PROGRAMMING THE BASIC COMPUTER

INTRODUCTION

Those concerned with computer architecture should have a knowledge of both hardware and software because the two branches influence each other.

Instruction Set of the *Basic Computer*

Symbol	*Hexa code*	*Description*
AND	0 or 8	AND M to AC
ADD	1 or 9	Add M to AC, carry to E
LDA	2 or A	Load AC from M
STA	3 or B	Store AC in M
BUN	4 or C	Branch unconditionally to m
BSA	5 or D	Save return address in m and branch to m+1
ISZ	6 or E	Increment M and skip if zero
CLA	7800	Clear AC
CLE	7400	Clear E
CMA	7200	Complement AC
CME	7100	Complement E
CIR	7080	Circulate right E and AC
CIL	7040	Circulate left E and AC
INC	7020	Increment AC, carry to E
SPA	7010	Skip if AC is positive
SNA	7008	Skip if AC is negative
SZA	7004	Skip if AC is zero
SZE	7002	Skip if E is zero
HLT	7001	Halt computer
INP	F800	Input information and clear flag
OUT	F400	Output information and clear flag
SKI	F200	Skip if input flag is on
SKO	F100	Skip if output flag is on
ION	F080	Turn interrupt on
IOF	F040	Turn interrupt off

m: effective address
M: memory word (operand) found at m

MACHINE LANGUAGE

- Program
  A list of instructions or statements for directing the computer to perform a required data processing task

- Various types of programming languages
  - Hierarchy of programming languages

  - Machine-language
    - Binary code
    - Octal or hexadecimal code

  - Assembly-language (Assembler)
    - Symbolic code

  - High-level language (Compiler)

COMPARISON OF PROGRAMMING LANGUAGES

- Binary Program to Add Two Numbers

Location	Instruction Code
0	0010 0000 0000 0100
1	0001 0000 0000 0101
10	0011 0000 0000 0110
11	0111 0000 0000 0001
100	0000 0000 0101 0011
101	1111 1111 1110 1001
110	0000 0000 0000 0000

- Hexa program

Location	Instruction
000	2004
001	1005
002	3006
003	7001
004	0053
005	FFE9
006	0000

- Program with Symbolic OP-Code

Location	Instruction		Comments
000	LDA	004	Load 1st operand into AC
001	ADD	005	Add 2nd operand to AC
002	STA	006	Store sum in location 006
003	HLT		Halt computer
004	0053		1st operand
005	FFE9		2nd operand (negative)
006	0000		Store sum here

- Assembly-Language Program

```
        ORG   0      /Origin of program is location 0
        LDA   A      /Load  operand from location A
        ADD   B      /Add  operand from location B
        STA   C      /Store sum in location C
        HLT          /Halt computer
A,      DEC   83     /Decimal operand
B,      DEC   -23    /Decimal operand
C,      DEC   0      /Sum stored in location C
        END          /End of symbolic program
```

- Fortran Program

```
INTEGER  A, B, C
DATA  A,83 / B,-23
C = A + B
END
```

ASSEMBLY LANGUAGE

Syntax of the BC assembly language
- Each line is arranged in three columns called fields
- *Label* field
  - May be empty or may specify a symbolic address consists of up to 3 characters
  - Terminated by a comma
- *Instruction* field
  - Specifies a machine or a pseudo instruction
  - May specify one of
    - * Memory reference instr. (MRI)
      MRI consists of two or three symbols separated by spaces.
      ADD OPR (direct address MRI)
      ADD PTR I (indirect address MRI)
    - * Register reference or input-output instr.
      Non-MRI does not have an address part
    - * Pseudo instr. with or without an operand
      Symbolic address used in the instruction field must be defined somewhere as a label
- *Comment* field
  - May be empty or may include a comment

PSEUDO-INSTRUCTIONS

ORG N
Hexadecimal number N is the memory loc. for the instruction or operand listed in the following line

END
Denotes the end of symbolic program

DEC N
Signed decimal number N to be converted to the binary

HEX N
Hexadecimal number N to be converted to the binary

Example: Assembly language program to subtract two numbers

```
        ORG 100     / Origin of program is location 100
        LDA SUB     / Load subtrahend to AC
        CMA         / Complement AC
        INC         / Increment AC
        ADD MIN     / Add minuend to AC
        STA DIF     / Store difference
        HLT         / Halt computer
MIN,    DEC 83      / Minuend
SUB,    DEC -23     / Subtrahend
DIF,    HEX 0       / Difference stored here
        END         / End of symbolic program
```


TRANSLATION TO BINARY

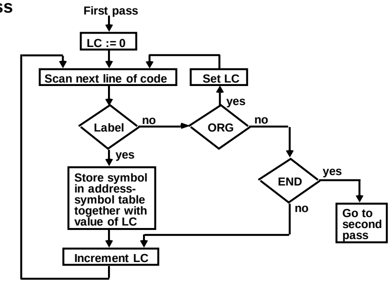
Hexadecimal Code		*Symbolic Program*	
Location	*Content*		
			ORG 100
100	2107		LDA SUB
101	7200		CMA
102	7020		INC
103	1106		ADD MIN
104	3108		STA DIF
105	7001		HLT
106	0053	MIN,	DEC 83
107	FFE9	SUB,	DEC -23
108	0000	DIF,	HEX 0
			END

ASSEMBLER - FIRST PASS -

Assembler
- Source Program - Symbolic Assembly Language Program
- Object Program - Binary Machine Language Program

Two pass assembler
- 1st pass: generates a table that correlates all user defined (address) symbols with their binary equivalent value
- 2nd pass: binary translation

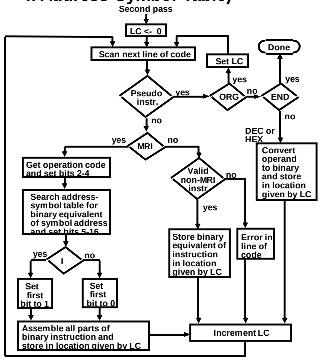
First pass



ASSEMBLER - SECOND PASS -

Second Pass

Machine instructions are translated by means of table-lookup procedures;
(1. Pseudo-Instruction Table, 2. MRI Table, 3. Non-MRI Table
4. Address Symbol Table)



PROGRAM LOOPS

Loop: A sequence of instructions that are executed many times, each with a different set of data

Fortran program to add 100 numbers:

```
      DIMENSION  A(100)
      INTEGER  SUM,  A
      SUM = 0
      DO  3  J = 1,  100
3     SUM = SUM + A(J)
```

Assembly-language program to add 100 numbers:

```
        ORG  100        / Origin of program is HEX 100
        LDA  ADS        / Load first address of operand
        STA  PTR        / Store in pointer
        LDA  NBR        / Load -100
        STA  CTR        / Store in counter
        CLA             / Clear AC
LOP,    ADD  PTR  I     / Add an operand to AC
        ISZ  PTR        / Increment pointer
        ISZ  CTR        / Increment counter
        BUN  LOP        / Repeat loop again
        STA  SUM        / Store sum
        HLT             / Halt
ADS,    HEX  150        / First address of operands
PTR,    HEX  0          / Reserved for a pointer
NBR,    DEC  -100       / Initial value for a counter
CTR,    HEX  0          / Reserved for a counter
SUM,    HEX  0          / Sum is stored here
        ORG  150        / Origin of operands is HEX 150
        DEC  75         / First operand
         .
         .
        DEC  23         / Last operand
        END             / End of symbolic program
```


PROGRAMMING ARITHMETIC AND LOGIC OPERATIONS

Implementation of Arithmetic and Logic Operations

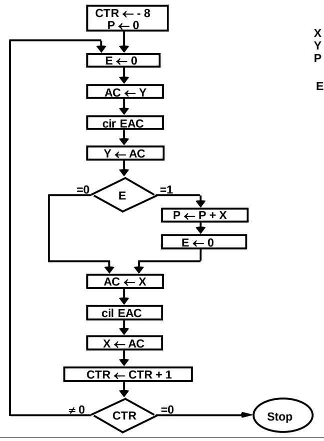
- Software Implementation
  - Implementation of an operation with a program using machine instruction set
  - Usually when the operation is not included in the instruction set

- Hardware Implementation
  - Implementation of an operation in a computer with one machine instruction

Software Implementation example:

* Multiplication
- For simplicity, unsigned positive numbers
- 8-bit numbers -> 16-bit product

FLOWCHART OF A PROGRAM - Multiplication -



X holds the multiplicand
Y holds the multiplier
P holds the product

Example with four significant digits

X =	0000 1111	P
Y =	0000 1011	0000 0000
	0000 1111	0000 1111
	0001 1110	0010 1101
	0000 0000	0010 1101
	0111 1000	1010 0101
	1010 0101	

ASSEMBLY LANGUAGE PROGRAM - Multiplication -

```
        ORG  100
LOP,    CLE          / Clear E
        LDA  Y       / Load multiplier
        CIR          / Transfer multiplier bit to E
        STA  Y       / Store shifted multiplier
        SZE          / Check if bit is zero
        BUN  ONE     / Bit is one; goto ONE
        BUN  ZRO     / Bit is zero; goto ZRO
ONE,    LDA  X       / Load multiplicand
        ADD  P       / Add to partial product
        STA  P       / Store partial product
        CLE          / Clear E
ZRO,    LDA  X       / Load multiplicand
        CIL          / Shift left
        STA  X       / Store shifted multiplicand
        ISZ  CTR     / Increment counter
        BUN  LOP     / Counter not zero; repeat loop
        HLT          / Counter is zero; halt
CTR,    DEC  -8      / This location serves as a counter
X,      HEX  000F    / Multiplicand stored here
Y,      HEX  000B    / Multiplier stored here
P,      HEX  0       / Product formed here
        END
```


ASSEMBLY LANGUAGE PROGRAM - Double Precision Addition -

```
LDA  AL     / Load A low
ADD  BL     / Add B low, carry in E
STA  CL     / Store in C low
CLA         / Clear AC
CIL         / Circulate to bring carry into AC(16)
ADD  AH     / Add A high and carry
ADD  BH     / Add B high
STA  CH     / Store in C high
HLT
```


ASSEMBLY LANGUAGE PROGRAM - Logic and Shift Operations -

- Logic operations
  - BC instructions : AND, CMA, CLA
  - Program for OR operation

```
LDA  A      / Load 1st operand
CMA         / Complement to get A'
STA  TMP    / Store in a temporary location
LDA  B      / Load 2nd operand B
CMA         / Complement to get B'
AND  TMP    / AND with A' to get A' AND B'
CMA         / Complement again to get A OR B
```

- Shift operations - BC has *Circular Shift* only
  - Logical shift-right operation

```
CLE
CIR
```

  - Logical shift-left operation

```
CLE
CIL
```

  - Arithmetic right-shift operation

```
CLE   / Clear E to 0
SPA   / Skip if AC is positive
CME   / AC is negative
CIR   / Circulate E and AC
```


SUBROUTINES

Subroutine
- A set of common instructions that can be used in a program many times.
- Subroutine *linkage* : a procedure for branching to a subroutine and returning to the main program

Example

```
Loc.
              ORG  100     / Main program
100           LDA  X       / Load X
101           BSA  SH4     / Branch to subroutine
102           STA  X       / Store shifted number
103           LDA  Y       / Load Y
104           BSA  SH4     / Branch to subroutine again
105           STA  Y       / Store shifted number
106           HLT
107    X,     HEX  1234
108    Y,     HEX  4321
                           / Subroutine to shift left 4 times
109    SH4,   HEX  0       / Store return address here
10A           CIL          / Circulate left once
10B           CIL
10C           CIL
10D           CIL          / Circulate left fourth time
10E           AND  MSK     / Set AC(13-16) to zero
10F           BUN  SH4 I   / Return to main program
110    MSK,   HEX  FFF0    / Mask operand
              END
```

SUBROUTINE PARAMETERS AND DATA LINKAGE

Linkage of Parameters and Data between the Main Program and a Subroutine
- via Registers
- via Memory locations
- ….

Example: Subroutine performing *LOGICAL OR operation*; Need two parameters

```
Loc.         ORG  200
200          LDA  X       / Load 1st operand into AC
201          BSA  OR      / Branch to subroutine OR
202          HEX  3AF6    / 2nd operand stored here
203          STA  Y       / Subroutine returns here
204          HLT
205   X,     HEX  7B95    / 1st operand stored here
206   Y,     HEX  0       / Result stored here
207   OR,    HEX  0       / Subroutine OR
208          CMA          / Complement 1st operand
209          STA  TMP     / Store in temporary location
20A          LDA  OR  I   / Load 2nd operand
20B          CMA          / Complement 2nd operand
20C          AND  TMP     / AND complemented 1st operand
20D          CMA          / Complement again to get OR
20E          ISZ  OR      / Increment return address
20F          BUN  OR  I   / Return to main program
210   TMP,   HEX  0       / Temporary storage
             END
```


SUBROUTINE - Moving a Block of Data -

```
                        / Main program
       BSA  MVE         / Branch to subroutine
       HEX  100         / 1st address of source data
       HEX  200         / 1st address of destination data
       DEC  -16         / Number of items to move
       HLT
MVE,   HEX  0           / Subroutine MVE
       LDA  MVE  I      / Bring address of source
       STA  PT1         / Store in 1st pointer
       ISZ  MVE         / Increment return address
       LDA  MVE  I      / Bring address of destination
       STA  PT2         / Store in 2nd pointer
       ISZ  MVE         / Increment return address
       LDA  MVE  I      / Bring number of items
       STA  CTR         / Store in counter
       ISZ  MVE         / Increment return address
LOP,   LDA  PT1  I      / Load source item
       STA  PT2  I      / Store in destination
       ISZ  PT1         / Increment source pointer
       ISZ  PT2         / Increment destination pointer
       ISZ  CTR         / Increment counter
       BUN  LOP         / Repeat 16 times
       BUN  MVE  I      / Return to main program
PT1,   --
PT2,   --
CTR,   --
```

• Fortran subroutine

```
   SUBROUTINE  MVE (SOURCE, DEST, N)
   DIMENSION  SOURCE(N), DEST(N)
   DO  20  I = 1, N
20 DEST(I) = SOURCE(I)
   RETURN
   END
```


INPUT OUTPUT PROGRAM

Program to Input one Character(Byte)

```
CIF,   SKI          / Check input flag
       BUN  CIF     / Flag=0, branch to check again
       INP          / Flag=1, input character
       OUT          / Display to ensure correctness
       STA  CHR     / Store character
       HLT
CHR,   --           / Store character here
```

Program to Output a Character

```
       LDA  CHR     / Load character into AC
COF,   SKO          / Check output flag
       BUN  COF     / Flag=0, branch to check again
       OUT          / Flag=1, output character
       HLT
CHR,   HEX  0057    / Character is "W"
```


CHARACTER MANIPULATION

Subroutine to Input 2 Characters and pack into a word

```
IN2,   --           / Subroutine entry
FST,   SKI
       BUN  FST
       INP          / Input 1st character
       OUT
       BSA  SH4     / Logical Shift left 4 bits
       BSA  SH4     / 4 more bits
SCD,   SKI
       BUN  SCD
       INP          / Input 2nd character
       OUT
       BUN  IN2  I  / Return
```

PROGRAM INTERRUPT

Tasks of Interrupt Service Routine

- Save the Status of CPU
  Contents of processor registers and Flags

- Identify the source of Interrupt
  Check which flag is set

- Service the device whose flag is set
  (Input Output Subroutine)

- Restore contents of processor registers and flags

- Turn the interrupt facility on

- Return to the running program
  Load PC of the interrupted program

INTERRUPT SERVICE ROUTINE

Loc.			
0	ZRO,	-	/ Return address stored here
1		BUN SRV	/ Branch to service routine
100		CLA	/ Portion of running program
101		ION	/ Turn on interrupt facility
102		LDA X	
103		ADD Y	/ Interrupt occurs here
104		STA Z	/ Program returns here after interrupt
			/ Interrupt service routine
200	SRV,	STA SAC	/ Store content of AC
		CIR	/ Move E into AC(1)
		STA SE	/ Store content of E
		SKI	/ Check input flag
		BUN NXT	/ Flag is off, check next flag
		INP	/ Flag is on, input character
		OUT	/ Print character
		STA PT1 I	/ Store it in input buffer
		ISZ PT1	/ Increment input pointer
	NXT,	SKO	/ Check output flag
		BUN EXT	/ Flag is off, exit
		LDA PT2 I	/ Load character from output buffer
		OUT	/ Output character
		ISZ PT2	/ Increment output pointer
	EXT,	LDA SE	/ Restore value of AC(1)
		CIL	/ Shift it to E
		LDA SAC	/ Restore content of AC
		ION	/ Turn interrupt on
		BUN ZRO I	/ Return to running program
	SAC,	-	/ AC is stored here
	SE,	-	/ E is stored here
	PT1,	-	/ Pointer of input buffer
	PT2,	-	/ Pointer of output buffer