MODULE 4

CST 305- SYSTEM SOFTWARE

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SYLLABUS (8 hours)

Basic Loader Functions

- Design of Absolute Loader.
- Simple Bootstrap Loader.

Machine Dependent Loader Features

- Relocation
- Program Linking
- Algorithm and Data Structures of Two Pass Linking Loader.

Machine Independent Loader Features

- Automatic Library Search
- Loader Options

Loader Design Options.

LOADERS AND LINKERS

- Loader is a system program that performs the loading function.
- Many loaders also support relocation and linking.
- Some systems have a linker (linkage editor) to perform the linking operations and a separate loader to handle relocation and loading.
- One system loader or linker can be used regardless of the original source programming language.

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.

- Type of loaders
  - assemble-and-go loader
  - absolute loader (bootstrap loader)
  - relocating loader (relative loader)
  - direct linking loader

Assemble-and-go Loader

- Characteristic
  - the object code is stored in memory after assembly
  - single JUMP instruction
- Advantage
  - simple, developing environment
- Disadvantage
  - whenever the assembly program is to be executed, it has to be assembled again
  - programs have to be coded in the same language

BASIC LOADER FUNCTIONS

Fundamental functions of a loader:

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

Design of an Absolute Loader

For a simple absolute loader, all functions are accomplished in a single pass as follows:

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

Fig. 3.2 Algorithm for an absolute loader

Begin
read Header record
verify program name and length
read first Text record
while record type is not ‘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

```
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 ←COPY
1030	000000xx	xxxxxxxx	xxxxxxxx	xxxxxxxx
⋮	⋮	⋮	⋮	⋮
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.

Object Code Representation

- Figure 3.1 (a)
  - » each byte of assembled code is given using its hexadecimal representation in character form
  - » easy to read by human beings
- In general
  - » each byte of object code is stored as a single byte
  - » most machine store object programs in a binary form
  - » we must be sure that our file and device conventions do not cause some of the program bytes to be interpreted as control characters

Design of an Absolute Loader

- Absolute Loader
  - Advantage
    - Simple and efficient
  - Disadvantage
    - the need for programmer to specify the actual address
    - difficult to use subroutine libraries
- Program Logic
  - Next slice

SIMPLE BOOTSTRAP LOADER

- 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

- The bootstrap begins at address 0 in the memory of the machine.
- It loads the operating system at address 80.
- 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.
- GETC is used to read and convert a pair of characters from device F1 representing 1 byte of object code to be loaded.
- For example, two bytes = C “D8” → ‘4438’H converting to one byte ‘D8’H.
- The resulting byte is stored at the address currently in register X, using STCH instruction that refers to location 0 using indexed addressing.
- The TIXR instruction is then used to add 1 to the value in X.

Fig. 3.3 SIC Bootstrap Loader Logic

Begin
X=0x80 (the address of the next memory location to be loaded
Loop
    A←GETC (and convert it from the ASCII character code to the value of the hexadecimal digit)
    save the value in the high-order 4 bits of S
    A←GETC
    combine the value to form one byte A← (A+S)
    store the value (in A) to the address in register X
    X←X+1
End

0~9 : 48
A~F : 65

GETC	A←read one character
	if A=0x04 then jump to 0x80
	if A<48 then GETC
	A ← A-48 (0x30)
	if A<10 then return
	A ← A-7 (48+7=55)
	return

```
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.

A Simple Bootstrap Loader

- Bootstrap Loader
  - » When a computer is first tuned on or restarted, a special type of absolute loader, called *bootstrap loader* is executed
  - » This bootstrap loads the first program to be run by the computer -- usually an operating system
- Example (SIC bootstrap loader)
  - » The bootstrap itself begins at address 0
  - » It loads the OS starting address 0x80
  - » No header record or control information, the object code is consecutive bytes of memory

MACHINE-DEPENDENT LOADER FEATURES

- The absolute loader 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.

Machine Dependent loader features

- Relocation.
- Program linking.
- Algorithm and data structures for a linking loader.

- 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.
- Loaders that allow for program relocation are called relocating loaders or relative loaders.

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
```

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

Relocation

- The loader 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.

```
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.

- 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.

Line	Loc	Source statement			Object code
5	0000	COPY	START	0	
10	0000	FIRST	STL	RETADR	140033
15	0003	CLOOP	JSUB	RDREC	481039
20	0006		LDA	LENGTH	000036
25	0009		COMP	ZERO	280030
30	000C		JEQ	ENDFIL	300015
35	000F		JSUB	WRREC	481061
40	0012		J	CLOOP	3C0003
45	0015	ENDFIL	LDA	EOF	00002A
50	0018		STA	BUFFER	0C0039
55	001B		LDA	THREE	00002D
60	001E		STA	LENGTH	0C0036
65	0021		JSUB	WRREC	481061
70	0024		LDL	RETADR	080033
75	0027		RSUB		4C0000
80	002A	EOF	BYTE	C'EOF'	454F46
85	002D	THREE	WORD	3	000003
90	0030	ZERO	WORD	0	000000
95	0033	RETADR	RESW	1	
100	0036	LENGTH	RESW	1	
105	0039	BUFFER	RESB	4096	
110		.			

```
                    .       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.

```
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 3.6 SIC/XE relocation loader algorithm.

- Consider a Relocatable program for a Standard SIC machine
- The Modification record is not well suited for use with all machine architectures.
- Consider, for example, the program in Fig (2) .
- This is a relocatable program written for standard version for SIC.
- The important difference between this example and the one in Fig (1) is that 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 Fig (1).

The second method

- 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.

```
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.

- The relocation bits are gathered together into a bit mask following the length indicator in each Text record.
- In Fig (3) 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.

- 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.

- Example: Note that the LDX instruction on line 210 (Fig (2)) begins a new Text record.

- 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 generated from line 185.

```
begin
  get PROGADDR from operating system
  while not end of input do
    begin
      read next record
      while record type ≠ 'E' do
      while record type = 'T'
        begin
          get length = second data
          mask bits(M) as third data
            For(i = 0, i < length, i++)
              if M_i = 1 then
                add PROGADDR at the location PROGADDR + specified
                    address
              else
                move object code from record to location PROGADDR +
                    specified address
          read next record
        end
    end
end
```

Figure 3.9 SIC relocation loader algorithm.

Program Linking

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

Program 1 (PROGA):

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	

Program 2 (PROGB):

```
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
```

Program 3 (PROGC):

```
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

Corresponding object programs PROGA:

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

Corresponding object programs PROGB

```
HPROGB 00000000007F
DLISTB 000060ENDB  000070
RLISTA ENDA  LISTC ENDC
.
.
T0000360B031000007720270510000
.
.
T0000700F000000FFFFF6FFFFFFFFFFF0000060
M00003705+LISTA
M00003E05+ENDA
M00003E05-LISTA
M00007006+ENDA
M00007006-LISTA
M00007006+LISTC
M00007306+ENDC
M00007306-LISTC
M00007606+ENDC
M00007606-LISTC
M00007606+LISTA
M00007906+ENDA
M00007906-LISTA
M00007C06+PROGB
M00007C06-LISTA
E
```

Corresponding object programs PROGC

```
H^PROGC ^000000^000051
D^LISTC ^000030^ENDC  ^000042
R^LISTA ^ENDA  ^LISTB ^ENDB
.
.
T^000018^0C^031000^000077^100004^051000^00
.
.
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.

Fig (4): The three programs as they might appear in memory after loading and linking.

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	
⋮	⋮	⋮	⋮	⋮	

- Fig. 3.10
- Load address for control sections
  - PROGA 004000 63
  - PROGB 004063 7F
  - PROGC 0040E2 51
- Load address for symbols
  - LISTA: PROGA+0040=4040
  - LISTB: PROGB+0060=40C3
  - LISTC: PROGC+0030=4112
- REF4 in PROGA
  - ENDA-LISTA+LISTC=14+4112=4126
  - T0000540F000014FFFFF600003F000014FFFFC0
  - M00005406+LISTC

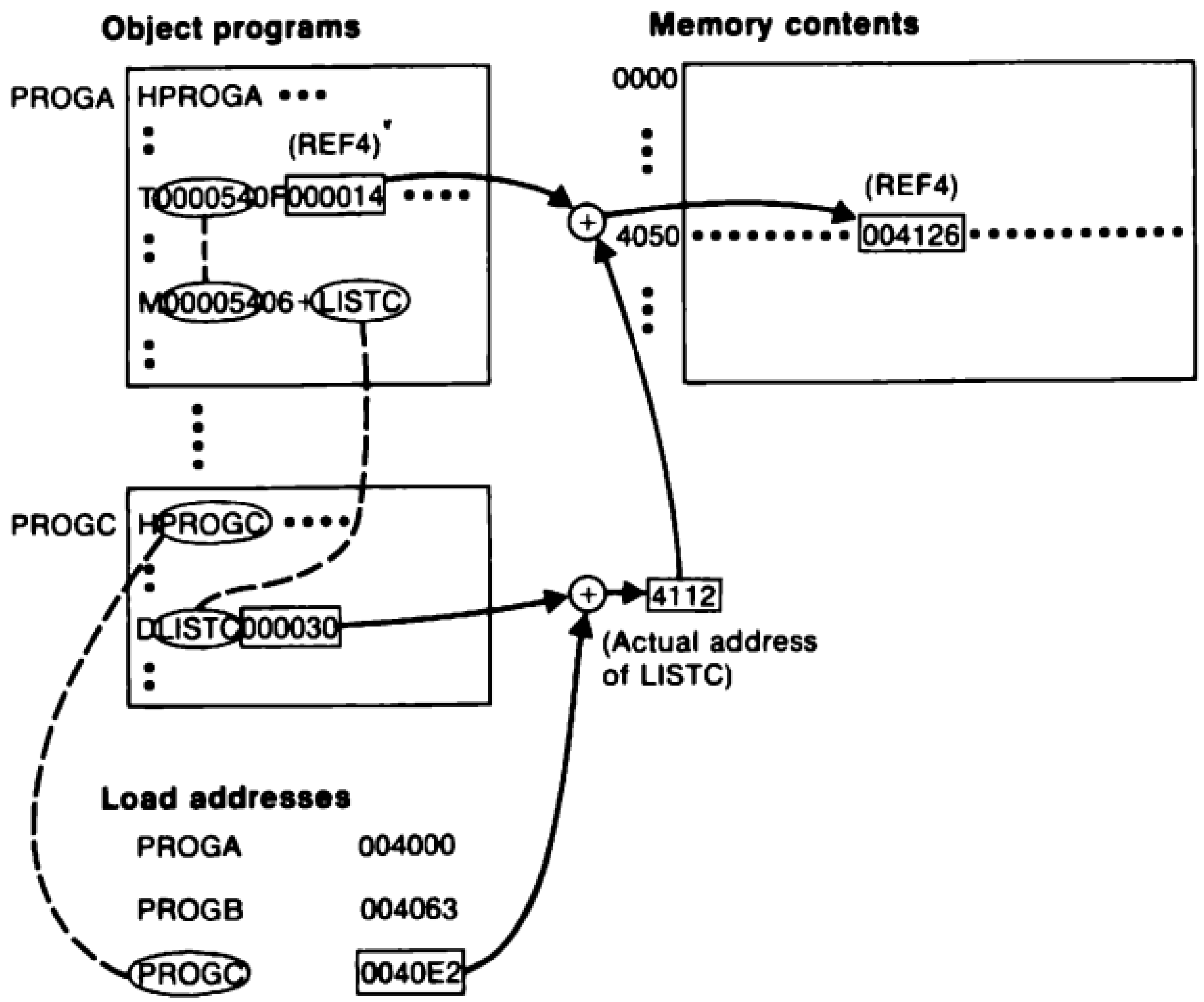


Figure 3.10(b) Relocation and linking operations performed on REF4 from PROGA.

Algorithm and Data Structures for a Linking Loader

- The algorithm for a linking loader is considerably more complicated than the absolute loader algorithm.
- 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- External symbol table

- 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.
- It 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

- During Pass 1, the loader is concerned only with **Header and Define record types** in the control sections.

1) 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.

- 2) 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.

- 3) 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 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

- Pass 2 performs the actual loading, relocation, and linking of the program.
- Algorithm for Pass 2 of a Linking loader

1) As each Text record is read, the object code is moved to the specified address (plus the current value of CSADDR).
2) When a Modification record is encountered, the symbol whose value is to be used for modification is looked up in ESTAB.
3) This value is then added to or subtracted from the indicated location in memory.
4) 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.

```
HPROGA 000000000063
DLISTA 000040ENDA  000054
R02LISTB 03ENDB  04LISTC 05ENDC
•
•
T0000200A03201D77100004050014
•
•
T0000540F000014FFFF600003F000014FFFFC0
M00002405+02
M00005406+04
M00005706+05
M00005706-04
M00005A06+05
M00005A06-04
M00005A06+01
M00005D06-03
M00005D06+02
M00006006+02
M00006006-01
E000020
```

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

```
HPROGB 00000000007F
DLISTB 000060ENDB  000070
R02LISTA 03ENDA  04LISTC 05ENDC
•
•
T0000360B0310000077202705100000
•
•
T0000700F000000FFFF6FFFFFFFFFFF0000060
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
```

```
HPROGC 000000000051
DLISTC 000030ENDC  000042
R02LISTA 03ENDA  04LISTB 05ENDB
:
T0000180C03100000771000040510000
:
T000042 0F000030000008000011000000000000
M00001905+02
M00001D05+04
M00002105+03
M00002105-02
M00004206+03
M00004206-02
M00004206+01
M00004806+02
M00004B06+03
M00004B06-02
M00004B06-05
M00004B06+04
M00004E06+04
M00004E06-02
E
```

Figure 3.12 *(cont'd)*

MACHINE-INDEPENDENT LOADER FEATURES

- They 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.

1. Automatic Library Search.
2. Loader Options.

Automatic Library Search

- Many linking loaders can **automatically incorporate routines** from a subprogram library into the program being loaded.
- 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.

- Here the programmer just mentioning the subroutine names as external references in the source program.
- This feature is also referred to as automatic library call.
- 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.
- Enter the symbols from each refer record into the symbol table(ESTAB).

- These entries are marked to indicate that the symbol has not yet been defined.
- When the definition is encountered , the address assigned to the symbol is filled in to the complete 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 libraries to be searched by the loader contain assembled or compiled version of the subroutine(object programs).
- Here a special file structure is used for the libraries.
- This structure contains a directory that gives the name of each routine and a pointer to its address within the file.
- The library search itself really involves a search of the directory ,followed by reading the object programs indicated by the this search.

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 the options.
- Some times there is a separate input file to the loader that contains such control statements.
- Some times these statements can be embedded in the primary input streams between object programs.

Typical loader option 1:

- Allows the selection of alternative sources of input.

INCLUDE program-name (library-name)

- It 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.

DELETE csect-name

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

CHANGE name1, name2

- It 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.

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.

Example

```
INCLUDE   READ(UTLIB)
INCLUDE   WRITE(UTLIB)
DELETE    RDREC, WRREC
CHANGE    RDREC, READ
CHANGE    WRREC, WRITE
```

- This command direct the loader to include control sections READ and WRITE from the library UTLIB and to delete the control sections RDREC and WRREC from the load.
- The first CHANGE command would cause all external references to symbol RDREC to be changed to refer to symbol READ.
- Similarly references to WRREC would be changed to WRITE.

LOADER DESIGN OPTIONS

- Linking loaders perform all linking and relocation at load time.

There are two alternatives:

1. **Linkage editors,** which perform linking prior to load time.
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.

- 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.

- 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.

Linkage Editors

- 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.

- If a program is to be executed many times without being reassembled, the use of a linkage editor substantially reduces the overhead required.

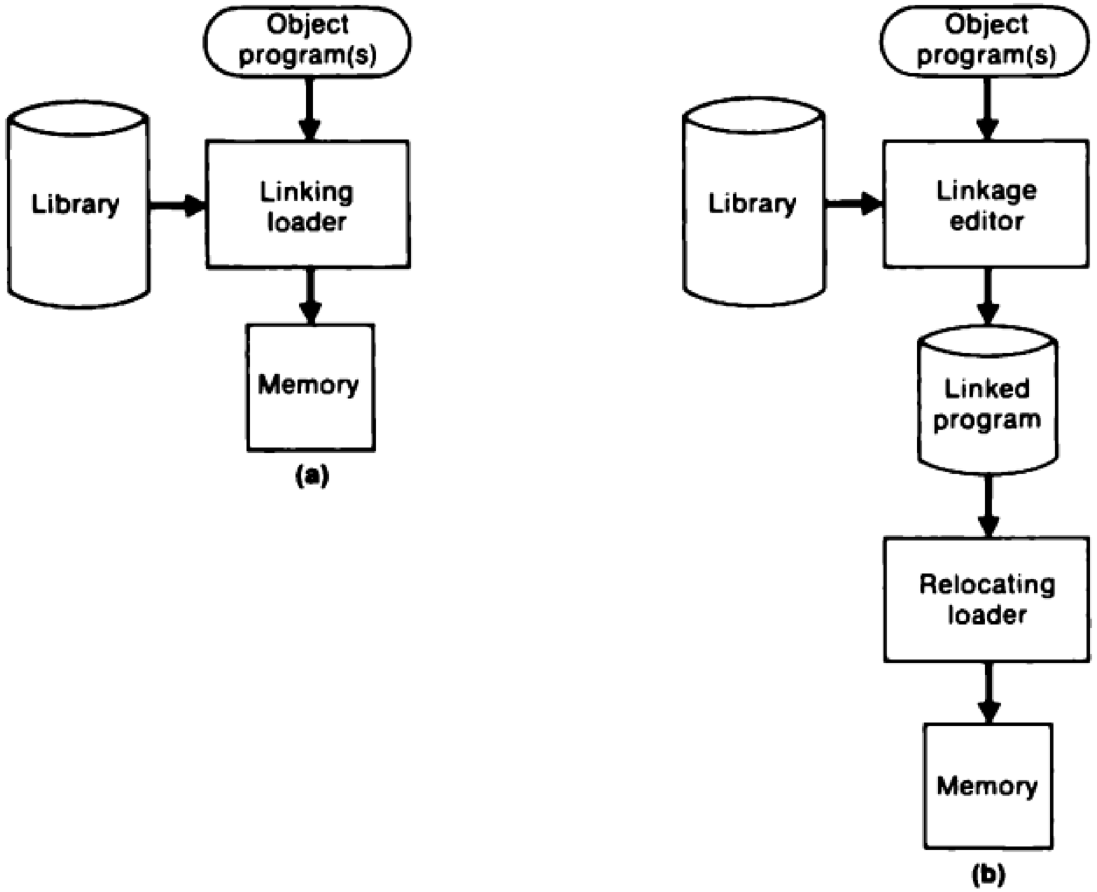


Figure 3.13 Processing of an object program using (a) linking loader and (b) linkage editor.

- All external references are resolved, and relocation is indicated by some mechanism such as modification record or a bit mask.
- If the actual address at which the program will be loaded is known in advance , the linkage editor can perform all of the needed relocation.
- The result is a linked program that is an exam image of the way the program will appear in memory during execution.
- Which are same as absolute object program.

- Linkage editors can perform many useful functions besides simply preparing an object program for execution. Ex., a typical sequence of linkage editor commands used:

```
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.

Difference between linking loader and linkage editor

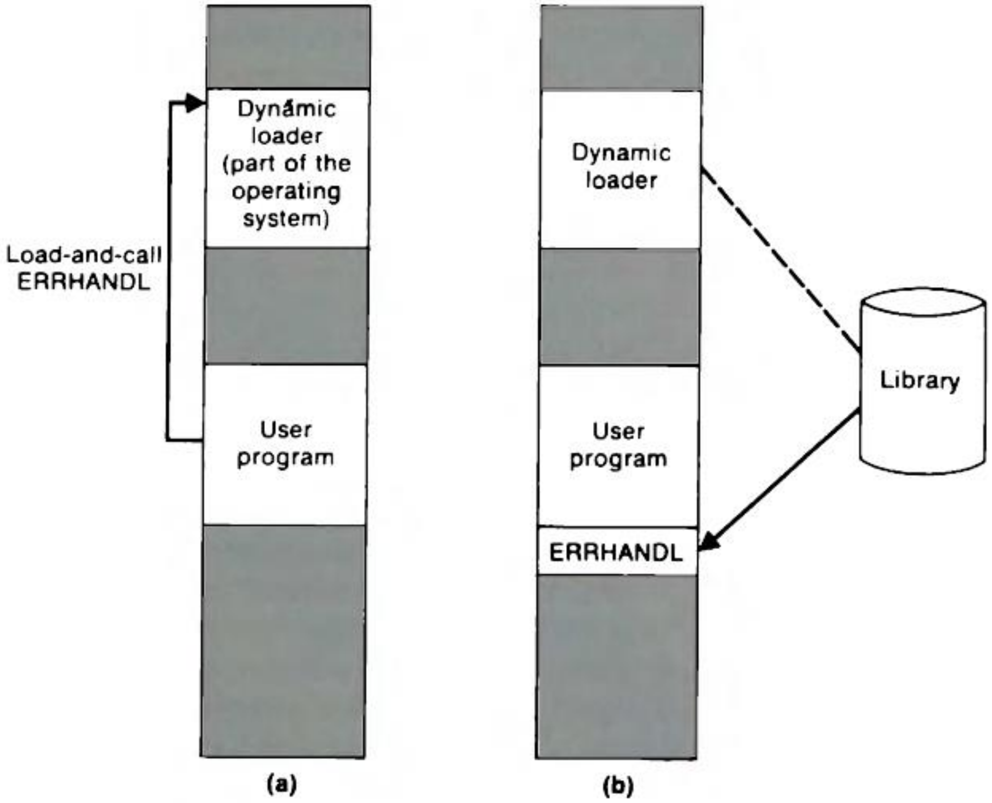
Linking Loader	Linkage Editor
Performs all linking and relocation operations, including automatic library search, and loads the linked program into memory for execution.	**Produces a Linked version of the program, which is normally written to a file or library for later execution.**
Suitable when a program is reassembled for nearly every execution.	Suitable when a program is executed many times without being reassembled.
Resolution of external reference and library searching is performed more than once.	**Resolution of external reference and library searching is performed only once.**
Linking loaders perform linking operations at load time.	Linkage editors perform linking operations before the program is loaded for execution
There is no need of relocating loader.	**The relocating loader loads the load module into the memory**
The Loading may requires two passes.	The Loading can be accomplished in one pass.
When program is in development stage then at that time the linking loader can be used.	**When the program development is finished or when the library is built then linkage editor can be used.**

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, ex. run-time support routines for a high-level language like C.

- 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.


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

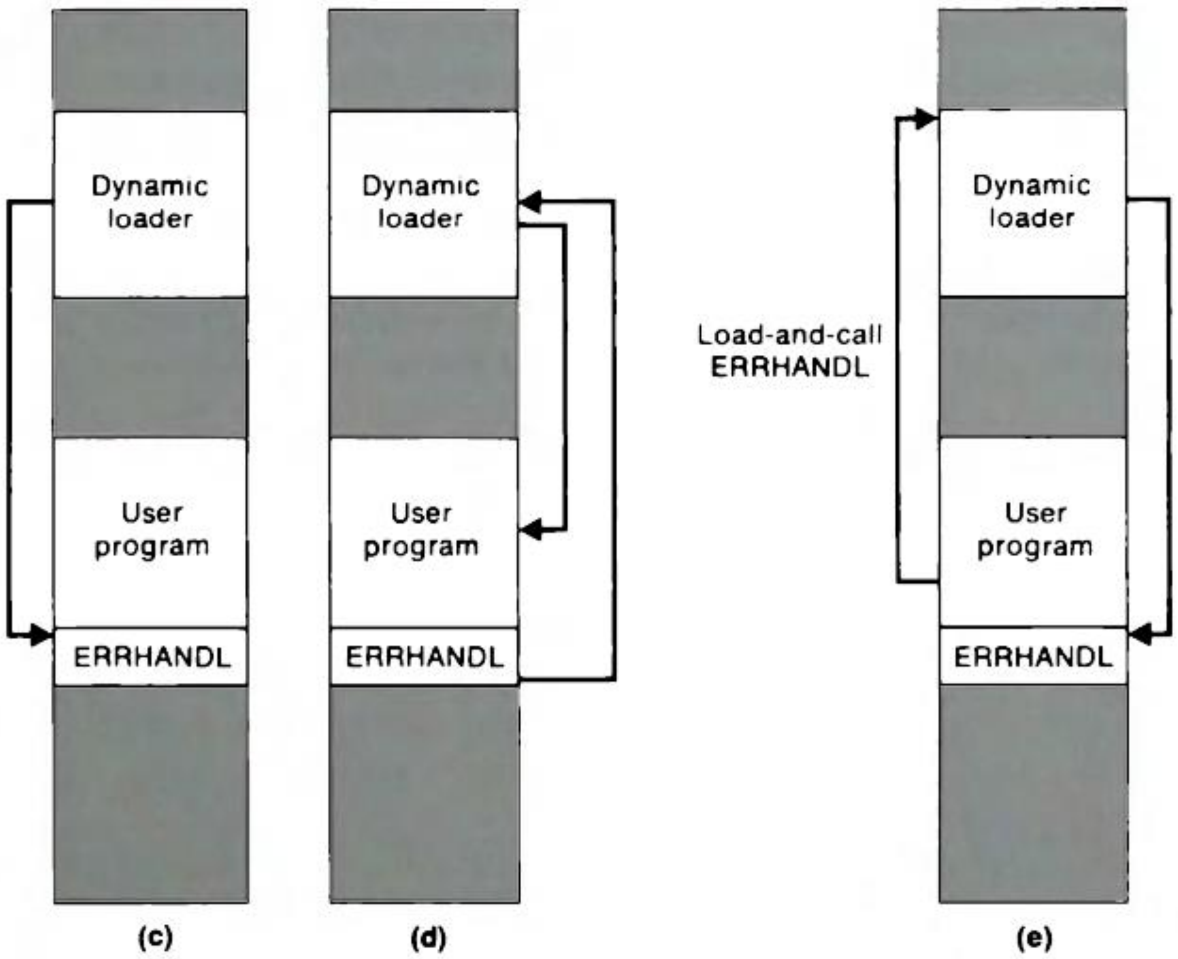


Figure 3.14 Loading and calling of a subroutine using dynamic linking.

- **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

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.
- 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.

2. To have the absolute loader program permanently resident in a ROM.

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

- When some hardware signal 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.
- 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, which contains machine where the record was stored, which contains machine instructions that load the absolute program that follow

- 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 – boots trap.

- The first record 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.

University questions…

- Write an algorithm for an absolute loader.
- Given an idle computer with no programs in memory, how do we get things started.
- Explain bootstrap loader for SIC/XE.
- Write SIC/XE relocation loader algorithm.
- What is the use of bitmask in program relocation?
- List out and explain the data structures used for linking loaders.
- Write short notes on automatic library search.
- Distinguish between linking loader and linkage editor.
- With suitable examples explain dynamic linking.

- Explain relocation by modification records in detail.
- Write the algorithm for pass 1 of a linking loader.
- Write short notes on the linkage editor.
- Explain different loader design options in detail.
- With the data structures used, state and explain two pass algorithms for a linking loader.
- Explain the algorithm for Pass 1 of Linking Loader.
- List and explain the different machine independent features of loaders
- Compare absolute loader and relocating loader in detail.
- Explain different machine dependent features of loaders.