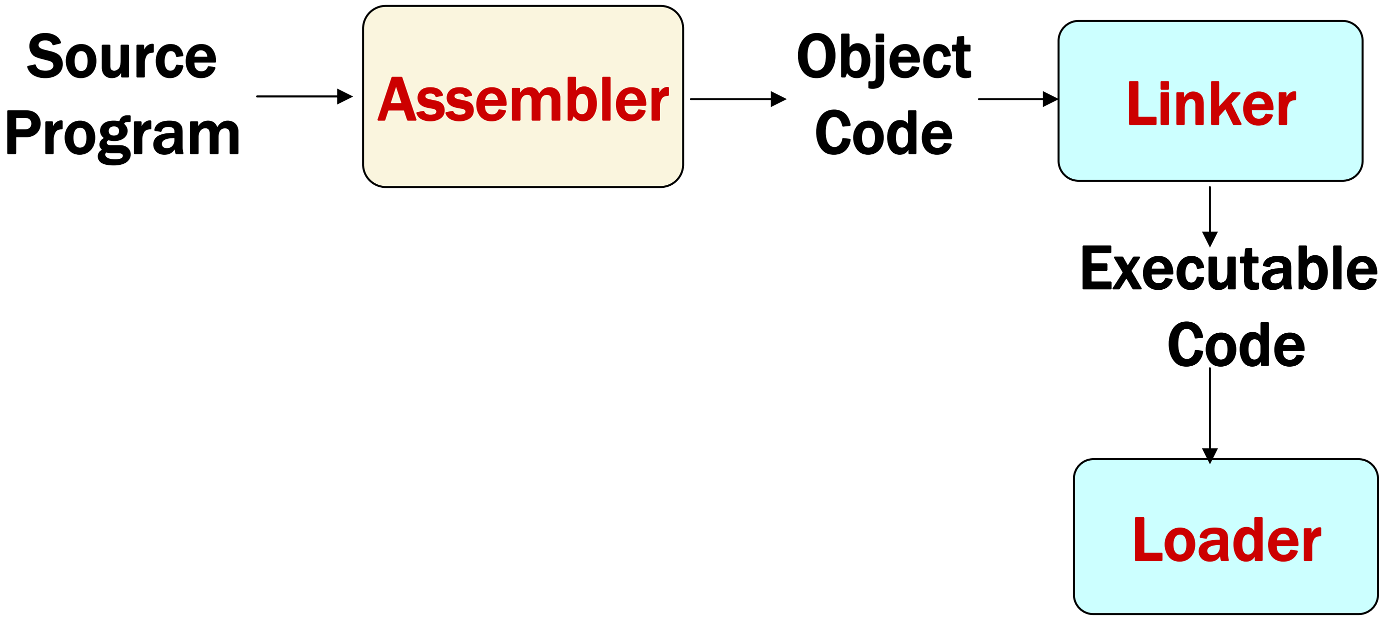
Chapter 3
Loaders and Linkers



3.1 Basic Loader Functions

- In Chapter 2, we discussions
  - *Loading:* brings the OP into memory for execution
  - *Relocating:* modifies the OP so that it can be loaded at an address different form the location originally specified.
  - *Linking:* combines two or more separate OPs (set 2.3.5)
- In Chapter 3, we will discussion
  - A *loader* brings an object program into memory and starting its execution.
  - A *linker* performs the linking operations and a separate loader to handle relocation and loading.

3.1 Basic Loader Functions

3.1.1 Design of an Absolute Loader

- Absolute loader (for SIC), in Figures 3.1 and 3.2.
  - Does not perform linking and program relocation.
  - The contents of memory locations for which there is no Text record are shown as xxxx.
  - Each byte of assembled code is given using its Hex representation in character form.

```
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

3.1.1 Design of an Absolute Loader

- Absolute loader, in Figure 3.1 and 3.2.
  - STL instruction, *pair of characters* 14, when these are read by loader, they will occupy *two* bytes of memory.
  - 14 (Hex 31 34) —-> 00010100 (one byte)
  - For execution, the operation code must be store in a single byte with hexadecimal value 14.
  - Each pair of bytes must be packed together into one byte.
  - Each printed character represents one half-byte.

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 3.1 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 3.2 Algorithm for an absolute loader.

3.1.2 A Simple Bootstrap Loader

- A bootstrap loader, Figure 3.3.
  - Loads the first program to be run by the computer—usually an operating system.
  - The bootstrap itself begins at address 0 in the memory.
  - It loads the OS or some other program starting at address 80.

3.1.2 A Simple Bootstrap Loader

- A bootstrap loader, Figure 3.3.
  - Each byte of object code to be loaded is represented on device F1 as two Hex digits (by GETC subroutines).
  - The ASCII code for the character 0 (Hex 30) is converted to the numeric value 0.
  - The object code from device F1 is always loaded into consecutive bytes of memory, starting at address 80.

```
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 3.3 Bootstrap loader for SIC/XE.

3.2 Machine-Dependent Loader Features

- Absolute loader has several potential disadvantages.
  - The actual address at which it will be loaded into memory.
  - Cannot run several independent programs together, sharing memory between them.
  - It difficult to use subroutine libraries efficiently.
- More complex loader.
  - Relocation
  - Linking
  - Linking loader

3.2.1 Relocation

- Relocating loaders, two methods:
  - Modification record (for SIC/XE)
  - Relocation bit (for SIC)

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	

```
              .
              .       SUBROUTINE TO READ RECORD INTO BUFFER
              .
1036   RDREC   CLEAR   X                 B410
1038           CLEAR   A                 B400
103A           CLEAR   S                 B440
103C          +LDT     #4096             75101000
1040   RLOOP   TD      INPUT             E32019
1043           JEQ     RLOOP             332FFA
1046           RD      INPUT             DB2013
1049           COMPR   A,S               A004
104B           JEQ     EXIT              332008
104E           STCH    BUFFER,X          57C003
1051           TIXR    T                 B850
1053           JLT     RLOOP             3B2FEA
1056   EXIT    STX     LENGTH            134000
1059           RSUB                      4F0000
105C   INPUT   BYTE    X'F1'             F1
```

```
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
```

Figure 3.4 Example of a SIC/XE program (from Fig. 2.6).

3.2.1 Relocation

- Modification record, Figure 3.4 and 3.5.
  - To described each part of the object code that must be changed when the program is relocated.
  - The extended format instructions on lines 15, 35, and 65 are affected by relocation. (absolute addressing)
  - In this example, all modifications add the value of the symbol COPY, which represents the starting address.
  - Not well suited for *standard version of SIC*, <u>all the instructions</u> except RSUB must be modified when the program is relocated. (absolute addressing)

```
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
```

Figure 3.5 Object program with relocation by Modification records.

3.2.1 Relocation

- Figure 3.6 needs 31 Modification records.
- Relocation bit, Figure 3.6 and 3.7.
  - A *relocation bit* associated with each word of object code.
  - The relocation bits are gathered together into a *bit mask* following the length indicator in each Text record.
  - If bit=1, the corresponding word of object code is relocated.

Line	Loc	Source statement			Object code	
5	0000	COPY	START	0		
10	0000	FIRST	STL	RETADR	140033	1
15	0003	CLOOP	JSUB	RDREC	481039	1
20	0006		LDA	LENGTH	000036	1
25	0009		COMP	ZERO	280030	1
30	000C		JEQ	ENDFIL	300015	1
35	000F		JSUB	WRREC	481061	1
40	0012		J	CLOOP	3C0003	1
45	0015	ENDFIL	LDA	EOF	00002A	1
50	0018		STA	BUFFER	0C0039	1
55	001B		LDA	THREE	00002D	1
60	001E		STA	LENGTH	0C0036	1
65	0021		JSUB	WRREC	481061	1
70	0024		LDL	RETADR	080033	1
75	0027		RSUB		4C0000	0
80	002A	EOF	BYTE	C'EOF'	454F46	0
85	002D	THREE	WORD	3	000003	0
90	0030	ZERO	WORD	0	000000	0
95	0033	RETADR	RESW	1		
100	0036	LENGTH	RESW	1		
105	0039	BUFFER	RESB	4096		

```
                .
                .        SUBROUTINE TO READ RECORD INTO BUFFER
                .
      1039      RDREC    LDX      ZERO                    040030   1
      103C               LDA      ZERO                    000030   1
      103F      RLOOP    TD       INPUT                   E0105D   1
      1042               JEQ      RLOOP                   30103F   1
      1045               RD       INPUT                   D8105D   1
      1048               COMP     ZERO                    280030   1
      104B               JEQ      EXIT                    301057   1
      104E               STCH     BUFFER,X                548039   1
      1051               TIX      MAXLEN                  2C105E   1
      1054               JLT      RLOOP                   38103F   1
      1057      EXIT     STX      LENGTH                  100036   1
      105A               RSUB                             4C0000   0
      105D      INPUT    BYTE     X'F1'                   F1       0
      105E      MAXLEN   WORD     4096                    001000   0
```

```
                .
                .         SUBROUTINE TO WRITE RECORD FROM BUFFER
                .
        1061    WRREC     LDX       ZERO              040030  1
        1064    WLOOP     TD        OUTPUT            E01079  1
        1067              JEQ       WLOOP             301064  1
        106A              LDCH      BUFFER,X          508039  1
        106D              WD        OUTPUT            DC1079  1
        1070              TIX       LENGTH            2C0036  1
        1073              JLT       LOOP              381064  1
        1076              RSUB                        4C0000  0
        1079    OUTPUT    BYTE      X'05'             05      0
                          END       FIRST
```

Figure 3.6 Relocatable program for a standard SIC machine.

3.2.1 Relocation

- Relocation bit, Figure 3.6 and 3.7.
  - In Figure 3.7, T000000^1E^FFC^ (111111111100) specifics that all 10 words of object code are to be modified.
  - On line 210 begins a new Text record even though there is room for it in the preceding record.
  - Any value that is to be modified during relocation must coincide with one of these 3-byte segments so that it corresponding to a relocation bit.
  - Because of the 1-byte data value generated form line 185, this instruction must begin a new Text record in object program.

1111 1111 1100

```
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.

1110 0000 0000

3.2.2 Program Linking

- In Section 2.3.5 showed a program made up of three controls sections.
  - Assembled together or assembled independently.

3.2.2 Program Linking

- Consider the three programs in Fig. 3.8 and 3.9.
  - Each of which consists of a single control section.
  - A list of items, LISTA—ENDA, LISTB—ENDB, LISTC—ENDC.
  - Note that each program contains exactly the same set of references to these external symbols.
  - Instruction operands (REF1, REF2, REF3).
  - The values of data words (REF4 through REF8).
  - Not involved in the relocation and linking are omitted.

```
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     +LISTA-1                         00003F
005D    REF7     WORD     ENDA-LISTA-( )                   000014
0060    REF8     WORD     -LISTA                           FFFFC0
                 END      REF1
```

```
HPROGA 000000000063
DLISTA 000040ENDA   000054
RLISTB ENDB   LISTC ENDC
•
•
T0000200A03201D77100004050014
•
•
T0000540F000014FFFF600003F000014FFFFC0
M00002405+LISTB        REF2
M00005406+LISTC        REF4
M00005706+ENDC         REF5
M00005706-LISTC
M00005A06+ENDC
M00005A06-LISTC        REF6
M00005A06+PROGA
M00005D06-ENDB         REF7
M00005D06+LISTB
M00006006+LISTB        REF8
M00006006-PROGA
E000020
```

Figure 3.9 Object programs corresponding to Fig. 3.8.

```
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
```

Figure 3.8 Sample programs illustrating linking and relocation.

```
H^PROGB ^000000^00007F
D^LISTB ^000060^ENDB   ^000070
R^LISTA ^ENDA   ^LISTC ^ENDC
•
•
T^000036^0B^03100000^772027^05100000
•
•
T^000070^0F^000000^FFFF6^FFFFFF^FFFFF0^000060
M^000037^05^+LISTA        REF1
M^00003E^05^+ENDA         REF3
M^00003E^05^-LISTA
M^000070^06^+ENDA
M^000070^06^-LISTA        REF4
M^000070^06^+LISTC
M^000073^06^+ENDC         REF5
M^000073^06^-LISTC
M^000076^06^+ENDC         REF6
M^000076^06^-LISTC
M^000076^06^+LISTA
M^000079^06^+ENDA         REF7
M^000079^06^-LISTA
M^00007C^06^+PROGB        REF8
M^00007C^06^-LISTA
E
```

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		

```
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        REF1
M^00001D^05^+LISTB        REF2
M^000021^05^+ENDA         REF3
M^000021^05^-LISTA
M^000042^06^+ENDA         REF4
M^000042^06^-LISTA
M^000042^06^+PROGC
M^000048^06^+LISTA        REF6
M^00004B^06^+ENDA
M^00004B^06^-LISTA        REF7
M^00004B^06^-ENDB
M^00004B^06^+LISTB
M^00004E^06^+LISTB        REF8
M^00004E^06^-LISTA
E
```

Figure 3.9 *(cont'd)*

3.2.2 Program Linking

- REF1,

```
LDA     LISTA     03201D        03100000
```

  - In the PROGA, REF1 is simply a reference to a label.
  - In the PROGB and PROGC, REF1 is a reference to an external symbols.
  - Need use extended format, Modification record.

- REF2 and REF3.

```
LDT       LISTB+4      772027            77100004
LDX       #ENDA-LISTA  050014            05100000
```

3.2.2 Program Linking

- REF4 through REF8,
  - `WORD ENDA-LISTA+LISTC 000014+000000`
- Figure 3.10(a) and 3.10(b)
  - Shows these three programs as they might appear in memory after loading and linking.
  - PROGA 004000, PROGB 004063, PROGC 0040E2.
  - REF4 through REF8 in the same value.
  - For the references that are instruction operands, the calculated values after loading do not always appear to be equal.
  - Target address, REF1 4040.

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.

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

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

Ref No.	Symbol	Address
1	PROGB	4063
2	LISTA	4040
3	ENDA	4054
4	LISTC	4112
5	ENDC	4124

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

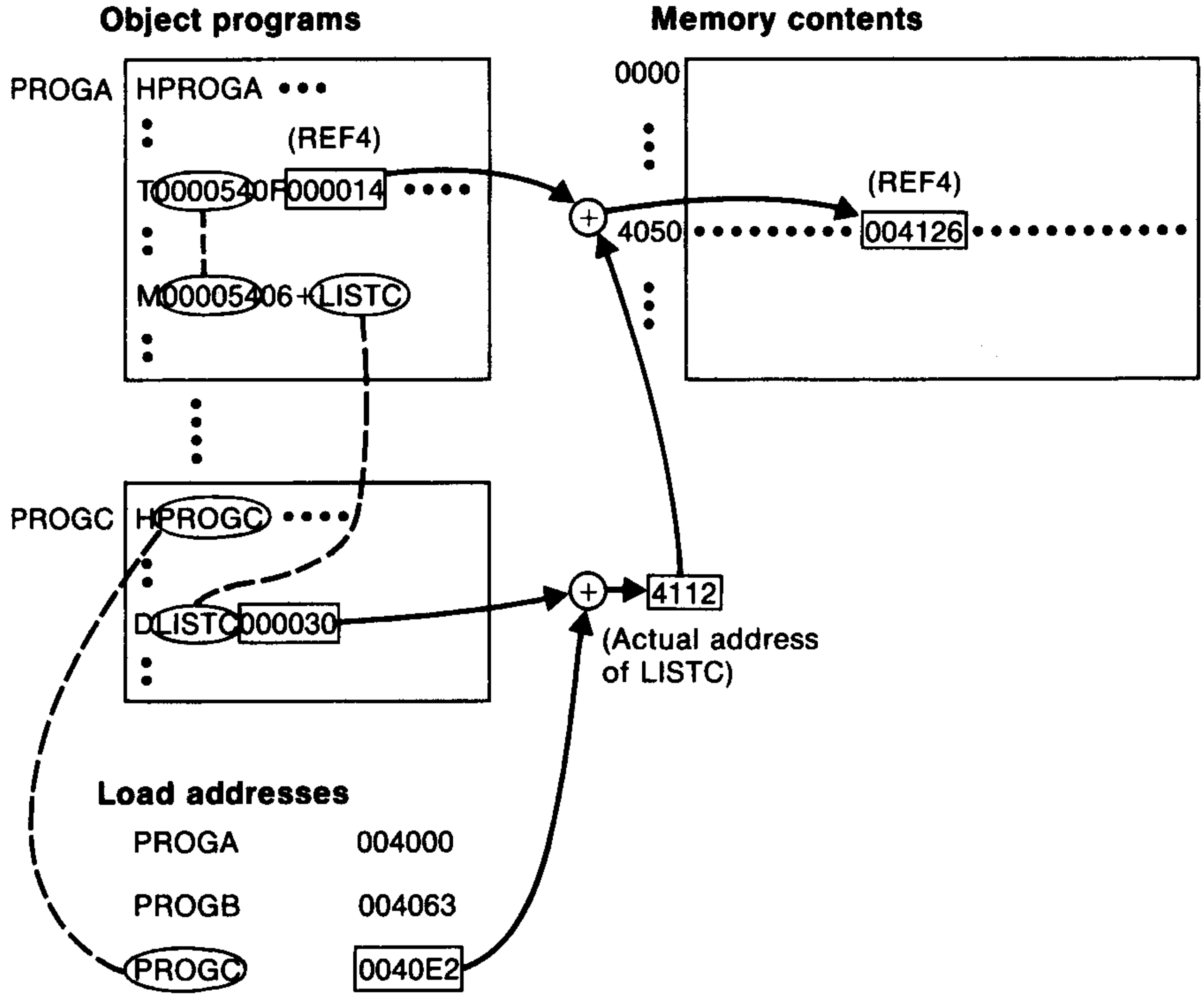


Figure 3.10(b) Relocation and linking operations performed on REF4 from PROGA.

3.2.3 Algorithm and Data Structure for a Linking Loader

- A linking loader usually makes two passes
  - Pass 1 assigns addresses to all external symbols by creating ESTAB.
  - Pass 2 performs the actual loading, relocation, and linking by using ESTAB.
  - The main data structure is ESTAB (hashing table).

3.2.3 Algorithm and Data Structure for a Linking Loader

- A linking loader usually makes two passes
  - ESTAB is used to store the name and address of each external symbol in the set of control sections being loaded.
  - Two variables PROGADDR and CSADDR.
  - PROGADDR is the beginning address in memory where the linked program is to be loaded.
  - CSADDR contains the starting address assigned to the control section currently being scanned by the loader.

3.2.3 Algorithm and Data Structure for a Linking Loader

- The linking loader algorithm, Fig 3.11(a) & (b).
  - In Pass 1, concerned only Header and Defined records.
  - CSADDR+CSLTH = the next CSADDR.
  - A load map is generated.
  - In Pass 2, 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.

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.

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.

3.2.3 Algorithm and Data Structure for a Linking Loader

- The algorithm can be made more efficient.
  - A *reference number*, is used in Modification records.
  - The number 01 to the control section name.
  - Figure 3.12, 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.

```
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
```

```
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
```

Figure 3.12 Object programs corresponding to Fig. 3.8 using reference numbers for code modification. (Reference numbers are underlined for easier reading.)

Figure 3.9 Object programs corresponding to Fig. 3.8.

```
HPROGB 00000000007F
DLISTB 000060ENDB  000070
R02LISTA 03ENDA  04LISTC 05ENDC
•
•
T0000360B0310000077202705100000
•
•
T0000700F000000FFFFF6FFFFFFFFFFF0000060
M00003705+02
M00003E05+03
M00003E05-02
M00007006+03
M00007006-02
M00007006+04
M00007306+05
M00007306-04
M00007606+05
M00007606-04
M00007606+02
M00007906+03
M00007906-02
M00007C06+01
M00007C06-02
E
```

```
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
```

Figure 3.12 (*cont'd*)

3.3 Machine-Independent Loader Features
3.3.1 Automatic Library Search

- Many linking loaders
  - Can automatically incorporate routines form a subprogram library into the program being loaded.
  - A standard system library
  - The subroutines called by the program begin loaded are automatically fetched from the library, linked with the main program, and loaded.

3.3.1 Automatic Library Search

- Automatic library call
  - At the end of Pass 1, the symbols in ESTAB that remain undefined represent unresolved external references.
  - The loader searches the library

3.3.2 Loader Options

- Many loaders allow the user to specify options that modify the standard processing.
  - Special command
  - Separate file
  - INCLUDE program-name(library-name)
  - DELETE csect-name
  - CHANGE name1, name2

```
INCLUDE     READ(UTLIB)
INCLUDE     WRITE(UTLIB)
DELETE      RDREC, WRREC
CHANGE      RDREC, READ
CHANGE      WRREC, WRITE
LIBRARY     MYLIB
NOCALL      STDEV, PLOT, CORREL
```

3.4 Loader Design Options
3.4.1 Linkage Editors

- Fig 3.13 shows the difference between linking loader and linkage editor.
  - The source program is first assembled or compiled, producing an OP.
- Linking loader
  - 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.

- The essential difference between a linkage editor and a linking loader

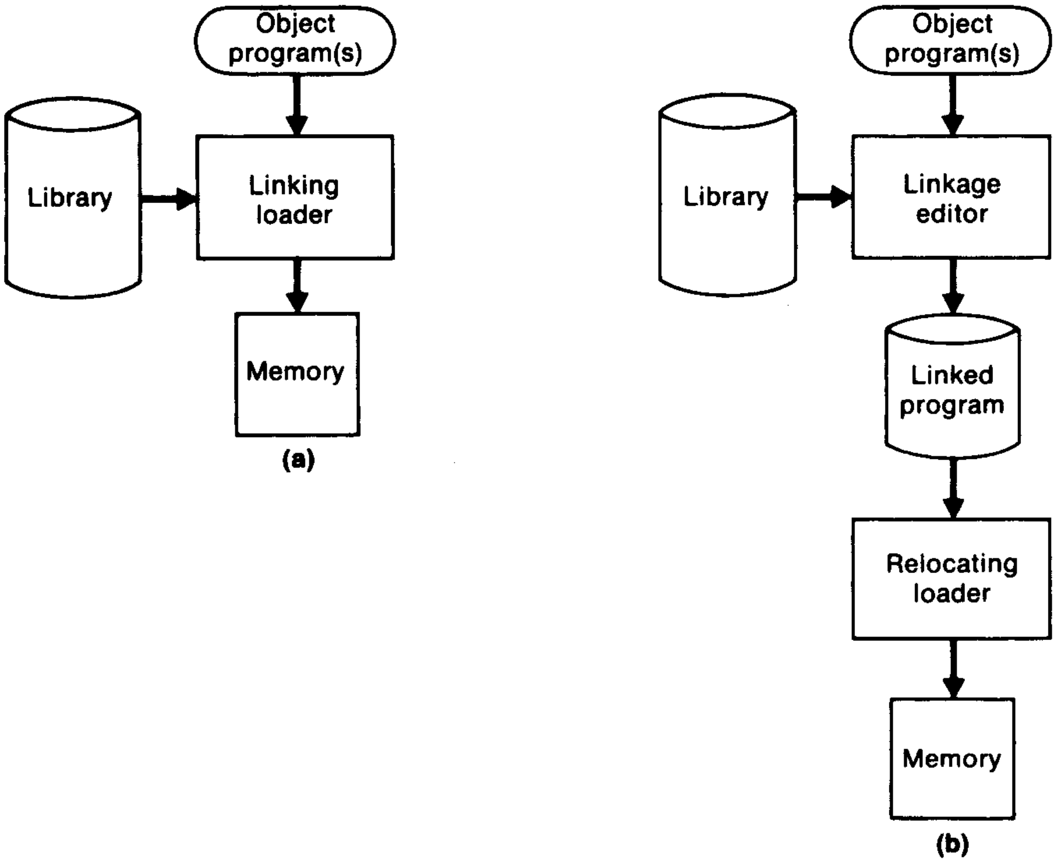


Figure 3.13 Processing of an object program using (a) linking loader and (b) linkage editor.

3.4.1 Linkage Editors

- Linkage editor
  - 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 LE performs relocation of all control sections relative to the start of the linked program.

3.4.1 Linkage Editors

- All items that need to be modified at load time have values that are relative to the start of the linked program.
- If a program is to be executed many times without being reassembled, the use of a LE substantially reduces the overhead required.
- LE can perform many useful functions besides simply preparing an OP for execution.

```
INCLUDE   PLANNER(PROGLIB)
DELETE    PROJECT            {DELETE from existing PLANNER}
INCLUDE   PROJECT(NEWLIB)    {INCLUDE new version}
REPLACE   PLANNER(PROGLIB)

INCLUDE   READR(FTNLIB)
INCLUDE   WRITER(FTNLIB)

INCLUDE   BLOCK(FTNLIB)
INCLUDE   DEBLOCK(FTNLIB)
INCLUDE   ENCODE(FTNLIB)
INCLUDE   DECODE(FTNLIB)
.
.
.
SAVE      FTNIO(SUBLIB)
```

3.4.2 Dynamic Linking

- Linking loaders perform these same (linking) operations at load time.
- Linkage editors perform linking operations before the program is load for execution.
- Dynamic Linking postpones the linking function until execution time.

3.4.2 Dynamic Linking

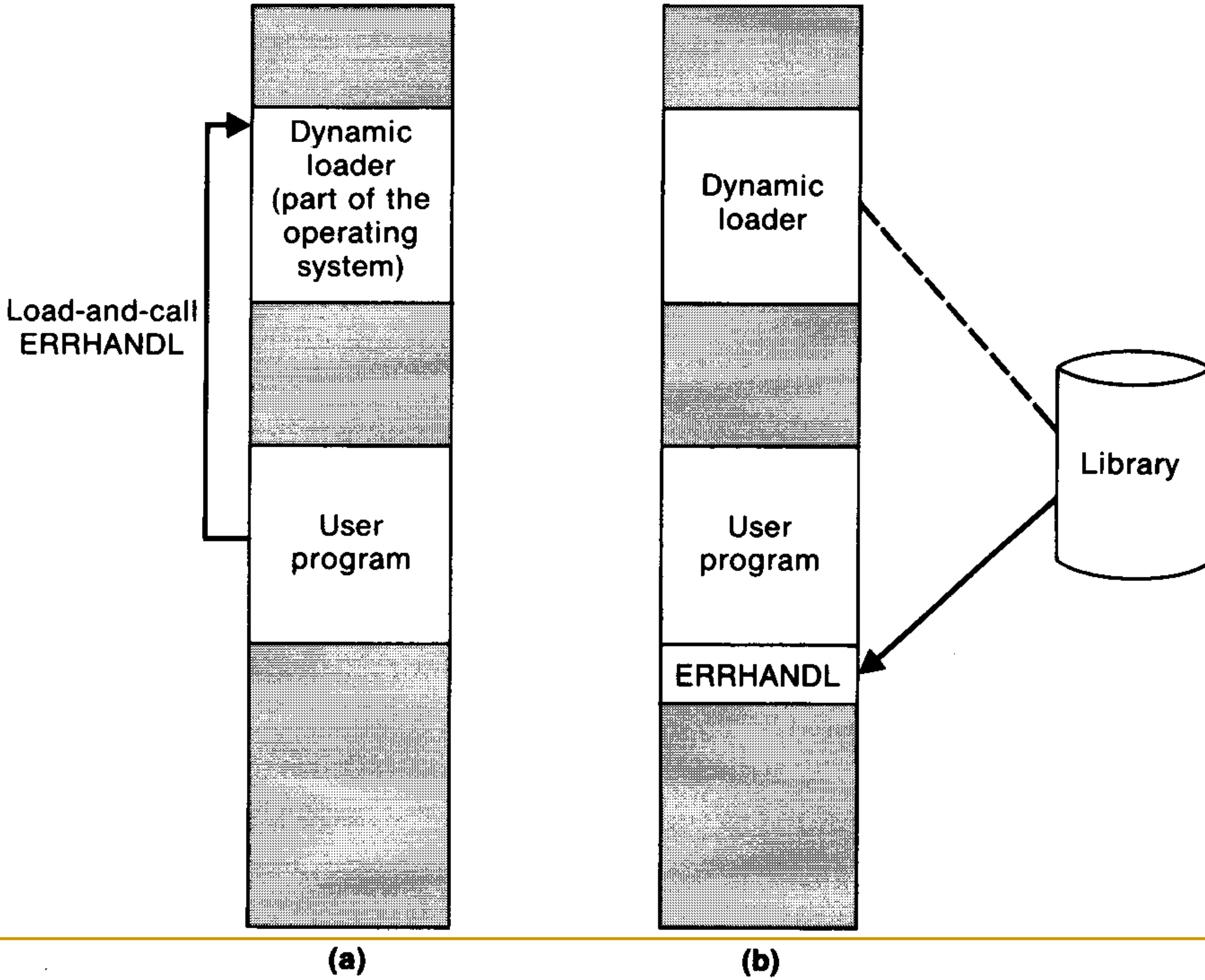
- Dynamic linking (dynamic loading, load on call)
  - Postpones the linking function until execution time.
  - A subroutine is loaded and linked to the rest the program when is first loaded.
  - Dynamic linking is often used to allow several executing program to share one copy of a subroutine or library.
    - Run-time library (C language), dynamic link library
    - A single copy of the routines in this library could be loaded into the memory of the computer.

3.4.2 Dynamic Linking

- Dynamic linking provides the ability to load the routines only when (and if) they are needed.
  - For example, that a program contains subroutines that correct or clearly diagnose error in the input data during execution.
  - If such error are rare, the correction and diagnostic routines may not be used at all during most execution of the program.
  - However, if the program were completely linked before execution, these subroutines need to be loaded and linked every time.

3.4.2 Dynamic Linking

- Dynamic linking avoids the necessity of loading the entire library for each execution.
- Fig. 3.14 illustrates a method in which routines that are to be dynamically loaded must be called via an operating system (OS) service request.


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

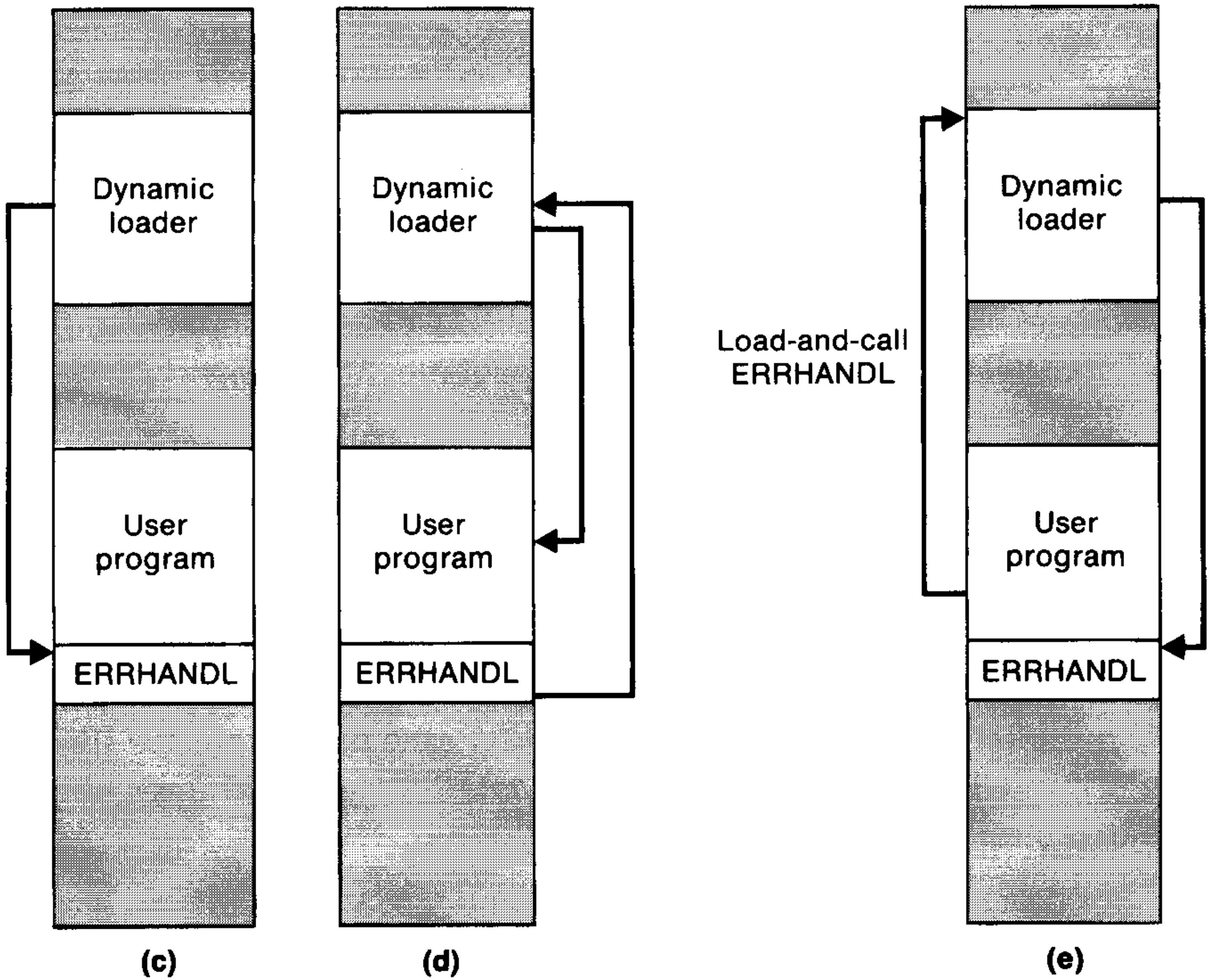


Figure 3.14 Loading and calling of a subroutine using dynamic linking.

3.4.2 Dynamic Linking

- The program makes a load-and-call service request to OS. The parameter argument (ERRHANDL) of this request is the symbolic name of the routine to be loaded.
- OS examines its internal tables to determine whether or not the routine is already loaded. If necessary, the routine is loaded form the specified user or system libraries.
- Control id then passed form OS to the routine being called.
- When the called subroutine completes its processing, OS then returns control to the program that issued the request.
- If a subroutine is still in memory, a second call to it may not require another load operation.

3.4.3 Bootstrap Loaders

- An absolute loader program is permanently resident in a read-only memory (ROM)
    - Hardware signal occurs
- The program is executed directly in the ROM
- The program is copied from ROM to main memory and executed there.

3.4.3 Bootstrap Loaders

- Bootstrap and bootstrap loader
  - Reads a fixed-length record form some device into memory at a fixed location.
  - After the read operation is complete, control is automatically transferred to the address in memory.
  - If the loading process requires more instructions than can be read in a single record, this first record causes the reading of others, and these in turn can cause the reading of more records.