System Software

Semester : VI	**Course Code :** 15CS63
Course Title : System Software AND Compiler Design	
Faculty : Niranjan Murthy C	
Dept : Computer Science & engineering	

Prerequisites:	Basic concepts of microprocessors (10CS45)
Description	This **course** gives an introduction to the design and implementation of various types of system software. A central theme of the course is the relationship between machine architecture and system software. The design of an assembler or an operating system is greatly influenced by the architecture of the machine on which it runs. These influences are emphasized and demonstrated through the discussion of actual pieces of system softare fo a variety of real machines.

Outcomes

The students should be able to:

1. Student able to Define System Sotware such as Assembler and Macroprocessor.
2. Student able to Define System Sotware such as Loaders and Linkers
3. Student able to lexical analysis and syntax analysisFamiliaize with source file ,object and executable file structures and libraries
4. Describe the front and back end phases of compiler and their importance to students

MODULE- 1

- **Introduction to System Software,**
- **Machine Architecture of SIC and SIC/XE.**
- **Assemblers: Basic assembler functions, machine dependent assembler features,**
- **machine independent assembler features, assembler design options.**
- **Macroprocessors: Basic macro processor functions, ->10 Hours**

MACHINE ARCHITECTURE

System Software:

- System software consists of a variety of programs that support the operation of a computer.
- Application software focuses on an application or problem to be solved.
- System softwares are the machine dependent softwares that allows the user to focus on the application or problem to be solved, without bothering about the details of how the machine works internally.

Examples: Operating system, compiler, assembler, macroprocessor, loader or linker, debugger, text editor, database management systems, etc.

Difference between System Software and application software

System Software	Application Software
System software is machine dependent	Application software is not dependent on the underlying hardware.
System software focus is on the computing system.	Application software provides solution to a problem
Examples: Operating system, compiler, assembler	Examples: Antivirus, Microsoft office

SIC – Simplified Instructional Computer

Simplified Instructional Computer (SIC) is a hypothetical computer that includes the hardware features most often found on real machines. There are two versions of SIC, they are, standard model (SIC), and, extension version (SIC/XE) (extra equipment or extra expensive).

SIC Machine Architecture:

We discuss here the SIC machine architecture with respect to its Memory and Registers, Data Formats, Instruction Formats, Addressing Modes, Instruction Set, Input and Output.

Memory:

There are 215 bytes in the computer memory, that is 32,768 bytes. It uses Little Endian format to store the numbers, 3 consecutive bytes form a word , each location in memory contains 8-bit bytes.

Registers:

There are five registers, each 24 bits in length. Their mnemonic, number and use are given in the following table.

Mnemonic	Number	Use
A	0	Accumulator; used for arithmetic operations
X	1	Index register; used for addressing
L	2	Linkage register; JSUB
PC	8	Program counter
SW	9	Status word, including CC

Data Formats:

Integers are stored as 24-bit binary numbers. 2's complement representation is used for negative values, characters are stored using their 8-bit ASCII codes.No floating-point hardware on the standard version of SIC.

Instruction Formats:

Opcode(8)	x	Address (15)

X is used to indicate indexed-addressing mode.

All machine instructions on the standard version of SIC have the 24-bit format as shown above.

Addressing Modes:

Only two modes are supported: Direct and Indexed

Mode	Indication	Target address calculation
Direct	x= 0	TA = address
Indexed	x= 1	TA = address + (x)

() are used to indicate the content of a register.

Instruction Set

- Load and store registers (LDA, LDX, STA, STX)
- Integer arithmetic (ADD, SUB, MUL, DIV), all involve register A and a word in memory.
- Comparison (COMP), involve register A and a word in memory.
- Conditional jump (JLE, JEQ, JGT, etc.)
- Subroutine linkage (JSUB, RSUB)

Input and Output

- One byte at a time to or from the rightmost 8 bits of register A.
- Each device has a unique 8-bit ID code.
- Test device (TD): test if a device is ready to send or receive a byte of data.
- Read data (RD): read a byte from the device to register A
- Write data (WD): write a byte from register A to the device.

SIC/XE Machine Architecture:

Memory

- Maximum memory available on a SIC/XE system is 1 Megabyte (2 20 bytes).

Registers

- Additional B, S, T, and F registers are provided by SIC/XE, in addition to the registers of SIC.

Mnemonic	Number	Special use
B	3	Base register
S	4	General working register
T	5	General working register
F	6	Floating-point accumulator (48 bits)

Floating-point data type:

- There is a 48-bit floating-point data type, F*2(e-1024)

Instruction Formats :

The new set of instruction formats fro SIC/XE machine architecture are as follows.

Format 1 (1 byte): contains only operation code (straight from table).

Format 2 (2 bytes): first eight bits for operation code, next four for register 1 and following four for register 2. The numbers for the registers go according to the numbers indicated at the registers section (ie, register T is replaced by hex 5, F is replaced by hex 6).

Format 3 (3 bytes): First 6 bits contain operation code, next 6 bits contain flags, last 12 bits contain displacement for the address of the operand. Operation code uses only 6 bits, thus the second hex digit will be affected by the values of the first two flags (n and i). The flags, in order, are: n, i, x, b, p, and e. Its functionality is explained in the next section. The last flag e indicates the instruction format (0 for 3 and 1 for 4).

Format 4 (4 bytes): same as format 3 with an extra 2 hex digits (8 bits) for addresses that require more than 12 bits to be represented.

Addressing Modes:

Five possible addressing modes plus the combinations are as follows.

1. Direct (x, b, and p all set to 0): operand address goes as it is. n and i are both set to the same value, either 0 or 1. While in general that value is 1, if set to 0 for format 3 we can assume that the rest of the flags (x, b, p, and e) are used as a part of the address of the operand, to make the format compatible to the SIC format.

2. Relative (either b or p equal to 1 and the other one to 0): the address of the operand should be added to the current value stored at the B register (if b = 1) or to the value stored at the PC register (if p = 1)

3. Immediate(i = 1, n = 0): The operand value is already enclosed on the instruction (ie. lies on the last 12/20 bits of the instruction)

4. Indirect(i = 0, n = 1): The operand value points to an address that holds the address for the operand value.

5. Indexed (x = 1): value to be added to the value stored at the register x to obtain real address of the operand. This can be combined with any of the previous modes except immediate.

The various flag bits used in the above formats have the following meanings

e - > e = 0 means format 3, e = 1 means format 4

Bits x,b,p : Used to calculate the target address using relative, direct, and indexed addressing Modes.

Bits i and n: Says, how to use the target address b and p - both set to 0, disp field from format 3 instruction is taken to be the target address.

For a format 4 bits b and p are normally set to 0, 20 bit address is the target address

x -x is set to 1, X register value is added for target address calculation

i=1, n=0 Immediate addressing, TA: TA is used as the operand value, no memory reference

i=0, n=1 Indirect addressing, ((TA)): The word at the TA is fetched. Value of TA is taken as the address of the operand value

i=0, n=0 or i=1, n=1 Simple addressing, (TA):TA is taken as the address of the operand value

Two new relative addressing modes are available for use with instructions assembled using format 3.

Instruction Set:

SIC/XE provides all of the instructions that are available on the standard version. In addition we have, Instructions to load and store the new registers LDB, STB, etc, Floating-point arithmetic operations, ADDF, SUBF, MULF, DIVF, Register move instruction : RMO, Register-to-register arithmetic operations, ADDR, SUBR, MULR, DIVR and, Supervisor call instruction : SVC.

Input and Output:

There are I/O channels that can be used to perform input and output while the CPU is executing other instructions. Allows overlap of computing and I/O, resulting in more efficient system operation. The instructions SIO, TIO, and HIO are used to start, test and halt the operation of I/O channels.

Example programs SIC:

Example 1: Simple data and character movement operation

```
            LDA     FIVE
            STA     ALPHA
            LDCH    CHARZ
            STCH    C1
ALPHA       RESW    1
FIVE        WORD    5
CHARZ       BYTE    C'Z'
C1          RESB    1
```

Example 2: Arithmetic operations

```
            LDA     ALPHA
            ADD     INCR
            SUB     ONE
            STA     BETA
```

……..

```
……..
……..
ONE         WORD        1
ALPHA       RESW        1
BEETA       RESW        1
INCR        RESW        1
```

Example 3: Looping and Indexing operation

```
            LDX         ZERO            ;       X = 0
MOVECH      LDCH        STR1, X
            STCH        STR2, X
            TIX         ELEVEN
            JLT         MOVECH
. . . . . .
. . . . . .
. . . . . .
STR1        BYTE        C ‘HELLO WORLD’
STR2        RESB        11
ZERO        WORD        0
ELEVEN      WORD        11
```

Example 4: Input and Output operation

```
INLOOP      TD          INDEV       ; TEST INPUT DEVICE
            JEQ         INLOOP      ; LOOP UNTIL DEVICE IS READY
            RD          INDEV       ; READ ONE BYTE INTO A
            STCH        DATA        ; STORE A TO DATA
.
.
OUTLP       TD          OUTDEV      ; TEST OUTPUT DEVICE
            JEQ         OUTLP       ; LOOP UNTIL DEVICE IS READY
            LDCH        DATA        ; LOAD DATA INTO A
            WD          OUTDEV      ; WRITE A TO OUTPUT DEVICE
.
.
INDEV       BYTE        X ‘F5’      ; INPUT DEVICE NUMBER
OUTDEV      BYTE        X ‘08’      ; OUTPUT DEVICE NUMBER
DATA        RESB        1           ; ONE-BYTE VARIABLE
```

Example 5: To transfer two hundred bytes of data from input device to memory

```
            LDX         ZERO
CLOOP       TD          INDEV
            JEQ         CLOOP
            RD          INDEV
            STCH        RECORD, X
            TIX         B200
            JLT         CLOOP
.
.
INDEV       BYTE        X ‘F5’
RECORD      RESB        200
ZERO        WORD        0
B200        WORD        200
```

Example Programs (SIC/XE)

Example 1: Simple data and character movement operation

```
                LDA     #5
                STA     ALPHA
                LDA     #90
.
.
.
ALPHA           RESW    1
C1              RESB    1
```

Example 2: Arithmetic operations

```
                LDS     INCR
                LDA     ALPHA
                ADD     S,A
                SUB     #1
                STA     BETA
……
……
ALPHA           RESW    1
BETA            RESW    1
INCR            RESW    1
```

Example 3: Looping and Indexing operation

```
                LDT     #11
                LDX     #0          ;X = 0
MOVECH          LDCH    STR1, X     ; LOAD A FROM STR1
                STCH    STR2, X     ; STORE A TO STR2
                TIXR    T
                JLT     MOVECH
.
.
STR1            BYTE    C 'HELLO WORLD'
STR2            RESB    11
```

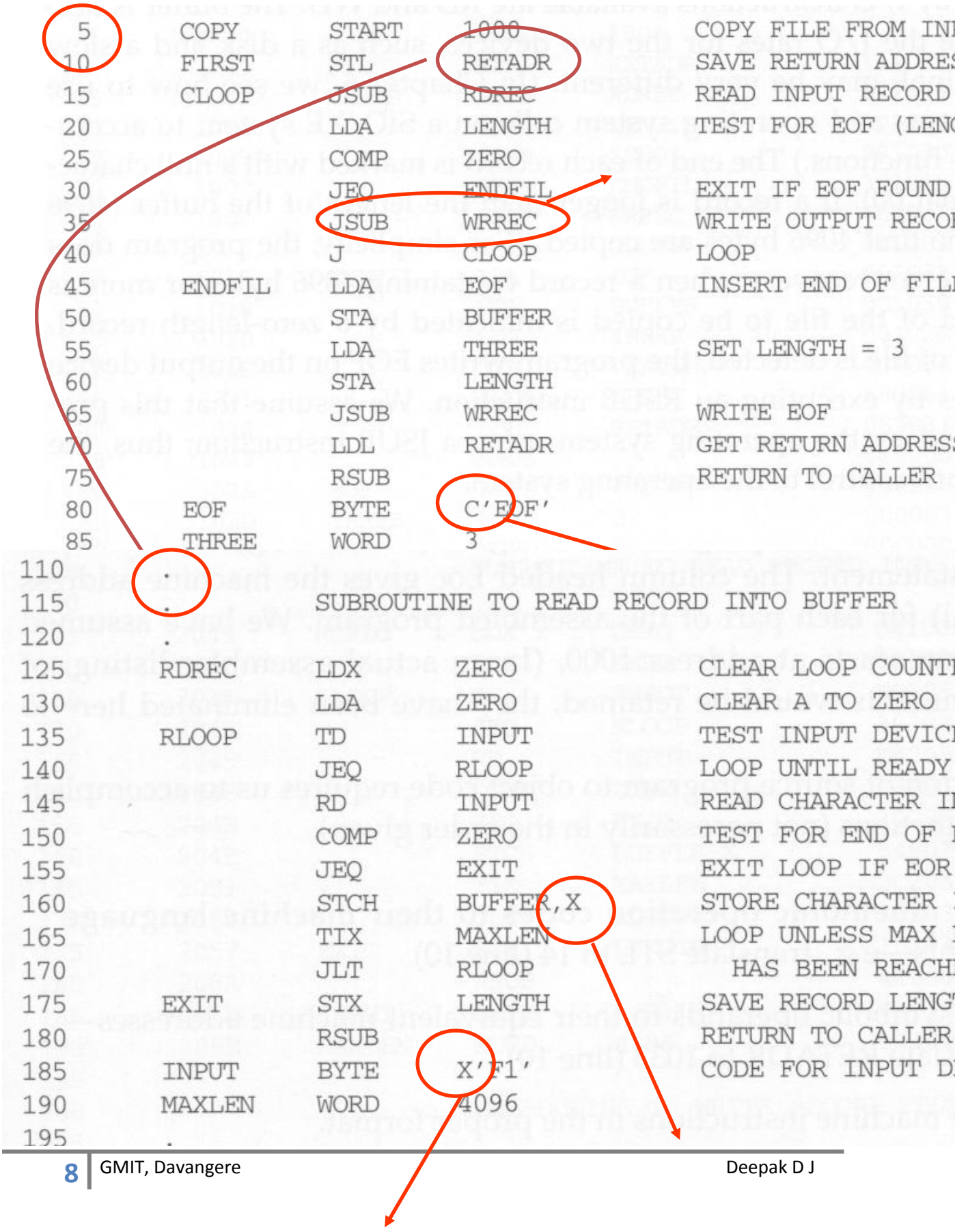
Assemblers - 1

A Simple Two-Pass Assembler

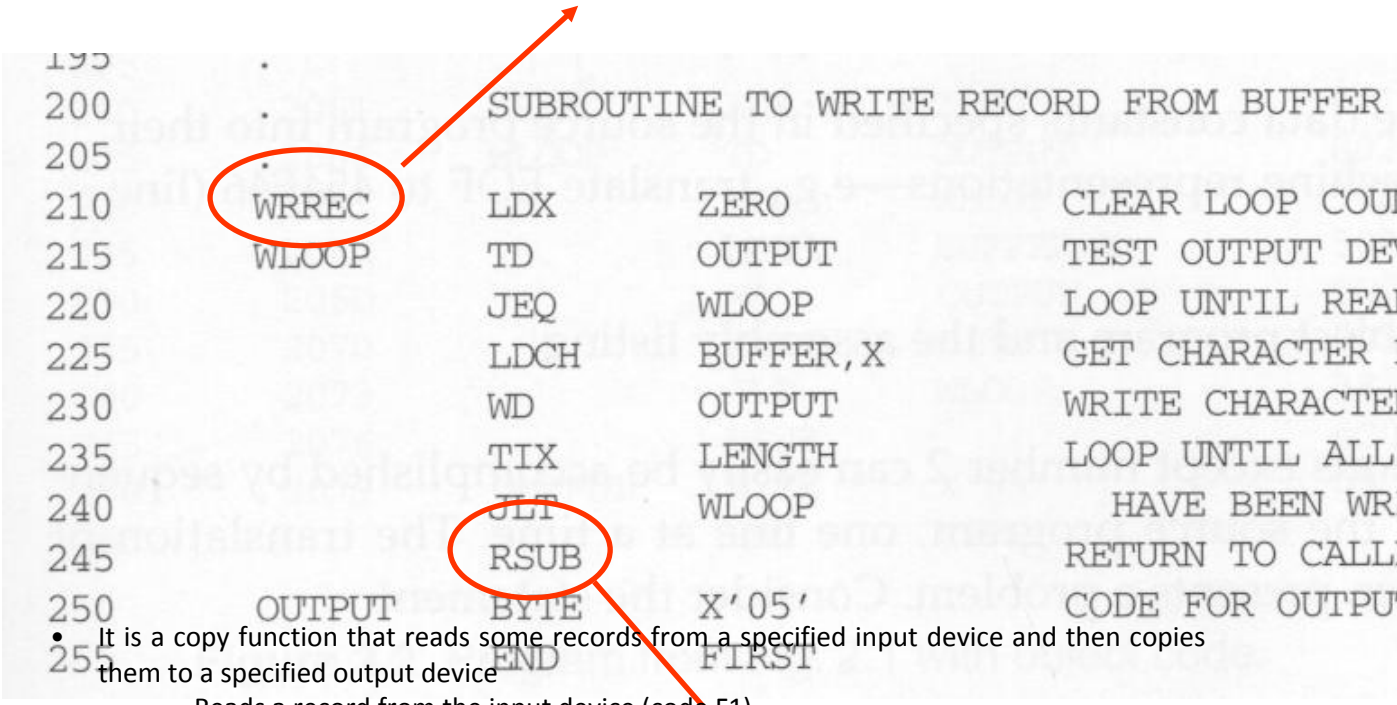
Main Functions

- Translate mnemonic operation codes to their machine language equivalents
- Assign machine addresses to symbolic labels used by the programmers
- Depend heavily on the source language it translates and the machine language it produces.
- E.g., the instruction format and addressing modes

Basic Functions of an Assembler



```
 5     COPY      START   1000          COPY FILE FROM INP
10     FIRST     STL     RETADR        SAVE RETURN ADDRES
15     CLOOP     JSUB    RDREC         READ INPUT RECORD
20               LDA     LENGTH        TEST FOR EOF (LENG
25               COMP    ZERO
30               JEQ     ENDFIL        EXIT IF EOF FOUND
35               JSUB    WRREC         WRITE OUTPUT RECOR
40               J       CLOOP         LOOP
45     ENDFIL    LDA     EOF           INSERT END OF FIL
50               STA     BUFFER
55               LDA     THREE         SET LENGTH = 3
60               STA     LENGTH
65               JSUB    WRREC         WRITE EOF
70               LDL     RETADR        GET RETURN ADDRES
75               RSUB                  RETURN TO CALLER
80     EOF       BYTE    C'EOF'
85     THREE     WORD    3
110    .
115    .         SUBROUTINE TO READ RECORD INTO BUFFER
120    .
125    RDREC     LDX     ZERO          CLEAR LOOP COUNTE
130              LDA     ZERO          CLEAR A TO ZERO
135    RLOOP     TD      INPUT         TEST INPUT DEVICE
140              JEQ     RLOOP         LOOP UNTIL READY
145              RD      INPUT         READ CHARACTER IN
150              COMP    ZERO          TEST FOR END OF R
155              JEQ     EXIT          EXIT LOOP IF EOR
160              STCH    BUFFER,X      STORE CHARACTER
165              TIX     MAXLEN        LOOP UNLESS MAX
170              JLT     RLOOP           HAS BEEN REACHE
175    EXIT      STX     LENGTH        SAVE RECORD LENGT
180              RSUB                  RETURN TO CALLER
185    INPUT     BYTE    X'F1'         CODE FOR INPUT DE
190    MAXLEN    WORD    4096
195    .
```



```
195         .
200         .       SUBROUTINE TO WRITE RECORD FROM BUFFER
205         .
210  WRREC  LDX     ZERO            CLEAR LOOP COU
215  WLOOP  TD      OUTPUT          TEST OUTPUT DE
220         JEQ     WLOOP           LOOP UNTIL REA
225         LDCH    BUFFER,X        GET CHARACTER
230         WD      OUTPUT          WRITE CHARACTE
235         TIX     LENGTH          LOOP UNTIL ALL
240         JLT     WLOOP             HAVE BEEN WR
245         RSUB                    RETURN TO CALL
250  OUTPUT BYTE    X'05'           CODE FOR OUTPU
255         END     FIRST
```

- It is a copy function that reads some records from a specified input device and then copies them to a specified output device
  - Reads a record from the input device (code F1)
  - Copies the record to the output device (code 05)
  - Repeats the above steps until encountering EOF.
  - Then writes EOF to the output device
  - Then call RSUB to return to the caller
  -

RDREC and WRREC

- Data transfer
  - A record is a stream of bytes with a null character (0016) at the end.
  - If a record is longer than 4096 bytes, only the first 4096 bytes are copied.
  - EOF is indicated by a zero-length record. (I.e., a byte stream with only a null character.
  - Because the speed of the input and output devices may be different, a buffer is used to temporarily store the record
- Subroutine call and return
  - On line 10, "STL RETADDR" is called to save the return address that is already stored in register L.
  - Otherwise, after calling RD or WR, this COPY cannot return back to its caller.

Assembler Directives

- Assembler directives are pseudo instructions
  - They will not be translated into machine instructions.
  - They only provide instruction/direction/information to the assembler.
- Basic assembler directives :
  - START : Specify name and starting address for the program
  - END : Indicate the end of the source program, and (optionally) the first executable instruction in the program. Assembler Directives (cont'd)
  - BYTE : Generate character or hexadecimal constant, occupying as many bytes as needed to represent the constant.

- WORD : Generate one-word integer constant
- RESB : Reserve the indicated number of bytes for a data area
- RESW : Reserve the indicated number of words for a data area

An Assembler's Job

- Convert mnemonic operation codes to their machine language codes
- Convert symbolic (e.g., jump labels, variable names) operands to their machine addresses
- Use proper addressing modes and formats to build efficient machine instructions
- Translate data constants into internal machine representations
- Output the object program and provide other information (e.g., for linker and loader)

Object Program Format

- Header

  Col. 1 H

  Col. 2~7 Program name

  Col. 8~13 Starting address of object program (hex)

  Col. 14-19 Length of object program in bytes (hex)

- Text

  Col.1 T

  Col.2~7 Starting address for object code in this record (hex)

  Col. 8~9 Length of object code in this record in bytes (hex)

  Col. 10~69 Object code, represented in hexa (2 col. per byte)

- End

  Col.1 E

  Col.2~7 Address of first executable instruction in object program (hex)

The Object Code for COPY

H COPY 001000 00107A

T 001000 1E 141033 482039 001036 281030 301015 482061 3C1003

00102A 0C1039 00102D

T 00101E 15 0C1036 482061 081044 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

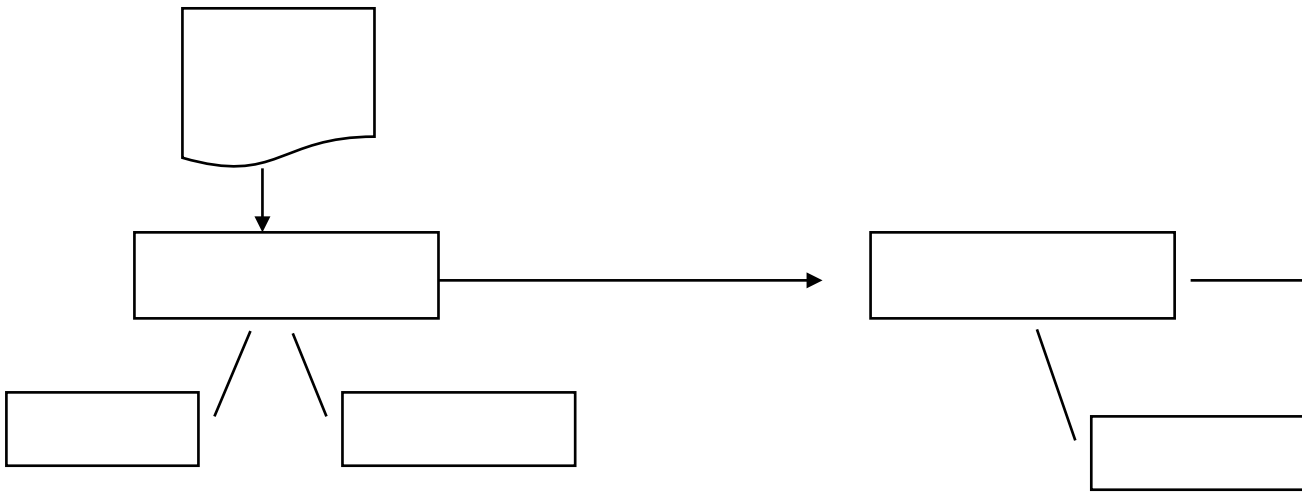
E 001000

NOTE: There is no object code corresponding to addresses 1033-2038. This storage is simply reserved by the loader for use by the program during execution.

Two Pass Assembler

- Pass 1
  - Assign addresses to all statements in the program
  - Save the values (addresses) assigned to all labels (including label and variable names) for use in Pass 2 (deal with forward references)
  - Perform some processing of assembler directives (e.g., BYTE, RESW, these can affect address assignment)
- Pass 2
  - Assemble instructions (generate opcode and look up addresses)
  - Generate data values defined by BYTE, WORD
  - Perform processing of assembler directives not done in Pass 1
  - Write the object program and the assembly listing

A Simple Two Pass Assembler Implementation



Algorithms and Data Structures

Three Main Data Structures

- Operation Code Table (OPTAB)
- Location Counter (LOCCTR)
- Symbol Table (SYMTAB)

OPTAB (operation code table)

- Content
  - The mapping between mnemonic and machine code. Also include the instruction format, available addressing modes, and length information.
- Characteristic
  - Static table. The content will never change.
- Implementation

  - Array or hash table. Because the content will never change, we can optimize its search speed.
- In pass 1, OPTAB is used to look up and validate mnemonics in the source program.
- In pass 2, OPTAB is used to translate mnemonics to machine instructions.

Location Counter (LOCCTR)

- This variable can help in the assignment of addresses.
- It is initialized to the beginning address specified in the START statement.
- After each source statement is processed, the length of the assembled instruction and data area
- to be generated is added to LOCCTR.
- Thus, when we reach a label in the source program, the current value of LOCCTR gives the address to be associated with that label.

Symbol Table (SYMTAB)

- Content
  – Include the label name and value (address) for each label in the source program.
  – Include type and length information (e.g., int64)
  – With flag to indicate errors (e.g., a symbol defined in two places)
- Characteristic
  – Dynamic table (I.e., symbols may be inserted, deleted, or searched in the table)
- Implementation
  – Hash table can be used to speed up search – Because variable names may be very similar (e.g., LOOP1, LOOP2), the selected hash function must perform well with such non-random keys.

The Pseudo Code for Pass 1

```
Begin
        read first input line
        if OPCODE = 'START' then begin
                save #[Operand] as starting addr
                initialize LOCCTR to starting address
                write line to intermediate file
                read next line
        end( if START)
        else
                initialize LOCCTR to 0
        While OPCODE != 'END' do
        begin
                if this is not a comment line then
```

```
begin
        if there is a symbol in the LABEL field then
        begin
                search SYMTAB for LABEL
                if found then
                set error flag (duplicate symbol)
                else
                (if symbol)
                search OPTAB for OPCODE
                if found then
                        add 3 (instr length) to LOCCTR
                else if OPCODE = 'WORD' then
                        add 3 to LOCCTR
                else if OPCODE = 'RESW' then
                        add 3 * #[OPERAND] to LOCCTR
                else if OPCODE = 'RESB' then
                        add #[OPERAND] to LOCCTR
                else if OPCODE = 'BYTE' then
                begin
                        find length of constant in bytes
                        add length to LOCCTR
                end
                else
                        set error flag (invalid operation code)
                end (if not a comment)
        write line to intermediate file
        read next input line
end { while not END}
write last line to intermediate file
Save (LOCCTR – starting address) as program length
```

End {pass 1}

The Pseudo Code for Pass 2

```
Begin
        read 1st input line
        if OPCODE = 'START' then
        begin
                write listing line
                read next input line
        end
        write Header record to object program
        initialize 1st Text record
        while OPCODE != 'END' do
        begin
                if this is not comment line then
                begin
                        search OPTAB for OPCODE
                        if found then
                        begin
                                if there is a symbol in OPERAND field then
                                begin
                                        search SYMTAB for OPERAND field then
                                        if found then
                                        begin
                                        store symbol value as operand address
                                        else
                                        begin
                                                store 0 as operand address
                                                set error flag (undefined symbol)
                                        end
```

```
                    end (if symbol)
                    else store 0 as operand address
                        assemble the object code instruction
                    else if OPCODE = 'BYTE' or 'WORD" then
                        convert constant to object code
                    if object code doesn't fit into current Text record then
                    begin
                        Write text record to object code
                        initialize new Text record
                    end
                    add object code to Text record
                end {if not comment}
                write listing line
                read next input line
            end
            write listing line
            read next input line
            write last listing line
End {Pass 2}
```

Machine dependent Assembler Features

Assembler Features

- Machine Dependent Assembler Features
  - Instruction formats and addressing modes (SIC/XE)
  - Program relocation
- Machine Independent Assembler Features
  - Literals
  - Symbol-defining statements
  - Expressions

- Program blocks
- Control sections and program linking

A SIC/XE Program

```
  5     COPY      START   0               COPY FILE FROM INPUT TO OUTPUT
 10     FIRST     STL     RETADR          SAVE RETURN ADDRESS
 12               LDB     #LENGTH         ESTABLISH BASE REGISTER
 13               BASE    LENGTH
 15     CLOOP     +JSUB   RDREC           READ INPUT RECORD
 20               LDA     LENGTH          TEST FOR EOF (LENGTH = 0)
 25               COMP    #0
 30               JEQ     ENDFIL          EXIT IF EOF FOUND
 35               +JSUB   WRREC           WRITE OUTPUT RECORD
 40               J       CLOOP           LOOP
 45     ENDFIL    LDA     EOF             INSERT END OF FILE MARKER
 50               STA     BUFFER
 55               LDA     #3              SET LENGTH = 3
 60               STA     LENGTH
 65               +JSUB   WRREC           WRITE EOF
 70               J       @RETADR         RETURN TO CALLER
 80     EOF       BYTE    C'EOF'
 95     RETADR    RESW    1
100     LENGTH    RESW    1               LENGTH OF RECORD
105     BUFFER    RESB    4096            4096-BYTE BUFFER AREA
110     .
115     .         SUBROUTINE TO READ RECORD INTO BUFFER
120     .
125     RDREC     CLEAR   X               CLEAR LOOP COUNTER
130               CLEAR   A               CLEAR A TO ZERO
132               CLEAR   S               CLEAR S TO ZERO
133               +LDT    #4096
135     RLOOP     TD      INPUT           TEST INPUT DEVICE
140               JEQ     RLOOP           LOOP UNTIL READY
145               RD      INPUT           READ CHARACTER INTO REGISTER A
150               COMPR   A,S             TEST FOR END OF RECORD (X'00')
155               JEQ     EXIT            EXIT LOOP IF EOR
160               STCH    BUFFER,X        STORE CHARACTER IN BUFFER
165               TIXR    T               LOOP UNLESS MAX LENGTH
170               JLT     RLOOP             HAS BEEN REACHED
175     EXIT      STX     LENGTH          SAVE RECORD LENGTH
180               RSUB                    RETURN TO CALLER
185     INPUT     BYTE    X'F1'           CODE FOR INPUT DEVICE
195     .
```

```
200     .     SUBROUTINE TO WRITE RECORD FROM BUFFER
205     .
210     WRREC   CLEAR   X           CLEAR LOOP COUNTER
212             LDT     LENGTH
215     WLOOP   TD      OUTPUT      TEST OUTPUT DEVICE
220             JEQ     WLOOP       LOOP UNTIL READY
225             LDCH    BUFFER,X    GET CHARACTER FROM BUFFER
230             WD      OUTPUT      WRITE CHARACTER
235             TIXR    T           LOOP UNTIL ALL CHARACTERS
240             JLT     WLOOP         HAVE BEEN WRITTEN
245             RSUB                RETURN TO CALLER
250     OUTPUT  BYTE    X'05'       CODE FOR OUTPUT DEVICE
255             END     FIRST
```

SIC/XE Instruction Formats and Addressing Modes

- PC-relative or Base-relative (BASE directive needs to be used) addressing: **op m**
- Indirect addressing: **op @m**
- Immediate addressing: **op #c**
- Extended format (4 bytes): **+op m**
- Index addressing: **op m,X**
- Register-to-register instructions

Relative Addressing Modes

- PC-relative or base-relative addressing mode is preferred over direct addressing mode.
  - Can save one byte from using format 3 rather than format 4.
    - Reduce program storage space
    - Reduce program instruction fetch time
  - Relocation will be easier.

The Differences Between the SIC and SIC/XE Programs

- Register-to-register instructions are used whenever possible to improve execution speed.
  - Fetch a value stored in a register is much faster than fetch it from the memory.
- Immediate addressing mode is used whenever possible.
  - Operand is already included in the fetched instruction. There is no need to fetch the operand from the memory.
- Indirect addressing mode is used whenever possible.

– Just one instruction rather than two is enough.

The Object Code

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					

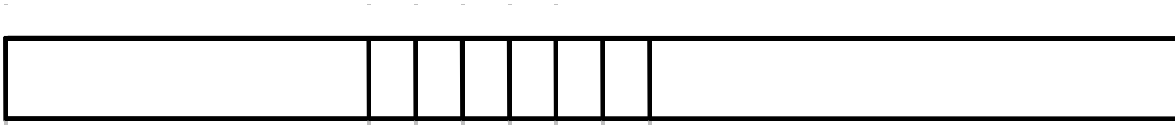
```
195         .
200         .     SUBROUTINE TO WRITE RECORD FROM BUFFER
205         .
210  105D  WRREC  CLEAR   X          B410
212  105F        LDT     LENGTH     774000
215  1062  WLOOP TD      OUTPUT     E32011
220  1065        JEQ     WLOOP      332FFA
225  1068        LDCH    BUFFER,X   53C003
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
```

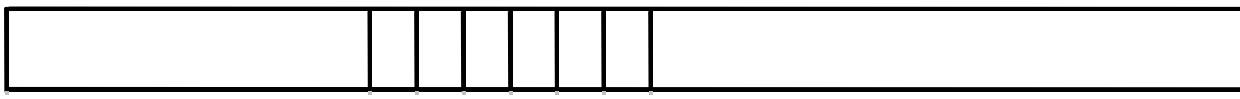
Generate Relocatable Programs

- Let the assembled program starts at address 0 so that later it can be easily moved to any place in the physical memory.
    - Actually, as we have learned from virtual memory, now every process (executed program) has a separate address space starting from 0.
- Assembling register-to-register instructions presents no problems. (e.g., line 125 and 150)
    - Register mnemonic names need to be converted to their corresponding register numbers.
    - This can be easily done by looking up a name table.

PC or Base-Relative Modes

- Format 3: 12-bit displacement field (in total 3 bytes)
    - Base-relative: 0~4095
    - PC-relative: -2048~2047
- Format 4: 20-bit address field (in total 4 bytes)
- The displacement needs to be calculated so that when the displacement is added to PC (which points to the following instruction after the current instruction is fetched) or the base register (B), the resulting value is the target address.
- If the displacement cannot fit into 12 bits, format 4 then needs to be used. (E.g., line 15 and 125)
    - Bit e needs to be set to indicate format 4.
    - A programmer must specify the use of format 4 by putting a + before the instruction. Otherwise, it will be treated as an error.



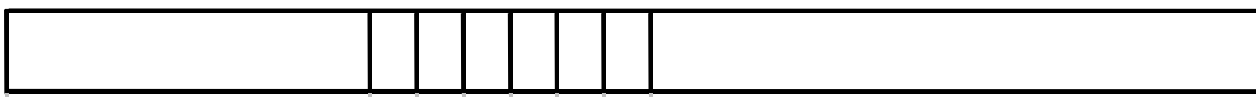


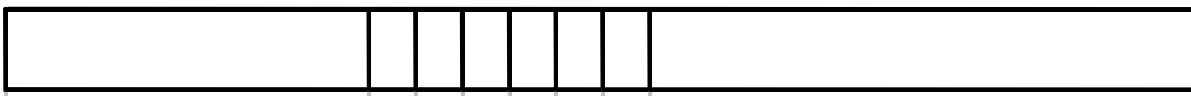
Base-Relative v.s. PC-Relative

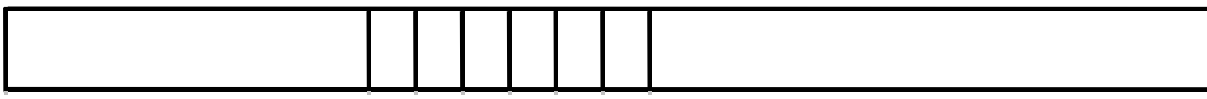
- The difference between PC and base relative addressing modes is that the assembler knows the value of PC when it tries to use PC-relative mode to assembles an

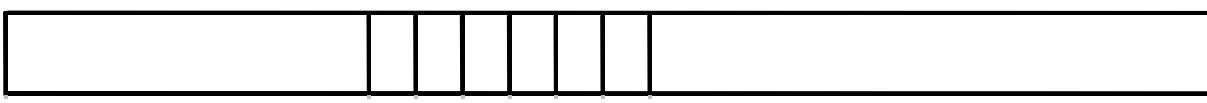
instruction. However, when trying to use base-relative mode to assemble an instruction, the assembler does not know the value of the base register.

- Therefore, the programmer must tell the assembler the value of register B.
- This is done through the use of the BASE directive. (line 13)
- Also, the programmer must load the appropriate value into register B by himself.
- Another BASE directive can appear later, this will tell the assembler to change its notion of the current value of B.
- NOBASE can also be used to tell the assembler that no more base-relative addressing mode should be used.







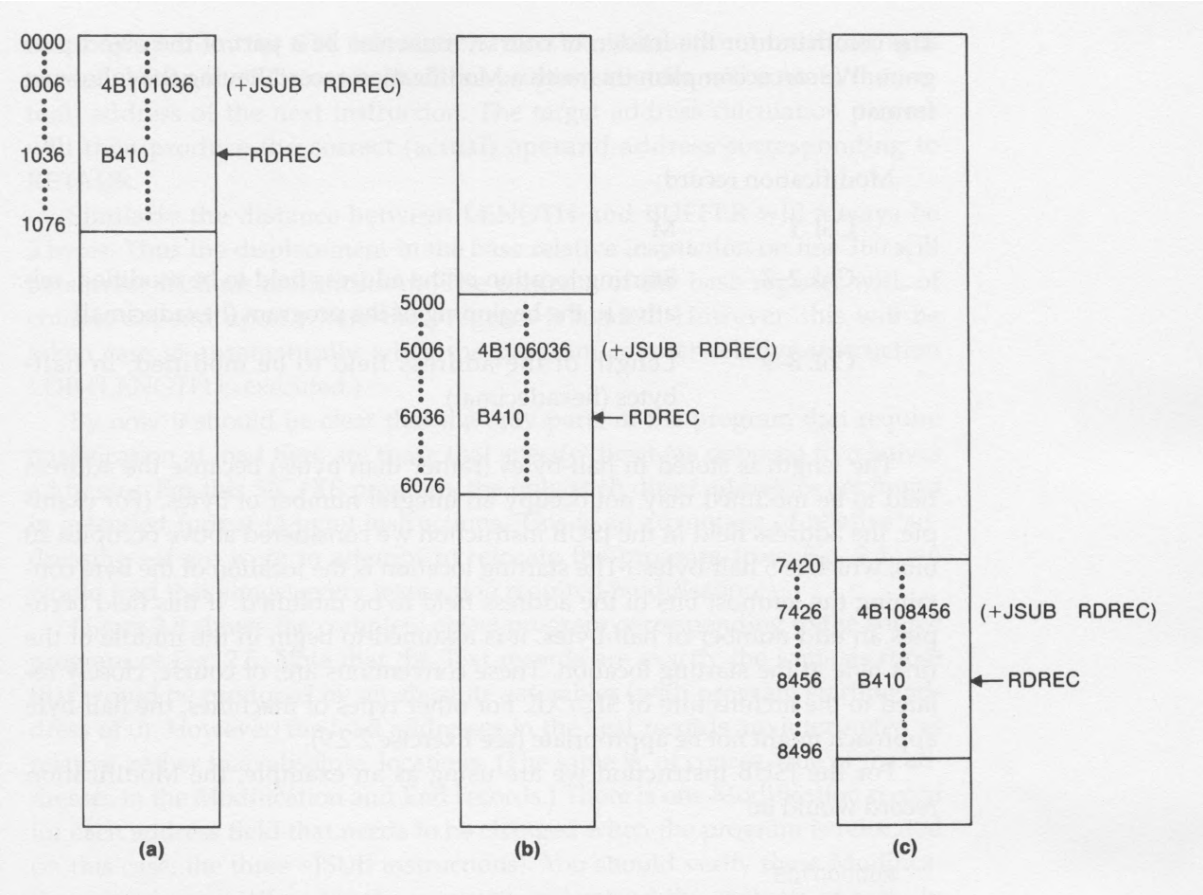


Relocatable Is Desired

- The program in Fig. 2.1 specifies that it must be loaded at address 1000 for correct execution. This restriction is too inflexible for the loader.
- If the program is loaded at a different address, say 2000, its memory references will access wrong data! For example:
  - 55 101B LDA THREE 00102D
- Thus, we want to make programs relocatable so that they can be loaded and execute correctly at any place in the memory.

Address Modification Is Required

If we can use a hardware relocation register (MMU), software relocation can be avoided here. However, when linking multiple object Programs together, software relocation is still needed.



What Instructions Needs to be Modified?

- Only those instructions that use absolute (direct) addresses to reference symbols.
- The following need not be modified:
  - Immediate addressing (no memory references)
  - PC or Base-relative addressing (Relocatable is one advantage of relative addressing, among others.)
  - Register-to-register instructions (no memory references)

The Modification Record

- When the assembler generate an address for a symbol, the address to be inserted into the instruction is relative to the start of the program.
- The assembler also produces a modification record, in which the address and length of the need-to-be-modified address field are stored.
- The loader, when seeing the record, will then add the beginning address of the loaded program to the address field stored in the record.

Modification record:

Col. 1	M
Col. 2–7	Starting location of the address field to b ative to the beginning of the program (he
Col. 8–9	Length of the address field to be mo bytes (hexadecimal)

The Relocatable Object Code

```
HCOPY  000000001077
T0000001D17202D69202D4B10103603202629000033200 74B10105D3F2FEC032010
T00001D130F20160100030F200D4B10105D3E2003454F46
T001036 1DB410B400B44075101000E32019332FFADB2013A00433200857C003B850
T001053 1D3B2FEA1340004F0000F1B410774000E32011332FFA53C003DF2008B850
T001070 073B2FEF4F000005
M00000705
M00001405
M00002705
E000000
```