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Macro assembler for mc68000 series

Grace Horng Chung

"MACRO ASSEMBLER for MC68000 SERIES"

by

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Title of Thesis : Macro Assembler for MC68000 Series

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Abstract

The objective of this thesis is to use UNIX* utility Yacc (Yet Another Compiler-Compiler) as a language developing tool to design and implement a MC68000 macro assembler. The assembler can support four MC68000 machine languages -- MC68000, MC68008, MC68010, and MC68020.

The MC68000 macro assembler translates source statements written in the series of M68000 assembly language into their machine codes, assigns storage locations to instructions and data, and performs auxiliary assembler actions designated by the programmer.

This is a two-pass assembler which scans the source text twice: first, to develop a symbol table and to expand macro definitions; second, to assemble the source program with reference to the symbol table developed in pass one and generate the object code and assembly listing.

Keyworks:

Cross-assembler, Grammer, Lexical Analysis, Macro definition, Macro expansion, Macro processor, Opcode Table, Parser, Pseudo instruction, Symbol Table, Syntactic analysis, Token, Top-down design, Yacc.

Computing Review Subject Codes : D.1.1 Applicative (Functional) Programming

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CONTENTS

1. *INTRODUCTION AND BACKGROUND*

Motorola introduced the first implementation of the MC68000 with a 16-bit data bus and 24-bit address bus in 1979. It was only the first in a family of processors which implement a comprehensive, extensible computer architecture. It was soon followed by the MC68008, with an 8-bit data bus and 20-bit address bus, and by the MC68010, which introduced the virtual machine aspects of the M68000 architecture. Later, in 1984, a full 32-bit implementation of the M68000 Family of microprocessors, MC68020, was introduced. The MC68020 is object- code compatible with the earlier members of the M68000 family but has new addressing modes in support of high-level languages.

The paper which follows presents a project undertaken for the thesis requirement in the Masters Degree program in Computer Science at the Rochester Institute of Technology in Rochester, New York. The project involved the design and implementation of a cross- assembler which translates source statements written in the series of M68000 assembly language into their machine codes, assigns storage locations to instructions and data, and performs auxiliary assembler actions designated by the programmer. The basic aims of the assembler are:

1. To provide the programmer with the means to translate source statements into object code which is required by M68000 machine.

2. To provide a printed listing containing the source language input, assembler object code, and error codes, if any, which

are useful to the programmer.

The cross-assembler makes two passes over the source code. The first pass is responsible for developing a symbol table, and defining and expanding macros. The second pass is to assemble the object program with reference to the symbol table developed in pass one. During pass two, the object code and the assembly listing will be generated. Each source language line will be processed before the next line will be read.

The use of yacc (Yet Another Compiler-Compiler) made the syntactic analysis for M68000 very easy when developing the assembler and will be discussed more in the later chapters.

2. *IMPLEMENTATION of THE MACRO ASSEMBLER.*

2.1 *Functional Specification.*

Mnemonic operation code

The operation code may be represented symbolically. For example, the mnemonics ADD and MOVE are more likely to be used for instructions which add and move data than are the bit configurations which represent those operations.

Symbolic Address

A programmer may select a symbol to refer to the location for an item which is needed when the program is executed. In this cross-assembly system, the programmer may write

```
HOLD    MOVE  3,THREE
```

and leave it up to the assembler to decide where the instruction HOLD is to be placed. Somewhere else in his program he would have a data item named THREE.

Storage Reservation

Some data-defining pseudo-instructions are provided for storage reservation and constant definition. A storage specification may optionally be preceded by a label. The label references the lowest address of the defined storage area.

Symbol Table

The symbol table keeps the coalescence of data relating to the various elements of the source text and provides the data for describing certain relationships between the text and the M68000 machine.

Code Generation

For each instruction in pass two, the assembler creates the equivalent machine language instruction accepted by the M68000 machine.

Location Counter

M68000 instructions are of variable length, so the increment of the location counter is based upon data item size, such as byte, word and long word and the addressing mode of the operand. A single location counter is implemented.

User-Defined Macro

By using a macro instruction, the M68000 user is spared the tedium of repetitive coding. The macro instructions can be thought of as statements in a higher-level language which are particularly useful

to the programmer because he has defined them along with their formal parameters.

Pseudo-Operations

The pseudo-operations provided in this assembler allow the programmer to define and manipulate symbols (such as EQU), allocate storage (such as DS,DC), and control assembly processing (such as ORG,END). Those pseudo-operations are instructions to the assembler itself rather than instructions to be translated into object code.

Listing

The programmer may require a listing of both source and object code. As part of this listing, each symbol defined in the program is listed together with its value.

Error checking

The assembler checks the source program for several different types of errors, such as undefined symbol, wrong number of operands, inappropriate operands, and a variety of syntax errors.

2.2 *Architectural Design.*

The assembler is accomplished in two passes. The tasks performed in each pass are listed; associated with each task are one or more assembler modules.

Pass1:

- Read source program line by line. (input.c)

- Lexical and Syntactic analysis. (yylex.c, parse.y)
- Determine the address corresponding to each symbol. (parse.y)
- Place symbols and their addresses in symbol table. (yylex.c, symbol.c)
- Increment location counter based upon opcode and operand. (instr.c)
- Reserve storage for instructions and data. (instr.c)
- Copy macro definitions into each macro-definition strings. (macro.c)
- Expand macro calls. (expmacro.c)

Pass2:

- Read source program again. (input.c)
- Lexical and Syntactic analysis. (yylex.c, parse.y)
- Replace symbolic operation codes by machine operation code. (instr.c)
- Replace symbolic addresses by numeric addresses. (instr.c)
- Generate extension words for each instruction. (extend.c)
- Increment location counter as Pass1. (instr.c)
- Reserve storage for instructions and data. (instr.c)
- Expand macro calls. (expmacro.c)

- Check for different types of errors. (error.c and all the modules)

- Give listing as required. (output.c)

In initial processing some functions are performed:

- Initialize symbol table. (mas.c)

- Define operation code table. (symbol.c)

- Define pseudo-ops for the assembler. (instr.c)

The following is the structure of main program for the assembler:

```
main()
    get command ;              /* command line options */
    yyparse();                 /* pass 1 */
    if (status == 0) {
         pass = 2;
         yyparse();            /* pass 2 */

exit (status);
```

yyparse() in the main program, is produced by Yacc as a parser to control the input process (see Figure 1 and Figure 2). When it is called, it in turn repeatedly calls yylex() to obtain input tokens. These tokens are organized according to the M68000 assembly language grammar rules. If one of these rules is recognized, some C routines are invoked to accomplish the rest of the assembler's jobs-- symbol table management, macro processing, code generation and so on.

Parser (in the case of pass 1):

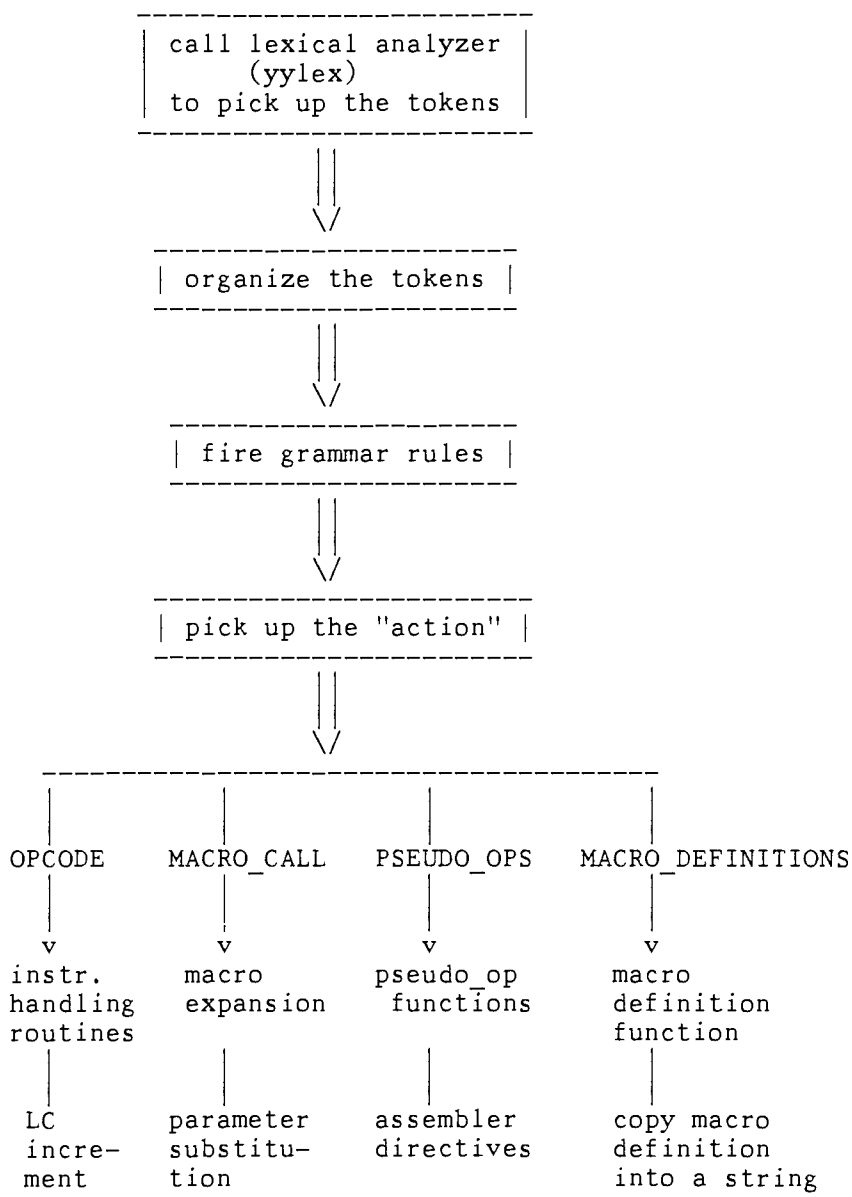


Figure 1. Parsing Function- Pass 1

Parser (in the case of pass 2):

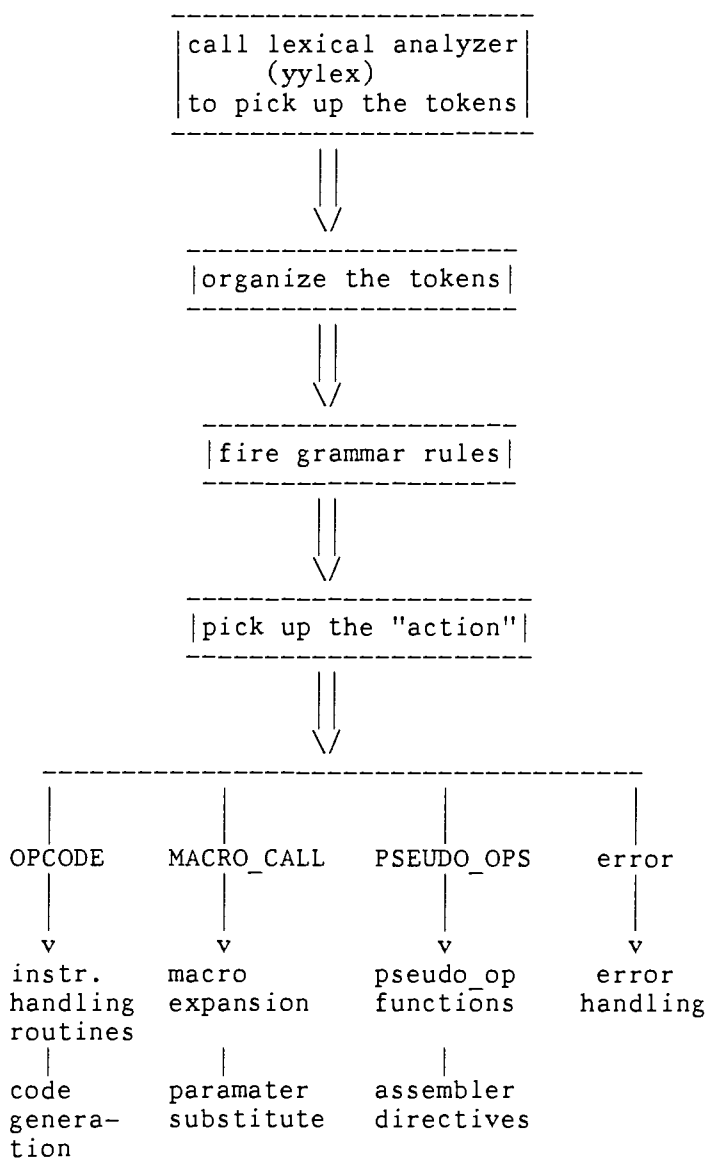


Figure 2. Parsing Function- Pass 2

In order to produce a parser like this, a grammar for the M68000 assembly language, executable code to be invoked when a grammar rule is recognized, and a lexical analyzer to do the basic input are provided to yacc. This is shown in Figure 3.

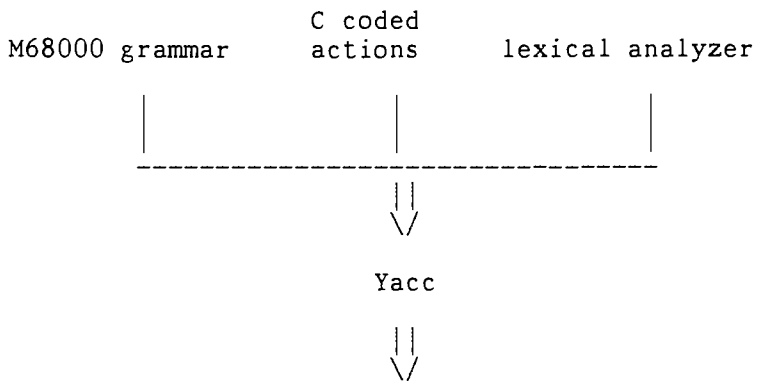


Figure 3. Generating of Parsing Function

Yacc processes the M68000 grammar along with the actions into the parsing function yyparse(), and writes it out as a C function. The parser and the lexical analyzer are compiled and linked together with other C routines, and executed.

2.3 *Interface Specification.*

2.3.1 *External Interfaces.*

The assembler in its default mode provides assembly of instructions for the MC68000 processor. However, the assembly of MC68008. MC68010, and MC68020 instructions can be enabled from the command line. For example, if a MC68020 instruction set is desired, the user can issue the command:

```
mas -2 -l source_file
```

where -2 selects the MC68020 machine instruction and -l requests an assembly listing.

The cross-assembler could be executed under any operating systems which has C compiler.

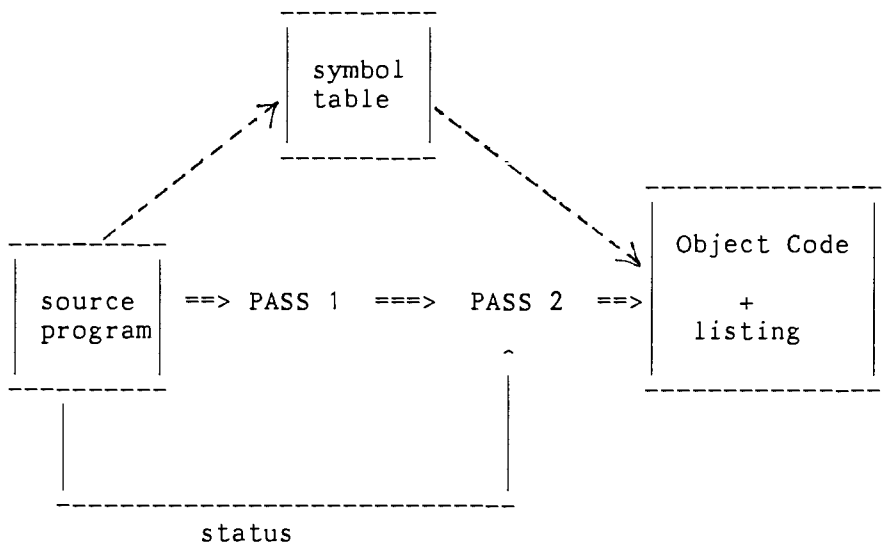


Figure 4. Internal and External Interfaces.

2.3.2 *Internal Interfaces*.

The internal interfaces between two passes are the execution status and the symbol table generated by Pass1 (Figure 4). A successful execution of Pass1 returns a status of 0, however, any syntactic errors detected by parser during Pass1 or a symbol table overflow cause a non-zero value to be returned. If a non-zero status occurred, the assembler displays any error messages at the terminal and terminates the execution instead of executing Pass2.

2.4 *Module Designs.*

Top-down development, also known as modular development, is considered as a very important design concept in developing the algorithms of this assembler. It offers efficiency, reliability and flexibility of design and makes the job of incorporating additional features and changes easy. Table 1 lists all the modules that comprise the cross-assembler.

Global data structures

Parser -- Grammar with actions

Lexical analyzer

Instructions handling routines

Word extension

Symbol table management

Macro processor

Input handling routines

Macro expansion

Output formatting

Error handling routines -- yyerror, and error message

String handling

Table 1. Module Design

This chapter describes the techniques used to implement each of the above mentioned modules. Where appropriate pseudo code will be included to aid in the presentation of ideas and techniques. To avoid complexity, the pseudo code does not show details which are

not important in understanding the logic of a routine.

2.4.1 *Lexical Analysis*

The process by which the contents of input characters are converted into the form that is used within the translator is called Lexical Analysis. Every time the Lexical Analyzer is called it returns a number that represents the kind of token read. The communication between the parser and the lexical analyzer is through a variable, which is assigned the information associated with that token. The type of token determines which data structure is to be used when accessing the variable. (see Figure 7 for the data structure of each token type.)

The major types of token in MC68000 are words, numbers, and operators, each of which can be further divided into few subtypes. For example, a word may be a reserved word (e.g. "MACRO" for macro calls), an opcode (e.g. "MOVE" instruction), or an identifier. The determination of "MACRO" as a reserved word can be done by either the parser or the scanner. Because the distinction between lexical and syntactic analysis is not firm, one way to scan text is to include scanning as part of the parsing. This is accomplished by using a grammar whose terminal symbols are the characters themselves. Some substantial effort is needed to transform the entire grammar into a suitable form for recursive descent without backtracking. However, if the grammar which describes the lexical analysis is simple enough, such as MC68000 assembly language, a particularly efficient scanner can be designed.

To identifying and classifying tokens, the scanner needs to isolate

each token from its neighbors. In MC68000, a token is delimited by any nonalphabetic, nonnumeric character. Figure 5 is the state diagram which describes the scanning process for MC68000 lexical analyzer. All the token types returned by the lexical analyzer are shown on the right.

Generally, the scanner skips blanks and tabs, converts strings of digits into a numeric value, looks up the symbol table and the opcode table to determine the token type of an ASCII string, and return any other character as itself.

The identification of each character is in principle trivial. The state diagram is to be studied carefully to ensure that the lexical classes are properly defined. Also, a character recognizer which fetches the next input character and discards comments and nonsignificant blanks is necessary for the scanner.

2.4.2 *Parsing*

Before generating code, the translator must determine the content of the source-language text to be translated. A lexical analyzer is required to separate the source-language text into the elements of which the language is composed. Syntactic analysis is required to ascertain the structural relationships among those elements.

Much knowledge has been developed about parsing programs; however, to write a parsing function is difficult and is not our intention here. The UNIX system has provided a very powerful compiler-writing system -- yacc to help compiler writing. Yacc is a parser generator which serves the specification of a grammars input and produces a parser for the grammar. Yacc provides a way to

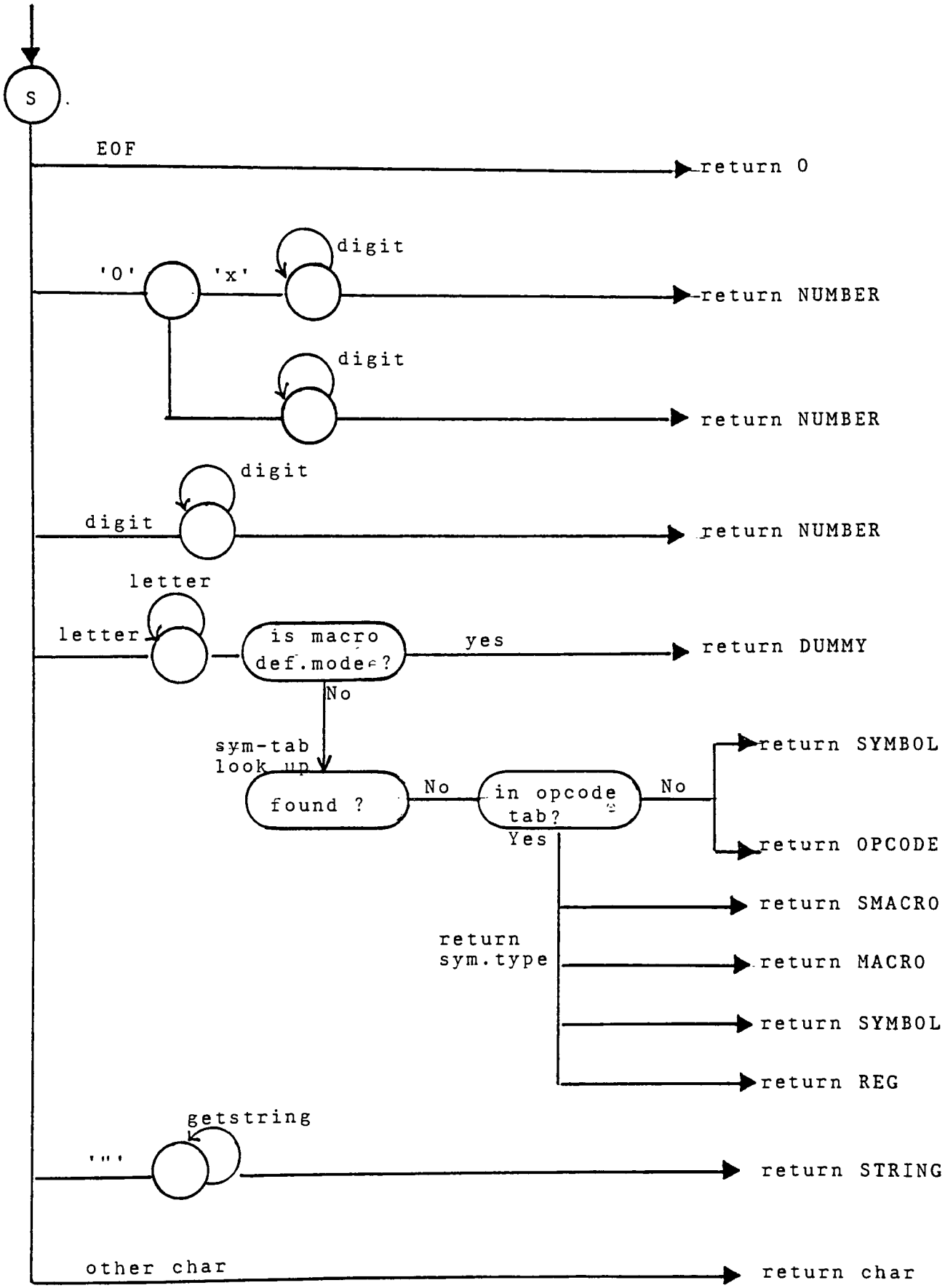


Figure 5. State Diagram of the Lexical Analyzer

associate meanings with the components of the grammar in such a way that as the parsing takes place, the meaning can be evaluated as well.

The yacc user has to prepare a specification of input process; this includes a grammar, a lexical analyzer,and the code to be invoked when grammar rule is recognized. Yacc then generates a parsing function to control the input process. This parsing function calls the lexical analyzer to pick up the tokens from the input stream. These tokens are organized according to the grammar rules; when one of these rules has been recognized, then user supplied code for this rule is invoked.

The advantage of yacc is that the parser generated by yacc is small, correct and efficient; many nasty parsing problems are taken care of automatically. The error handling in yacc is provided as part of the input specifications which permits the reentry of bad data, or the continuation of the input after skipping over the bad data.

For an assembly language like MC68000, the syntactic analysis is rather simple compared to that performed in a compiler. (The structure of address mode expressions must be specified, keyword parameters must be distinguished from positional.) This is because the syntax of assembley language is constrained to be simple; interline syntax is particularly restricted. It is true that an MC68000 assembler may have to face address expressions and macro calls, both of which are rather complex. These are, however, rarely as intricate as the statements faced by a compiler.

It is customary to use the notation of BNF in representing a grammar. The following is the yacc BNF format for MC68000 assembly language.

```
module  : line
        | module line
        ;

line    : label stmt   /* blank */
        | /* blank */
        | error   /* blank */   { yyerrok; }
        ;
label   :
        | label SYMBOL ":"
              { if(undefined($2))
                $2->sy_numb = pc;}
        ;
stmt    : OPCODE addrlist
              { (*($1->sy_func))($1,$2);}
        | MACRO paralist
              { expmacro($1,$2);}
        | SMACRO dumlist
              { defmacro($2); }
        ;
addrlist: addr ',' addrlist
              { $$ = addlist() }
        | addr
              { $$ = addlist() }
        ;
dummlist:       /* this is for macro definition */
paralist:       /* this is for parameter list for macro */

                                  /* addressing mode starts here */
addr    : REG    /* Dn */
              { $$.ad_reg = $1->sy_numb ;
                $$.ad_mode = 0;
              }
        | "("REG")"    /* (An)  */
              { $$.ad_reg = $1->sy_numb;
                $$.ad_mode = 0;
              }
              .
              .
              .
              .
        | "#"expr   /* #<data>  */
              { $$.ad_expr = $2;
                $$.ad_mode = 11 ;
              }                    /* addressing mode ends here */

 expr   : NUMBER
              { $$.ex_numb = $1;}
        | SYMBOL
```

```
                { $$.ex_symb = $1;
                  $$.ex_numb = $1->sy_numb;
                }
        | expr "+" expr
                .
                .
                .
        | "-" expr
        ;
```

Characters between two braces are not parts of BNF but are, instead, the notations for yacc to indicate which actions should be executed after a certain grammar rule is recognized.

The grammar is later used for determination whether a given string is in the MC68000 language. The determination of its structure is called parsing. The task of parsing is to apply a grammar like the above to a source MC68000 language program and determine the tree structure which represents its syntactic structure.

2.4.3 *Symbol Table Management*

A symbol table is used to hold the meanings associated with user-defined symbols. The meaning of a symbol is expressed by means of its attributes. Possible attributes are source-text line number, types, value, and pointer to other data structures. (see Figure 8 for example)

The first reference to a symbol serves as an declaration and inserts the symbol into the table. This access occurs an insertion of the attribute. However, most accesses retrieve attributes. Retrievals require a search for the designated symbol; in practice, insertion also require such a search. Because of these frequent searches, effective symbol table management is crucial to efficient translation, whether in an assembler or macro processor.

A binary search is quite efficient, but it requires that the elements of the array be sorted. This means that the enter subroutine would have to adjust the table for each new entry, so that the table was always sorted into the correct order. Thus, although a binary search might be quick, the combination of a binary search plus an ordered enter might be very expensive.

Another alternative is hashing. Different hashing functions can be used. For example, we can add together the character codes for the different characters of the symbol, or multiply them, or shift some of them a few bits and exclusive-or them with the other characters, or whatever we wish.

The objective of all this calculation is to arrive at an address for a symbol which hopefully is unique for each symbol. But since there are millions of 10-character symbols and only a few hundred table entries, collisions occur. The problem with using hashing is defining a good hashing function; a good hash function will result in very few collisions.

Consider that a linear search is efficient for small tables. Many assembly language programs have less than 200 different symbols, and so a linear search may be quite reasonable. This is why linear search is used in our symbol table management. A linear search allows the enter routine to simply put any new symbol and its value at the end of the table. Thus, both the search and enter routines are simple.

2.4.4 *Macro Processing*

A straightforward implementation of the macro processor is to add another pass to an existing assembler to expand all macros. Thus, an existing two-pass assembler can be converted into a three-pass macro assembler. The first pass expands all macros, the second pass defines the symbol table, and the third pass generates the output.

The macro expansion pass copies all assembly language statements except macro definitions and macro calls. A macro definition is entered into the macro name table, and the assembly language statements which follow are stored in the macro definition string until an closing delimiter is encountered. During pass 2 when a macro call is encountered, the corresponding prototype is found by following a pointer which was placed in the symbol table when the definition was collected during pass 1. Parameter substitution is performed as the macro definition is copied out.

The advantages of this three-pass division are that space requirements are modest and that forward references are permitted. However, forward references to macro definitions in the input text are not as important as forward references to symbols in assembler-language text, because requiring macros to be defined before use makes no hardship. Passing the text twice then incurs unnecessary cost. Therefor, in this project, a two-pass macro assembler is implemented.

When the opening delimiter of a macro definition (in our assembler a ".macro" statement) is encountered, all succeeding instructions of the definition are entered in a macro-definition string. Each

formal parameter in the body of definition is replaced by a number which gives the position of the formal parameter in the parameter list. A pseudo-function to do this is described as follows:

```
def_macro(sym_list)
            /* copy the definition into macro_def_string */
            /* keep the list of macro name and dummies */
    get macro name
    put macro name on symbol table
    get dummy arguments and prepare a dummy list
    initial a string buffer for definition

    while (not EOF)
       get symbol
       while (not EOLN)
          get symbol
          if it is dummy
             get index notation from dummy list and substitute
       end
    end (EOF)

    put address of string into symbol_table
end
```

Meanwhile, the macro name and the pointer of its definition string are stored in symbol table marked "macro" to distinguish macro calls from other instructions.

2.4.5 *Code Generation*

MC68000 instructions are of variable length. For each instruction in the MC68000 instruction set there is one corresponding instruction handling routine in the code generation module, each handling routine is passed two parameters: the opcode itself and the operand list. The instruction routine increments the location counter properly in Pass 1, and generates the code and the extension words for the instruction in Pass 2.

The value added to the location counter depends on the instruction length. Most instructions specify the location of an operation by

using the effective address field in the operation word. The effective address is composed of two fields: the addressing mode field and the register field. It may require additional information for the effective address field to fully specify the operand. The additional information is contained in one or a few following extension words (depends on the addressing mode).

During Pass 1, the instruction handling routine simply gets the source and destination addressing mode of the operands from its second parameter (operand list) and determines the value to be added to the location counter.

During Pass 2, the location counter is advanced just as during Pass 1. Each field in the operation word, such as source and destination registers, source and destination modes and instruction size(.L, .W or .B) is inserted into the operation word for code generation.

Extension words for MC68000 instructions may be immediate operand, branch displacements, extensions to the effective address mode specified in the operation word, bit number specifications, special register specifications, trap operands or argument counts. See appendix A for the extension word requirements for MC68000.

2.5 *Data Bases.*

The Data Bases in the assembler are:

Input source program

Location Counter – Used to keep track of each instruction's location.

Symbol Table – Used to keep each symbol encountered along with its corresponding value. Notice that the macro name, registers, and other system defined symbols are also considered as "symbols" in this assembler, so they are stored in the symbol table too.

Opcode Table – Each Opcode Table entry contains the symbolic opcode, the pointer to its instruction handling routine and is operation size. Pseudo-ops are kept here also.

String Buffer – Used to hold series of symbols like macro definitions and quoted Ascii strings.

Input File structure – A structure that contains pieces of information about the input file: a pointer to a buffer, a pointer to the next character, a count of the characters left, and the file descriptor.

Data Structures for each token type – Structures for terminals: Symbol for token type SYMBOL, Number for token type NUMBER and String for token type STRING. Structures for the nonterminals: Addr for addressing mode, Expr for expression, and List for string of symbols.

An assembler must translate two different kinds of symbols: assembler-defined symbols which are mnemonics for the machine instructions and pseudo-instructions; and programmer-defined symbols which are the symbols defined in the label field of statements by the programmers. These two kinds of symbols are translated by two different tables: the opcode table and the symbol table.

In one way, they are quite alike: they both translate symbols into proper numeric equivalents which are accepted by the machine. Thus, in this assembler, they are designed with the same data structure for their table entries (Figure 6-1 and 6-2). Also, by generalizing the table formats, the opcode tabel and pseudo-op table are combined into one table.

symbolic name	symbol types	value	Address of routine to process instruction	Pointer to macro definition string
"XYZ"	SYMBOL	UND	NULL	NULL
"T1"	MACRO	0	NULL	234123
..	.			..
..	.			..
..	.			..
..	.			..

Figure 6-1. Symbol Table

symbolic name	symbol types	value	Address of routine to process instruction	Pointer to macro definition string
"ADD"	OPCODE	0	add	NULL
"MOVE"	OPCODE	0	move	NULL
"UNPK"	OPCODE	20	unpk	NULL
..	.			..
..	.			..
..	.			..

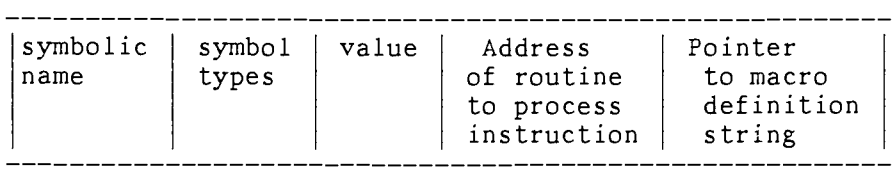
Figure 6-2 Opcode Table

- The field "Address of routine to process instruction" contains a value only when the symbol is an instruction.
- The field "Pointer to macro definition string" contains a value only when the symbol type is MACRO.
- Field "value" in the Opcode Table is used for indicating the

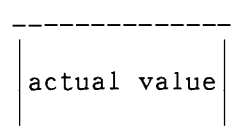
type of instruction set (0 for MC68000, 20 for MC68020).

By default, the values returned by the lexical analyzer are integers. In order to allow tokens return sufficient information about themselves it is necessary to make the values of specific data structures. The followings (Figure 7) are the data structure formats for the terminal and nonterminal token types.

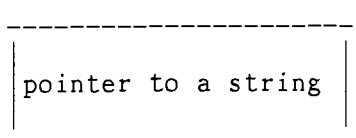
Symbol(terminal):



Number(terminal):



String(terminal):



Address(nonterminal):

base displacement	address register	index register	addressing mode	outer displacement

- Base displacement and Outer displacement both contain a pointer to an Expr.
- Address register contains 2 fields: register numb and register size (only for implicit PC mode).
- Index register contains 3 fields: index register number, size and scale.

Expression(nonterminal):

symbol	value

List(nonterminal):

pointer to next item	item

The following is the data structure that describes the input file. It contains the most important messages about input function such as input line count and a workspace for unget character.

Input:

input type	line count	buffer count	unget buffer	file pointer file name ptr into macro definition ptr into current parameter list of parameters

- input type is either MACRO or FILE.
- line count keeps track of input line number.
- buffer count is the number of characters left in unget buffer.
- unget buffer is the buffer for unget characters.
- the last field is either for regular FILE information or for MACRO information.

Figure 7. Data Structure Formates

2.6 *Communications among Modules.*

The communications among each module are shown in Figure 8-1 and 8-2.

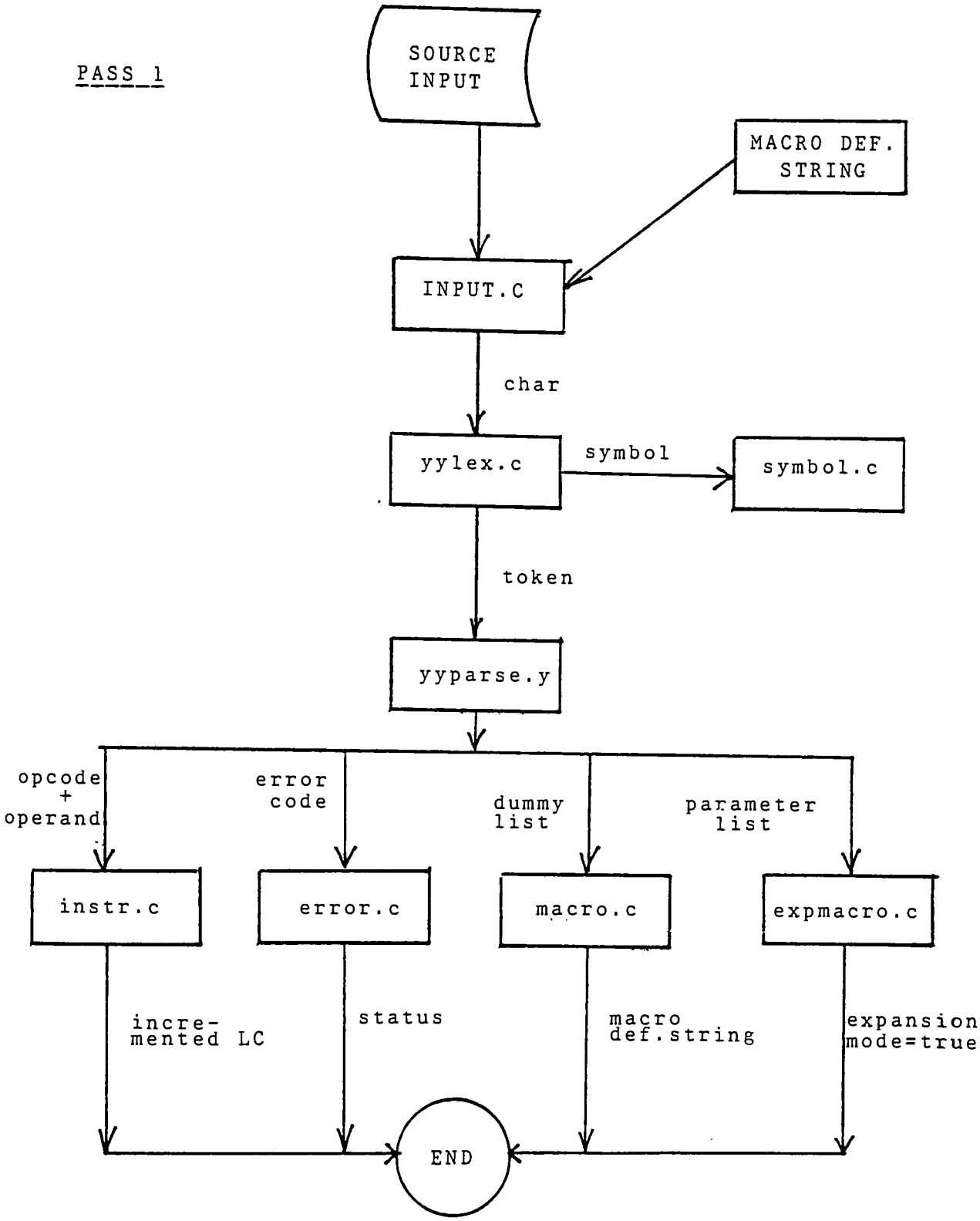


Figure 8-1. Communications among Modules

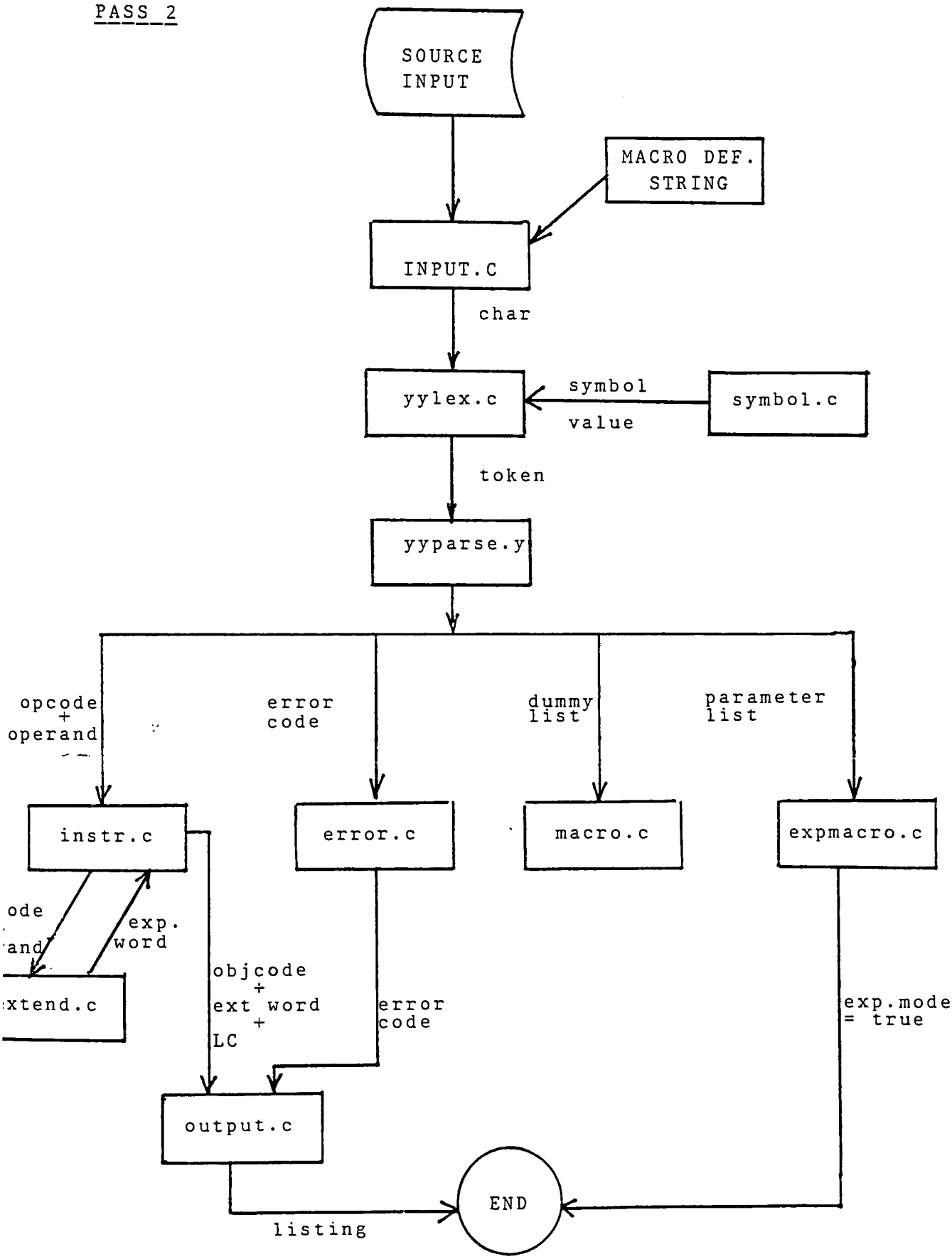


Figure 8-2. Communications among Modules

3. *VERIFICATION AND VALIDATION.*

3.1 *Test Plan.*

Since exhaustive testing is impossible, a carefully selected set of data can greatly ease the problem of detecting errors. In the stage of the system development we use a simple test data set to test all possible program logic paths. For example, in testing the lexical analyzer we were concerned if the returned token type was correct; a small set of token types was adequate for this test.

However, the goal of this test plan is to ensure that the system solves the problem that it is supposed to solve and that it yields the correct answer under all conditions by means of a scientifical testing methodology. We will concentrate on discussing system testing. The testing of the system is performed by several test procedures.

3.2 *Test Procedures.*

3.2.1 *Instruction set*

A. Collect a complete set of instructions for 68020. the test data should look like the following:

```
move d0,a0
add  d0,a0
     .
     .
     .
bra  start
nbcd d0
     .
     .
     .
rts
nop
     .
     .
     .
end
```

B. Assemble the test data and validate the result to see there is any illegal instruction value of instruction code.

C. Assemble the test data for all target machines to see there is any illegal instruction.

3.2.2 *Address mode*

A. Select test instructions so that each instruction represents a class of instructions. For example:

```
addi, andi, ori, subi, etc..
bcc, bcs, beq, bge, etc..
     .
     .
     .
divs, divsl, divu, divul, etc..
```

The test data should look like the following:

```
addi #0x55,d1
addi #0x55,a1
addi #0x55,(a2)
addi #0x55,(a3)+
addi #0x55,-(a4)
addi #0x55,(10000,a5)
addi #0x55,(100,a5,d2)
addi #0x55,(1000000,a5,d2)
addi #0x55,([1000000,a5,d2],0x40)
addi #0x55,([1000000,a5],d2,0x40)
addi #0x55,0x40
        .
        .
        .
eor d2,d3
eor d2,(a1)
eor d2,(a1)+
eor d2,-(a1)
eor d2,(10000,a5)
eor d2,(100,a5,d2)
eor d2,(1000000,a5,d2)
eor d2,([1000000,a5,d2],0x40)
eor d2,([1000000,a5],d2,0x40)
eor d2,0x40
        .
        .
        .
```

B. Assemble the test data for all target machines to see there is any illegal addressing mode value of instruction code and extension words

3.2.3 *Instruction size*

A. Modify the size of instructions in the test data of addressing mode (i.e. replace eor with eor.b, eor.w or eor.l etc.).

B. Assemble the test data for all target machines to see there is any illegal instruction size value of instruction code and extension words

3.2.4 *Pseudo code*

A. Add all pseudo operation into the test data of addressing mode (i.e. org, ds, dc, equ, list,etc.)

B. Assemble the test data for all target machines and validate the result of location counter, data storage, symbol table.

3.2.5 *Macro definition and Macro call*

A. Add macro definition and macro call into the test data of addressing mode

B. Assemble the test data for all target machines and validate the result of location counter, data storage, symbol table, output listing and the value of expanding macro codes.

3.2.6 *Error handling*

A. This test procedure should include all the error detecting such as redefined symbol, undefined symbol, symbol table overflow, invalid value for expression, illegal register, etc..

3.3 *Test Results*.

See appendix B.

4. *CONCLUSIONS.*

4.1 *Problems Encountered and Solved.*

In traditional two-pass assembler an intermediate file is generated for pass 2 to save time of redoing macro call expansion. In order to speed up the assembling time we eliminated the intermediate file. During pass 2 whenever macro call expansion is needed , system directs input routine to macro definition string instead of source file.

4.2 *Discrepancies and Shortcomings of the System.*

Users must specify all the user-specified values such as base displacement(bd), index register, scale, base register, program counter and outer displacement(od) in 68020.

The format of object codes is not suitable for commercial eprom programmers.

The format of a register list has to be d0/d1/.../d6 instead of d0-d6.

Due to the unclear definition in M68020 manuals of how to handle pc-relative mode in pc indirect with index addressing mode and pc memory indirect modes in 68020, pc-relative mode is not allowed in these addressing modes.

This is a non-optimizing assembler; i.e., you have to explicitly request an immediate or quick operation to get one.

4.3 *Lessons Learned.*

4.3.1 *Alternative Approaches for Improved System.*

The assembler should separate pseudo macros and pseudo directives from the opcode table and put them into different tables. This will not only improve search time, but will also decrease the size of the table by eliminating some unused data.

The performance of the assembler can be improved by using a hashing function to build up a symbol table.

4.3.2 *Suggestions for Future Extensions*

With a few additions (such as external symbol definition and multiple location counters) this assembler can be easily upgraded to a complete link-loader assembler. It will not be a completed 68020 assembler without coprocessor capability. It is possible to add a coprocessor into this system as long as the specification of coprocessor is available.

4.3.3 *Related Thesis Topics for the Future.*

Conditional assembly, linkage editor, and high-level structure assembly may very well be some related thesis topics for the future.

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Appendix A. *Extension Word Requirement*

mode	assembly notation MC68000	MC68020	extension_word
101	d16(An)	(d16,An)	16-bit Displacement
110	d8(An,Xi)	(d8,An,Xi)	Combined Index Descriptor/ Displacement Word
	-	(bd,An,Xi)	Full Format Descriptor/ Base-Outer Displacement
	-	([bd,An],Xi,od)	see above
	-	([bd,An,Xi],od)	see above
111	d16(PC)	(d16,PC)	16-bit Displacement
111	d16(PC,Xi)	(d8,PC,Xi)	Combined Index Descriptor/ Displacement Word
111	-	(bd,PC,Xi)	see above
111	-	([bd,PC],Xi,od)	see above
111	-	([bd,PC,Xi],od)	see above
111	#xxx	#xxx	1 or 2 words depending upon the operation size
111	xxx.L	xxx.L	2 extension words -1st, high part of const -snd, low part of const
111	xxx.W	xxx.W	16-bit constant

Appendix B. *EXAMPLE OUTPUT LISTING*

EXAMPLE OUPUT LISTING FOR MC68000

```
1                00100000                    ORG     0x100000
2   100000       6000     START:  BRA        PROC
                 0002
3   100004       2e7c     PROC:   MOVEA.L    #0x1000,A7
                 00001000
4   10000a       303c             MOVE       #NOENT,D0
                 000a
5   10000e       4879             PEA        TABLE
                 00100088
6   100014       4282             CLR.L      D2
7   100016       4283             CLR.L      D3
8   100018       4eb9             JSR        SORT
                 00100022
9   10001e       4e72             STOP       #32
                 0020
11  100022       2c6f     SORT:   MOVEA.L    4(a7),a6
                 0004
12  100026       2200             MOVE.L     D0,D1
13  100028       4e71     SLOOP:  NOP
14  10002a       83fc             DIVS       #2,D1
                 0002
15  10002e       c2bc             AND.L      #0xFFFF,D1
                 0000ffff
16  100034       b27c             CMP        #0,D1
                 0000
17  100038       6700             BEQ        RET1
                 0006
18  10003c       6000             BRA        CONT1
                 0004
19  100040       4e75     RET1:   RTS
20  100042       2400     CONT1:  MOVE.L     D0,D2
21  100044       9441             SUB        D1,D2
22  100046       363c             MOVE       #1,D3
                 0001
23  10004a       2243     INITX1: MOVEA.L    D3,a1
24  10004c       2449     CKXTRAN:MOVEA.L    A1,A2
25  10004e       d4c1             ADDA       D1,A2
26  100050       1836             MOVE.B     0(a6,a1),D4
                 9000
27  100054       b836             CMP.B      0(a6,a2),D4
                 a000
28  100058       6f1e             BLE.B      CKXLIM
29  10005a       13f6     DOXTR:  MOVE.B     0(a6,a1),TEMPHOLD
                 9000
                 00100093
30  100062       1db6             MOVE.B     0(a6,a2),1(a6,a1)
                 a000
                 9001
31  100068       1db9             MOVE.B     TEMPHOLD,0(a6,a2)
                 00100093
```

```
                 a000
32   100070      92c1     NXTXLOW:SUBA     D1,A1
33   100072      b2fc              CMPA     #0,A1
                 0000
34   100076      6dd4              BGT.B    CKXTRAN
35   100078      d67c     CKXLIM:  ADD      #1,D3
                 0001
36   10007c      3a03              MOVE     D3,D5
37   10007e      9a42              SUB      D2,D5
38   100080      ba7c              CMP      #0,D5
                 0000
39   100084      6da2              BGT.B    SLOOP
40   100086      5fc2              BRA.B    INITX1
42   100088      5a       TABLE:   DC.B     'Z'
43   100089      0a                DC.B     10
44   10008a      09                DC.B     9
45   10008b      08                DC.B     8
46   10008c      07                DC.B     7
47   10008d      06                DC.B     6
48   10008e      05                DC.B     5
49   10008f      04                DC.B     4
50   100090      03                DC.B     3
51   100091      02                DC.B     2
52   100092      01       ENDTAB:  DC.B     1
53               0000000a          NOENT:   EQU      ENDTAB-TABLE
54   100093      0001     TEMPHOLD:         DS.B     1
55                                         END
** TOTAL ERRORS ** 0

SYMBOL TABLE

START           100000
PROC            100004
NOENT           a
TABLE           100088
SORT            100022
SLOOP           100028
RET1            100040
CONT1           100042
INITX1          10004a
CKXTRAN         10004c
CKXLIM          100078
DOXTR           10005a
TEMPHOLD        100093
NXTXLOW         100070
ENDTAB          100092
```

EXAMPLE OUPUT LISTING FOR MC68020

```
1                   00000200        try:    EQU     0x200
2                   00001000                ORG      0x1000
3   001000          058c            MOVEP    d2,(14,a4)
                    000e
4   001004          4c91            MOVEM    (a1),d0 / d3 / d4
                    0019
5   001008          4e7b            MOVEC    a1,VBR
                    9801
6   00100a          4e7a            MOVEC    CACR,d2
                    2002
7   00100c          282f            MOVE.L   (4,a7),d4
                    0004
8   001010          2400            MOVE.L   d0,d2
9   001012          363c            MOVE.W   #32760,d3
                    7ff8
10  001016          2203            MOVE.L   d3,d1
11  001018          2409            MOVE.L   a1,d2
12  00101a          1db6            MOVE.B   (0,a6,a2*1),(0,a6,a1*1)
                    a000
                    9000
13  001020          3039            MOVE     try,d0
                    00000200
14                                  .macro   foobar x y
15                                  MOVE     x,y
16                                  .endm
17  001026          3039            foobar   try,d0
                    00000200
18  00102c          3409    abc :   MOVE     a1,d2
19  00102e          33c0            MOVE     d0,abc
                    0000102c
20  001034          0a              DC.B     10
21  001035          62              DC.B     'b'
22  001036          0005            DS.B     5
23                                  END
** TOTAL ERRORS ** 0

SYMBOL TABLE

try             200
abc             102c
```

Appendix C. *USER MANUAL*

C.1 *SOURCE PROGRAM CODING.*

C.1.1 *Comments.*

A comment may be inserted at the beginning of a line.

Examples: | This entire line is a comment.

C.1.2 *Executable Instruction Format.*

Each source statement has an overall format that is some combination of the following four fields: a. label b. operation c. operand d. comment.

a. Label Field A label starts in any column and terminates with a colon (:).

b. Operation Field The operation field follows the label field and is separated from it by at least one space. Entries in the field fall under one of the following categories:

- Operation codes -- which correspond to the MC68000 series instruction set.
- Directives -- pseudo-operation codes for controlling the assembly process, and macro calls for inserting a previously-defined macro.

The size of the data field effected by an instruction is determined. Some instructions can operate on more than one data size. For these instructions, the data size code must be specified or a default size of word(16-bit) will be

assumed. The data size is specified by a period (.), appended to the operation code, and followed by B (byte), W (word), or L (long word).

c. Operand Field

When two or more operand subfields appear within a statement, they must be separated by a comma.

C.2 *EXPRESSIONS.*

An expression is a combination of symbols, constants, algebraic operators, and parentheses. The expression is used to specify a value which is to be used as an operand. The operators in the assembler are:

+ , - , * , / , and unary minus.

C.3 *SYMBOLS.*

A symbol is a string of alphanumeric characters, whose first character is alphabetic. The symbols A0-A7, D0-D7, CCR,SR,SP,USP,CACR,CAAR,VBR, SFC and DFC are special symbols used by the assembler, and cannot be used in the label field.

Some of the expressions cannot be evaluated during the first pass because they may contain references to symbols which have not yet been defined. If a symbol is not defined before being used in the second pass, it is treated as an error.

C.4 *NUMBERS.*

A number may be used as a term of an expression or as a single value. A number may assume any of the following formats:

Decimal	a string of decimal digits. ex. 2321
Hexadecimal	0x followed by a string of hexadecimal digits. ex. 0x34fa
Octal	a 0 followed by a string of octal digits. ex. 02344
ASCII	a string of ASCII characters enclosed in apostrophes. ex. 'z'

C.5 *REGISTERS.*

The following registers are recognized by the assembler:

d0-d7,D0-D7	Data Registers
a0-a7,A0-A7	Address Registers
a7,A7,SP	System stack pointer of the active system state.
SR	Status Register
CCR	Condition Code Register
CACR	Cache Control Register
CAAR	Cache Address Register
VBR	Vector Base Register
DFC,SFC	Destination and Source Function Code Registers

C.6 *VARIATIONS OF INSTRUCTION TYPE.*

Certain instructions (ADD,AND,CMP,MOVE,NEG,OR,and SUB) allow variations in their basic opcodes. The variations are recognized by a single letter suffix appended to the opcode: A(for address), I(for immediate), Q(for quick), M(for memory), and X (for extend).

If one of these forms was desired, the programmer has to declare it explicitly.

C.7 *ADDRESSING MODES.*

Please see the user's manual.

C.8 *ASSEMBLER OUTPUT.*

Assembler outputs include an assembly listing, a symbol table , and an object code file. An example of assembly listing is given in the appendix B.

C.9 *ASSEMBLER DIRECTIVES.*

ORG The ORG directive changes the program counter to the value specified by the expression in its operand field.

ORG <expression>

END The END directive indicates to the assembler that the source is finished. Subsequent source statements are ignored.

END

EQU The EQU directive assigns the value of the expression in the operand field to the symbol in the label field.

<label> EQU <expression>

DC The function of the DC directive is to define a constant in memory.

DC.B <operand>

DS The DS directive is used to reserve memory locations. The contents of the memory reserved are not initialized in any way.

DS.B <operand>

LIST Print the assembly listing on the output device.

LIST

NOLIST Suppress the printing of the assembly listing.

```
NOLIST
```

NOOBJ Suppress the generation of object code.

```
NOOBJ
```

C.10 *DEFINING A MACRO*

The definition of a macro consists of three parts: the header, the body and the terminator.

```
Example:        .macro   TAG a,b,c
                 ADD     a,D1
                 ADDX    b,D1
                 SUB     c,D1
                 .endm
```

The header contains the macro name which is TAG and the dummy arguments a,b,c. The body contains the pattern of source statements. The terminator is the .endm directive.

In this assembler the nesting of macro definition is not permitted.

C.11 *CALLING A MACRO*

The macro call statement is made up of two basic fields: the operation field (containing the macro name) and the operand field (containing substitutable values).

```
Example:          TAG     A0,A1,A2
```

C.12 *INVOKING THE CROSS ASSEMBLER*

The command line format for the assembler is:

```
        mas  <machine type>  <options>  <source file>
```

The assembler recognizes the following options on the command line:

-o	produce object code
-l	produce listing

The machine types are:

-0	accept MC68000 machine instruction set (default)
-8	accept MC68008 machine instruction set
-1	accept MC68010 machine instruction set
-2	accept MC68020 machine instruction set

Example: mas -0 -l -o input.mas

The file name of the object code is objcod. The listing file is called outlis.

C.13 *ERROR CODES*

203 IMPROPER TERMINATION OF OPERAND FIELD -- the operand field is not terminated correctly.

205 SIZE SUBFIELD NOT ALLOWED FOR THIS OPCODE -- this opcode does not allow the specified size of B, W, or L.

208 DISPLACEMENT RATE (SIZE) ERROR -- the number of bytes between this instruction and the address referenced is too large.

209 ILLEGAL ADDRESS MODE FOR THIS INSTRUCTYION -- an illegal address mode has been used for this type of opcode.

219 TOO MANY OPERANDS FOR THIS INSTRUCTION -- more operands are specified for this opcode than it requires.