Module-3
Machine-Dependent Assembler Features:

In this section we consider the design and implementation of SIC/XE assembler.

- Instruction formats and addressing modes
- Program relocation.

Instruction formats and Addressing Modes

1. Translation of Register to Register instructions

In this the assembler must simply convert the opcode to machine language and change each register to its numeric value.

Eg:

COMPR A, S A004

(The opcode for COMPR is A0 , the number of register A is 0 and register S is 4.)

2. Translation of Format 4 instructions

This format contains 20 bit address field . No displacement is calculated.

Eg:

CLOOP +JSUB RDREC 4B101036

Here the opcode for JSUB instruction is 48 and the address of RDREC is 1036. Write the instruction format and set the bits n, i and e to 1.

(If neither immediate nor indirect mode is used set the bits n and i to 1. Format 4 is identified by the prefix + . If format 4 is not specified assembler first attempts to translate the instruction using program counter relative addressing. If this is not possible, (because the required displacement is out of range), the assembler then attempts to use base relative addressing. If neither form of relative addressing is applicable and the extended format is not specified then the instruction can not be properly assembled. In this case the assembler must generate an error message.)

3. Translation PC relative instructions

In this format-3 instruction format is used. The instruction contains the opcode followed by a 12-bit displacement value. In PC relative addressing made TA = disp + [PC]

disp = TA –[PC]

Eg:1

0000 FIRST STL RETADR 17202D

$(14)_{16}$ 1 1 0 0 1 0 $(02D)_{16}$

displacement= RETADR - PC = 30-3 = 2D

Eg: 2

0017 J CLOOP 3F2FEC

$(3C)_{16}$ 1 1 0 0 1 0 $(FEC)_{16}$

displacement= CLOOP-PC= 6 - 1A= -14= FEC

4. Translation of Base relative instructions

In this format-3 instruction format is used. The instruction contains the opcode followed by a 12-bit displacement value. In Base relative addressing made TA = disp + [B]

disp = TA –[B]

The displacement calculation process for base relative addressing is much the same as for PC relative addressing. In this the programmer must tell the assembler what the base register will contain during execution of the program so that assembler can compute displacements. This is done with the assembler directive BASE. For example, the statement BASE LENGTH informs the assembler that the base register will contain the address of LENGTH. The register B will contain this address until another BASE statement is encountered.

If the base register has to be used for another purpose the programmer must use NOBASE directive to inform the assembler that the contents of the base register is not used for addressing.

```
              LDB   #LENGTH
              BASE  LENGTH
104E          STCH  BUFFER, X    57C003
```

$(54)_{16}$ 1 1 1 1 0 0 $(003)_{16}$

(54) 1 1 1 0 1 0 0036-1051= $-101B_{16}$

displacement= BUFFER - B = 0036 - 0033 = 3

5. Translation of Immediate addressing

In this no memory reference is involved. Convert the immediate operand into its internal representation and insert it into its internal representation.

Eg:

- 0020 LDA #3 010003

  $(00)_{16}$ 0 1 0 0 0 0 $(003)_{16}$

- 103C +LDT #4096 75101000

  $(74)_{16}$ 0 1 0 0 0 1 $(01000)_{16}$

6. Translation involving indirect addressing

In this the displacement is computed to produce the target address.. Then bit n is set to 1. The example given below is indirect and PC relative.

Eg:

002A J @RETADR 3E2003

(3C)$_{16}$ 1 0 0 0 1 0 (003) $_{16}$

- TA=RETADR=0030
- TA=(PC)+disp=002D+0003

Program Relocation

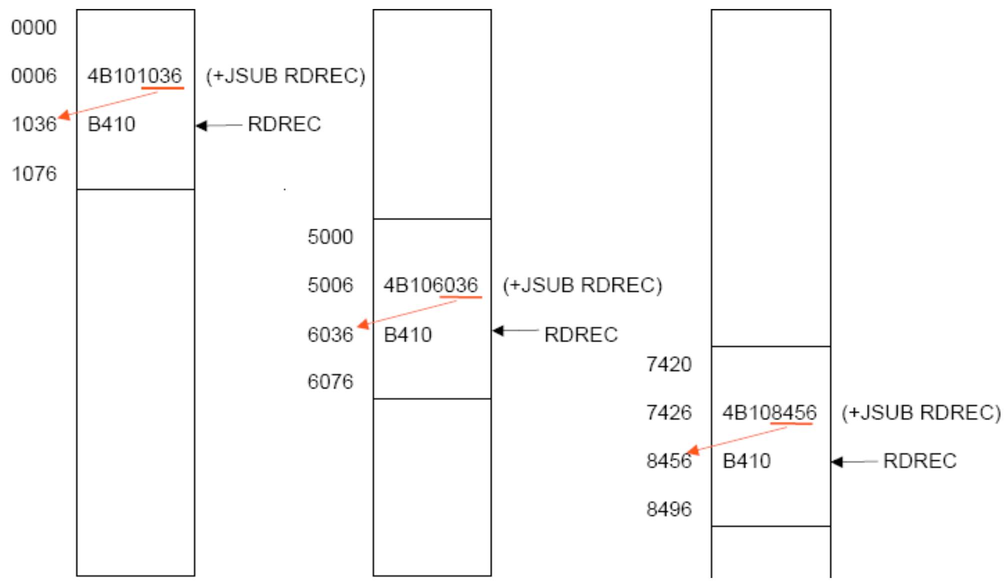
- Sometimes it is required to load and run several programs at the same time. The system must be able to load these programs wherever there is place in the memory. Therefore the exact starting is not known until the load time.
- Absolute Program- In this the address is mentioned during assembling itself. This is called *Absolute Assembly.*

Eg: Consider the instruction:

101B LDA THREE 00102D

- This statement says that the register A is loaded with the value stored at location 102D. Suppose it is decided to load and execute the program at location 2000 instead of location 1000.
- Then at address 102D the required value which needs to be loaded in the register A is no more available. The address also gets changed relative to the displacement of the program. Hence we need to make some changes in the address portion of the instruction so that we can load and execute the program at location 2000.
- Apart from the instruction which will undergo a change in their operand address value as the program load address changes. There exist some parts in the program which will remain same regardless of where the program is being loaded.
- Since assembler will not know actual location where the program will get loaded, it cannot make the necessary changes in the addresses used in the program. However, the assembler identifies for the loader those parts of the program which need modification.

- An object program that has the information necessary to perform this kind of modification is called the **relocatable program**.



- The above diagram shows the concept of relocation. Initially the program is loaded at location 0000. The instruction JSUB is loaded at location 0006.
- The address field of this instruction contains 01036, which is the address of the instruction labeled RDREC. The second figure shows that if the program is to be loaded at new location 5000.
- The address of the instruction JSUB gets modified to new location 6036. Likewise the third figure shows that if the program is relocated at location 7420, the JSUB instruction would need to be changed to 4B108456 that correspond to the new address of RDREC.
- The only part of the program that require modification at load time are those that specify direct addresses(format 4 instructions). The rest of the instructions need not be modified. The instructions which doesn't require modification are the ones that is not a memory address (immediate addressing) and PC-relative, Base-relative instructions.
- For an address label, its address is assigned relative to the start of the program (START 0). The assembler produces 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. The Modification has the following format:

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)

One modification record is created 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.

Eg: Consider the instruction

CLOOP +JSUB RDREC 4B101036

where RDREC is at the address 1036. The modification record for this instruction can be written as

M00000705

- There is one modification record for each address field that needs to be changed when the program is relocated(ie. For each format 4 instructions in the program).

Machine-Independent features:

These are the features which do not depend on the architecture of the machine. Such features are more related to software than to machine architecture. These are:

- Literals
- Symbol defining statements
- Expressions
- Program blocks
- Control sections

Literals:

- It is easy for a programmer to write the value of a constant operand as part of the instruction that uses it.
- This avoids defining the constant elsewhere in the program and making a label for it. Such an operand is called a literal because the value is stated literally in the instruction.
- A literal is defined with a prefix = followed by a specification of the literal value.

Example:

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

- The example above shows a 3-byte operand whose value is a character string EOF. The object code for the instruction is also mentioned. It shows the relative displacement value of the location where this value is stored. In the example the value is at location (002D) and hence the displacement value is (010). As another example the given statement below shows a 1-byte literal with the hexadecimal value '05'.

```
215   1062   WLOOP   TD   =X'05'   E32011
```

- **The difference between a constant defined as a literal and a constant defined as an immediate operand-** In case of literals the assembler generates the specified value as a constant at some other memory location. In immediate mode the operand value is assembled as part of the instruction itself. Example

  0020 LDA #03 010003

- All the literal operands used in a program are gathered together into one or more *literal pool*s. This is usually placed at the end of the program. The assembly listing of a program containing literals usually includes a listing of this literal pool, which shows the assigned addresses and the generated data values.

  Eg: 1076 * =X'05' 05

- In some cases it is placed at some other location in the object program. An assembler directive LTORG is used. Whenever the LTORG is encountered, it creates a literal pool that contains all the literal operands used since the beginning of the program. The literal pool definition is done after LTORG is encountered. It is better to place the literals close to the instructions.

  LTORG

  002D * =C'EOF' 454F46

- **Recognizing Duplicate literals –** That is the same literal used in more than one place in a program and store only one copy of the data value. For example, the literal =X'05' is used in different instructions in a program, but only one data area with this value is created.
  - Duplicate literals can be identified by comparing character strings. Eg: X'05'
  - Otherwise, generated value can be compared. For eg: the literals =C'EOF' and =X'454F46' are identical operand values.
- The value of some literals depends on their location in the program. Literals referring to the current value of the location counter (denoted by the symbol *) . Such literals are useful for loading base registers.

  Eg: BASE *

  LDB *

  Such literal operands will have different values in different places of the program since they hold the current value of the locaton counter.

- **Handling of literals by the assembler -** A literal table is created for the literals which are used in the program. The literal table contains the literal name, operand value and length and the address assigned to the operand. The literal table is usually created as a hash table using the literal name or value as the key.

– **During Pass-1:**The literal encountered is searched in the literal table. If the literal already exists, no action is taken; if it is not present, the literal is added to the LITTAB (leaving the address unassigned. When Pass 1 encounters a LTORG statement or the end of the program, the assembler makes a scan of the literal table. At this time each literal currently in the table is assigned an address. As addresses are assigned, the location counter is updated to reflect the number of bytes occupied by each literal.

– **During Pass-2:**The assembler searches the LITTAB for each literal encountered in the instruction and replaces it with its equivalent value.

Symbol-Defining Statements:

EQU Statement:

- Most assemblers provide an assembler directive that allows the programmer to define symbols and specify their values. The directive used for this **EQU** (Equate). The general form of the statement is

```
Symbol          EQU       value
```

- This statement defines the given symbol (i.e., entering in the SYMTAB) and assigning to it the value specified. The value can be a constant or an expression involving constants. One common usage is to define symbolic names that can be used to improve readability in place of numeric values. For example , instead of +LDT #4096 we can write

```
MAXLEN   EQU       4096

         +LDT      #MAXLEN
```

- When the assembler encounters EQU statement, it enters the symbol MAXLEN along with its value in the symbol table. During the assembly of LDT instruction the assembler searches the SYMTAB for its entry and its equivalent value as the operand in the instruction. The object code generated is the same for both the options discussed, but is easier to understand. If the maximum length is changed from 4096 to 1024, it is difficult to change if it is mentioned as an immediate value wherever required in the instructions. We have to scan the whole program and make changes wherever 4096 is used. If we mention this value in the instruction through the symbol defined by EQU, we may not have to search the whole program but change only the value of MAXLENGTH in the EQU statement (only once).
- Another common usage of EQU statement is **for defining values for the general- purpose registers**. The assembler can use the mnemonics for register usage like a-register A , X – index register and so on. But there are some instructions which requires numbers in place of names in the instructions. For example in the instruction RMO 0,1 instead of RMO A,X. The programmer can assign the numerical values to these registers using EQU directive.

```
A       EQU     0
X       EQU     1 and so on
```

These statements will cause the symbols A, X, L… to be entered into the symbol table with their respective values. An instruction RMO A, X would then be allowed. As another usage if in a machine that has many general purpose registers named as R1, R2,…, some may be used as base register, some may be used as accumulator. Their usage may change from one program to another. In this case we can define these requirement using EQU statements.

```
BASE    EQU     R1
```

INDEX	EQU	R2
COUNT	EQU	R3

- One restriction with the usage of EQU is whatever symbol occurs in the right hand side of the EQU should be predefined. For example, the following statement is not valid:

BETA	EQU	ALPHA
ALPHA	RESW	1

As the symbol ALPHA is assigned to BETA before it is defined. The value of ALPHA is not known.

ORG Statement:

- This directive can be used to indirectly assign values to the symbols. This assembler directive changes the value in the location counter. The directive is usually called ORG (for origin). Its general format is:

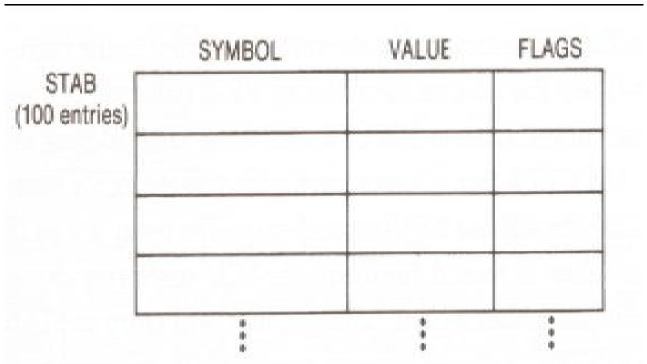
```
ORG        value
```

Where value is a constant or an expression involving constants and previously defined symbols. When this statement is encountered during assembly of a program, the assembler resets its location counter (LOCCTR) to the specified value. Since the values of symbols used as labels are taken from LOCCTR, the ORG statement will affect the values of all labels defined until the next ORG is encountered. ORG is used to control assignment storage in the object program.

- ORG can be useful in label definition. Suppose we need to define a symbol table with the following structure:

SYMBOL	6 Bytes
VALUE	3 Bytes
FLAG	2 Bytes

The table looks like the one given below.



- The symbol field contains a 6-byte user-defined symbol; VALUE is a one-word representation of the value assigned to the symbol; FLAG is a 2-byte field specifies symbol type and other information. The space for the ttable can be reserved by the statement:

```
STAB        RESB        1100
```

If we want to refer to the entries of the table using indexed addressing, place the offset value of the desired entry from the beginning of the table in the index register. To refer to the fields SYMBOL, VALUE, and FLAGS individually, we need to assign the values first as shown below:

```
SYMBOL      EQU         STAB
VALUE       EQU         STAB+6
FLAGS       EQU         STAB+9
```

To retrieve the VALUE field from the table indicated by register X, we can write a statement:

```
LDA         VALUE, X
```

The same thing can also be done using ORG statement in the following way:

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

The first statement allocates 1100 bytes of memory assigned to label STAB. In the second statement the ORG statement initializes the location counter to the value of STAB. Now the LOCCTR points to STAB. The next three lines assign appropriate memory storage to each of SYMBOL, VALUE and FLAG symbols. The last ORG statement reinitializes the LOCCTR to a new value after skipping the required number of memory for the table STAB (i.e., STAB+1100).

- While using ORG, the symbol occurring in the statement should be predefined as is required in EQU statement. For example for the sequence of statements below:

```
          ORG     ALPHA
BYTE1     RESB    1
BYTE2     RESB    1
BYTE3     RESB    1
          ORG
ALPHA     RESB    1
```

The sequence could not be processed as the symbol used to assign the new location counter value is not defined. In first pass, as the assembler would not know what value to assign to ALPHA, the other symbol in the next lines also could not be defined in the symbol table. This is a kind of problem of the forward reference.

Expressions:

- Assemblers also allow use of expressions in place of operands in the instruction. Each such expression must be evaluated to generate a single operand value or address. Assemblers generally arithmetic expressions formed according to the normal rules using arithmetic operators +, - *, /. Division is usually defined to produce an integer result.
- Individual terms may be constants, user-defined symbols, or special terms. The only special term used is * (the current value of location counter) which indicates the value of the next unassigned memory location. Thus the statement

```
BUFFEND     EQU         *
```

Assigns a value to BUFFEND, which is the address of the next byte following the buffer area. Some values in the object program are relative to the beginning of the program and some are absolute (independent of the program location, like constants).

- Expressions are classified as either absolute expression or relative expressions , neither absolute nor relative depending on the type of value they produce.

  – **Absolute Expressions:** The expression that uses only absolute terms is absolute expression. Absolute expression may contain relative term provided the relative terms occur in pairs with opposite signs for each pair. None of the relative terms enter into multiplication or division. Example:

```
MAXLEN      EQU         BUFEND-BUFFER
```

In the above instruction the difference in the expression gives a value that does not depend on the location of the program and hence gives an absolute value irrespective of the relocation of the program. The expression can have only absolute terms. Example:

```
MAXLEN      EQU         1000
```

  – **Relative Expressions:** All the relative terms except one can be paired . The remaining unpaired relative term must have a positive sign. None of the relative terms must enter into multiplication or division. A relative term represents some location within the program. Example:

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

– **Neither absolute nor relative:** Expressions that are legal are those expressions whose value remains meaningful when the program is relocated. Expressions that do not meet the conditions for either absolute or relative are neither absolute nor relative. They are considered as errors.

Eg: BUFEND + BUFFER, 100-BUFFER, 3*BUFFER

- **Handling the type of expressions:** to find the type of expression, we must keep track the type of symbols used. This can be achieved by defining the type in the symbol table against each of the symbol as shown in the table below:

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

Program Blocks:

- Program blocks allow the generated machine instructions and data to appear in the object program in a different order by Separating blocks for storing code, data, stack, and larger data block.
- Program blocks refer to segments of code that are rearranged within a single object program unit.

- **Assembler Directive USE*:*** indicates which portion of the program belong to the various blocks.

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. Assemblers rearrange 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. In the example below 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

Example Code

```
(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
```

- **How the assembler handles program blocks –**

Pass 1

- – A separate location counter for each block is maintained.
- – The location counter for a block is initialized to zero when the block is first started.
- – The current value of the location counter is saved when switching to another block.
- – The saved value is continued when resuming previous block.
- – After pass 1 the symbol table will be having labels with block no along with address.(For absolute symbol there is no block number.)
- – At the end of pass 1 latest value of location counter or each block gives the length of that block.
- – Assembler constructs a block table that contains starting addresses and lengths of all blocks

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

Pass 2

- – Code generation during pass2 the assembler needs the address relative to the start of the program. (not the start of the individual program block). Assembler adds the label address with its block starting address.

Pass1 algorithm of Program blocks

Pass2 algorithm for program blocks

- **Advantage-** Separation of programs into blocks has reduced the addressing problem. Since the larger buffer are is moved to the end of the object program extended format instructions need not be used. The use of program blocks has achieved the effect of rearranging the source statements without actually rearranging them. The loader will load the object program at the indicated address.

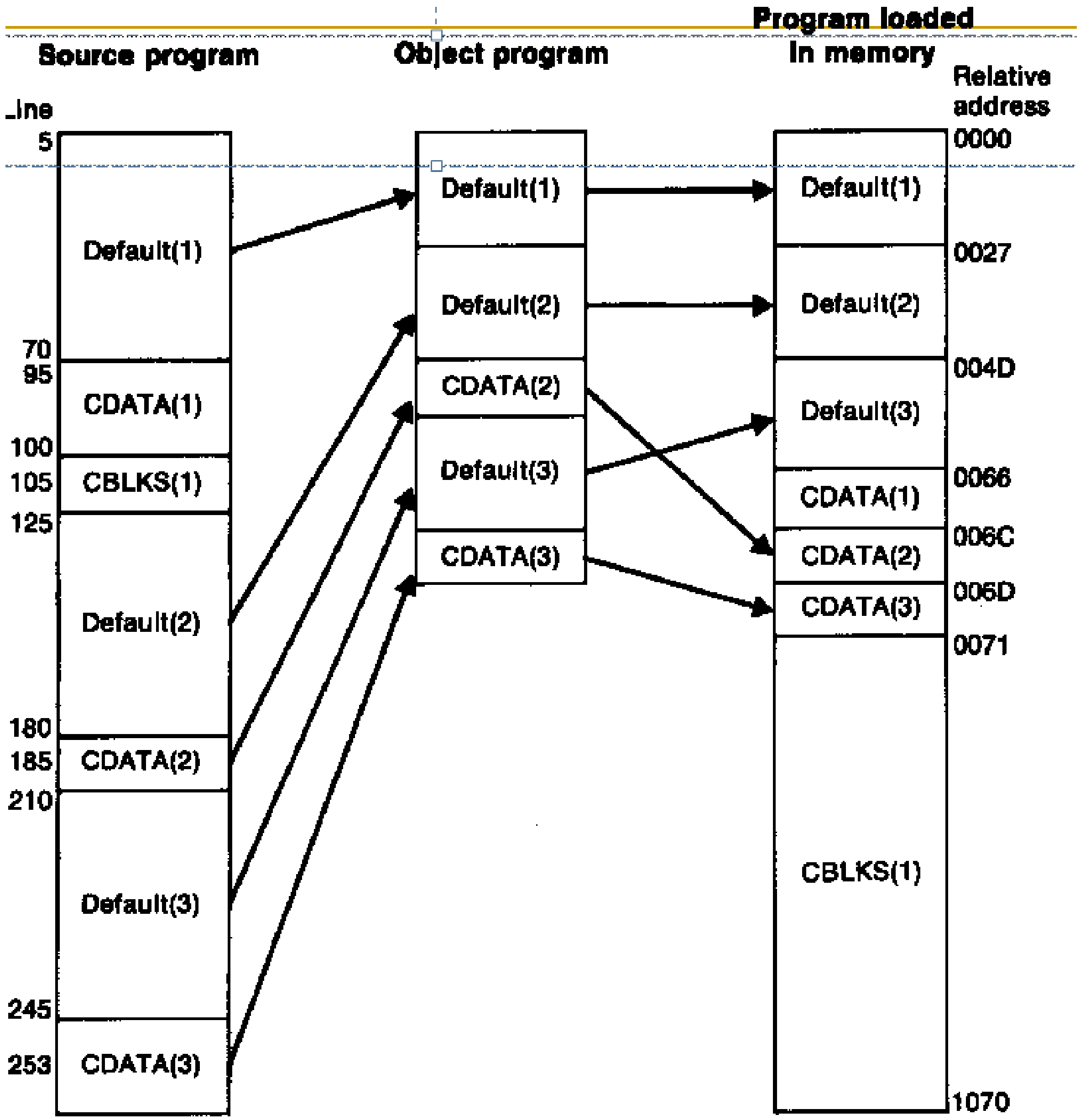


Fig:Program blocks traced through the assembly and loading processes

Pass1 of program blocks

```
begin
  block number = 0 LOCCTR[i] = 0 for all i
  read the first input line .
  if OPCODE = 'START' then
  begin
    write line to intermediate file
    read next input line
  end {if START}
  while OPCODE ≠ 'END' do
  if OPCODE = 'USE'
  begin
    if there is no OPEREND name then
      set block name as default
    else block name as OPERAND name
    if there is no entry for block name then
      insert (block name, block number ++) in block table
    i = block number for block name
    if this is not a comment line then
      begin
      if there is a symbol in the LABEL field then
        begin
        search SYMTAB for LABEL
        if found then
          set error flag (duplicate symbol)
        else
          insert (LABEL, LOCCTR[i]) into SYMTAB
        end {if symbol}
      Search OPTAB for OPCODE
      if found then
        add 3 instruction length to LOCCTR[i]
      else if OPCODE = 'WORD' then
        add 3 to LOCCTR[i]
      else if OPCODE = 'RESW' then
        add 3 * #[OPERAND] to LOCCTR[i]
      else if OPCODE = 'RESB' then
        add #[OPERAND] to LOCCTR[i]
      else if OPCODE = 'BYTE' then
      begin
        find length of constant in bytes
        add length to LOCCTR[i]
      end {if byte}
else
```

```
    Set error flag
    end {if not a comment}
  write line to intermediate file
  read Text input line
  end {while not END}
write last line to intermediate file
save Length[i] as LOCCTR[i] for all i
Address[o] = starting address
Address[i] = address(i - 1) + Length(i - 1)
                [for i = 1 to max(block number)]
insert(address[i], Length[i]) in block table for all i
end {Pass 1}
```

Pass2 of Program blocks

```
If OPCODE = 'USE' then
  set block number for block name with OPERAND field
  search SYMTAB for OPERAND
  store symbol value + address [block number] as operand address
end {Pass 2}
```

Control Sections:

- A *control section* is a part of the program that maintains its identity after assembly; each control section can be loaded and relocated independently of the others.
- Different control sections are most often used for subroutines or other logical subdivisions. 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. For example, instructions in one control section may refer to the data or instructions of other control sections.
- Since control sections are independently loaded and relocated, the assembler is unable to process these references in the usual way. Such references between different control sections are called *external references.*
- The assembler generates the information about each of the external references that will allow the loader to perform the required linking.
- When a program is written using multiple control sections, the beginning of each of the control section is indicated by an assembler directive
  - assembler directive: **CSECT**

  The syntax

  controlsectionname CSECT

  - separate location counter for each control section
- Control sections differ from program blocks in that they are handled separately by the assembler. Symbols that are defined in one control section may not be used directly another control section; they must be identified as external reference for the loader to handle. The external references are indicated by two assembler directives:
  - EXTDEF (external Definition): It is the statement in a control section, names symbols that are defined in this section but may be used by other control sections. Control section names

do not need to be named in the EXTREF as they are automatically considered as external symbols.

– EXTREF (external Reference): It names symbols that are used in this section but are defined in some other control section. The order in which these symbols are listed is not significant. The assembler must include proper information about the external references in the object program that will cause the loader to insert the proper value where they are required.

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
```

Handling External Reference

Case 1

15   0003   CLOOP   +JSUB   RDREC   4B100000

- The operand RDREC is an external reference.
  - The assembler has no idea where RDREC is
  - inserts an address of zero
  - can only use extended formatto provide enough room (that is, relative addressing for external reference is invalid)
- The assembler generates information for each external reference that will allow the loaderto perform the required linking.

Case 2

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

Case 3

190 0028 MAXLEN WORD BUFEND-BUFFER 000000

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

Object Code for the example program:

```
0000   COPY      START    0
                 EXTDEF   BUFFER,BUFFEND,LENGTH
                 EXTREF   RDREC,WRREC
0000   FIRST     STL      RETADR                 172027
0003   CLOOP    +JSUB     RDREC                  4B100000   Case 1
0007             LDA      LENGTH                 032023
000A             COMP    #0                      290000
000D             JEQ      ENDFIL                 332007
0010            +JSUB     WRREC                  4B100000
0014             J        CLOOP                  3F2FEC
0017   ENDFIL    LDA     =C'EOF'                 032016
001A             STA      BUFFER                 0F2016
001D             LDA     #3                      010003
0020             STA      LENGTH                 0F200A
0023            +JSUB     WRREC                  4B100000
0027             J       @RETADR                 3E2000
002A   RETADR    RESW     1
002D   LENGTH    RESW     1
                 LTORG
0030   *        =C'EOF'                          454F46
0033   BUFFER    RESB     4096
1033   BUFEND    EQU      *
1000   MAXLEN    EQU      BUFEND-BUFFER        case 2
```

```
0000    RDREC    CSECT
         .       SUBROUTINE TO READ RECORD INTO BUFFER
         .
                 EXTREF   BUFFER,LENGTH,BUFEND
0000             CLEAR    X                        B410
0002             CLEAR    A                        B400
0004             CLEAR    S                        B440
0006             LDT      MAXLEN                   77201F
0009    RLOOP    TD       INPUT                    E3201B
000C             JEQ      RLOOP                    332FFA
000F             RD       INPUT                    DB2015
0012             COMPR    A,S                      A004
0014             JEQ      EXIT                     332009
0017            +STCH     BUFFER,X                 57900000
001B             TIXR     T                        B850
001D             JLT      RLOOP                    3B2FE9
0020    EXIT    +STX      LENGTH                   13100000
0024             RSUB                              4F0000
0027    INPUT    BYTE     X'F1'                    F1
0028    MAXLEN   WORD     BUFFEND-BUFFER           000000   Case 3
```

```
0000    WRREC    CSECT

         .       SUBROUTINE TO WRITE RECORD FROM BUFFER
         .
                 EXTREF   LENGTH,BUFFER
0000             CLEAR    X                        B410
0002            +LDT      LENGTH                   77100000
0006    WLOOP    TD       =X'05'                   E32012
0009             JEQ      WLOOP                    332FFA
000C            +LDCH     BUFFER,X                 53900000
0010             WD       =X'05'                   DF2008
0013             TIXR     T                        B850
0015             JLT      WLOOP                    3B2FEE
0018             RSUB                              4F0000
                 END      FIRST
001B    *       =X'05'                             05
```

The assembler must also include information in the object program that will cause the loader to insert the proper value where they are required. The assembler maintains two new record in the object code and a changed version of modification record.

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 (hexadecimal)

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 (hexadecimal)

Col. 8-9 Length of the field to be modified, in half-bytes (hexadecimal)

Col.11-16 External symbol whose value is to be added to or subtracted from the indicated field

A define record gives information about the external symbols that are defined in this control section, i.e., symbols named by EXTDEF.A refer record lists the symbols that are used as external references by the control section, i.e., symbols named by EXTREF.

The new items in the modification record specify the modification to be performed: adding or subtracting the value of some external symbol. The symbol used for modification may be defined either in this control section or in another section.

The object program is shown below. There is a separate object program for each of the control sections. In the *Define Record* and *refer record* the symbols named in EXTDEF and EXTREF are included.

COPY

```
HCOPY  000000001033
DBUFFER000033BUFEND001033LENGTH00002D
RRDREC WRREC
T0000001D1720274B1000000320232900003320074B1000003F2FEC0320160F2016
T00001D0D0100030F200A4B1000003E2000
T00003003454F46
M00000405+RDREC
M00001105+WRREC
M00002405+WRREC
E000000
```

RDREC

```
HRDREC 00000000002B
RBUFFERLENGTHBUFEND
T0000001DB410B400B44077201FE3201B332FFADB2015A00433200957900000B850
T00001D0E3B2FE9131000004F0000F1000000
M00001805+BUFFER
M00002105+LENGTH
M00002806+BUFEND
M00002806-BUFFER
E
```

BUFEND - BUFFER

WRREC

```
HWRREC 00000000001C
RLENGTHBUFFER
T0000001CB410771000000E3201232FFA53900000DF2008B8503B2FEE4F000005
M00000305+LENGTH
M00000D05+BUFFER
E
```

- In the case of *Define,* the record also indicates the relative address of each external symbol within the control section.For EXTREF symbols, no address information is available. These symbols are simply named in the *Refer record.*
- **Handling Expressions in Multiple Control Sections**: The existence of multiple control sections that can be relocated independently of one another makes the handling of expressions complicated. It is required that in an expression that all the relative terms be paired (for absolute expression), or that all except one be paired (for relative expressions).
- When it comes in a program having multiple control sections then we have an extended restriction that:
  - Both terms in each pair of an expression must be within the same control section

    If two terms represent relative locations within the same control section , their difference is an absolute value (regardless of where the control section is located.

    Legal: BUFEND-BUFFER (both are in the same control section)

  - If the terms are located in different control sections, their difference has a value that is unpredictable.

    Illegal: RDREC-COPY (both are of different control section) it is the difference in the load addresses of the two control sections. This value depends on the way run-time storage is allocated; it is unlikely to be of any use.
- **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.

Assembler Design Options

- There are two design options or the assembler.
  - One pass assembler: is used when it is necessary to avoid a second pass over the source program.
  - Multipass Assembler: allows an assembler to handle forward references.

One-Pass Assembler

The main problem in designing the assembler using single pass was to resolve forward references. We can avoid to some extent the forward references by:

- Eliminating forward reference to data items, by defining all the storage reservation statements at the beginning of the program rather at the end.
- Unfortunately, forward reference to labels on the instructions cannot be avoided. (forward jumping)
- To provide some provision for handling forward references by prohibiting forward references to data items.

There are two types of one-pass assemblers:

- One that produces object code directly in memory for immediate execution **(Load- and-go assemblers).**
- The other type produces **the usual kind of object code** for later execution.

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

- o 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.

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

Forward Reference in One-Pass Assemblers: In load-and-Go assemblers when a forward reference is encountered :

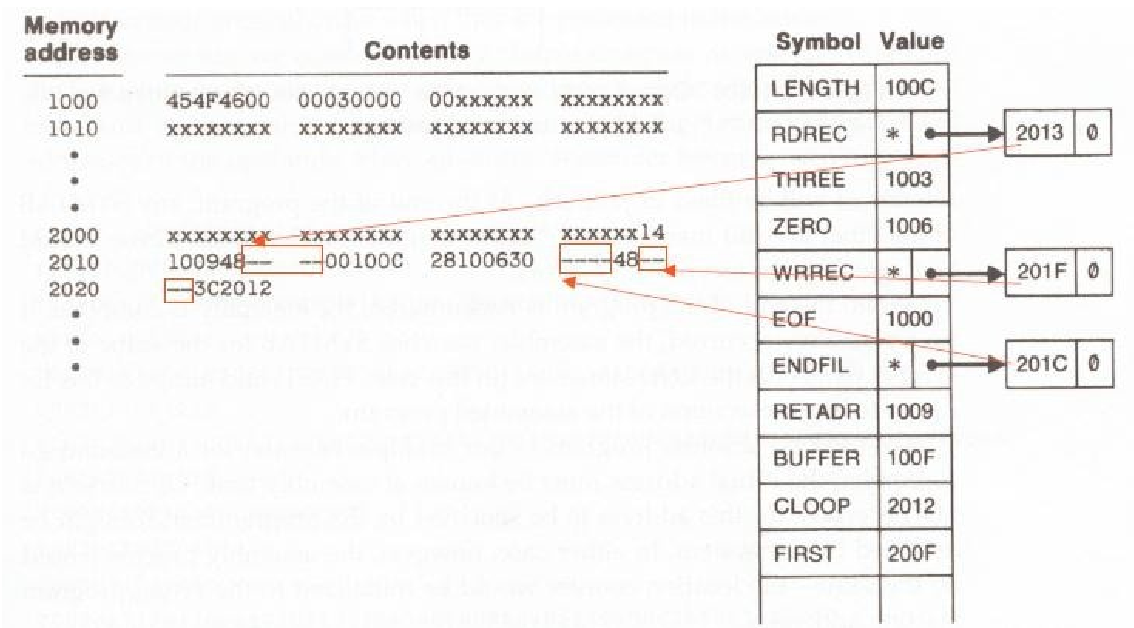
- Omits the operand address if the symbol has not yet been defined
- Enters this undefined symbol into SYMTAB and indicates that it is undefined
- Adds the address of this operand address to a list of forward references associated with the SYMTAB entry
- When the definition for the symbol is encountered, 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
    - o Search SYMTAB for the symbol named in the END statement and jumps to

this location to begin execution if there is no error

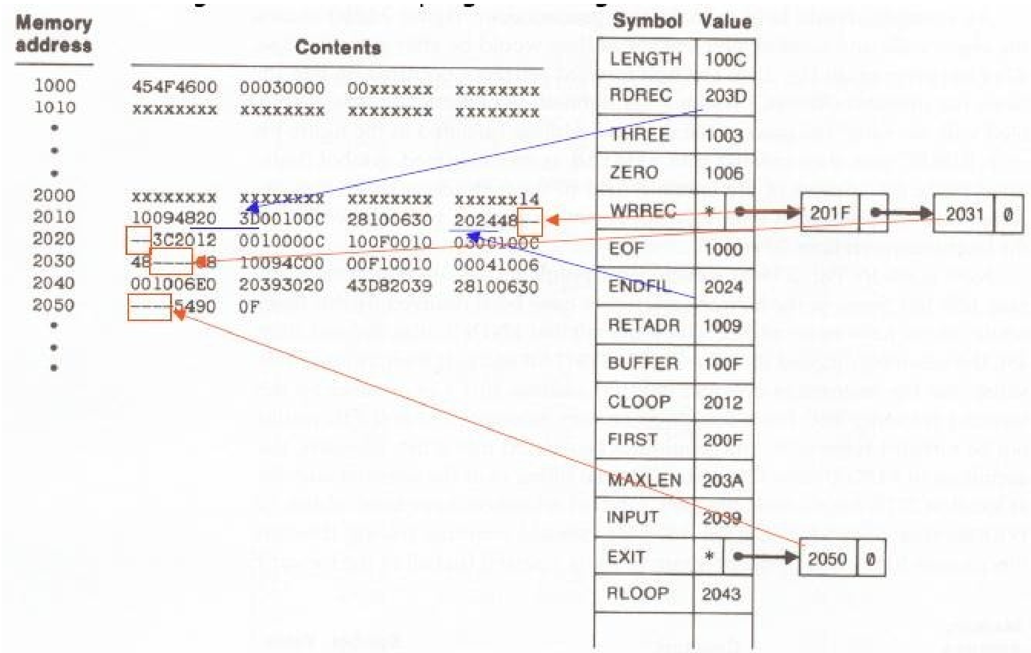
After Scanning line 40 of the program:

40 2021 J` CLOOP 302012

The status is that upto this point the symbol RREC is referred once at location 2013, ENDFIL at 201F and WRREC at location 201C. None of these symbols are defined. The figure shows that how the pending definitions along with their addresses are included in the symbol table.



The status after scanning line 160, which has encountered the definition of RDREC and ENDFIL is as given below:



One-Pass Assembler that generates object code:

- 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.

```
HCOPY  00100000107A
T00100009454F46000003000000
T00200F151410094800000100C2810063000004800003C2012
T00201C022024
T002024190010000C100F0010030C100C4800000810094C0000F1001000
T00201302203D
T00203D1E041006001006E02039302043D82039281006300000054900F2C203A382043
T00205002205B
T00205B0710100C4C000005
T00201F022062
T002031022062
T002062180410006E0206130206550900FDC20612C100C3820654C0000
E00200F
```

Algorithm for one pass assembler

```
begin
  read first input line
  if OPCODE = 'START' then
    begin
      save #[OPERAND] as starting address
      initialize LOCCTR as starting address
      read next input line
    end {if START}
  else
    initialize LOCCTR to 0
while OPCODE ≠ 'END' do
    begin
      if there is not a comment line then
        begin
          if there is a symbol in the LABEL field then
            begin
              search SYMTAB for LABEL
                if found then
              begin
                  if symbol value as null
                  set symbol value as LOCCTR and search
                     the linked list with the corresponding
                     operand
                  PTR addresses and generate operand
                     addresses as corresponding symbol
                     values
                  set symbol value as LOCCTR in symbol
                     table and delete the linked list
              end
            else
              insert (LABEL, LOCCTR) into SYMTAB
          end
            search OPTAB for OPCODE
              if found then
                begin
                  search SYMTAB for OPERAND address
              if found then
                if symbol value not equal to null then
                  store symbol value as OPERAND address
                else
                  insert at the end of the linked list
                    with a node with address as LOCCTR
                else
                  insert (symbol name, null)
```

```
        add 3 to LOCCTR
      end
      else if OPCODE = 'WORD' then
        add 3 to LOCCTR & convert comment to
          object code
      else if OPCODE = 'RESW' then
        add 3 #[OPERAND] to LOCCTR
      else if OPCODE = 'RESB' then
        add #[OPERAND] to LOCCTR
      else if OPCODE = 'BYTE' then
        begin
          find length of constant in bytes
          add length to LOCCTR
          convert constant to object code
        end
    if object code will not fit into current
      text record then
      begin
        write text record to object program
        initialize new text record
      end
    add object code to Text record
   end
  write listing line
  read next input line
 end
 write last Text record to object program
 write End record to object program
 write last listing line
end {Pass 1}
```

MultiPass Assembler:

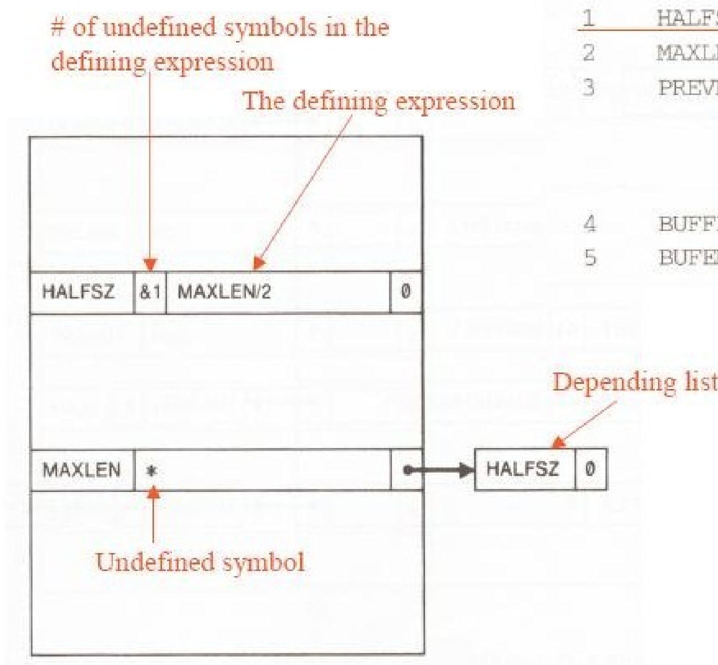
- For a two pass assembler, in EQU assembler directive we required that any symbol on the right hand side be defined previously in the program. This is because o the two pass.If multipass is possible this restriction can be avoided. Eg:

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

Working of Multipass Assembler:

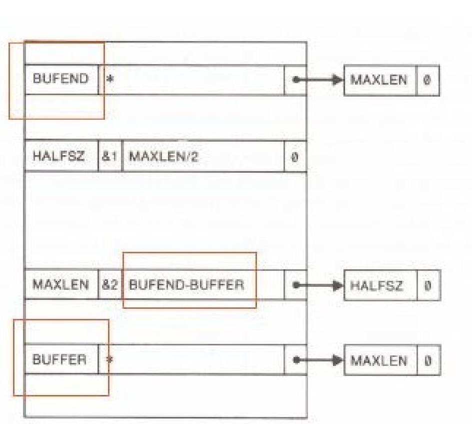
- A multipass assembler can make as many passes as needed to process the definition of symbols.
- For a forward reference in symbol definition, we store in the SYMTAB:
  - The symbol name
  - The defining expression
  - The number of undefined symbols in the defining expression
- The undefined symbol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

Multi-Pass Assembler Example Program

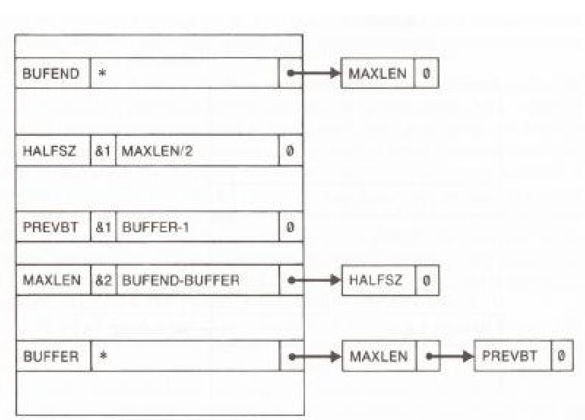



```
1   HALFSZ   EQU    MAXLEN/2
2   MAXLEN   EQU    BUFEND-BUFFER
3   PREVBT   EQU    BUFFER-1
                    .
                    .
                    .
4   BUFFER   RESB   4096
5   BUFEND   EQU    *
```

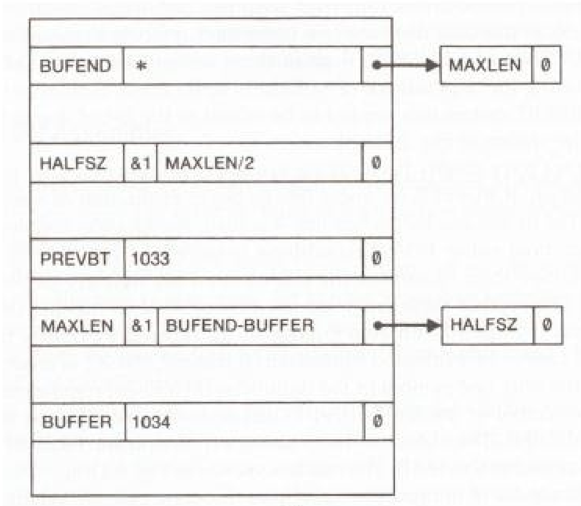
Multi-Pass Assembler : Example for forward reference in Symbol Defining Statements:



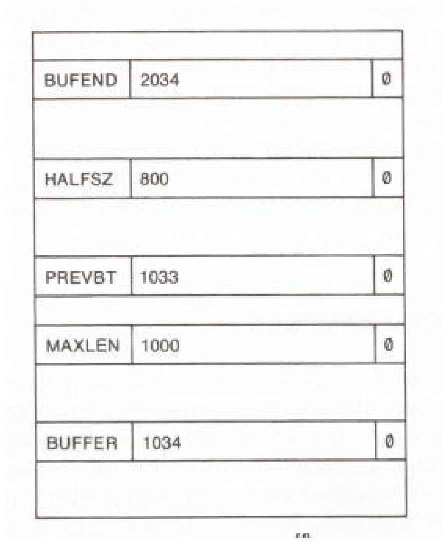
2 MAXLEN EQU BUFEND-BUFFER



3 PREVBT EQU BUFFER-1



4 BUFFER RESB 4096



5 BUFEND EQU *

Implementation Example: MASM ASSEMBLER

- Microsoft MASM assembler works for Petium and other ×86 systems.
- In this system memory is considered as segments.
- An MASM assembly language program is written as collection of segments. Each segment is defined as belonging to a particular class, corresponding to its contents. Commonly used classes are CODE, DATA, CONST and STACK
- During program execution the segments are addressed via the ×86 segment registers. Code segments are addressed using register CS and stack segments are addressed using register SS. These segment registers are automatically set by the system loader when a program is loaded for execution.
- Register CS is set to indicate the segment that contains the starting label specified in the END statement of the program. Register SS is to indicate the last stack segment processed by the loader.
- Data segments (including constant segments) are normally addressed using DS, ES, or GS.
- By default the assembler assumes that all references to data segments use register DS. This assumption can be changed by the assembler directive ASSUME.

  ASSUME ES: DATASEG2
- Registers DS, ES, FS and GS must be loaded by the program before they can be used to address data segments. Eg:

MOV AX, DATASEG2

MOV ES, AX

Would set ES to indicae the data segment DATASEG2

- Jump instructions are assembled in two different ways, depending on whether the target of the jump is in the same code segment (near jump) or in a different code segment(far jump).
- The length of the assembled instruction depends on the operands that are used. An operand that specifies a memory location may take varying amounts of space in the instruction depending upon the location o the operand.
- First pass of the ×86 assembler must analyze the operands of an instruction, in addition to looking at the opcode.
- Segments in a MASM source program can be written in more than one place using the assembler directive SEGMENT.
- References between segments that are assembled together are automatically handled by the assembler.
- MASM can also produce an instruction timing listing that shows the number of clock cycles required to execute each machine instruction.