ASSEMBLERS

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Design Specifications

- 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 the task

Synthesis Phase

- MOVER BREG, ONE
  - Address of the memory word with which name ONE is associated (depends on source program, so it must be made available by the analysis phase)
  - Machine op codes corresponding to the mnemonic MOVER (not depends on source program, it depends on the assembly language)
- Use two data structures:
  - Symbol Table (name, address) – build by analysis phase
  - Mnemonic Table (mnemonic, opcode, length)

Analysis Phase

- The primary function is of building of the symbol table.
- Concept of “Memory Allocation”
- To implement memory allocation a data structure called location counter (LC) is used.
- The LC is always made to contain the address of the next memory word in the target program.
- It is initialized to the constant specified in the START statement.
- To update the contents of LC, analysis phase needs to know lengths of different instructions.

Data structures of the assembler

Mnemonic	Opcode	Length
ADD	01	1
SUB	02	1

Mnemonic Table

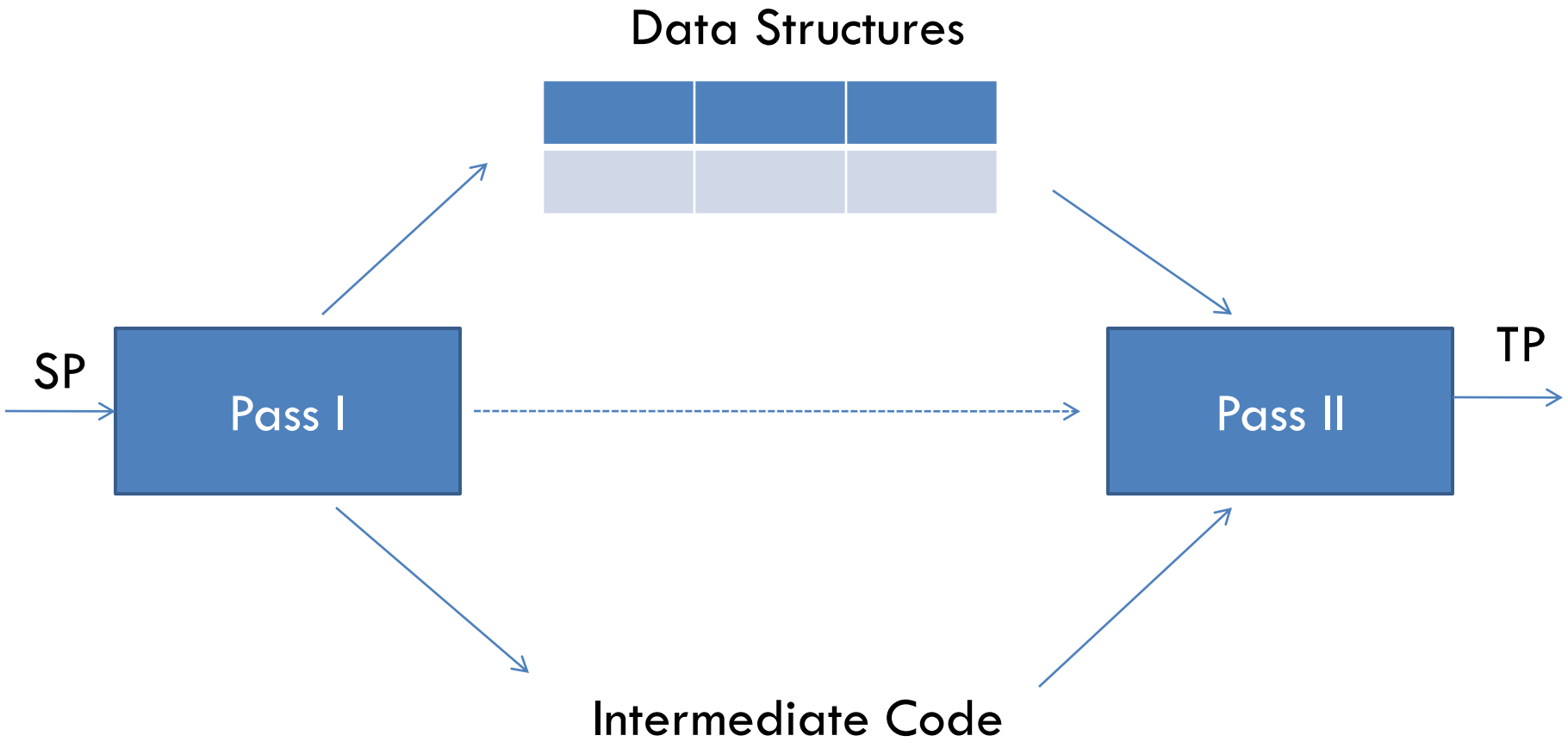
Symbol	Address
AGAIN	104
N	113

Symbol Table

Pass Structure of Assembler

- Two Pass Translation
  - It can handle forward references easily.
  - LC processing is performed in the first pass and symbol defined in the program are entered into the symbol table.
  - The second pass synthesizes the target form using the address information found in the symbol table.
  - In effect, the first pass performs analysis of the source program while the second pass performs synthesis of the target program.

Two pass assembly



Pass Structure of Assembler

- Single Pass Translation
  - LC processing and construction of the symbol table proceeds as in two pass translation.
  - The problem of forward references is tacked using a process called “backpatching”
  - The operand field of an instruction containing a forward reference is left blank initially. The address of the forward referenced symbol is put into this field when its definition is encountered.
  - MOVER BREG, ONE [ONE is forward reference]
  - Table of Incomplete Instruction (TII)

Advanced Assembler Directives

- ORIGIN
  - 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>.
  - It is useful when the target program does not consist of consecutive memory words.

Advanced Assembler Directives

- EQU
  - <symbol> EQU <address spec>
  - Where <address spec> is an <operand spec> or <constant>
  - It defines the symbol to represent <address spec>.
- LTORG
  - It permits a programmer to specify where literals should be placed.
  - By default, assembler places it after the END statement

Literals

```
ADD   AREG, ='5'     ⇒          ADD     AREG, FIVE
                                -- --
                        FIVE    DC      '5'
```

(a) (b)

- At every LTORG statement, as also at the END statement, the assembler allocates memory to the literals of a literal pool. The pool contains all literals used in the program since the start of the program or since the last LTORG statement.

```
 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
```

Design of a Two Pass Assembler

- Tasks performed by the passes of a two pass assembler are as follows:
- Pass I
  - Separate the symbol, mnemonic opcode, operand fields
  - Build the symbol table
  - Perform LC processing
  - Construct intermediate representation
- Pass II
  - Synthesis the target program

Pass I of an assembler

- It uses the following data structures:
  - OPTAB – A table of mnemonic opcodes and related information
  - SYMTAB – Symbol Table
  - LITTAB – A table of literals used in the program

Data Structures of assembler Pass I

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

Algorithm- Assembler First Pass

1. *loc_cntr* := 0; (default value)
   pooltab_ptr := 1; POOLTAB [1] := 1;
   littab_ptr := 1;
2. While next statement is not an END statement
   (a) If label is present then
   this_label := symbol in label field;
   Enter (*this_label*, *loc_cntr*) in SYMTAB.
   (b) If an LTORG statement then
   (i) Process literals LITTAB [POOLTAB [*pooltab_ptr*]] ... LITTAB [*littab_ptr*−1] to allocate memory and put the address in the *address* field. Update *loc_cntr* accordingly.
   (ii) *pooltab_ptr* := *pooltab_ptr* + 1;
   (iii) POOLTAB [*pooltab_ptr*] := *littab_ptr*;
   (c) If a START or ORIGIN statement then
   loc_cntr := value specified in operand field;
   (d) If an EQU statement then
   (i) *this_addr* := value of <*address spec*>;
   (ii) Correct the symtab entry for *this_label* to (*this_label*, *this_addr*).

(e) If a declaration statement then

(i) *code* := code of the declaration statement;

(ii) *size* := size of memory area required by DC/DS.

(iii) *loc_cntr* := *loc_cntr* + *size*;

(iv) Generate IC '(DL, *code*) ⋯'.

(f) If an imperative statement then

(i) *code* := machine opcode from OPTAB;

(ii) *loc_cntr* := *loc_cntr* + instruction length from OPTAB;

(iii) If operand is a literal then

this_literal := literal in operand field;

LITTAB [*littab_ptr*] := *this_literal*;

littab_ptr := *littab_ptr* + 1;

else (i.e. operand is a symbol)

this_entry := SYMTAB entry number of operand;

Generate IC '(IS, *code*)(S, *this_entry*)';

3. (Processing of END statement)

(a) Perform step 2(b).

(b) Generate IC '(AD,02)'.

(c) Go to Pass II.

Intermediate code for Imperative Statements

We consider two variants of intermediate code which differ in the information contained in their operand fields. For simplicity, the address field is assumed to contain identical information in both variants.

Variant I and Variant II

Variant I

```
        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)
        ...                     ...
```

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

(*operand class, code*)

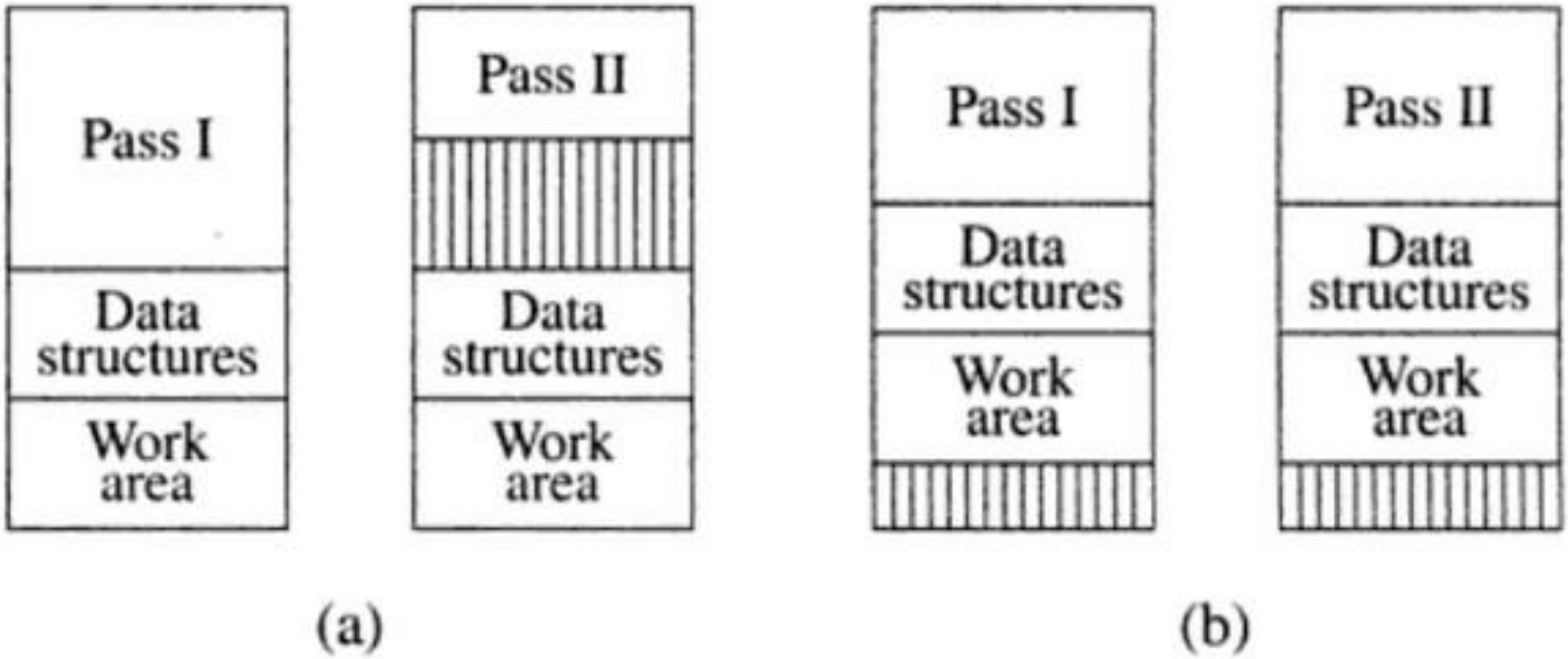
where *operand class* is one of C, S and L standing for constant, symbol and literal, respectively (see Fig. 4.12). For a constant, the *code* field contains the internal representation of the constant itself. For example, the operand descriptor for the statement START 200 is (C, 200). For a symbol or literal, the *code* field contains the ordinal number of the operand's entry in SYMTAB or LITTAB. Thus entries for a symbol XYZ and a literal ='25' would be of the form (S, 17) and (L, 35) respectively.

Variant II

This variant differs from variant I of the intermediate code in that the operand fields of the source statements are selectively replaced by their processed forms (see Fig. 4.13). For declarative statements and assembler directives, processing of the operand fields is essential to support LC processing. Hence these fields contain the processed forms. For imperative statements, the operand field is processed only to identify literal references. Literals are entered in LITTAB, and are represented as (L, *m*) in IC. Symbolic references in the source statement are not processed at all during Pass I.

```
        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)
```

Comparison of the variants



Memory requirements using (a) variant I, (b) variant II

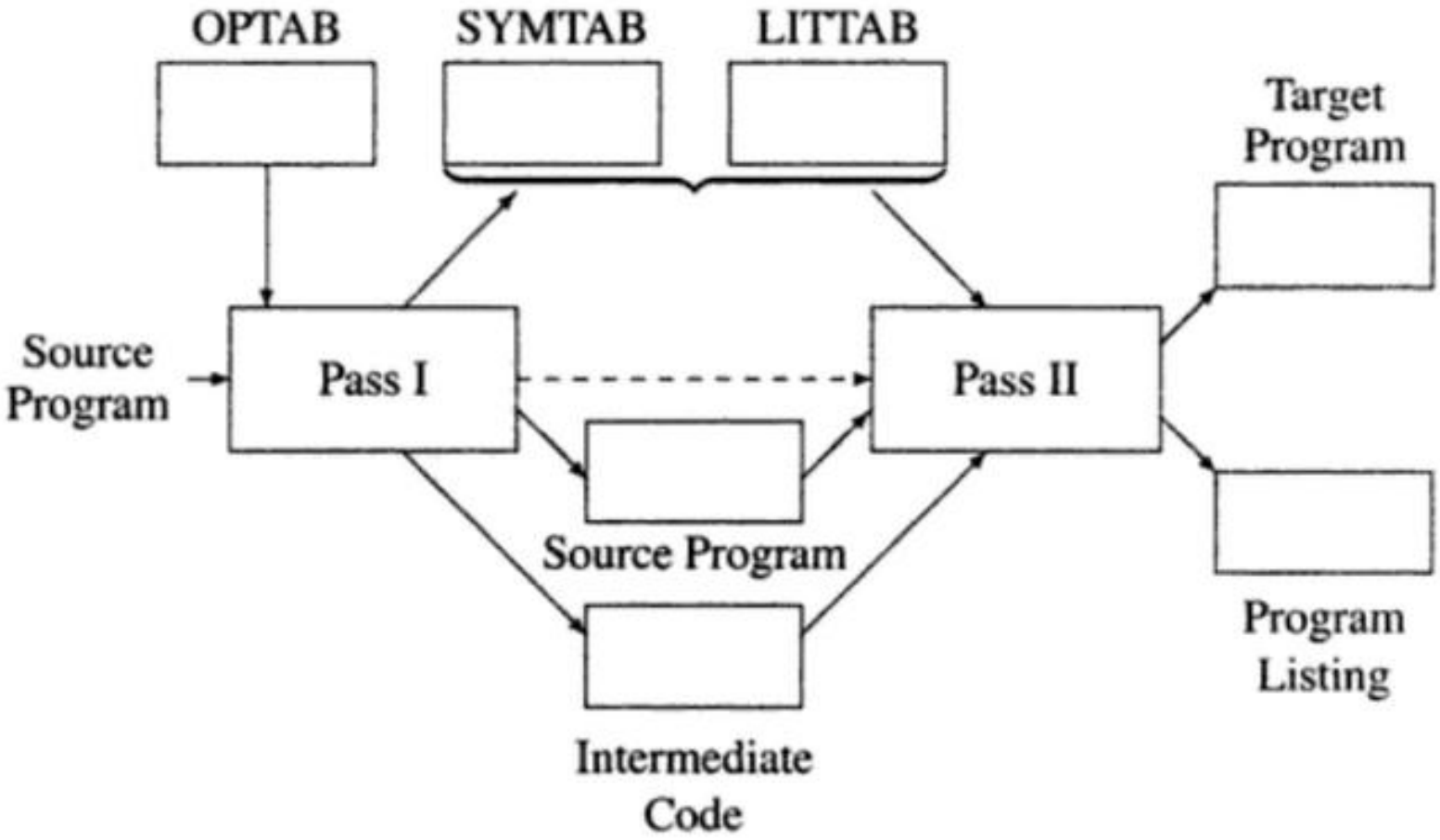
Comparison of the variants

Variant I of the intermediate code appears to require extra work in Pass I since operand fields are completely processed. However, this processing considerably simplifies the tasks of Pass II—a look at the IC of Fig. 4.12 confirms this. The functions of Pass II are quite trivial. To process the operand field of a declaration statement, we only need to refer to the appropriate table and obtain the operand address. Most declarations do not require any processing, e.g. `DC`, `DS` (see Section 4.4.5), and `START` statements, while some, e.g. `LTORG`, require marginal processing. The IC is quite compact—it can be as compact as the target code itself if each operand reference like (S, *n*) can be represented in the same number of bits as an operand address in a machine instruction.

Comparison of the variants

Variant II reduces the work of Pass I by transferring the burden of operand processing from Pass I to Pass II of the assembler. The IC is less compact since the memory operand of a typical imperative statement is in the source form itself. On the other hand, by making Pass II to perform more work, the functions and memory requirements of the two passes get better balanced. Figure 4.14 illustrates the advantages of this aspect. Part (a) of Fig. 4.14 shows memory utilization by an assembler using variant I of IC. Some data structures, viz. symbol table, are passed in the memory while IC is presumably written in a file. Since Pass I performs much more processing than Pass II, its code occupies more memory than the code of Pass II. Part

Pass II of an assembler



Pass II of an assembler

- Tables

For efficiency reasons SYMTAB must remain in main memory throughout Passes I and II of the assembler. LITTAB is not accessed as frequently as SYMTAB, however it may be accessed sufficiently frequently to justify its presence in the memory. If memory is at a premium, it is possible to hold only part of LITTAB in the memory because only the literals of the current pool need to be accessible at any time. For obvious reasons, no such partitioning is feasible for SYMTAB. OPTAB should be in memory during Pass I.

Pass II of an assembler

- Source Program and Intermediate Code

The source program would be read by Pass I on a statement by statement basis. After processing, a source statement can be written into a file for subsequent use in Pass II. The IC generated for it would also be written into another file. The target code and the program listings can be written out as separate files by Pass II. Since all these files are sequential in nature, it is beneficial to use appropriate blocking and buffering of records.

MACRO AND MACRO PROCESSORS

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Introduction

- Macro are used to provide a program generation facility through macro expansion.
- Many programming language provide built in facilities for writing macros. E.g. Ada,C and C++.
- Higher version of processor family also provide such facility.

Cont.

- “A macro is a unit of specification for program generation through expansion.
- Macro consist of name, a set of formal parameters and a body of code.
- “The use of macro name with a set of actual parameters is replaced by some code generated from its body, this is called **macro expansion**.”

Cont.

- Two kind of expansion
  - Lexical expansion:
    - Lexical expansion implies replacement of character string by another character string during program generation.
    - Lexical expansion is typically employed to replace occurrences of formal parameter by corresponding actual parameters.
  - Semantic Expansion:
    - Semantic expansion implies generation of instructions tailored to the requirements of a specific usage
    - Example: generation of type specific instruction for manipulation of byte and word operands.

- Example: the following sequence of instruction is used to increment the value in a memory word by a constant:
  - Move the value from the memory word into a machine register.
  - Increment the value in the machine register.
  - Move the new value into the memory word.
- Using lexical expansion the macro call INCR A,B,AREG can lead to the generation of a MOVE-ADD-MOVE instruction sequence to increment A by the value B using AREG.

Example

- Macro
- INCR &MEM_VAL, &INCR_VAL, &REG
- MOVER &REG, &MEM_VAL
- ADD &REG,&INCR_VAL
- MOVEM &REG, &MEM_VAL
- MEND

Macro definition and call

- Macro definition:
  - A macro definition is enclosed between a macro header statement and macro end statement.
  - Macro definition are typically located at the start of program .
  - Macro definition consist of
    - A macro prototype statement
    - One or more model statement
    - Macro preprocessor statement

Cont.

- A macro prototype statement
  - The macro prototype statement declares the name of a macro and the names and kinds of its parameters.
  - <macro name> [<formal parameter spec>, …]
  - Where name appears in the mnemonic field of assembly statement and <formal parameter spec> is of the form &<parameter name>[<parameter kind>]
- Model statement
  - A model statement is a statement from which an assembly language statement may be generated during macro expansion.
- Macro preprocessor statement
  - A preprocessor statement is used to perform auxiliary functions during macro expansion.

Macro call

- A macro is called by writing the macro name in the mnemonic field of an assembly statement.
- <macro name> [<actual parameter spec>,…]
- Where an actual parameter typically an operand specification in an assembly language statement.

Macro Expansion

- A macro call leads to macro expansion, during macro expansion, the macro call statement is replaced by a sequence of assembly statements.
- '+' is used to differentiate between the original statement of program and macro statement.

Macro Expansion

- Two key notions concerning macro expansion are:
  - Expansion time control flow:
    - This determines the order in which model statements are visited during macro expansion.
  - Lexical substitution:
    - Lexical substitution is used to generate an assembly statement from a model statement.

Flow of control during expansion

- Flow of control during expansion
  - The default flow of control during macro expansion is sequential. its start with statement following the macro prototype statement and ending with the statement preceding the MEND statement.
  - A preprocessor statement can alter the flow of control during expansion such that some model statements are never visited during expansion is called **conditional expansion.**
  - Same statement are repeatedly visited during expansion is called **loops expansion.**

Algorithm – Micro Expansion

- Macro expansion is implemented using a macro expansion counter (MEC).
- Algorithm: (Outline of macro expansion)
  - *MEC=statement number of first statement following the prototype statement;*
  - *While statement pointed by MEC is not a MEND statement*
    - *(a) if a model statement then*
      - *(i) Expand the statement*
      - *(ii) MEC=MEC+1;*
    - *(b) Else (i.e. a preprocessor statement)*
      - *(i) MEC= new value specified in the statement;*
  - *Exit from macro expansion.*

Lexical Substitution

- Lexical Substitution:
  - Model statement consists of 3 type of strings
    - An ordinary string, which stands for itself.
    - The name of a formal parameter which is preceded by the character '&'.
    - The name of preprocessor variable, which is also preceded by the character '&'.
  - During lexical expansion, string of type 1 are retained without substitution.
  - String type 2 and 3 are replaced by the corresponding actual parameter values.
  - The value of formal parameter depends on the kind of parameter.

Types of Parameters

- Positional parameters
- Keyword parameters
- Default specification of parameter
- Macro with mixed parameter lists
- Other uses of parameters

Positional parameters

- Positional parameters
  - A positional formal parameter is written as &<parameter name>. The <actual parameter spec> in call on a macro using positional parameters is simply an <ordinary string>.
  - Step-1 find the ordinal position of XYZ in the list of formal parameters in the macro prototype statement.
  - Step-2 find the actual parameter specification occupying the same ordinal position in the list of actual parameters in macro call statement.

Positional parameters – Example

- INCR A, B, AREG
- The rule of positional association values of the formal parameters are:
- Formal parameter value

  MEM_VAL A

  INCR_VAL B

  REG AREG

  Lexical expansion of model statement now leads to the code

  + MOVER AREG, A

  + ADD AREG, B

  + MOVEM AREG, A

Keyword parameters

- Keyword parameters
  - <parameter name > is an ordinary string and <parameter kind> is the string '=' in syntax rule.
  - The <actual parameter spec> is written as <formal parameter name>=<ordinary string>.
  - The keyword association rules:
    - Step-1 find the actual parameter specification which has the form XYZ=<ordinary string>
    - Step-2 Let <ordinary string> in the specification be the string ABC. Then the value of formal parameter XYZ is ABC.

Keyword parameters

- Example :

```
INCR_M      MEM_VAL=A, INCR_VAL=B, REG=AREG
...
INCR_M      INCR_VAL=B, REG=AREG, MEM_VAL=A
```

```
MACRO
INCR_M      &MEM_VAL=, &INCR_VAL=, &REG=
MOVER       &REG, &MEM_VAL
ADD         &REG, &INCR_VAL
MOVEM       &REG, &MEM_VAL
MEND
```

Default specification of parameters

- Default specification of parameters
  - A default is a standard assumption in the absence of an explicit specification by programmer.
  - Default specification of parameters is useful in situations where a parameter has the same value in most calls.
  - When desired value is different from the default value, the desired value can be specified explicitly in a macro call.

Default specification of parameters

- Example:

  Call the macro

  ```
  INCR_D      MEM_VAL=A, INCR_VAL=B
  INCR_D      INCR_VAL=B, MEM_VAL=A
  INCR_D      INCR_VAL=B, MEM_VAL=A, REG=BREG
  ```

  MARCO DIFINITION

  ```
  MACRO
  INCR_D      &MEM_VAL=,&INCR_VAL=,&REG=AREG
  MOVER       &REG, &MEM_VAL
  ADD         &REG, &INC_VAL
  MOVEM       &REG, &MEM_VAL
  MEND
  ```

Macro with mixed parameter lists

- Macro with mixed parameter lists
  - A macro may be defined to use both positional and keyword parameters.
  - All positional parameters must precede all keyword parameters.
  - Example: SUMUP A,B,G=20,H=X
  - Where A,B are positional parameters while G,H are keyword parameters.

Other uses of parameters

- Other uses of parameters
  - The model statements have used formal parameters only in operand fields.
  - Formal parameter can also appear in the label and opcode fields of model statements.

Other uses of parameters-Example

```
        MACRO
        CALC        &X, &Y, &OP= MULT, &LAB=

&LAB    MOVER       AREG, &X
        &OP         AREG, &Y
        MOVEM       AREG, &X
        MEND
```

Expansion of the call `CALC A, B, LAB=LOOP` leads to the following code:

```
+ LOOP  MOVER       AREG, A
+       MULT        AREG, B
+       MOVEM       AREG, A
```

Nested Macro Call

- A model statement in macro may constitute a call on another macro, such calls are known as nested macro calls.
- The macro containing the nested call is called outer macro.
- The called macro called inner macro.
- Expansion of nested macro calls follows the last-in-first-out(LIFO) rule.

Nested Macro Call - Example

```
MACRO
COMPUTE     &FIRST, &SECOND
MOVEM       BREG, TMP
INCR_D      &FIRST, &SECOND, REG=BREG
MOVER       BREG, TMP
MEND
```

```
COMPUTE  X,Y  + MOVEM   BREG,TMP [1]
              + INCR_D  X,Y
                          + MOVER  BREG,X [2]
                          + ADD    BREG,Y [3]
                          + MOVEM  BREG,X [4]
              + MOVER   BREG,TMP [5]
```

```
+       MOVEM       BREG, TMP
+       MOVER       BREG, X
+       ADD         BREG, Y
+       MOVEM       BREG, X
+       MOVER       BREG, TMP
```

Advanced Macro Facilities

- Advance macro facilities are aimed at supporting semantic expansion.
  - Facilities for alteration of flow of control during expansion.
  - Expansion time variables
  - Attributes of parameters.

Alteration of flow of control during expansion

- Alteration of flow of control during expansion:
  - Expansion time sequencing symbols (SS).
  - Expansion time statements AIF, AGO and ANOP.

  Sequencing symbol has syntax

  .<ordinary string>

  A SS is defined by putting it in the label field of statement in the macro body.

  It is used as operand in an AIF, AGO statement for expansion control transfer.

Cont.

- An AIF statement has syntax

  AIF (<expression>) <sequencing symbol>

- Where, <expression> is relational expression involving ordinary strings, formal parameters and their attributes, and expansion time variables.
- If the relational expression evaluates to true, expansion time control is transferred to the statement containing <sequencing symbol> in its label field.

Cont.

- An AGO statement the syntax

  AGO <sequencing symbol>

- Unconditionally transfer expansion time control to the statement containing <sequencing symbol> in its label field.
- An ANOP statement is written as

  <sequencing symbol> ANOP

- Simply has the effect of defining the sequencing symbol.

Expansion Time Variable (EV's)

- Expansion Time Variable
  - Expansion time variable are variables which can only be used during the expansion of macro calls.
  - Local EV is created for use only during a particular macro call.
  - Global EV exists across all macro calls situated in program and can be used in any macro which has a declaration for it.

LCL <EV specification>[,<EV specification>…]

GBL <EV specification>[,<EV specification>…]

Cont.

- <EV specification>has syntax &<EV name>, where EV name is ordinary string.
- Initialize EV by preprocessor statement SET.

  <EV Specification> SET <SET-expression>

EV's Example

```
        MACRO
        CONSTANTS
        LCL     &A
&A      SET     1
        DB      &A
&A      SET     &A+1
        DB      &A
        MEND
```

A call on macro CONSTANTS is expanded as follows: The local EV A is created. The first SET statement assigns the value '1' to it. The first DB statement thus declares a byte constant '1'. The second SET statement assigns the value '2' to A and the second DB statement declares a constant '2'.

Attributes of formal parameters

- **Attributes of formal parameters:**

  <attribute name>' <formal parameter spec>

Represents information about the value of the formal parameter about corresponding actual parameter.

The type, length and size attributes have the name T,L and S.

Example

```
                MACRO
                DCL_CONST    &A
                AIF          (L'&A EQ 1) .NEXT
                - -
.NEXT           - -
                - -
                MEND
```

Here expansion time control is transferred to the statement having .NEXT in its label field only if the actual parameter corresponding to the formal parameter A has the length of '1'.

Cont.

- **Conditional expansion:**
  - Conditional expansion helps in generating assembly code specifically suited to the parameters in macro call.
  - A model statement is visited only under specific conditions during the expansion of a macro.
  - AIF and AGO statement used for this purpose.

Cont.

- Example: evaluate A-B+C in AREG.

```
                MACRO
                EVAL        &X, &Y, &Z
                AIF         (&Y EQ &X)          .ONLY
                MOVER       AREG, &X
                SUB         AREG, &Y
                ADD         AREG, &Z
                AGO         .OVER
.ONLY MOVER         AREG, &Z
.OVER MEND
```

Cont.

- Expansion time loop
  - To generate many similar statements during the expansion of a macro.
  - This can be achieved by similar model statements in the macro.
  - Example:

```
MACRO
CLEAR       &A
MOVER       AREG, ='0'
MOVEM       AREG, &A
MOVEM       AREG, &A+1
MOVEM       AREG, &A+2
MEND
```

Cont.

- Expansion time loops can be written using expansion time variables and expansion time control transfer statement AIF and AGO.

Example:

```
                MACRO
                CLEAR           &X, &N
                LCL             &M
&M              SET             0
                MOVER AREG,='0'
.MOVE  MOVEM            AREG, &X+&M
&M              SET             &M+1
                AIF             (&M NE N)       .MORE
                MEND
```

Cont.

- Comparison with execution time loops:
  - Most expansion time loops can be replaced by execution time loops.
  - An execution time loop leads to more compact assembly programs.
  - In execution time loop programs would execute slower than programs containing expansion time loops.

Cont.

- Other facilities for expansion time loops:
  - REPT statement
    - Syntax: **REPT <expression>**
    - <expression> should evaluate to a numerical value during macro expansion.
    - The statements between REPT and an ENDM statement would be processed for expansion <expression> number of times.

Cont.

- Example

```
        MACRO
        CONST10
        LCL     &M
&M      SET     1
        REPT    10
        DC      '&M'
&M      SETA    &M+1
        ENDM
        MEND
```

Cont.

- IRP statement

  IRP <formal parameter>, <argument-list>

- Formal parameter mentioned in the statement takes successive values from the argument list.
- The statements between the IRP and ENDM statements are expanded once.

Cont.

- Example:

```
MACRO
CONSTS    &M, &N, &Z
IRP       &Z, &M=7, &N
DC        '&Z'
ENDM
MEND
```

A MACRO call CONSTS 4, 10 leads to declaration of 3 constants with the values 4,7 and 10.

Cont.

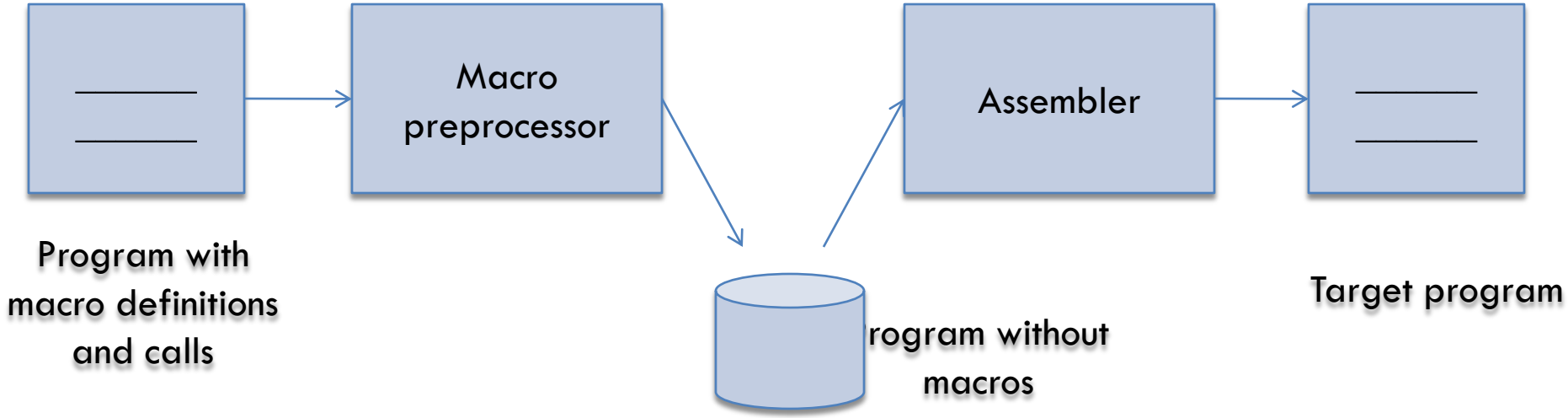
- Semantic Expansion:
  - Semantic expansion is the generation of instructions tailored to the requirements of a specific usage.

Example:

```
            MACRO
            CREATE_CONST    &X, &Y
            AIF             (T'&X  EQ  B)   .BYTE
&Y          DW              25
            AGO             .OVER
.BYTE       ANOP
&Y          DB              25
.OVER       MEND
```

DESIGN OF A MACRO PREPROCESSOR

- The macro preprocessor accepts an assembly program containing definitions and calls and translates it into an assembly program which does not contain any macro definition or call.



Cont.

- Design overview
  - Listing all tasks involved in macro expansion
    - Identify macro calls in the program.
    - Determine the values of formal parameters.
    - Maintain the values of expansion time variables declared in a macro.
    - Organize expansion time control flow.
    - Determine the values of sequencing symbols.
    - Perform expansion of a model statement.

Cont.

- The following 4 step procedure is followed to arrive at a design specification for each task:
  - Identify the information necessary to perform a task.
  - Design a suitable data structure to record the information.
  - Determine the processing necessary to obtain the information.
  - Determine the processing necessary to perform the task.

Cont.

- Identify macro calls:
  - A table called the macro name table (MNT) is designed to hold the name of all macro defined in program.

- Determine values of formal parameters
  - A table called actual parameter table (APT) is designed to hold the values of formal parameters during the expansion of a macro call.
  - It contains (<formal parameter name>,<value>)
  - A table called parameter default table(PDT) is used for each macro.
  - Accessible from the MNT entry of macro.
  - It contain pairs of the form (<formal parameter name>,<default value>).
  - If macro call statement does not specify a value for some parameter then its default value would be copied from PDT to APT.

Cont.

- Maintain expansion time variables:
  - An expansion time variables table (EVT) is maintained for this purpose.
  - Table contain pairs of the form
  - (<EV name>,<value>)
  - It accessed when a preprocessor statement or model statement under expansion refers to an EV.

Cont.

- Organize expansion time control flow
  - The body of macro contained set of model statements and preprocessor statement in it, is stored in a table called the macro definition table (MDT) for use during macro expansion.
  - The flow of control during macro expansion determines when a model statement is to be visited for expansion.

Cont.

- Determine values of sequencing symbols:
  - A sequencing symbol table (SST) is maintained to hold this information
  - Table contains pairs of the form
  - (<sequencing symbol name>,<MDT entry#>)
  - Where <MDT entry#> is the number of the MDT entry which contains the model statement defining the sequencing symbol.

Cont.

- Perform expansion of a model statement
  - Task are as follow
    - MEC points to the MDT entry containing the model statement.
    - Values of formal parameters and EV's are available in APT and EVT, respectively
    - The model statement defining a sequencing symbol can be identified from SST.
  - Expansion of a model statement is achieved by performing a lexical substitution for the parameters and EV's used in the model statement.

Data structures

- To obtain a detailed design of the data structure it is necessary to apply the practical criteria of processing efficiency and memory requirements.
- The table APT,PDT and EVT contain pairs which are searched using the first component of the pairs as a key- the formal parameter name is used as the key to obtain its value from APT.

Cont.

- This search can be eliminated if the position of an entity within a table is known when its value is accessed.
- The value of formal parameter ABC is needed while expanding a model statement using it

  MOVER AREG, &ABC
- Let the pair (ABC,5) occupy entry #5 in APT. the search in APT can be avoided if the model statement appears as

  MOVER AREG, (P,5)
- In the MDT, where (P,5) stand for the word 'parameter #5'.

Cont.

- The first component of the pairs stored in APT is no longer used during macro expansion e.g. the information (P,5) appearing in model statement is sufficient to access the value of formal parameter ABC.
- APT containing (<formal parameter name>,<value>) pairs is replaced by another table called APTAB which only contains <value>'s.
- Ordinal number are assigned to all parameters of macro, a table named ***parameter name table*** (PNTAB) is used for this purpose.
- Parameter name are entered in PNTAB in same order in which they appear in the prototype statement.

Cont.

- The information (<formal parameter name>,<value>) in APT has been split into two tables

PNTAB- which contains formal parameter names

APTAB- which contains formal parameter values

PNTAB is used while processing a macro definition while APTAB is used during macro expansion.

Cont.

- Similar analysis leads to splitting of EVT into EVNTAB and EVTAB and SST into SSNTAB and SSTAB.
- EV name are entered in EVNTAB while processing EV declarations.
- SS name are entered in SSNTAB while processing an SS reference or definition, whichever occur earlier.

Cont.

- The positional parameter of macro appear before keyword parameters in the prototype statement.
- If macro have p positional parameter and k keyword parameters, then keyword parameters have the ordinal number p+1, p+2 …P+k
- Due to this numbering redundancies appear in PDT.
- Entry only needs to exist for parameter number p+1, P+2 …P+k.
- So, replace parameter default table(PDT) by a keyword parameter default table (KPDTAB), this table have only k entries.

Cont.

- MNT has entries for all macros defined in a program, each entry contains three pointers MDTP,KPDTP and SSTP which are pointers to MDT,KPDTAB and SSNTAB for the macro respectively.

Cont.

- Macro preprocessor data structure can be summarized as follows:
  - PNTAB and KPDTAB are constructed by processing the prototype statement.
  - Entries are added to EVNTAB and SSNTAB as EV declarations and SS definitions/references are encountered.
  - MDT entries are constructed while processing model statements and preprocessor statements in macro body.
  - SSTAB entries, when the definition of sequencing symbol in encountered.
  - APTAB is constructed while processing a macro.
  - EVTAB is constructed at the start of expansion of macro.

Tables of the macro preprocessor

Table	Fields in each entry
Macro name Table(MNT)	Macro name, Number of positional parameter(#PP), Number of keyword parameter(#KP), Number of expansion time variables(#EV), MDT pointer (MDTP). KPDTAB pointer (KPDTP). SSTAB pointer (SSTP)
Parameter Name Table(PNTAB)	Parameter name
EV Name Table (EVNTAB)	EV name
SS Name Table (SSNTAB)	SS name
Keyword Parameter Default Table(KPDTAB)	Parameter name, default value
Macro Definition Table(MDT)	Label, Opcode, Operands
Actual Parameter Table(APTAB)	Value
EV Table (EVTAB)	Value
SS Table (SSTAB)	MDT entry #

Cont.

```
        MACRO
        CLEARMEM  &X, &N, &REG=AREG
        LCL       &M
&M      SET       0
        MOVEM     &REG, =‘0’
.MORE   MOVEM     &REG, &X+&M
&M      SET       &M+1
        AIF       (&M NE N) .MORE
        MEND
```

PNTAB

X
N
REG

EVNTAB

M

SSNTAB

MORE

MNT

	#PP	#KP	#EV	MDTP	KPDTP	SSTP
CLEARMEM	2	1	1	25	10	5

KPDTAB 10

REG	AREG

SSTAB 5

28

MDT

25	LCL	(E,1)	
26	(E,1)	SET	0
27		MOVER	(P,3)='0'
28		MOVEM	(P,3),(P,1)+(E,1)
29	(E,1)	SET	(E,1)+1
30		AIF	((E,1) NE (P,2)) (S,1)
31		MEND	

Processing of Macro definitions

- KPDTAB_pointer = 1
- SSTAB_ptr = 1;
- MDT_ptr = 1;
- Algorithm :(Processing of a macro definition)

1. *SSNTAB_ptr=1;*

   PNTAB_ptr=1;

2. *Process the macro prototype statement and form the MNT entry*

   (a) name= macro name

   (b) for each positional parameter

   (i) Enter parameter name in PNTAB[PNTAB_ptr]

   (ii) PNTAB_ptr= PNTAB_ptr+1;

   (iii) #PP=#PP+1;

Cont.

(c) KPDTP=KPDTAB_ptr;

(d) for each keyword parameter

(i) Enter parameter name and default value (if any) , in KPDTAB[KPDTAB_ptr].

(ii) Enter parameter name in PNTAB[PNTAB_ptr].

(iii) KPDTAB_ptr=KPDTAB_ptr+1;

(iv) PNTAB_ptr=PNTAB_ptr+1;

(v) #KP=#KP+1;

(e) MDTP=MDT_ptr;

(f) #EV=0;

(g) SSTP=SSTAB_ptr;

Cont.

3. *While not a MEND statement*

(a) if an LCL statement then

(i) Enter expansion time variable name in EVNTAB.

(ii) #EV=#EV+1;

(b) if a model statement then

(i) if label field contains a sequencing symbol then

if symbol is present in SSNTAB then

q= entry number in SSNTAB;

else

Enter symbol in SSNTAB[SSNTAB_ptr];

q= SSNTAB_ptr;

SSNTAB_ptr=SSNTAB_ptr+1;

SSTAB[SSTP+q-1]=MDT_ptr;

(ii) For a parameter, generate the specification (P,#n)

(iii) For an expansion variable, generate the specification (E,#m);

(iv) Record the IC in MDT[MDT_ptr];

(v) MDT_ptr=MDT_ptr+1;

(c) If Preprocessor statement then

(i) if a SET statement

search each expansion time variable name used in the statement in EVNTAB and generate the spec (E,#m).

(ii) if an AIF or AGO statement then

if sequencing symbol used in the statement is present in SSNTAB then

q=entry number in SSNTAB;

else

enter symbol in SSNTAB[SSNTAB_ptr]

q=SSNTAB_ptr;

SSNTAB_ptr=SSNTAB_ptr+1

replace the symbol by (S, SSTP+q-1)

Cont.

(iii) Record the IC in MDT[MDT_ptr]

(iV) MDT_ptr=MDT_ptr+1

4. (MEND statement)

if SSNTAB_ptr =1 (SSNTAB is empty) then

SSTP=0

else

SSTAB_ptr=SSTAB_ptr+SSNTAB_ptr-1

if #KP=0 then KPDTP=0;

Macro expansion

- We use the following data structure to perform macro expansion:
  - APTAB – Actual parameter table
  - EVTAB – EV table
  - MEC – Macro expansion counter
  - APTAB_ptr – APTAB pointer
  - EVTAB_ptr – EVTAB pointer
- Number of entries in APTAB equals to the sum of values in the #PP and #KP fields of the MNT entry of macro.

Cont.

- Algorithm 5.3 (Macro Expansion)
  1. Perform initialization for the expansion of a macro
     a) MEC= MDTP field of MNT entry;
     b) Create EVTAB with #EV entries and set EVTAB_ptr.
     c) Create APTAB with #PP+#KP entries and set APTAB_ptr.
     d) Copy keyword parameter defaults from the entries KPDTAB[KPDTP] to KPDTAB[KPDTP+#KP-1] into APTAB[#PP+1] to APTAB[#PP+#KP].
     e) Process positional parameters in the actual parameter list and copy them into APTAB[1] to APTAB[#PP].

Cont.

f) For keyword parameters in the actual parameter list

search the keyword name in parameter name field of KPDTAB[KPDTP] to KPDTAB[KPDTP+#KP-1]. Let KPDTAB[q] contain a matching entry. Enter value of keyword parameter in the call (if any) in APTAB[#PP+q-KPDTP+1].

2) While statement pointed by MEC is not MEND statement

a) if a model statement then

(i) Replace operands of the form (P,#n) and (E,#m) by values in APTAB[n] and EVTAB[m] respectively.

(ii) Output the generated statement.

(iii) MEC=MEC+1;

Cont.

(b) If a SET statement with the specification (E,#m) in the label field then

(i) Evaluate the expression in the operand field and set an appropriate value in EVTAB[m].

(ii) MEC=MEC+1;

(c) If an AGO statement with (S,#s) in operand field then

MEC=SSTAB[SSTP+s-1];

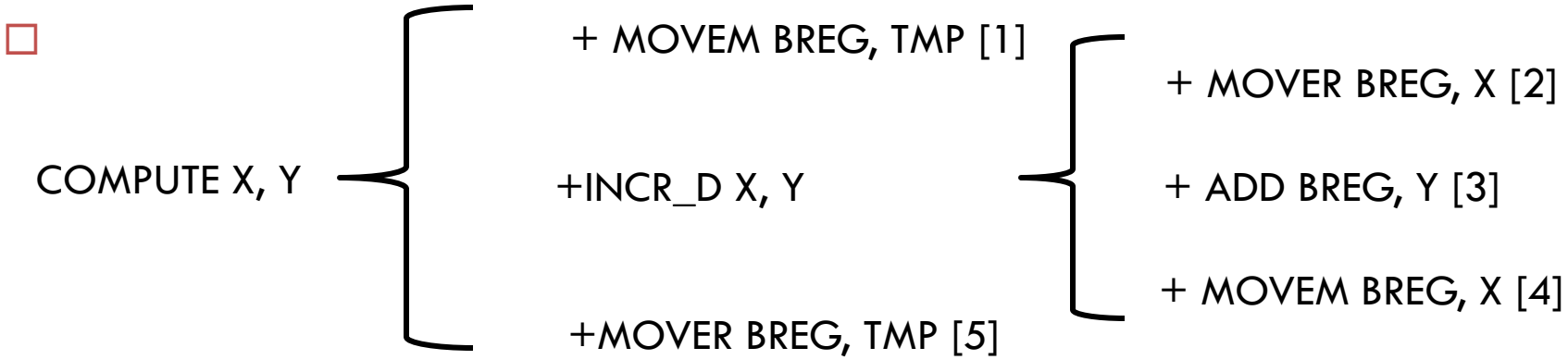
(d) If an AIF statement with (S,#s) is operand field then

if condition in AIF statement is true then

MEC=SSTAB[SSTP+s-1];

(3) Exit from macro expansion.

Nested macro calls



Cont.

- Two basic alternatives exist for processing nested macro calls.
  - In this code macro calls appearing in the source program have been expanded but statements resulting from the expansion may themselves contain macro calls.
  - This first level expanded code to expand these macro calls, until we obtain a code form which dose not contain any macro calls.
  - This scheme would require a number of passes of macro expansion, which makes it quite expensive.

Cont.

- Efficient alternative would be to examine each statement generated during macro expansion to see if it is itself macro call.
- A provision can be made to expand this call before continuing with the parent macro call.
- This avoid multiple passes of macro expansion.

Cont.

- Two provisions are required to implement the expansion of nested macro calls:
  - Each macro under expansion must have its own set of data structures, (MEC,APTAB,EVTAB,APTAB_ptr and EVTAB_ptr).
  - An expansion nesting counter(Nest_cntr) is maintained to count the number of nested macro calls. Nest_cntr is incremented when a macro call is recognized and decremented when MEND statement is encountered.

Cont.

- Creating many copies of the expansion time data structure, this arrangement provides access efficiency but it is expensive in terms of memory requirements.
- Difficult in design decision- how many copies of the data structures should be created?
- If too many copies are created then some may never be used.
- If too few are created, some assembly programs may have to be rejected.

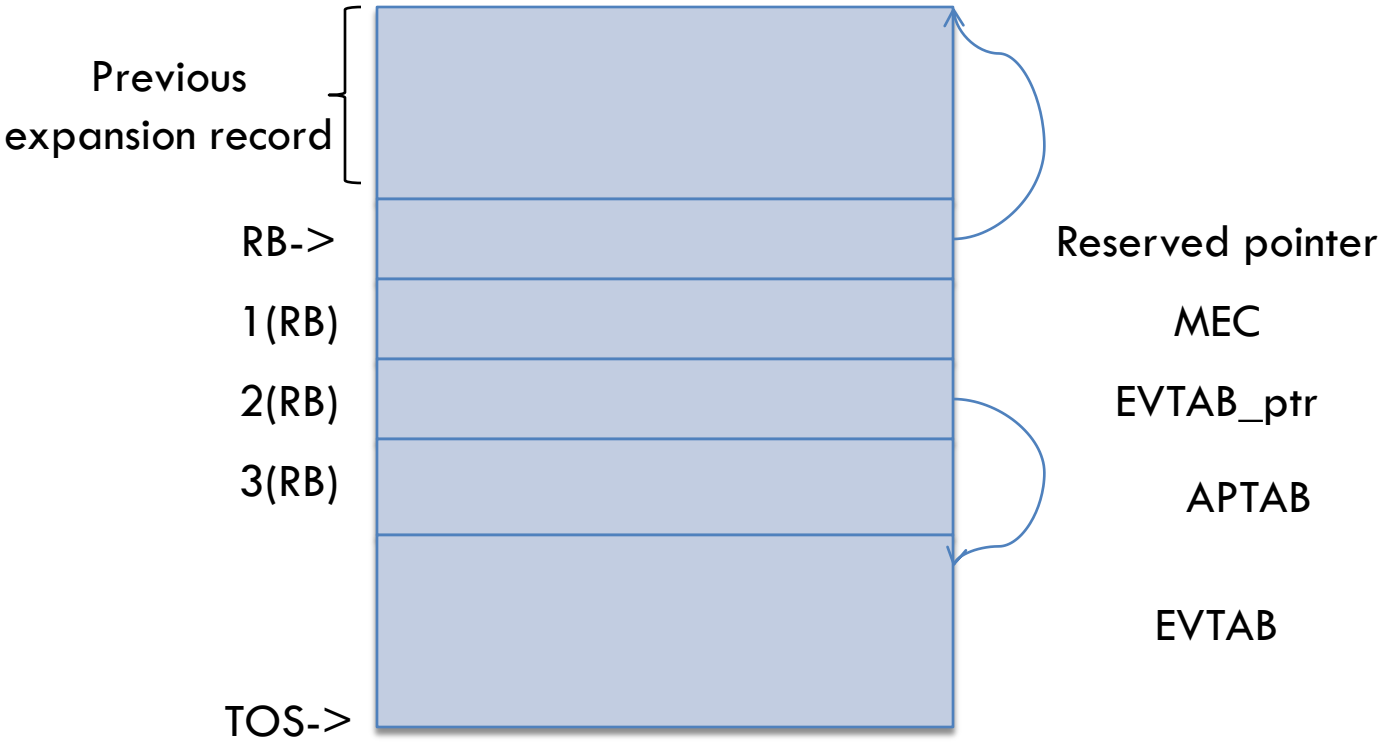
Cont.

- Macro calls are expanded in LIFO manner, the stack consists of expansion records, each expansion record accommodating one set of expansion time data structures.
- Expansion record at the top of stack corresponds the macro call currently being expanded.
- When a nested macro call is recognized, a new expansion record is pushed on the stack to hold the data structures for the call.
- At MEND an expansion record is popped off the stack.

Cont.

- Record base (RB) is a pointer pointing to the start of this expansion record.
- TOS point to the last occupied entry in stack.
- When nested macro call is detected, another set of data structure is allocated on the stack.

Cont.


Previous
expansion record
RB->
1(RB)
2(RB)
3(RB)
TOS->
Reserved pointer
MEC
EVTAB_ptr
APTAB
EVTAB

Cont.

Data structure	Address
Reserved pointer	0(RB)
MEC	1(RB)
EVTAB_ptr	2(RB)
APTAB	3(RB) to e_{APTAB}+2(RB)
EVTAB	Contents of EVTAB_ptr

Cont.

- The start of expansion

No.	Statement
1.	TOS=TOS+1;
2.	TOS* = RB;
3.	RB=TOS;
4.	1(RB)=MDTP entry of MNT;
5.	2(RB)= RB+#e_{APTAB};
6.	TOS=TOS+#e_{APTAB}+#e_{EVTAB}+2

Cont.

- First statement increment TOS to point at the first word of the new expansion record. This is reserved pointer.
- Second statement deposits the address of the previous record base into this word.
- New RB is established in statement 3.
- MEC and EVTAB_ptr set in statement 4 and 5 respectively.

At the end of Expansion

No.	Statement
1.	TOS=RB-1;
2.	RB = RB*;

- The first statement pops an expansion record off the stack by resetting TOS to the value it had while the outer macro was being expanded.
- RB is then made to point at the base of previous record.

Design of macro assembler

- Macro preprocessor followed by conventional assembler is an expensive way of handling macro since the number of passes over the source program is large and many function get duplicated.
- Example:
  - A source statement to detect macro calls require us to process the mnemonic field. Similar function is required in first pass of the assembler. Similar functions of the preprocessor and assembler can be merged if macros are handled by a macro assembler which perform macro expansion and program assembly simultaneously.

Cont.

- Macro expansion perform in single pass is not true, as certain kinds of forward references in macros cannot be handled in a single pass.
- This problem leads to the classical two pass organization for macro expansion.
  - First pass collects information about the symbols defined in a program.
  - second pass perform macro expansion.

Cont.

- Pass structure of a macro-assembler
  - First merge the function of macro preprocessor with the function of conventional assembler, then the functions can be structured into passes of the macro assembler.
- Pass-I
  - Marco definition processing
  - SYMTAB construction
- Pass-II
  - Macro expansion
  - Memory allocation and LC processing
  - Processing of literals
  - Intermediate code generation.
- Pass-III
  - Target code generation.

Cont.

- The pass structure can be simplified if attributes of actual parameter are not to be supported.
- Pass-I
  - Macro definition processing
  - Macro expansion
  - Memory allocation, LC Processing and SYMTAB Construction
  - Processing of Literals
  - Intermediate code generation.
- Pass-II
  - Target code generation.

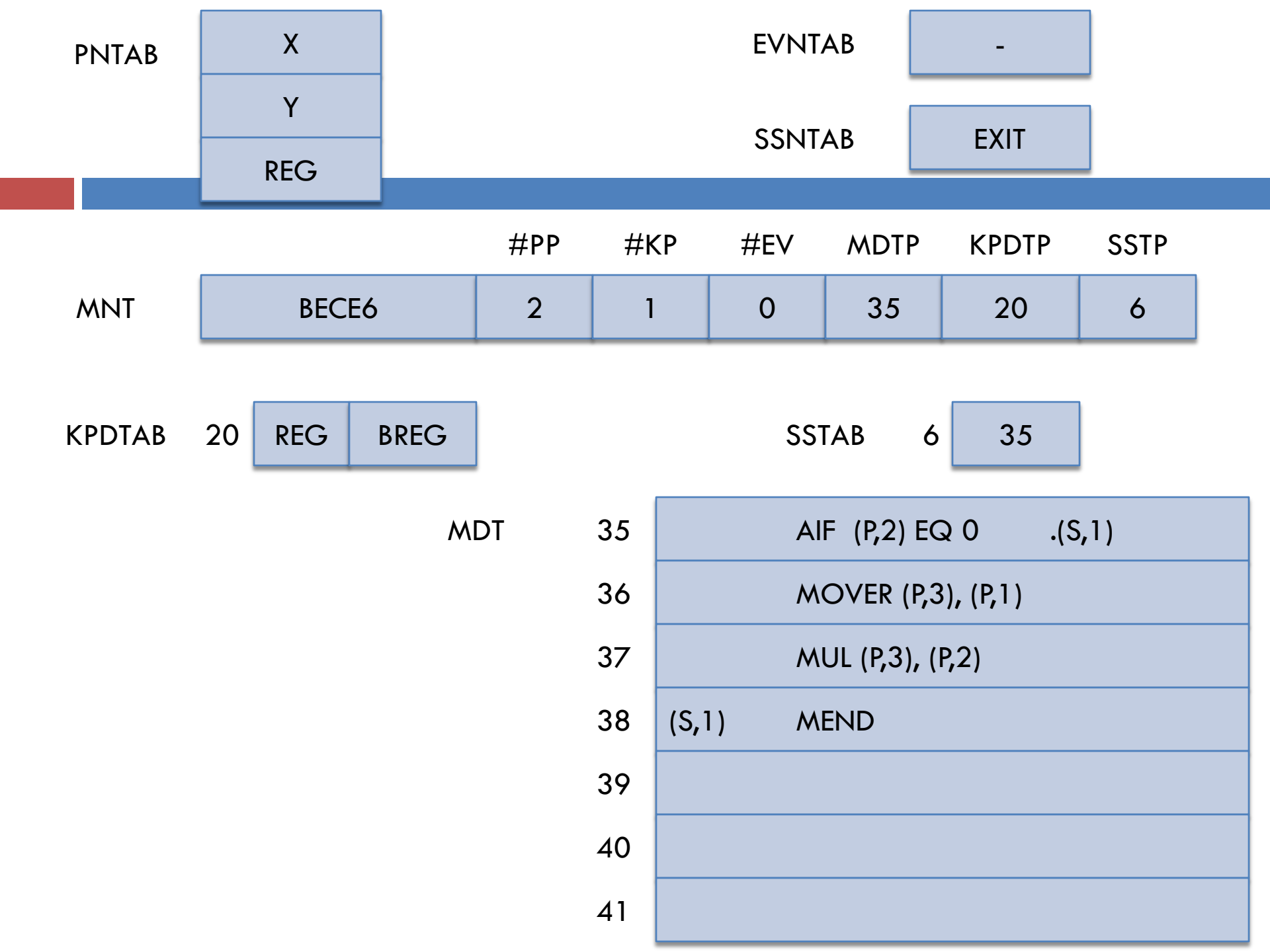
Examples Questions

- Construct all data structure for the MACRO

```
        MACRO
        BECE6       &X, &Y, &REG=BREG
        AIF         (&Y EQ 0)   .EXIT
        MOVER       &REG, &X
        MUL         &REG, &Y
.EXIT   MEND
```

- Generate the statement for these macro calls.

```
        BECE6       6, 8, REG=AREG
        BECE6       3,0
```


PNTAB
X
Y
REG
EVNTAB
-
SSNTAB
EXIT
#PP
#KP
#EV
MDTP
KPDTP
SSTP
MNT
BECE6
2
1
0
35
20
6
KPDTAB
20
REG
BREG
SSTAB
6
35
MDT
35
AIF (P,2) EQ 0 .(S,1)
36
MOVER (P,3), (P,1)
37
MUL (P,3), (P,2)
38
(S,1) MEND
39
40
41

- Generate the statement for these macro calls.

  BECE6 6, 8, REG=AREG

  BECE6 3,0

- For first one BECE6 6, 8, REG=AREG

  + MOVER AREG, 6

  + MUL AREG, 8