Module 4

Linker and Loader

LOADER AND LINKER

Ques 1) What is loading and linking?

Or

Define terms:

i) Loading
ii) Relocation
iii) Linking

Ans: Loading and Linking

The Source Program written in assembly language or high level language will be converted to object program, which is in the machine language form for execution. This conversion either from assembler or from compiler, contains translated instructions and data values from the source program, or specifies addresses in primary memory where these items are to be loaded for execution. This contains the following three processes, and they are,

1) **Loading:** It allocates memory location and brings the object program into memory for execution - **(Loader)**
2) **Linking:** It combines two or more separate object programs and supplies the information needed to allow references between them - **(Linker)**
3) **Relocation:** It modifies the object program so that it can be loaded at an address different from the location originally specified - **(Linking Loader)**

Ques 2) What is loader? List the various steps of loader. Also list the various types of loaders.

Ans: Loader

A loader is a utility of an operating system. It copies programs from a storage device to a computer's main memory, where the program can then be executed. Loader performs the loading function. It is responsible for initiating the execution of the process.

Various Steps a Loader Performs

The various steps required for working of loader are as follows:

Step 1: Read executable file's header to determine the size of text and data segments.

Step 2: Create a new address space for the program.

Step 3: Copies instructions and data into address space.

Step 4: Copies arguments passed to the program on the stack.

Step 5: Initializes the machine registers including the stack pointer.

Step 6: Jumps to a start-up routine that copies the program's arguments from the stack to registers and calls the program's main routine.

Types of Loader

1) Assemble-and-Go Loader
2) Relocating Loader (Relative Loader)
3) Absolute Loader (Bootstrap Loader)
4) Direct Linking Loader

Ques 3) What are the basic functions of a loader? (2020[03])

Ans: Basic Loader Functions

A loader is a system program that performs the loading function. It brings object program into memory and starts its execution. The role of loader is as shown in the **figure 4.1**:

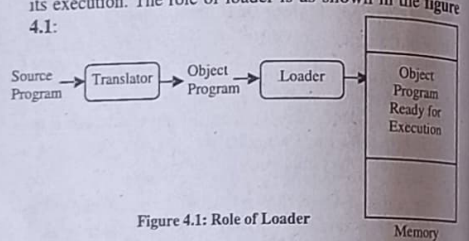


Figure 4.1: Role of Loader

Translator may be assembler/compiler, which generates the object program and later loaded to the memory by the loader for execution.

In **figure 4.2** the translator is specifically an assembler, which generates the object loaded, which becomes input to the loader:

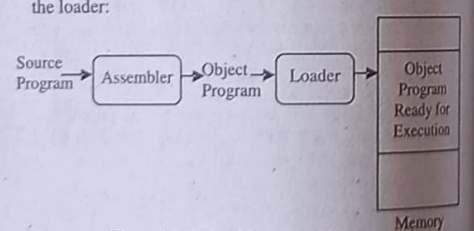


Figure 4.2: Role of Loader with

Figure 4.3 shows the role of both loader and linker:

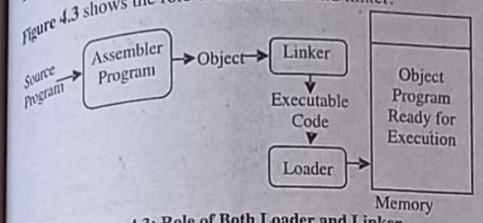


Figure 4.3: Role of Both Loader and Linker

Ques 4) Discuss assemble-and-go loader with their advantages and disadvantages.

Ans: Assemble-and-Go Loader

A assemble-and-go loader is one in which the assembler itself does the process of compiling and then places the assembled instructions in the designated memory locations. The assembling process is done first and then the assembler causes a transfer to the first instruction of the program. This loading scheme is also known as Assembler-and-Go. The loader here has just one instruction that directs the loading of the newly assembled code into the memory. **For example,** WATFOR FORTRAN compiler

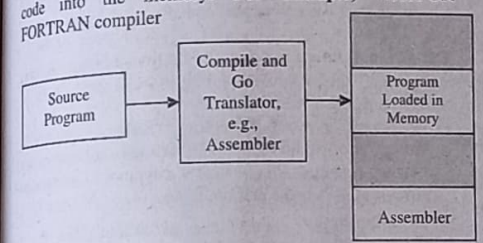


Figure 4.4: Compile and Go Loader

Advantages of Assemble-and-go loader

1) It is relatively easy to implement.
2) Involves no extra procedures.

Disadvantages of Assemble-and-go loader

1) A portion of memory is wasted.
2) It is necessary to re-translate the user's program every time it is run.
3) It is very difficult to handle multiple segments.
4) It is very difficult to produce orderly module programs.

Ques 5) Discuss relocating loader with their advantages and disadvantages.

Ans: Relocating Loader (Relative Loader)

The heart of a linker or loader's actions is **relocation** and **code modification**. The process of modifying the addresses used in the address dependent instructions of a program such that the program can execute from any allocated area of the memory is called **Program Relocation**. Loaders performing such a task is called **relocating loader**. As part of the loading process, the loader modifies the object code to reflect the actual addresses assigned. Relocating loaders are versatile when compared to the absolute loaders, when it comes to re-assembling routines every time when a single routine is changed.

Advantages of Relocating Loaders

1) Program can be loaded and executed in different parts of memory irrespective of the address.
2) Relocation is done by the usage of relocation bits.
3) Allocation is done by the availability of program length.
4) Linking is also done, as a part of the loading process itself.
5) Loader performs all the four functions given below:
   i) Memory allocation,
   ii) Subroutine linkages,
   iii) Relocation, and
   iv) Loading of code into the memory.

Disadvantages of Relocating Loaders

1) The complexity of the loader increases with the program size and capability to handle larger number of subroutines.
2) There is an increased overhead on memory as there is increase in number of subroutines.

Ques 6) Discuss bootstrap loader (absolute loader) with their advantages and disadvantages.

Ans: Absolute Loader (Bootstrap Loader)

The absolute loader is the simplest of all the loaders.

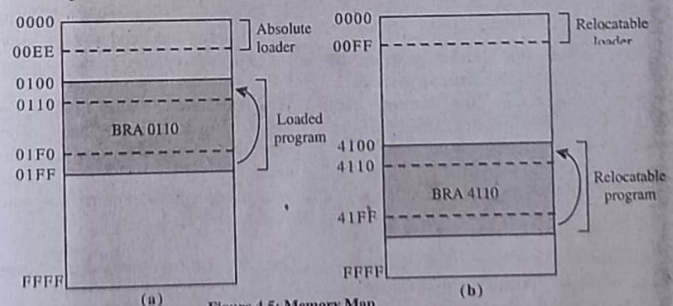


Figure 4.5: Memory Map

It can read a machine language program from the specified backup storage and place it in memory starting from a pre-determined address (**figure 4.5**). The machine language program so loaded will work correctly only if it is loaded starting from the specified address. Absolute type of loader is impractical, as there are lots of complications involved in loading the program. "Bootstrap loader" is an example of absolute loader.

Advantages of Absolute Loader

1) The absolute loader simply performs input and output operation to load a program into the main memory.
2) An absolute loader is coded in very few machine instructions.
3) Program is stored in the library in their ready-to-execute form. Such a library is called a Phase Library.

Disadvantages of Absolute Loader

1) The programmer must explicitly specify the assembler the memory where the program is to be loaded.
2) Handling multiple subroutines become difficult since the programmer must specify the address of the routines wherever they are referenced to perform subroutine linkages.
3) When dealing with lots of subroutines the manual shuffling and re-shuffling of memory address references in the routines become tedious and complex.

Ques 7) Given an idle computer with no program in memory, how do we get things started? (2020[03])

Ans: In this situation, with the machine empty and idle, there is no need for program relocation. We can simply specify the absolute address for whatever program is first loaded. Most often, this program will be the operating system, which occupies a predefined location in memory. This means that we need some means of accomplishing the functions of an absolute loader.

Some early computers required the operator to enter into memory the object code for an absolute loader, using switches on the computer console. However, this process is much too inconvenient and error-prone to be a good solution to the program.

On some computers, an absolute loader program is permanently resident in a read-only memory (ROM). When some hardware signal occurs (**for example,** the operator pressing a "system start" switch), 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.

However, some machines do not have such read-only storage. In addition, it can be inconvenient to change a ROM program if modifications in the absolute loader are required.

Ques 8) Discuss direct linking loader with their advantages and disadvantages.

Ans: Direct Linking Loader

A direct linking loader is a general relocatable loader, and is perhaps the most popular scheme presently used. It allows programming multiple procedure segments and multiple data segment. This gives the programmer more convenience, since there is no need to reference data or instructions present in other segment. This provides flexible reference and accessing ability, while at the same time allowing independent accessing ability of the program. The assembler gives the loader the following information:

1) The length of the segment.
2) A list of all symbols in the segment that may be referenced by other segments and their relative location within the segment.
3) A list of all symbols that are not defined in the segment but referenced in the segment.
4) Conveys the entry point of the program which is to know where the loader is to transfer the control and when the instructions are loaded.

The assembler does not provide its own symbol table to the loader. The assembler provides following types of cards in the object (deck).

1) **External Symbol Directory (ESD):** It provides information about all symbols defined and used in the source program. It is basically a symbol dictionary or look-up. This is the symbol table.
2) **Text (TXT):** It contains the actual translated object code, non-relocated data, initial values and so on.
3) **Relocatable and Linkage Directory (RLD):** It contains information about address sensitive instructions in the source program. They need to be relocated as performed in relocating loader.
4) **End (END):** It signifies the end of the object deck. This is the last card in an object deck.

Advantages of Direct Linking Loader

1) It provides the programmer with multiple procedure segments & multiple data segments.
2) It provides endorsement referencing & accessing ability.
3) It allows independent translations of programs along with above benefits.

Disadvantages of Direct Linking Loader

The linking and loading need to be postponed until the execution. During the execution if at all any subroutine is needed then the process of execution needs to be suspended until the required subroutine gets loaded in the main memory.

Ques 9) Discuss the design of absolute loader.

Or

Give the algorithm for an absolute loader. (2017 [03])

Or

Design an algorithm for an absolute loader. (2019[03])

Ans: Design of an Absolute Loader

The operation of absolute loader is very simple. The object code is loaded to specified locations in the memory. At the end the loader jumps to the specified address to begin execution of the loaded program. The role of absolute loader is as shown in the **figure 4.6**:

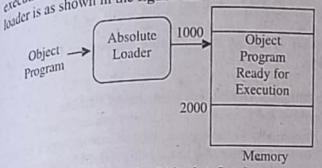


Figure 4.6: Role of Absolute Loader

Algorithm for an 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
```

The **advantage** of absolute loader is simple and efficient. But the **disadvantages** are, the need for programmer to specify the actual address, and, difficult to use subroutine libraries.

The algorithm for this type of loader is given below. The object program and, the object program loaded into memory by the absolute loader are also shown. Each byte of assembled code is given using its hexadecimal representation in character form which is easy to read by human beings.

Each byte of object code is stored as a single byte. Most machine store object programs in a binary form, and it is necessary that file and device conventions do not cause some of the program bytes to be interpreted as control characters.

```
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

One byte character

Memory address	Contents			
0000	xxxxxxxx	xxxxxxxx	xxxxxxxx	xxxxxxxx
0010	xxxxxxxx	xxxxxxxx	xxxxxxxx	xxxxxxxx
⋮	⋮	⋮	⋮	⋮
0FF0	xxxxxxxx	xxxxxxxx	xxxxxxxx	xxxxxxxx
1000	141033 48	203900 10	362810 30	301015 48
1010	206130 10	030010 2A	0C1039 00	102D 0C 10
1020	364820 61	081033 4C	000045 4F	460000 03
1030	000000 xx	xxxxxxxx	xxxxxxxx	xxxxxxxx
⋮	⋮	⋮	⋮	⋮
2030	xxxxxxxx	xxxxxxxx	xx041D 30	001030 E0
2040	205D3020	3FD8205D	281030 30	205754 90
2050	392C205E	38203F10	10364C 00	00F10010
2060	000410 30	E020793 0	206450 90	39DC2079
2070	2C1036 38	20644C00	0005 xxxx	xxxxxxxx
2080	xxxxxxxx	xxxxxxxx	xxxxxxxx	xxxxxxxx
⋮	⋮	⋮	⋮	⋮

Half-byte

← COPY

(b) Program Loaded in Memory

Figure 4.7: Loading of an Absolute Program

The **Header record** is first checked. Then, each **Text record** is read to memory. When the **End record** is encountered, the loader jumps to the specified address.

Ans: Object Program Format

In our object program, each byte of assembled code is given using its hexadecimal representation in **character form**.

For example, the opcode for **STL** instruction would be represented by the pair of characters "1" and "4".

1) When they are read by the loader, they occupy two bytes of memory and must be stored in a singly byte with hexadecimal value 14.
2) Each pair of bytes from the object program record must be packed together into one byte during loading.

This method of representing an object program is inefficient in terms of **space** and **execution time**.

Therefore, most machines store object program in a **binary form** – Each byte of object code is stored as a single byte in the object program. The file and device conventions should not cause some of the object program bytes to be interpreted as control character.

For example, indicating the end of a record with a byte containing hexadecimal 00 would clearly be unsuitable for use with a binary object program. Object program stored in binary form do not lend themselves well to printing or to reading by human beings. Therefore, we continue to use character representations of object programs in this course.

Ques 11) Discuss the issues related with absolute loader.

Ans: Issues of Absolute Loaders

1) On a larger and more advanced machine, one does not know in advance where a program will be loaded.
2) Efficient sharing of the machine requires that one writes relocatable programs instead of absolute one.
   i) Most such libraries contain many more subroutines than will be used by any one program.
   ii) To make efficient use of memory, it is important to be able to select and load exactly those routines that are needed.

Ques 12) Describe the machine dependent features of loader.

Ans: Machine Dependent Features of Loader

Features of machine dependent loader are as follows:

1) 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.
2) Linking is not a machine-dependent function, but it has the same implementation techniques for loaders – The process of linking usually involves relocation of some of the routines being linked together.

Ques 13) What is relocation?

Ans: Relocation

The concept of program relocation is, the execution of the object program using any part of the available and sufficient memory. The object program is loaded into memory wherever there is room for it. The actual starting address of the object program is not known until load time.

Relocation provides the efficient sharing of the machine with larger memory and when several independent programs are to be run together.

It also supports the use of subroutine libraries efficiently. Loaders that allow for program relocation are called relocating loaders or relative loaders.

Ques 14) Explain various methods of specifying relocation.

Or

With the help of an Algorithm, explain how relocation is done using modification bits and direct addressing with relocation bits.

Or

What is the use of Bitmask in program relocation? **(2018[03])**

Ans: Methods for Specifying Relocation

Two methods for specifying relocation in object programs:

1) **Use Modification Records:** A Modification record is used to describe each part of the object code that must be changed when the program is relocated.

Figure 4.8 shows a SIC/XE program to illustrate this first method of specifying relocation:

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.

Figure 4.9 displays the object program corresponding to the source in **figure 4.8:**

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

Use Modification records

Figure 4.8

```
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,B85
T,001070,07,3B2FEF,4F0000,05
M,000007,05+COPY
M,000014,05+COPY
M,000027,05+COPY
E,000000
```

Modification records for + JSUB

Figure 4.9 object program corresponding to the source in figure 4.8

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 (**figure 4.10**).

SIC/XE Relocation Loader Algorithm

```
begin
  get PROGADDR from operating system
  while not end of input do
    begin
      read next record
      while record type ≠ 'E' do
        begin
          read next input record
          while record type = 'T' then
            begin
              move object code from record to location
                ADDR + specified address
            end
          while record type = 'M'
            add PROGADDR at the location PROGADDR +
              specified address
        end
    end
end
```

Figure 4.10: SIC/XE Relocation Loader Algorithm

The Modification record scheme is a convenient means for specifying program relocation; however, it is not well suited for use with all machine architectures. **For example,** consider the program in **figure 4.11**.

Line Number	Machine Address	Label	Instruction	Operand	Object Code
5	1000	COPY	START	1000 (Starting address)	
10	1000	FIRST	STL	RETADR	141033
15	1003	CLOOP	JSUB	RDREC	482039
20	1006		LDA	LENGTH	001036
25	1009		COMP	ZERO	281030
30	100C		JEQ	ENDFIL	301015
35	100F		JSUB	WRREC	482061
40	1012		J	CLOOP	3C1003
45	1015	ENDFIL	LDA	EOF	00102A
50	1018		STA	BUFFER	0C1039
55	101B		LDA	THREE	00102D
60	101E		STA	LENGTH	0C1036
65	1021		JSUB	WRREC	482061
70	1024		LDL	RETADR	081033
75	1027		RSUB	PC ← (L)	4C0000
80	102A	EOF	BYTE	C'EOF'	454F46
85	102D	THREE	WORD	3	000003
90	1030	ZERO	WORD	0	000000
95	1033	RETADR	RESW	1	
100	1036	LENGTH	RESW	1	
105	1039	BUFFER	RESB	4096	
110					
115			SUBROUTINE TO READ RECORD INTO BUFFER		
120					
125	2039	RDREC	LDX	ZERO	041030
130	203C		LDA	ZERO	001030
135	203F	RLOOP	TD	INPUT	E0205D
140	2042		JEQ	RLOOP	30203F
145	2045		RD	INPUT	D8205D
150	2048		COMP	ZERO	281030
155	204B		JEQ	EXIT	302057
160	204E		STCH	BUFFER, X	549039
165	2051		TIX	MAXLEN	2C205E
170	2054		JLT	RLOOP	38203F
175	2057	EXIT	STX	LENGTH	101036
180	205A		RSUB		4C0000
185	205D	INPUT	BYTE	X'F1'	F1
190	205E	MAXLEN	WORD	4096	001000
195					
200			SUBROUTINE TO WRITE RECORD FROM BUFFER		
205					
210	2061	WRREC	LDX	ZERO	041030
215	2064	WLOOP	TD	OUTPUT	E02079
220	2067		JEQ	WLOOP	302064
225	206A		LDCH	BUFFER, X	509039
230	206D		WD	OUTPUT	DC2079
235	2070		TIX	LENGTH	2C1036
240	2073		JLT	WLOOP	382064
245	2076		RSUB		4C0000
250	2079	OUTPUT	BYTE	X'05'	05
255			END	FIRST	

Begin a new Text record

Figure 4.11

This is a relocatable program written for the standard version of SIC. The important **difference** between this example and the one in **figure 4.8** is that the standard SIC machine does not use relative addressing. In this program the addresses in all the instructions except RSUB must be 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 **figure 4.9**.

2) Use **Direct Addressing with Relocation Bits:** On a machine that primarily uses direct addressing and has a fixed instruction format, it is often more efficient to specify relocation using a different technique. **Figure 4.12** show this method applied to SIC program example:

```
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,F1,000000
T,001061,19,FE0,040030,E01079,301064,509039,DC1079,2C0036,381064,4C0000,05
E,000000
```

No modification is needed for RSUB

Data content. No modification is needed

Bit mask: Each relocation bit is associated with each word of object code

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 from Line 185.

Each relocation bit is associated with a 3-byte segment of object code in the Text record

Figure 4.12: Object Program with Relocation Bits

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. The relocation bits are gathered together into a **bit mask** following the

2) **EXTREF (External Reference):** The EXTREF statement names symbols used in this (present) control section and are defined elsewhere. **For example,** EXTREF RDREC, WRREC
EXTREF LISTB, ENDB, LISTC, ENDC

Implementation of EXTDEF and EXTREF

The assembler must include information in the object program that will cause the loader to insert proper values where they are required – in the form of Define record (D) and, Refer record(R).

1) **Define Record:** The format of the Define record (D) along with examples is as shown here:
   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

   Example Records
   D LISTA 000040 ENDA 000054
   D LISTB 000060 ENDB 000070

2) **Refer Record:** The format of the Refer record (R) along with examples is as shown here:
   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

   Example Records
   R LISTB ENDB LISTC ENDC
   R LISTA ENDA LISTC ENDC
   R LISTA ENDA LISTB ENDB

Here are the three programs named as PROGA, PROGB and PROGC, which are separately assembled and each of which consists of a single control section. LISTA, ENDA in PROGA, LISTB, ENDB in PROGB and LISTC, ENDC in PROGC are external definitions in each of the control sections. Similarly LISTB, ENDB, LISTC, ENDC in PROGA, LISTA, ENDA, LISTC, ENDC in PROGB, and LISTA, ENDA, LISTB, ENDB in PROGC, are external references. These sample programs given here are used to illustrate linking and relocation. The **following figures** give the sample programs and their corresponding object programs, which contain D and R records along with other records.

Program Linking Example (PROGA)

```
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-     000014
                   LISTB)
0060 REF8  WORD    LISTB-LISTA           FFFFC0
           END     REF1
```

Program Linking Example (PROGB)

```
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-     FFFFF0
                   LISTB)
007C REF8  WORD    LISTB-LISTA           000060
           END
```

Program Linking Example (PROGC)

```
0000 PROGC START      0
           EXTDEF  LISTC,
                   ENDC
           EXTREF  LISTA.  ENDB,   LISTB,
                   ENDB
           ..........
           ..........
0018 REF1  +LDA    LISTA                 03100000
001C REF2  +LDT    LISTB+4               77100004
0020 REF3  +LDX    #ENDA-                05100000
                   LISTA

0030 LISTC EQU     *

0042 ENDC  EQU     *
0042 REF4  WORD    ENDA-                 000030
                   LISTA+LISTC
0045 REF5  WORD    ENDC-LISTC-           000008
                   10
0045 REF6  WORD    ENDC-                 000011
                   LISTC+LISTA-1
004B REF7  WORD    ENDA-LISTA-           000000
                   (ENDB-LISTB)
004E REF8  WORD    LISTB-LISTA           000000
           END
```


Ques 17) Define the data structure for linking loader.

Or

What is ESTAB?

Or

Describe the data structure used for the linking loads algorithm. (2017 [2.5])

Or

Justify the need for having two passes in a linking loader. Illustrate the data structures used for a linking loader, showing how they are used in each pass. (2019[04])

Ans: Need for Two Passes in Linking Loader

The algorithm for a linking loader is considerably more complicated than the absolute loader algorithm. The input to such a loader consists of a set of object programs (i.e., control sections) that are to be linked together. It is possible (and common) for a control section to make an external reference to a symbol whose definition does not appear until later in this input stream.

In such a case the required linking operation cannot be performed until an address is assigned to the external symbol (that is, until the later control section is read). Thus 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:

1) Pass 1 assigns addresses to all external symbols
2) Pass 2 performs the actual loading, relocation and linking.

Data Structures for a Linking Loader

The algorithm for a linking loader is considerably more complicated than the absolute loader program. The concept given in the program linking section is used for developing the algorithm for linking loader. The modification records are used for relocation so that the linking and relocation functions are performed using the same mechanism. Linking loader uses two-passes logic:

Pass 1: Assign addresses to all external symbols.

Pass 2: Perform the actual loading, relocation, and linking.

ESTAB (External Symbol Table) is the main data structure for a linking loader:

1) It is to store the **name** and **address** of each external symbol.
2) It is similar to SYMTAB in the assembler.
3) It indicates in which control section the symbol is defined.
4) A **hash organisation** is typically used for this table.
5) Two variables are defined:
   i) **PROGADDR (Program Load Address):** Indicate the beginning address in memory where the linked program is to be loaded. Its value is supplied to loader by the operating system.
   ii) **CSADDR (Control Section Address):** Contain the starting address assigned to the control section currently being scanned by the loader.

For example, ESTAB (refer three programs PROGA, PROGB, and PROGC) given is as shown below. The ESTAB has four entries in it; they are name of the control section, the symbol appearing in the control section, its address and length of the control section.

Control Section	Symbol	Address	Length
PROGA		4000	63
	LISTA	4040	
	ENDA	4054	
PROGB		4063	7F
	LISTB	40C3	
	ENDB	40D3	
PROGC		40E2	51
	LISTC	4112	
	ENDC	4124	

Use of Data Structure in Pass 1

During the first pass, the loader is concerned only with Header and Define record types in the control sections. The beginning load address for the linked program (PROGADDR) is obtained from the operating System. This becomes the starting address (CSADDR) for the first control section in the input sequence. The control section name from the 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. When the End record is read, the control section length CSLTH (which was saved from the Header record) is added to CSADDR. This calculation gives the starting address for the next control section in sequence. At the end of Pass I, 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. This information is often useful in program debugging.

Use of Data Structure in Pass 2

Pass 2 of our loader performs the actual loading, relocation, and linking of the program. CSADDR is used in the same way it was in Pass 1– it always contains the actual starting address of the control section currently being loaded. As each Text record is read, the object code is moved to the specified address (plus the current value of CSADDR). When a Modification record is encountered, the symbol whose value is to be used for modification is looked up in ESTAB. This value is then added to or subtracted from the indicated location in memory.

Ques 18) Describe the program logic for pass 1 of linking loader. Also write its algorithm.

Or

Give the algorithm for pass 1 of the linking loader. (2020[04]) (2017 [2.5])

Or

Explain the algorithm for Pass 1 of Linking Loader. (2018 [06])

Ans: Program Logic for Pass 1

Pass 1 assign addresses to all external symbols. The variables and Data structures used during pass 1 are,

PROGADDR (Program Load Address) from OS, CSADDR (Control Section Address), CSLTH (Control Section Length) and ESTAB. The pass 1 processes the Define Record. In Pass 1, the loader is concerned only with **Header** and **Define** record types in the control sections:

1) **Initialisation**
   i) The beginning load address for the linked program (PROGADDR) is obtained from the operating system.
   ii) This becomes the starting address (CSADDR) for the first control section in the input sequence.
2) **Record Scanning**
   i) The control section name from the Header record is entered into ESTAB, with value given by CSADDR.
   ii) All external symbols appearing in the Define record for the control section are also entered into ESTAB.
   iii) External symbols' addresses are obtained by adding the value specified in the Define record to CSADDR. (Specified address + CSADDR).
   iv) When End record is read, the control section length CSLTH (obtained from Header record) is added to CSADDR to calculate the starting address for the next control section. (CSADDR = CSAADR + CSLTH)

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. This information is useful in program debugging.

Algorithm for Pass 1 of Linking Loader

The algorithm for Pass 1 of Linking Loader is given below:

```
begin
get PROGADDR from operating system
set CSADDR to PROGADDR (for first control section)

while not end of input do //Each iteration processes one
control section
    begin
        read next input record {Header record for control
    section}
        set CSLTH to control section length
        //Header record
        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    //Define
                record
                    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'}      //reach End record
            add CSLTH to CSADDR {starting address for
            next control section}
        end {while not EOF}
end {Pass 1}
```


Ques 19) Describe the program logic for pass 2 of linking loader. Also write its algorithm.

Or

Give the algorithm for pass 2 of a linking loader.

(2019[04])

Ans: Program Logic for Pass 2

Pass 2 of linking loader perform the actual loading, relocation, and linking. It uses modification record and lookup the symbol in ESTAB to obtain its address. Finally it uses end record of a main program to obtain transfer address, which is a starting address needed for the execution of the program. The pass 2 process Text record and Modification record of the object programs:

1) CSADDR is used in the same way as it was in Pass 1 – It always contains the actual starting address of the control section currently being loaded.
2) As each **Text record** is read, the object code is moved to the specified address plus the current value of CSADDR. (specified address + CSADDR)
3) When a **Modification record** is encountered, the symbol whose value is to be used for modification is looked-up in ESTAB – This value is then added to or subtracted from the indicated location in memory.

The last step of Pass 2 is to transfer control to the loaded program to begin execution:

1) The **End record** for each control section may contain the address of the first instruction in that control section to be executed.
2) Two scenarios could be encountered:
   i) If more than one control section specifies a transfer address, the loader arbitrarily uses the last one encountered.
   ii) If no control section contains a transfer address, the loader uses the beginning of the linked program (i.e., PROGADDR) as the transfer point.
3) Normally, a transfer address would be placed in the **End record** for a **main program**, but not for a subroutine.

Algorithm for Pass 2 of Linking Loader

The algorithm for Pass 2 of Linking Loader is given below:

```
begin
set CSADDR to PROGADDR
set EXECADDR to PROGADDR
while not end of input do
    begin    //Each iteration processes one control section
        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    //Text record
                    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
                //Modification record
                    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)
            //End record: transfer address is specified
        add CSLTH to CSADDR          //Move to next
        CS
    end {while not EOF}
    jump to location given by EXECADDR{start execution of
    loaded program}
end {Pass 2}
```

Ques 20) Describe the advanced method for external symbol.

Ans: Advanced Method for External Symbols

One can improve the efficiency of the linking loader. Also observe that, even though he/she has defined Refer record (R), he/she has not made use of it. The efficiency can be improved by the use of local searching instead of multiple searches of ESTAB for the same symbol. For implementing this one assigns a reference number to each external symbol in the Refer record:

1) One can assign a reference number to each external symbol referred to in a control section.
2) This reference number is used in Modification records.

For example:

i) Control section name with reference number 01.
ii) The other external reference symbols are assigned numbers as part of the **Refer record** for the control section.

3) The main **advantage** of this reference-number mechanism is that it avoids multiple searches of ESTAB for the same symbol during the loading of a control section:
   i) An external reference symbol can be looked up in ESTAB once for each control section that uses it.
   ii) The value for code modification can then be obtained by simply indexing into an array of these values.

The object programs for PROGA, PROGB and PROGC are shown below, with above modification to Refer record:

Advanced Method for External Symbols (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
```

⇒

```
H,PROGA      ,000000,000063
D,LISTA      ,000040,ENDA     ,000054
R,02,LISTB   ,03,ENDB   ,04,LISTC   ,05,ENDC
T,000020,0A,03201D,77100004,050014
T,000054,0F,000014,FFFFF6,00003F,000014,FFFFC0
M,000024,05,+02
M,000054,06,+04
M,000057,06,+05
M,000057,06,-04
M,00005A,06,+05
M,00005A,06,-04
M,00005A,06,+01
M,00005D,06,-03
M,00005D,06,+02
M,000060,06,+02
M,000060,06,-01
E,000020
```

Figure 4.15

Advanced Method for External Symbols (PROGB)

```
H,PROGB  ,000000,00007F
D,LISTB  ,000060,ENDB  ,000070
R,LISTA  ,ENDA ,LISTC  ,ENDC
T,000036,0B,03100000,772027,05100000
T,000070,0F,000000,FFFFF6,FFFFFF,FFFFF0,000060
M,000037,05,+LISTA
M,00003E,05,+ENDA
M,00003E,05,-LISTA
M,000070,06,+ENDA
M,000070,06,-LISTA
M,000070,06,+LISTC
M,000073,06,+ENDC
M,000073,06,-LISTC
M,000076,06,+ENDC
M,000076,06,- LISTC
M,000076,06,+LISTA
M,000079,06,+ENDA
M,000079,06,-LISTA
M,00007C,06,+PROGB
M,00007C,06,-LISTA
E
```

⇨

```
H,PROGB  ,000000,00007F
D,LISTB  ,000060,ENDB  ,000070
R,02LISTA ,03ENDA  ,04LISTC  ,05ENDC
T,000036,0B,03100000,772027,05100000
T,000070,0F,000000,FFFFF6,FFFFFF,FFFFF0,000060
M,000037,05,+02
M,00003E,05,+03
M,00003E,05,-02
M,000070,06,+03
M,000070,06,-02
M,000070,06,+04
M,000073,06,+05
M,000073,06,-04
M,000076,06,+05
M,000076,06,-04
M,000076,06,+02
M,000079,06,+03
M,00007C,09,-02
M,00007C,06,-01
M,00007C,06,-02
E
```

Figure 4.16

Advanced Method for External Symbols (PROGC)

```
H,PROGC  ,000000,000051
D,LISTC  ,000030,ENDC  ,000042
R,LISTA  ,ENDA  ,LISTB  ,ENDB
T,000018,0C,03100000,77100004,05100000
T,000042,0F,000030,000008,000011,000000,
000000
M,000019,05,+LISTA
M,00001D,05,+LISTB
M,000021,05,+ENDA
M,000021,05,-LISTA
M,000042,06,+ENDA
M,000042,06,-LISTA
M,000042,06,+PROGC
M,00004B,06,+LISTA
M,00004B,06,+ENDA
M,00004B,06,-LISTA
M,00004B,06,-ENDB
M,00004B,06,+LISTB
M,00004E,06,+LISTB
M,00004E,06,-LISTA
E
```

⇨

```
H,PROGC  ,000000,000051
D,LISTC  ,000030,ENDC  ,000042
         ,03ENDA  ,04LISTB  ,05ENDB
T,000018,0C,03100000,77100004,05100000
T,000042,0F,000030,000008,000011,000000,
000000
M,000019,05,+02
M,00001D,05,+04
M,000021,05,+03
M,000042,06,+03
M,000042,06,-02
M,000042,06,+01
M,00004B,06,+02
M,00004B,06,+03
M,00004B,06,-02
M,00004B,06,-05
M,00004B,06,+04
M,00004E,06,+04
M,00004E,06,-02
E
```

Figure 4.17

Symbol and Addresses in PROGA, PROGB and PROGC are as **shown below**. These are the entries of ESTAB. The main **advantage** of reference number mechanism is that it avoids multiple searches of ESTAB for the same symbol during the loading of a control section.

PROGA

Reference No.	Symbol	Address
1	PROGA	4000
2	LISTB	40C3
3	ENDB	40D3
4	LISTC	4112
5	ENDC	4124

PROGB

Reference No.	Symbol	Address
1	PROGB	4063
2	LISTA	4040
3	ENDA	4054
4	LISTC	4112
5	ENDC	[illegible]

PROGC

Reference No.	Symbol	Address
1	PROGC	4063
2	LISTA	4040
3	ENDA	4054
4	LISTB	40C3
5	ENDB	40D3

Ques 21) Discuss the machine independent features of loader. Also list the loader design options.

Or

Write notes on machine independent loader features. (2017 [04])

Or

Write notes on the different loader design options. (2017 [04])

Or

List and explain the different machine independent features of loaders. (2018[03])

Or

Write short notes on the following:

i) Automatic Library Search

ii) Loader Options

Or

List and explain the different machine independent loader features. (2019[04])

Or

Explain the concept of automatic library search. (2020[03])

Ans: Machine Independent Loader Features

Some loader features are not directly related to machine architecture and design. Automatic Library Search and Loader Options are such Machine-independent Loader Features.

1) **Automatic Library Search:** This feature allows a programmer to use standard subroutines without explicitly including them in the program to be loaded. The routines are automatically retrieved from a library as they are needed during linking. This allows programmer to use subroutines from one or more libraries. The subroutines called by the program being loaded are automatically fetched from the library, linked with the main program and loaded. The loader searches the library or libraries specified for routines that contain the definitions of these symbols in the main program. Automatic library search allows programmer to use subroutines from one or more libraries.

2) **Loader Options:** Many loaders have a special command language that is used to specify options. Sometimes there is a separate input file to the loader that contains such control statements. Sometimes these same statements can also be embedded in the primary input stream between object programs. Loader options allow the user to specify options that modify the standard processing. The options may be specified in three different ways. They are:
   1) Specified using a command language,
   2) Specified as a part of job control language that is processed by the operating system, and
   3) Be specified using loader control statements in

Loader Design Options

There are some common alternatives for organising the loading functions, including relocation and linking. s

1) **Linking Loaders:** It Perform all linking and relocation at load time. The Other Alternatives are Linkage editors, which perform linking prior to load time

2) **Dynamic Linking:** In this linking function is performed at execution time

Ques 22) Write a note on linkage editors.

Or

What is linkage editor? Compare it with linking loader.

Or

Differentiate between linking loaders and linkage editors. (2017, 2019 [03])

Ans: Linkage Editors

It performs linking prior to the load time. The linkage editors are found in many computing systems instead of linking loader and the concept of dynamic linking loads subprograms at the time of first call. A linkage editor performs linking and relocation, and the linked program is written on a file or library instead of loading it immediately into the memory.

It produces a linked version of the program which is written onto a file or library for execution. When the user is ready to run the linked program, a simple relocation loader is used to load the program into memory.

In contrast, a linking loader performs all the linking and relocation operations, including automatic library search, if specified and loads the linked program directly into the memory for execution. The **figure 4.18** illustrates the processing of linking loader and linkage editor:

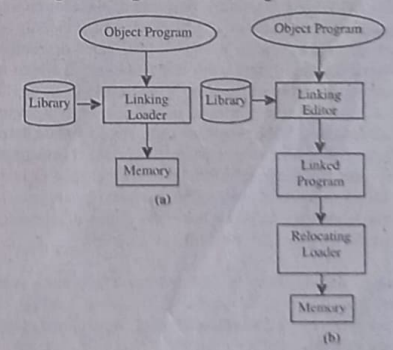


Figure 4.18: Processing of an Object Program using (a) Linking Loader and (b) Linkage Editor

If a program is executed many times without being re-assembled, the use of a linkage editor substantially reduces the overhead. Resolution of external references and library searching are performed only once. In contrast, a linking loader searches library and resolves external references

every time the program is executed. The linked program produced by the linkage editor is generally in a form that is suitable for processing by a Relocating Loader. All external references are resolved and relocation is indicated by certain mechanism such as Modification Records or a Bit Mask. Even though all the linking has been performed, the information concerning external references is often retained in the linked program. Therefore subsequent re-linking of the program is done to replace the control section and modify external references.

Comparison of Linking Loader and Linkage Editor

Linking Loader	Linkage Editor
The linking loader performs all the linking and relocation operations including automatic library search. It then loads the program directly into the memory for execution.	The linkage editor produces a linked version of the program. Such a linked version is also called as Load Module or Executable Image. This load module is generally written in file or library for later execution.
There is no need for relocating loader.	The relocating loader loads the load module into the memory.
The linking loader searches the libraries and resolves the external references every time the program is executed.	If the program is executed many times without being re-assembled then linkage editor is the best choice.
The loading requires two passes.	The loading is accomplished in one pass.

Ques 23) Illustrate the process of dynamic linking. (2020[06])

Or

Discuss the dynamic linking with their advantages.

Or

Write short note on Dynamic Linking. (2018[03])

Ans: Dynamic Linking

In this the linking function is performed at execution time. Dynamic linking allows a module to include only the information the system needs at load time or runtime. Dynamic linking differs from static linking, in which the linker copies a library function's code into each module that calls it, which is not done in the case of dynamically linked modules. If the program is completely linked before execution, the subroutines need to be loaded and linked every time the program is run. Dynamic linking provides the ability to load the routines only when they are in need. If subroutines are large or have any external references, saving in memory space and time is achieved.

Dynamic linking offers the ability to load the routines only when (and if) they are required. The actual loading and linking can be accomplished using operating system service request.

1) Linkage editors perform linking before the program is loaded for execution.
2) Linking loaders perform these same operations at load time.
3) Dynamic linking 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 Advantage

1) The subroutines that diagnose errors may never need to be called at all. However, without using dynamic linking, these subroutines must be loaded and linked every time the program is run.
2) Using dynamic linking can save both space for storing the object program on disk and in memory, and time for loading the bigger object program
3) 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. For example, a single copy of the standard C library can be loaded into memory.
4) All C programs currently in execution can be linked to this one copy, instead of linking a separate copy into each object program.
5) In an object-oriented system, dynamic linking is often used for references to software object.
6) This allows the implementation of the object and its method to be determined at run time.
7) The implementation can be changed at any time, without affecting the program that makes use of the object

Ques 24) Define the implementation of dynamic linking.

Ans: Dynamic Linking Implementation

A subroutine that is to be dynamically loaded must be called via an operating system service request. This method can also be thought of as a request to a part of the loader that is kept in memory during execution of the program. Instead of executing a JSUB instruction to an external symbol, the program makes a load-and-call service request to the OS. The parameter of this request is the symbolic name of the routine to be called. The OS examines its internal tables to determine whether the subroutine is already loaded. If needed, the subroutine is loaded from the library. Then control is passed from the OS to the subroutine being called. When the called subroutine completes its processing, it returns to its caller (operating system). The OS then returns control to the program that issues the request. After the subroutine is completed, the memory that was allocated to it may be released.

However, often this is not done immediately. If the subroutine is retained in memory, it can be used by later calls to the same subroutine without loading the same subroutine multiple times. Control can simply pass from the dynamic loader to the called routine directly. **Figure 4.19** illustrates a method in which routines that are to be dynamically loaded must be called via an OS service request. 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 (**Figure 4.19(a)**).

In **figure 4.19(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. Control is then passed from OS to the routine being called (**FIGURE 4.19(c)**). 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 (**figure 4.19(d)**).

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 (**Figure 4.19(e)**).

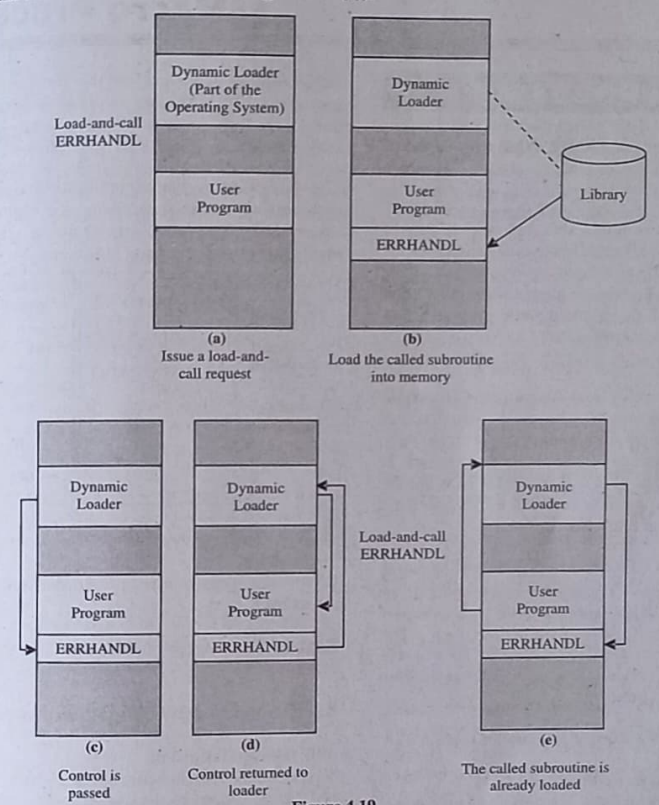


Figure 4.19

Module 5

Macro Processors

MACRO PROCESSORS

Ques 1) What is macro processor? What do you mean by expanding macros?

Ans: Macro Processor
A macro processor is a program that copies a stream of text from one place to another, making a systematic set of replacements as it does so. Macro processors are often embedded in other programs, such as assemblers and compilers. Sometimes they are standalone programs that can be used to process any kind of text.

Expanding the Macros
A macro is a unit of specifications for program generation through expansion. Macros are special code fragments that are defined once in the program and are used repetitively by calling them from various places within the program. It is similar to the subprogram in the sense that both can be used to organize the program better by separating-out the frequently used fragment into a different block.

The main program calls this block of code as and when needed. Both of them can have an associated list of parameters. A macro represents a commonly used group of statements in the source programming language. The macro processor replaces each macro instruction with the corresponding group of source language statements. This is called **expanding the macros**.

Ques 2) Write the basic macro processor function.

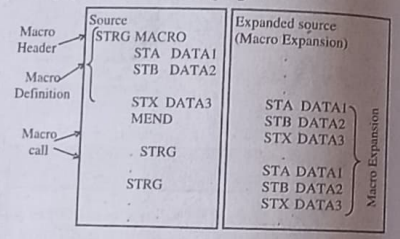
Ans: Basic Macro Processor Functions
A macro represents a commonly used group of statements in the source programming language.

The macro processors do macro expansion by replacing each macro instruction with the corresponding group of source language statements. Macro instructions allow the programmer to write a shorthand version of a program, and leave the mechanical details to be handled by the macro processor.

For example, use a macro SAVEREGS to save the contents of all registers on SIC/XE machine, instead of a sequence of seven instructions (STA, STB, etc.).

The functions of a macro processor involve the substitution of one group of characters or lines for another. The design and capabilities of a macro processor may be influenced by the form of the programming language statements. The meaning of these statements and their translation into machine languages are of no concern during the macro expansion.

The design of a macro processor is usually machine independent. Macro processors are commonly used in assemblers, high-level programming languages, and operating system command languages.



Ques 3) Explain the macro definition. **(2020[02])**

Or

Write the syntax of macro definition and define MEND directive.

Or

Explain the concept of macro definition with the help of examples. **(2017 [2.5])**

Or

Illustrate macro definition using an example. **(2019[02])**

Ans: Macro Definition
A macro definition consists of three parts:
1) Macro prototype statement.
2) One or more model statements.
3) Macro preprocessor statements.

Note: Each parameter in macro defintion begins with the character '&'(ampersand), this facilitates substitution of parameters douring macro expansion.

A macro is defined using the follwing **syntax:**

```
MACRO
        <Name> [parameter List]
        -  -  -  - - -
        -  -  -  -
        <assembly language code>
        -  -  -  - - -
        -
MEND
```

termination of macro definition the following code

```
MACRO                          //macro header
statement
SUM  &x, &y                    //macro prototype
statement
LOAD  &x                       //model statement
ADD  &y                        // model statement
STORE &x                       //model statement
MEND                           //End of defintion unit
```

The macro header statement indicates the existence of a macro definition unit. The next statement in the defintion unit is the prototype for a macro call. It consists of the name of the macto and the list of parameters. In the above example name of the macro is SUM and the list of formal parameters are &x and &y. the prototype id follwed by the so called model statements. These are assembly statements which replace the macro call as a result of macro expansion.

Ques 4) What is macro invocation?

Ans: Macro Invocation
After defining the macro the nest stage is to call the macro. Macro invocation statement gives the name of the macro instruction being invoked and the actual parameters to be used in expanding the macro. The macro invocation statement is often referred to as a macro call. In the above example, the macro is called by its macro name along with actual parameters.

SUM MN → Actual parameters
//macro call

Ques 5) Define macro expansion. Write its algorithm.

Or

What is macro expansion? Discuss the flow of control during expansion.

Or

Explain the concept of expansion with the help of examples. **(2017 [2.5])**

Or

Explain the macro expansion. **(2020[02])**

Or

Illustrate macro definition and expansion using an example. **(2019[01])**

Ans: Macro Expansion
After the calling stage macro expansion is the next stage. The assembly statements (model statements) replace the macro call as a result of macro expansion. The macro expansion for the above example is given as:

```
LOAD    M
ADD     N
STORE   M
```

Two key notions concerning macro expansion are as follows:
1) **Expansion Time Control Flow:** This determines the order in which model statements are visited during macro expansion.

Flow of Control during Expansion
The default flow of control during macro expansion is sequential. Thus, in the absence of preprocessor statements, the model statements of a macro are visited sequentially starting with the statement following the macro prototype statement and ending with the statement preceding the MEND statement.

A pre-processor statement can alter the flow of control during expansion such that some model statements are either never visited during expansion, or are repeatedly visited during expansion. The former results in conditional expansion and the latter in expansion time loops. The flow of control during macro expansion is implemented using a **Macro Expansion Counter** (MEC).

Algorithm: Macro Expansion
After the calling stage macro expansion is the next stage. The assembly statements (model statements) replace the macro call as a result of macro expansion. The flow of control during macro expansion is implemented using a **Macro Expansion Counter** (MEC).

The algorithm is shown below:
1) (Macro Expansion Counter (MEC):= statement number of first statement following the prototype statement;
2) While statement pointed by MEC is not a MEND statement
   i) If a model statement then
      a) Expand the statement
      b) MEC := MEC + 1;
   ii) Else(i.e., a preprocessor statement)
      MEC: = new value specified in the statement;
3) Exit from macro expansion.

MEC is set to point at the statement following the prototype statement. It is incremented by 1 after expanding a model statement. Execution of a preprocessor statement can set MEC to a new value to implement conditional expansion or expansion time loops.

Ques 6) What is the use of lexical substitution?

Ans: Use of Lexical Substitution
Lexical substitution is used to generate an assembly statement from a model statement. A model statement consists of 3 types of strings:
1) An ordinary string, which stands for itself.
2) The name of a formal parameter which is preceded by the character '&'.
3) The name of a preprocessor variable, which is also preceded by the character '&'.

During lexical expansion, strings of type 1 are retained without substitution. Strings of types 2 and 3 are replaced by the 'values' of the formal parameters or preprocessor variables. The value of a formal parameter is the corresponding actual parameter string

Ans: SIC/XE Program Using Macro Instructions

Figure 5.1 shows an example of a SIC/XE program using macro instructions. The definitions of these macro instructions (RDBUFF and WRBUFF) appear in the source program following the START statement.

```
                                  Macro                                  Parameters
Line                              Name
     5 COPY    START    0                    COPY FILE FROM INPUT TO OUTPUT
    10 RDBUFF  MACRO                  &INDEV, &BUFADR, &RECLTH
    15
    20         MACRO TO READ RECORD INTO BUFFER
    25
    30         CLEAR    X                    CLEAR LOOP COUNTER
    35         CLEAR    A
    40         CLEAR    S
    45         +LDT     #4096                SET MAXIMUM RECORD LENGTH
    50         TD       =X' &INDEV'          TEST INPUT DEVICE
    55         JEQ      * –3                 LOOP UNTIL READY
    60         RD       =X' &INDEV'          READ CHARACTER INTO REG A
    65         COMPR    A, S                 TEST FOR END OF RECORD
    70         JEQ      *+11                 EXIT LOOP IF EOR
    75         STCH     &BUFADR, X           STORE CHARACTER IN BUFFER
    80         TIXR     T                    LOOP UNLESS MAXIMUM LENGTH
    85         JLT      * –19                HAS BEEN REACHED
    90         STX      &RECLTH              SAVE RECORD LENGTH
    95         MEND                                                      Macro Definition
   100 WRBUFF  MACRO                  &OUTDEV, &BUFADR, &RECLTH
   105
   110         MACRO TO WRITE RECORD FROM BUFFER
   115
   120         CLEAR    X                    CLEAR LOOP COUNTER
   125         LDT      &RECLTH
   130         LDCH     &BUFADR, X           GET CHARACTER FROM BUFFER
   135         TD       =X' &OUTDEV'         TEST OUTPUT DEVICE
   140         JEQ      * –3                 LOOP UNTIL READY
   145         WD       =X' &OUTDEV'         WRITE CHARACTER
   150         TIXR     T                    LOOP UNTIL ALL CHARACTERS
   155         JLT      * –14                HAVE BEEN WRITTEN
   160         MEND
   165
   170         MAIN PROGRAM
   175
   180 FIRST   STL      RETADR               SAVE RETURN ADDRESS
   190 CLOOP   RDBUFF   F1, BUFFER, LENGTH   READ RECORD INTO BUFFER
   195         LDA      LENGTH               TEST FOR END OF FILE
   200         COMP     #0
   205         JEQ      ENDFIL               EXIT IF EOF FOUND
   210         WRBUFF   05, BUFFER, LENGTH   WRITE OUTPUT RECORD
   215         J        CLOOP                LOOP                        Macro Invocation
   220 ENDFIL  WRBUFF   05, EOF, THREE       INSERT EOF MARKER
   225         J        @RETADR
   230 EOF     BYTE     C'EOF'
   235 THREE   WORD     3
   240 RETADR  RESW     1
   245 LENGTH  RESW     1                    LENGTH OF RECORD
   250 BUFFER  RESB     4096                 4096-BYTE BUFFER AREA
   255         END      FIRSTZ
```

Figure 5.1: Use of Macros in a SIC/XE Program

Two new assembler directives (MACRO and MEND) are used in macro definitions.

The first MACRO statement (line 10) identifies the beginning of a macro definition. The symbol in the label field (RDBUFF) is the name of the macro, and the entries in the operand field identify the parameters of the macro instruction.

In macro language, each parameter begins with the character &, which facilitates the substitution of parameters during macro expansion. The macro name and parameters define a pattern or prototype for the macro instructions used by the programmer.

The MACRO directive are the statements that make up the body of the macro definition. The MEND assembler directive marks the end of the macro definition. **Figure 5.2** shows the output that would be generated. Each macro invocation statement has been expanded into the statements that form the body of the macro, with the arguments from the macro invocation substituted for the parameters in the macro prototype.

For example, in expanding the macro invocation on line 190, the argument F1 is substituted for the parameter &INDEV wherever it occurs in the body of the macro.

Similarly, BUFFER is substituted for &BUFADR, and LENGTH is substituted for &RECLTH.

The comment lines within the macro body have been deleted. Note that the macro invocation statement itself has been included as a comment line. This serves as documentation of the statement written by the programmer.

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.

Note: The two invocations of WRBUFF specify different arguments, so they produce different expansions.

After macro processing, the expanded file (**figure 5.2**) can be used as input to the assembler. In general, the statements that form the expansion of a macro are generated (and assembled) each time the macro is invoked. Statements in a subroutine appear only once, regardless of how many times the subroutine is called.

```
Line        Source Statement
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
195           LDA      LENGTH     TEST FOR END OF FILE
200           COMP     #0
205           JEQ      ENDFIL     EXIT IF EOF FOUND
210           WRBUFF   05, BUFFER, LENGTH   WRITE OUTPUT RECORD
210a          CLEAR    X          CLEAR LOOP COUNTER
210b          LDT      LENGTH
210c          LDCH     BUFFER, X  GET CHARACTER FROM BUFFER
210d          TD       =X'05'     TEST OUTPUT DEVICE
210e          JEQ      *–3        LOOP UNTIL READY
210f          WD       =X'05'     WRITE CHARACTER
210g          TIXR     T          LOOP UNTIL ALL CHARACTERS
210h          JLT      *–14       HAVE BEEN WRITTEN
215           J        CLOOP      LOOP
220  ENDFIL   WRBUFF   05, EOF, THREE   INSERT EOF MARKER
220a ENDFIL   CLEAR    X          CLEAR LOOP COUNTER
220b          LDT      THREE
220c          LDCH     EOF, X     GET CHARACTER FROM BUFFER
220d          TD       =X'05'     TEST OUTPUT DEVICE
220e          JEQ      *–3        LOOP UNTIL READY
220f          WD       =X'05'     WRITE CHARACTER
220g          TIXR     T          LOOP UNTIL ALL CHARACTERS
220h          JLT      *–14       HAVE BEEN WRITTEN
225           J        @RETADR
230  EOF      BYTE     C'EOF'
235  THREE    WORD     3
240  RETADR   RESW     1
245  LENGTH   RESW     1          LENGTH OF RECORD
250  BUFFER   RESB     4096       4096-BYTE BUFFER AREA
255           END      FIRST
```

Figure 5.2: Program from Figure 5.1 with Macros Expanded

Ques 8) Is it possible to use labels within the macro body? Explain your answer with the help of examples. Also illustrate a possible solution for the same. (2019[05])

Ans: Body of a macro instruction does not contain labels generally. So the source statement level contains relative addressing. **For example**, the definition of WRBUFF in **Figure 5.3** is considered here. On line 135, if we placed label for TD instruction, label will be defined twice once for each invocation of WRBUFF. This duplicate definition would prevent correct assembly of the resulting expanded program.

Jump instructions on line 140 and 155 were written using the relative operands * – 3 and * – 14. Because of this, it was not possible to place label on line 135. Only for sort jump instruction, it is i.e. "JEQ* –3".

For longer jump instruction, which spans several instructions, this type of natation is very inconvenient, error prone and difficult to read.

By creating special types of labels within macro instruction, many processor avoids these problems.

Figure 5.3 shows the generation of unique labels within a macro expansion.

```
25  RDBUFF  MACRO   &INDEV, &BUFADR, &RECLTH
30          CLEAR   X
35          CLEAR   A
40          CLEAR   S
45          +LDT    #4096
50  $LOOP   TD      =X'&INDEV'
55          JEQ     $LOOP
60          RD      =X'&INDEV'
65          COMPR   A,S
70          JEQ     $EXIT
75          STCH    &BUFADR, X
80          TIXR T
85          JLT     $LOOP
90  $EXIT   STX     &RECLTH
95          MEND
```

(a) RDBUF Macro Definition

RDBUF F1		BUFER, Length
30		CLEAR X
35		CLEAR A
40		CLEAR S
45		+ LDT # 4096
50	$AALOOP	TD = X' F1
55		JEQ $ AALOOP
60		RD = X' F1'
65		COMPR A,S
70		JEQ SEXIT
75		STCH & BUFFER, X
80		TIXR T
85		JLT $ AALOOP
90	$AAEXIT	STX LENGTH

(b) Resulting Macro Expansion

Figure 5.3:

Labels used within the macro body begin with the special character $in **Figure 1(a)**. In **Figure 1(b)**, each symbol beginning with $ has been modified by replacing $ with $AA.

Ques 9) Define the two approaches for macro processor design.

Ans: Approaches for Macro Processor Design

Approach 1: 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 the second pass.

However, such a two-pass macro processor would not allow the body of one macro instruction to contain definitions of other macros (because all macros would have to be defined during the first pass before any macro invocations were expanded).

Approach 2: A one-pass macro processor that can alternate between macro definition and macro expansion is able to handle macros like those in **figure 5.4**. However, one-pass may be enough because all macros would have to be defined during the first pass before any macro invocations were expanded.

The definition of a macro must appear before any statements that invoke that macro. Moreover, the body of one macro can contain definitions of the other macro.

Consider the **example** of a Macro defining another Macro. In the example below, the body of the first Macro (MACROS) contains statement that define RDBUFF, WRBUFF and other macro instructions for SIC machine. The body of the second Macro (MACROX) defines the same macros for SIC/XE machine. A proper invocation would make the same program to perform macro invocation to run on either SIC or SIC/XE machine.

MACROS for SIC Machine

```
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}
```

Figure 5.4 (a)

MACROS for SIC/XE Machine

```
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}
```

Figure 5.4 (b)

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. However, defining MACROS or MACROX does not define RDBUFF and WRBUFF. These definitions are processed only when an invocation of MACROS or MACROX is expanded.

Ques 10) How could a recursive macro processor be implemented?

Or

Explain recursive macro expansion with example.

(2017 [05])

Or

What do you mean by recursive macro expansion? What are the possible problems associated with it? (05)

Ans: Recursive Macro Processor Implementation

There can be a condition that invocation of one macro is done by another. The purpose of RDCHAR is to read one character from a specified device into register A, taking care of the necessary test-and-wait loop. It is convenient to use a macro like RDCHAR in the definition of RDBUFF so that the programmer who is defining RDBUFF need not worry about the details of device access and control.

The **advantages** of using RDCHAR in this way would be even greater on a more complex machine, where the code to read a single character might be longer and more complicated.

The expansion of RDCHAR would also proceed normally. At the end of this expansion, however, a problem would appear.

When the end of the definition of RDCHAR was recognized, EXPANDING would be set to FALSE. If a programming language that supports recursion is not available, the programmer must take care of handling such items as return addresses and values of local variables.

An **example** is shown in **figure 5.5**:

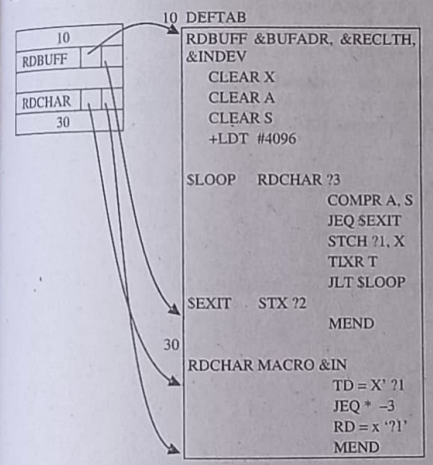


Figure 5.5

Problem Associated with Recursive Macro Expansion

Previous Macro Design Does not take care of recursive macro expansion.

Solutions

1) Write the macro processor in a programming language which automatically takes care of the recursive calls thus retaining the local variables.

2) If written in a language without recursion support, use a stack to take care of pushing and popping the local variables and return addresses thus retaining their values.

1.	SP = –1	
2.	Call RDBUFF BUFFER, LENGTH, F1	
	SP = 1	
	S (1)	–1
	S (2)	10+1+1+1+1+1
	S (3)	
	S (4)	BUFFER
	S (5)	LENGTH
	S (6)	F1

Macros expanded

```
CLEAR   X
CLEAR   A
CLEAR   S
+LDT    #4096
```

3.	SP = 7	
	S (1)	–1
	S (2)	15
	S (3)	
	S (4)	BUFFER
	S (5)	LENGTH
	S (6)	F1
	S (7)	1
	S (8)	30+1+1+1+1
	S (9)	
	S (10)	F1

```
TD = X 'F1'
JEQ * –3
RD = X 'F1'
```

N = SP – S (SP) – 2
= 7 – 1 – 2
= 4
SP = S (SP) = 1

4.	SP = 1	
	S (1)	–1
	S (2)	15+1+1+1+1+1+1
	S (3)	
	S (4)	BUFFER
	S (5)	LENGTH
	S (6)	F1

```
COMPR A, S
STCH
BUFFER, X
TIXR      T
JLT
  $LOOP
$EXIT     STX
  LENGTH
```

N = 1 + 1 – 2
= 0
SP = S (SP) = S (1) = 1

Figure 5.6: Recursive Macro Expansion for the Example in Figure 5.5

Ques 11) Discuss the one pass macro processor. Also write its algorithm and data structure used for this.

Or

Write the one pass macro processor algorithm.

(2020[07])

Or

Write and explain the algorithm for One Pass Macroprocessor. Briefly discuss various Data structures for a design of One Pass Macroprocessor.

Or

Describe the data structures used in a one pass macro processor algorithm. **(2017 [03])**

Or

Give the algorithm for a one pass macro processor.

(2017 [07])

Or

Explain the working of one pass Macro Processor.

(2018[07])

Or

What are the data structures required for a microprocessor algorithm? Explain the format of each.

(2019[04])

Or

Design an iterative algorithm for a one pass macroprocessor. **(2019[06])**

Or

How does a one pass macroprocessor handle recursive macro expansion? Explain with example. **(2020[06])**

Ans: 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.

Restriction

1) The definition of a macro must appear in the source program before any statements that invoke that macro.
2) This restriction does not create any real inconvenience.

Data Structures

Data structures involved in the design of a macro processor are as follows:

1) **Macro Definition Table (DEFTAB):** It holds the macro definitions present in the input source file. As the macro processor scans through the source lines, it comes across the definition of newer macros.
2) **Macro Name Table (NAMTAB):** This table holds one entry for each macro defined in the input source file. Typical entries in this table include the following:
   i) **Name:** The name of the macro being defined.
   ii) **Num-of-parameters:** The number of parameters that the macro uses.
   iii) **DEFTAB -start-index:** The index of the DEFTAB from which the body of the macro is stored in MDT.
   iv) **DEFTAB -end-index:** The index of the DEFTAB upto which the body of the macro occupies in DEFTAB.
3) **Argument List Table (ARGTAB):** This is a table dynamically created upon encountering a macro call to hold the arguments passed. The content of this table is utilized during the expansion process.

The **figure 5.7** shows the different data structures described and their relationship:

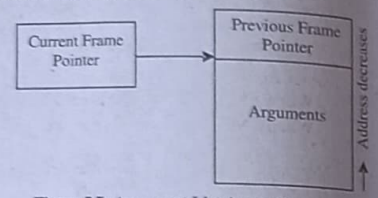


Figure 5.7: Argument List Array Structure

Figure 5.8(a) shows the definition of RDBUFF stored in DEFTAB, with an entry in NAMTAB identifying the beginning and end of the definition.

Note: The positional notation that has been used for the parameters – &INDEV → ?1 (indicating the first parameter in the prototype), &BUFADR → ?2, etc.

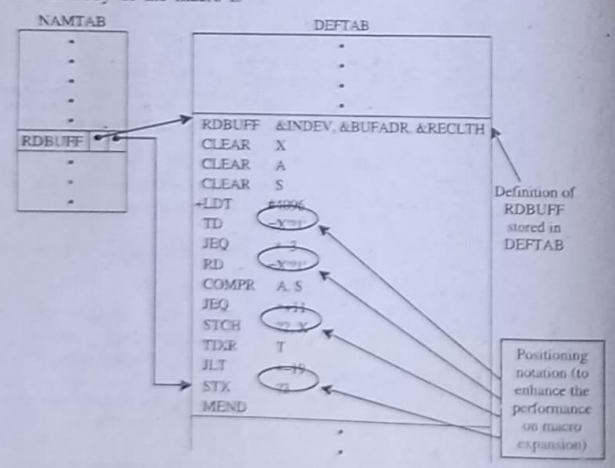


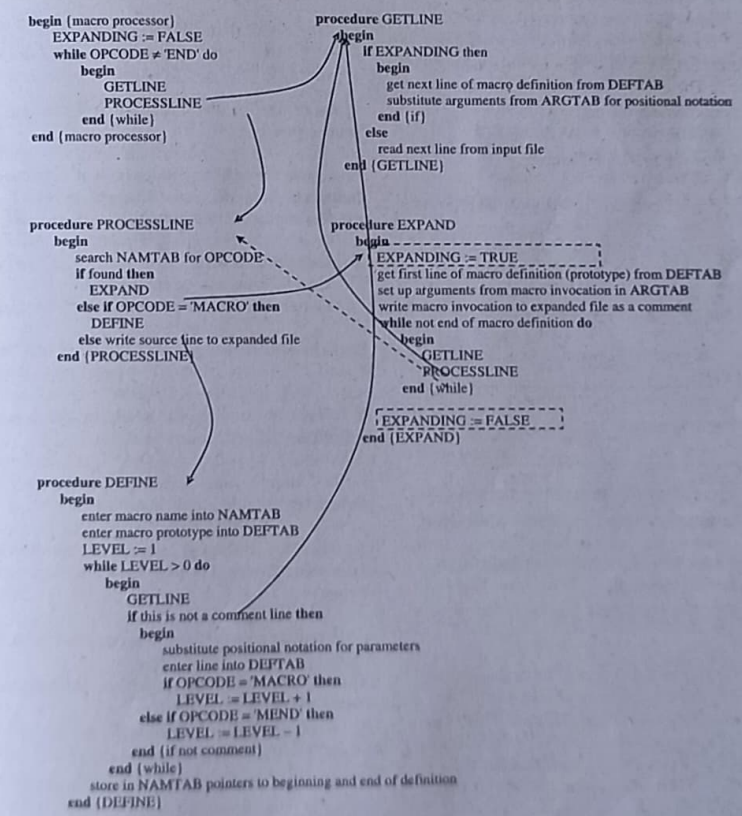
Figure 5.8

Figure 5.8(b) shows ARGTAB as it would appear during expansion of the RDBUFF statement on line 190. In this case (this invocation), the first argument is F1, the

One-Pass Macro Algorithm

1) Procedure **DEFINE**:
   i) Being called when the beginning of a macro definition is recognised.
   ii) Make appropriate entries in DEFTAB and NAMTAB.
2) Procedure **EXPAND**:
   i) Being called to set-up the argument values in ARGTAB.
   ii) Expand a macro invocation statement.
3) Procedure **GETLINE**:
   i) Being called at several points to get a line in the algorithm:
   ii) The line may come from:
      a) The input file (EXPANDING = FALSE)
      b) The DEFTAB (EXPANDING = TRUE)
4) Counter **LEVEL** – Count the macro level (similar to match left and right parentheses):
   i) When a MACRO directive is encountered, LEVEL is advanced by 1.
   ii) When a MEND directive is encountered, LEVEL is decreased by 1.

Note: Most macro processors allow the definitions of commonly used macro instructions to appear in a standard system library (to make macro uses convenient).



Ques 12) Discuss different types of parameters used in macro with example.

Or

Write notes on keyword macro parameters, giving suitable examples. **(2017 [05])**

Or

Differentiate between Keyword and Positional macro parameters. **(2018[03])**

Ans: Types of Parameters in Macro

1) **Positional Parameter:** The parameter from macro prototype and arguments from the macro call are associated with each other according to their positions. A positional parameter is written as &<parameter name>. **For example,** &SAMPLE, where SAMPLE is the name of a parameter. The value of a positional formal parameter XYZ is determined by the rule of positional association as follows:
   i) Find the ordinal position of XYZ in the list of formal parameters in the macro prototype statement.
   ii) Find the actual parameter specification occupying the same ordinal position in the list of actual parameters in the macro call statement.

   Example: consider the call

   INCR A, B, AREG

   In the following macro definition:

```
MACRO
INCR      &MEM_VAL,  &INCR_VAL,
&REG
MOVER     &REG, &MEM_VAL
ADD       &REG, &INCR_VAL
MOVEM     &REG, &MEM_VAL
MEND
```

Following the rule of positional association, values of the formal parameters are:

Formal Parameter	Value
MEM_VAL	A
INCR_VAL	B
REG	AREG

2) **Keyword Parameter:** For keyword parameters, <parameter name> is an ordinary string and <parameter kind> is the string '='. The <actual parameter spec> is written as

   <formal parameter name> = <ordinary string>

   The value of the formal parameter XYZ is determined by the rule of keyword association as follows:
   i) Find the actual parameter specification which has the form XYZ = <ordinary string>.
   ii) Let <ordinary string> in the specification be the string ABC. Then the value of the formal parameter is ABC.

   Example: the macro definition using keyword parameters

```
MACRO
INCR_M      &MEM_VAL=,
&INCR_VAL=, &REG=
MOVER       &REG, &MEM_VAL
ADD         &REG, &INCR_VAL
MOVEM       &REG, &MEM_VAL
MEND
```

   Consider the following macro calls

   INCR_M MEM_VAL = A, INCR_VAL = B, REG = AREG

   .....

   INCR_M INCR_VAL = B, REG = AREG, MEM_VEL = A

   are now equivalent.

Difference between Positional and Keyword Parameters

1) In positional parameters there is one to one correspondence between macro definition and macro call. The calling sequence should be same as defined sequence
2) In keyword parameters sequence is not important and number of parameters used while calling the macro are also not important

Ques 13) Define the machine independent features of macro processor.

Or

List the machine independent macro processor features. Also discuss different types of parameters used in macro with example.

Or

Explain the following:

1) **Conditional macro expansion**
2) **Generation of unique labels**

Or

Explain conditional macro expansion with an example. **(2017 [05])**

Or

Is it possible to include labels in the body of macro definition? Justify your answer. **(2018[06])**

Or

Write short note on concatenation of macro parameters within a character string. **(2018[04])**

Or

Explain the different types of conditional macro expansion statements and their implementation with examples. **(2018[10])**

Or

Write notes on conditional macro expansion. **(2019[05])**

Or

Explain the following machine independent macro processor features: **(2020[10])**

1) **Generation of unique labels.**
2) **Keyword macro parameters**

Ans: Machine Independent Macro Processor Features

The design of macro processor doesn't depend on the architecture of the machine. Some extended features for macro processor are:

1) **Concatenation of Macro Parameters:** Most macro processor allows parameters to be concatenated with other character strings. **For example,** consider that the parameter to such a macro instruction is named &ID. The body of the macro definition might contain a statement like

   LDA X&ID1

   &ID is concatenated after the string "X" and before the string "1".

   LDA XA1 (&ID = A)
   LDA XB1 (&ID = B)

   & is the starting character of the macro instruction; but the end of the parameter is not marked. So in the case of &ID1, the macro processor could deduce the meaning that was intended.

2) **Generation of Unique Labels:** It is **not possible to use labels** for the instructions in the macro definition, since every expansion of macro would include the label repeatedly which is not allowed by the assembler. This in turn forces us to use relative addressing in the jump instructions. Instead we can use the technique of generating unique labels for every macro invocation and expansion. During macro expansion each $ will be replaced with $XX, where XX is a two-character alphanumeric counter of the number of macro instructions expansion.

3) **Conditional Macro Expansion:** If the macro is expanded depends upon some conditions in macro definition (depending on the arguments supplied in the macro expansion) then it is called as conditional macro expansion. Macro definition is designed in such a way that it generates different instruction sequences when different relations hold between the actual parameters of a call.

   Macro-Time Variables

   Macro-time variables (often called as **SET Symbol**) can be used to store working values during the macro expansion. Any symbol that begins with symbol & and not a macro instruction parameter is considered as macro-time variable. All such variables are initialised to zero.

   If the value of this expression **TRUE**:
   1) The macro processor continues to process lines from the DEFTAB until it encounters the ELSE or ENDIF statement.
   2) If an ELSE is found, macro processor skips lines in DEFTAB until the next ENDIF.
   3) Once it reaches ENDIF, it resumes expanding the macro in the usual way.

   If the value of the expression is **FALSE**:
   i) The macro processor skips ahead in DEFTAB until it encounters next ELSE or ENDIF statement.
   ii) The macro processor then resumes normal macro expansion.

   WHILE-ENDW Structure
   i) When an WHILE statement is encountered during the expansion of a macro, the specified Boolean expression is evaluated.
   ii) **TRUE**:
      a) The macro processor continues to process lines from DEFTAB until it encounters the next ENDW statement.
      b) When ENDW is encountered, the macro processor returns to the preceding WHILE, re-evaluates the Boolean expression, and takes action based on the new value.
   iii) **FALSE:** The macro processor skips ahead in DEFTAB until it finds the next ENDW statement and then resumes normal macro expansion.

4) **Keyword Macro Parameters:** The types of macro parameter are classified as:
   i) **Positional Parameter:** Parameters and arguments are associated according to their positions in the macro prototype and invocation. If an argument is to be omitted, a null argument (two consecutive commas) should be used to maintain the proper order in macro invocation:

      For example, RDBUFF 0E, BUFFER, LENGTH, , 80

      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.

   ii) **Keyword Parameter:** 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.

      For example, GENER TYPE=DIRECT, CHANNEL=3

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

Ques 14) Differentiate between a Macro and a Subroutine. **(2019[03])**

Or

What is the difference between macro invocation and subroutine call? **(2020[03])**

Ans: Difference between Macro and Subroutine

Table 2 shows the difference between Macro and Subroutine:

Table 2: Difference between Macro and Subroutine

Macros	Procedure
The corresponding machine code is written every time a macro is called in a program.	The Corresponding m/c code is written only once in memory
Program takes up more memory space.	Program takes up comparatively less memory space.
No transfer of program counter	Transferring of program counter is required.

Ques 15) Discuss the various design options for macro processors.

Ans: Macro Processors Design Options

1) **Recursive Macro Expansion:** There can be a condition that invocation of one macro is done by another. The purpose of RDCHAR is to read one character from a specified device into register A, taking care of the necessary test-and-wait loop. It is convenient to use a macro like RDCHAR in the definition of RDBUFF so that the programmer who is defining RDBUFF need not worry about the details of device access and control.

An **example** is shown in **figure 5.9**:

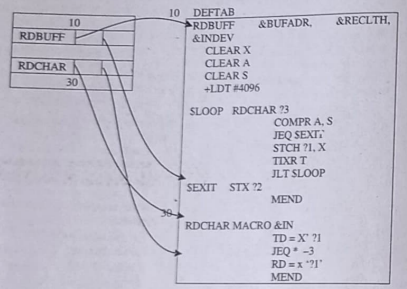


Figure 5.9

1.	SP = –1	
2.	Call RDBUFF BUFFER, LENGTH, F1	
	SP = 1	
	S (1)	–1
	S (2)	10+1+1+1+1+1
	S (3)	
	S (4)	BUFFER
	S (5)	LENGTH
	S (6)	F1

Macros expanded

```
CLEAR  X
CLEAR  A
CLEAR  S
+LDT   #4096
```

3.	SP = 7	
	S (1)	–1
	S (2)	15
	S (3)	
	S (4)	BUFFER
	S (5)	LENGTH
	S (6)	F1
	S (7)	1
	S (8)	30+1+1+1+1
	S (9)	
	S (10)	F1

```
TD = X 'F1'
JEQ * –3
RD = X 'F1'
```

N = SP – S (SP) – 2
= 7 – 1 – 2
= 4
SP = S (SP) = 1

4.	SP = 1	
	S (1)	–1
	S (2)	15+1+1+1+1+1+1
	S (3)	
	S (4)	BUFFER
	S (5)	LENGTH
	S (6)	F1

```
      COMPR A, S
      STCH
        BUFFER, X
      TIXR      T
      JLT       $LOOP
SEXIT           STX
        LENGTH
```

N = 1 + 1 – 2

Figure 5.10: Recursive Macro Expansion for the Example in Figure 5.9

2) **General-Purpose Macro Processors:** The most common use of macroprocessors is as an aid to assembler language programming. Often such macroprocessors are combined with, or closely related to, the assembler. Macroprocessors have also been developed for some high-level programming languages.

3) **Macro Processor within Language Translators:** The macro processors might be called pre-processors. That is, they process macro definitions and expand macro invocations, producing an expanded version of the source program. This expanded program is then used as input to an assembler or compiler. In this case macro processing functions are combined with the language translator itself. The simplest method of achieving this sort of combination is a line-by-line macro processor. Using this approach, the macro processor reads the source program statements and performs all of its functions. However, the output lines are passed to the language translator as they are generated (one at a time), instead of being written to an expanded source file. Thus, the macro processor operates as a sort of input routine for the assembler or compiler.

Ques 16) List the advantages and disadvantages of general purpose macro processor and macro processor wwith in language translators.

Ans: Advantages General-Purpose Macro Processors

1) The programmer does not need to learn about a different macro facility for each compiler or assembler language, so much of the time and expense involved in training are eliminated.

2) The costs involved in producing a general-purpose macro processor are somewhat greater than those for developing a language-specific processor. However, this expense does not need to be repeated for each language; the result is a substantial overall saving in software development cost.

3) Savings in software maintenance effort should also be realized. Over a period of years, these maintenance costs may be even more significant than the original cost for software development.

Disadvantage General-Purpose Macro Processors

One potential problem with general-purpose macro processors involves the syntax used for macro definitions and macro invocation statements. With most special-purpose macro processors, macro invocations are very similar in form to statements in the source programming language.

Advantages Macro Processor within Language Translators

1) It avoids making an extra pass over the source program (writing and then reading the expanded source file), so it can be more efficient than using a macro pre-processor.

2) Some of the data structures required by the macro processor and the language translator can be combined. Many utility subroutines and functions can be used by both the language translator and the macro processor. These include such operations as scanning input lines, searching tables, and converting numeric values from external to internal representations.

Disadvantages Macro Processor within Language Translators

1) They must be specially designed and written to work with a particular implementation of an assembler or compiler (not just with a particular programming language).

2) The costs of macro processor development must therefore be added to the cost of the language translator, which results in a more expensive piece of software.

DEVICE DRIVERS

Ques 17) What is device driver? Define the anatomy of device driver.

Or

What is a Device Driver? What are the major design issues of a Device Driver? (2018[05])

Or

Explain the anatomy of a device driver with the help of diagrams. (2019[05])

Ans: Device Driver

A device driver is a program routine that links a peripheral device to an operating system of a computer. It is essentially a software program that allows a user to employ a device, such as a printer, monitor, or mouse. It is written by programmers who comprehend the detailed knowledge of the device's command language and characteristics and contains the specific machine language necessary to perform the functions requested by the application. When a new hardware device is added to the computer, such as a CD-ROM drive, a printer, or a sound card, its driver must be installed in order to run it. The operating system "calls" the driver, and the driver "drives" the device.

The basic input/output (I/O) hardware features, such as ports, buses, and device controllers, accommodate a wide variety of I/O devices. To encapsulate the details and unique features of different devices, the kernel of an operating system is set up to use device driver modules. The device drivers present a uniform device-access interface to the I/O subsystem.

Each of the different types of I/O devices is accessed through a standardized set of functions--an interface. The tangible differences are encapsulated in kernel modules (i.e., device drivers) that internally are customized for each device, but that export and utilize one of the standard interfaces.

Design Issues of a Device Driver

To make the design of device drivers easier, we have divided the issues to be considered into three broad categories (Design issues of a device driver):

1) Operating system/Driver communications
2) Driver/Hardware Communications
3) Driver Operations

The first category covers all of the issues related to the exchange of information between the device driver and operating system. It also includes support functions that the kernel provides for the benefits of the device driver. The second covers those issues related to the exchange of the information between the device driver and the device it controls. This also includes issues such as how software talks to hardware – and how the hardware talks back.

The third covers issues related to the actual internal operation of the driver itself. This includes:

1) Interpreting commands received from the operating system
2) Scheduling multiple outstanding requests for service.
3) Managing the transfer of data across both interfaces (operating system and hardware)
4) Accepting and processing hardware interrupts
5) Maintaining the integrity of the driver's and the kernel's data structures.

Anatomy of Device Drivers

Device driver take on a special role in Linux kernel. They are "black boxes" that make a particular piece of hardware respond to a well-defined internal programing interface. The driver translates between the hardware commands understand by the device and the stylized programing interface used by the kernel. User activities are performed by means of a set of standardised calls that are independent of the specific operations that act on a real hardware is then the role of the device driver.A device driver has three sides:

1) One talks to the hardware and
2) One talk to the user.
3) While one side talks to the rest of the kernel.

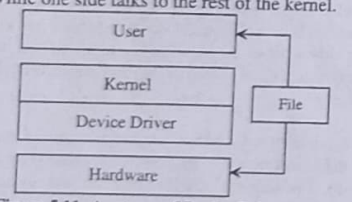


Figure 5.11: Anatomy of Device Drivers

A device driver performs the following jobs:

1) To accept request from the device independent software above to it.
2) Interact with the device controller to take and give I/O and perform required error handling.
3) Making sure that the request is executed successfully.

Ques 18) Define the various types of device drivers. Also differentiate character and block device driver.

Or

Differentiate between characters and block device drives. (2017, 2020 [05])

Or

Distinguish between Character and Block Device Drivers. (2018[05])

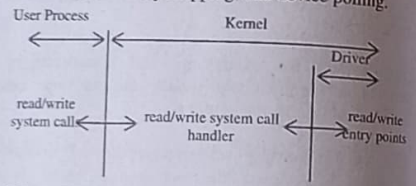
Or

Differentiate between Character and Block Device Drivers. (2019[04])

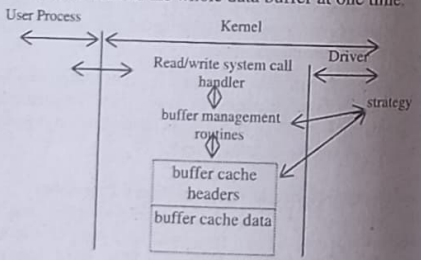
Ans: Types of Device Drivers

Depending upon how data is fetched by the devices, device drivers can be divided into two categories:

1) **Character Device Drivers:** Character device drivers are intended for those devices, which have a simple character based interface such as the keyboard. Such devices do not require any buffering as they send and receive data in single character chunks. Character device drivers normally perform I/O in a byte stream. They can also provide additional interfaces not present in block drivers, such as I/O control (ioctl) commands, memory mapping, and device polling.



2) **Block Device Drivers:** Devices that support a file system are known as block devices. Drivers written for these devices are known as **block** device drivers. Block device drivers are intended for those devices that have a data block based interface such as the hard disk. In order to improve speed and efficiency, these devices transfer the whole data buffer at one time.



Block device drivers take a file system request, in the form of a buf(9S) structure, and issue the I/O operations to the disk to transfer the specified block. The main interface to the file system is the strategy(9E) routine. Block device drivers can also provide a character driver interface that allows utility programs to bypass the file system and access the device directly. This device access is commonly referred to as the raw interface to a block device. **For example,** disks are commonly implemented as block devices.

Difference between Character and Block Device Driver

Character Device Drivers	Block Device Drivers
Perform input and output one character at a time.	Transfers data in blocks, rather than one byte at a time.
Support single hardware.	Support more than one hardware unit.
Have logical name assigned to them.	Do not have file-like logical names.
Usually control terminal or printer.	Usually control floppy-disk, fixed or magnetic tape drives.
Examples: sound cards, parallel cards, serial ports	**Examples:** USB cameras, hard disk. Disk-on-key

Ques 19) Give the general design of a device driver. (2017 [05])

Or

Describe the general design of a device driver. (2020[05])

Or

Explain the general design and anatomy of a device driver with the help of diagrams. (2019[05])

Ans: Design of Device Drive

When you design your system it is very good if you can split up the software into two parts, one that is hardware independent and one that is hardware dependent, to make it easier to replace one piece of the hardware without having to change the whole application. In the hardware dependent part you should include:

1) Initialisation routines for the hardware
2) Device drivers
3) Interrupt drivers

The device can then be called from the application using RTOS standard calls. The RTOS creates during its own initialisation tables that contain function pointers to all the device driver's routines. But as device drivers are initialized after the RTOS has been initialized you can in your driver use the functionality of the RTOS. When you design your system, you also have to specify which type of device driver design you need. Should the device driver be interrupt driven, which is most common today, or should the application be polling the device? It depends on the device itself, but also on your deadlines in your system. But you also need to specify if your device driver should called synchronously or asynchronously.

1) **Synchronous Device Driver:** When a task calls synchronous device driver it means that the task will until the device has some data that it can give to the task (**figure 5.12**). In this example the task is blocked on a semaphore until the driver hat been able to read any data from the device.

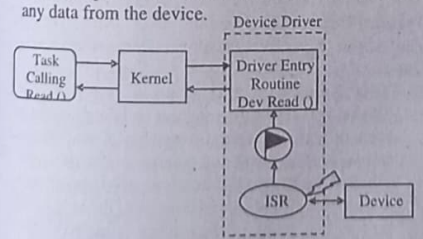


Figure 5.12: Synchronous device driver

The task calls the device driver via a kernel device call. The device entry routine gets blocked on a semaphore and blocks the task in that way. When an input comes from the device, it generates an interrupt and the ISR releases the semaphore and the device Entry routine returns the data to the task and the task continues it execution.

2) **Asynchronous Device Driver:** When a task calls an asynchronous device driver it means that the task will only check if the device has some data that it can give to the task (**figure 5.13**). In this example the task is just checking if there is a message in the queue. The device driver can independently of the task send data into queue.

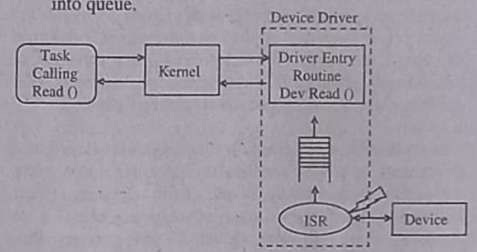


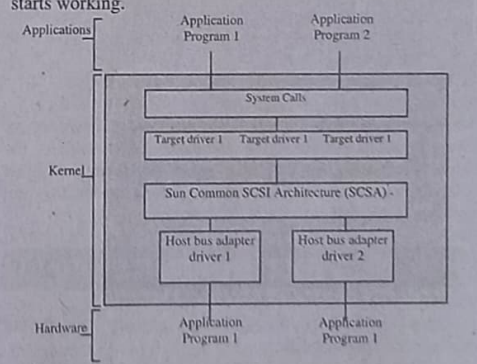
Figure 5.13: Asynchronous device driver

The task calls the device driver via a kernel device call. The device entry routine receives a message from the queue and returns the data to the task. When new data arrives from the device the ISR puts the data in a message and sends the message to the queue.

Ques 20) Describe the working of device driver.

Ans: Working of Device Driver

When we get a peripheral device such as printer, scanner, keyboard or modem, the device comes together with a driver CD which needs to be installed before the device starts working.



As soon we install the driver software into the computer, it detects and identifies the peripheral device and we become able to control the device with the computer. A device driver is a piece of software that allows your computer's

operating system to communicate with a hardware device, the driver is written for. Generally a driver communicates with the device through the computer bus which is used to connect the device with the computer. Device drivers works within the kernel layer of the operating system. Kernel is the part of the operating system that directly interacts with the physical structure of the system. Instead of accessing a device directly, an operating system loads the device drivers and calls the specific functions in the driver software in order to execute specific tasks on the device. Each driver contains the device specific codes required to carry out the actions on the device.

Consider an **example** of a printer, when it is connected to the computer and the specific device driver is installed, a device object is created on the computer which is designed to control the device. This device object represents the printer and its physical structure modes that allow your computer's operating system to control its functions.

When we choose an operation (like Control + P to print a document) on the printer then this command goes to the device driver through the kernel of the operating system. Resultantly a calling program invokes a routine in the device driver and the driver issues corresponding commands to the microcontrollers within the printer. Further these microcontrollers control the components of the printer like motors etc. to start printing the document.

Ques 21) What is a Device Driver Entry Point?

Ans: Device Driver Entry Point

An entry point is a function within a device driver that can be called by an external entity to get access to some driver functionality or to operate a device. Each device driver provides a standard set of functions as entry points.The illumos kernel uses entry points for these general task areas:

1) Loading and unloading the driver
2) Autoconfiguring the device – Autoconfiguration is the process of loading a device driver's code and static data into memory so that the driver is registered with the system.
3) Providing I/O services for the driver

Drivers for different types of devices have different sets of entry points according to the kinds of operations the devices perform. A driver for a memory-mapped character-oriented device, while a block driver does not support this entry.

TEXT EDITORS

Ques 22) What is the meaning of editing? Define various types of editors.

Or

What is editing? List the steps involved in document-editing process in an interactive user-computer dialogue.

Or

List out the main four tasks associated with the Document Editing Process. **(2018[02])**

Ans: Editing

An interactive editor is a computer program that allows a user to create and revise a target document. Document includes objects such as computer diagrams, text, equations tables, diagrams, line art, and photographs. In text editors, character strings are the primary elements of the target text.

Steps Involved in Document-Editing Process

Document-editing process in an interactive user-computer dialogue has four tasks:

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

The above task involves:

1) **Travelling:** Selection of the part of the document to be viewed and edited. It involves first travelling through the document to locate the area of interest such as "next screenful", "bottom", and "find pattern".
2) **Filtering:** The selection of what is to be viewed and manipulated is controlled by filtering. Filtering extracts the relevant subset of the target document at the point of interest, such as next screenful of text or next statement.
3) **Formatting:** Formatting then determines how the result of filtering will be seen as a visible representation (the view) on a display screen or other device.
4) **Editing:** In the actual editing phase, the target document is created or altered with a set of operations such as insert, delete, replace, move or copy. Manuscript-oriented editors operate on elements such as single characters, words, lines, sentences, and paragraphs; Program-oriented editors operate on elements such as identifiers, key words and statements.

Editing phase involves:

a. Insert b. Delete
c. Replace d. Move
e. Copy f. Cut
g. Paste, etc.

Types of Editors

The editors may be classified into two types as given below:

1) **Text Editors:** A text editor is a program, which allows the user to create the source program in the form of text into the main memory. Generally the user prepares HLL program or any source program. The creation, editing modification, deletion, updating of document or files can be done with the help of the text editor. The scope of the editing is limited to the text only.

Index	Element
1	22
2	33
3	66
4	05
5	44
6	89

05

Figure 5.14(a)

Index	Element
1	22
2	33
3	66
4	05
5	44
6	89

05

Figure 5.14(b)

2) **Graphical Editors:** Graphical editors are GUI (Graphical User Interface) based editors. These are much user-friendly. The Window-based editors are best example for the graphical editors. Notepad is an example for a graphical editor.

Ques 23) Define text editor. Also define the various types of text editors.

Ans: Text Editors

A text editor is a tool that allows a user to create and revise documents in a computer. Though this task can be carried out in other modes, the word text editor commonly refers to the tool that does this interactively. A popular text editor in IBM's large or mainframe computers is called **XEDIT**. In UNIX systems, the two most commonly used text editors are **Emacs** and **vi**. In personal computer systems, word processors are more common than text editors. However, there are variations of mainframe and UNIX text editors that are provided for use on personal computers. An **example** is KEDIT, which is basically XEDIT for Windows.

Types of Text Editors

1) **Line Editors:** During original creation lines of text are recognised and delimited by end-of-line markers, and during subsequent revision, the line must be explicitly specified by line number or by some pattern context. **For example,** edlin editor in early MS-DOS systems.
2) **Stream Editors:** The idea here is similar to line editor, but the entire text is treated as a single stream of characters. Hence the location for revision cannot be specified using line numbers. Locations for revision are either specified by explicit positioning or by using pattern context. **For example,** sed in Unix/Linux. Line editors and stream editors are suitable for text-only documents.
3) **Screen Editors:** These allow the document to be viewed and operated upon as a two dimensional plane, of which a portion may be displayed at a time. Any portion may be specified for display and location for revision can be specified anywhere within the displayed portion. **For example,** vi, emacs, etc.
4) **Word Processors:** Provides additional features to basic screen editors. Usually support non-textual contents and choice of fonts, style, etc.

Ques 24) Describe the salient aspects of Text Editor.

Ans: Salient Aspects of Text Editor

A text editor has to cover the following main aspects related to document creation, storage and revision:

1) **Interactive User Interface:** An important consideration of a document is its layout to a human reader. For this it is essential to present a document in a rectangular form, on the monitor screen (terminal) or via a printer (as an output of the interactive process). Further since a document can potentially be very large and since in a computer terminal can display only a limited size of a document at a time, hence it is necessary for a text editor to display only a portion (page) of a large document that cannot be displayed in entirety at once.

   The process of creating and revising a document in a computer is called **editing**. For interactive editing a text editor displays a document on the terminal and accepts various types of input from the user through different types of input devices, viz., keyboard, mouse, data-tablet (flat, rectangular, electromagnetically sensitive panel over which a ball-point-pen-like stylus is moved and the coordinates of the stylus is sent to the system). Initially the text editor may display the starting portion of the document. During editing the user may give inputs to bring other portions to the display. Besides the displayed page, there is the notion of a point within the page, indicated by an easily distinguishable symbol called the cursor, where the next insertion, deletion or modification will be effective.

   Many text editors allow pictures and other non-text information to be included in a document. Such editors provide mechanisms to either create/modify such information or embed such objects inside the document. The output of an editing process, i.e., the document, can be either saved as file(s) in the secondary storage or sent to some destination in the network, such as a printer or some remote host.

2) **Appropriate Format for Storing the Document in File in Secondary Storage:** The most natural way to visualise a document is as a planar layout of the information, within some bounded space. Thus, one possible format to save (store) the document in secondary storage is to save the attributes of each visible point (pixel) by traversing the layout in some order, say, left-to-right lines from top to bottom. However, this is not the done for obvious reasons. For textual information, there are widely used code-sets (e.g., ASCII, EBCDIC, ISCII, Unicode, etc.) that are used to encode the information. These code sets also contain codes for white spaces and new-line, and hence most textual information can be conveniently represented preserving the desired layout. Many text editors allow the appearance (script, size, colour and style) of text to be specified by the user. From the point of view of storing such variations of appearance

of text, this is usually achieved by storing extra information describing the appearance along with the actual text. Thus in secondary storage, the file corresponding to a document contains the textual information as well as attributes of the text, sometimes called **metadata** that controls the appearance of the text in output medium. Similarly, if the document has to contain non-textual information, that too is embedded using suitable metadata.

3) **Efficient Transfer of Information between the User Interface and the File in Secondary Storage:** The user interface of a text editor has to give emphasis to the visual appearance of the portion of the document that is displayed at any time, and convenience of the user to perform editing operations and viewing the document. On the other hand the format in which the document is stored in the secondary storage basically provides an unambiguous, static, and non-visual model of the document. Thus the text editor has to convert the user input into the file format, and file format into the display format. This conversion is one of the basic requirements for the text editor design.

Ques 25) Discuss about the criteria for the user interface design.

Or

Write notes on the user interface of a text editor. **(2017 [05])**

Or

Describe the user interfaces used in a text editor. **(2019[05])**

Ans: User Interface

Conceptual model of the editing system provides an easily understood abstraction of the target document and its elements. **For example,** Line editors – simulated the world of the key punch – 80 characters, single line or an integral number of lines. Screen editors – Document is represented as a quarter-plane of text lines, unbounded both down and to the right.

The user interface (UI) is concerned with, the input devices, the output devices and, the interaction language. The input devices are used to enter elements of text being edited, to enter commands. The output devices, lets the user view the elements being edited and the results of the editing operations and, the interaction language provides communication with the editor. A user interface plays important role in simplifying the interaction of a user with an application. UI functionalities have two important aspects. User interface is concerned with the input devices, the output devices, and the interaction language of the system, which are as follows:

1) **Input Devices:** These are used to enter elements of the text being edited, to enter commands, and to designate editable elements. These devices, as used with editors, can be divided into there categories, which are as follows:
   i) **Text or String Devices:** These are typically typewriter-like keyboards on which a user presses and releases keys, sending a unique code for each key. Text devices with arrow (cursor) keys can be used to simulate locator devices. Voice-input devices, which translate spoken words to their textual equivalents, may prove to be the text input devices of the future. Voice recognizers are currently available for command input on some systems.
   ii) **Button or Choice Devices:** These generate an interrupt or set a system flag, usually causing invocation of an associated application-program action. Such devices typically include a set of special function keys on an alphanumeric keyboard or on the display itself.
   iii) **Locator Devices:** These are two-dimensional analog-to-digital converters that position a cursor symbol on the screen by observing the user's movement of the device. The most common such devices for editing applications are the mouse and the data tablet. Locator devices usually incorporate one or more buttons that can be used to specify editing operations.
2) **Output Devices:** Formerly limited in range, output devices for editing are becoming more diverse. The output device lets the user view the elements being edited and the results of the editing operation. The first output devices were teletypewriters and other character-printing terminals that generated output on paper.
3) **Interaction Language:** The interaction language of a text editor is generally one of several common types. The user communicates with the editor by typing text strings both for command names and for operands. These strings are sent to the editor and are usually echoed to the output device. Typed specification often requires the user to remember the exact form of all commands, or at least their abbreviations. If the command language is complex, the user must continually refer to a manual or an on line help function for a description of less frequently used commands. In addition, the typing required can be time consuming, especially for inexperienced users. The function-key interface addresses these deficiencies. Here each command has associated with it a marked key on the user's keyboard.

Ques 26) Discuss the design of an Editor.

Ans: Design of an Editor

The structure of a text editor depends largely on the types of editing features and displaying capabilities that are to be supported. To implement the displaying capabilities, the semantics of the metadata that may be present in the document file needs to be implemented as display actions. **For example,** if the metadata implies a particular colour to be used for a segment of text, editor should invoke methods to affect that colour for the particular segment of text. Since at a time only a finite portion of the document can be displayed, such actions are to be taken for a portion of the information in the file. However, the user may specify some other portion to be displayed (through page-up, page-down, pattern search, etc.), in which case the display actions must be performed for that portion. Thus the editor program should keep track of the size of the display window, and the boundaries of the current displayed portion in terms of offsets from some fixed point in the document (such as line number of the first and the last displayed lines, etc.). The choice of data structure for the memory image (buffers) is important, since it has to support efficient insertion and deletion, while allowing the size of the document to vary from small to very large.

A simple 2-dimensional array with each row containing a line of text, may not suit for obvious reasons (what are the reasons?). A linked list may facilitate easy insertion and deletion, but having each letter in a single node in the linked list may be wasteful of memory. Also, user commands such as page-up, page-down, etc., may become inefficient.

Thus some kind of combination of array and linked list may have to be used. For example, the entries of an array may point to individual buffers for each line of the document. The buffer for a line may either be arrays or linked lists (with, say, a word in each node). For very large documents it may not be a good idea to hold the entire document in such buffers since only a small portion is displayed at a time and editing operations for a reasonable duration are likely to be in the neighbourhood of the displayed portion.

In such situations, a text editor may load only the required portion of the document into memory buffers, but be able to load any other portion as and when required. It needs to be remembered that in the memory image too it is essential to represent the metadata corresponding to the different portions of the document.

Ques 27) Explain the structure of typical editor with the help of diagram.

Or

Explain the structure of a text editor with the help of a diagram. **(2017 [05])**

Or

Draw the structure of a Typical Text Editor and describe the functions of each block. **(2018[08])**

Or

With the help of a diagram describe the structure of a text editor. **(2021[10])**

Or

Explain the structure of text editor with the help of diagram. **(2019[06])**

Ans: Structure of Text Editor

Most text editors have a structure similar to that shown in **figure 5.16**, regardless of the particular features they offer and the computers on which they are implemented.

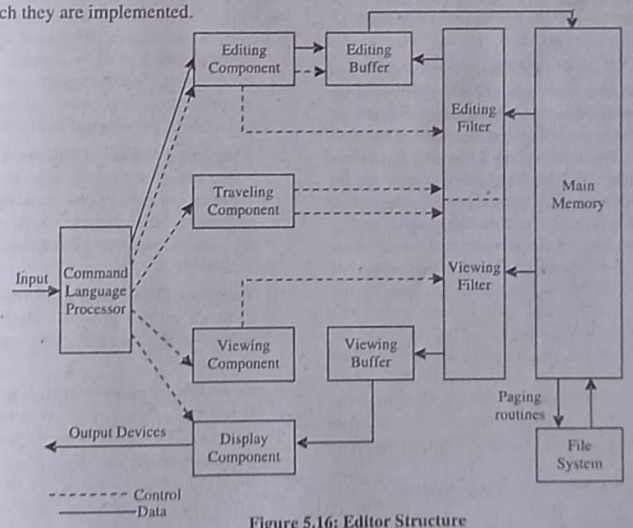


Figure 5.16: Editor Structure

The major components of editors are:

1) **Command Language Processor:** The command language processor accepts input from the user's input devices, and analyzes the tokens and syntactic structure of the commands.
2) **Editing Component:** In editing a document, the start of the area to be edited is determined by the current editing pointer maintained by the editing component, which is the collection of modules dealing with editing tasks.

3) **Travelling Component:** The travelling component of the editor actually performs the setting of the current editing and viewing pointers, and thus determines the point at which the viewing and/or editing filtering begins.

4) **Viewing Component:** In viewing a document, the start of the area to be viewed is determined by the current viewing pointer. This pointer is maintained by the viewing component of the editor, which is a collection of modules responsible for determining the next view.

5) **Display Component:** This produces a display by mapping the buffer to a rectangular subset of the screen, usually called a **window**.

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

7) **Viewing and Editing Filter:** This component filters the document to generate a new viewing buffer based on the current viewing pointer as well as on the viewing filter parameters. This viewing buffer is then passed to the display component of the editor.

DEBUGGERS

Ques 28) What do you mean by debugging? Explain.

Ans: Debugging

Debugging means locating (and then removing) bugs (faults in programs). In the entire process of program development errors may occur at various stages and efforts to detect and remove them may also be made at various stages. However, the word debugging is usually in context of errors that manifest while running the program during testing or during actual use. The most common steps taken in debugging are to examine the flow of control during execution of the program, examine values of variables at different points in the program, examine the values of parameters passed to functions and values returned by the functions, examine the function call sequence, etc. To overcome several such drawbacks of debugging by inserting extra statements in the program, there is various kind of tool called **debugger** that helps in debugging programs by giving the programmer some control over the execution of the program and some means of examining and modifying different program variables during runtime.

Ques 29) Discuss Interactive Debugging System.

Ans: Interactive Debugging Systems

Debugging is a methodical process of finding ad reducing the number of debugs, or defects in a computer program. An interactive debugging system provides programmers with facilities that aid in the testing and debugging of programs. The approaches to debugging are:

1) Print statements
2) Printing to log files
3) Sprinkling the code with assertions
4) Using post-mortem dumps
5) Having programs that provide function call stacks on termination
6) Profiling
7) Heap checking
8) System call tracing tools
9) Interactive source-level debugging
10) Reverse execution etc.

The basic principles of debugger are:

1) **Heisenberg Principle:** This principle says that the debugger must intrude on the debuggee in a minimal way.

2) **Truthful Debugging:** The debugger must be truthful so the programmer always trusts it.

3) **Providing Context Information:** The debugger should provide the program context information during debugging. Program context information are
   i) Source code, ii) Stack back-track, iii) Variable values, iv) Thread information

Ques 30) Discuss the basic operations supported by a debugger.

Ans: Basic Operations Supported by a Debugger

A debugger provides an interactive interface to the programmer to control the execution of the program and observe the proceedings. The program (executable file) to be debugged is provided as an input to the debugger. The basic operations supported by a debugger are:

1) **Breakpoints:** Setting breakpoints at various positions in the program. The breakpoints are points in the program at which the programmer wishes to suspend normal execution of the program and perform other tasks.

2) **Examining Values of Different Memory Locations:** When the execution of a program is suspended, the contents of specified memory locations can be examined. This includes local variables (usually on the stack), function parameters, and global (extern) variables.

3) **Examining the Contents of the program Stack:** The contents of the program stack reveals information related to the function call sequence that is active at that moment.

4) **Depositing Values in Different Memory Locations:** While the execution of the debugged program is not underway (yet to start or suspended at a breakpoint), the programmer can deposit any value in the memory locations corresponding to the program variables, parameters to subroutines, and processor registers.

Ques 31) Describe the important functions and capabilities of an interactive debugging system.

Or

Explain the debugging functions and debugging capabilities.

Or

Write notes on the debugging functions and capabilities of an interactive debugging system. (2017 [05])

Or

Describe the functions and capabilities of an Interactive Debugging System. (2018[06])

Ans: Debugging Functions and Debugging Capabilities

Following points highlight the debugging functions and capabilities:

1) Debugging system should provide functions such as tracing and traceback.
2) Tracing can be used to track the flow of execution logic and data modifications. It can also be based on conditional expressions.
3) Traceback can show the path by which the current statement was reached. It can also show which statements have modified a given variable or parameter.
4) Debugging system have a good program display capabilities. It must be possible to display the program being debugged, complete with statement numbers.
5) The system should save all the debugging specifications across such a recompilation, so the user does not need to reissue all of these debugging commands.
6) Debugging system must be sensitive to the specific language being debugged so that procedural, arithmetic and conditional logic can be coded in the syntax of that language.
7) The debugger should be able to switch its context when a program written in one language calls a program written in a different language.
8) A debugging system must be able to deal with optimised code. Application code used in production environments is usually optimised.

Ques 32) What are the different components of a debugging system? Explain.

Ans: Components of Debugging System

The major components of debugging system are:

1) **Debugging Database System:** Debugging database system contains a database with persistent debugging information (a . . . n) for a variety of executions of programs. The term persistent is used here in to mean that the debugging information remains available in the database after execution of the program has ceased. Database is managed by debug database server, which responds to queries from the other components of debugging system by writing to or reading from debug information as required by the query. Conceptually, debug data base server has two sets of clients:
   i) **Debugger client** which provides update queries containing debug information to database, and
   ii) **One or more user interface clients** which provide queries that read selected debug information from database.

   Debug data base system may be specially implemented for system or it may be one of the many commercial database systems. One of the functions of debugger is to ensure that a read query never attempts to read data which is not yet available in database; in others, it may be necessary to ensure that what is read is the last complete write done by debugger client. One method of coordinating reads and writes is to treat each read and write as a transaction and to use standard database transaction processing techniques; where consistency requirements are less stringent, the overhead of transaction processing can be avoided and sufficient coordination of reads and writes may be achieved by ordering the writes such that information which a given record in the data base depends on is written to the database before the record itself is written, thereby ensuring that all the information needed to respond to a query for which the given record is a result is in the database by the time the record itself can be queried.

2) **Debugger Client:** Debugger client is a debugger which is executing a program being debugged in debugger process. For purposes of the present discussion, a debugger client may be any entity which executes a computer program in such a fashion that information about the execution which would not normally be available to a user of the program becomes available. Thus, debugger client may be implemented expressly for system or it may be any kind of existing interactive debugger. Debugger client may have access to both the source code and object code for program. Debugger client may interpret source code, but more generally, it will execute object code and use source code to make debug info more understandable to the user of the debugger.

   Debug information obtained from source code and by means of execution of object code is written to debug database by means of update queries to debug database server. In some embodiments there may be more than one debugger client; **for example,** a programmer may want to watch the behavior of two closely-cooperating programs, or there may be debugger clients specialized for different programming languages or for different programming problems.

3) **User Interface Client:** Each user interface client receives inputs from a user, responds to some inputs by making a read query (Rquery) for debug data base server, and responds to the results of Rquery by formatting the results and providing the formatted results to the user as formatted output. The forms of the inputs received and the outputs provided by a given interface client depends on the kind of interactive interface employed by the user. Again, the interactive interface may be any presently existing or future interactive interface. Debugger client and the user interface clients further communicate with each other by means of control channel, which may be any arrangement which permits transfer of messages between debugger client and a user interface client. User interface client uses control channel to transfer debugger commands to debugger client, while

debugger client uses control channel to transfer debugger event messages to user interface client. **For example,** a first debugger command may instruct the debugger concerning the kinds of information it is to output, while another may instruct the debugger to stop execution of program at a predetermined point.

Ques 33) List out the criteria that should be met by the user interface of an Efficient Debugging System.
(2018[04])

Ans: Criteria Required to Meet by User Interface of an Efficient Debugging System

1) User friendly.
2) Use full screen display and windowing display.
3) Use menu bars:
   i) Menus should have the heading of the task.
   ii) Possible to go directly to menus and it should not entire hierarchy.
4) Command Language:
   i) It must be clear, logical, simple syntax.
   ii) Should minimise punctuations, eg : { }, /, etc ....
5) Available Help Facility.

Ques 34) Explain the relationship of debugger with other parts of the system.

Ans: Relationship with Other Parts of the System

The important requirement for an interactive debugger is that it always be available.

1) Debugger must appear as part of the run-time environment and an integral part of the system.
2) When an error is discovered, immediate debugging must be possible.
3) The debugger must communicate and cooperate with other operating system components such as interactive subsystems.
4) Debugging is more important at production time than it is at application- development time. When an application fails during a production run, work dependent on that application stops.
5) The debugger must also exist in a way that is consistent with the security and integrity components of the system.
6) The debugger must coordinate its activities with those of existing and future language compilers and interpreters.

Ques 35) Discuss the various methods of debugging.

Or

How induction and deduction methods are used for debugging?

Or

How backtracking is used for debugging?

Or

Describe any two commonly used debugging methods.
(2017 [05])

Or

Explain the following methods of debugging: (2020[10])

1) **Induction**
2) **Deduction**

3) **Backtracking**

Or

List and explain the different debugging techniques.
(2019[05])

Ans: Methods/Techniques Used for Debugging

Following are the method used for debugging:

1) **Debugging by Brute Force:** The most common and least effective method of program debugging is by "brute force". It requires little thought and is the least mentally taxing of all the methods. The brute-force methods are characterized by either debugging with a memory dump; scattering print statements throughout the program, or debugging with automated debugging tools. Using a memory dump to try to find errors suffers from the following drawbacks:
   i) Establishing the correspondence between storage locations and the variables in the source program is difficult.
   ii) Massive amounts of data, most of which is irrelevant, must be dealt with.
   iii) A dump shows only the static state of the program at only one instant in time. The dynamics of the program (i.e., state changes over time) are needed to find most errors.
   iv) The dump is rarely produced at the exact-time of the error. Hence the dump does not show the program's state at the time of the error.
   v) No formal procedure exists for finding the cause of an error analyzing a storage dump.
2) **Debugging by Induction:** Many errors can be found by using a disciplined thought process without ever going near the computer. One such thought process is induction, where one proceeds from the particulars to the whole. By starting with the symptoms of the error, possibly in the result of one or more test cases, and looking for relationships among the symptoms, the error is often uncovered. The induction process is illustrated in **figure 5.17** and described by Myers as follows:
   i) **Locate the Pertinent Data:** A major mistake made when debugging a program is failing to take account of all available data or symptoms about the problems. The first step is the enumeration of all that is known about what the program did correctly and what it did incorrectly (i.e., the symptoms that led one to believe that an error exists). Additional valuable clues are provided by similar, but different, test cases that do not cause the symptoms to appear.
   ii) **Organise the Data:** Remembering that induction implies that one is progressing from the particulars to the general, the second step is the structuring of the pertinent data to allow one to observe patterns, of particular importance is the search for contradictions (i.e., "the errors occurs only when the pilot perform a left turn while climbing").

   A particularly useful organizational technique that can be used to structure the available data is

shown in the following table. The "What" boxes list the general symptoms, the "Where" boxes describe where the symptoms were observed, the "When" boxes list anything that is known about the times that the symptoms occur, and the "To What Extent" boxes describes the scope and magnitude of the symptoms. Notice the "Is" and "Is Not" columns. They describe the contradictions that may eventually lead to a hypothesis about the error.

?	Is	Is Not
What		
Where		
When		
To what Extent		

   iii) **Devise a Hypothesis:** The next steps are to study the relationships among the clues and devise, using the patterns that might be visible in the structure of the clues, one or more hypotheses about the cause of the error. If one cannot devise a theory, more data are necessary, possibly obtained by devising and executing additional test cases. If multiple theories seem possible, the most probable one is selected first.
   iv) **Prove the Hypothesis:** A major mistake at this point, given the pressures under which debugging is usually performed, is skipping this step by jumping to conclusions and attempting to fix the problem. However, it is vital to prove the reasonableness of the hypothesis before proceeding.

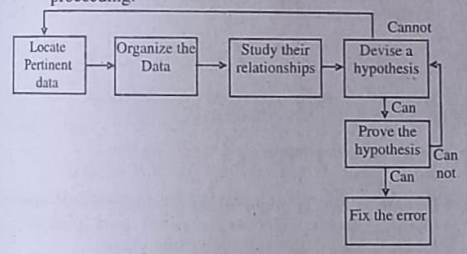


Figure 5.17: Inductive Debugging Process

3) **Debugging By Deduction:** An alternate thought process that of deduction, is a process of proceeding from some general theories or premises, using the processes of elimination and refinement, to arrive at a conclusion. This process is illustrated in **figure 5.18** and also described by Myers as follows:
   i) **Enumerate the Possible Causes or Hypotheses:** The first step is to develop a list of all conceivable causes of the error. They need not be complete explanations; they are merely theories through which one can structure and analyze the available data.
   ii) **Use the Data to Eliminate Possible Causes:** By a careful analysis of the data, particularly by looking for contradictions (the previous table could be used here), one attempt to eliminate all but one of the possible causes. If all are eliminated, additional data are needed (e.g., by devising additional test cases) to devise new theories. If more than one possible cause remains, the most probable cause (the prime hypothesis) is selected first.
   iii) **Refine the Remaining Hypothesis:** The possible cause at this point might be correct, but it is unlikely to he specific enough to pinpoint the error. Hence, the next step is to use the available clues to refine the theory to something more specific.
   iv) **Prove the Remaining Hypothesis:** This vital step is identical to the fourth step in the induction method.

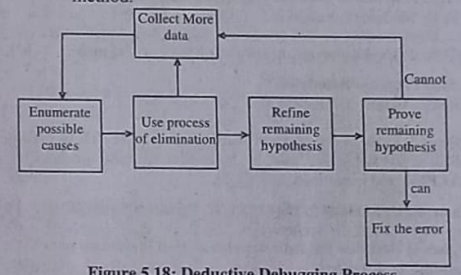


Figure 5.18: Deductive Debugging Process

4) **Debugging by Backtracking:** For small programs, the method of backtracking is often used effectively in locating errors. To use this method, start at the place in the program where an incorrect result was produced and go backwards in the program one step at a time, mentally executing the program in reverse order, to derive the state (or values of all variables) of the program at the previous step. Continuing in this fashion, the error is localized between the point where the state of the program was what was expected and the first point where the state was not what was expected.
5) **Debugging by Testing:** The use of additional test cases is another very powerful debugging method which is often used in conjunction with the induction method to obtain information needed to generate a hypothesis and/or to prove a hypothesis and with the deduction method to eliminate suspected causes, refine the remaining hypothesis, and/or prove a hypothesis. The test cases for debugging differ from those used for integration and testing in that they are more specific and are designed to explore a particular input domain or internal state of the program.

   Test cases for integration and testing tend to cover many conditions in one test, whereas test cases for debugging tend to cover only one or a very few conditions. The former are designed to detect the error in the most efficient manner whereas the latter are designed to isolate the error most efficiently