MODULE-2

- **Loaders and Linkers: Basic Loader Functions,**
- **Machine Dependent Loader**
- **Features, Machine Independent Loader Features,**
- **Loader Design Options,**
- **Implementation Examples.**

Machine Independent Assembler Features

These are the features which do not depend on the architecture of the machine. These are:

- Literals
- Expressions
- Program blocks
- Control sections

Literals

A literal is defined with a prefix = followed by a specification of the literal value.

Example:

45 001A ENDFIL LDA =C‟EOF‟ 032010

-

-

93 002D * LTORG =C‟EOF‟ 454F46

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

It is important to understand 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

55 0020 LDA #03 010003

All the literal operands used in a program are gathered together into one or more literal pools. 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. 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.

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. The literal table is usually created as a hash table on the literal name.

Implementation of Literals:

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 and for the address value, it waits till it encounters LTORG for literal definition. 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 as if these values are generated by BYTE or WORD. If a literal represents an address in the program, the assembler must generate a modification relocation for, if it all it gets affected due to relocation. The following figure shows the difference between the SYMTAB and 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

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 and any othersymbol which is already defined. One common usage is to define symbolic names that can be used to improve readability in place of numeric values.

For example

```
+LDT    #4096
```

This loads the register T with immediate value 4096, this does not clearly show what exactly this value indicates. If a statement is included as:

```
MAXLEN  EQU    4096                                  and then
            +LDT    #MAXLEN
```

Then it clearly indicates that the value of MAXLEN is some maximum length value. When the assembler encounters EQU statement, it enters the symbol MAXLEN along with its value in the symbol table. During LDT 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).

ORG Statement:

This directive can be used to indirectly assign values to the symbols. 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.Sometimes altering the values may result in incorrect assembly.

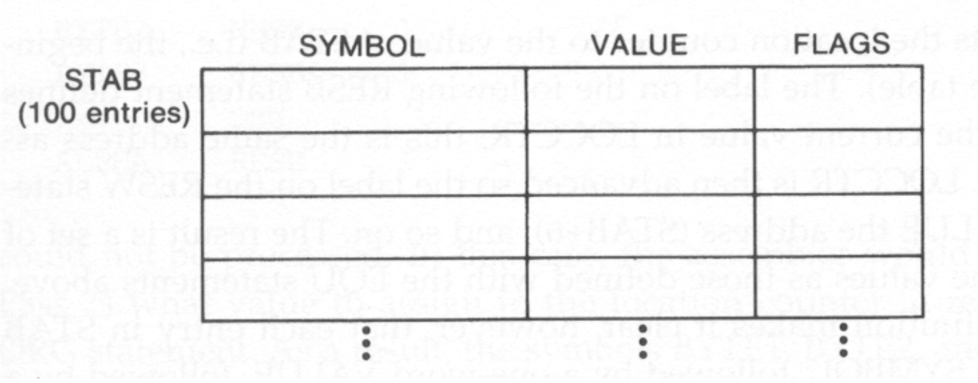
ORG can be useful in label definition. Suppose we need to define a symbol table with the following structure:

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 table 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). Hence, expressions are classified as either absolute expression or relative expressions 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. 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 immaterial o 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 as described in “absolute”. The remaining unpaired relative term must have a positive sign. Example:

STAB EQU OPTAB + (BUFEND – 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.

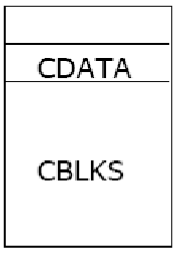
Assembler Directive USE:

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. 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



```
(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
```

```
0027   0   RDREC    USE                     (default) block
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
```

```
004D   0            USE                     (default) block
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
```

Arranging code into program blocks:

Pass 1

A separate location counter for each program block is maintained.

Save and restore LOCCTR when switching between blocks.

At the beginning of a block, LOCCTR is set to 0.

Assign each label an address relative to the start of the block.

Store the block name or number in the SYMTAB along with the assigned relative address of the label

Indicate the block length as the latest value of LOCCTR for each block at the end of Pass1

Assign to each block a starting address in the object program by concatenating the program blocks in a particular order

Pass 2

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

The starting address of this block

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 :

secname 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
```

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
```

```
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 2

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 my 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.

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.

COPY

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

```
RDREC
HRDREC 00000000002B
RBUFFERLENGTHBUFEND
T0000001DB410B400B44077201FE3201B332FFADB2015A00433200957900000B850
T00001D0E3B2FE9131000004F0000F1000000
M00001805+BUFFER
M00002105+LENGTH
M00002806+BUFEND      BUFEND - BUFFER
M00002806-BUFFER
E
WRREC
HWRREC 00000000001C
RLENGTHBUFFER
T0000001CB41077100000E3201232FFA53900000DF2008B8503B2FEE4F000005
M00000305+LENGTH
M00000D05+BUFFER
E
```

Assembler Design Options

One and Multi-Pass Assembler

- So far, we have presented the design and implementation of a two-pass assembler.
- Here, we will present the design and implementation of
  - One-pass assembler
    - If avoiding a second pass over the source program is necessary or desirable.
  - Multi-pass assembler
    - Allow forward references during symbol definition.

One-Pass Assembler

- The main problem is about forward reference.
- Eliminating forward reference to data items can be easily done.
  - Simply ask the programmer to define variables before using them.
- However, eliminating forward reference to instruction cannot be easily done.
  - Sometimes your program needs a forward jump.
  - Asking your program to use only backward jumps is too restrictive.

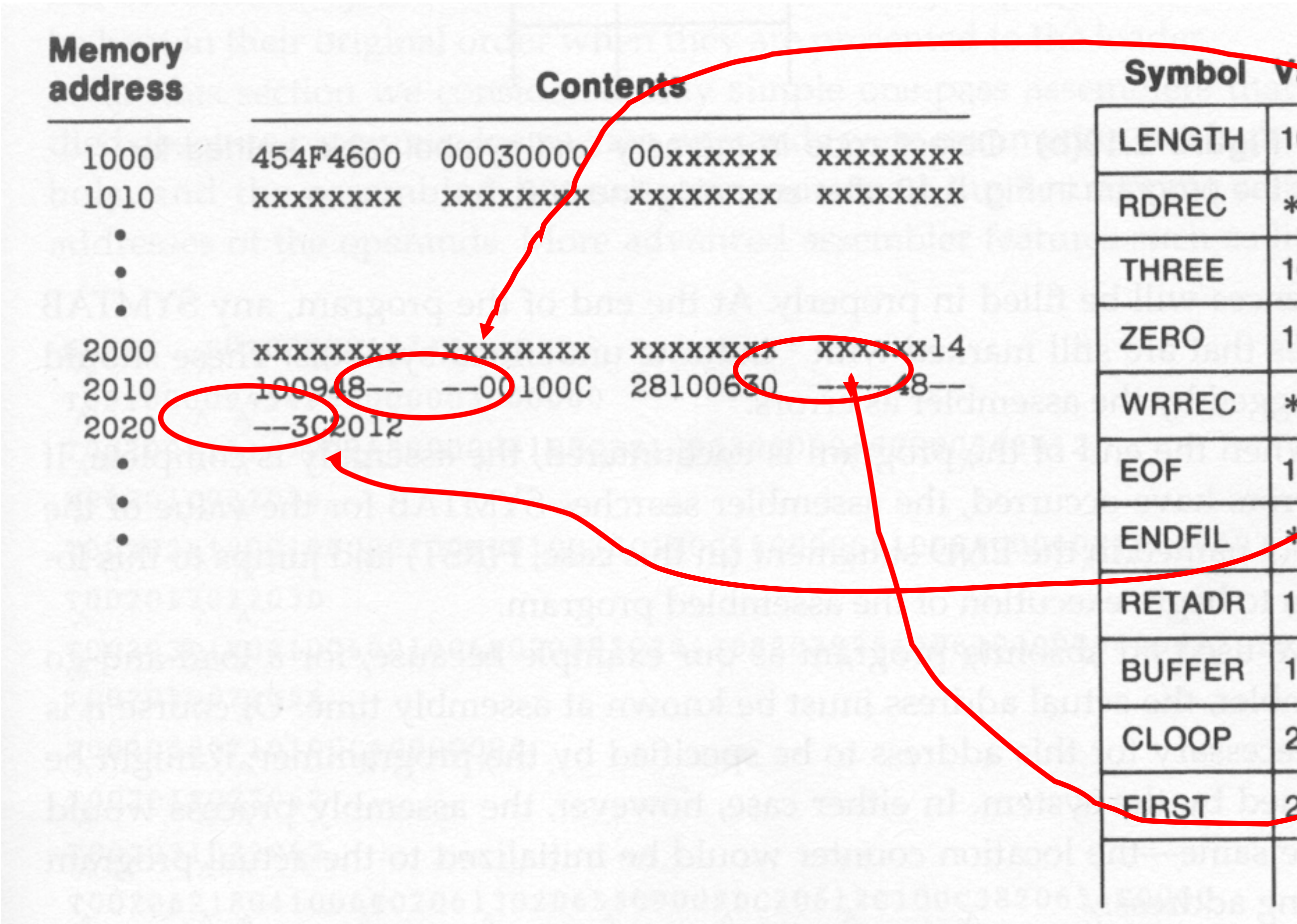
Line	Loc	Source statement			Object c
0	1000	COPY	START	1000	
1	1000	EOF	BYTE	C'EOF'	454F46
2	1003	THREE	WORD	3	000003
3	1006	ZERO	WORD	0	000000
4	1009	RETADR	RESW	1	
5	100C	LENGTH	RESW	1	
6	100F	BUFFER	RESB	4096	
9		.			
10	200F	FIRST	STL	RETADR	141009
15	2012	CLOOP	JSUB	RDREC	48203D
20	2015		LDA	LENGTH	00100C

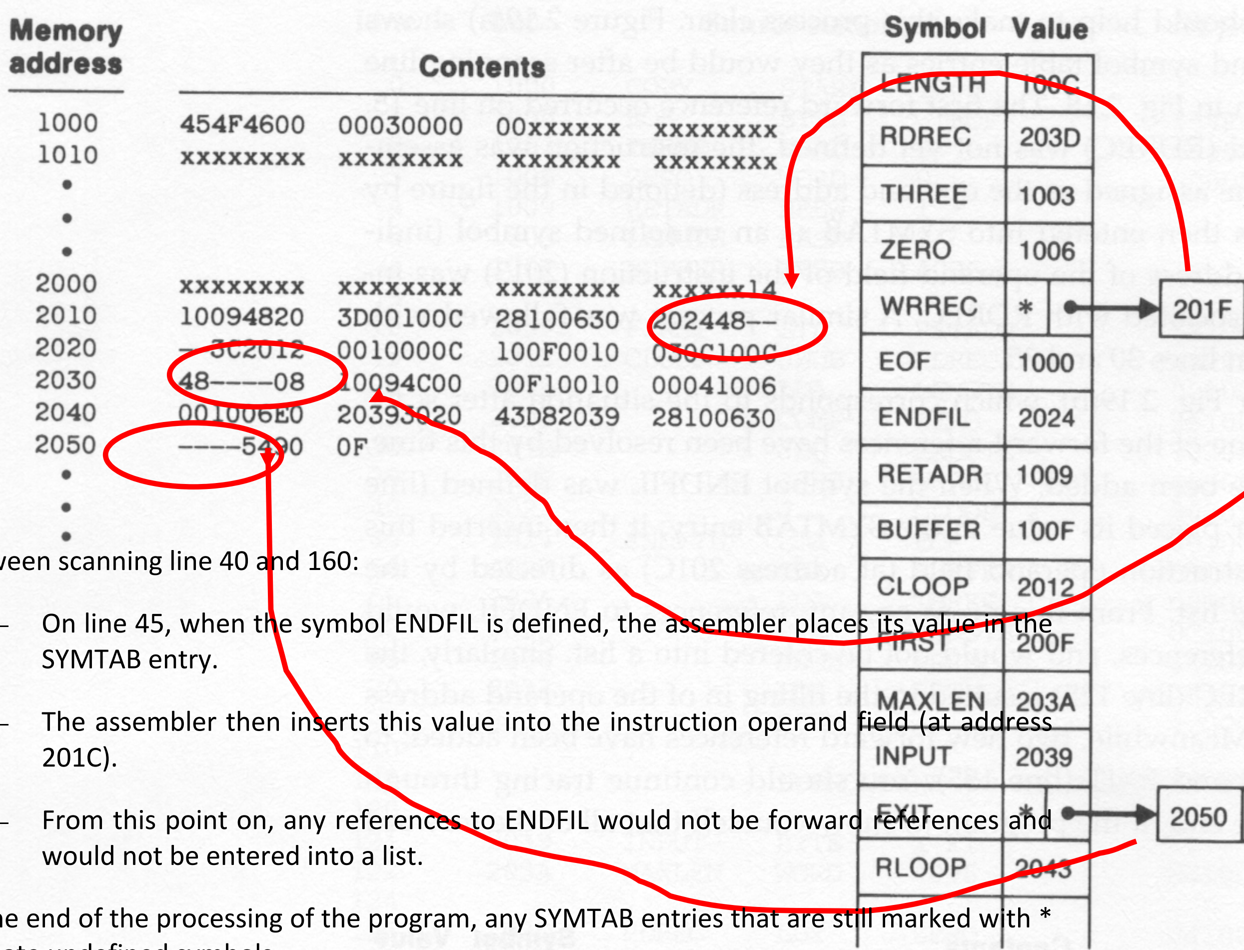
110		.			
115		.	SUBROUTINE TO READ RECOR		
120		.			
121	2039	INPUT	BYTE	X'F1'	F
122	203A	MAXLEN	WORD	4096	0
124		.			
125	203D	RDREC	LDX	ZERO	0
130	2040		LDA	ZERO	0
135	2043	RLOOP	TD	INPUT	E
140	2046		JEQ	RLOOP	3
145	2049		RD	INPUT	D
150	204C		COMP	ZERO	2
155	204F		JEQ	EXIT	3
160	2052		STCH	BUFFER,X	5
165	2055		TIX	MAXLEN	2
170	2058		JLT	RLOOP	3
175	205B	EXIT	STX	LENGTH	1
180	205E		RSUB		4

- There are two types of one-pass assembler:
  - Produce object code directly in memory for immediate execution
    - No loader is needed
    - Load-and-go for program development and testing
    - Good for computing center where most students reassemble their programs each time.
    - Can save time for scanning the source code again
  - Produce the usual kind of object program for later execution

Internal Implementation

- The assembler generate object code instructions as it scans the source program.
- If an instruction operand is a symbol that has not yet been defined, the operand address is omitted when the instruction is assembled.
- The symbol used as an operand is entered into the symbol table.
- This entry is flagged to indicate that the symbol is undefined yet.
- The address of the operand field of the instruction that refers to the undefined symbol is added to a list of forward references associated with the symbol table entry.
- When the definition of the symbol is encountered, the forward reference list for that symbol is scanned, and the proper address is inserted into any instruction previously generated.





- Between scanning line 40 and 160:
  - On line 45, when the symbol ENDFIL is defined, the assembler places its value in the SYMTAB entry.
  - The assembler then inserts this value into the instruction operand field (at address 201C).
  - From this point on, any references to ENDFIL would not be forward references and would not be entered into a list.
- At the end of the processing of the program, any SYMTAB entries that are still marked with * indicate undefined symbols.
  - These should be flagged by the assembler as errors.

Multi-Pass Assembler

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

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

- 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.

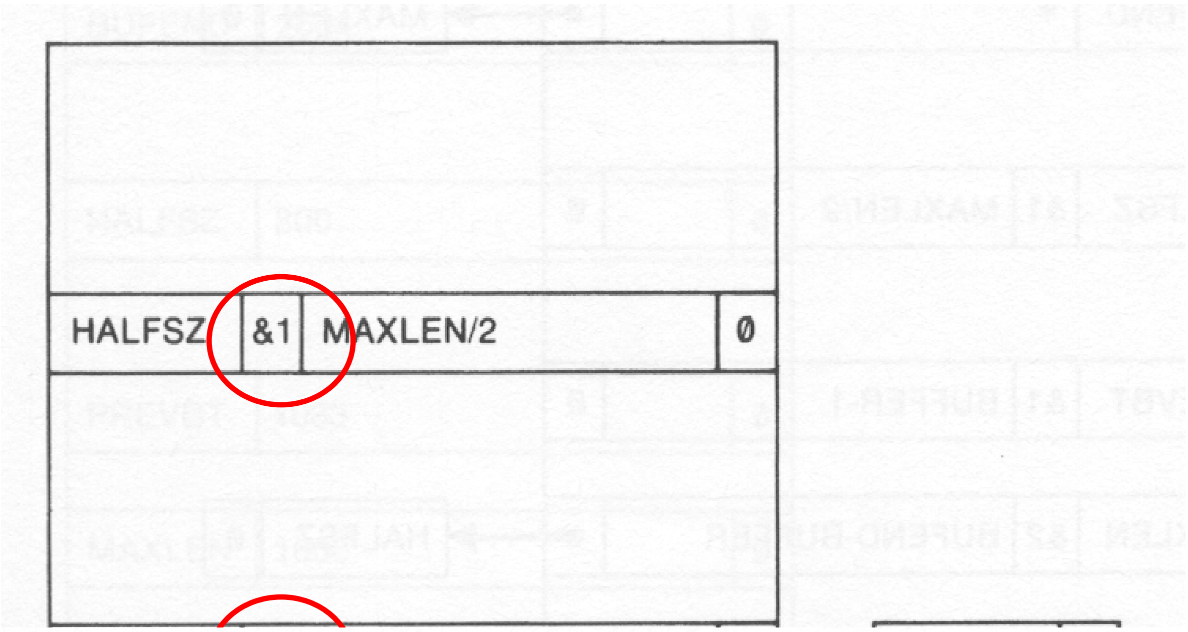
- It is unnecessary for a multi-pass assembler to make more than two passes over the entire program.
- Instead, only the parts of the program involving forward references need to be processed in multiple passes.
- The method presented here can be used to process any kind of forward references.

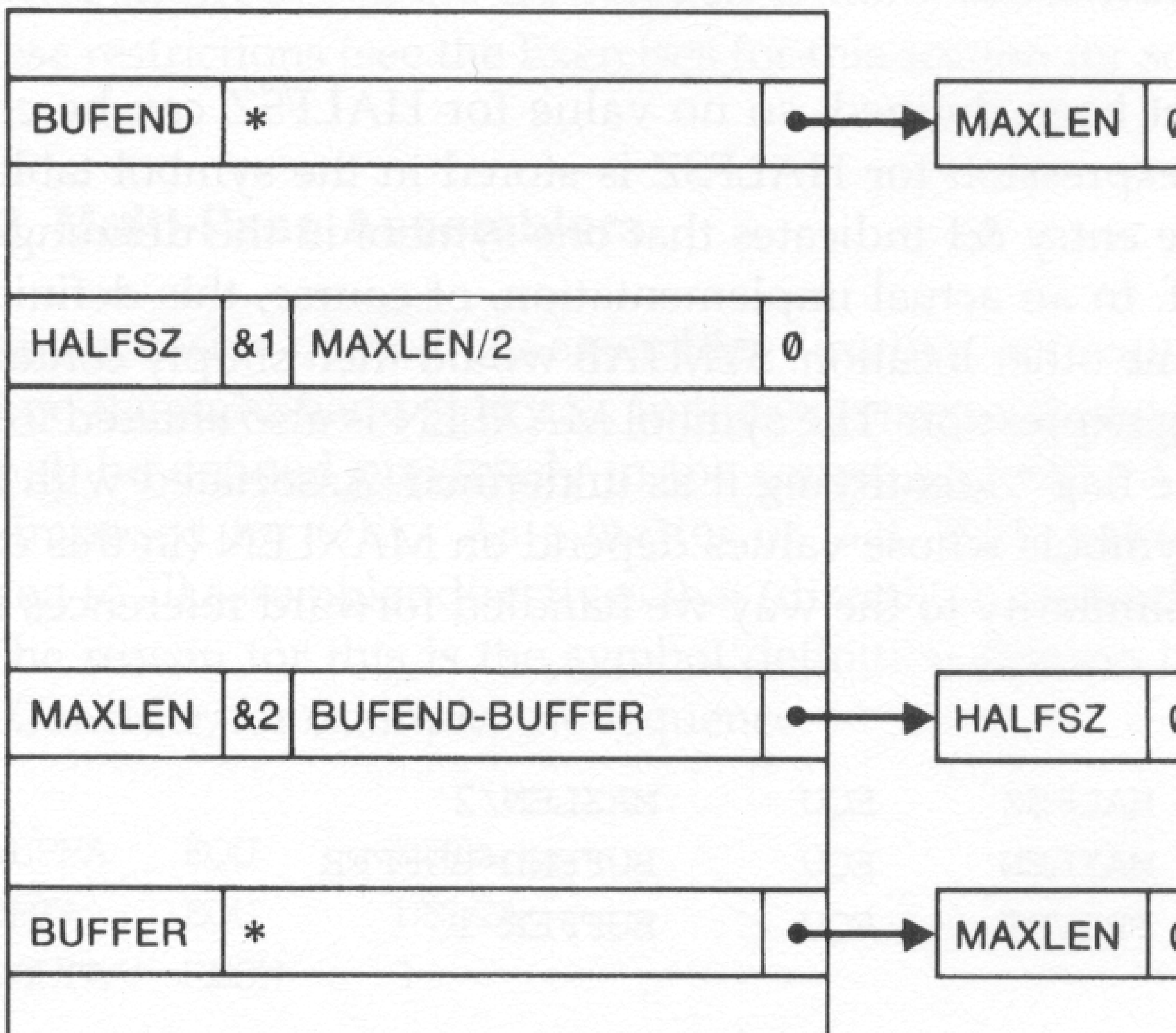
Multi-Pass Assembler Implementation

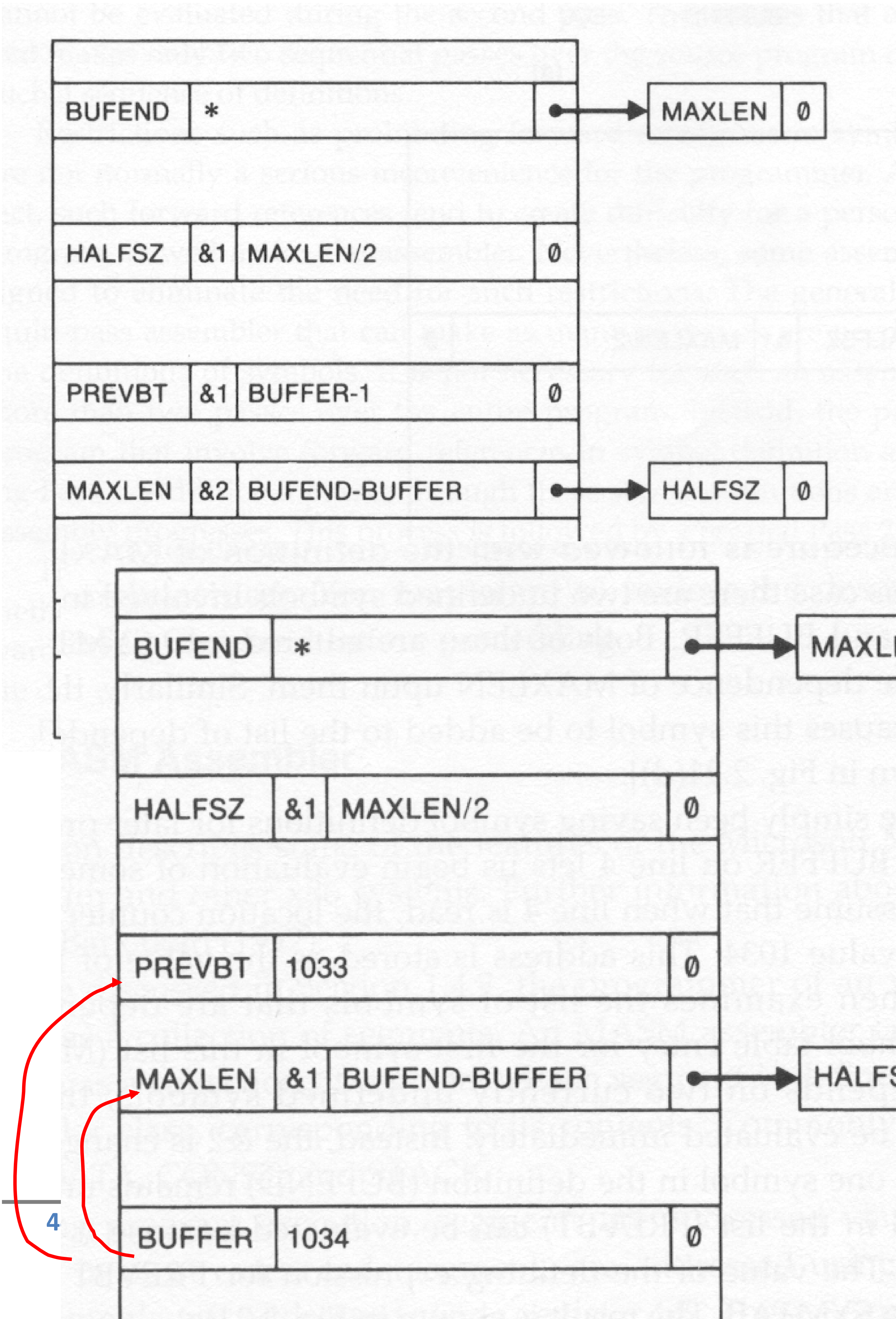
Steps:

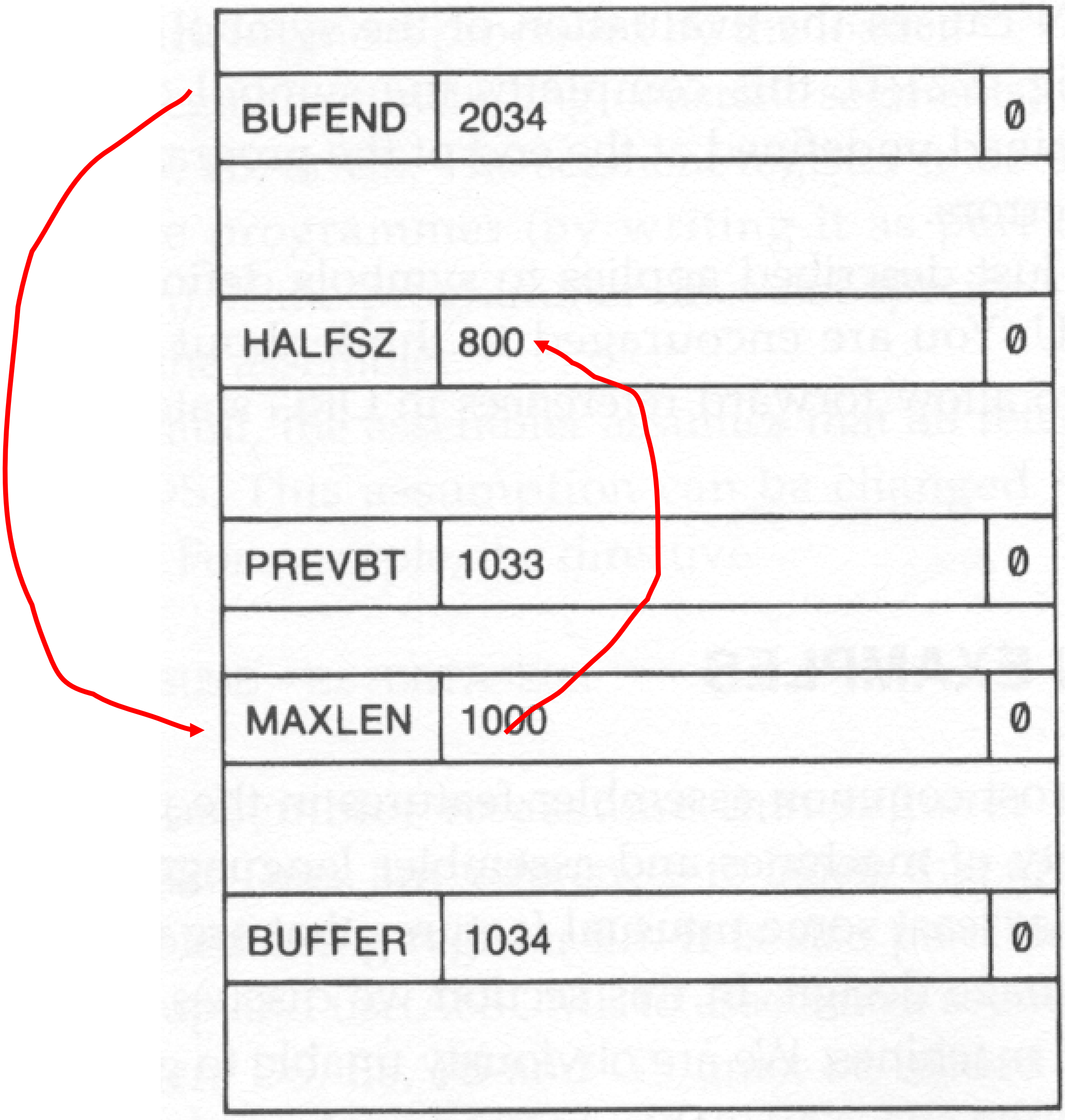
- Use a symbol table to store symbols that are not totally defined yet.
- For a undefined symbol, in its entry,
  - We store the names and the number of undefined symbols which contribute to the calculation of its value.
  - We also keep a list of symbols whose values depend on the defined value of this 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.

```
HALFSZ    EQU    MAXLEN/2
MAXLEN    EQU    BUFEND-B
PREVBT    EQU    BUFFER-1
                 .
                 .
                 .
BUFFER    RESB   4096
BUFEND    EQU    *
```


HALFSZ
&1
MAXLEN/2
Ø


BUFEND
*
MAXLEN
HALFSZ
&1
MAXLEN/2
Ø
MAXLEN
&2
BUFEND-BUFFER
HALFSZ
BUFFER
*
MAXLEN


BUFEND
*
MAXLEN
0
HALFSZ
&1
MAXLEN/2
0
PREVBT
&1
BUFFER-1
0
MAXLEN
&2
BUFEND-BUFFER
0
HALFSZ
0
BUFEND
*
MAXL
HALFSZ
&1
MAXLEN/2
0
PREVBT
1033
0
MAXLEN
&1
BUFEND-BUFFER
HALFS
BUFFER
1034
0


BUFEND
2034
∅
HALFSZ
800
∅
PREVBT
1033
∅
MAXLEN
1000
∅
BUFFER
1034
∅