Systems Software

Assembler

B.Tech. III (CO) Semester – 6	L	T	P	C
CO304 : SYSTEM SOFTWARE (CS-2)	3	1	2	5

- **ASSEMBLER**

  Introduction, Cross Assembler, Micro Assembler, Meta Assembler, Single pass Assembler, Two Pass Assembler, Design of Operation code table, Symbol table, Literal table.

- **MACRO PROCESSOR**

  Introduction of Macros, Macro processor design, Forward reference, Backward reference, positional parameters, keyword parameters, conditional assembly, Macro calls within Macros, Implementation of macros within Assembler.

  Designing Macro name table, Macro Definition table, Kew word parameter table, Actual parameter table, Expansion time variable storage.

- **RUN TIME ENVIRONMENT**
- Absolute loader, Relocation - Relocating loader, Dynamic loader, Bootstrap loader, Linking-loader, Program relocatibility, Design of Absolute Loader, Design of direct-linking editor, other Loader scheme e.g. (Binders, Linking Loaders, Overlays, Dynamic Binders).
- **Books**
- 1). A.V.Aho, R.Sethi & J D.Ullman, “Compilers-Principles, Techniques and Tools”. Pearson, 2006
  2). Leland L. Beck ,” System Software -An Introduction to System Programming”, 3/E, Addision Wesley,reprint 2003
  3). Louden , Kenneth C :” Compiler Construction-Principles and Practice”,1/E, Thomson, 1997
  4). D. M. Dhamdhere : “ System Programming and Operating System”.,2/E,TMH,1999
  5). Houlb : Compiler Design in C, PHI, EEE, 1995

Assembler Definition

- An assembly language is a low-level programming language for microprocessors and other programmable devices.
- Each assembly language is specific to a particular computer architecture.
- Assembly language is machine dependent, low-level programming language which is specified to a certain computer system(or a family of computer system).
- Assembly language is converted into executable machine code by a **utility program(according to computer infrastructure)** referred to as an *assembler.*

Cross Assembler

- A cross assembler is a program which generates machine code for a processor other than the one it is currently run on.
- An assembler is a program that converts assembly language into the actual binary processor specific machine code.
- Normally the machine code generated is for the processor used in the machine it is run on. A cross assembler takes this conversion process a step further by allowing you to generate machine code for a *different* processor than the one the compiler is run on.

- Cross-assembling facilitates the development of programs for systems that do not have the resources to support software development, such as an embedded system. In such a case, the resulting object code must be transferred to the target system, either via read-only memory (ROM, EPROM, etc.)

Microassembler

- A microassembler is a computer program that helps prepare a microprogram, called *firmware(*permanent software programmed into a read-only memory.*)*, to control the low level operation of a computer in much the same way an assembler helps prepare higher level code for a processor.
- The difference is that the microprogram is usually only developed by the processor manufacturer and works intimately with the computer hardware.
- The use of a microprogram allows the manufacturer to fix certain mistakes, including working around hardware design errors, without modifying the hardware.

Meta Assembler

- **meta-assembler** A program that accepts the syntactic and semantic description of an assembly language, and generates an assembler for that language.

- **Basic three features for simplify programming**

- **Mnemonic operation codes(mnemonic opcodes):**
  - Assembly language uses a mnemonic to represent each low-level machine instruction or operation
  - Eliminates to memorize numerical opcodes.
  - Provides helpful diagnostics.

- **Symbolic operands**
  - Symbolic names can be associated with data or instructions
  - It can also be used as operands in assembly language.
  - Specify the data required by the operation
  - Executable instructions can have zero to three operands
  - Operands can be registers, memory variables, or constants

- **Data Declaration**
  - Data can be declared in verity of notations
  - Avoids manual conversation of constants into their internal machine representation.

Statement Format

- Assembly language statement format

- [label] <Opcode> <Operand spec>[, <Operand spec>..]
- Anything Between this [..] is optional field.
- When label is their then it contains symbolic name

- <Operand spec> has following syntax:

- **<symbolic name> [+<displacement>][(index register)]**

- examples

- Statement Format:
  - [Label] <Opcode> <operand spec> [,<operand spec>…]
  - <operand spec> format:
    - <Symbolic name> [+<displacement>][(<index register>)]

    Ex. AREA+5(4)

Memory word with which name AREA is associated

Displacement /offset from AREA

Operand address is obtained by adding the contents of index register 4 to the address of AREA

  - Example's specification is a combination of previous two.

Instruction opcode	Assembly mnemonic	
00	STOP	Stop execution
01	ADD	First operand is modified
02	SUB	First operand is modified
03	MULT	First operand is modified
04	MOVER	Register $\rightarrow$ memory move
05	MOVEM	memory $\leftarrow$ Register move
06	COMP	
07	BC	Branch on condition
08	DIV	Analog to SUB
09	READ	First operand is not used
10	PRINT	First operand is not used

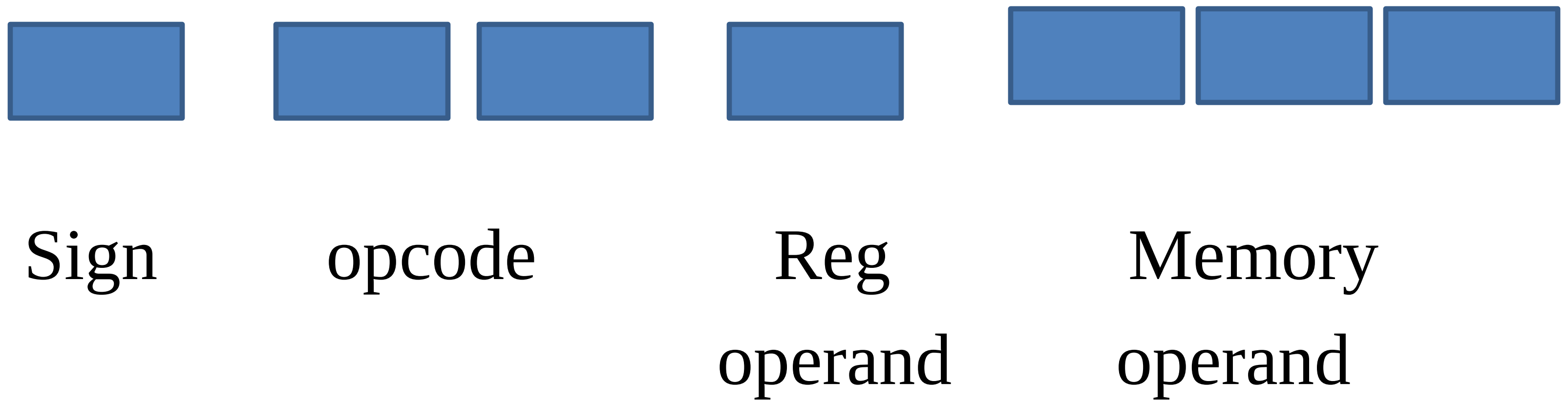
Simple assembly languages

- In Assembly language each statement has 2 operands
  - First operand is always a register
  - Second is memory word using a symbolic name & optional displacement
  - *MOVER*: Second operand is source& first is target
  - *MOVEM*: opposite to MOVER
  - All arithmetic is performed in a registe.
  - Condition code can be tasted by a Branch on Condition (BC) instruction.
    - *BC <condition code spec>, <memory address>*
    - Transfers control to the memory word with memory address> if current value of condition code matches <condition code spec>.

- Conditional Code
- It can be tested by Branch on condition (BC) instruction.
- **Format:**
- **BC <conditional code spec> ,<memory address>**
- Conditional codes are LE,EQ,GE,LT,GT,ANY

Machine instruction format

- Machine instruction format
- In this format all the addresses and constants are shown in decimal rather than octal or hexadecimal.



```
        START   101
        READ    N               101)   + 09  0  113
        MOVER   BREG,ONE        102)   + 04  2  115
        MOVEM   BREG, TERM      103)   + 05  2  116
AGAIN   MULT    BREG, TERM      104)   + 03  2  116
        MOVER   CREG, TERM      105)   + 04  3  116
        ADD     CREG, ONE       106)   + 01  3  115
        MOVEM   CREG, TERM      107)   + 05  3  116
        COMP    CREG, N         108)   + 06  3  113
        BC      LE, AGAIN       109)   + 07  2  104
        MOVEM   BREG, RESULT    110)   + 05  2  114
        PRINT   RESULT          111)   + 10  0  114
        STOP                    112)   + 00  0  000
N       DS      1               113)
RESULT  DS      1               114)
ONE     DC      ‘1’             115)
TERM    DS      1               116)   + 00  0  001
        END
```

- Assembly and equivalent machine language

Assembly language statements

- Assembly program contains three kindes of statements

- Imperative statements
- Declaration Statements
- Assembler Directives

- **Imperative statements:**
- Actions to be performed during the execution of assembled program.
- Imperative statements represent machine instructions in symbolic form.
- For example, add means an addition instruction and mov denotes a data transfer instruction.

- **Declaration Statements:**
- Syntax of declaration statement

[Label] DS <constant>

[Label] DC '<Value>'

- DS (declare storage) :
  - Reserves area of memory and associated name with them

- Statements are

```
X        DS        1
Z        DS        100
```

- First statement reserves 1 word with the name X.
- Second statement ?

- DC (Declare Constant)
  - It constructs memory words containing constans

```
XYZ        DC        ‘1’
```

- It assigns memory word containing the value ‘1’ to XYZ

- Constants
  - DC doesn’t implement constants its only initialize block with the value.
  - This value can be changed
  - MOVEM CREG , XYZ
- Constants can be implemented in two ways
  - Immediate operands
  - Literals

- For ex

  ADD   AREG , 5

Note: simple assembly language doesn't support this ,but intel 8086 supports it.

- Literal
  - It is operand with **='<value>'** syntax
  - Its differ from constant because its location cannot be specified in assembly program.
  - Its value cannot be changed during the execution of program

ADD BREG , ='50'

- Assembler Directives
  - It instruct the assembler to perform certain action during program

    START <constants>

  - Starts the target program with particular address

    END

  end of source program

Advantages of assembly language:

- Use of symbolic operand specifications:
    - insertion of one statement in assembly program leads to changes in address of constants and reserved memory areas.
    - So addresses used in most instructions of the program had to change.
    - Such changes are not needed in assembly program.

```
        START   101
        READ    N               101)   + 09  0  114
        MOVER   BREG,ONE        102)   + 04  2  116
        MOVEM   BREG, TERM      103)   + 05  2  117
AGAIN   MULT    BREG, TERM      104)   + 03  2  117
        MOVER   CREG, TERM      105)   + 04  3  117
        ADD     CREG, ONE       106)   + 01  3  116
        MOVEM   CREG, TERM      107)   + 05  3  117
        COMP    CREG, N         108)   + 06  3  114
        BC      LE, AGAIN       109)   + 07  2  104
        DIV     BREG, TWO       110)   + 08  2  118
        MOVEM   BREG, RESULT    111)   + 05  2  115
        PRINT   RESULT          112)   + 10  0  115
        STOP                    113)   + 00  0  000
N       DS      1               114)
RESULT  DS      1               115)
ONE     DC      ‘1’             116)   + 00  0  001
TERM    DS      1               117)
TWO     DC      ‘2’             118)   + 00  0  001
        END
```

- Design Specifications of an assembler:
  - Identify the information necessary to perform a task
  - Design a suitable data structure to record the information
  - Determine the processing necessary to obtain and maintain the information
  - Determine the processing necessary to perform a task

- *The fundamental info requirements arise in the synthesis phase.*

Synthesis Phase

Consider the assembly statement

```
MOVER        BREG, ONE
```

- We must have the following information to synthesize the machine instruction
  - Address of the memory word with which ONE is associated
    - » It depends on source program
    - » So, it must be made available by analysis phase.
  - Machine operation code corresponding to the mnemonic MOVER
    - Does not depend on source program, but depend upon assembly language
    - Hence the synthesis phase can determine this information Itself.

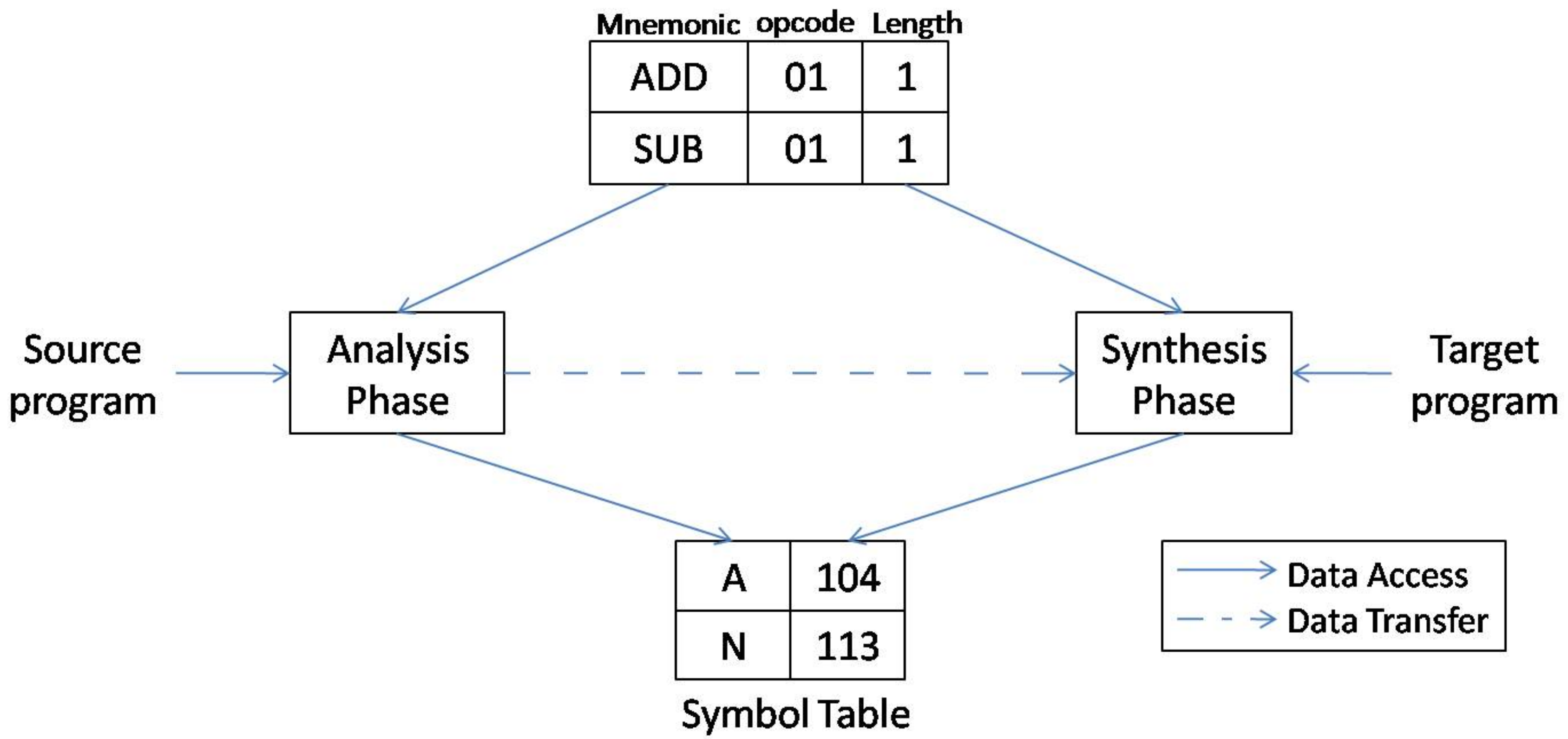
- During synthesis phase, two data structures are used:-
  - Symbol Table
    - symbol table's each entry has two fields:-
      - **name and address.**
    - This table is built by analysis phase and used during synthesis.
  - Mnemonics Table
    - An entry in the mnemonics table has two fields:-
      - **mnemonic and opcode.**
    - fixed table and merely accessed by analysis and synthesis phases.
- By using symbol table, synthesis phase obtains the machine address with which name is associated.

- By using Mnemonics table, synthesis phase obtains machine opcode corresponding to a mnemonic.

Analysis phase

- The primary function performed by the analysis phase is the building of the symbol table.
  - For this, it must determine the addresses with which symbolic names used in a program are associated.
  - Some addresses can be determined directly (Eg. Address of first instruction in program) while some other must be inferred. (Eg. In prog. for determining address of N, we must fix address of all program elements preceding it.) This is called **memory allocation**.

- Location Counter
  - Location Counter (LC) is a data structure which use to implement memory allocation
  - The location counter contains the address of the next memory word in the target program.
  - LC is initialized to the constant specified in the START statement.
- To update the contents of LC, analysis phase needs to know the lengths of different instructions.
  - This info. Depends on the assembly language.
  - To include this Mnemonic table can be extended and a new field called as length is used
- The processing involved to maintain the LC is called **LC processing**.



Data Structure of an Assembler

- Tasks performed by Analysis Phases:-
  1. Isolate the label, mnemonic opcode and operand fields of a statement.
  2. If a label is present, enter the pair (symbol,<LC contents>) in a new entry of symbol table.
  3. Check validity of mnemonic opcode by look-up in Mnemonics table.
  4. Perform LC processing i.e. update value contained in LC.

- Tasks performed by Synthesis Phase:-
  1. Obtain the machine opcode corresponding to mnemonics from mnemonics table.
  2. Obtain address of memory operand from symbol table.
  3. Synthesize the machine form of a constant, if any.

Pass Structure of Assemblers

- The pass of a language processor is one complete scan of the source program.
- There are mainly tow assembly schemes:-
  1. Two pass assembly scheme
  2. One pass assembly scheme.

Two Pass Translator / Two Pass Assembler

- can handle forward references easily.
- The LC processing is performed in the first pass and symbols defined in the program are entered into the symbol table in this pass.
- The first pass performs analysis of the source program while the second pass performs the synthesis of the target program.
- The first pass constructs an intermediate representation (IR) of the source program for use by the second pass.
  - This representation consists of two main components
    - data structures e.g. Symbol table
    - a processed form of source program. Also called as Intermediate Code (IC).

Single Pass Translation / Single Pass Assembler

- In a single pass assembler, the LC processing and construction of symbol table proceeds as in two pass assembler.
- The problem of forward references is tackled using a process called back patching.
- Initially, operand field of an instruction containing a forward reference is left blank.
- When the definition of forward referenced symbol in encountered, its address is put into this field which is left blank initially.

- ONE is a forward reference.
- The instruction opcode and address of BREG will be assembled to reside in location 101 and the insertion of second operand’s address at a later stage can be indicated by adding an entry of the Table of Incomplete Instructions.(TII)
  - This entry is a pair ([instruction address], [symbol]).
    - e.g. (101, ONE) in this case.
- By the time, the END statement is processed, the symbol table would contain the addresses of all symbols defined in the source program and TII would contain info. describing forward references.

Design of a Two Pass Assembler

- **PASS 1**:-
  1. Separate the symbol, mnemonic opcode and operand fields.
  2. Build the symbol table.
  3. Perform LC processing.
  4. Construct intermediate representation
- **PASS 2**:-
- **1. synthesize the target program**
  - The Pass 1 performs analysis of the source program and synthesis of the intermediate representation
  - while Pass 2 processes the intermediate representation (IR) to synthesize the target program.

Advanced Assembler Directives

- **<u>(i) ORIGIN</u>:-**
  - The syntax of this directive is

    ORIGIN [address spec]

    where [address spec] is an [operand spec] or [constant].
  - This directive indicates that LC should be set to the address given by [address spec].
  - The ‘ORIGIN’ statement is useful when the target program does not consist of consecutive memory words. The ability to use an [address spec] in the ORIGIN statement provides the ability to perform LC processing in a relative manner rather than absolute manner.

```
 1           START   200
 2           MOVER   AREG, ='5'        200)   +04 1 211
 3           MOVEM   AREG, A           201)   +05 1 217
 4   LOOP    MOVER   AREG, A           202)   +04 1 217
 5           MOVER   CREG, B           203)   +05 3 218
 6           ADD     CREG, ='1'        204)   +01 3 212
 7           ...

12           BC      ANY, NEXT         210)   +07 6 214
13           LTORG
                     ='5'              211)   +00 0 005
                     ='1'              212)   +00 0 001
14           ...
15   NEXT    SUB     AREG, ='1'        214)   +02 1 219
16           BC      LT, BACK          215)   +07 1 202
17   LAST    STOP                      216)   +00 0 000
18           ORIGIN  LOOP+2
19           MULT    CREG, B           204)   +03 3 218
20           ORIGIN  LAST+1
21   A       DS      1                 217)
22   BACK    EQU     LOOP
23   B       DS      1                 218)
24           END
25                   ='1'              219)   +00 0 001
```

- **(ii) EQU:-**
  - The syntax of this directive is

    [symbol]   EQU   [address spec]

  where [address spec] is an [operand spec] or [constant].
  - The EQU statement defines the symbol to represent [address spec].
  - BACK EQU LOOP

- ***LTORG:-***
  - *The LTORG statement permits a programmer to specify where literals should be placed.*
  - *By default, assembler places the literals after the END statement.*
  - *At every LTORG statement, the assembler allocates memory to the literals of a literal pool.*
    - *This pool contains all the literals used in the program.*

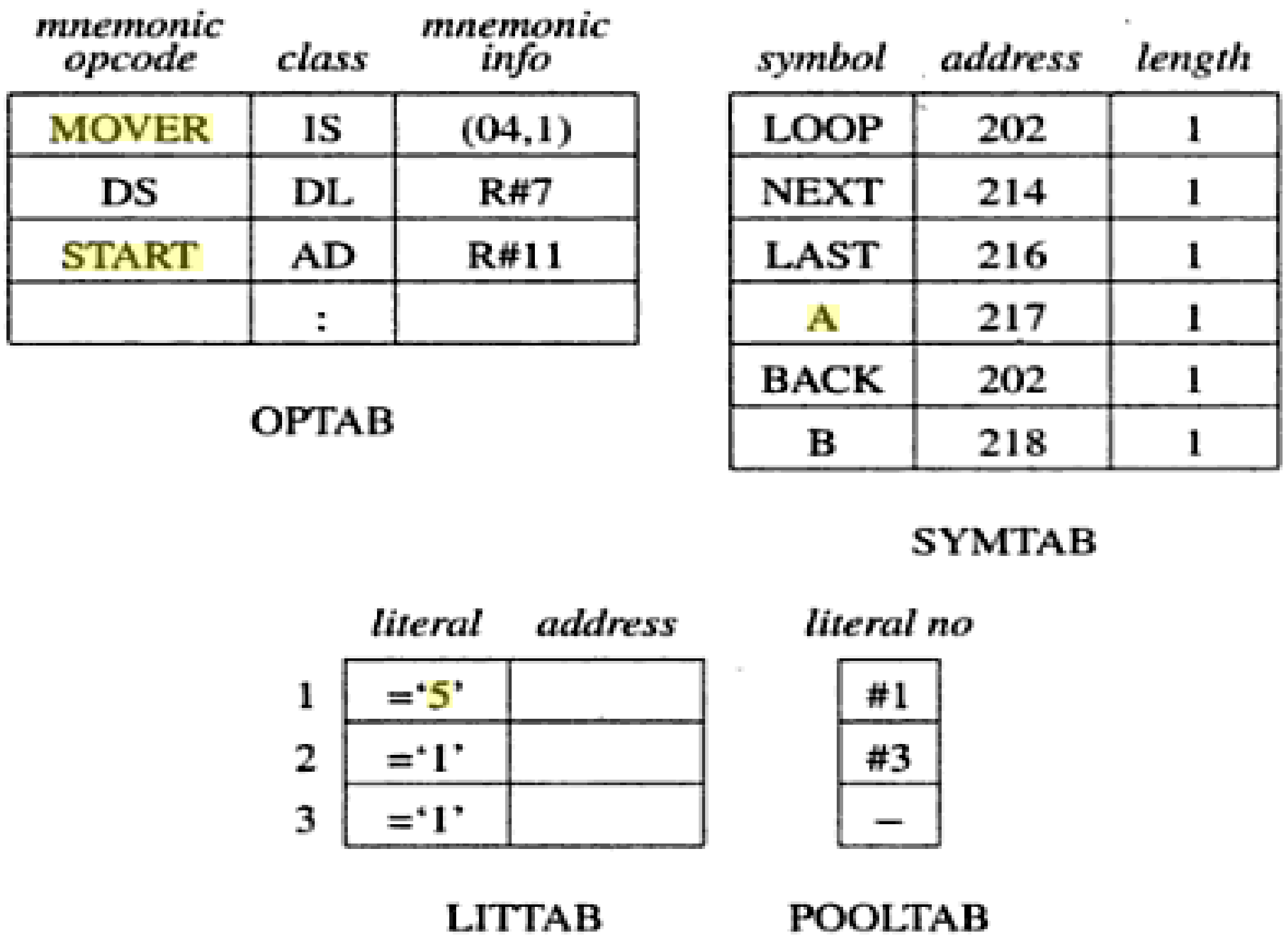
Pass 1 of the Assembler

- Pass 1 uses the following data structures:
  - **OPTAB: -** A table of mnemonic opcodes and related info.
  - **SYMTAB: -** Symbol Table. (contains the fields address and length)
  - **LITTAB: -** A table of literals used in the program.(contains the fields literal and address.)

- **OPTAB: Static table:** The content will never change
  - contains the fields mnemonic opcode, class and mnemonic information.
  - The ‘class’ field indicates whether the opcode corresponds to
    - an imperative statement (IS),
    - a declaration statement (DL) or
    - an assembler directive (AD)
  - If an imperative statement is present,
    - then the mnemonic info. field contains the pair (machine opcode, instruction length)
  - else it contains the pair id of a routine to handle the declaration or directive statement.

  - 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.
- **SYMTAB**
  - Include the label name and value (address) for each label in the source program
  - Dynamic table (I.e., symbols may be inserted, deleted, or searched in the table)

- The LITTAB is used to collect all literals used in the program. The awareness of different literals pools in maintained by an auxiliary table POOLTAB. This table contains the literal no. of starting literal of each literal pool.



mnemonic opcode	*class*	*mnemonic info*
MOVER	IS	(04,1)
DS	DL	R#7
START	AD	R#11
	:	

OPTAB

symbol	*address*	*length*
LOOP	202	1
NEXT	214	1
LAST	216	1
A	217	1
BACK	202	1
B	218	1

SYMTAB

	literal	*address*
1	='5'	
2	='1'	
3	='1'	

LITTAB

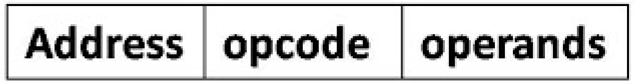
literal no
#1
#3
–

POOLTAB

Data Structure of Assembler pass 1

Intermediate Code forms

- The intermediate code consists of a set of IC units, each IC unit consisting of following three fields: -
  1. Address
  2. Representation of mnemonic op code
  3. Representation of operands

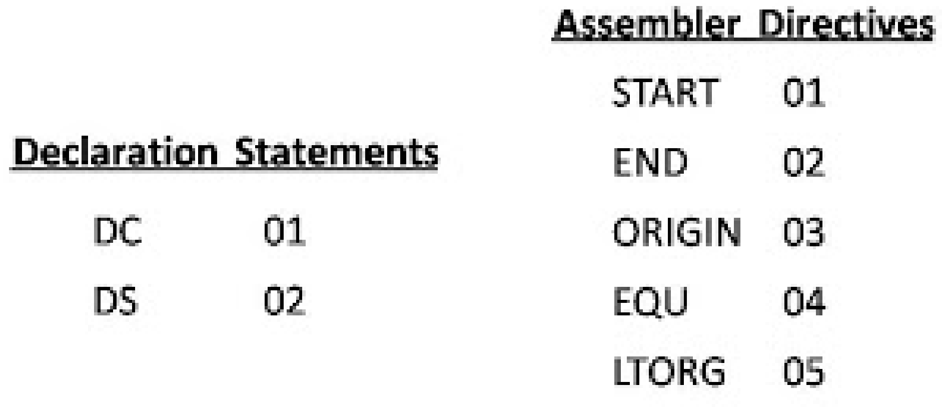


Address	opcode	operands

IC unit

- There are generally two criteria for choice of intermediate code (IC)
  - processing efficiency
  - memory economy.
- Arise of some variants forms of intermediate code mainly operand and address fields is due to trade off between processing efficiency and memory economy.

- The mnemonic field contains a pair of the form (statement class, code)
- Here, statement class can be one of the imperative (IS) (DL) (AD).
  - For (IS), code is the instruction opcode in machine language.
  - For DL and AD, code in an ordinal number within class.



Declaration Statements

DC	01
DS	02

Assembler Directives

START	01
END	02
ORIGIN	03
EQU	04
LTORG	05

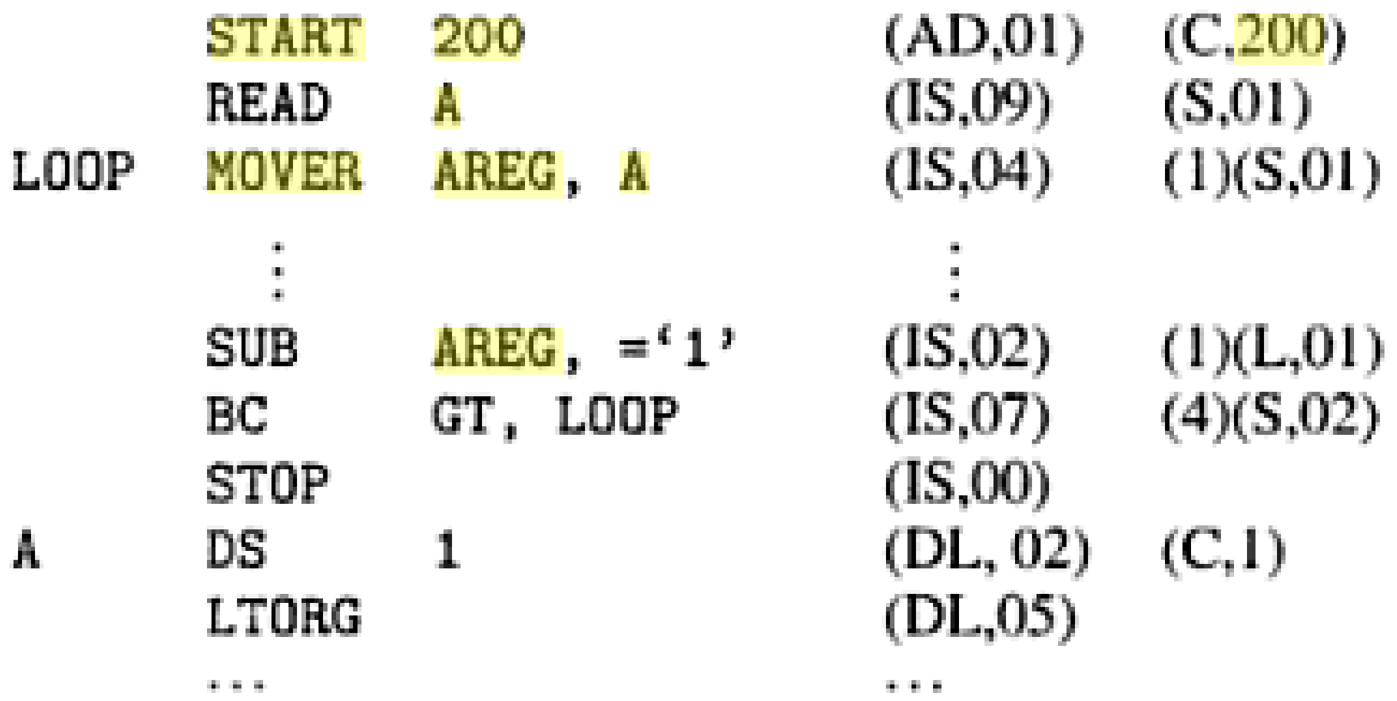
Intermediate Code for Imperative Statement

Variant I:

- The first operand is represented by a single digit number which is a code for register (i.e. 1-4 for AREG – DREG) or condition code itself (1-6 for LT-ANY)
- The second operand, which is memory operand, is represented by a pair of form (operand class, code)

where operand class is one of C, S and L standing for constant, symbol and literal resp.

- For a constant, code field contains internal representation of constant itself.
- For symbol or literal, code field contains the ordinal no. of operand’s entry in SYMTAB or LITTAB.



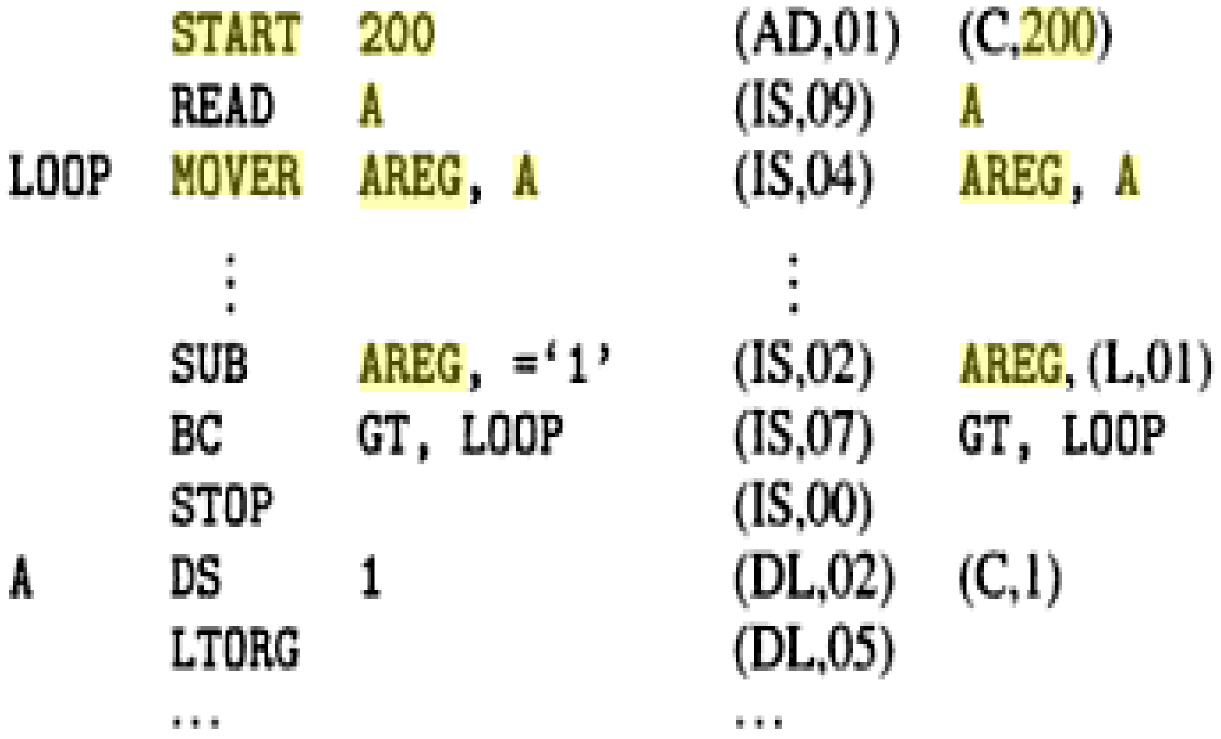
```
        START   200              (AD,01)    (C,200)
        READ    A                (IS,09)    (S,01)
LOOP    MOVER   AREG, A          (IS,04)    (1)(S,01)
          :                        :
        SUB     AREG, ='1'       (IS,02)    (1)(L,01)
        BC      GT, LOOP         (IS,07)    (4)(S,02)
        STOP                     (IS,00)
A       DS      1                (DL, 02)   (C,1)
        LTORG                    (DL,05)
        ...                      ...
```

Intermediate Code- Variant I

Variant II:

- This variant differs from variant 1 in that the operand fields of source statements are replaced by their processed forms.
- For declarative statements and assembler directives, processing of operand fields contain processed forms.
- For imperative statements, the operand field is processed only to identify literal references.

- Variant 2 reduces the work of Pass 1 by transferring burden of operand processing from Pass 1 to pass 2.



```
        START   200              (AD,01)  (C,200)
        READ    A                (IS,09)  A
LOOP    MOVER   AREG, A          (IS,04)  AREG, A
          :                         :
        SUB     AREG, ='1'       (IS,02)  AREG, (L,01)
        BC      GT, LOOP         (IS,07)  GT, LOOP
        STOP                     (IS,00)
A       DS      1                (DL,02)  (C,1)
        LTORG                    (DL,05)
        ...                      ...
```