     ' '
ZERO           WORD      0
TWENTY WORD          20
```

2. **Write a sequence of instructions for SIC/XE to clear a 20-byte string to all blanks. Use immediate addressing and register-to-register instructions to make the process as efficient as possible.**

   **Assembly Code:**

```
LDT        #20
LDX       #0
LOOP      LDCH #0
STCH      STR1,X
TIXR      T
JLT       LOOP
:
:
STR1      RESW       20
```

## TUTORIAL – V:

**Topic: SIC / XE Indexing**

1. **Suppose that ALPHA is an array of 100 words, (Alpha is 100 word). Write a sequence of instructions for SIC/XE to set all 100 elements of the array to 0. Use immediate addressing and register-to-register instructions to make the process as efficient as possible.**

**Assembly Code:**

```
            LDS         #3
            LDT         #300
            LDX         #0
LOOP        LDA         #0
            STA         ALPHA, X
            ADDR        S, X
            COMPR       X, T
            JLT         LOOP
            ….

ALPHA       RESW        100\
```

2. **Suppose that ALPHA and BETA are the two arrays of 100 words. Another array of GAMMA elements are obtained by multiplying the corresponding ALPHA element by 4 and adding the corresponding BETA elements.**

**Assembly Code:**

```
                    LDS         #3
                    LDT         #300
                    LDX         #0
ADDLOOP             LDA         ALPHA, X
                    MUL         #4
                    ADD         BETA, X
                    STA         GAMMA, X
                    ADDR        S, X
```

```
            COMPR   X, T
            JLT     ADDLOOP
            ….
ALPHA       RESW    100
BETA        RESW    100
GAMMA       RESW    100
```

3. **Suppose that ALPHA is an array of 100 words. Write a sequence of instructions for SIC/XE to find the maximum element in the array and store results in MAX.**

**Assembly Code:**

```
            LDS     #3
            LDT     #300
            LDX     #0
CLOOP       LDA     ALPHA, X
            COMP    MAX
            JLT     NOCH
            STA     MAX
NOCH        ADDR S, X
            COMPR   X, T
            JLT     CLOOP
            ….
ALPHA       RESW    100
MAX         WORD    -32768
```

# TUTORIAL – VI:

**Topic: SIC, SIC / XE : I/O Programming**

1. **Suppose that RECORD contains a 100-byte record. Write a subroutine for SIC that will write this record on to device 05.**

   **Assembly Code:**

```
                JSUB    WRREC
                :
                :
WRREC           LDX     ZERO
WLOOP           TD      OUTPUT
                JEQ     WLOOP
                LDCH    RECORD, X
                WD      OUTPUT
                TIX     LENGTH
                JLT     WLOOP
                RSUB
                :
                :
ZERO            WORD    0
LENGTH          WORD    1
OUTPUT          BYTE    X '05'
RECORD          RESB    100
```

2. **Write a subroutine for SIC/XE that will read a record into a buffer. The record may be any length from 1 to 100 bytes. The end of record is marked with a "null" character (ASCII code 00). The subroutine should place the length of the record read into a variable named LENGTH. Use immediate addressing and register-to-register instructions to make the process as efficient as possible.**

**Assembly Code:**

```
                JSUB   RDREC
                :
```

```
                :
RDREC           LDX       #0
                LDT       #100
                LDS       #0
RLOOP           TD        INDEV
                JEQ       RLOOP
                RD        INDEV
                COMPR     A, S
                JEQ       EXIT
                STCH      BUFFER, X
                TIXR      T
                JLT       RLOOP
EXIT            STX       LENGTH
                RSUB
                :
                :
INDEV           BYTE      X 'F1'
LENGTH          RESW      1
BUFFER          RESB      100
```

# TUTORIAL – VII:

**Topic: Object Code Translation**

1. **Obtain the object code for the instructions in the following lines in the program sequence:**
   - ✓ **Line 10**
   - ✓ **Line 12**
   - ✓ **Line 15**
   - ✓ **Line 40**
   - ✓ **Line 55**

| | | | | | |
|---|---|---|---|---|---|
| 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 | |

Format 3

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| op(6) | n | i | x | b | p | e | disp(12) |

Format 4

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| op(6) | n | i | x | b | p | e | address(20) |

- Line 10: STL=14, n=1, i=1→ni=3, op+ni=14+3=17, RETADR=0030, x=0, b=0, p=1, e=0→xbpe=2, PC=0003, disp=RETADR-PC=030-003=02D, xbpe+disp=202D, obj=17202D

- Line 12: LDB=68, n=0, i=1→ni=1, op+ni=68+1=69, LENGTH=0033, x=0, b=0, p=1, e=0→xbpe=2, PC=0006, disp=LENGTH-PC=033-006=02D, xbpe+disp=202D, obj=69202D
- Line 15: JSUB=48, n=1, i=1→ni=3, op+ni=48+3=4B, RDREC=01036, x=0, b=0, p=0, e=1, xbpe=1, xbpe+RDREC=101036, obj=4B101036
- Line 40: J=3C, n=1, i=1→ni=3, op+ni=3C+3=3F, CLOOP=0006, x=0, b=0, p=1, e=0→xbpe=2, PC=001A, disp=CLOOP-PC=0006-001A=-14=FEC(2's complement), xbpe+disp=2FEC, obj=3F2FEC
- Line 55: LDA=00, n=0, i=1→ni=1, op+ni=00+1=01, disp=#3→003, x=0, b=0, p=0, e=0→xbpe=0, xbpe+disp=0003, obj=010003

**2. Obtain the object code for the instructions in the following lines in the program sequence:**

- ✓ Line 125
- ✓ Line 133
- ✓ Line 160

```
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                .
```

| op(8) | r1(4) | r2(4) |
|---|---|---|
| | | |

- Line 125: CLEAR=B4, r1=X=1, r2=0, obj=B410
- Line 133: LDT=74, n=0, i=1→ni=1, op+ni=74+1=75, x=0, b=0, p=0, e=1→xbpe=1, #4096=01000, xbpe+address=101000, obj=75101000
- Line 160: STCH=54, n=1, i=1→ni=3, op+ni=54+3=57, BUFFER=0036, B=0033, disp=BUFFER-B=003, x=1, b=1, p=0, e=0→xbpe=C, xbpe+disp=C003, obj=57C003

## TUTORIAL – VIII:

**Topic: Object Code generation for SIC program**

**1. Generate the object code for the following SIC source program.**

| | | |
|---|---|---|
| SUM | START | 1000 |
| FIRST | LDX | ZERO |
| | LDA | ZERO |
| LOOP | ADD | TABLE,X |
| | TLX | COUNT |
| | JLT | LOOP |
| | STA | TOTAL |
| | RSUB | |
| TABLE | RESW | 2328 |
| COUNT | RESW | 1 |
| ZERO | WORD | 0 |
| TOTAL | RESW | 1 |
| END | FIRST | |

| LABEL | OPERATION | OPERAND | OPCODE |
|---|---|---|---|
| SUM | START | 1000 | |
| FIRST | LDX | ZERO | 04 3340 |
| LDA | ZERO | | 00 3340 |
| LOOP | ADD | TABLE,X | 18 9015 |
| TLX | COUNT | | 2C 333D |

| | | | |
|---|---|---|---|
| JLT | LOOP | | 38 1006 |
| STA | TOTAL | | 0C 3343 |
| RSUB | | | 4C 0000 |
| TABLE | RESW | 2328 | |
| COUNT | RESW | 1 | |
| ZERO | WORD | 0 | 000000 |
| TOTAL | RESW | 1 | |
| END | FIRST | | |

3000*3=9000

IN DECIMAL

# TUTORIAL – IX:

**Topic: Object Code generation for SIC / XE program**

**1. Generate the object code for the following SIC / XE source program.**

| | | |
|---|---|---|
| SUM | START | 0 |
| FIRST | LDX | #0 |
| | LDA | #0 |
| | +LDB | #TABLE 32 |
| LOOP | ADD | TABLE,X |
| | ADD | TABLE2,X |
| | TLX | COUNT |
| | JLT | LOOP |
| | +STA | TOTAL |
| | STA | @TOTAL |
| | RSUB | |
| COUNT | RESW | 1 |
| TABLE | RESW | 2328 |
| TABLE2 | RESW | 2328 |
| TOTAL | RESW | 1 |
| | END FIRST | |

| LABEL | OPERATION | OPERAND | OPCODE |
|---|---|---|---|
| SUM | START | 0 | |
| FIRST | LDX | #0 | 04 050000 |

```
            LDA       #0           00 010000
            +LDB      #TABLE 32    68 69
     10234B
LOOP        ADD       TABLE,X      18 113AO
16
            ADD       TABLE2,X     18
     1BCOOO
            TLX       COUNT        2C
     217200D
            JLT       LOOP         38 3B2FF4
            +STA      TOTAL        OC
     OF104673
            STA       @TOTAL       WOR
            RSUB                   4C
     4FOO00
COUNT       RESW      1
TABLE       RESW      2328
TABLE2      RESW      2328
TOTAL       RESW      1
END         FIRST
```

## TUTORIAL – X:

**Topic: Loader**

**1. What is the difference between given set of codes?**

**SET – I**

```
        LDA       LENGTH

        SUB       #1
```

**SET – II**

```
        LDA       LENGTH-1

0033    LENGTH    WORD
```

**If length is defined by address 0033 with the value 5. The result of the given statement is:**

a. A is loaded with value 5 and subtracted by 1, thus giving the result 4.

b. A is loaded with value defined in location 0032

2. **Find the object code for the program that has to be loaded into the memory.**

| LOCATION | SOURCE STATEMENT |
|---|---|
| 0000 | COPY START 0000 |
| 0000 | FIRST STL RETADR |
| 0003 | LDB #LENGTH |
| - | BASE LENGTH |
| 0006 | CLOOP +JSUB RDREC |
| 000A | LDA LENGTH |
| 000D | COMP #0 |
| 0010 | JEQ ENDFIL |

| | |
|---|---|
| 0013 | +JSUB WRREC |
| 0017 | J CLOOP |
| 001A | ENDFIL LDA =C'EOF' |
| - | LTORG |
| 0020 | STA BUFFER,X |
| 0023 | LDA #3 |
| 0026 | STA LENGTH |
| 0029 | RETADR RESW 1 |
| 002C | LENGTH RESW 1 |
| 002F | BUFFER RESB 4096 |
| - | END FIRST |

**Solution:**

| LOCATION | SOURCE STATEMENT | OBJECT CODE |
|---|---|---|
| 0000 | COPY START 0000 | - |
| 0000 | FIRST STL RETADR | 172026 |
| 0003 | LDB #LENGTH | 692026 |
| - | BASE LENGTH | - |
| 0006 | CLOOP +JSUB RDREC | 4B5100A |
| 000A | LDA LENGTH | 03201F |
| 000D | COMP #0 | 290000 |
| 0010 | JEQ ENDFIL | 332007 |
| 0013 | +JSUB WRREC | 4B51031 |
| 0017 | J CLOOP | 3F2FEC |
| 001A | ENDFIL LDA =C'EOF' | 032003 |
| - | LTORG | - |
| 0020 | STA BUFFER,X | 0FC003 |
| 0023 | LDA #3 | 030003 |
| 0026 | STA LENGTH | 0F2003 |
| 0029 | RETADR RESW 1 | - |
| 002C | LENGTH RESW 1 | - |
| 002F | BUFFER RESB 4096 | - |
| - | END FIRST | - |

<u>**TUTORIAL – XI:**</u>

**Topic: Loader**

1. **Write a sequence of instructions for SIC/XE to divide BETA by GAMMA, setting ALPHA to the value of the quotient, rounded to the nearest integer. Use register-to-register instructions to make the calculation as efficient as possible**

```
        LDF     BETA
        DIVF    GAMMA
        FIX
        STA     ALPHA
        ….
ALPHA   RESW    1
BETA    RESW    1
GAMMA   RESW    1
```

2. **Write a subroutine for SIC that will read a record into a buffer. The record may be any length from 1 to 100 bytes. The end of record is marked with a "null" character (ASCII code 00). The subroutine should place the length of the record read into a variable named LENGTH.**

```
        JSUB    RDREC
        ….
RDREC   LDX     ZERO
RLOOP   TD      INDEV
        JEQ     RLOOP
        RD      INDEV
        COMP    NULL
        JEQ     EXIT
        STCH    BUFFER, X
        TIX     K100
        JLT     RLOOP
EXIT    STX     LENGTH
        RSUB
….
ZERO    WORD    0
NULL    WORD    0
K100    WORD    1
```

```
INDEV      BYTE      X 'F1'
LENGTH     RESW       1
BUFFER     RESB      100
```

## TUTORIAL – XII:

**Topic: Loader**

1. **Write a subroutine for SIC/XE that will read a record into a buffer. The record may be any length from 1 to 100 bytes. The end of record is marked with a "null" character (ASCII code 00). The subroutine should place the length of the record read into a variable named LENGTH. Use immediate addressing and register-to-register instructions to make the process as efficient as possible.**

```
            JSUB        RDREC
            ….

RDREC       LDX         #0
            LDT         #100
            LDS         #0
RLOOP       TD          INDEV
            JEQ         RLOOP
            RD          INDEV
            COMPR       A, S
            JEQ         EXIT
            STCH        BUFFER, X
            TIXR        T
            JLT         RLOOP
EXIR        STX         LENGTH
            RSUB
….
INDEV       BYTE        X 'F1'
LENGTH      RESW        1
BUFFER      RESB        100
```

2. **Generate the object code given for loading during load time**

**SIC/XE program**

```
EXAMPLE         START       100

                LDA         #12         LOAD 12 INTO REG A

                ADD         #7          ADD 7 TO REG A
```

| | | | |
|---|---|---|---|
| | J | STORE | STORE A IN MEMORY |
| SAVA | RESW | 10 | |
| STORE | STA | SAVA | |
| | RSUB | RETURN | |
| | END | EXAMPLE | |

**The object code is as follows:**

| Loc | code | | | |
|---|---|---|---|---|
| | | EXAMPLE | START | 100 |
| **0100** | **01000C** | | LDA | #12 |
| **0103** | **190007** | | ADD | #7 |
| **0106** | **0F2003** | | J | STORE |
| **0109** | | SAVA | RESW | 10 |
| **0127** | **0F2FDF** | STORE | STA | SAVA |
| **012A** | **4F0000** | RSUB | | |
| | | END | EXAMPLE | |

## TUTORIAL – XIII:

**Topic: Macro processor**

1. **Give the parameter table content when the macro given below is executed.**

*Source program* *Macro definition*

```
…                          ALPHA      MACRO  ARG1, ARG2, ARG3
ALPHA     A, 2, C
…                                     …
                                      ENDM
```

**Parameter table**

| Dummy parameter | Real parameter |
|---|---|
| ARG1 | A |
| ARG2 | 2 |
| ARG3 | C |

2. **Write a macro to add two integer numbers using SIC instruction set.**

```
SUM    MACRO    ALPHA, BETA
       LDA      ALPHA
       ADD      BETA
```

3. **Suppose we have the macro definition of ABSDIFF as**

   #define ABSDIFF(X,Y) X > Y ? X - Y : Y - X

   #define DISPLAY(EXPR) printf(#EXPR "= %d\n", EXPR)

   **Expand the macro invocation**

   a. DISPLAY( ABSDIFF(3-1, 9+3) );

   b. If we execute the C program containing this statement, what output will be produced?

   **Solution:**

   a. printf("ABSDIFF(3-1, 9+3)" "= %d\n", 3-1 > 9+3 ? 3-1 - 9+3 : 9+3 - 3-1);
   b. ABSDIFF(3-1, 9+3)= 8

4. **Refer to the definition of RDBUFF that appears below. Each of the following macro invocation statements contains an error. Which of these errors would be detected by the macro processor, and which would be detected by the assembler?**
   a. **RDBUFF F3, BUF, RECL, ZZ**
      i. **{ illegal value specified for &EOR }**
   b. **RDBUFF F3, BUF, RECL, 04, 2048, 01**
      i. **{ too many arguments }**
   c. **RDBUFF F3, ,RECL, 04**
      i. **{ no value specified for &BUFADR }**
   d. **RDBUFF F3, RECL, BUF**
      i. **{ arguments specified in wrong order }**

```
25   RDBUFF   MACRO   &INDEV,&BUFADR,&RECLTH,&EOR,&MAXLTH
26            IF      (&EOR NE '')
27   &EORCK   SET     1
28            ENDIF
30            CLEAR   X                 CLEAR LOOP COUNTER
35            CLEAR   A
38            IF      (&EORCK EQ 1)
40            LDCH    =X'&EOR'          SET EOR CHARACTER
42            RMO     A,S
43            ENDIF
44            IF      (&MAXLTH EQ '')
45           +LDT     #4096             SET MAX LENGTH = 4096
46            ELSE
47           +LDT     #&MAXLTH          SET MAXIMUM RECORD LENGTH
48            ENDIF
50   $LOOP    TD      =X'&INDEV'        TEST INPUT DEVICE
55            JEQ     $LOOP             LOOP UNTIL READY
60            RD      =X'&INDEV'        READ CHARACTER INTO REG A
63            IF      (&EORCK EQ 1)
65            COMPR   A,S               TEST FOR END OF RECORD
70            JEQ     $EXIT             EXIT LOOP IF EOR
73            ENDIF
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
```

(a)

**Solution:**

1. Assembler will complain that the value is not a legal hexidecimal number.
2. Macro processor will detect that there are too many arguments.
3. Assembler will complain about a syntax error on line 75 "STCH ,X". Note that a macro processor simply replaces "&BUBADR" with an empty string. See the example in Figure above.
4. None: Synax is correct, but there will be a run-time error.

## TUTORIAL – XIV:

**Topic: Macro processor**

**1. Write a macro to multiply two one-byte fields.**

```
MPYBYTE    MACRO      BYTE1,BYTES,PRODUCTER1
                                          ;Define Macro to multiply two
                                          one-           byte fields
           MOV  AL,BYTE1                  ;Move multiplicand into AL
           MUL  BYTES                     ;Product is stored in AX
           MOV  PRODUCTER1,AX             ;Stores the resulting product in
product
           ENDM                           ;End of Macro
```

**2. Write a macro to multiply two one-word fields.**

```
MPYWORD    MACRO      WORD1,WORD2,PRODUCT,PRODUCT
                                 ;Define Macro to multiply two one-word
                             fields
           MOV  AX,WORD1         ;Move the multiplicand into AX
           MUL  WORD2            ;Product is stored in DX:AX
           MOV  PRODUCT,AX       ;Store product upper half AX
           MOV  PRODUCT+2,DX     ;lower half DX
           ENDM                  ;End of Macro
```

## TUTORIAL – XV:

**Topic: Macro processor**

**1. Write a macro to display a string of characters**

```
PUTCHAR      MACRO      CHAR        ;CHAR IS THE
ARGUMENT
             MOV        AH,2
             MOV        DL,CHAR
             INT        21H
             ENDM
DISPLAYSTR   MACRO      STR, LNG    ;ARGUMENTS ARE
OFFSET AND
                                    ; LENGTH OF STRING TO
                                    BE DISPLAYED
             LOCAL      TOP
             MOV        SI,0     ;INDEX OF NEXT CHARACTER IN
                              STRING
             MOV        CX,LNG
TOP:         PUTCHAR    STR[SI]     ;OUTPUT CURRENT
CHARACTER
             INC        SI          ;POINT TO NEXT
CHARACTER
             LOOP       TOP         ;REPEAT
             ENDM
```

**2. Write a macro to determine absolute value and expand it with an example**

```
      ABS    MACRO   X
             CMP     X,0
             JGE     DONE
             NEG     X      ;REVERSE SIGN IF NEGATIVE
      DONE:
             ENDM
```

Let's use this macro in the following code (source and expansion):

```
      ...
      MOV    AX,-5
      ABS    AX                 ;x will be replaced by AX
             Cmp    AX,0
             Jge    done
             Neg    AX
 Done:
      ...
      ...
```

```
        MOV     BL,2
        ABS     BL                      ;x will be replaced by BL
                CMP     BL,0
                JGE     DONE
                NEG     BL
Done:                                   ;*** this is an error -- done is a duplicate
label!!         ...
```