Module 4
LOADER

FUNCTIONS OF LOADER

Loading - Brings the object program into memory for execution.

Relocation - Modifies the object program so that it can be loaded at an address different from the location originally specified.

Linking - Combines two or more separate object programs and supplies the information needed to allow references between them.

- Only loading:- Absolute loader
- loading + relocation:- relocating loader
- Loading + relocation +linking :-linking loader
- Linking only:- linker

4.1 BASIC LOADER FUNCTIONS

Fundamental functions of a loader:

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

4.1.1 Design of an Absolute Loader

- No linking and program relocation is needed
- For a simple absolute loader, all functions are accomplished in a single pass as follows:

- The **Header record** of object programs is checked to verify that the correct program has been presented for loading.
- As each **Text record** is read, the object code it contains is moved to the indicated address in memory.
- When the **End record** is encountered, the loader jumps to the specified address to begin execution of the loaded program.

```
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

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

(b) Program loaded in memory

Figure 4.1 Loading of an absolute program

```
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
```

Figure 4.2 Algorithm for an absolute loader

- In the object program 4.1(a) each byte of the assembled code is given using its hexadecimal representation in character form
- For eg: The machine opcode for STL would be represented by the characters “1” and “4”.
- When these are read by the loader, they will occupy 2 bytes of memory.
- In the instruction as loaded for execution, this operation code must be stored in a single byte with hexadecimal value 14.
- Thus each pair of bytes from the object program must be packed together into a single byte during loading

- It is very important to realize that in Fig 4.1 (a), each printed character represents one byte of the object program record.
- In Fig 4.1(b), on the other hand, each printed character represents one hexadecimal digit in memory (a half-byte).
- Therefore, to save space and execution time of loaders, most machines store object programs in a binary form, with each byte of object code stored as a single byte in the object program.
- In this type of representation a byte may contain any binary value.

4.1.2 A Simple Bootstrap Loader

- Special type of Absolute loader
- It loads the very first pgm, required by the computer and begins execution
- OS
- It is an absolute loader that loads operating system into memory for execution

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

Working of a simple Bootstrap loader

- Bootstrap loader itself is a PGM
- The bootstrap begins at address 0 in the memory of the machine.
- It loads the operating system at address 80.
- There is no Header Record, Text Record or Control Record

OS program to be loaded

17202D48 470012XX   XX…….

.

.

.

2010110C 1039XXX………

Problem of Reading OS pgm

- While reading the object Pgm it consider each digit of the object code as a character
- So every character occupies 1 byte instead of half bytes
- Every object code is a hexadecimal digit
- It needs a half bye memory

```
BOOT     START    0        BOOTSTRAP LOADER FOR SIC/XE
.
. THIS BOOTSTRAP READS OBJECT CODE FROM DEVICE F1 AND ENTERS IT
. INTO MEMORY STARTING AT ADDRESS 80 (HEXADECIMAL). AFTER ALL OF
. THE CODE FROM DEVF1 HAS BEEN SEEN ENTERED INTO MEMORY, THE
. BOOTSTRAP EXECUTES A JUMP TO ADDRESS 80 TO BEGIN EXECUTION OF
. THE PROGRAM JUST LOADED.  REGISTER X CONTAINS THE NEXT ADDRESS
. TO BE LOADED.
.
         CLEAR    A        CLEAR REGISTER A TO ZERO
         LDX     #128      INITIALIZE REGISTER X TO HEX 80
LOOP     JSUB     GETC     READ HEX DIGIT FROM PROGRAM BEING LOADED
         RMO      A,S      SAVE IN REGISTER S
         SHIFTL   S,4      MOVE TO HIGH-ORDER 4 BITS OF BYTE
         JSUB     GETC     GET NEXT HEX DIGIT
         ADDR     S,A      COMBINE DIGITS TO FORM ONE BYTE
         STCH     0,X      STORE AT ADDRESS IN REGISTER X
         TIXR     X,X      ADD 1 TO MEMORY ADDRESS BEING LOADED
         J        LOOP     LOOP UNTIL END OF INPUT IS REACHED
.
. SUBROUTINE TO READ ONE CHARACTER FROM INPUT DEVICE AND
. CONVERT IT FROM ASCII CODE TO HEXADECIMAL DIGIT VALUE. THE
. CONVERTED DIGIT VALUE IS RETURNED IN REGISTER A. WHEN AN
. END-OF-FILE IS READ, CONTROL IS TRANSFERRED TO THE STARTING
. ADDRESS (HEX 80).
.
GETC     TD       INPUT    TEST INPUT DEVICE
         JEQ      GETC     LOOP UNTIL READY
         RD       INPUT    READ CHARACTER
         COMP    #4        IF CHARACTER IS HEX 04 (END OF FILE),
         JEQ      80           JUMP TO START OF PROGRAM JUST LOADED
         COMP    #48       COMPARE TO HEX 30 (CHARACTER '0')
         JLT      GETC     SKIP CHARACTERS LESS THAN '0'
         SUB     #48       SUBTRACT HEX 30 FROM ASCII CODE
         COMP    #10       IF RESULT IS LESS THAN 10, CONVERSION IS
         JLT      RETURN     COMPLETE. OTHERWISE, SUBTRACT 7 MORE
         SUB     #7          (FOR HEX DIGITS 'A' THROUGH 'F')
RETURN   RSUB              RETURN TO CALLER
INPUT    BYTE     X'F1'    CODE FOR INPUT DEVICE
         END      LOOP
```

Figure 4.3 Bootstrap loader for SIC/XE

- BOOT is the program name
- It is available at address 0
- It loads the OS into the address 80

```
BOOT    START   0       BOOTSTRAP LOADER FOR SIC/XE
.
        CLEAR   A       CLEAR REGISTER A TO ZERO
        LDX     #128    INITIALIZE REGISTER X TO HEX 80
LOOP    JSUB    GETC    READ HEX DIGIT FROM PROGRAM BEING LOADED
        RMO     A,S     SAVE IN REGISTER S
        SHIFTL  S,4     MOVE TO HIGH-ORDER 4 BITS OF BYTE
        JSUB    GETC    GET NEXT HEX DIGIT
        ADDR    S,A     COMBINE DIGITS TO FORM ONE BYTE
        STCH    0,X     STORE AT ADDRESS IN REGISTER X
        TIXR    X,X     ADD 1 TO MEMORY ADDRESS BEING LOADED
        J       LOOP    LOOP UNTIL END OF INPUT IS REACHED
```

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

- Each byte of object code to be loaded is represented on device F1 as two hexadecimal digits just as it is in a Text record of a SIC object program.
- The object code from device F1 is always loaded into consecutive bytes of memory, starting at address 80.
- The main loop of the bootstrap keeps the address of the next memory location to be loaded in register X.
- After all of the object code from device F1 has been loaded, the bootstrap jumps to address 80, which begins the execution of the program that was loaded.

- Much of the work of the bootstrap loader is performed by the subroutine GETC.
- This subroutine reads one character from device F1 and converts it from the ASCII character code to the value of the hexadecimal digit that is represented by that character.
- For eg:
  - ASCII code for character “0” is converted to numerical value 0.
  - Similarly ASCII code for characters “1 “through “9”(hexadecimal 31 through 39) are converted to numeric values 1 through 9.
  - This is done by subtracting 48 (hex 30)from the character codes for 0 through 9.
  - Similarly ASCII code for “A” through “F” (hexadecimal 41 through 46)are converted to the values 10 through 15 by subtracting 55 (hex 37)from the codes for A through F.
  - It skips all the other input characters that have ASCII codes less than 48(hexadecimal 30)

- The main loop of the bootstrap keeps the address of the next memory location to be loaded in register X.
- GETC is used to convert a pair of characters from device F1(representing 1 byte of object code to be loaded).
- These two hexadecimal digit values are combined into a single byte by shifting the first one left 4 bit positions and adding the second to it.
- The resulting byte is stored at the address currently in X, using a STCH instruction that refers to location 0 using indexed addressing.
- The TIXR instruction is then used to add 1 to the value in register X.

4.2 MACHINE-DEPENDENT LOADER FEATURES

- The absolute loader is simple and efficient. But it has several potential disadvantages.
- One of the most obvious is the need for the programmer to specify the actual address at which it will be loaded into memory.
  - On a simple computer with a small memory the actual address at which the program will be loaded can be specified easily.
  - On a larger and more advanced machine, we often like to run several independent programs together, sharing memory between them. We do not know in advance where a program will be loaded. Hence we write relocatable programs instead of absolute ones.
- Writing absolute programs also makes it difficult to use subroutine libraries efficiently. This could not be done effectively if all of the subroutines had preassigned absolute addresses.

- The need for program relocation is an indirect consequence of the change to larger and more powerful computers.
- The way relocation is implemented in a loader is also dependent upon machine characteristics.

4.2.1 Relocation

- Loaders that allow for program relocation are called relocating loaders or relative loaders.
- **Two methods for specifying relocation as part of the object program:**
- **The first method :**
- A Modification is used to describe each part of the object code that must be changed when the program is relocated.
- Most of the instructions in this program use relative or immediate addressing.
- The only portions of the assembled program that contain actual addresses are the extended format instructions on lines 15, 35, and 65. Thus these are the only items whose values are affected by relocation .

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

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

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

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

```
Loc     Source statement                          Object code

0000    COPY      START     0
0000    FIRST     STL       RETADR                140033
0003    CLOOP     JSUB      RDREC                 481039
0006              LDA       LENGTH                000036
0009              COMP      ZERO                  280030
000C              JEQ       ENDFIL                300015
000F              JSUB      WRREC                 481061
0012              J         CLOOP                 3C0003
0015    ENDFIL    LDA       EOF                   00002A
0018              STA       BUFFER                0C0039
001B              LDA       THREE                 00002D
001E              STA       LENGTH                0C0036
0021              JSUB      WRREC                 481061
0024              LDL       RETADR                080033
0027              RSUB                            4C0000
002A    EOF       BYTE      C'EOF'                454F46
002D    THREE     WORD      3                     000003
0030    ZERO      WORD      0                     000000
0033    RETADR    RESW      1
0036    LENGTH    RESW      1
0039    BUFFER    RESB      4096
                  .
                  .         SUBROUTINE TO READ RECORD INTO BUFFER
                  .
1039    RDREC     LDX       ZERO                  040030
103C              LDA       ZERO                  000030
103F    RLOOP     TD        INPUT                 E0105D
1042              JEQ       RLOOP                 30103F
1045              RD        INPUT                 D8105D
1048              COMP      ZERO                  280030
104B              JEQ       EXIT                  301057
104E              STCH      BUFFER,X              548039
1051              TIX       MAXLEN                2C105E
1054              JLT       RLOOP                 38103F
1057    EXIT      STX       LENGTH                100036
105A              RSUB                            4C0000
105D    INPUT     BYTE      X'F1'                 F1
105E    MAXLEN    WORD      4096                  001000
                  .
                  .         SUBROUTINE TO WRITE RECORD FROM BUFFER
                  .
1061    WRREC     LDX       ZERO                  040030
1064    WLOOP     TD        OUTPUT                E01079
1067              JEQ       WLOOP                 301064
106A              LDCH      BUFFER,X              508039
106D              WD        OUTPUT                DC1079
1070              TIX       LENGTH                2C0036
1073              JLT       LOOP                  381064
1076              RSUB                            4C0000
1079    OUTPUT    BYTE      X'05'                 05
                  END       FIRST
```

Figure 3.6 Relocatable program for a standard SIC machine.

The second method :

- In the case of a machine that primarily uses direct addressing(SIC) and has a fixed instruction format, relocation is specified using a different technique.
- 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 length indicator in each Text record. In Figure this mask is represented (in character form) as three hexadecimal digits.
- If the relocation bit corresponding to a word of object code is set to 1, the program's starting address is to be added to this word when the program is relocated. A bit value of 0 indicates that no modification is necessary.
- If a Text record contains fewer than 12 words of object code, the bits corresponding to unused words are set to 0.

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

Figure 3.7 Object program with relocation by bit mask.

- For example, the bit mask FFC (representing the bit string 111111111100) in the first Text record specifies that all 10 words of object code are to be modified during relocation.

4.2.2 Program Linking

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

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

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

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

- Consider first the reference marked REF1.
- For the first program (PROGA), REF1 is simply a reference to a label within the program.
- It is assembled in the usual way as a PC relative instruction.
- No modification for relocation or linking is necessary.
- In PROGB, the same operand refers to an external symbol.
- The assembler uses an extended-format instruction with address field set to 00000.
- The object program for PROGB contains a Modification record instructing the loader to add the value of the symbol LISTA to this address field when the program is linked.
- For PROGC, REF1 is handled in exactly the same way.

```
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^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^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^000048^06^+LISTA
M^00004B^06^+ENDA
M^00004B^06^-LISTA
M^00004B^06^-ENDB
M^00004B^06^+LISTB
M^00004E^06^+LISTB
M^00004E^06^-LISTA
E
```

- The reference marked **REF2** is processed in a similar manner.
- **REF3** is an **immediate operand** whose value is to be the difference between ENDA and LISTA (that is, the length of the list in bytes).
- In PROGA, the assembler has all of the information necessary to compute this value.
- During the assembly of PROGB (and PROGC), the values of the labels are unknown.
- In these programs, the expression must be assembled as an external reference (with two Modification records) even though the final result will be an absolute value independent of the locations at which the programs are loaded.

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

- PROGA has been loaded starting at address 4000, with PROGB and PROGC immediately following.
- For example, the value for reference REF4 in PROGA is located at address 4054 (the beginning address of PROGA plus 0054).

	Starting address	Pgm length	Ending address
PGM A	4000	0063	4062
PGM B	4063	007F	40E2
PGM C	40E3	0051	4133

CONTROL SECTION	SYMBOL NAME	ADDRESS	LENGTH
PGM A		4000	0063
	LISTA	4040	
	ENDA	4054	
PGM B		4063	007F
	LISTB	40C3	
	ENDB	40D3	
PGM C		40E2	
	LISTC	4112	
	ENDC	4124	

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

Figure 3.10(a) Programs from Fig. 3.8 after linking and loading.

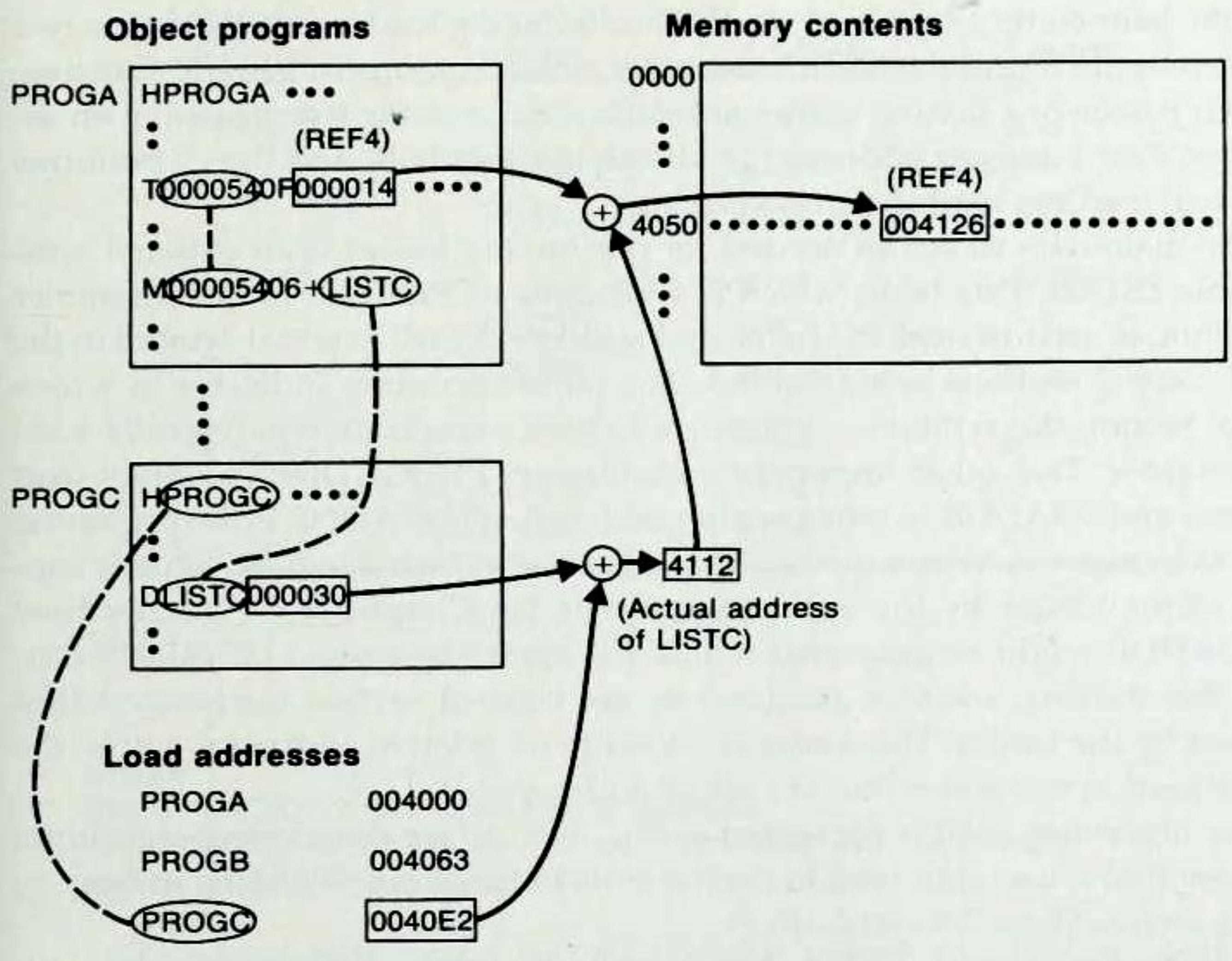


Figure 3.10(b) Relocation and linking operations performed on REF4 from PROGA.

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

4.2.3 Algorithm and Data Structures for a Linking Loader

- The algorithm for a linking loader is considerably more complicated than the absolute loader algorithm.
- The input consists of a set of object programs(i.e. control sections) that are to be linked together.
- Control section can make external reference to symbols. The linking operation cannot be performed until an address is assigned to the external symbol involved.

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

ESTAB

- This table, which is analogous to SYMTAB in our assembler algorithm, is used to store the name and address of each external symbol in the set of control sections being loaded.
- The table also indicates in which control section the symbol is defined.
- A hashed organization is typically used for this table.

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

Pass 1:

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

Figure 3.11(a) Algorithm for Pass 1 of a linking loader.

- During Pass 1, 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 OS.
- This becomes the starting address (CSADDR) for the first control section in the input sequence.

- The control section name from Header record is entered into ESTAB, with value given by CSADDR.
- All **external symbols appearing in the Define record for the control** section are also entered into ESTAB.
- Their addresses are obtained by adding the value specified in the Define record to CSADDR.

- When the End record is read,
- the control section length CSLTH (which was saved from the End record) is added to CSADDR.
- This calculation gives the starting address for the next control section in sequence.

- At the end of Pass 1, ESTAB contains all external symbols defined in the set of control sections together with the address assigned to each.
- Many loaders include as an option the ability to print a **load map that shows these** symbols and their addresses

Control section	Symbol name	Address	Length
PROGA		4000	0063
	LISTA	4040	
	ENDA	4054	
PROGB		4063	007F
	LISTB	40C3	
	ENDB	40D3	
PROGC		40E2	0051
	LISTC	4112	
	ENDC	4124	

- Pass 2 performs the actual loading, relocation, and linking of the program.
- 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.
- The last step performed by the loader is usually the transferring of control to the loaded program to begin execution.

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

Pass 2:

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

Figure 3.11(b) Algorithm for Pass 2 of a linking loader.

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

```
H^PROGA ^000000^000063
D^LISTA ^000040^ENDA  ^000054
R^02LISTB ^03ENDB  ^04LISTC ^05ENDC
•
•
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 3.12 Object programs corresponding to Fig. 3.8 using reference numbers for code modification. (Reference numbers are underlined for easier reading.)

```
HPROGB 000000000007F
DLISTB 000060ENDB  000070
R02LISTA 03ENDA  04LISTC 05ENDC
•
•
T0000360B0310000077202705100000
•
•
T0000700F000000FFFFF6FFFFFFFFFFF0000060
M00003705+02
M00003E05+03
M00003E05-02
M00007006+03
M00007006-02
M00007006+04
M00007306+05
M00007306-04
M00007606+05
M00007606-04
M00007606+02
M00007906+03
M00007906-02
M00007C06+01
M00007C06-02
E
```

```
H^PROGC ^000000^000051
D^LISTC ^000030^ENDC  ^000042
R^02LISTA ^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^000021^05^-02
M^000042^06^+03
M^000042^06^-02
M^000042^06^+01
M^000048^06^+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
```

4.3 MACHINE-INDEPENDENT LOADER FEATURES

- Loading and linking are often thought of as OS service functions.
- Machine independent loader features include
- the use of an automatic library search process for handling external reference and some common options that can be selected at the time of loading and linking.

4.3.1 Automatic Library Search

- Many linking loaders can automatically incorporate routines from a subprogram library into the program being loaded
- In most cases there is a standard system library for this purpose.
- Other libraries may be specified by control statements or by parameters to the loader.
- This feature allows the 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. On some systems this feature is referred to as automatic library call(or search).**

- Linking loaders that support automatic library search must keep track of
- external symbols that are referred to, but not defined, in the primary input to the loader.
- For this, enter symbols from each Refer record into ESTAB unless these symbols are already present.

- These symbols are marked to indicate that symbol has not yet defined.
- When the definition is seen, the address assigned to the symbol is filled in to complete the entry.
- At the end of Pass 1, the symbols in ESTAB that remain undefined represent unresolved external references.
- The loader searches the library or libraries specified for routines that contain the definitions of these symbols,
- and processes the subroutines found by this search exactly as if they had been part of the primary input stream.

- The subroutines fetched from a library in this way may themselves contain external references.
- It is therefore necessary to repeat the library search process until all references are resolved.
- If unresolved external references remain after the library search is completed, these must be treated as errors.

- The process (above) allows the programmer to override standard subroutines in the library by supplying his or her own routines.
- For example the main program refers to standard subroutine named SQRT which is automatically included in the library search function.
- If the programmer wants to use a different version of SQRT, it is done by including it as input to the loader.
- By the end of pass1 of the loader , SQRT would be already defined and it will not be included in any library search.

- Libraries to be searched contains the assembled or compiled versions of the subroutines
- To search these libraries, scanning the object programs for define records is quite inefficient.
- A special file structure is used for libraries. This structure contains a directory that gives the name of each routine and a pointer to its address within the file.
- If the subroutine is to be callable by more than one name, both names are entered into the directory but the object program is stored only once.

4.3.2 Loader Options

- Many loaders allow the user to specify options that modify the standard processing.
- 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.
- The control statements can also be embedded in the primary input stream between object programs.
- In other case, the programmer can include the loader control statements in the source program and the assembler or compiler retains these commands as a part of the object program.

- **Typical loader option 1:**

  Allows the selection of alternative sources of input.

  Ex : INCLUDE program-name (library-name)

  might direct the loader to read the designated object program from a library and treat it as if it were part of the primary loader input.

- **Loader option 2:**

  Allows the user to delete external symbols or entire control sections.

  Ex : DELETE csect-name

  might instruct the loader to delete the named control section(s) from the set of programs being loaded.

  CHANGE name1, name2

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

Loader option 3:

Involves the automatic inclusion of library routines to satisfy external references.

Ex. : LIBRARY MYLIB

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

- NOCALL STDDEV, PLOT, CORREL

To instruct the loader that these external references are to remain unresolved.

This avoids the overhead of loading and linking the unneeded routines, and saves the memory space that would otherwise be required.

- Another common option involves output from the loader

  Eg: Through control statements the use can specify if a load map is to be printed or not and if printed, the level of details can be selected(CS names, addresses, external symbol names, addresses etc)

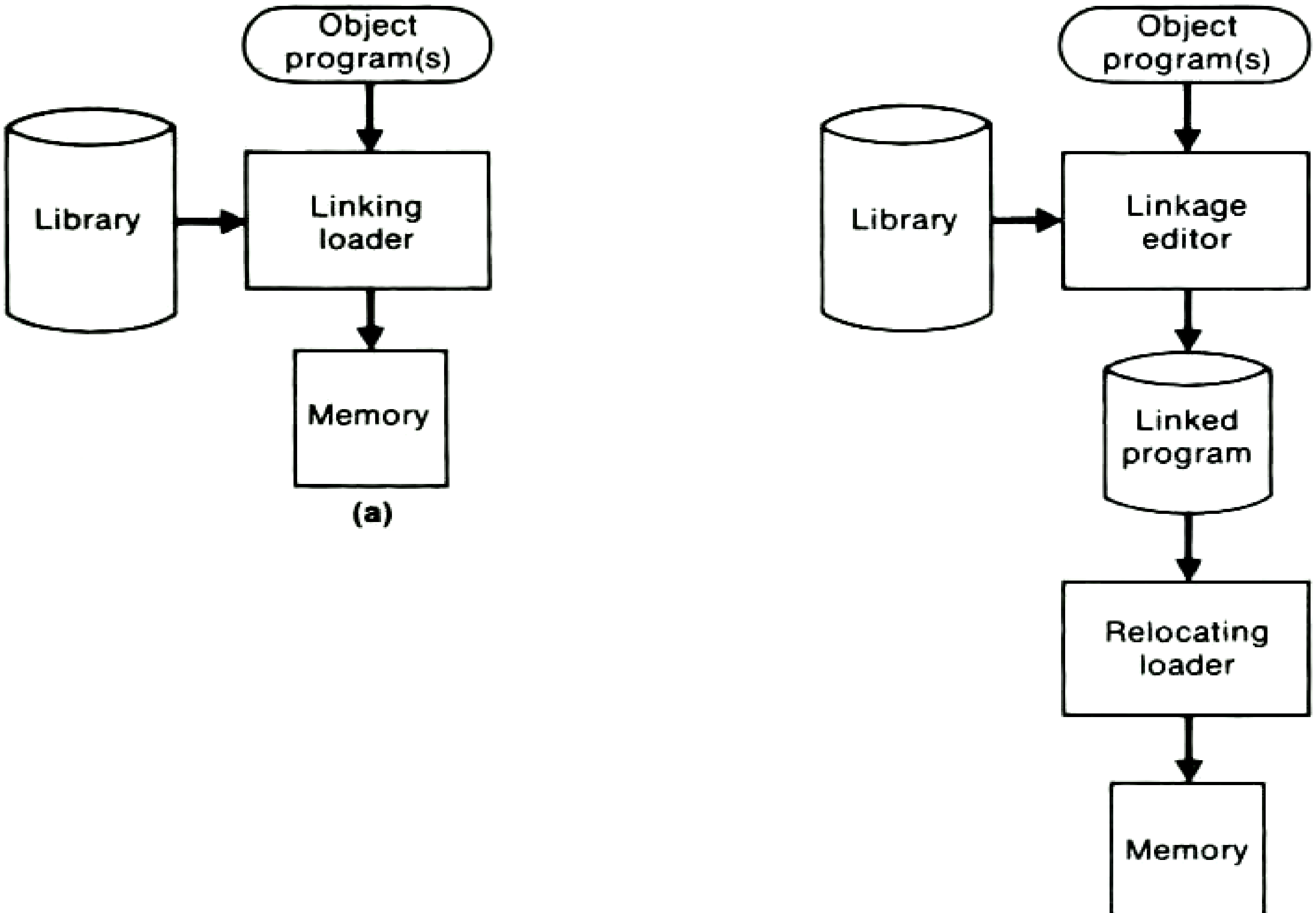
- Another option is the ability to specify the location at which the execution is to begin(overriding any information in the object programs.

- Another option is the ability to control whether or not the loader should attempt to execute the program if errors are detected during load(eg: unresolved external references)

4.4 LOADER DESIGN OPTIONS

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

4.4.1 Linkage Editors



Processing of an object program using (a) Linking loader (b) Linkage editor

4.4.1 Linkage Editors

- A linkage editor produces a linked version of the program (load module or executable image), which is written to a file or library for later execution.
- When the user is ready to run the linked program, a simple relocating loader can be used to load the program into memory.
- The only object code modification necessary is the addition of an actual load address to relative values within the program.
- The linkage editor performs relocation of all control sections relative to the start of the linked program. Thus, all items that need to be modified at load time have values that are relative to the start of the linked program.
- This means that the loading can be accomplished in one pass with no external symbol table required.
- This involves much less overhead than using a linking loader.

- If a program is to be executed many times without being reassembled, the use of a linkage editor substantially reduces the overhead required.
- Resolution of external references and library searching are performed only once(when the program is link edited). In contrast a linking loader searches libraries and resolves external references every time the program is executed.
- In certain situations such as program development and testing, the program is reassembled for every execution. In certain situation when a program is not used frequently, the linked version of the program to be stored is not worthwhile. In the above cases, a linking loader is used which avoids the steps of writing and reading the linked program.
- In linkage editor, even after linking the information concerning external references is retained because if this is not retained the program cannot be reprocessed by the linkage editor; it can only be loaded and executed.

- Linkage editors can perform many useful functions besides simply preparing an object program for execution.
- Eg., A progam named PLANNER has a subroutine named PROJECT which is to be changed for some reason. After the new version of PROJECT is assembled, the linkage editor replace the old version with the updated version of PLANNER as follows:

INCLUDE PLANNER (PROGLIB)

DELETE PROJECT **{delete from existing PLANNER}**

INCLUDE PROJECT (NEWLIB) **{include new version}**

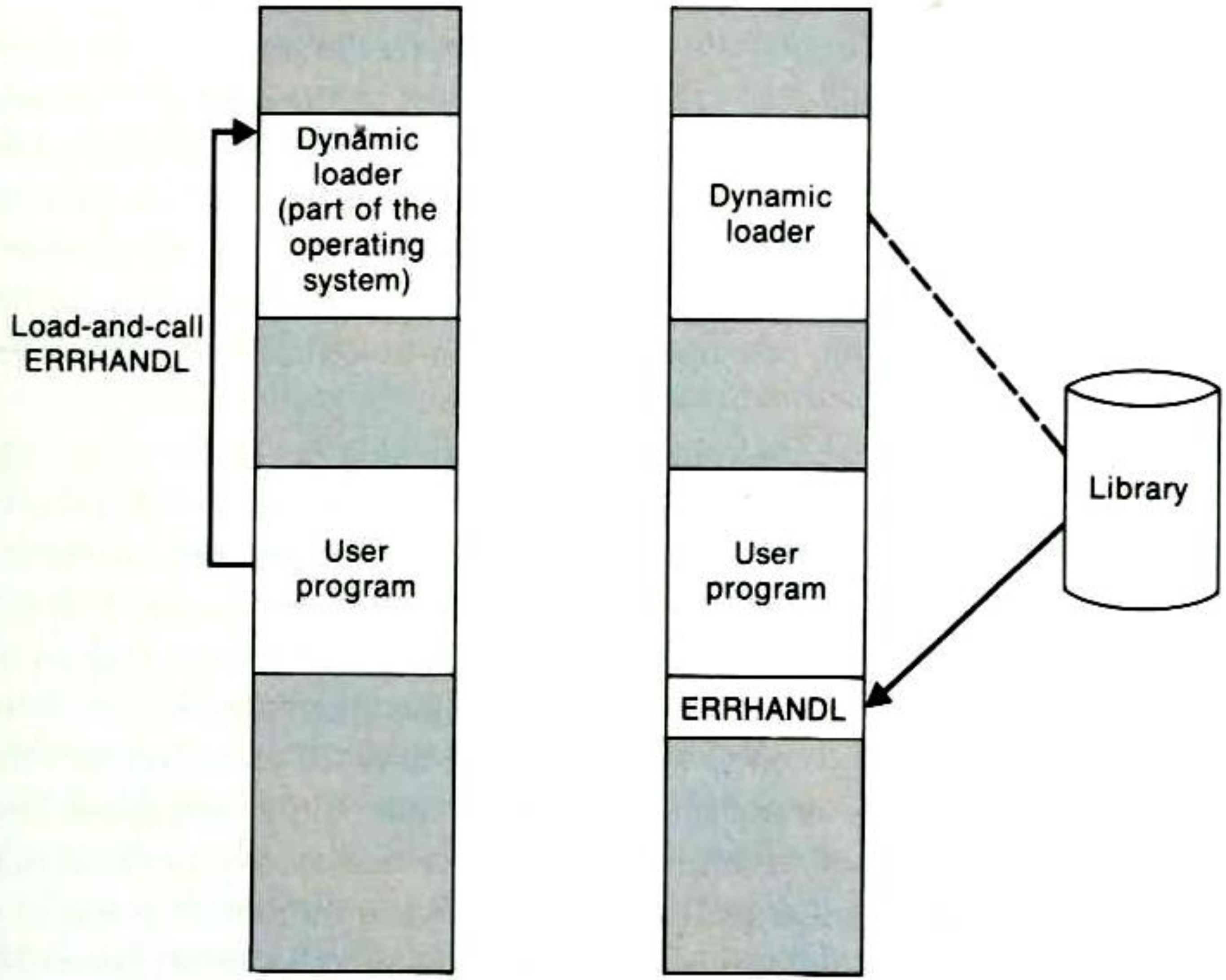
REPLACE PLANNER (PROGLIB)

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

4.4.2 Dynamic Linking

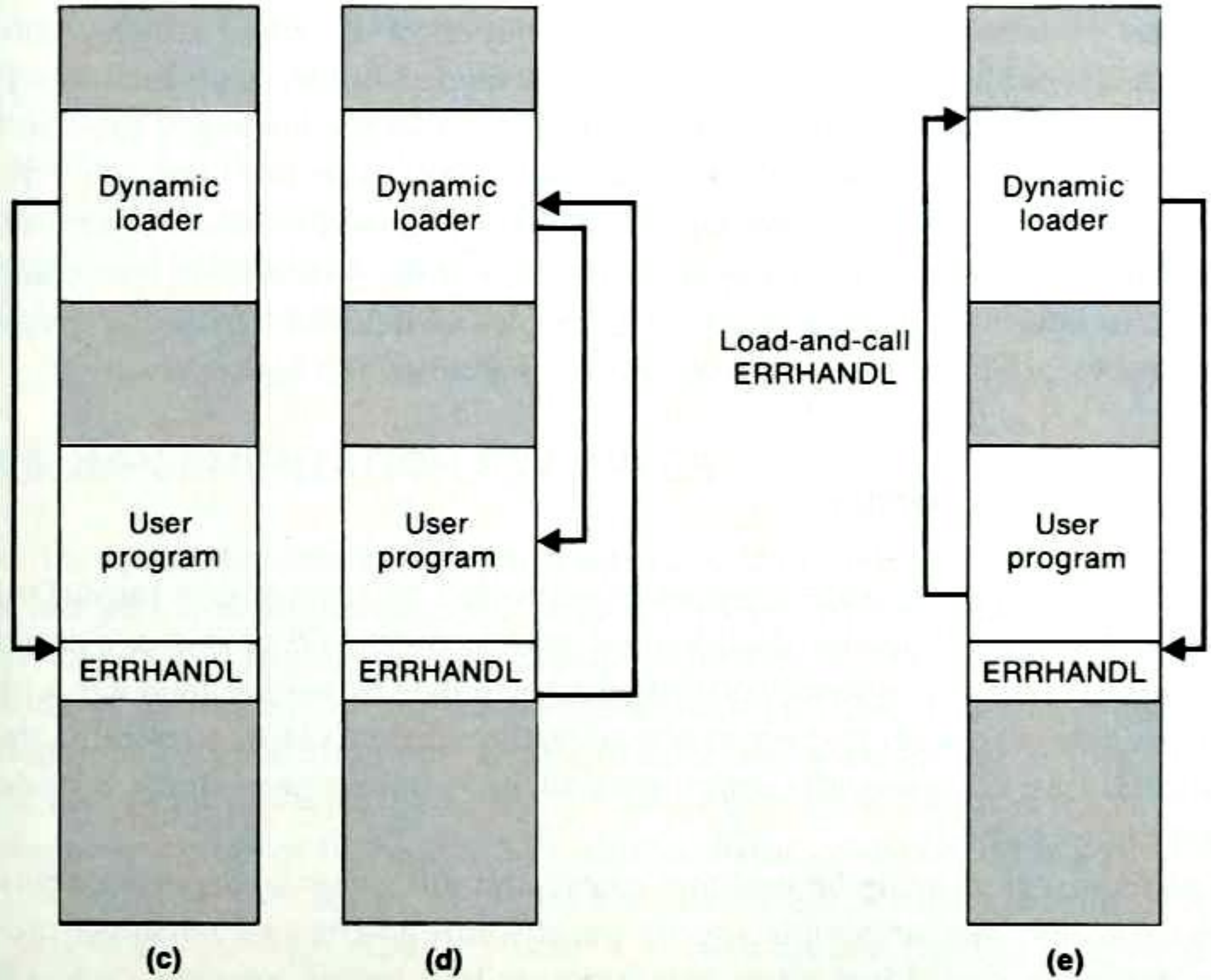
- Linkage editors perform linking operations before the program is loaded for execution.
- Linking loaders perform these same operations at load time.
- Dynamic linking, dynamic loading, or **load on call** postpones the linking function until execution time: a subroutine is loaded and linked to the rest of the program when it is first called.
- Dynamic linking is often used to allow several executing programs to share one copy of a subroutine or library, eg: run-time support routines for a high-level language like C.
- Dynamic linking provides the ability to load the routines only when they are needed.
- If the subroutines involved are large or have many external references, this can result in substantial savings of time and memory space.

- With a program that allows its user to interactively call any of the subroutines of a large mathematical and statistical library, all of the library subroutines could potentially be needed, but only a few will actually be used in any one execution.
- Dynamic linking can avoid the necessity of loading the entire library for each execution except those necessary subroutines.
- Figure illustrates a method in which routines that are to be dynamically loaded must be called via an operating system service request. This method could also be thought of as a request to a part of the loader that is kept in memory during execution of the program.


Dynamic
loader
(part of the
operating
system)
Load-and-call
ERRHANDL
User
program
Dynamic
loader
Library
User
program
ERRHANDL

(a)

(b)


Dynamic loader
User program
ERRHANDL
(c)
Dynamic loader
User program
ERRHANDL
(d)
Load-and-call ERRHANDL
Dynamic loader
User program
ERRHANDL
(e)

- **Fig (a):** Instead of executing a JSUB instruction referring to an external symbol, the program makes a load-and-call service request to OS. The parameter of this request is the symbolic name of the routine to be called.
- **Fig (b):** OS examines its internal tables to determine whether or not the routine is already loaded. If necessary, the routine is loaded from the specified user or system libraries.
- **Fig (c)**: Control is then passed from OS to the routine being called
- **Fig (d):** When the called subroutine completes it processing, it returns to its caller **(**i.e.,OS). OS then returns control to the program that issued the request.
- **Fig (e):** If a subroutine is still in memory, a second call to it may not require another load operation. Control may simply be passed from the dynamic loader to the called routine.

4.4.3 Bootstrap Loaders

- With the machine empty and idle there is no need for program relocation.
- We can specify the absolute address for whatever program is first loaded and this will be the OS, which occupies a predefined location in memory.
- This means that we need some means of accomplishing the functions of an absolute loader.

1. To have the operator enter into memory the object code for an absolute loader, using switches on the computer console. However the process is much too inconvenient and error – prone to be a good solution to the problem

- 2. To have the absolute loader program permanently resident in a ROM. When some hardware signal(pressing a start switch) occurs, the machine begins to execute this ROM program. On some computers, the program is executed directly in the ROM: on others, the program is copied from ROM to main memory and executed there. Modification to the absolute program cannot be done since it is in ROM.

3. To have a built –in hardware function that reads a fixed –length record from some device into memory at a fixed location.

- The particular device to be used can often be selected via console switches. After the read operation is complete, control is automatically transferred to the address in memory where the record was stored. This record contains machine instructions that load the absolute program that follows.
- If the loading process requires more instructions that can be read in a single record, this first record causes the reading of others, and these in turn can cause the reading of still more records – hence the term boots trap.
- The first record(or records) is generally referred to as bootstrap loader:· Such a loader is added to the beginning of all object programs that are to be loaded into an empty and idle system.
- This includes the OS itself and all stand-alone programs that are to be run without an OS.