The Assembly Language Level

Chapter 7

Definitions

- Translator
  – Converts user program to another language
- Source language
  – Language of original program
- Target language
  – Language into which source code is converted
  – Object code or executable binary
- Interpretation
  – Source translated, immediately executed

Steps of Translation

1. Generation of equivalent program in target language

2. Execution of newly generated program
   – Happens only after Step 1 completed
   – Contrast to interpretation

Assembly Language

- One-to-one correspondence between machine instructions and statements in assembly program

- Provides better performance and access to the machine

- Statements can contain:
  - Label field
  - Operation (opcode) field
  - Operand field
  - Comments field

Format of an Assembly Language Statement (1)

Label	Opcode	Operands	Comments
FORMULA:	MOV	EAX,I	; register EAX = I
	ADD	EAX,J	; register EAX = I + J
	MOV	N,EAX	; N = I + J
I	DD	3	; reserve 4 bytes initialized to 3
J	DD	4	; reserve 4 bytes initialized to 4
N	DD	0	; reserve 4 bytes initialized to 0

(a)

Figure 7-1. Computation of N = I + J. (a) x86.

Format of an Assembly Language Statement (2)

Label	Opcode	Operands	Comments
FORMULA	MOVE.L	I, D0	; register D0 = I
	ADD.L	J, D0	; register D0 = I + J
	MOVE.L	D0, N	; N = I + J
I	DC.L	3	; reserve 4 bytes initialized to 3
J	DC.L	4	; reserve 4 bytes initialized to 4
N	DC.L	0	; reserve 4 bytes initialized to 0

(b)

Figure 7-1. Computation of N = I + J. (b) Motorola 680x0.

Format of an Assembly Language Statement (3)

Label	Opcode	Operands	Comments
FORMULA:	SETHI	%HI(I),%R1	! R1 = high-order bits of the address of I
	LD	[%R1+%LO(I)],%R1	! R1 = I
	SETHI	%HI(J),%R2	! R2 = high-order bits of the address of J
	LD	[%R2+%LO(J)],%R2	! R2 = J
	NOP		! wait for J to arrive from memory
	ADD	%R1,%R2,%R2	! R2 = R1 + R2
	SETHI	%HI(N),%R1	! R1 = high-order bits of the address of N
	ST	%R2,[%R1+%LO(N)]	
I:	.WORD 3		! reserve 4 bytes initialized to 3
J:	.WORD 4		! reserve 4 bytes initialized to 4
N:	.WORD 0		! reserve 4 bytes initialized to 0

(c)

Figure 7-1. Computation of N = I + J. (c) SPARC.

Pseudoinstructions (1)

Pseudoinstruction	Meaning
SEGMENT	Start a new segment (text, data, etc.) with certain attributes
ENDS	End the current segment
ALIGN	Control the alignment of the next instruction or data
EQU	Define a new symbol equal to a given expression
DB	Allocate storage for one or more (initialized) bytes
DW	Allocate storage for one or more (initialized) 16-bit (word) data items
DD	Allocate storage for one or more (initialized) 32-bit (double) data items
DQ	Allocate storage for one or more (initialized) 64-bit (quad) data items
PROC	Start a procedure
ENDP	End a procedure
MACRO	Start a macro definition
ENDM	End a macro definition

Figure 7-2. Some of the pseudoinstructions available in the MASM assembler (MASM).

Pseudoinstructions (2)

ENDP	End a procedure
MACRO	Start a macro definition
ENDM	End a macro definition
PUBLIC	Export a name defined in this module
EXTERN	Import a name from another module
INCLUDE	Fetch and include another file
IF	Start conditional assembly based on a given expression
ELSE	Start conditional assembly if the IF condition above was false
ENDIF	End conditional assembly
COMMENT	Define a new start-of-comment character
PAGE	Generate a page break in the listing
END	Terminate the assembly program

Figure 7-2. Some of the pseudoinstructions available in the MASM assembler (MASM).

Macro Definition

Macro header giving name of macro being defined

Text – body of the macro

Pseudoinstruction marking end of definition

Macro Call, Expansion (1)

```
MOV    EAX,P                SWAP   MACRO
MOV    EBX,Q                       MOV EAX,P
MOV    Q,EAX                       MOV EBX,Q
MOV    P,EBX                       MOV Q,EAX
                                   MOV P,EBX
MOV    EAX,P                       ENDM
MOV    EBX,Q
MOV    Q,EAX                       SWAP
MOV    P,EBX
                                   SWAP

       (a)                         (b)
```

Figure 7-3. Assembly language code for interchanging P and Q twice. (a) Without a macro. (b) With a macro.

Macro Call, Expansion (2)

Item	Macro call	Procedure call
When is the call made?	During assembly	During program execution
Is the body inserted into the object program every place the call is made?	Yes	No
Is a procedure call instruction inserted into the object program and later executed?	No	Yes
Must a return instruction be used after the call is done?	No	Yes
How many copies of the body appear in the object program?	One per macro call	One

Figure 7-4. Comparison of macro calls with procedure calls.

Macros with Parameters

```
MOV    EAX,P                 CHANGE    MACRO P1, P2
MOV    EBX,Q                           MOV EAX,P1
MOV    Q,EAX                           MOV EBX,P2
MOV    P,EBX                           MOV P2,EAX
                                       MOV P1,EBX
MOV    EAX,R                           ENDM
MOV    EBX,S
MOV    S,EAX                           CHANGE P, Q
MOV    R,EBX
                                       CHANGE R, S

       (a)                             (b)
```

Figure 7-5. Nearly identical sequences of statements. (a) Without a macro. (b) With a macro.

Pass 1 of Two Pass Assembler

Label	Opcode	Operands	Comments	Length	ILC
MARIA:	MOV	EAX, I	EAX = I	5	100
	MOV	EBX, J	EBX = J	6	105
ROBERTA:	MOV	ECX, K	ECX = K	6	111
	IMUL	EAX, EAX	EAX = I * I	2	117
	IMUL	EBX, EBX	EBX = J * J	3	119
	IMUL	ECX, ECX	ECX = K * K	3	122
MARILYN:	ADD	EAX, EBX	EAX = I * I + J * J	2	125
	ADD	EAX, ECX	EAX = I * I + J * J + K * K	2	127
STEPHANY:	JMP	DONE	branch to DONE	5	129

Figure 7-6. The instruction location counter (ILC) keeps track of the address where the instructions will be loaded in memory. In this example, the statements prior to MARIA occupy 100 bytes.

Tables Kept by Pass 1

- Symbol table
- Pseudoinstruction table
- Opcode table
- Literal table

Information Kept in Symbol Table

- Length of data field associated with symbol
- Relocation bits
- Is the symbol is accessible outside the procedure

Example Symbol Table

Symbol	Value	Other information
MARIA	100	
ROBERTA	111	
MARILYN	125	
STEPHANY	129	

Figure 7-7. A symbol table for the program of Fig. 7-6.

Opcode Table

Opcode	First operand	Second operand	Hexadecimal opcode	Instruction length	Instruction class
AAA	—	—	37	1	6
ADD	EAX	immed32	05	5	4
ADD	reg	reg	01	2	19
AND	EAX	immed32	25	5	4
AND	reg	reg	21	2	19

Figure 7-8. A few excerpts from the opcode table for an x86 assembler

Results of Pass One (1)

```
public static void pass_one( ) {
    // This procedure is an outline of pass one of a simple assembler.
    boolean more_input = true;                  // flag that stops pass one
    String line, symbol, literal, opcode;       // fields of the instruction
    int location_counter, length, value, type;  // misc. variables
    final int END_STATEMENT = –2;               // signals end of input

    location_counter = 0;                       // assemble first instruction at 0
    initialize_tables( );                       // general initialization

    while (more_input) {                        // more_input set to false by END
        line = read_next_line( );               // get a line of input
        length = 0;                             // # bytes in the instruction
        type = 0;                               // which type (format) is the instruction

        if (line_is_not_comment(line)) {
            symbol = check_for_symbol(line);    // is this line labeled?
            if (symbol != null)                 // if it is, record symbol and value
                enter_new_symbol(symbol, location_counter);
            literal = check_for_literal(line);  // does line contain a literal?
            if (literal != null)                // if it does, enter it in table
                enter_new_literal(literal);

            // Now determine the opcode type. –1 means illegal opcode.
```

Figure 7-9. Pass one of a simple assembler.

Results of Pass One (2)

```
        enter_new_literal(literal);

      // Now determine the opcode type.  –1 means illegal opcode.
      opcode = extract_opcode(line);          // locate opcode mnemonic
      type = search_opcode_table(opcode); // find format, e.g. OP REG1,REG2
      if (type < 0)                            // if not an opcode, is it a pseudoinstruction?
          type = search_pseudo_table(opcode);
      switch(type) {                           // determine the length of this instruction
          case 1: length = get_length_of_type1(line);  break;
          case 2: length = get_length_of_type2(line);  break;
          // other cases here
      }
    }

    write_temp_file(type, opcode, length, line);    // useful info for pass two
    location_counter = location_counter + length;      // update loc_ctr
    if (type == END_STATEMENT) {                 // are we done with input?
      more_input = false;                        // if so, perform housekeeping tasks
      rewind_temp_for_pass_two( );               // like rewinding the temp file
      sort_literal_table( );                     // and sorting the literal table
      remove_redundant_literals( );              // and removing duplicates from it
    }
  }
}
```

Figure 7-9. Pass one of a simple assembler.

Pass Two (1)

```
public static void pass_two( ) {
    // This procedure is an outline of pass two of a simple assembler.
    boolean more_input = true;              // flag that stops pass two
    String line, opcode;                    // fields of the instruction
    int location_counter, length, type;     // misc. variables
    final int END_STATEMENT = –2;           // signals end of input
    final int MAX_CODE = 16;                // max bytes of code per instruction
    byte code[ ] = new byte[MAX_CODE];      // holds generated code per instruction

    location_counter = 0;                   // assemble first instruction at 0

    while (more_input) {                    // more_input set to false by END
        type = read_type( );                // get type field of next line
        opcode = read_opcode( );            // get opcode field of next line
        length = read_length( );            // get length field of next line
        line = read_line( );                // get the actual line of input

        if (type != 0) {                    // type 0 is for comment lines
            switch(type) {                  // generate the output code
                case 1: eval_type1(opcode, length, line, code); break;
```

Figure 7-10. Pass two of a simple assembler

Pass Two (2)

```
        length = read_length( );                        // get length field of next line
        line = read_line( );                            // get the actual line of input

        if (type != 0) {                                // type 0 is for comment lines
            switch(type) {                              // generate the output code
                case 1: eval_type1(opcode, length, line, code);  break;
                case 2: eval_type2(opcode, length, line, code);  break;
                // other cases here
            }
        }

        write_output(code);                             // write the binary code
        write_listing(code, line);                      // print one line on the listing
        location_counter = location_counter + length;       // update loc_ctr
        if (type == END_STATEMENT) {                    // are we done with input?
            more_input = false;                         // if so, perform housekeeping tasks
            finish_up( );                               // odds and ends
        }
    }
}
```

Figure 7-10. Pass two of a simple assembler

Dealing with Typical Code Errors

Examples:

- A symbol has been used but not defined
- A symbol has been defined more than once
- The name in the opcode field is not a legal opcode
- An opcode is not supplied with enough operands
- An opcode is supplied with too many operands
- An number contains an invalid character like 143G6
- Illegal register use (e.g., a branch to a register)
- The END statement is missing

The Symbol Table (1)

Andy	14025	0
Anton	31253	4
Cathy	65254	5
Dick	54185	0
Erik	47357	6
Frances	56445	3
Frank	14332	3
Gerrit	32334	4
Hans	44546	4
Henri	75544	2
Jan	17097	5
Jaco	64533	6
Maarten	23267	0
Reind	63453	1
Roel	76764	7
Willem	34544	6
Wiebren	34344	1

(a)

Figure 7-11. Hash coding. (a) Symbols, values, and the hash codes derived from the symbols.

The Symbol Table (2)

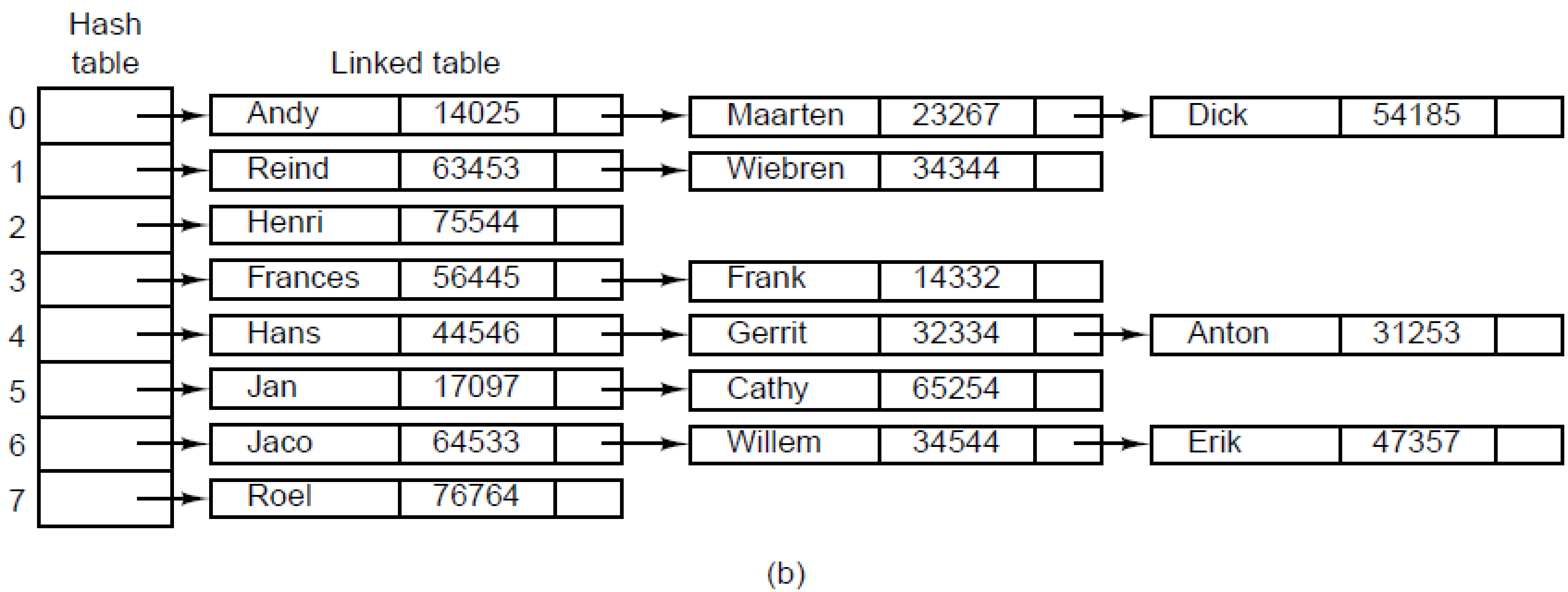


Figure 7-11. Hash coding. (b) Eight-entry hash table with linked lists of symbols and values.

Linking and Loading

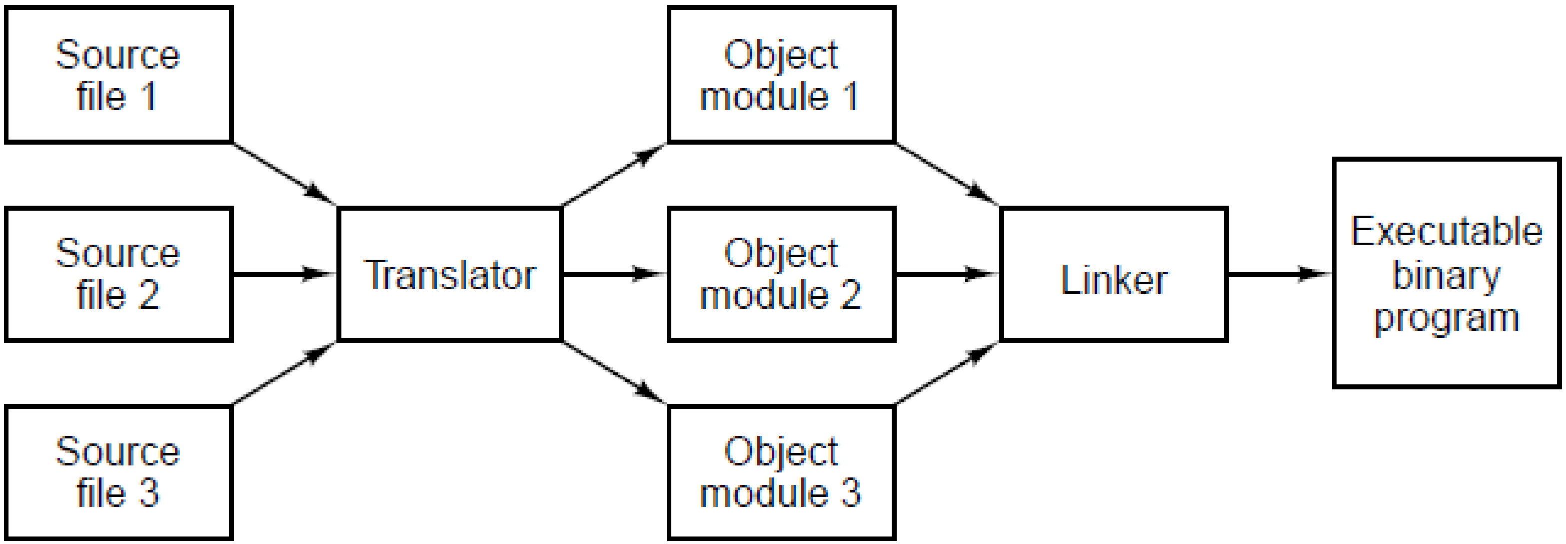


Figure 7-12. Generation of an executable binary program from a collection of independently translated source procedures requires using a linker.

Tasks Performed by the Linker (1)

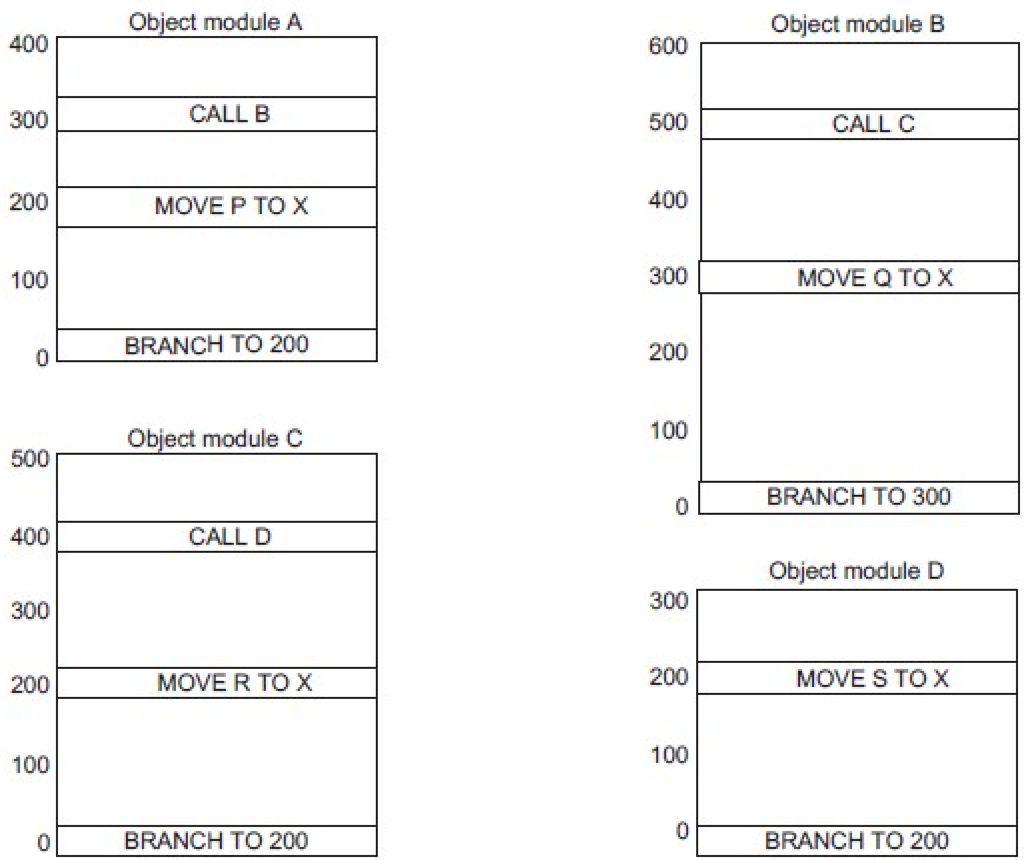


Figure 7-13. Each module has its own address space, starting at 0.

Tasks Performed by the Linker (2)

- Constructs table of all object modules, lengths
- Assigns base address to each object module
- Relocates all instructions that reference memory
- Links instructions that reference other procedures

Tasks Performed by the Linker (3)

Module	Length	Starting address
A	400	100
B	600	500
C	500	1100
D	300	1600

Figure 7-14. Object module table constructed in step 1 shown for the modules of Fig. 7-14. Gives name, length, and starting address of each module.

Structure of an Object Module (2)

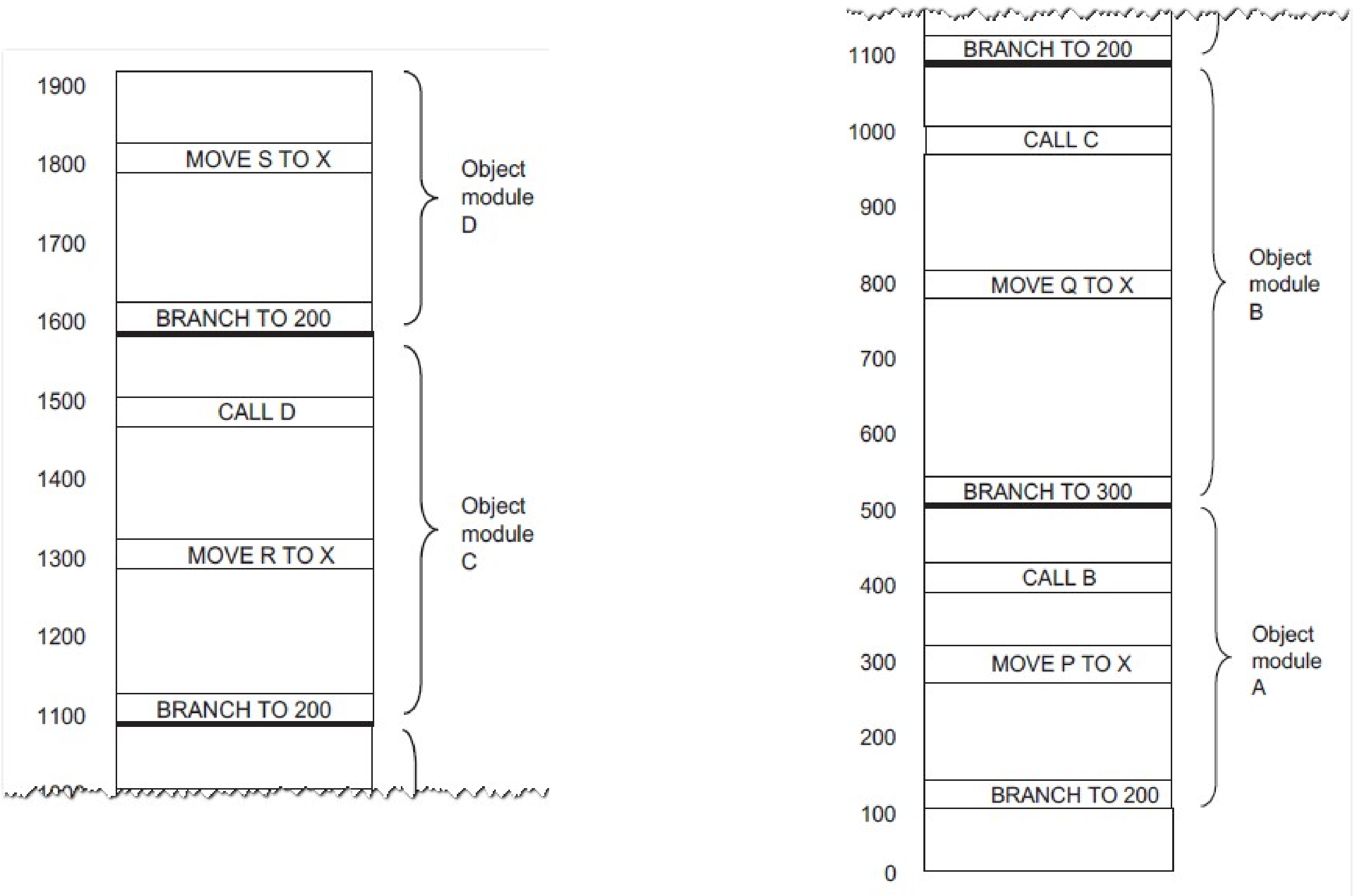
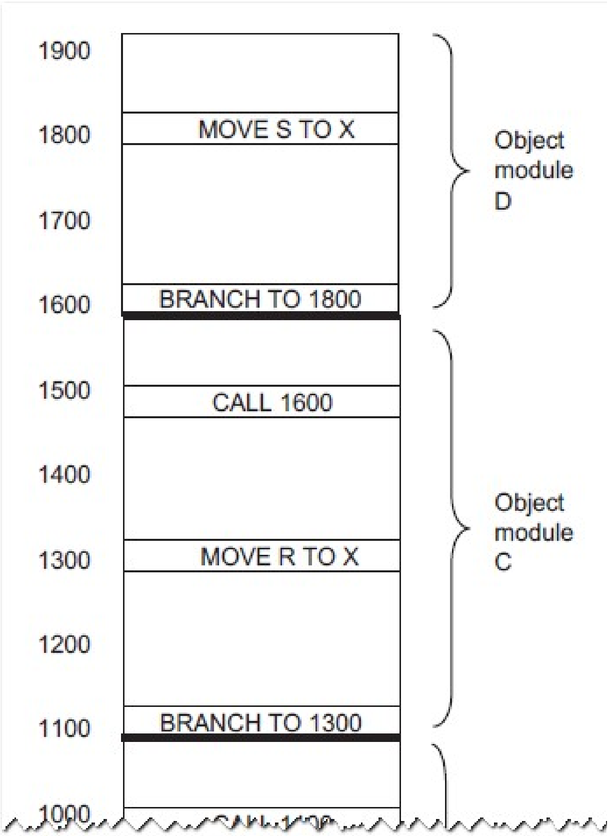


Figure 7-14. (a) object modules of Fig. 7-13 after being positioned in the binary image but before being relocated and linked.

Structure of an Object Module (3)



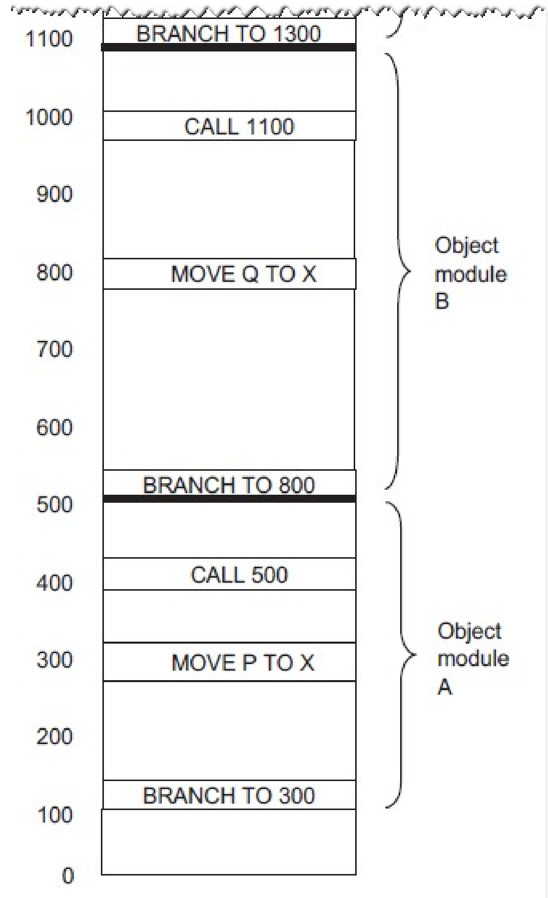


Figure 7-14. (b) The same object modules after linking and after relocation has been performed.

Structure of an Object Module (1)

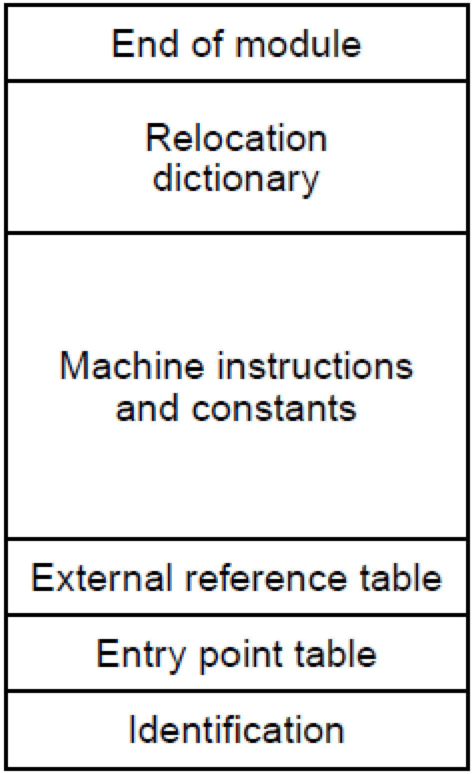


Figure 7-15. The internal structure of an object module produced by a translator. The *Identification* field comes first.

Binding Time and Dynamic Relocation (1)

Possibilities:

- When program is written
- When program is translated
- When program is linked but before it is loaded
- When program is loaded
- When a base register used for addressing is loaded
- When instruction containing the address is executed

Binding Time and Dynamic Relocation (2)

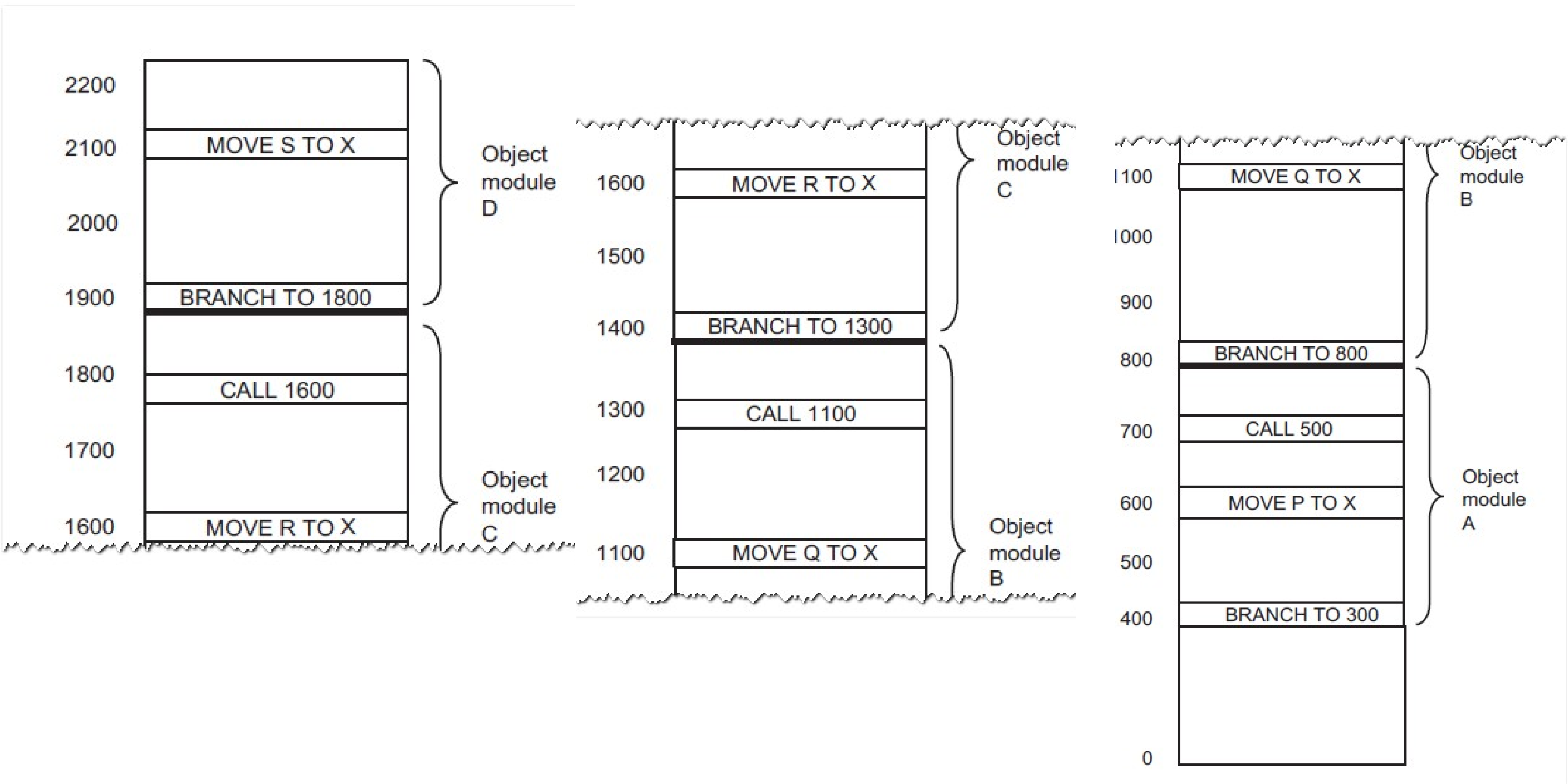
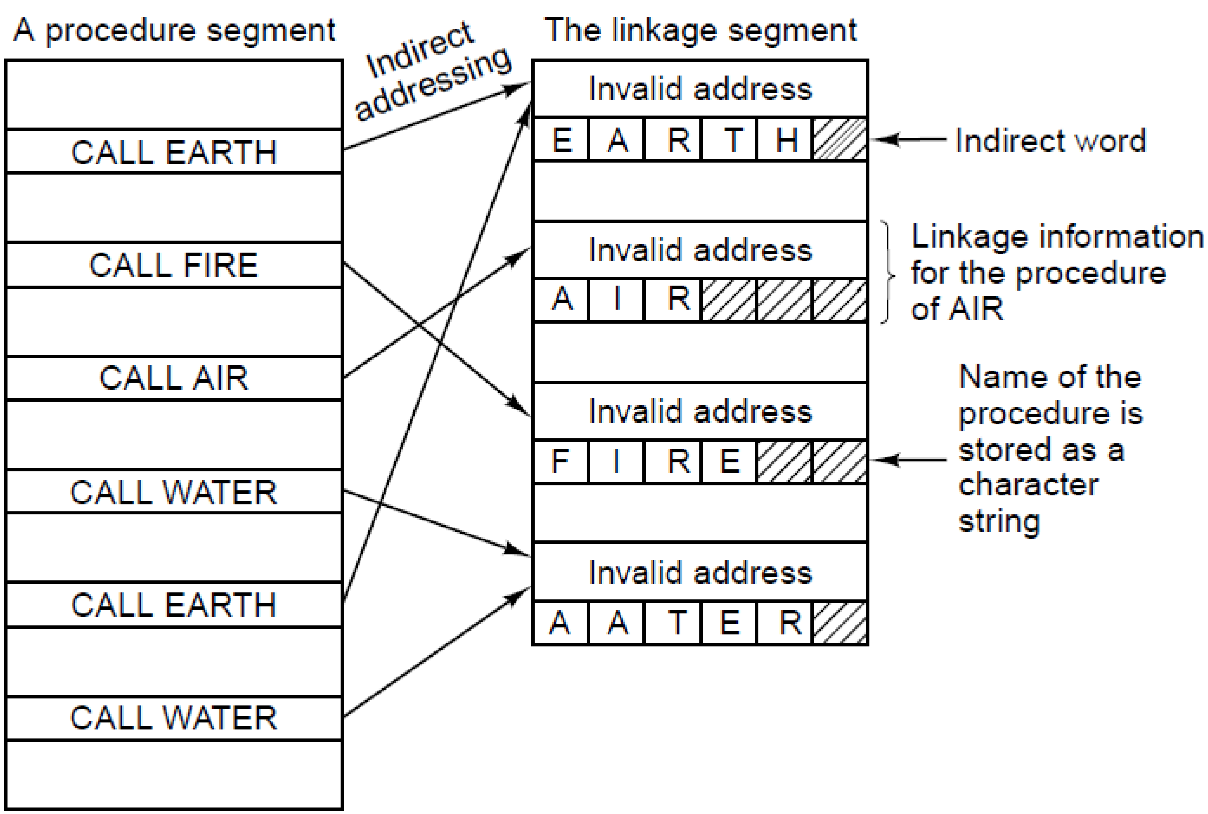


Figure 7-16. The relocated binary program of Fig. 7-14(b) moved up 300 addresses. Many instructions now refer to an incorrect memory address.

Dynamic Linking (1)



(a)

Figure 7-17. Dynamic linking. (a) Before *EARTH* is called.

Dynamic Linking (2)

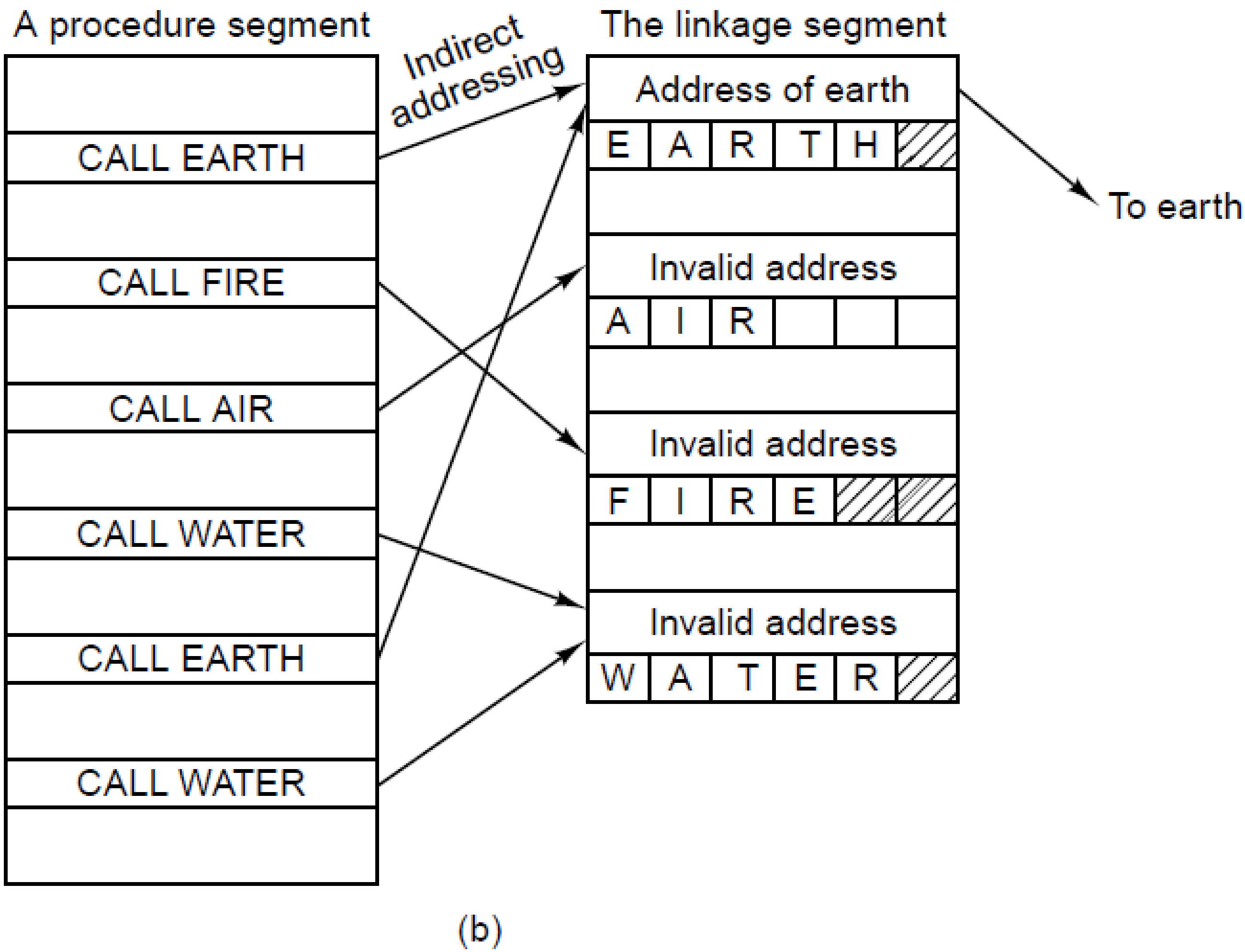


Figure 7-17. Dynamic linking. (b) After *EARTH* has been called and linked.

Dynamic Linking (3)

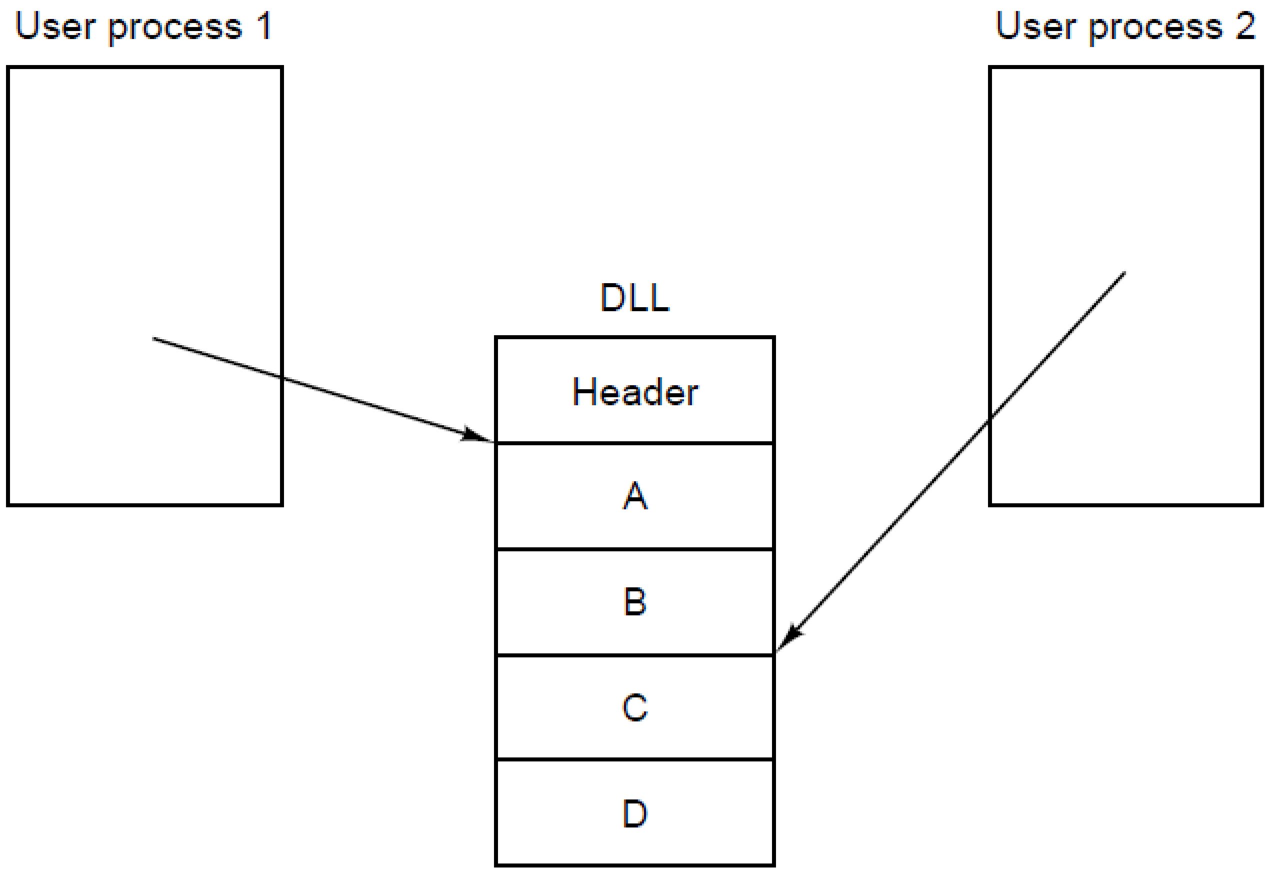


Figure 7-18. Use of a DLL file by two processes.

End

Chapter 7