A LISP INTERPRETER: SCANNER AND PARSER

by

DAVID CLARENCE BOSSERMAN

B.G.S., University of Nebraska at Omaha, 1969

A MASTER'S REPORT

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Computer Science

KANSAS STATE UNIVERSITY

Manhattan, Kansas
1977

Approved by:

Linda Shapiro
Major Professor

TABLE OF CONTENTS

SECTION NAME CHAPTER THREE SCANNER PAGE

SECTION NAME CHAPTER FOUR PAGE
PARSER

CHAPTER FIVE
INTERDATA 8/32 INFORMATION

CHAPTER SIX
TESTING

APPENDICES

ILLUSTRATIONS

Chapter 1

PROJECT CONCEPTS AND DESIGN

1.1 INTRODUCTION

In this paper a portion of a LISP Interpreter is proposed for use on minicomputers. The development of the interpreter was done in the FORTRAN Language. The purpose of the project was:

(1) To design a LISP Interpreter.
(2) To code the scanner and parser in a high-level language.
(3) To exercise the program on the INTERDATA 8/32 computer.

Before the details of the program are discussed, program concepts will be addressed, and a discussion of the interaction with the INTERDATA 8/32 will be presented.

1.2 LISP LANGUAGE

The LISP language is a LISt Processing language. It is designed primarily for symbolic data processing and has been used extensively in solving mathematical problems, working with electrical circuit theory, game playing and other applications of artificial intelligence.

LISP is a formal mathematical language. As such, it is possible to give a clear, concise and complete definition of it. Due to these qualities, it is an excellent language to work with in designing, coding and implementing an interpreter.

This project deals with the implementation of the LISP

1.5 Programming Language. It is not restricted at all by the design structure of the scanner or parser. In fact, the scanner and parser modules were designed for maximum portability and adaptability.[1]

1.3 LISP INTERPRETER SYSTEM DESIGN

The interpreter's system design consists of one driver module and five major subsystem driver modules. (See Figure 1-1.) Each module will be discussed separately.

1.3.1 LISP DRIVER

The LISP DRIVER module contains two major categories of data: (1) information concerning the module itself; and (2) the common data declared for intersubroutine use. The code for this module is in APPENDIX B.

1.3.2 INITIALIZER DRIVER

The function of the INITIALIZER module is to: (1) control memory management; (2) initialize the function tables; and (3) initialize the argument tables. This driver and its functional routines were prepared by Lee R. Whitley and are discussed in his report.

---

[1] John McCarthy et al., LISP 1.5 Programmer's Manual (Cambridge: The M.I.T. Press, 1973), p.1.

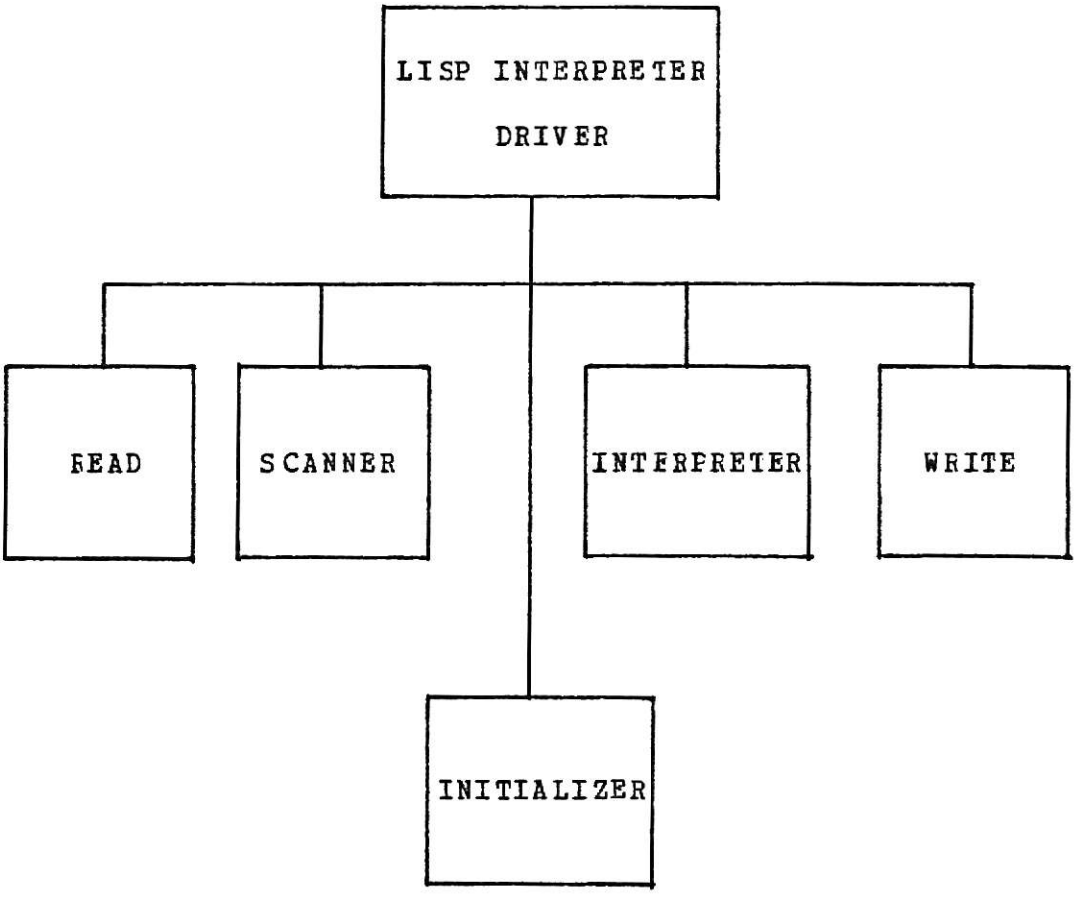


Figure 1-1

1.3.3 READ MODULE

The read routine is responsible for: (1) requesting memory space from the memory management routines; and (2) reading the user's program into addressable storage locations. The code for the read routine is found in APPENDIX C.

1.3.4 SCANNER DRIVER

The scanner routine is a driver routine. It calls the token generator routine and symbol table search routines. It causes the user's program to be scanned. From this scan an address array is generated showing: (1) the location of each symbol/string in the user's program; (2) the length of each symbol/string; (3) its keyword/function status; and (4) its location within a keyword/function table, if applicable. The scanner code is in APPENDIX D.

1.3.5 INTERPRETER DRIVER

The interpreter performs two major functions. It initially creates a general tree representation of the user's program. Once the general tree has been created, it is passed to the execution modules. The general tree construction modules are in APPENDIX E. The execution routines have not been completed and are to be the subject of a future reports. The interpreter module is in APPENEIX E.

1.4 MODULE CONSTRUCTION AND INTERACTION

The modules utilized in this interpreter were designed using a top-down structured programming approach. Each module has been restricted to one path into the module and one path out upon completion of its function. Each module has also been restricted in the number of lines of code

which it contains. No module contains more than 100 lines of executable code.

The modular concepts have also been implemented in module interaction. Except for several modules calling memory management routines, no modules interact outside the span of control of a mutual driver. Any passing of data is done through call parameters or common storage.

1.5 INTERDATA 8/32

The INTERDATA 8/32 Computer was used to test the interpreter. It provided an excellent contrast of small vs large computer procedures. The INTERDATA is a very reliable computer but, due to the newness of its hardware and software, caused many problems during project completion. The INTERDATA and its peculiarities will be discussed in greater detail in Chapter 5.

1.6 SUMMARY

The project discussed in this report is one part of a three part effort to develop a high-level language LISP interpreter. The specific parts of the interpreter covered by this report are: (1) the READ module; (2) the SCANNER modules; and (3) a portion of the INTERPRETER modules. All portions covered by this report are complete and have been tested.

The INTERDATA 8/32 was used to test the interpreter modules. It provided an excellent vehicle for the testing

as it demonstrated the pitfalls and frustrations to be encountered on a computer which is relatively new and without complete maintenance and software packages.

Although users working on smaller computers will find that more time and effort is required to accomplish tasks, this report shows that with perseverance and hard work, comparable results to large computer output can be obtained.

Chapter 2

READING THE USER'S PROGRAM

2.1 INTRODUCTION

This chapter presents information concerning the specifics and requirements of the read module. The read module (named INREAD) does not drive any other modules. Its function is simply to read the user's program into storage so that the program may be processed by other modules. The code for INREAD is in APPENDIX C.

2.2 INREAD SPECIFICS

The INREAD module is designed to read the user's program into storage. The module is called from the LISP INTERPRETER DRIVER module and has the relationship shown in Figure 2-1. Note that INREAD only calls one module, ISINIT. ISINIT is the routine that gets space from memory management when required.

2.2.1 PARAMETERS

The INREAD parameters are: (1) IFIRST, the beginning logical address in memory of the user's program; (2) IDONE, the ending logical address in memory of the user's program; and (3) ISTART, the last logical address passed to the routine by memory management. The IFIRST and IDONE variables are used by the scanner routines to convert the

user's program into a sequence of tokens.

READ MODULE RELATIONSHIP

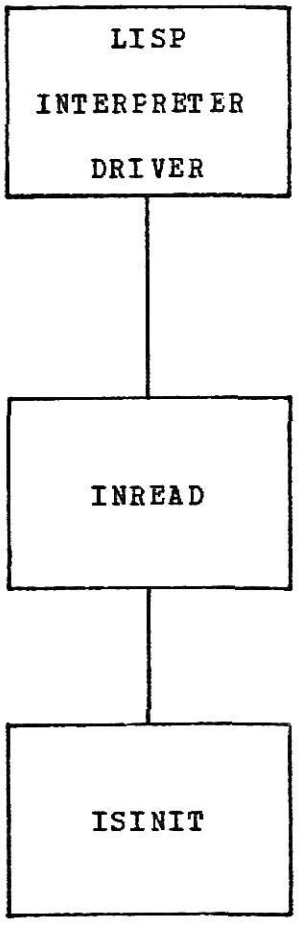


Figure 2-1

2.2.2 INPUT

The input required by the INREAD module are: (1) the user's program; and (2) a portion of an array called ISPACE which is acquired from memory management. As stated in chapter one, the user's program will be read from a file

created by the user. The file may be created by sitting at a terminal and typing it, or by allocating space for the file at a terminal and reading cards from the card reader into the file. The association of the input file with the reader logical unit in the program is done after the program tasks are loaded. In the interpreter, all reader logical units are logical unit 5. Therefore, if the user created his input file and called it INPROG, his assignment would be:

AS 5,INPROG

The other input required by this program is the logical addresses of space allocated by memory management to store the user's program. Logical addresses in this sense mean the array elements allocated. A contiguous block of space is requested so that later processing can be efficiently accomplished. Contiguous space is assured by sending a code to the memory management routine. A code of IBLOCK=0 causes contiguous space allocation whereas a code of IBLOCK=1 informs the memory routines that headers may be written for the space acquired.

2.2.3 OUTPUT

The output produced by INREAD is: (1) the user's source program stored in an array called ISPACE; (2) space allocated to enter the level of parentheses; (3) the array element which contains the start of the user's program; and (4) the array element which contains the ending of the user's program.

The user's source program with appropriately numbered parentheses is retained until execution of the program is completed. This is done for several reasons. First, it provides a list file of the program for output purposes. Second, it allows for error marking if desired in later implementations. Finally, it is required because other modules simply point to the various keywords/strings contained in the program. Therefore, there is no requirement for any rewriting of strings into any storage space.

Note that space is also allocated for the numbering of parentheses. This is done so that the parentheses levels, when determined can be retained. This precludes having to call a level determining routine every time the level is required. It also enhances the tree construction in the INTERPRETER modules.

Chapter 3

SCANNER

3.1 INTRODUCTION

This chapter presents information concerning the scanner modules. The scanner modules are designed to: (1) scan the user's program and record each string's position and length; and (2) update the token to provide information concerning whether a string is a keyword, and if so, in which symbol table it is found and its location within the table.

The scanner driver routine is called ISCAN. ISCAN calls the routines ISTKGN and ISSMTB to accomplish its mission. The relationship of the modules is shown in Figure 3-1.

3.1.1 GRAMMAR

The grammar used by the interpreter consists of the following reductions:

(1) <LETTER>::= A|B|C|D...|Z|SPECIAL CHARACTERS

(2) <NUMBER>::= 0|1|2|3...|9

(3) <BLANKS>::= ONE OR MORE BLANKS

(4) <ATOMIC SYMBOL NON-NUMERIC>::=<LETTER><ATOM PART>

(5) <ATOMIC SYMBOL NUMERIC>::=<ATOMIC SYMBOL INTEGER>|
<ATOMIC SYMBOL FLOAT>

(6) <ATOMIC SYMBOL INTEGER>::=<NUMBER>|
<NUMBER><ATOMIC SYMBOL INTEGER>

(7) <ATOMIC SYMBOL FLOAT>::=<ATOMIC SYMBOL INTEGER>.|
<ATOMIC SYMBCL INTEGER>.<ATOMIC SYMBOL INTEGER>|
0.<ATOMIC SYMBOL INTEGER>

(8) <ATOM PART>::=<NULL>|<NUMBER><ATOM PART>|
<LETTER><ATOM PART>

(9) <S-EXPRESSICN>::=<ATOMIC SYMBOL NON-NUMERIC>|
<ATOMIC SYMBOL NUMERIC>|
(<LIST>)

(10) <LIST>::=<S-EXPRESSION>|
<S-EXPRESSION><SEPARATERS><LIST>

(11) <SEPARATERS>::= <BLANK>|<BLANK.>[2]

The atomic symbol, or atom, is the most elementary type of S-expression. It can be numeric or non-numeric. If the string is non-numeric, it is considered a literal atom and consists of a string of capital letters and decimal digits having a letter as the first character. The atomic symbol is called atomic because it is taken as a whole and not viewed as individual characters.

S-expressions are non-atomic. They are built of atomic symbols and punctuation marks. The S-expression is always surrounded by a set of parentheses and always has two parts, a left part and a right part. Either part can be a null string. The S-expression can be either: (1) an atom; (2) a pair of atoms separated by a dot or spaces; or (3) a pair of S-expressions separated by a dot or spaces.[3]

---

[2] Ibid., p.8.
[3] Clark Weissman, LISP 1.5 Primer (Belmont, California: Dickenson Publishing Company, Inc., 1967), pp.5-6.

3.1.2 OVERVIEW

The user's program is scanned in two separate phases. The first phase, using the ISTKGN modules, causes: (1) a token to be stored for each string, left parenthesis and right parenthesis; and (2) all space delimiters and period delimiters to be ignored. Each token generated contains the logical address and length of a parenthesis or string in storage. These tokens are expanded in the second phase of the scan.

The ISSMTB modules perform the remainder of the scanner operation. They process each initial token and determine if the token represents a keyword found in the keyword tables. If so, the token is expanded to record in which table the keyword was found and where within the table it was found. If not, the token is expanded to record that the string is program unique. Once all tokens are expanded, control is returned to the LISP INTERPRETER DRIVER and a parse of the tokens is begun.

3.2 ISCAN

The ISCAN module causes tokens to be generated which provide: (1) the location of a string in memory; (2) the length of the string; (3) the key word table that the string is listed in, if applicable; and (4) the location of the string within the table, if applicable.

The ISCAN routine does no processing of the user's program per se. It simply acts as a driver routine and

calls the routines ISTKGN and ISSMTB in that order. ISTKGN is responsible for identifying strings and recording their location and length. ISSMTB is responsible for performing the table lookup function to complete the token. The ISCAN module's code is located in APPENDIX D.

SCANNER MODULES RELATIONSHIP

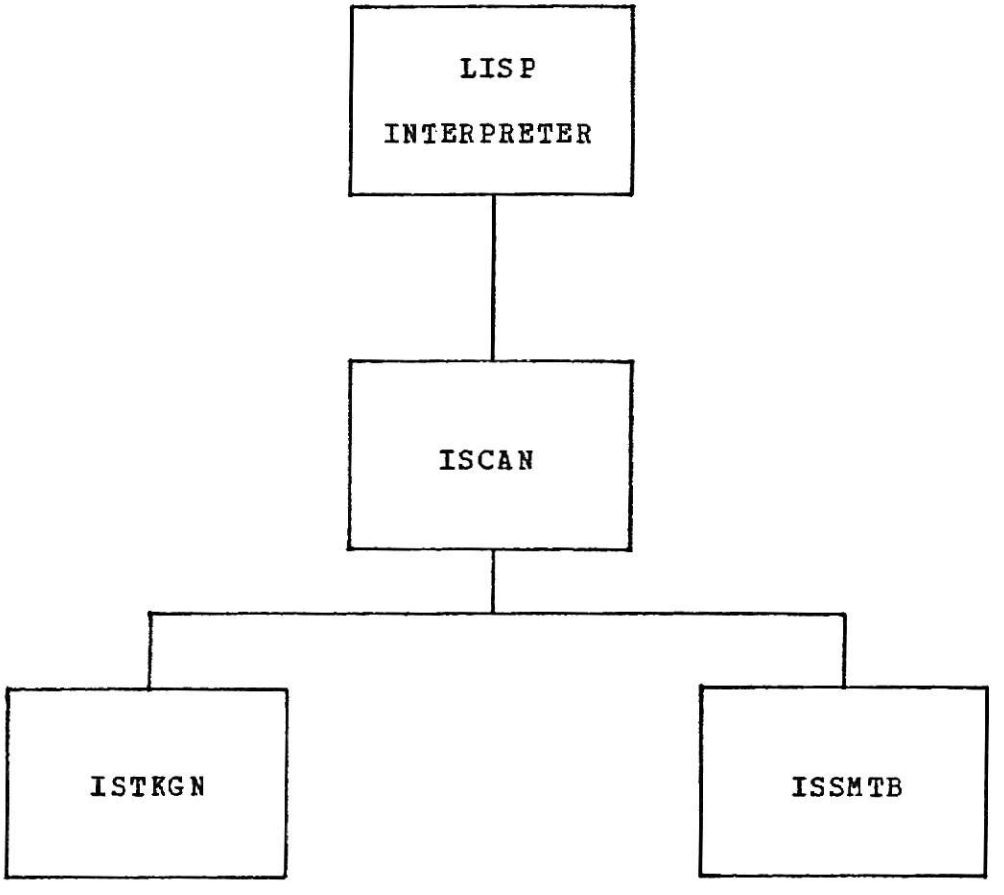


Figure 3-1

3.3 ISTKGN

The ISTKGN module causes the first two items of a

general token to be processed and placed in a token array. The array created will remain in existance until the user's program has completed execution. The space acquired from memory management will again be contiguous space to facilitate future processing.

ISTKGN is not a driver module. Its purpose is to process each array element containing the user's program and call the appropriate subroutine: (1) if a parenthesis is encountered; (2) if a string is enccuntered; and (3) if a null s-expression is encountered.

The format of the initial token generated by ISTKGN is as shcwn in Figure 3-2. In the ISSMIB routines the tokens generated by ISTKGN will be expanded to show the location of the strings within keyword tables, if applicable.

INITIAL TOKEN FORMAT

Figure 3-2

3.3.1 PARAMETERS

The ISTKGN parameters are: (1) IFIRST, which represents the first element in the array ISPACE containing the user's program; (2) IDONE, which represents the last

element in the array ISPACE containing the user's program; (3) IJUMP, which represents the first element in the array ISPACE containing the tokens generated; and (4) ISTART, which is initially equal to IDONE and is updated to represent the last element in the array ISPACE containing a token.

3.3.2 INPUT

The majority of the input to this routine is done through parameters passed. The only other input is the array elements allocated, upon request, by memory management to store the tokens generated.

3.3.3 OUTPUT

The output generated by this routine is a sequence of tokens representing the beginning address and length of each string in the user's program. These tokens are stored in the array ISPACE and their locations are passed to other routines by passing the beginning element (IJUMP) and the ending element (ISTART).

3.3.4 MODULAR ORGANIZATION

Although the routine ISTKGN is not solely a driver module, it does call three other modules to process the symbols. Those modules in turn call the module ISINIT to acquire space from memory management. The modular

relationship is shown in Figure 3-3.

ISTKGN MODULAR RELATIONSHIP

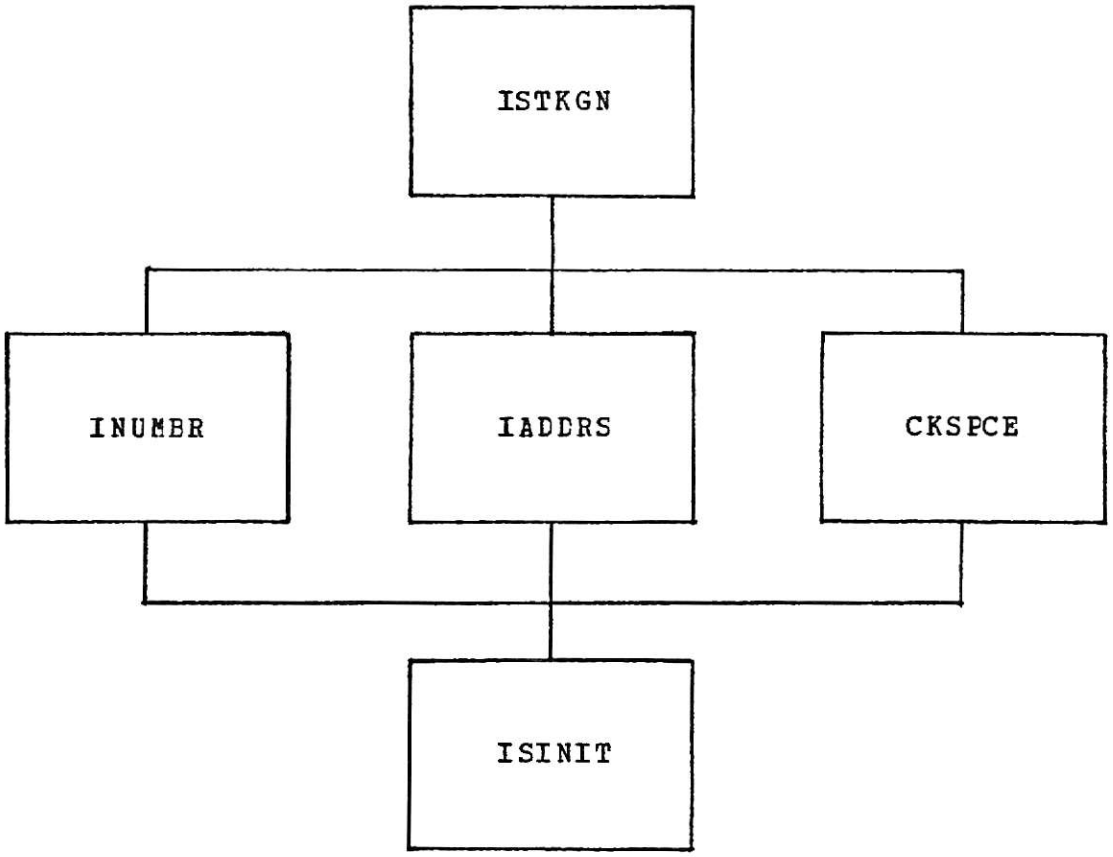


Figure 3-3

3.3.5 OVERVIEW

The high-level algorithm used by the scanner is shown in Figure 3-4. As the algorithm shows, ISTKGN accomplishes its function by looking at every character represented in the user's program. Because parentheses are used abundantly

in LISP programming to show levels, the module first looks

SCANNER HIGH-LEVEL ALGORITHM

```
DO WHILE NOT END OF FILE;
  GET NEXT CHARACTER

CASE 1   CHARACTER IS LEFT PARENTHESIS
         GET TOKEN SPACE
         PUT LOCATION AND LENGTH=1 IN SPACE

CASE 2   CHARACTER IS RIGHT PARENTHESIS; NUMCHR=0
         GET TOKEN SPACE
         PUT LOCATION AND LENGTH= 1 IN SPACE

CASE 3   CHARACTER IS RIGHT PARENTHESIS; NUMCHR GT 0
         GET TOKEN SPACE
         PUT STRING AND NUMCHR IN SPACE
         GET TOKEN SPACE
         PUT LOCATION OF PARENTHESIS AND
           LENGTH=1 IN SPACE

CASE 4   CHARACTER IS SPACE; NUMCHR=0
         IF LOCATION-1 IS LEFT PARENTHESIS AND
            LOCATION+1 IS RIGHT PARENTHESIS
          THEN: GET SPACE
                PUT LOCATION AND LENGTH=1 IN SPACE
          ELSE: NULL

CASE 5   CHARACTER IS SPACE; NUMCHR GT 0
         GET SPACE
         PUT LOCATION-NUMCHR AND LENGTH IN SPACE

CASE 6   CHARACTER IS PERIOD; NUMCHR=0
         NULL

CASE 7   CHARACTER IS NOT CASE 1 - CASE 6
         INCREMENT NUMCHR

END DO WHILE;
```

Figure 3-4

to see if an element contains a parenthesis. If so, the routine INUMBR is called to process it. If it is a left parenthesis the level number assigned to it will be one greater than the last left parenthesis unless a right parenthesis has appeared since the last left parenthesis. If this is the case, it will carry the same number as the last left parenthesis as it is at the same level. If the parenthesis encountered is a right parenthesis, INUMBR is called to assign it the proper number. Whenever INUMBR is called, a token is generated.

If the element processed is not a parenthesis, it could be a delimiter (space or period) or a string. If it is a string, a counter is incremented and processing continues until a parenthesis or delimiter is encountered.

Once a delimiter is encountered, the string represented by the length counter is placed in the token array. One exception to this procedure is made. If a space is encountered, and the length counter is zero, the routine called ICKSPC is called to check the space to see if it is in fact a null string. If so, a token is generated. A null string is defined as a left parenthesis, single blank character, and a right parenthesis. If any other combinations of parentheses and blank characters occur they will not be recognized as a null string.

3.4 INUMBR

The INUMBR routine is responsible for numbering

parentheses. The parentheses' numbers are called level numbers and are stored in memory in the space allocated when the user's program was read. (See Paragraph 2.2.3.) After storage they are used by the parser to determine argument and S-expression length. They are also available to be printed by the WRITE modules for user convenience. The routine must deal with two major situations. The first is the situation of a left parenthesis. The procedure then is to simply number the parenthesis with the appropriate number. The second situation is the case of a right parenthesis which closes a string. In this case the routine is required to construct a token for the string and a token for the parenthesis. The code for INUMER is in APPENDIX D. The only other module called by INUMBR is ISINIT to get space to store the tokens generated.

3.4.1 INPUT

The input data to the INUMBR routine are: (1) whether the element is a left or a right parenthesis (INB); (2) the location of the array element pointer (I); (3) the number of characters found in the string; and (4) the current parenthesis level (N).

Of course, there is a continuing global input from memory management. This input provides the space to store the tckens generated.

3.4.2 OUTPUT

The output data are provided to allow modules to properly continue processing. IPROCE is a code which keeps ISTKGN from double processing an element. ISTART is passed so that the end address of the token array can be set.

3.5 IADDRS

The IADDRS routine is called when a string exists and a space delimiter is encountered. The existence of a string is known because NUMCHR is greater than zero. Note that the period delimiter does not enter into this routine because period delimiters are preceded by a space and succeeded by a space. Thus, a period is essentially read and skipped. The code for IADDRS is in APPENDIX D.

3.5.1 INPUT

The input required for the IADDRS routine consists of those variables necessary to identify the end of the string (I), and the length (NUMCHR). With this data the necessary token can be generated

In this module, an additional input is required from memory management. Memory management must provide the array element to store the token generated.

3.5.2 OUTPUT

The data output by this module are; (1) the token

representing the beginning address and the length; and (2) the pointer to the array element which contains the token.

The variable IPROCE is assigned a code value and passed back to the calling routine. This code prevents double processing of an element.

3.6 CKSPCE

The CKSPCE routine performs the function of testing blank characters, when NUMCHR is equal to zero, to see if the blank character represents a null string. To accomplish this task, the routine requires one look back and one look forward. The look back and look forward are done to see if the space is surrounded by parentheses.

CKSPCE only requires the pointer to the blank character in the source program. Using that pointer a look back and look forward can be accomplished. IPROCE is used as stated above, as is ISTART.

3.7 ISINIT

Although the ISINIT routine is not used only by the ISCAN routines, it will be discussed at this time. The ISINIT routine is a utility routine used to get space from memory management.

Three parameters are passed to ISINIT. The two input parameters are: (1) NUMRQD, the number of array elements required from ISPACE; and (2) IBLOCK, a code which informs memory management when contiguous storage is needed and when

to cancel it. If IBLOCK equals 1, contiguous storage is required. If IBLOCK equals 0, contiguous storage is either no longer required or not required at all. The output parameter ISTART contains the beginning array element allocated by memory management.

As a utility routine ISINIT is called by any routine requiring space in memory. The code for ISINIT is in APPENDIX D.

3.8 ISSMTB

ISSMTB processes the tokens generated by ISTKGN and expands them. In the expanded token, a table location and table are added to the already existing beginning address and length. The code for ISSMTB is found in APPENDIX D. The format of the expanded token is shown in Figure 3-5.

The digit representation for the token is: (1) Beginning Address=(4 digits); (2) Length=(2 digits); (3) Table Location=(2 digits); (4) Table=(1 digit); and (5) Mark=(1 digit). The beginning address and length are the same as determined in ISTKGN. The number placed in the table field is the number of the keyword table in which the string was found. The table location field contains the element within the table which represents the string. The keyword tables are initialized by the INITIALIZER modules and remain in storage until execution is complete. The mark field is not used by the scanner or parser. It was implemented to be used by the execution modules. For example, in Figure 4-2, CAR is represented in token form as

1030310. This shows that it is stored in position one of the user's program and has a length of 3. It is also contained in keyword table 3 in position 1.

EXPANDED TOKEN FORMAT

BEGINNING ADDRESS	LENGTH	TABLE LOCATION	TABLE	MARK

Figure 3-5

3.8.1 INPUT

The input data to ISSMTB are the array containing the tokens generated in ISTKGN along with the beginning (IJUMP) and ending (ISTART) pointers. No other input is required.

3.8.2 OUTPUT

ISSMTB outputs an expanded token array. It requires no additional space from memory management. IFINSH is output as a pointer to the last element in the token array. As the expanded tokens occupy the same array elements as the tokens generated in ISTKGN, no other pointers are required.

3.9 ISYMCK

ISYMCK is called by ISSMTB. It takes the data passed from ISSMTB and conducts a table search of the appropriate key word table to see if a match of data occurs. The purpose of this routine is to provide to ISSMTB the table number and table location of a string. If the string is not found, zeroes are returned indicating a program unique string. The code for ISYMCK is in APPENDIX D.

3.9.1 INPUT

The input data, I and ILNGTH, are used to load a dummy array (ICCNVT) with the string being processed. However, if the length is greater than 12, a return to the calling routine is made. This is because none of the key words are greater than twelve. Because FORTRAN only allows eight characters to be stored in a double word, all words of length nine through twelve are truncated to eight. All key words of length eight to twelve are in the same table. This causes no great concern because the eight character key words and the truncated words are unique. The one caution to be made is to the user. He or she must be aware of this peculiarity to preclude the use of a character string which would match a truncated word. The strings in question are DIFFEREN, EVALQUOT, INTERSEC, LEFTSHIF, REMAINDE, FACTORIA, and UNSPECIA.

3.9.2 OUTPUT

The output provided by ISYMCK consists of the table in which a string is found (ITABLE), the location within the table (ILOCAT), or 0 for ITABLE and ILOCAT if the string is either too long or not found.

3.9.3 OVERVIEW

The user's program is stored one character to a full word. This was done for ease of processing in other modules. In this module the data in up to eight full words must be compacted into one double word. This is accomplished through a core-to-core read.

For convenience the string data is read into an eight element array. A process called ENCODE is then performed. ENCODE causes the string to be read and changes the format from A4 to A1. Thus, only the first byte of each word is read. However, the INTERDATA routine requires a block of 132 bytes to use the ENCODE function. The format shows the 132 bytes, but only the first eight are used in the comparison.

To compact the first eight characters into one double word the INTERDATA process called DECODE is performed. By writing the first eight bytes of the ENCODED block into a double word (ICHECK), using a format of A8, the string is then in the same format as the strings found in the keyword tables.

After this is accomplished, a normal table lookup procedure is followed. Each table is of the same length,

and as such some tables have empty elements. To preclude having to search all elements in a table, all empty elements are filled with a sentinel represented by '<'. If the sentinel is encountered before a match is found, a return to the calling routine is made. If not, IFOUND, is set to 1 and a return is made.

Chapter 4

PARSER

4.1 INTRODUCTION

This chapter presents information concerning the implementation of the INTERPRETER modules. The INTERPRETER modules are designed to: (1) construct nodes to provide a general tree representation of the user's program; (2) execute the user's program.

This project is only concerned with the first case and will not address the execution phase at all. The general tree construction routines require the interaction of eleven modules. The modules are called depending on the string being processed. The modular relationship of the INTERPRETER is shown in Figure 4-1.

4.1.1 OVERVIEW

The INTERPRETER modules perform a parse of the user's program using the expanded tokens generated in ISSMTB. The parse consists of looking at the token representations and creating a general tree. The nodes used for the tree are discussed in section 4.2 below. The creation of a general tree representation of a short program is shown in Figure 4-2.

The figure shows the relationship between the nodes of the tree. Each node consists of sixteen bytes. The sixteen bytes allowed are divided, from left to right as follows:

FIELD	LENGTH	DESCRIPTION
1	4	LOCATION
2	4	LENGTH
3	4	SON
4	3	BROTHER
5	1	MARK

The LOCATION field contains the logical address in storage of the expanded token being represented by the node. The LENGTH field contains the number of expanded tokens represented by the node, if the node LOCATION field points to a left parenthesis expanded token. If it does not, the LENGTH field is zero as the node represents only one expanded token. The SON field points to the next level subordinate node. The BROTHER field points to a node of equal status at the same level. The MARK field is designed to be used in testing and future applications. It has no current significance and is set to 2. For example, in Figure 4-2, CAR has the one argument (A B). The son field of the CAR node contains a 2, indicating that the argument is found in node 2. Node 2 represents a string starting with the expanded token array element 162 and has a length of 4 (from the LENGTH field). Node 2 is not terminal since it has a pointer in its SON field. Following the pointer, it can be seen that node 3 (A) is a son of node 2. Node 3 represents a terminal node because its SON field is null. Its brother field contains a pointer to B. The tree representation is then complete.

To create this type of general tree requires the use of the high-level algorithm shown in Figure 4-3. Note that the entire algorithm is based on processing parentheses or strings. The separators have been eliminated during the

scanning process.

INTERPRETER MODULAR RELATIONSHIP

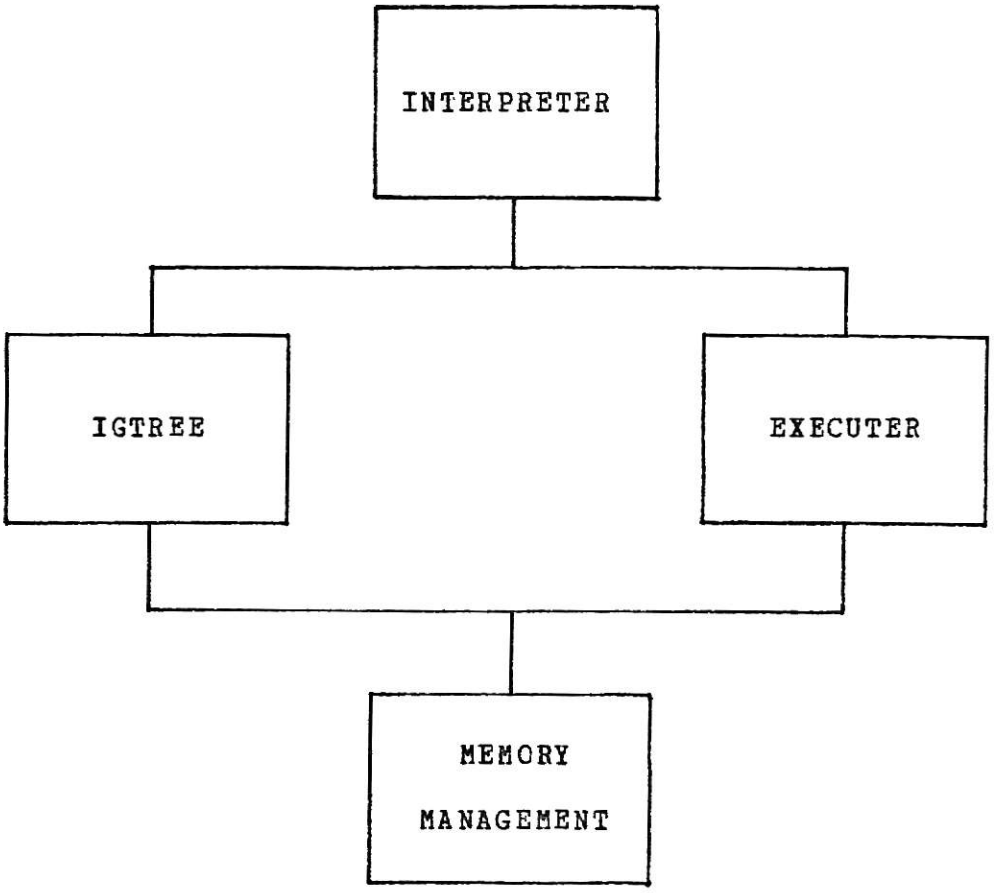


Figure 4-1

4.1.2 DRIVER

The driver module for the interpreter modules is called by the LISP INTERPRETER DRIVER. It in turn calls the module IGTREE which generates a double word array of tokens representing a general tree. Eventually, the driver will also call the necessary module to cause the execution of the

program.

The driver module receives the beginning array address and the ending array address of the tokens generated by ISCAN. It will pass on to the executer the beginning and ending addresses of the nodes representing the general tree.

GENERAL TREE REPRESENTATION

PROGRAM: CAR (A B)

EXPANDED TOKENS:

STRING	TOKEN	ARRAY ELEMENT
CAR	1030130	161
(	5010110	162
A	6010000	163
B	8010000	164
)	9010210	165

GENERAL TREE NODES:

NODE	NODE NUMBER
1610000000020002	1
1620004000300C002	2
1630000000000042	3
1640000000000002	4

TREE STRUCTURE

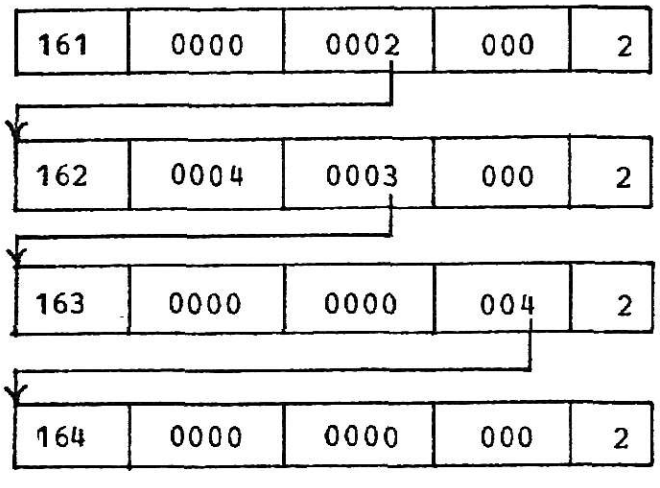


Figure 4-2

HIGH-LEVEL PARSE ALGORITHM

```
DO WHILE ALL TOKENS NOT PROCESSED;

  GET NEXT NODE

CASE 1  INITIAL NODE
          GET FIRST TOKEN;
          PROCESS INTO NODE;
          PROCESSES ALL SAME LEVEL NODES;

CASE 2  NEXT NODE ON STACK
          IF TERMINAL
             THEN: GET NEXT NODE
             ELSE: PROCESS SON INTO NODE
```

Figure 4-3

4.2 IGTREE

The general tree routine is designed to produce an array of double words which represent a LISP program. Each double word contains information fields which provide the data necessary to traverse the general tree.

The IGTREE module acts as a control routine and calls the appropriate subroutine based on the character being processed. The code for IGTREE is in APPENDIX E.

4.2.1 INPUT

The input required to successfully execute this module

are: (1) IJUMP, the beginning array element of the expanded tokens being processed; (2) ISTART, the last array element containing the expanded tokens being processed; (3) the tokens stored in ISPACE; (4) the user's program stored in ISPACE; (5) the double word array to be filled by nodes; and (6) additional space in ISPACE to create a stack.

The space required in the double word array is similar to the space used to store the user's program. It must be contiguous and must remain in storage until the execution of the user's program is complete.

4.2.2 OUTPUT

IGTREE will output the beginning and ending array element containing the nodes constructed to represent the user's program. The nodes are stored in a double word array and will remain in the array until execution is complete. This allows the execution modules to access them as required.

4.2.3 OVERVIEW

IGTREE begins the processing by extracting the ISPACE array element address of the first symbol in the user's program from the first token. It then determines if the character at that address is a character, left parenthesis, right parenthesis, or a period. If it is a right parenthesis or a period, a fatal error message is returned and the program is terminated.

If the item is a character, the routine VARBLE is called to process it. If it is a left parenthesis, the routine ILPARN is called to process it. The continual look at a character and process it is a 'do while' operation. As FORTRAN does not have a 'do while' statement, a continuous loop GO TO is used with the exit parameter being the processing of all nodes.

When VARBLE or ILPARN is called, a new node is constructed. The pointer NXTPT will always point to a node that requires processing until all nodes are terminal. Thus, the node to be processed is determined by extracting the scn from the next node to be processed. The son field is the only field that contains a temporary address. Until the SON field is set to point to the double word array element representing the son, it is set to point to the ISPACE element representing the token of the first character of the SON. The first character in conjunction with the length acquired from the temporary stack provides the necessary data to continue processing.

4.3 VARBLE

The VARBLE routine is designed to process strings. It accomplishes its function by: (1) placing the token address within ISPACE in the location field; (2) if the string is followed by a left parenthesis, place the token address within ISPACE in the SON field; (3) if the string is followed by a left parenthesis, call a routine to find the rightmost same level parenthesis; and (4) if the entire

program has not been processed, continue steps 1-3 until complete.

By following the above procedures, the first pass of the user's program will produce all top level strings. These top level strings will point to each other in a hierarchy of first found to second and so forth until n-1 points to n. The pointing at the same level is done by filling the brother field of a node. Each top level node will contain in its son field the token address of its next level string.

4.3.1 PARAMETERS PASSED

The parameters passed by VARBLE are: (1) I, the token storage array element being processed; (2) IFINIT, the ending address of the token array; (3) NXTPT, the pointer to the next node to be processed; (4) IDSTA, a pointer to the first node of the general tree; (5) ISETD, the pointer to the last node of the general tree; (6) ISTART, a pointer to the last available space of a temporary stack; (7) IPARPT, a pointer to the temporary stack which contains the length of the next node to be processed; and (8) ICODE, a code which precludes double processing.

4.3.2 OVERVIEW

VARBIE is called from several routines and is called to process strings. Different treatment is required if the string is the initial item processed, or if the string

occurs after a set of parentheses. Thus, early in the routine there are conditional statements which cause branching to the appropriate part of the routine.

The node is initialized by multiplying the token's address by 1000000000000.D0 and placing the result in a double word array element obtained from memory management. Note that INTERDATA requires that a number as large as the node be handled as a double precision number. If the .D0 is not placed at the end of the number, there will occur an overflow loss of data and the results stored will not be precise.

Once the basic node is created, tests are made to see if it has a son and/or brother. If so, the node is updated to point to the son token's and/or brother token's array address. Processsing is then continued. When a son's address is placed in the parent node, its length is also stored on a tempory stack. The combination of the address and length will facilitate future processing.

4.4

ILPARN

ILPARN is a driver module. It performs the basic function of calling the appropriate routine to process a left parenthesis. If the left parenthesis is the first token being processed, LPFST is called. If the left parenthesis is encountered later in the program, LPLTR is called.

4.5 IRPARN AND IRERCD

IRPARN and IRERCD are error routines. If a right parenthesis is encountered for processing, an error is detected. This is due to the way in which parentheses are processed. When a node contains a left parenthesis, the son of that node is assigned the length of the node minus two. Using this approach, matched right parentheses are disposed of at the same time as the left parenthesis.

If a period is encountered for processing, an error is again apparent. This is because period separators are skipped during processing just like spaces.

Both modules print an appropriate error and return a fatal error code which causes program termination.

4.6 LRARN AND NXTPAR

LPARN is designed to find the furtherest same-level right parenthesis such that the token after the right parenthesis is not a same-level left parenthesis. This finds all the sub-expressions of an S-expression. It accomplishes this mission with the aid of routine NXTPAR. When a same-level right parenthesis is found NXTPAR is called. NXTPAR then looks ahead to the next character. If it is a same-level left parenthesis, processing is continued until another same-level right level parenthesis is found.

The code for LPARN and NXTPAR is found in APPENDIX E.

4.6.1 OVERVIEW

LPARN is called when a left parenthesis has been found. By the time LPARN is called a parent node for the left parenthesis has already been created. The routine then assigns the level of the left parenthesis to a varible called LEVEL. It then enters a loop to look at each character, in order, to find the right parenthesis with the same level number.

Once a right parenthesis with the same level number is found, NXTPAR is called. NXTPAR is designed to look ahead one character. If the look ahead causes the pointer IFINIT, the pointer to the last character, to be exceeded, a return is made immediately. If the next character is a left parenthesis, control is returned to LPARN and processing continues to find the appropriate right parenthesis. If not, a return to LPARN is made with a code of 1 meaning the next character is not a left parenthesis.

4.7 IFFST

IFFST is called if the first expanded token encountered by IGTREE is a left parenthesis. Its purpose is to create double word nodes representing the top level of the user's program and then to return control to IGTREE for further processing.

4.7.1 INPUT

The input to LPFST consists of: (1) I, the address in the expanded token array of the first character/string to be processed; (2) IFINIT, the address in the expanded token array of the last character/string of the user's program. The input is used to establish the bounds of a do loop to process the program and create general tree nodes.

4.7.2 OUTPUT

The output from LPFST consists of: (1) IPARPT, the pointer to the next element on the length temporary stack; (2) ISETD, the last double word array element obtained from memory management; (3) IDSTA, the first double word array element obtained from memory management; (4) ISTART, the last element of the length temporary stack; and (5) NXTPT, a pointer to the next node to be processed. The output parameters allow IGTREE to continue to process the nodes generated without double processing a node or asking for an element address that does not represent a node.

4.7.3 OVERVIEW

LPFST processes the initial level of nodes, if the first expanded token representing the user's program is a left parenthesis. It performs its functions by getting the necessary double word space from memory management and filling the space with node representations. The nodes are generated in the format discussed in IGTREE and portrayed in

Figure 4-2.

The code for LPFST is in APPENDIX E.

4.8 LPLTR AND IPROCL

LPLTR is designed to process S-expressions found between two same level parentheses. This entails creating a son node and putting a pointer to that node in the parent's SON field.

The length of the new parent node representation is retrieved from the length temporary stack. It must be remembered that LPLTR is only called when a left parenthesis is found as the first character of a SON field. Therefore, a loop is entered to look at all characters between the first left parenthesis and the last character in the length. When the same level right parenthesis is found IPROCL is called. IPROCL performs a similar function to NXTPAR. However, it is more powerful.

IPROCL first looks at the code passed. If the code is equal to 1, a brother is being processed. The brother field is set to point to the next node.

If the code is equal to 0, the parent node's son field is set to point to the next node to be acquired from memory management.

After acquisition, the creation of a parent node is accomplished for the string being processed. Then the length of the string is stacked on the length temporary stack.

After the new parent node is created a one character

look ahead is executed. If the next character exceeds the length of the string, a return is made. If not, and the next character is a left parenthesis, a return is made. If not, and the next character is a variable, the brother field is set and VARBLE is called.

The code for LPLTR and IPROCL is in APPENDIX E.

Chapter 5

INTERDATA 8/32 INFORMATION

5.1 INTERDATA 8/32

The INTERDATA 8/32 computer used to test the interpreter is owned by the Computer Science Department and is located in their computer facility. It has 64K bytes of memory and all required peripheral devices to enter, process and output a LISP program.

5.2 HARDWARE

The INTERDATA 8/32 hardware proved to be very reliable during the period of writing and testing this project. This is not to say that no problems occurred. There were faulty memory problems, disk overheat problems, and console problems. However, none of the problems occurred because a high level language LISP interpreter was being run.

One hardware characteristic does affect the manner in which the user's program must be entered in the system. The card reader (Model 080416P, True Data Corporation) does not have a capability for sensing an end of file and causing that status to be relayed. Therefore, the user must read his program into a local file and assign the local file name to the reader logical unit number when he desires to execute his program. If he attempts to assign the card reader to the reader logical unit number, he will receive an error message informing him that the card reader is empty.

5.3 SOFTWARE

The software package supplied with the INTERDATA 8/32 consists of: (1) nonproduction INTERDATA software; and (2) software generated by the personnel in the Computer Science Department. Generally speaking, the software caused the greatest time delays in completing this project. The major sources for the delays were: (1) system crashes caused by the software when legal commands were entered at the terminals; (2) faulty software which caused undecodeable error messages; and (3) a FORTRAN compiler that provides only bare essentials and little or no extensions to the FORTRAN language.

Some specific problems/peculiarities that occurred, and the solutions developed or implemented are discussed below.

5.3.1 COMMON DATA.

A problem occured when certain combinations of letters were used in conjunction with certain specification statements. An example of this type of error was the addition to common of an array called IALIST when IARG had been specified INTEGER*2. The program would compile, but upon execution a task error of 'WRONG PROG' would appear. After several days of debugging and tracing, it was determined that a change of name could cause the error to disappear. When an INTERDATA representative visited the department, the problem was brought to his attention. He

was nct aware of any solution to the problem although he did recall that the problem had surfaced at other installations. Because this one 'glitch' was critical, a call was made to the INTERDATA software manager in Chicago. He knew immediately what our problem was and provided a patch solution. He was able to convey, over the phone, that there was erroneous data stored in two addresses of the Task Establisher Task (TET) program. The addresses along with the proper data to be read into those addresses were passed to our software people. The data changes took approximately two minutes. The lesson learned was to contact the software people when a thorough analysis at KSU provided no insight into the problem.

5.3.2 DOUBLE PRECISION

The INTERDATA FORTRAN compiler does not have the power that the IBM compiler has. There are few extensions to the basic FORTRAN requirements of a compiler. A case in point is the treatment of double precision numbers. This project required a set of sixteen consecutive digits to act as node representations of a general tree structure. An integer representation was ruled out due to the limited number of integer digits allowed. A double precision number contains exactly the sixteen digits required. The IBM compiler has an extension to its compiler that treats any numerical operation performed during assignment to a double precision variable as a double precision number. Thus, if IDSPAC were declared as double precision and the assignment

IDSPAC=961*1000000000. were made, IDSPAC would contain 961000000000.. However, INTERDATA does not contain this extension. To obtain the same results from the INTERDATA compiler all numbers in an operation that produce more than ten digits must end in '.D0'. The above example would be entered as 961*1000000000.D0 to obtain the same assignment. Failure to do this causes the overflow of the least significant digits to be lost at each step in an operation.

5.3.3 JOB CONTROL LANGUAGE

The job control language on the INTERDATA does not provide any significant problems. It is not as powerful or as complete as IBM JCL. For example, when executing a FORTRAN program, the user must: (1) assign his object file to the proper logical unit; (2) assign his data to the proper reader logical unit; (3) assign his output to the proper printer logical unit; (4) load his own program for execution; and (5) start the execution. This lack of automatic assignments plus requirements for extensive user interaction in the execution of a program, causes many typographic errors and an increased time to run a program. A run time comparison of the general tree portion of this project was made. On the IBM computer it took 1 minute and 48 seconds from the time the start button on the card reader was pushed until the printer stopped printing. On the INTERDATA computer, the same program took 4 minutes and 12 seconds. Both runs were made in the early morning hours when little or no other activity was being processed.

5.3.4 DOWN TIME

When working with the INTERDATA 8/32 a considerable amount of frustration is generated as a result of the frequent crashes encountered. Equally as frustrating, is the amount of time the computer is not available for use due to maintenance backlog and environmentally created failures. An example of down time due to maintenance backlog is the period of approximately two weeks when there was a bad piece of memory. The bad memory had to be partitioned out of possible use. The partition size used almost 30% of available space. This caused considerable inconvenience because at the same time a PASCAL package was being tested for delivery. If, during this period, a user wanted to be sure of getting enough space to work when he wanted, he had to use the computer in the late evening and early morning hours. An example of environmental failures is the recurring loss of one disk drive due to the heat in the computer room. The climatic control devices in the computer facility are archaic and do not, during cold periods, keep the room at an appropriate operating temperature.

5.4 RUNTIME JCL

The runtime JCL for this program is in APPENDIX F. PART I shows the JCL to read a deck of cards into a file called INREAD. PART II shows the JCL required to establish the tasks for the program and PART III shows the JCL

required to run the program.

During the completion of this project, the JCL has changed three times. The data in APPENDIX F is the most current. User's will have to verify the JCL prior to use, to insure that no changes have been made.

Chapter 6

TESTING

6.1 INTRODUCTION

The scanner and parser were tested on the INTERDATA 8/32 using test programs with varying levels of difficulty. The simplest test was the input of atom 'A'. A more difficult test is the one found in APPENDIX H which is a factorial program with a trace option. The factorial program allows a good test of most of the subroutines written.

6.2 LEVEL OF TESTING

The factorial test program requires a tree construction with 19 levels. In addition, it provides several branches to brcther nodes with subsequent breakdowns. Therefore, the test of this program tests each subroutine except LPFST and LPROCE. LPFST and LPROCE were tested using programs such as (A B)(C D) and (A . B) and were found to function properly.

6.3 TEST PROGRAM

PART I of APPENDIX H shows the program being tested. Note that although it is a relatively short program, it has three nodes at the initial level, DEFINE, TRACE, and FACTORIAL. It also has a parentheses level count that goes as high as 9. Although 9 is the highest level achieved in

this test program, levels are actually limited only by the user's program. The program and the parentheses levels are shown in PART II of APPENDIX G to illustrate how the program is stored in memory. The subroutines used to accomplish PART I and PART II of the test were INREAD, ISCAN, ISTKGN and INUMBR.

6.4 TOKENS

The token generations are shown in PART III nad and PART IV of APPENDIX H. PART III shows the incomplete token generated by the routines called by ISTKGN. The incomplete tokens contain only the address within the array ISPACE and the length of the string. The last two digits contain the length and the first four contain the address. The first token represents the string DEFINE which is found in array element 8 and has a length of 6.

The expanded tokens are found in PART IV. The expansion is done in module ISSMTB and the modules it calls. As stated previously, an expanded token contains the keyword table in which a string is found, and its location within the table, if applicable. Again the first token shows that DEFINE is in table number 6 (same as length) at position number 2. The table number is the second digit from the right and the location is the third and fourth digit. Position number 1 is not used. It was originally intended to be used as a mark field. It was left as such for possible use by the EXECUTER.

Token number 9, N in the program, is a program unique

token as it was not found in a keyword table. The zeroes in position 2 through 4 indicate the program unique string.

A comparison of the extended tokens and the test program shows a one for one match of all strings/symbols. The comparison also shows a correct length applied for each string/symbol as well as a correct array element address. When dots or spaces were used in test programs, the results were also perfect.

6.5 NODES

The test program causes a total of thirty-four nodes to be generated. The node construction has been discussed in Chapter Four. The nodes generated by this program are in PART V of APPENDIX H.

The first three nodes represent strings which are at the highest level. These strings, as discussed before, are DEFINE, TRACE, and FACTORIAL. DEFINE is represented by node 1 and points to the level 1 parentheses subordinate to it, and also points to TRACE as a brother node. The TRACE node points to the level 1 parentheses subordinate to it, and also to FACTORIAL as a brother node. FACTORIAL has no additional brother so it only points to the level 1 parentheses subordinate to it. This type of continual breakdown is repeated until the entire program is processed and represented by a general tree.

APPENDIX A

McCarthy, John; Abrams, Paul W.; Edwards, Daniel J.; Hart, Timothy P.; and Levin, Michael I. LISP 1.5 Programmer's Manual. Cambridge: The M.I.T. Press, 1973.

Weissman, Clark. LISP 1.5 Primer. Belmont, California: Dickenson Publishing Company, Inc., 1967.

APPENDIX B

```
C**************************************************
C THIS ROUTINE IS A DRIVER ROUTINE TO CALL THE READ
C ROUTINE. THE READ ROUTINE WILL READ A DECK OF CARDS
C REPRESENTING A LISP PROGRAM. AT THE SAME TIME IT WILL
C LEAVE SPACE TO NUMBER ALL PARENTHESES ENCOUNTERED.
C****************************** **********************
C THIS DRIVER WAS WRITTEN BY:
C                ************************
C                *                      *
C                *  DAVID C. BOSSERMAN  *
C                *     OCTOBER 1976     *
C                *                      *
C                ************************
      INTEGER*2 IARG
      DOUBLE PRECISION FUNCT, IDSPAC
      COMMON/TABLE/FUNCT(8,24),IARG(8,24)
      COMMON/SPACE/IPTABL(50),ISPACE(2000)
     1,IPUSED,IFREE,IPSIZE,ISIZE
      COMMON/DOUBLE/IDSPAC(500)
      CALL INREAD(IFIRST,IDONE,ISTART)
C**************************************************
C AFTER THE READ ROUTINE HAS COMPLETED ITS FUNCTION,
C CONTROL IS RETURNED TO THIS PROGRAM. UPON RETURN ALL
C AVAILABLE PROGRAM DATA HAVE BEEN STORED IN MEMORY. AT
C THIS TIME THE DRIVER ROUTINE CALLS ANOTHER DRIVER
C ROUTINE CALLED ISCAN. ISCAN WILL CALL THE NECESSARY
```

```
MODULES TO SCAN THE DATA STORED IN MEMORY.
*****************************************************
      CALL ISCAN(IFIRST,IDONE,IJUMP,ISTART,IFINSH)
      CALL INTERP(IJUMP,IFINSH,IDSTA,IDSTOP,ISTART)
      STOP
      END
```

APPENDIX C

```
      SUBROUTINE INREAD(IFIRST,IDONE,ISTART)
  ***************************************************
THIS ROUTINE IS  DESIGNED TO READ A LISP  PROGRAM TO BE
PROCESSED.  THE READING OF DATA  IS ACCOMPLISHED IN THE
FOLLOWING MANNER:
  1. THE  ISINIT ROUTINE IS  CALLED TO OBTAIN  SPACE TO
READ
     A CARD.
  2. A CARD IS READ INTO THE SPACE ACQUIRED.
  3. THE ISINIT ROUTINE IS CALLED TO OBTAIN SPACE TO
     NUMBER ALL PARENTHESIS.
  4. CONTINUE THE STEPS 1-3 UNTIL ALL CARDS ARE READ.
 *****************************************************
THE INREAD ROUTINE WAS WRITTEN BY:
                  **************************
                  *                        *
                  *  DAVID C. BOSSERMAN    *
                  *      OCTOBER 1976      *
                  *                        *
                  **************************
 ************************************************ *****
SPECIFIC INREAD DATA ARE AS FOLLOWS:
FUNCTION NAME - INREAD
DOMAIN:
      (I) INPUT - THE USER'S LISP PROGRAM.
      (II)  GLOBAL DATA  - PORTION  OF  AN ARRAY  CALLED
```

ISPACE

FROM MEMORY MANAGEMENT.

RANGE:

1. THE USER'S SOURCE PROGRAM STORED IN ISPACE.
2. A PLACE TO ENTER PARENTHESES NUMBERS IN ISPACE.
3. THE START ARRAY SUBSCRIPT WHICH PERTAINS TO THE USER'S PROGRAM.
4. THE END ARRAY SUBSCRIPT WHICH PERTAINS TO THE USER'S PROGRAM.

RULE-OF-CORRESPONDENCE:

INREAD CAUSES THE USER'S PROGRAM TO BE PLACED IN THE SPACE ALLOCATED BY THE MEMORY MANAGEMENT ROUTINES. IT ALSO RESERVES A PORTION OF THE PROGRAM STORAGE AREA TO BE USED FOR PARENTHESES NUMBERING.

```
**********************************************************
      INTEGER*2 IARG
      DOUBLE PRECISION FUNCT
      COMMON/TABLE/FUNCT(8,24),IARG(8,24)
      COMMON/SPACE/IPTABL(50),ISPACE(2000)
     1,IPUSED,IFREE,IPSIZE,ISIZE
**********************************************************
```

THE SPACE RCUTINE IS CALLED. NUMRQD REPRESENTS THE NUMBER OF SPACES THAT THIS ROUTINE REQUIRES FROM MEMORY MANAGEMENT AT A TIME. ISTART IS THE ADDRESS IN THE MEMORY THAT DATA IS BEING READ INTO. ONLY 80 WORDS ARE PASSED AT A TIME (ONE CARD LENGTH) SO THE ISTOP PARAMETER REPRESENTS THE STOP POINT IN MEMORY. THE SAME WILL HOLD TRUE LATER WHEN NUMBERS ARE ASSOCIATED WITH THE PARENTHESES. IBLOCK IS A CODE

REPRESENTATION TO MEMORY MANAGEMENT INFORMING IT THAT A CONTIGUOUS BLOCK OF MEMORY IS REQUIRED. THEREFORE, NO HEADER COUNTS WILL BE WRITTEN UNTIL AN IBLOCK=1 IS SENT.

```
**********************************************************
      N=0
      IFIRST=0
      ISTART=0
      ISTCP=0
      NUMRQD=80
      IBLOCK=0
**********************************************************
```

A ROUTINE CALLED ISINIT IS CALLED TO ACQUIRE SPACE FROM MEMORY MANAGEMENT. THE ISINIT ROUTINE IS THE ONLY DIRECT LINK WITH MEMORY MANAGEMENT FROM THIS ROUTINE.

```
**********************************************************
10    CALL ISINIT(NUMRQD,ISTART,IBLOCK)
**********************************************************
```

A VARIABLE CALLED IFIRST IS INITIALIZED WITH THE FIRST ISTART PASSED. IFIRST WILL ALLOW SUBSEQUENT ROUTINES TO BEGIN AT THE FIRST MEMORY STORAGE LOCATION. AN IF STATEMENT IS INCLUDED TO PRECLUDE REINITIALIZATION OF IFIRST.

```
**********************************************************
      IF(IFIRST.EQ.0) IFIRST=ISTART
      ISTCP=(ISTART+NUMRQD)-1
**********************************************************
```

A CARD IS READ.

```
**********************************************************
```

```
      READ(5,500,END=505)(ISPACE(II),II=ISTART,ISTOP)
500   FORMAT(80A1)
 ******************************************************
ISINIT IS CALLED TO GET AN ADDITIONAL 80 WORDS OF
SPACE. THIS SPACE WILL BE USED EVENTUALLY TO NUMBER
THE PROGRAM'S PARENTHESES. CURRENTLY A LOOP IS ENTERED
TO SET ALL VALUES TO SPACES.
 ******************************************************
      CALL ISINIT(NUMRQD,ISTART,IBLOCK)
      ISTOP=(ISTART+NUMRQD)-1
      DO 600 I=ISTART,ISTOP
      ISPACE(I)=' '
600   CONTINUE
      GO TO 10
505   ISTOP=ISTOP-80
      IDONE=ISTOP
      NUMRQD=-80
      IBLOCK=1
      CALL ISINIT(NUMRQD,ISTART,IBLOCK)
      ISTART=ISTART-1
      RETURN
      END
```

APPENDIX D

```
      SUBROUTINE
     ISCAN(IFIRST,IDONE,IJUMP,ISTART,IFINSH)
       ************************************************
     THIS MODULE IS A DRIVER MODULE FOR TWO SEPARATE MODULES
     AS FOLLOWS:
     1. ISTKGN - THE SCANNER TOKEN GENERATOR MODULE IS
                 DESIGNED TO SCAN THE DATA INPUT BY THE
                 INREAD ROUTINE.  IT THEN GENERATES
                 APPROPRIATE TOKENS REPRESENTING THE LISP
                 PROGRAM.
     2. ISSMTB - THE SCANNER SYMBOL TABLE MODULE IS DESIGNED
                 TO ACCEPT INPUT FROM ISTKGN AND PROCESS
                 IT.  PROCESSING CONSISTS OF SEARCHING THE
                 COMMON KEY WORD TABLES IN AN ATTEMPT TO
                 FIND THE STRING REPRESENTED BY THE TOKEN.
                 IF IT IS FOUND THE TABLE NUMBER AND
                 LOCATION WITHIN THE TABLE ARE ADDED TO THE
                 TOKEN.  IF NOT, ZEROES ARE ADDED TO THE
                 TOKEN TO SHOW THAT THE TOKEN POINTS TO A
                 PROGRAM UNIQUE STRING.
    ************************************************
    ************************************************
THE SCANNER MODULE WAS WRITTEN AS A DRIVER ROUTINE BY:
                 ************************
                 *                      *
                 *  DAVID C. BOSSERMAN  *
```

```
*      OCTOBER 1976      *
*                        *
**************************
```

```
*****************************************************
```

SPECIFIC SCANNER DATA ARE AS FOLLOWS:

FUNCTION NAME - ISCAN

DOMAIN:

(I) INPUT - THE ARRAY CALLED ISPACE FROM INREAD.
THE BEGINNING ADDRESS OF THE USER'S PROGRAM.
THE ENDING ADDRESS OF THE USER'S PROGRAM.

(II) GLOBAL DATA:

1. FUNCTION NAMES USED IN LISP STORED AS COMMON DATA.
2. KEY WORDS USED IN LISP - STORED AS COMMON DATA.

RANGE: A TOKEN ARRAY REPRESENTING THE SOURCE PROGRAM.

RULE-OF-CORRESPONDENCE:

ISCAN READS THE DATA READ INTO STORAGE BY INREAD AND MATCHES:

1. EACH PARENTHESIS TO ITS PROPER LEVEL NUMBER.
2. EACH KEY WORD OR FUNCTION NAME TO A STORED COMMON SYMBOL TABLE.

IT THEN PASSES THE TOKENS GENERATED TO THE INTERPRETER FOR PARSING.

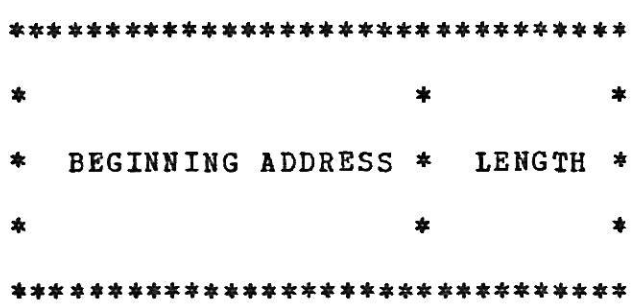
```
*****************************************************
```

```
      CALL ISTKGN(IFIRST,IDONE,IJUMP,ISTART)
      CALL ISSMTB(IJUMP,ISTART,IFINSH)
```

```
      RETURN
      END
```

```
      SUBROUTINE ISTKGN(IFIRST,IDONE,IJUMP,ISTART)
    ************************************************
THIS  MODULE  PERFORMS  THE FUNCTION  OF  READING  A  USER'S
PROGRAM CHARACTER BY CHARACTER AND:
     1. NUMBERING EACH PARENTHESIS.
     2. IDENTIFYING DELIMITERS.
     3. PROVIDING THE START POINT AND LENGTH OF EACH
        STRING IN THE USER'S PROGRAM.
    ************************************************
THE TOKEN GENERATION MODULE WAS WRITTEN BY:
                 ************************
                 *                      *
                 *  DAVID C. BOSSERMAN  *
                 *     OCTOBER 1976     *
                 *                      *
                 ************************
    ************************************************
SPECIFIC TOKEN GENERATION DATA ARE AS FOLLOWS:
FUNCTION NAME - ISTKGN C DOMAIN:
     (I) INPUT - THE ARRAY CALLED ISPACE.
                 THE BEGINNING ADDRESS OF THE USER'S
                 PROGRAM.
                 THE ENDING ADDRESS OF THE USER'S
                 PROGRAM.
                 THE ADDRESS OBTAINED FROM ISINIT TO
                 PLACE ADDRESSES AND LENGTHS OF STRINGS.
(II) GLOBAL DATA:
        THE DELIMITERS FOR LISP PROGRAMS.
RANGE: AN ARRAY OF  STRING ADDRESSES AND LENGTHS  TO BE USED
```

BY THE ISSMTB MODULE. THE FORMAT OF THE ADDRESS ARRAY ELEMENT IS:



RULE-OF-CORRESPONDENCE:

CONVERT THE USER'S PROGRAM INTO AN ARRAY WHICH CONTAINS THE LOCATION AND THE LENGTH OF ALL STRINGS IN THE PROGRAM.

****

A DO LOOP IS ENTERED TO PROCESS EACH CHARACTER. THE PROCESSING STARTS AT ISTART AND ENDS AT IDONE. NOTE THAT THE VARIABLE IJUMP IS INITIALIZED WITH THE FIRST ARRAY SUBSCRIPT TO HELP OTHER MODULES FIND THE BEGINNING OF THE ADDRESS RETURNED FROM ISINIT. IT WILL BE PASSED AT THE END OF THE MODULE.

****

```
      INTEGER*2 IARG
      DOUBLE PRECISION FUNCT
      COMMON/TABLE/FUNCT(8,24),IARG(8,24)
      COMMON/SPACE/IPTABL(50),ISPACE(2000)
     1,IPUSED,IFREE,IPSIZE,ISIZE
      IPROCE=0
      IJUMP=0
      NUMRQD=1
      NUMCHR=0
      IBLOCK=0
```

```
      ICOUNT=0
      ISKIP=0
      N=0
      DO 100 I=IFIRST,IDONE
      INCR=1
      IDEC=-1
      ICOUNT=ICOUNT+1
      IF(ICOUNT.GT.80) ISKIP=ISKIP+1
      IF(ISKIP.GT.80) ICOUNT=1
      IF(ISKIP.GT.80) ISKIP=0
      IF(ICOUNT.GT.80) GO TO 100
    ******************************************************
```

FIRST THE CHARACTER IS CHECKED TO SEE IF IT IS A PARENTHESIS. IF IT IS, A NUMBER IS ASSIGNED TO IT AND IT IS PLACED IN THE APPROPRIATE ARRAY POSITION RESERVED IN INREAD.

```
    ******************************************************
      IF(ISPACE(I).EQ.'(') CALL INUMBR(I,INCR,N,IPROCE,
     1NUMCHR,ISTART)
      IF(ISPACE(I).EQ.')') CALL INUMBR(I,IDEC,N,IPROCE,
     1NUMCHR,ISTART)
    ******************************************************
```

A CHECK IS MADE AT THIS POINT TO DETERMINE IF MATCHED PARENTHESES ARE BEING CONSTRUCTED. IF NOT, AN ERROR MESSAGE IS PRINTED.

```
    ******************************************************
      ILINE=(I/80)+1
      IPOSIT=I
      IF(N.LT.0) WRITE(6,10) ILINE,IPOSIT
10    FORMAT(' ','MISMATCHED PARENTHESES FOUND AT LINE
```

```
     1,I3,'  POSITION    ',I2,' .')
    ****************************************************
```

NEXT THE DELIMITERS '.' AND ' ' ARE CHECKED. IF A SPACE IS ENCOUNTERED, THE COUNTER NUMCHR IS CHECKED TO SEE IF IT IS GREATER THAN 0. IF SO, A STRING HAS BEEN IDENTIFIED. ANOTHER CASE IS THE EMPTY EXPRESSION OR NIL. THEREFORE, IF A SPACE IS ENCOUNTERED, A LOOKBACK AND LOOKFORWARD IS ACCOMPLISHED TO DETERMINE IF THE SPACE REPRESENTS A NIL.

```
    ****************************************************
      IF(ISPACE(I).EQ.'.'.AND.NUMCHR.GT.0) GO TO 100
      IF(ISPACE(I).EQ.' '.AND.NUMCHR.GT.0) CALL IADDRS
     1(I,NUMCHR,IPROCE,ISTART)
      IF(ISPACE(I).EQ.' '.AND.NUMCHR.EQ.0) CALL CKSPCE
     1(I,IPROCE,ISTART)
      IF(IPROCE.NE.999) NUMCHR=NUMCHR+1
      IF(ISPACE(I).EQ.' ') NUMCHR=NUMCHR-1
      IF(IPROCE.NE.999) GO TO 100
      IF(IJUMP.EQ.0) IJUMP=ISTART
      NUMCHR=0
      IPROCE=0
100   CONTINUE
   ****************************************************
```

ISINIT IS CALLED TO RELEASE THE ROUTINES FROM PROVIDING CONTIGUOUS SPACE.

```
   ****************************************************
      NUMRQD=0
      IBLOCK=0
      CALL ISINIT(NUMRQD,ISTART,IBLOCK)
      RETURN
```

```
END
```

```
      SUBROUTINE INUMBR(I,INB,N,IPROCE,NUMCHR,ISTART)
   ******************************************************
THIS ROUTINE WAS WRITTEN BY:
                  ************************
                  *                      *
                  *  DAVID C. BOSSERMAN  *
                  *     OCTOBER 1976     *
                  *                      *
                  ************************
   ******************************************************
THE INUMBR ROUTINE IS A UTILITY ROUTINE WHICH KEEPS TRACK OF
THE CURRENT  PARENTHESIS LEVEL NUMBER  AND UPDATES  IT.  THE
ROUTINE THEN  ASSIGNS THE  APPROPRIATE NUMBER  TO THE  SPACE
ALREADY ALLOCATED IN INREAD.  WHEN  PRINTED, THE NUMBER WILL
APPEAR DIRECTLY BELOW THE APPLICABLE PARENTHESIS.  THE FIRST
DETERMINATION TO  BE MADE IS WHETHER  NUMCHR IS EQUAL  TO 0.
IF  SO,  THE  PARENTHESIS  STANDS  ALONE  AND  IS  PROCESSED
STARTING AT  LINE 10  AS A  PARENTHESIS.  IF  NOT, A  STRING
PRECEEDS THE PARENTHESIS AND THE STRING MUST BE PUT IN TOKEN
FORM BEFORE THE PARENTHESIS IS PROCESSED.
   ******************************************************
      INTEGER*2 IARG
      DOUBLE PRECISION FUNCT
      COMMON/TABLE/FUNCT(8,24),IARG(8,24)
      COMMON/SPACE/IPTABL(50),ISPACE(2000)
     1,IPUSED,IFREE,IPSIZE,ISIZE
      NUMRQD=1
      IBLOCK=0
      IF(NUMCHR.EQ.0) GO TO 10
```

```
   ********************************************************
J REPRESENTS THE ARRAY ELEMENT  LOCATION IN ISPACE WHERE THE
BEGINNING CHARACTER OF  A STRING IS FOUND.  TKLOC REPRESENTS
THE LCCATION AND THE LENGTH.
   ********************************************************
      J=(I-NUMCHR)*100
      TKLOC=J+NUMCHR
      CALL ISINIT(NUMRQD,ISTART,IBLOCK)
      ISPACE(ISTART)=TKLOC
   ********************************************************
INB  IS  A  COUNTER  USED TO  KEEP  THE  PARENTHESIS  NUMBER
CORRECT.  NOTE THAT A RIGHT LEFT PARENTHESIS COMBINATION HAS
THE  SAME  NUMBER.  THUS,  A  RIGHT  PARENTHESIS  DOES  NOT
SUBTRACT FROM THE NUMBER.
   ********************************************************
10    IF(INB.EQ.1) INB=N+INB
      IF(INB.EQ.-1) JJ=-1
      IF(INB.EQ.-1) INB=N
      N=INB
      ISPACE(I+80)=INB
      IF(JJ.EQ.-1) N=N-1
      JJ=0
      IPROCE=999
      TKLOC=(I*100)+1
      CALL ISINIT(NUMRQD,ISTART,IBLOCK)
      ISPACE(ISTART)=TKLCC
      RETURN
      END
```

```
      SUBROUTINE IADDRS(I,NUMCHR,IPROCE,ISTART)
   ********************************************************
THIS ROUTINE WAS WRITTEN BY:
                  ************************
                  *                      *
                  *  DAVID C. BOSSERMAN  *
                  *                      *
                  *     OCTOBER 1976     *
                  *                      *
                  ************************
    ******************************************************
THIS ROUTINE IS WRITTEN TO PROCESS THE DATA TO BE PLACED IN
AN ARRAY ELEMENT.  THE DATA  PROCESSED PROVIDES THE LOCATION
WITHIN A PROGRAM  OF A STRING AND ITS  LENGTH.  THIS ROUTINE
IS  ONLY  CALLED  WHEN  A  SPACE  OR  PERIOD  DELIMITER  IS
ENCOUNTERED AND NUMCHR IS GREATER THAN ZERO.
    ******************************************************
      INTEGER*2 IARG
      DOUBLE PRECISION FUNCT
      COMMON/TABLE/FUNCT(8,24),IARG(8,24)
      COMMON/SPACE/IPTABL(50),ISPACE(2000)
     1,IPUSED,IFREE,IPSIZE,ISIZE
      NUMRQD=1
      IBLOCK=0
      J=(I-NUMCHR)*100
      TKLOC=J+NUMCHR
      IPROCE=999
      CALL ISINIT(NUMRQD,ISTART,IBLOCK)
      ISPACE(ISTART)=TKLOC
```

```
RETURN

END
```

```
      SUBROUTINE CKSPCE(I,IPROCE,ISTART)
   ******************************************************
THIS ROUTINE WAS WRITTEN BY:
                  ************************
                  *                      *
                  *  DAVID C. ROSSERMAN  *
                  *     OCTOBER 1976     *
                  *                      *
                  ************************
    ******************************************************
THIS ROUTINE IS WRITTEN TO PROCESS THE DATA TO BE PLACED IN
AN ARRAY ELEMENT. IT IS SPECIFICALLY CHECKING THE SPACE
CHARACTER TO SEE IF IT IS A NIL.
    ******************************************************
      INTEGER*2 IARG
      DOUBLE PRECISION FUNCT
      COMMON/TABLE/FUNCT(8,24),IARG(8,24)
      COMMON/SPACE/IPTABL(50),ISPACE(2000)
     1,IPUSED,IFREE,IPSIZE,ISIZE
      NUMRQD=1
      IBLOCK=0
      IF(ISPACE(I-1).NE.'(') RETURN
      IF(ISPACE(I+1).NE.')') RETURN
      TKLOC=(I*100)+1
      IPROCE=999
      CALL ISINIT(NUMRQD,ISTART,IBLOCK)
      ISPACE(ISTART)=TKLOC
      RETURN
      END
```

```
      SUBROUTINE ISINIT(NUMRQD,ISTART,IBLOCK)
    ***************************************************
THE SCANNER INITIALIZER ROUTINE IS DESIGNED TO INTERACT WITH
THE MEMORY MANAGEMENT ROUTINE. ITS PURPOSE IS TO ACQUIRE
SPACE FROM MEMORY MANAGEMENT.
    ***************************************************
    ***************************************************
THE SCANNER INITIALIZER ROUTINE WAS WRITTEN AS A UTILITY
ROUTINE BY:
                  ************************
                  *                      *
                  *  DAVID C. BOSSERMAN  *
                  *     OCTOBER 1976     *
                  *                      *
                  ************************
    ***************************************************
SPECIFIC INITIALIZER DATA ARE AS FOLLOWS:
FUNCTION NAME: ISINIT
DOMAIN:
     (I) INPUT : NUMBER OF WORDS REQUIRED FROM FREESPACE.
     (II) GLOBAL DATA: THE DECLARED ARRAY REPRESENTING
                       FREESPACE.
RANGE:          THE LOWER AND UPPER LOGICAL ADDRESS FOR THE
                THE FREESPACE ARRAY TO BE USED FOR
                TOKEN GENERATION.
RULE OF CORRESPONDENCE:
ISINIT REQUESTS FROM MEMORY MANAGEMENT THE LOGICAL ADDRESS
OF AVAILABLE FREESPACE TO BE USED FOR TOKEN GENERATION.
    ***************************************************
```

```
CALL GETBLK(NUMRCD,ISTART,IBLOCK)

RETURN

END
```

```
      SUBROUTINE ISSMTB(IJUMP,ISTART,IFINSH)
    ***************************************************
THIS MODULE PERFORMS  THE FUNCTION OF COMPARING  THE ADDRESS
ARRAY  TOKENS WITH  THOSE  FOUND  IN THE  KEY  WORD/FUNCTION
TABLES.  IF THE VALUES ARE NOT FOUND, THEY ARE MARKED AS 00.
AT THIS TIME THE ADDRESS ARRAY TOKEN IS EXPANDED TO SHOW NOT
ONLY THE  LOCATION OF THE SYMBOL  IN THE USER'S  PROGRAM BUT
ALSO THE TABLE LOCATION IF FOUND, OR A 0 IF NCT FOUND.
    ***************************************************
    ***************************************************
THE SYMBOI TABLE IDENTIFICATION MODULE WAS WRITTEN BY:
                  ************************
                  *                      *
                  *  DAVID C. BOSSERMAN  *
                  *     OCTOBER 1976     *
                  *                      *
                  ************************
    ***************************************************
SPECIFIC SYMBOL TABLE DATA ARE AS FOLIOWS:
FUNCTION NAME - ISSMTB
DOMAIN:
     (I) INPUT - THE BEGINNING ADDRESS OF THE ADDRESS
                 ARRAY GENERATED IN ISTKGN.
                 THE ENDING ADDRESS OF THE ADDRESS ARRAY
                 GENERATED IN ISTKGN.
     (II) GLOBAL DATA:
                 THE ARRAY CALLED ISPACE.
                 THE KEY WORD/FUNCTION TABLES.
RANGE:
```

AN ARRAY OF STRING/SYMBOL ADDRESSES AND LENGTHS AND THE TABLE LOCATION OF THOSE STRINGS/SYMBOLS. THE FORMAT OF THE FULL TOKEN ARRAY IS:

```
**********************************************************
*                    *        *                  *       *
* BEGINNING ADDRESS * LENGTH * TABLE LOCATION * TABLE *
*                    *        *                  *       *
**********************************************************
```

RULE-OF-CORRESPONDENCE:

USE THE ADDRESS ARRAY GENERATED IN ISTKGN AND ADD POINTERS TO THE SYMBOL TABLE LOCATION OF THE SYMBOLS CONTAINED IN THE USER'S PROGRAM, IF APPLICABLE.

```
**************************************************
      INTEGER*2 IARG
      DOUBLE PRECISION FUNCT
      COMMON/TABLE/FUNCT(8,24),IARG(8,24)
      COMMON/SPACE/IPTABL(50),ISPACE(2000)
     1,IPUSED,IFREE,IPSIZE,ISIZE
      IBLOCK=0
      IFINSH=ISTART
**************************************************
```

A DO ICOP IS ENTERED TO PROCESS EACH SYMBOL FROM THE ADDRESS ARRAY.

```
**************************************************
      DO 100 I=IJUMP,IFINSH
**************************************************
```

SUBROUTINE ISYMCK, SYMBOL CHECK, IS CALLED TO CHECK THE USER'S STRINGS AGAINST KEY WORD/FUNCTIONS FOUND IN THE GLOBAL DATA TABLES.

ALTHCUGH A DOUBLE WORD WILL ONLY CONTAIN EIGHT CHARACTERS, THE FIRST 8 CHARACTERS OF ALL KEYWORD/FUNCTICNS ARE UNIQUE. THE USER MUST BE CAUTIONED NOT TO USE THE UNIQUE 8 OR LESS LETTER COMBINATICNS IN HIS PROGRAM UNLESS HE DOES IN FACT WANT THE KEYWORD/FUNCTION TO APPLY. EVEN THCUGH THE USER'S PROGRAM WILL HAVE GREATER THAN 8 CHARACTERS, THEY WILL BE POINTED TC BY THE TOKEN GENERATED.

```
**************************************************
  IADDR=ISPACE(I)/100
  ILNGTH=ISPACE(I)-(IADDR*100)
  CALL ISYMCK(I,ILNGTH,ITABLE,ILOCAT,
 1ISTART)
**************************************************
```

THE ABOVE CONDITICNAL EXPRESSION HAVE SERVED TO CALL THE APPROPRIATE ROUTINE TO PROCESS THE SYMBOIS INVOLVED. NOTE THAT IF A SYMBOL IS PROCESSED BY A SUBROUTINE AND NOT FOUND, ITABLE AND ILOCAT REMAINS ZERO. THEREFORE, ANY SYMBOL NOT FOUND OR GREATER THAN 12 CHARACTERS IS AUTOMATICALLY MARKED WITH A ZERO. AFTER THE STRING IS PROCESSED, THE TABLE NUMBER AND LOCATICN WITHIN THE TABLE ARE PASSED BACK TO THE CALLING ROUTINE IN THE VARIABLES ITABLE AND ILOCAT RESPECTIVELY. THIS DATA IS THEN PROCESSED INTO THE COMPLETED SYMBOL TOKEN. THE TABLES ARE NUMBERED AS FOLLOWS:

0 - THE PROGRAM UNIQUE SYMBOL.

1 - ONE CHARACTER SYMBOL TABIE.

2 - TWO CHARACTER SYMBOL TABLE.

3 - THREE CHARACTER SYMBOL TABLE.

4 - FCUR CHARACTER SYMBOL TAELE.

5 - FIVE CHARACTER SYMBOL TABLE.

```
      6    -    SIX CHARACTER SYMBOL TABLE.
      7    -    SEVEN CHARACTER SYMBOL TABLE.
      8    -    EIGHT CHARACTER SYMBOL TABLE.
     ******************************************************
       ISPACE(I)=((((IADDR*100)                +ILNGTH)*10000)
     +((ILCCAT*100) +ITABLE*10))
       IFOUND=0
  100  CONTINUE
       RETURN
       END
```

```
      SUBROUTINE
ISYMCK(I,ILNGTH,ITABLE,ILOCAT,IFOUND,ISTART)
   ******************************************************
THIS  MODULE IS  DESIGNED  TO SEARCH  THE  GLOBAL KEY  WORD/
FUNCTION TABLES  AND RETURN  THE TABLE  NUMBER AND  POSITION
WITHIN THE TABLE, IF A MATCH OCCURS BETWEEN THE STRING BEING
TESTED AND THE TABLE.
   ******************************************************
   ******************************************************
THE SYMBOL CHECK MCDULE WAS WRITTEN BY:
                  ************************
                  *                      *
                  *  DAVID C. BOSSERMAN  *
                  *     OCTOBER 1976     *
                  *                      *
                  ************************
   ******************************************************
SPECIFIC SYMBOL CHECK DATA ARE AS FOLLOWS:
FUNCTION NAME - ISYMCK
DOMAIN:
     (I). INPUT - THE STARTING ADDRESS OF THE STRING
                  TO BE PROCESSED.
     (II). GLOBAL DATA:
           THE ARRAY CALLED ISPACE.
           THE KEY WORD/FUNCTION TABLES.
RANGE:  THE TABLE NUMBER AND POSITION WITHIN THE TABLE,
        IF A STRING MATCH IS FOUND.
RULE-OF-CORRESPONDENCE:
     ACCOMPLISH A SEARCH OF KEY  WORD/FUNCTION TABLES TO SEE
```

```
IF THE STRING  USED BY THE USER IS A  KEY WORD/FUNCTION, AND
RETURN TABLE INFORMATION IF SO.
   ******************************************************
      INTEGER*2 IARG
      DIMENSION ICONVT(8), IPACK(33)
      DOUBLE PRECISION FUNCT, ICHECK, IDSPAC
      COMMON/TABLE/FUNCT(8,24),IARG(8,24)
      COMMON/SPACE/IPTABL(50),ISPACE(2000)
     1,IPUSED,IFREE,IPSIZE,ISIZE
      COMMON/DOUBLE/IDSPAC(500)
   ******************************************************
FIRST, THE  ADDRESS OF THE  STRING IN ISPACE  IS DETERMINED.
NEXT, THE LENGTH OF THE STRING  IS EXTRACTED.  IF THE LENGTH
IS EQUAL  TO 9-12, IT  IS CHANGED TO  8 BECAUSE ONLY  A FULL
WORD (8 BYTES) CAN BE CHECKED AT ONE TIME.  IF THE LENGTH IS
GREATER THAN 12, A RETURN TO THE CALLING PROGRAM IS MADE.
   ******************************************************
      ITABLE=0
      ILOCAT=0
      IADDR=ISPACE(I)/100
      N=IINGTH
      IF((N.GE.9).AND.(N.LE.12)) N=8
      IF(N.GT.12) RETURN
   ******************************************************
THE ARRAY  USED TC  CONVERT THE  STRING IS  INITIALIZED WITH
BLANKS.  THIS  IS FOLLOWED BY  ASSIGNING TO EACH  ELEMENT OF
THE ARRAY (UP TO 8) ONE CHARACTER OF THE STRING.
   ******************************************************
      DO 5 K=1,8
```

```
5       ICCNVT(K)=' '
        DO 7 J=1,N
        IPT=IADDR+(J-1)
        ICCNVT(J)=ISPACE(IPT)
7       CONTINUE
```

****

AN ENCODE ROUTINE IS USED TO READ THE CONVERSION ARRAY. THE CONVERSION ARRAY HOLDS ONE CHARACTER PER ELEMENT IN AN A4 FORMAT. THUS, ONE CHARACTER AND THREE SPACES ARE IN EACH ELEMENT. THE ENCODE CAUSES EACH ELEMENT TO BE READ, BUT ONLY THE FIRST BYTE (THE CHARACTER BYTE) IS READ AND THE SPACES SKIPPED. THE ENCODE ARRAY IS 33 ELEMENTS BECAUSE INTERDATA REQUIRES A MINIMUM OF 132 BYTES PER ENCODE.

****

```
        ENCODE(IPACK,6) ICONVT
6       FORMAT(33A1)
```

****

A DECODE IS ACCOMPLISHED TO CONVERT THE ENCODED BLOCK TO A DOUBLE WORD.

****

```
        DECODE(IPACK,10)ICHECK
10      FORMAT(A8)
        DO 100 J=1,24
```

****

THE APPROPRIATE KEY WORD/FUNCTION TABLE IS SEARCHED. THE LAST ELEMENT IN EACH TABLE IS REPRESENTED BY A '<'. IF THE TERMINAL SYMBOL IS FOUND BEFORE A MATCH, A RETURN IS MADE.

****

```
        IF(ICHECK.EQ.FUNCT(N,J)) GO TO 200
```

```
      IF(FUNCT(N,J).EQ.'<') GO TO 150
100   CONTINUE
   ********************************************************
THE APPROPRIATE  TABLE AND LOCATION ARE  SET, IF A  MATCH IS
MADE.  IFOUND IS  A SIGNAL  TO  THE CALLING  ROUTINE AS  TO
WHETHER A MATCH WAS MADE.
   ********************************************************
150   N=0
      J=0
200   ITABLE=N
      ILOCAT=J
      IFOUND=1
      RETURN
      END
```

APPENDIX E

```
      SUBROUTINE INTERP(IJUMP,IFINSE,IDSTA,IDSTOP,ISTART)
 ************************************************************
INTERP IS  A DRIVER  MODULE WHICH  CURRENTLY CALLS  ONLY THE
ROUTINE  WHICH  CONSTRUCTS  A GENERAL  TREE  OF  THE  USER'S
PROGRAM.  THE  ROUTINE IS CALLED  FROM THE  LISP INTERPRETER
DRIVER.
 ************************************************************
 ************************************************************
 THIS DRIVER WAS WRITTEN BY:
                  **************************
                  *                        *
                  *  DAVID C. BOSSERMAN    *
                  *     OCTOBER 1976       *
                  *                        *
                  **************************
 ************************************************************
SPECIFIC INTERPRETER DATA ARE AS FOLLOWS:
FUNCTION NAME - INTERP
DOMAIN:
     (I) INPUT
           - THE BEGINNING ADDRESS OF THE TOKEN ARRAY.
           - THE ENDING ADDRESS OF THE TOKEN ARRAY.
     (II) GLOBAL DATA
           - THE ARRAY CALLED ISPACE.
           - THE ARRAY CALLED IDSPAC.
RANGE: A SERIES OF NODES REPRESENTING A GENERAL TREE
```

```
      OF THE USER'S PROGRAM.
RULE-OF-CORRESPONDENCE
CONSTRUCT A GENERAL TREE STRUCTURE FROM THE TOKENS GENERATED
IN ISCAN.
 ************************************************************
      ICODE=0
      WRITE(6,1)
1     FORMAT(' ',2X,'INTERP WAS CALLED.')
      CALL IGTREE(IJUMP,IFINSH,IDSTA,IDSTOP,ISTART,IECODE)
      IF(IECODE.EQ.999) RETURN
      RETURN
      END
```

```
      SUBROUTINE
IGTREE(IJUMP,IFINSH,IDSTA,IDSTOP,ISTART,IECODE)
   ************************************************
```

THE GENERAL TREE ROUTINE IS DESIGNED TO PRODUCE AN ARRAY OF DOUBLE WORDS WHICH REPRESENT A LISP PROGRAM. EACH DOUBLE WORD CONTAINS INFORMATION FIELDS WHICH PROVIDE THE DATA NECESSARY TO CONSTRUCT A GENERAL TREE. THE SIXTEEN BYTES ALLOWED ARE DIVIDED, FROM LEFT TO RIGHT AS FOLLOWS:

FIELD	LENGTH	DESCRIPTION
1	4	LOCATION
2	4	LENGTH
3	4	SON
4	3	BROTHER
5	1	MARK

THE ROUTINE ACTS AS A CONTROL ROUTINE AND CALLS THE APPROPRIATE SUBROUTINE BASED ON THE CHARACTER BEING PROCESSED.

```
   ************************************************
```

THIS ROUTINE WAS WRITTEN BY:

```
                        ************************
                        *                      *
                        *  DAVID C. BOSSERMAN  *
                        *     NOVEMBER 1976    *
                        *                      *
                        ************************
      DOUBLE PRECISION IDSPAC
      COMMON/SPACE/IPTABL(50),ISPACE(2000)
     1,IPUSED,IFREE,IPSIZE,ISIZE
      COMMON/DOUBLE/IDSPAC(500)
```

```
      WRITE(6,1)
1     FORMAT(' ',2X,'IGTREE WAS CALLED.')
      N=0
      ICODE=0
      NXTPT=0
      I=IJUMP
 ************************************************************
```

A POINTER IS INITIALIZED TO CONTROL A STACK WHICH WILL HOLD THE LENGTH OF SCN NODES. THE POINTER IS CALLED IPARPT AND IS SET INITIALLY TO ZERO. AT THE SAME TIME A VARIABLE IFINIT IS ASSIGNED THE VALUE OF IFINISH. IFINIT WILL BE USED THROUGHOUT THE GENERAL TREE OPERATIONS TO CONTROL THE END LIMIT OF THE STRING BEING PROCESSED.

```
   ************************************************************
      IPARPT=0
      IFINIT=IFINSH
      ISETD=0
      IDSTA=0
   ************************************************************
```

A NUMBERED STATEMENT IS USED TO PERFORM IN THE SAME MANNER AS A PL1 DO WHILE STATEMENT. THE STATEMENTS FOLLOWING THE LINE NUMBERED 10 ARE TO BE EXECUTED UNTIL ALL SON NODES ARE PROCESSED DOWN TO THEIR TERMINAL NODE. THE EXIT FROM THE LOOP IS DEPENDENT UPON THE POINTER WHICH POINTS TO THE NEXT NODE BEING PROCESSED EXCEEDING THE NODES AVAILABLE.

```
   ************************************************************
   ************************************************************
```

THE ADDRESS ARRAY TOKEN IS PROCESSED TO YIELD THE ADDRESS OF THE STRING TO BE PROCESSED.

```
*************************************************************
10    IF(I.EQ.0) GO TO 20
*************************************************************
```

TERMINAL NODES HAVE NO LENGTH, OR SON. THEREFORE, I IS SET TO ZERO WHEN ONE IS PROCESSED. IF PROCESSING IS ALLOWED WITH I=0, AN ERROR CONDITION WILL RESULT. IF I=0 A TRANSFER IS MADE TO PROCESS THE NEXT NODE.

```
*************************************************************
      IADDR=ISPACE(I)/1000000
*************************************************************
```

ONCE THE ADDRESS IS DETERMINED, FOUR POSSIBILITIES EXIST. IF THE SYMBOL/STRING LOCATED AT THE ADDRESS IS A RIGHT PARENTHESIS OR A PERIOD, AN ERROR IS APPARANT AND A TRANSFER WILL BE MADE TO PRINT AN APPROPRIATE ERROR MESSAGE. IF A LEFT PARENTHESIS IS ENCOUNTERED, THE SUBROUTINE TO PROCESS PARENTHESES IS CALLED. IF THE FIRST THREE CONDITIONS ARE NOT MET, THE SYMBOL/ TOKEN IS TREATED AS A VARIABLE AND THE VARIABLE SUBROUTINE IS CALLED.

```
*************************************************************
      IF((ISPACE(IADDR).NE.'(').AND.(ISPACE(IADDR).NE.
     1')').AND.(ISPACE(IADDR).NE.'.')) CALL VARBLE(I,
     2IFINIT,NXTPT,IDSTA,ISETD,ISTART,IPARPT,ICODE)
      IF(ISPACE(IADDR).EQ.'(') CALL ILPARN(I,IFINIT
     1,NXTPT,IDSTA,ISETD,ISTART,IPARPT)
      IF(ISPACE(IADDR).EQ.')') CALL IRPARN(IECODE)
      IF(ISPACE(IADDR).EQ.'.') CALL IPEROD(IECODE)
      IF(IECODE.EQ.999) RETURN
      WRITE(6,100)(IDSPAC(J),J=IDSTA,ISETD)
*************************************************************
```

THE COMBINATION OF NXTPT (THE POINTER TO THE NEXT NODE TO BE PROCESSED) AND ISETD (THE POINTER TO THE LAST PARENT NODE CONSTRUCTED) ARE COMPARED. IF NXTPT EXCEEDS ISETD, THE 'DO WHILE' LOOP IS EXITED, INDICATING THAT THE GENERAL TREE IS COMPLETE.

```
C**********************************************************
20    IF(NXTPT.GT.ISETD) GO TO 150
C**********************************************************
```

IN THE CALLED ROUTINES, A POINTER CALLED NXTPT HAS BEEN SET TO THE THE NEXT NODE TO BE PROCESSED. THE NODE PROCESSING IS DONE WITH ONLY ONE PASS. THEREFORE, WHEN NO BROTHERS ARE BEING PROCESSED, THE ROUTINE WILL CONTINUE A CYCLE OF PROCESSING THE NEXT NODE - CREATE A SON NODE, CREATE A SON NODE AND/OR A BROTHER NODE, INCREMENT THE POINTER - PROCESS THE NEXT NODE. THE VARIABLE I REPRESENTS THE ADDRESS ARRAY LOCATION OF THE NEXT STRING/TOKEN TO BE PROCESSED.

```
C**********************************************************
      INTER=IDSPAC(NXTPT)/100000000.D0
      I=((IDSPAC(NXTPT)-(INTER*100000000.D0))/10000.D0)
      IDSPAC(NXTPT)=IDSPAC(NXTPT)+1.
      NXTPT=NXTPT+1
      WRITE(6,100) IDSPAC(NXTPT-1)
100   FORMAT(' ',2X,'IDSPAC=  ',F17.0)
      WRITE(6,101) I,IFINIT,NXTPT,IDSTA,ISETD
101   FORMAT(' ',2X,I4,2X,I4,2X,I3,2X,I3,2X,I3,2X,I3)
      GO TO 10
150   IDSTOP=ISETD
      RETURN
      END
```

```
      SUBROUTINE
VARBLE(I,IFINIT,NXTPT,IDSTA,ISETD,ISTART,IPARPT,ICODE)
   ********************************************************
THIS ROUTINE IS DESIGNED TO:
     1. PLACE THE VARIABLE'S LOCATION WITHIN THE ADDRESS
        ARRAY INTO THE LOCATION FIELD OF A DOUBLE WORD
        NODE.
     2. IF THE VARIABLE IS FOLLOWED BY A LEFT
        PARENTHESIS, PLACE THE ADDRESS OF THE LEFT
        PARENTHESIS IN THE SON FIELD OF THE NODE.
     3. IF THE VARIABLE IS FOLLOWED BY A LEFT
        PARENTHESIS, FIND THE FURTHEREST SAME LEVEL
        RIGHT PARENTHESIS.
     4. IF THE STRING TO THE RIGHT OF THE SAME
        LEVEL RIGHT PARENTHESIS IS A VARIABLE,
        COMPLETE ITS DOUBLE WORD NODE USING STEPS
        1-4.
   ********************************************************
THIS ROUTINE WAS WRITTEN BY:
                      ************************
                      *                      *
                      *  DAVID C. BOSSERMAN  *
                      *     NOVEMBER 1976    *
                      *                      *
                      ************************
      DOUBLE PRECISION IDSPAC
      COMMON/SPACE/IPTABL(50),ISPACE(2000)
     1,IPUSED,IFREE,IPSIZE,ISIZE
      COMMON/DOUBLE/IDSPAC(500)
```

```
      WRITE(6,1)
1     FORMAT(' ',2X,'VARBLE WAS CALLED.')
      IMODFY=0
      NUMRQD=1
      IBLOCK=0
      LENGTH =0
      IF(ICODE.EQ.1) GO TO 10
      IADDR=ISPACE(I)/1000000
      IF(NXTPT.GT.0) LENGTH=ISPACE(IPARPT)
      IF(NXTPT.GT.0) IPARPT=IPARPT+1
      IF(NXTPT.GT.0) IFINIT=(I+LENGTH)-1
      IF(NXTPT.GT.0) NODEPA=(NXTPT-1)+IMODFY
      IF(NXTPT.GT.0)
IDSPAC(NODEPA)=IDSPAC(NODEPA)-(I*10000.)
      IF(NXTPT.GT.0)
IDSPAC(NODEPA)=IDSPAC(NODEPA)+((ISETD+1)*10000.)
   ******************************************************
```

THE DATA TO OBTAIN A DOUBLE WORD FROM MEMORY MANAGEMENT IS INITIALIZED. AFTER THE DOUBLE WORD IS REQUESTED, THE START POINT OF THE GENERAL TREE ARRAY IS CAPTURED BY THE VARIABLE IDSTA. THEN THE ADDRESS ARRAY LOCATION (IADDR) IS PLACED IN THE LOCATION FIELD OF THE DOUBLE WORD. AS ALL FIELDS OF THE DOUBLE WORD WILL NOT BE COMPLETED IN ONE PASS, A POINTER CALLED NXTPT IS KEPT UP TO DATE. THIS POINTER POINTS TO THE DOUBLE WORD NODE TO BE PROCESSED WHEN AN OPERATION IS COMPLETED. INITIALLY IT WILL BE THE FIRST DOUBLE WORD. THE LAST FIELD OF THE DOUBLE WORD IS A MARK FIELD. A ONE IN THE MARK FIELD REPRESENTS THAT THE LOCATION FIELD AND LENGTH FIELD OF THE NODE HAVE BEEN COMPLETED NOTE THAT FOR A

```
VARIABLE THE  LENGTH IS  0.  FOR  A SET  OF PARENTHESES  THE
LENGTE  WILL BE  FROM  THE LEFT  TO THE  RIGHT  IN TERMS  OF
ADDRESS ARRAY ELEMENTS.
   ******************************************************
10     CALL ISINIT(NUMRQD,ISETD,IBLOCK)
       IF(IDSTA.EQ.0) IDSTA=ISETD
       IF(NXTPT.EQ.0) NXTPT=ISETD
       C=I
       IDSPAC(ISETD)=C*1000000000000.D0+1.
       WRITE(6,2)IDSPAC(ISETD)
2      FORMAT(' ',2X,'IDSPAC(ISETD)=  ',F17.0)
   ******************************************************
THE RCUTINE NOW LOOKS AT THE  NEXT ITEM IN THE ADDRESS ARRAY
TO DETERMINE ITS NATURE.  NOTE THAT FIRST A CHECK IS MADE TO
SEE IF THE NEXT ITEM IS OUTSIDE THE ADDRESS ARRAY.  IF SO, A
RETURN IS MADE.
   ******************************************************
       I=I+1
       IF(I.GT.IFINIT) RETURN
       IF(ICODE.EQ.1) RETURN
       IADDR=ISPACE(I)/1000000
   ******************************************************
THE PCSITION FCLLOWING  THE VARIABLE IS IDENTIFIED.  IF THE
POSITICN IS A LEFT PARENTHESIS, ITS ARRAY LOCATION IS PLACED
(AS A TEMPORARY MEASURE) IN THE SON FIELD OF THE NODE.  THIS
WILL  BE  USED  LATER  TO  PROCESS  THE  REMAINDER  OF  THE
STRINGS/SYMBOLS FCUND IN THE ADDRESS ARRAY.
   ******************************************************
       IF(ISPACE(IADDR).EQ.'(')
```

```
IDSPAC(ISETD)=IDSPAC(ISETD)+(I*10000.)
      WRITE(6,2) IDSPAC(ISETD)
   ********************************************************
IF THE NEXT POSITION IS A LEFT PARENTHESIS, THE LPARN
SUBROUTINE IS CALLED TO FIND THE FURTHERMOST SAME LEVEL
RIGHT PARENTHESIS.
   ********************************************************
      IF(ISPACE(IADDR).EQ.'(')     CALL     LPARN(I,IFINIT,
ISTART,IPARPT)
   ********************************************************
IF THE DATA RETURNED SHOWS THAT A SAME LEVEL PARENTHESIS WAS
FOUND AND THERE IS A NEXT SYMBOL, THE BROTHER FIELD OF THE
NODE IS COMPLETED.
   ********************************************************
      IF(I.LE.IFINIT)          IDSPAC(ISETD)=IDSPAC(ISETD)+
((ISETD+1.)*10.)
      WRITE(6,2)IDSPAC(ISETD)
      IF(I.LE.IFINIT) GO TO 10
   ********************************************************
THE REQUIRED ADDRESS ARRAY HAS BEEN SEARCHED FOR THE SAME
LEVEL VARIABLES. THEREFORE, A RETURN IS MADE.
   ********************************************************
      RETURN
      END
```

```
      SUBROUTINE
ILPARN(I,IFINIT,NXTPT,IDSTA,ISETD,ISTART,IPARPT)
      WRITE(6,100)
100   FORMAT(' ',2X,'ILPARN WAS CALLED.')
   ********************************************************
```

THIS ROUTINE MAY BE ENTERED IN ONE OF TWO CASES:

1. THE FIRST TOKEN OF A LISP PROGRAM MAY BE A LEFT PARENTHESIS AND, THEREFORE, THE SAME LEVEL CONTIGUOUS PARENTHESES BECOMES A PARENT NODE, WITH OR WITHOUT BROTHERS AND OR SONS.
2. THE SON OF A PARENT NODE MAY BE A SET OF MATCHED PARENTHESES.

TO HANDLE THESE EVENTUALITIES, THIS ROUTINE WILL FIRST DETERMINE WHICH CASE APPLIES AND WILL CALL LPFST, IF CASE ONE IS APPLICABLE AND LPLTR, IF CASE TWO IS APPLICABLE.

IL 1153

```
*********************************************************
      IF(IPARPT.NE.0) GO TO 20
      IF(IPARPT.EQ.0) CALL LPFST(I,IFINIT,IPARPT,ISETD
     1,IDSTA,ISTART,NXTPT)
      IF(I.GT.IFINIT) RETURN
      CALL VARBLE(I,IFINIT,NXTPT,IDSTA,ISETD,ISTART
     1,IPARPT,ICODE)
      RETURN
20    CALL LPLTR(I,IFINIT,IPARPT,ISETD,IDSTA,ISTART
     1,NXTPT)
      RETURN
      END
```

```
      SUBROUTINE              IRPARN(IECODE)                C
*************************************************************    IF
THE INITIAL STRING  PROCESSED IN THE GENERAL  TREE STRUCTURE
IS A RIGHT PARENTHESIS, AN  ERROR CONDITION EXISTS.  IF THAT
IS THE CASE,  AND ERROR MESSAGE IS PRINTED  AND THE VARIABLE
IECODE IS  SET TO 999. IECODE=999  WILL CAUSE RETURN  TO THE
LISP                                                  DRIVER.
*************************************************************
THIS ROUTINE WAS WRITTEN BY:
                        *************************
                        *                       *
                        *  DAVID C. BOSSERMAN   *
                        *     NOVEMBER 1976     *
                        *                       *
                        *************************
      WRITE(6,100)
100   FORMAT(' ',2X,'ERROR****A  RIGHT PARENTHESIS PRECEEDED
ALL OTHER STRINGS.')
      IECODE=999
      RETURN
      END
```

```
      SUBROUTINE IPEROD(IECODE)
   ********************************************************
IF THE INITIAL STRING PROCESSED IN THE GENERAL TREE
STRUCTURE IS A PERIOD, AN ERROR CONDITION EXISTS. IF THAT
IS THE CASE AN ERROR MESSAGE IS PRINTED AND THE VARIABLE
IECODE IS SET TC 999. IECODE=999 WILL CAUSE RETURN TO THE
LISP DRIVER.
   ********************************************************
THIS ROUTINE WAS WRITTEN BY:
                        ************************
                        *                      *
                        *  DAVID C. BOSSERMAN  *
                        *     NOVEMBER 1976    *
                        *                      *
                        ************************
      WRITE(6,100)
100   FORMAT('  ',2X,'ERROR****A PERIOD PRECEEDED  ALL OTHER
STRINGS.')
      IECODE=999
      RETURN
      END
```

```
      SUBROUTINE LPARN(I,IFINIT,ISTART,IPARPT)
   ********************************************************
THIS ROUTINE IS DESIGNED TO  FIND THE FURTHERMOST CONTIGUOUS
SAME LEVEL RIGHT PARENTHERIS AND  RETURN ITS LOCATION IN THE
ADDRESS ARRAY TO THE CALLING ROUTINE.
   ********************************************************
THIS ROUTINE WAS WRITTEN BY:
                        ************************
                        *                      *
                        *  DAVID C. BOSSERMAN  *
                        *     NOVEMBER 1976    *
                        *                      *
                        ************************
      COMMON/SPACE/IPTABL(50),ISPACE(2000)
     1,IPUSED,IFREE,IPSIZE,ISIZE
   ********************************************************
FIRST  THE LEVEL  NUMBER  IS ASSIGNED  TO  A CHECK  VARIABLE
CALLED LEVEL.
   ********************************************************
      WRITE(6,1)
1     FORMAT(' ',2X,'LPARN WAS CALLED.')
      NUMRQD=1
      IBLOCK=1
      IPARST=I
      LEVSAM=0
      IADDR=ISPACE(I)/1000000
      ICODE=0
      N=IADDR+80
      LEVEL=ISPACE(N)
```

```
   ********************************************************
```

A DO LOOP IS ENTERED TO CHECK ALL REMAINING ADDRESS ARRAY ELEMENTS UNTIL A SAME LEVEL PARENTHESIS IS FOUND.

```
   ********************************************************
      DO 100 J=I,IFINIT
      IADDR=ISPACE(J)/1000000
      N=IADDR+80
      IF(ISPACE(IADDR).EQ.')') LEVSAM=ISPACE(N)
   ********************************************************
```

A CHECK IS MADE TO SEE IF THE LEVEL IS A MATCH. IF SO A ROUTINE IS CALLED TO CHECK THE NEXT POSITION. IF THE NEXT POSITION IS A LEFT PARENTHESIS AND OF THE SAME LEVEL THE SEARCH IS CONTINUED, IF NOT IT IS TERMINATED.

```
   ********************************************************
      IF(LEVEL.EQ.LEVSAM)    CALL    NXTPAR(J,IFINIT,ICODE,
LEVEL,L)
      LEVSAM=0
      IF(ICODE.EQ.1) GO TO 200
100   CONTINUE
200   I=L
   ********************************************************
```

ONCE THE FURTHERMOST SAME LEVEL PARENTHESIS IS FOUND, THE TOTAL LENGTH OF THE ELEMENTS INCLUDED BY THE PARENTHESES IS STACKED. IPARPT WILL POINT TO THE INITIAL LENGTH ELEMENT. EACH SAME LEVEL PARENTHESIS WILL BE REPRESENTED AT ONE TIME OR ANOTHER IN THE STACK.

```
   ********************************************************
      CALL ISINIT(NUMRQD,ISTART,IBLOCK)
      ISPACE(ISTART)=L-IPARST
```

```
IF(IPARPT.EQ.0) IPARPT=ISTART
RETURN
END
```

```
      SUBROUTINE NXTPAR(J,IFINIT,ICODE,LEVEL,L)
   ********************************************************
THIS ROUTINE IS CALLED AFTER  A SAME LEVEL RIGHT PARENTHESIS
HAS BEEN  FOUND IN  SUBROUTINE LPARN.  THE PURPOSE  OF THIS
ROUTINE IS TO LOCK AT THE NEXT ELEMENT IN THE ADDRESS ARRAY.
IF IT IS  A  LEFT PARENTHESIS AND OF THE SAME  LEVEL, A CODE
OF 0 IS RETURNED TO LPARN.  IF NOT, A CODE OF 1 IS RETURNED.
   ********************************************************
THIS ROUTINE WAS WRITTEN BY:
                        *************************
                        *                       *
                        *  DAVID C. BOSSERMAN   *
                        *     NOVEMBER 1966     *
                        *                       *
                        *************************
      COMMON/SPACE/IPTABL(50),ISPACE(2000)
     1,IPUSED,IFREE,IPSIZE,ISIZE
      WRITE(6,1)
1     FORMAT(' ',2X,'NXTPAR WAS CALLED.')
      ICODE=1
      I=J+1
      IF(I.GT.IFINIT) I=I
      IF(I.GT.IFINIT) RETURN
      IADDR=ISPACE(I)/1000000
      IF(ISPACE(IADDR).EQ.'(') GO TO 10
      L=I
      RETURN
10    N=IADDR+80
      LEVSAM=ISPACE(N)
```

```
IF(LEVSAM.EQ.LEVEL) ICODE=0
L=I
RETURN
END
```

```
      SUBROUTINE
LPFST(I,IFINIT,IPARPT,ISETD,IDSTA,ISTART,NXTPT)
  ************************************************************
```

THIS ROUTINE IS CALLED IF THE FIRST TOKEN ENCOUNTERED IS A LEFT PARENTHESIS. ITS PURPOSE IS TO CREATE DOUBLE WORD NODES WITH THE FOLLOWING POSSIBILITIES:

1. IF THE ENTIRE PROGRAM IS INCLUDED IN THE SAME LEVEL PARENTHESIS:
   - A. CREATE A DOUBLE WORD NODE WHOSE LOCATION FIELD CONTAINS THE TOKEN ARRAY LOCATION OF THE BEGINNING LEFT PARENTHESIS.
   - B. PLACE THE LENGTH IN THE LENGTH FIELD.
   - C. STACK THE LENGTH MINUS TWO ON THE STRING LENGTH STACK.
   - D. PLACE THE ADDRESS OF THE NEXT TOKEN TO BE PROCESSED IN THE SON FIELD.
2. IF THE PROGRAM BEGINS WITH A LEFT PARENTHESIS AND OUTSIDE THE SAME LEVEL RIGHT PARENTHESIS IS FOUND VARIABLES:
   - A. PROCESS AS IN 1.
   - B. CREATE BROTHER NODES AS APPLICABLE WITH POINTERS.

```
 ************************************************************
```

THIS ROUTINE WAS WRITTEN BY:

```
                    *************************
                    *                       *
                    *  DAVID C. BOSSERMAN   *
                    *     NOVEMBER 1976     *
                    *                       *
```

```
                    ************************
 ************************************************************
      DOUBLE PRECISION FUNCT, IDSPAC
      COMMON/SPACE/IPTABL(50),ISPACE(2000)
     1,IPUSED,IFREE,IPSIZE,ISIZE
      COMMON/DOUBLE/IDSPAC(500)
      NUMRQD=1
      IBLOCK=1
 ************************************************************
THE FIRST STEP IS TO ACQUIRE A DOUBLE WORD NODE AND FILL THE
LOCATION FIELD.
 ************************************************************
      CALL ISINIT(NUMRQD,ISETD,IBLOCK)
      IDSTA=ISETD
      NXTPT=ISETD
      IDSPAC(ISETD)=I*1000000000000.D0+1.
 ************************************************************
THE NEXT  STEP IS  TO FIND  THE FURTHERMOST  CONTIGUOUS SAME
LEVEL PARENTHESES.  THIS IS DONE  BY SEARCHING  THE PROGRAM
FOR THE NEXT SAME LEVEL PARENTHESIS.
      ************************************************
      K=0
      IADDR=ISPACE(I)/1000000
      N=IADDR+80
      LEVEL=ISPACE(N)
      ************************************************
A DO  LOOP IS ENTERED TO  CHECK ALL REMAINING  ADDRESS ARRAY
ELEMENTS UNTIL A SAME LEVEL PARENTHESIS IS FOUND.
      ************************************************
```

```
      DO 100 J=I,IFINIT
      K=J
      IADDR=ISPACE(J)/1000000
      N=IADDR+80
      IF(ISPACE(IADDR).EQ.')') LEVSAM=ISPACE(N)
      IF(LEVEL.EQ.LEVSAM) CALL LPROCE(J,IFINIT,ISTART,I,
     1IPARPT,ISETD,IDSTA,NXTPT,IECODE)
      IF(IECODE.EQ.1) RETURN
      LEVSAME=0
100   CONTINUE
      RETURN
      END
```

```
      SUBROUTINE LPROCE(J,IFINIT,ISTART,I,IPARPT,ISETD,
     1IDSTA,NXTPT,IECODE)
      ************************************************
```

THIS ROUTINE IS DESIGNED TO FIND THE FUTHERMOST SAME LEVEL RIGHT PARENTHESIS WHEN CALLED FROM LPFST. IN ADDITION, IT IS RESPONSIBLE FOR LOOKING FOR ALL FIRST LEVEL BROTHER NODES.

```
      ************************************************
      ************************************************
```

THIS ROUTINE WAS WRITTEN BY:

```
                ************************
                *                      *
                *  DAVID C. BOSSERMAN  *
                *    NOVEMBER 1976     *
                *                      *
                ************************
      ************************************************
```

FIRST A TEST IS MADE TO SEE IF THE NEXT CHARACTER EXCEEDS THE PROGRAM LENGTH. IF SO, THE LENGTH IS STACKED AND A RETURN IS MADE.

```
      ************************************************
      NUMRCD=1
      IBLOCK=0
      IECODE=0
      ICODE=1
      K=J+1
      IF(K.GT.IFINIT) GO TO 100
      IADDR=ISPACE(K)/1000000
      IF(ISPACE(IADDR).EQ.'(') GO TO 200
```

```
      ************************************************
IF THE NEXT  CHARACTER IS A PERIOD OR  RIGHT PARENTHESIS, AN
ERROR IS APPARANT AND APPROPRIATE ERROR ROUTINES ARE CALLED.
      ************************************************
      IF(ISPACE(IADDR).EQ.'.') CALL IPEROD(IECODE)
      IF(ISPACE(IADDR).EQ.')') CALL IRPARN(IECODE)
      ************************************************
IF THE NEXT CHARACTER IS NONE OF THE ABOVE, IF IT REPRESENTS
A CHARACTER STRING SO THE  NODE BEING PROCESSED IS COMPLETED
AND SUBROUTINE VARBLE IS CALLED.
      ************************************************
      IF(IECODE.EQ.1) RETURN
      LENGTH=(J-I)+1
      CALL ISINIT(NUMRQD,ISTART,IBLOCK)
      IF(IPARPT.EQ.0) IPARPT=ISTART
      ISPACE(ISTART)=LENGTH-2
      IDSPAC(ISETD)=IDSPAC(ISETD)+(LENGTH*100000000.D0)
      IDSPAC(ISETD)=IDSPAC(ISETD)+((I+1)*10000.)
      IDSPAC(ISETD)=IDSPAC(ISETD)+((ISETD+1)*10.)
      I=K
50    CALL VARBLE(I,IFINIT,NXTPT,IDSTA,ISETD,ISTART,
     1IPARPT,ICODE)
      IF(I.GT.IFINIT) RETURN
      IDSPAC(ISETD)=IDSPAC(ISETD)+((ISETD+1)*10.)
      IADDR=ISPACE(I)/1000000
      IF(ISPACE(IADDR),EQ,'.') CALL IPEROD(IECODE)
      IF(ISPACE(IADDR).EQ.')') CALL IRPARN(IECODE)
      IF(ISPACE(IADDR).NE.'(') GO TO 50
      CALL ISINIT(NUMRQD,ISETD,IBLOCK)
```

```
      IDSPAC(ISETD)=(I*1000000000000.D0)+1.
      RETURN
      ************************************************
```

THE LENGTH OF THE STRING IS DETERMINED AND STORED IN THE PARENT NODE. THE SON FIELD IS SET IN THE PARENT NODE. THE SON'S LENGTH IS STORED ON A TEMPORARY STACK.

```
      ************************************************
100   CALL ISINIT(NUMRQD,ISTART,IBLOCK)
      IF(IPARPT.EQ.0) IPARPT=ISTART
      LENGTH=(J-I)+1
      ISPACE(ISTART)=LENGTH-2
      IDSPAC(ISETD)=IDSPAC(ISETD)+(LENGTH*100000000.D0)
      IDSPAC(ISETD)=IDSPAC(ISETD)+((I+1)*10000.)
      I=K
      RETURN
      ************************************************
```

IF THE NEXT CHARACTER TO BE PROCESSED IS ANOTHER LEFT PARENTHESIS, IT REPRESENTS THE BEGINNING OF A BROTHER STRING. TO GET READY TO PROCESS THE BROTHER THE NODE BEING PROCESSED IS COMPLETED BY SETTING ITS LENGTH, SON AND BROTHER FIELDS TO POINT TO THE APPROPRIATE DATA. THE STRING LENGTH OF THE NODE'S SON IS STACKED AND THEN THE BROTHER NODE IS CREATED. AFTER CREATION, A RETURN IS MADE TO LPFST TO CONTINUE PROCESSING.

```
      ************************************************
200   LENGTH =(J-I)+1
      CALL ISINIT(NUMRQD,ISTART,IBLOCK)
      IF(IPARPT.EQ.0) IPARPT=ISTART
      ISPACE(ISTART)=LENGTH-2
```

```
IDSPAC(ISETD)=IDSPAC(ISETD)+(LENGTH*100000000.D0)
IDSPAC(ISETD)=IDSPAC(ISETD)+((I+1)*10000.)
IDSPAC(ISETD)=IDSPAC(ISETD)+((ISETD+1)*10.)
CALL ISINIT(NUMRQD,ISETD,IBLOCK)
IDSPAC(ISETD)=(K*1000000000000.D0)+1.
I=K
RETURN
END
```

```
      SUBROUTINE
LPLTR(I,IFINIT,IPARPT,ISETD,IDSTA,ISTART,NXTPT)
 ************************************************************
THIS ROUTINE IS DESIGNED TO PROCESS THE STRING FOUND BETWEEN
TWO SAME LEVEL PARENTHESES.  I IS AN IN VARIABLE AND
REPRESENTS THE SCN OF A PARENT NODE.  THE FIRST ACTION WILL
BE TO SET THE PARENT'S SON FIELD TO ZERO.  NEXT A DOUBLE
WORD NODE WILL BE OBTAINED AND THE PARENT'S SON FIELD WILL
BE SET TO POINT TO THE SON NODE.  THEN THE SON WILL BE
PROCESSED.
 ************************************************************
THIS ROUTINE WAS WRITTEN BY:
                        **************************
                        *                        *
                        *  DAVID C. BOSSERMAN    *
                        *     NOVEMBER 1976      *
                        *                        *
                        **************************
      DOUBLE PRECISION FUNCT, IDSPAC
      COMMON/SPACE/IPTABL(50),ISPACE(2000)
     1,IPUSED,IFREE,IPSIZE,ISIZE
      COMMON/DOUBLE/IDSPAC(500)
      NUMRQD=1
      IBLOCK=1
      LEVEL=0
      LEVSAM=0
      LEVNUM=0
      WRITE(6,1)
1     FORMAT(' ',2X,'LPLTR WAS CALLED.')
```

```
      NODEPA=(NXTPT-1)
      IDSPAC(NODEPA)=IDSPAC(NODEPA)-(I*10000.)
 ************************************************************
THE LENGTH OF THE STRING IS RETRIEVED FROM THE STRING LENGTH
STACK.
 ************************************************************
      LENGTH=ISPACE(IPARPT)
      IPARPT=IPARPT+1
 ************************************************************
THE LENGTH REPRESENTS  THE LENGTH OF THE  SAME LEVEL STRING.
HOWEVER, THE  LENGTH COULD BE  DIVIDED INTO  SEVERAL BROTHER
NODES WHICH  SHARE THE TOTAL  LENGTH.  THEREFORE, A  LOOP IS
ENTERED TO PROCESS THE STRING.
 ************************************************************
      ICODE=0
      IFINIT=(I+LENGTH)-1
      IADDR=ISPACE(I)/1000000
      N=IADDR+80
      LEVEL=ISPACE(N)
      JJ=I
      DO 10 J=JJ,IFINIT
      IADDR=ISPACE(J)/1000000
      N=IADDR+80
      IF(ISPACE(IADDR).EQ.')') LEVSAM=ISPACE(N)
      IF(LEVEL.EQ.LEVSAM)                                   CALL
IPROCI(I,J,ICODE,ISETD,IBICCK,ISTART,
     1NODEPA,IFINIT,NXTPT,IPARPT,IDSTA)
      LEVSAM=0
10    CONTINUE
```

```
      RETURN
      END
```

```
      SUBROUTINE
IPROCL(I,J,ICODE,ISETD,IBLOCK,ISTART,NODEPA,IFINIT,
 ************************************************************
SUBROUTINE IPROCL  IS DESIGNED  TO PROCESS  A SECOND  SET OF
SAME LEVEL PARENTHESES  AT THE BROTHER LEVEL.  IT IS CALLED
BY ILELTR.
 ************************************************************
THIS ROUTINE WAS WRITTEN BY:
                        *************************
                        *                       *
                        *  DAVID C. BOSSERMAN   *
                        *                       *
                        *     NOVEMBER 1976     *
                        *                       *
                        *************************
     1NXTPT,IPARPT,IDSTA)
      DOUBLE PRECISION FUNCT, IDSPAC
      COMMON/SPACE/IPTABL(50),ISPACE(2000)
     1,IPUSED,IFREE,IPSIZE,ISIZE
      COMMON/DOUBLE/IDSPAC(500)
      WRITE(6,1)
1     FORMAT(' ',2X,'IPROCL WAS CALLED.')
      NUMRQD=1
      IBLOCK=1
 ************************************************************
IF  THE CODE  PASSED IS  NOT EQUAL  TO ZERO,  THEN ONE  PASS
THROUGH IPROCL  HAS BEEN MADE.  THEREFORE, A SECOND  SET OF
SAME LEVEL PARENTHESES IS ABOUT  TO BE PROCESSED.  THE FIRST
ACTION IS TO SET THE BROTHER FIELD TO POINT TO THE NEXT SET.
```

```
*************************************************************
      IF(ICODE.NE.0)
IDSPAC(ISETD)=IDSPAC(ISETD)+((ISETD+1.)*10.)
*************************************************************
```

SPACE IS ACQUIRED TO CREATE A NEW NODE. THE NEW NODE WILL CONSIST OF THE STARTING POINT OF A STRING INCLOSED BY PARENTHESES.

```
*************************************************************
      CALL ISINIT(NUMRQD,ISETD,IBLOCK)
      IDSPAC(ISETD)=I*1000000000000.D0+1.
*************************************************************
```

IF THE CODE EQUALS ZERO, THE PARENT NODE'S SON FIELD IS SET TO POINT TO THE NODE JUST CREATED.

```
*************************************************************
      IF(ICODE.EQ.0)
IDSPAC(NODEPA)=IDSPAC(NODEPA)+(ISETD*10000.)
      LENGTH=(J-I)+1
*************************************************************
```

THE LENGTH OF THE NEW SON NODE'S SON IS STACKED FOR FUTURE PROCESSING.

```
*************************************************************
      CALL ISINIT(NUMRQD,ISTART,IBLOCK)
      ISPACE(ISTART)=LENGTH-2
*************************************************************
```

THE LENGTH OF THE NEW NODE IS PLACED IN THE LENGTH FIELD.

```
*************************************************************
      IDSPAC(ISETD)=(LENGTH*100000000.D0)+IDSPAC(ISETD)
*************************************************************
```

THE NEW SON'S ADDRESS IS PLACED IN THE SON FIELD. THIS IS A

```
TEMPORARY POINTER AND  WILL BE REPLACED LATER  BY THE ACTUAL
SON'S NODE ADDRESS.
 ************************************************************
      IDSPAC(ISETD)=IDSPAC(ISETD)+((I+1)*10000.)
      ICODE=1
      I=J+1
      IF(I.GT.IFINIT) RETURN
      IADDR=ISPACE(I)/1000000
      IF(ISPACE(IADDR).EQ.'.') I=I+1
 ************************************************************
IF THERE ARE STILL TOKENS TO  BE PROCESSED IN THE STRING AND
THE NEXT ONE IS NOT A  LEFT PARENTHESIS, IT MUST REPRESENT A
VARIABLE.  THEREFORE, THE VARIABLE  ROUTINE IS CALLED.  NOTE
THAT THE BROTHER FIELD IS UPDATED FIRST.
 ************************************************************
      IF(ISPACE(IADDR).NE.'(')
IDSPAC(ISETD)=IDSPAC(ISETD)+((ISETD+1)*
     110.)
      IF(ISPACE(IADDR).NE.'(') CALL VARBLE(I,IFINIT
     1,NXTPT,IDSTA,ISETD,ISTART,IPARPT,ICODE)
      RETURN
      END
```

APPENDIX F

PART I

CARD DECK INPUT JCL

1. ALLOCATE INDEXED FILE SPACE OF 80 CHARACTER LENGTH RECORDS:

```
AL INREAD,IN,80
```

2. READ THE CARDS FROM THE CARD READER (CR:) INTO THE FILE:

```
MCOPYA CR:,INREAD
```

PART II
ESTABLISH PROGRAM TASKS

COMPILE THE PROGRAM (LISP):

```
MFORT LISP
TASK PAUSED--RETURNED BY COMPUTER
CLOSE 1
AS 1,SYS1:FVRTL.OBJ,SRO,1
CO
END OF TASK 0--RETURNED BY COMPUTER
```

PART III
JCL TO RUN PROGRAM

1. LOAD TASKS:

```
LO LISP
```

2. ASSIGN LOGICAL UNITS:

```
AS 5,INREAD
AS 6,PR:  --  PR:=PRINTER
```

3. START THE PROGRAM EXECUTION:

```
ST
```

APPENDIX G

PART I

PROGRAM

```
      DEFINE ((
 (FACTORIAL (LAMBDA (N) (COND ((ZEROP N) 1)
 ( T (TIMES N (FACTORIAL (SUB1 N)))))))
))
   TRACE (T)
FACTORIAL(6)
```

PART II

PROGRAM WITH PARENTHESIS LEVELS

```
      DEFINE ((
              12
 (FACTORIAL (LAMBDA (N) (COND ((ZEROP N) 1)
 3          4       5 5 5     67       7  6
 ( T (TIMES N (FACTORIAL (SUB1 N)))))))
 6   7        8          9      9876543
))
21
   TRACE (T)
         1 1
FACTORIAL(6)
         1 1
```

PART III
TOKEN ARRAY

806
1501
1601
16201
16309
17301
17406
18101
18201
18301
18501
18604
19101
19201
19305
19901
20001
20201
20301
32201
32401
32601
32705
33301
33501
33609
34601
34704
35201
35301
35401
35501
35601
35701
35801
35901
48101
48201
64305
64901
65001
65101
80109
81001
81101
81201

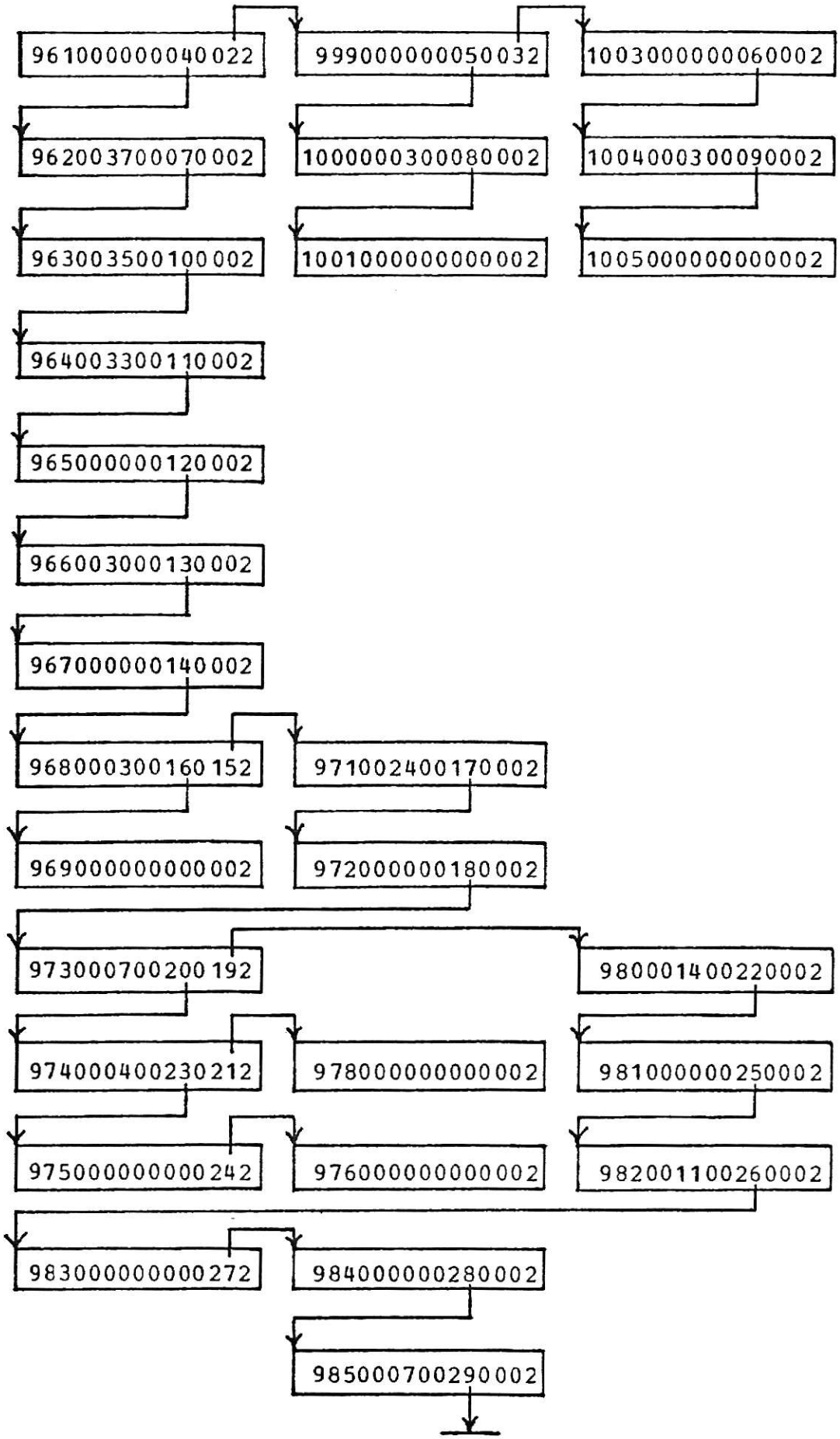
PART IV
EXPANDED TOKENS

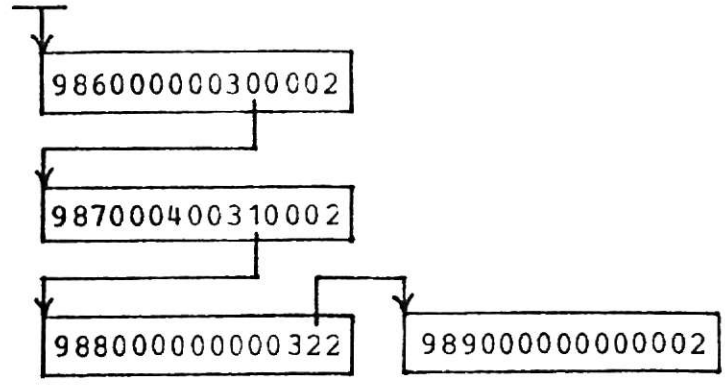
8060260
15010110
16010110
162010110
163090980
173010110
174062260
181010110
182010000
183010210
185010110
186041840
191010110
192010110
193051150
199010000
200010210
202010000
203010210
322010110
324010000
326010110
327051650
333010000
335010110
336090980
346010110
347040840
352010000
353010210
354010210
355010210
356010210
357010210
358010210
359010210
481010210
482010210
643051050
649010110
650010000
651010210
801090980
810010110
811010000
812010210

PART V
NODES

961000000040022
999000000050032
1003000000060002
962003700070002
1000000300080002
1004000300090002
963003500100002
1001000000000002
1005000000000002
964003300110002
965000000120002
966003000130002
967000000140002
968000300160152
971002400170002
969000000000002
972000000180002
973000700200192
980001400220002
974000400230212
978000000000002
981000000250002
975000000000242
976000000000002
982001100260002
983000000000272
984000000280002
985000700290002
986000000300002
987000400310002
988000000000322
989000000000002

PART VI
GENERAL TREE




9860000000300002
9870004003100002
9880000000000322
9890000000000002

A LISP INTERPRETER: SCANNER AND PARSER

by

DAVID CLARENCE BOSSERMAN

B.G.S, University of Nebraska at Omaha, 1969

AN ABSTRACT OF A MASTER'S REPORT

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Computer Science

KANSAS STATE UNIVERSITY

Manhattan, Kansas

1977

A LISP Interpreter is a program which interprets strings. This paper describes the design and format of three parts of a LISP Interpreter. The parts included are the reader, scanner and parser.

All parts are written in the FORTRAN language and have been tested on the INTERDATA 8/32 computer. The reader module reads the user's program into storage. The scanner modules convert the user's program into numeric tokens which are used as pointers by the other modules. The interpreter modules: (1) construct a general tree representation of the user's program; and (2) execute the user's program. The execution modules have not been completed and are to be the subject of a future report. The code for all modules completed and discussed as a part of this report are included in Appendices to the report.

The modules completed are to be integrated with memory management modules and execution modules to form an efficient high level language interpreter for use by miniccmputers. As such, the read, scan and interpreter modules are designed for maximum portability with minimum adaptation.